This is to certify that the
dissertation entitled

DETERMINING NUTRIENT AND IRRIGATION PROGRAMS

FOR TURFGRASSES

presented by

Sang-Kook Lee

has been accepted towards fulfillment
of the requirements for the

Doctoral degree in Crop and Soil Science

Major Professor's Signature

12/10/09

Date

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE

DETERMINING NUTRIENT AND IRRIGATION PROGRAMS FOR TURFGRASSES

By

Sang-Kook Lee

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILSOPHY

Crop and Soil Science

2009

ABSTRACT

DETERMINING NUTRIENT AND IRRIGATION PROGRAMS
FOR TURFGRASSES

By

Sang-Kook Lee

Two studies were conducted to determine fertilization and irrigation programs for turfgrass on home lawn. The objective of the first study was to determine the effect of nitrogen and phosphorus fertilizer applications on Kentucky bluegrass sod planted on a high clay, low P subsoil representative of newly constructed residential developments. P rate treatments did not affect turfgrass color and quality from 2004 through 2006 even though the soil P test results would have recommended annual P applications of 98 kg P_2O_5 ha^{-1}. For turfgrass established from sod grown on a soil with a sufficient soil P level, our research concludes that even when transplanting the sod to a low P soil, additional P applications are unnecessary. The objective of the second study was to determine the effect of three irrigation program and nutrient for two turfgrass species and a common lawn mixture. If water resource is limited, and turfgrass quality for low maintenance from July to September are not important, precipitation only treatment would be accepted under the weather condition of the research area. If maintaining turfgrass quality in summer months are important for the turfgrass manager, then either the every other day or the weekly irrigation treatment would be acceptable.

ACKNOWLEDGMENTS

I would like to acknowledge the members of my committee members, Dr. Kevin Frank, Dr. James Crum, Dr. Darryl Warncke, and Dr. Suzanne Lang. Their time dedicated, advice, and consideration made me to have great experience.

I want to especially thank my major professor, Dr. Kevin Frank for giving me the great opportunity to come to Michigan State University and start the program. He gave me continuous support and advice as well as thoughtful consideration. I would like to thank Dr. Paul Rieke for his resourceful advice. I would like to thank Jeff Bryan for his great help and friendship. I would like to thank Aaron, Alec, and Heidi for the friendship showed and they are true friends. I would like to thanks Carl for his broad knowledge of computer technique and friendship. I would like to thank Mark Collins, Frank Roggenbuck, and all of staff at the Hancock Turfgrass Research Center for their support and assistance. I also want to thank Jodie, Rita, Sandie, and Darlene for their tremendous help, kindness and knowing 'Qudoba day'.

I especially want to thank my family for their support, love, and sacrifices. I also thank my mom for her support and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

CHAPTER II

LIST OF FIGURES

CHAPTER I

CHAPTER II

CHAPTER I

PHOSPHORUS AND NITROGEN RATE EFFECTS FOR TURF GROWN ON A PHOSPHORUS DEFICIENT SOIL

ABSTRACT

Phosphorus (P) is an essential nutrient for plant growth and because it functions in the plant includes energy transformation reactions and as a component of genetic material. The effect of phosphorus on turfgrass establishment has been well investigated. Research has shown that when establishing turfgrass from seed, P applications increase top and root growth and increase seedling density. There has been less research on the effect of phosphorus applications on turfgrass establishment from sod. Although P is an essential nutrient for turfgrass growth, there are numerous studies that show minimal or no growth responses from P applications to established turfgrass. Although the majority of soils in Michigan have sufficient levels of soil P to support turfgrass growth, new residential construction often results in turfgrass being planted on sub-soils high in clay content, and low in soil P.

The research objective was to determine the effect of phosphorus and nitrogen fertilizer applications on Kentucky bluegrass (*Poa pratensis* L.) sod planted on a high clay, low P sub-soil representative of newly constructed residential developments. Research was initiated in the spring of 2004 at the Hancock Turfgrass Research Center on the campus of Michigan State University, East Lansing, Michigan. The soil in the research area was modified in 1992 by removing the existing soil to a depth of 30 cm and replacing it with the C horizon from a poorly drained clay loam soil to simulate an urban

subsoil that results from new home construction when the top soil is removed and not replaced. Initial soil P level as determined by the Olsen test was 7 mg kg^{-1}. The phosphorus (P) treatments were 0, 24, and 48 kg P_2O_5 ha^{-1} yr^{-1}. Phosphorus was applied using mono-potassium phosphate (0-52-34). Phosphorus was applied according to the application schedule for the N treatments. The nitrogen (N) rate treatments were 98, 156, and 208 kg N ha^{-1} yr^{-1} for the low, medium, and high N rate treatments, respectively. The low, medium, and high N rate treatments were applied over two, four, and six applications, respectively. Nitrogen was applied using a mixture of 25% sulfur coated urea (SCU) and 75% urea. In order to balance the potassium (K) applied from mono-potassium phosphate to a ratio of 2:1 (N:K_2O) for all treatments, muriate of potash (0-0-60) was applied. Although the low N rate treatment had the lowest clipping yields, and color and quality ratings, it maintained acceptable color and quality ratings of six over the 3-year period of the research. For a Kentucky bluegrass lawn where dark green color is not critical and lower clipping yields are desirable, the 98 kg N ha^{-1} yr^{-1} rate would be recommended. However, if the interval of N application is longer than 60 days, turfgrass color and quality ratings will likely decline below six. If a dark green color is important for the appearance of the lawn and higher clipping yields are not problematic, the high N rate treatment of 208 kg N ha^{-1} would provide the best results.

The soil P level in the sod thatch layer that was transplanted with the sod was analyzed from the no P treatment plots in 2006 and had a mean soil P level of 58 mg kg^{-1}. The sod thatch layer with high soil P level may have resulted in the lack of turfgrass response to P applications in 2004 as the turfgrass root system developed and rooted into the underlying soil. However, by 2005 and 2006 it was observed that the sod had rooted into the underlying low P soil but the turfgrass was still not responsive to P applications. For turfgrass established from sod grown on a soil with a high soil P level, our research concludes that even when transplanting the sod to a low P soil, the turfgrass may not respond with higher quality or increased growth response to P application, thus P fertilizer applications may be unnecessary.

INTRODUCTION AND LITERATURE REVIEW

Phosphorus (P) is an essential nutrient for plant growth because it is essential in plant energy transformation reactions and as a component of genetic material (Marschner, 1995). The effect of phosphorus on turfgrass establishment has been well investigated. Research has shown that when establishing turfgrass from seed, P applications increase top and root growth (Juska et al., 1965), increase seedling density (Westfall and Simmons, 1971) and improve seedling growth (McVey, 1967). There has been less research on the effect of phosphorus applications on turfgrass establishment from sod. Watschke et al. (1977) found that P applications enhanced rooting of Kentucky bluegrass sod plugs. However, Turner (1980) found no effect on Kentucky bluegrass rooting strength from P applications to a soil with low P levels.

Although P is an essential nutrient for turfgrass growth, there are numerous studies that show minimal or no growth responses from P applications to established turfgrass. Pritchett and Horn (1966) found that warm season grasses had minimal growth response to P applications. Liu et al. (2008) reported optimal growth of St. Augustinegrass (*Stenotaphrum secundatum*) can be achieved at soil P test levels below 10 mg kg^{-1}. Christians et al. (1979) found that P applications had little effect on Kentucky bluegrass or creeping bentgrass (*Agrostis stolonifera*) growth in a sand rootzone. Waddington et al. (1978) also found that P applications had little effect on creeping bentgrass growth on a low P soil while Christians (1996) reported there were no significant turfgrass responses to P applications to Kentucky bluegrass grown on soil with P levels as low as 7 mg kg^{-1}. P applications did not affect the growth of perennial ryegrass, Kentucky bluegrass, or creeping red fescue growing on a low P soil (Turner, 1980). Nus et al. (1993) applied 0 to 586 kg P ha^{-1} in a single application yearly for five years and measured soil test P levels. Nus et al. (1993) found soil test P levels ranged from 11 mg kg^{-1} for the no P treatment to 178 mg kg^{-1} for the highest P rate treatment. Regardless of the soil P level, significant P rate treatment effects on Kentucky bluegrass quality wasvnever observed over five years of research (Nus et al., 1993).

However, P deficiency symptoms can be found when sufficient P is not available for turfgrass growth. P deficiency in turfgrass may be diagnosed using visual observation of symptoms, soil tests, and tissue tests. Visible P deficiency symptoms of turfgrasses include stunted shoot growth and initially a dark green color that progresses to a purple discoloration of leaves that is caused by anthocyanin accumulation (Taiz and Zeigler, 1991). A darker green color of turfgrass on low P soils that were not receiving P fertilizer applications has been observed (Waddington et al., 1978; Turner, 1980). Likewise, tissue testing can be used to identify P sufficiency or deficiency levels in the plant. Phosphorus tissue levels have been measured within a range of 1 to 10 mg g^{-1} by dry weight with a sufficiency level range of 0.2 to 0.6 mg g^{-1} (Turner and Hummel, 1992; Carrow et al., 2001). P tissue levels below 0.2 mg g^{-1} and above 1.0 mg g^{-1} are considered deficient and excessive, respectively (Carrow et al., 2001).

Soil testing determines plant available P. Extractants are used to measure the ability of the soil to replenish P after plant uptake. Commonly Bray P_1, Mehlich III, and Olsen extractants are used to measure soil P levels. Bray P1 and Mehlich III extractants are used for soils with acid pH while the Olsen extractant is used for alkaline pH soils. The values used for soil P sufficiency levels vary among soil testing laboratories. For example, Carrow et al. (2001) categorized Olsen soil P levels above 29 mg kg^{-1} as high and below 7 mg kg^{-1} as very low. Incomparison, the Michigan State University Soil and Plant Nutrient Laboratory (MSUSPNL) categorizes Olsen soil P levels above 23 mg kg^{-1} as high and below 12 mg kg^{-1} as low.

Plant available P in soils can be consumed by turfgrass for growth, but P can be removed or lost from the turfgrass system in several ways including clipping removal, leaching, runoff, and sediment loss. Turfgrasses take up about 10 to 40% of fertilizer P applied (Carrow et al., 2001). Therefore, 60 to 90 % of fertilizer P applied is not immediately taken up by turfgrass. Turfgrass with sufficient P contained 0.2 to 0.6% P in their tissue based on dry weight. According to Kopp and Guillard (2002), about 1000 to 3000 kg ha^{-1} yr^{-1} of mixed cool-season grass clipping was produced at rates of 98 to 392 kg N ha^{-1} from two sites in Connecticut. If it is assumed that all turfgrass had sufficient P concentrations, total P removed from the clipping removal was 2 to 18 kg P ha^{-1} yr^{-1} from the sites. If those clippings were returned, the soil P level could be increased. According to Carpenter and Meyer (1999) about 50% of homeowners in North Carolina returned clippings to their lawns.

Compared to P application, clipping yield is significantly increased by N application (Badra et al., 2005). In fact, rapid tissue growth at high N rates application can result in dilution of tissue P concentration (Rehm et al., 1977). Frank et al. (2006) found 245 kg N ha^{-1} produced 182 % more clippings than the application of 98 kg N ha^{-1} applied to Kentucky bluegrass for two year periods. Walker et al. (2007) reported 196 kg N ha^{-1} resulted in 144% more clipping yields than unfertilized Kentucky bluegrass over a two year period. P application had little or no effect on increasing clipping yield. Liu et al. (2008) investigated the response of St. Augustine grass grown in sandy soil from five different rate P applications. They found 10.9 kg P ha^{-1} produced 25 to 75 % more clippings than the unfertilized treatment, but there were no differences among P rate treatments. These results are supported by Johnson et al. (2003), who found no P rate effects on clipping yields of creeping bentgrass between 28 and 110 kg P ha^{-1} applications. Although clipping yield is mainly affected by N application, unnecessary clipping yield by N application can cause more P loss through clipping removal.

P loss can be influenced by runoff and erosion, and source factors such as P rate, application timing, method, and type of P (Sharpley, 1995). P transport via surface runoff is the main pathway for P loss and transport is highly influenced by runoff volume (Sharpley and Rekolainen, 1997). Cole et al. (1997) investigated nutrient loss from surface runoff using a portable rainfall simulator. They found 10 to 15% of the total P applied to be found in the runoff created by a simulated rainfall event, and found only 2% of the total P applied in runoff for dry soil. Chichester (1977) found the greatest nutrient loss in runoff during summer months when rainfall intensities were high. According to Kussow (1995), an average of 0.36 kg P ha^{-1} in runoff were lost from urban lawn area for two years. Gaudreaue et al. (2002) found P loss of more than 2 mg L^{-1} in runoff from turfgrass treated with 50 and 100 kg ha^{-1} manure. Steinke et al. (2007) reported that the major runoff of P loss occurred in the winter over 6-year period when soils were frozen and found 87 % of total P loss in runoff from snowmelt on Kentucky bluegrass lawn occurred. However, Linde et al. (1994) reported the concentration of P in runoff from creeping bentgrass and perennial ryegrass maintained like a golf fairway rarely exceeded 5 mg L^{-1}. Thus, the total amount of P made unavailable for plant uptake can vary significantly based on the management system and the time of year in which runoff occurs.

Additionally, P transfer from soils to drainage water may become significant depending on soil types. Although P concentrations in drain water are generally less than 0.1 mg L^{-1}, sites consisting mainly of the sandy and clay soil showed a higher possibility to exceed P concentration in the surface water standard of 0.03 mg L^{-1} than medium-textured soils (Beauchemin et al., 1998).

Efforts to reduce P loss have been explored in previous research, based on buffer strips (Lowrance and Sheridan, 2005; Edwards et al, 1996; Moss et al, 2006; Cole et al., 1997), soil amendments (Stout et al, 2000), and P loss with soil types (Turner and Haygarth, 2000; Turtola and Jaakkola, 1995). However, limited information is available concerning P recommendations on landscape areas to reduce P loss to surface water.

The attention P has garnered and local P restrictions have resulted in turf professionals reducing or eliminating phosphorus from their fertilization programs relying on the assumption that soil P levels are adequate or application of P is unnecessary. Reducing the loading of P from urban landscapes is a major concern for local communities as they strive to meet federally mandated total maximum daily loads for nutrients through the Phase II implementation of the Clean Water Act (Rosen and Horgan, 2005). As a result of efforts to reduce P in surface water, P fertilizer applications to turfgrass have become scrutinized, and state and local governments in the Great Lakes region have passed restrictions on applying P fertilizer. Decision makers at the local, county and state level use models in an attempt to partition the amount of P detected in surface water to the land use or specific activity from which the P is generated.

The legislature in the state of Minnesota passed the P Fertilizer Bill that bans P applications to all established turf areas, with the exception of golf courses, unless there is a soil test that indicates a P application is necessary (Minnesota Statues 18C.60). In Michigan, about 31% of public access lakes contain high P levels (Phosphorus Policy Advisory Committee, 2007). Phosphorus movement that is unaccounted for by a specific activity or land use in urban settings is often attributed to lawn and landscape applications.

Low P fertilization programs have been used for preventing *Poa annua* encroachment into creeping bentgrass turf stands on golf courses for many years (Turner and Hummel, 1992). However, for home lawn fertilization programs the reduction or elimination of P applications is a more recent trend. Home lawn fertilizer programs are primarily based on the application of nitrogen (N) while P in most cases is applied based on a pre-determined ratio of $N:P_2O_5$. However, when available P is measured, many soils do not require any additional P applications. Most soil types in Michigan have phosphorus amounts that would support the growth of turfgrass. Darryl Warncke, director of the MSUSPNL analyzed a sub-sample of home lawn soil tests from three counties in southeast Michigan. Of the 500 soil samples submitted from 2000-2001, 74% of the samples tested high for phosphorus and would require no phosphorus applications, 24% tested medium, and only 2% tested low for phosphorus (2006, personal communication). Nemitz et al. (2004) investigated soil P levels from 102 home lawns in Indiana. They found that the average soil P level from all lawns was 45 mg P kg^{-1} and 67% of the home lawns tested had a high level of soil P (25 mg P kg^{-1}). Soldat et al. (2005) surveyed soil P from 803 samples from home lawns and athletic fields in New York and found 19% of all samples had a high soil P level (>20 mg P kg^{-1}).

Although, the majority of soils in Michigan have sufficient levels of soil P to support turfgrass growth, new construction often results in turfgrass being planted on sub-soils high in clay content, and low in soil P. The research objective was to determine the effect of nitrogen and phosphorus fertilizer applications on Kentucky bluegrass sod planted on a high clay, low P subsoil representative of newly constructed residential developments.

MATERIALS AND METHODS

Research was initiated in the spring of 2004 at the Hancock Turfgrass Research Center on the campus of Michigan State University, East Lansing, Michigan. The soil in the research area was modified in 1992 by removing the existing soil to a depth of 30 cm and replacing it with the C horizon from a Colwood-Brookston silty clay loam (Fine-loamy, mixed mesic Typic Haplaquolls). The C horizon was used to represent an urban subsoil that results from new home construction when the top soil is removed and not replaced on the landscape. Soil sampling and analysis in 2004 revealed a soil pH of 8.2 and soil particle size distributions were 202 g kg^{-1} sand, 298 g kg^{-1} silt, and 500 g kg^{-1} clay. Initial soil P level as determined by the Olsen test was 7 mg kg^{-1}. In May 2004 the research area was stripped of the existing turfgrass, and Kentucky bluegrass sod of 3.8 cm thickness and three years old from a local sod farm was planted on the site on 18 May.

Individual plot size was 1.2 by 2.1 meter. Fertilizer treatments were initiated on 18 June 2004. The treatment list and application timing are listed in Table 1. The nitrogen (N) rate treatments were 98, 156, and 208 kg N ha^{-1} yr^{-1} for the low, medium, and high N rate treatments, respectively. The low, medium, and high N rate treatments were applied over two, four, and six applications, respectively. There was an unscheduled fertilizer application of 49 kg N ha^{-1} to the entire plot area two weeks prior to clipping collection in 2006. Nitrogen was applied using a mixture of 25% sulfur coated urea (SCU) and 75% urea. The phosphorus (P) treatments were 0, 24, and 48 kg P_2O_5 ha^{-1} yr^{-1}. Phosphorus was applied using mono-potassium phosphate (0-52-34). Phosphorus was applied according to the application schedule for the N treatments. In following each fertilizer application, 1.3 cm of irrigation was applied. All N sources

Table 1-1. Fertilizer treatment schedule.

Treatment	Rate†		Application month‡						
	N	P_2O_5	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
1. Untreated	0	0							
2. No P + Low N	98	0	×				×		
3. Medium P + Low N	98	24	×				×		
4. High P + Low N	98	49	×				×		
5. No P + Medium N	156	0	×	×			×	×	
6. Medium P + Medium N	156	24	×	×			×	×	
7. High P + Medium N	156	49	×	×			×	×	
8. No P + High N	208	0	×	×	×		×	×	×
9. Medium P + High N	208	24	×	×	×		×	×	×
10. High P + High N	208	49	×	×	×		×	×	×

† Rate units are kg ha^{-1}.

‡ Application schedule for 2005 and 2006. In 2004, treatments ware applied from June to November.

were granular and applied with a hand shake container. Phosphorus and K fertilizers were applied as liquid solution with a CO_2 pressurized backpack sprayer equipped with a flat-fan nozzle, and calibrated to deliver 962 L water ha^{-1} at 207 kPa.

Turfgrass was mowed weekly with clippings collected. Turfgrass clippings were collected every two weeks from a 2.5 m^2 area of each plot, dried at 67 °C for 48 hours, weighed and analyzed for nitrogen, phosphorus, and potassium using Dumas method (AOAC 968.06). Irrigation was scheduled to return 80% of potential evapotranspiration (PET) as estimated with the modified Penman method calculated by the on-site WS-200 Rainbird Maxi weather station (Rainbird, Glendora, CA). Irrigation was applied approximately every other day unless precipitation made irrigation unnecessary. Turfgrass color was measured by visual evaluation every two weeks from 2004 through 2006 using a scale of 1 to 9 (1=straw brown, 6=acceptable, and 9=dark green). Turfgrass quality was measured by visual evaluation from 2004 through 2006 using a scale of 1 to 9 (1=worst, 6=acceptable, and 9=best). Soil samples were taken every month at two depths, 0 to 5 cm and 5 to 10 cm and analyzed for N, P, and K. The 0 to 5 cm depth was measured below the thatch layer; the thatch layer was removed and not included in the soil analysis. The Olsen P soil test was used for soil P and 1M NH_4OAc extractant was used for soil K analysis (Warncke and Brown, 1998).

The experimental design was a randomized complete block design with four replications and the treatment design was a two factor factorial. The factors were N and P rate. Initial statistical analysis indicated years were significantly different, therefore years were analyzed separately. Treatment differences were tested using Proc Mixed statistical analysis (SAS Institute Inc., 2001). When appropriate, means were separated using Fischer's LSD procedure at the 0.05 probability level.

RESULTS AND DISCUSSION

There were no significant interactions for any variable measured. There was a significant N rate main effect on all variables measured. There was a significant P rate main effect for tissue P, the amount of P removed in clippings, and on only two sampling dates in three years, clipping yield and soil P level. The ANOVA table for turfgrass color presented in Table 2 is representative of the experimental and treatment design for all variables measured. All ANOVA tables are presented in Appendix (Table A1-1 to A1-7).

Turfgrass Color

There was a significant N rate main effect for all years. The high N rate treatment had the highest or equal to the highest turfgrass color ratings throughout the three years with the exception of sampling dates in June 2004, and May, September, and October 2006 when there was no significant difference among treatments (Figure 1). In 2004, all N rate treatments produced higher color ratings than an acceptable color rating of six. The low N rate treatment had the lowest color rating on four of six rating dates but the color ratings on all dates were greater than six for the year.

In 2005 the medium and high N rate treatments had color ratings greater than seven for all rating dates. For the low N rate treatment there was only one rating date in August when the color rating was less than six, but there were two dates when the color rating was seven or higher. There were significant differences between the medium and high N rate treatments for the July and August rating dates.

In 2006 there were significant differences among N rate treatments in June, July, and August. In June and August, there were no significant differences between the

Table 1-2. Analysis of variance for turfgrass color.

Source	df	May	June	July	Aug.	Sep.	Oct.	Nov.
					2004			
Treatments	9	ND†	NS	**	**	**	**	**
N rate (NR)	2	ND	NS	**	**	**	NS	**
P rate (PR)	2	ND	NS	NS	NS	NS	NS	NS
NR×PR	4	ND	NS	NS	NS	NS	NS	NS
					2005			
Treatments	9	**	**	**	**	**	**	ND
N rate (NR)	2	**	**	**	**	**	**	ND
P rate (PR)	2	NS	NS	NS	NS	NS	NS	ND
NR×PR	4	NS	NS	NS	NS	NS	NS	ND
					2006			
Treatments	9	**	**	**	**	**	**	ND
N rate (NR)	2	NS	**	**	**	NS	NS	ND
P rate (PR)	2	NS	NS	NS	NS	NS	NS	ND
NR×PR	4	NS	NS	NS	NS	NS	NS	ND

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† Data not collected.

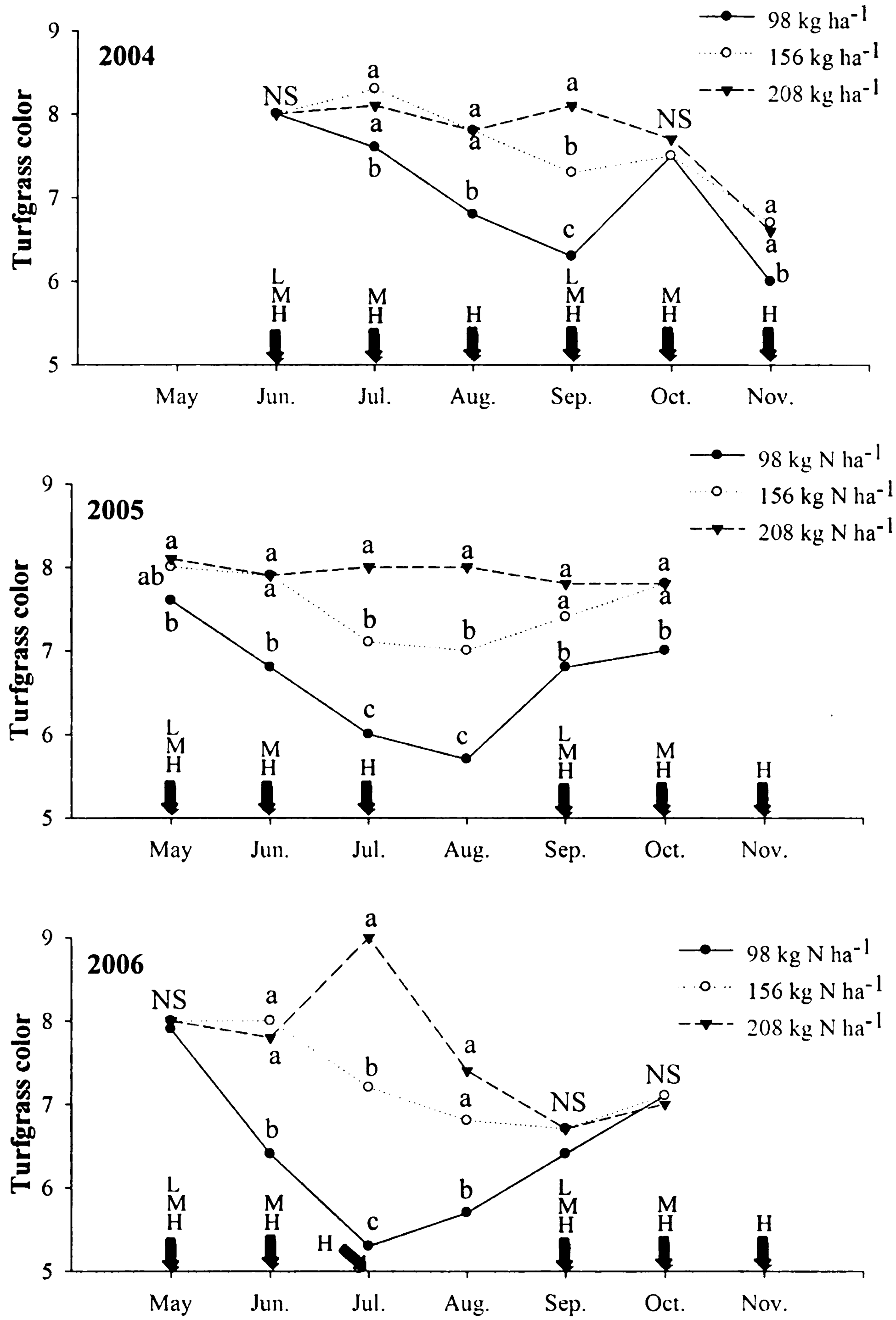

Figure 1-1. Mean turfgrass color for the nitrogen rate main effect for 2004 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05). The arrows with letter L, M, and H indicates fertilizer application dates for the low, medium, and high N rates.

medium and high N rate treatments. In July, the high N rate treatment had the highest turfgrass color rating. For the low N rate treatment the turfgrass color rating in July and August was less than the acceptable rating of six.

From 2004 through 2006, the medium and high N rate treatments had turfgrass color ratings between seven and eight for most rating dates. For all years, the low N rate treatments had turfgrass color ratings less than six only three times, and was the only treatment that had color ratings less than six was the low N rate treatment. The only rating dates when the low N rate treatment was less than six were August 2005, and July and August 2006. The optimum air temperature for shoot growth of cool-season grasses is 15 to 23 °C (Beard, 1973). The mean maximum air temperature for August 2005, and July and August 2006 was 29, 29, and 27 °C, respectively (Table 3). There was only one date in August of both 2005 and 2006 when the mean maximum air temperature was within the 15 to 23 °C optimum temperature range for cool-season turfgrass growth. Although average maximum air temperatures were higher than the optimum shoot growth temperatures for cool-season turfgrasses, the difference in N application timing among the N rate treatments likely had a greater effect on turfgrass color differences in the months of July and August than the maximum air temperatures. The low N rate treatment had two applications per year with a four month interval between applications. The N source was 75% urea and 25% SCU which would not be expected to last four months. If the interval between N applications for the low N rate treatment was shortened from four to two months the turfgrass color ratings in July and August may have been acceptable. However, this could result in lower color ratings later in the year. Walker et. al. (2007) measured the effect of N rate and application timing on shoot

Table 1-3. Temperature data for 2004, 2005 and 2006.

Month	2004		2005		2006	
	Min.	Max.	Min.	Max.	Min.	Max.
Apr.	4†	18	4	18	4	18
May	10	22	7	19	18	36
June	14	25	17	29	21	43
July	16	27	18	29	18	29
Aug.	14	25	17	29	16	27
Sep.	13	26	13	26	11	21
Oct.	7	17	7	18	4	14
Nov.	2	10	2	11	2	10

† Temperature units are Celsius (°C).

responses of cool-season lawn species. They found yearly mean canopy greenness of Kentucky bluegrass with two N applications per year was less than mean canopy greenness with three or four N applications per year. Bigelow et al. (2007) found the N rate range required for a Kentucky bluegrass lawn to be 98 to 196 kg N $ha^{-1}yr^{-1}$ to maintain dark green color and maximize turfgrass quality.

Turfgrass Quality

There were significant N rate main effects for turfgrass quality. The medium and high N rate treatments had quality ratings greater than the acceptable rating of six throughout the research (Figure 2). The high N rate treatment had higher quality ratings than the medium N rate treatment on four rating dates throughout the three years. The low N rate treatment had turfgrass quality ratings greater than six on 14 of 18 rating dates. The turfgrass quality rating dates when the low N rate treatment was less than six were November 2004, August 2005, and July and August 2006. As discussed for turfgrass color, the long interval between fertilizer applications for the low N rate treatment affected turfgrass quality for the July and August ratings. Based on our results, if maintaining turfgrass color and quality in July and August are important for the turfgrass manager on a low N fertilizer program, a shorter interval between the first and second applications would be recommended. The medium and high N rate treatments had the highest turfgrass quality ratings throughout the research.

Clipping Yield

There was an N rate main effect for clipping yield on 15 of 18 sampling dates. Three of the five sampling dates when clipping yield was not significantly different

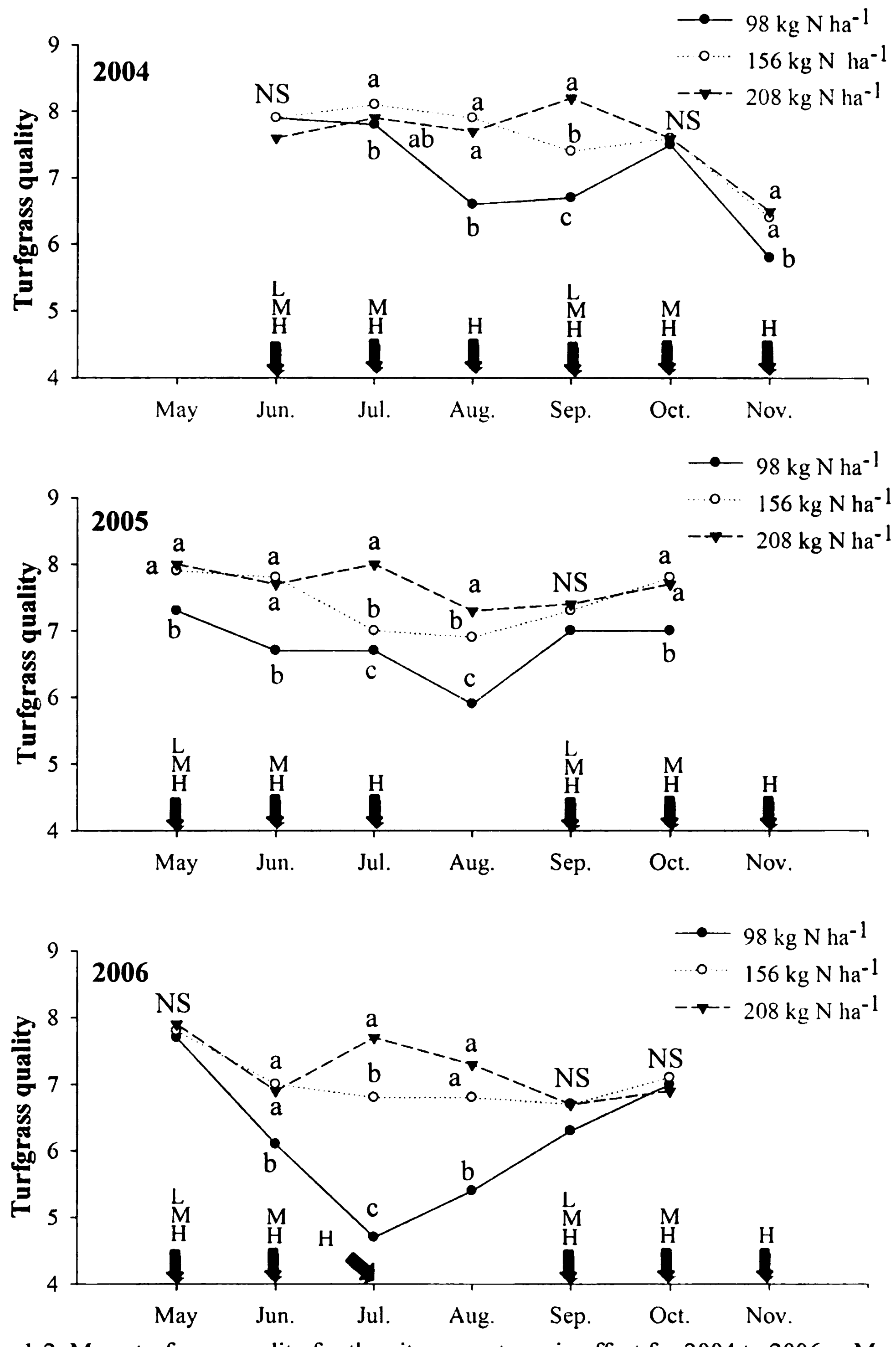

Figure 1-2. Mean turfgrass quality for the nitrogen rate main effect for 2004 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05). The arrows with letter L, M, and H indicates fertilizer application dates for the low, medium, and high N rates.

among N rate treatments were in the establishment year, 2004. In 2004, clipping yield was significantly different for the August and September sampling dates. For the August sampling date, the medium and high N rate treatment had the highest clipping yield (Figure 3). For the September sampling date, the high N rate treatment had the highest clipping yield and the low and medium N rate treatment had the lowest clipping yield.

In 2005, the high N rate treatment had the highest clipping yield for all sampling dates. The low N rate treatment had the lowest or equal to the lowest clipping yield for all sampling dates. Clipping yields were lower in August in comparison to June and July.

In 2006, the high N rate treatment had the highest or equal to the highest clipping yield for all sampling dates. The low N rate treatment had the lowest clipping yield throughout 2006. Clipping yields in August 2006 were high compared to 2004 and 2005 due to an unscheduled fertilizer application of 49 kg N ha^{-1} to the entire plot area two weeks prior to clipping collection.

The daily maximum air temperatures were above 23 °C for all of August in 2004 and 2005 (Table 3). The mean maximum temperatures in August 2004 and 2005 were 25 and 29 °C, respectively. Su et al. (2007) investigated the effects of high temperature and drought on a hybrid bluegrass compared with Kentucky bluegrass and tall fescue (*Festuca arundenacea* Schreb.), and found high temperatures decreased clipping yield at 35/25 °C (14-h day/10-h night) in Kentucky bluegrass by 88% when compared to 22/15 °C (14-h day/10-h night) temperatures. Although the maximum air temperatures may have some impact on clipping yield reduction in August, the effect of fertilizer treatment application interval appears to have a greater effect on clipping yield than air temperatures as supported by the clipping yields in August of 2006 following an

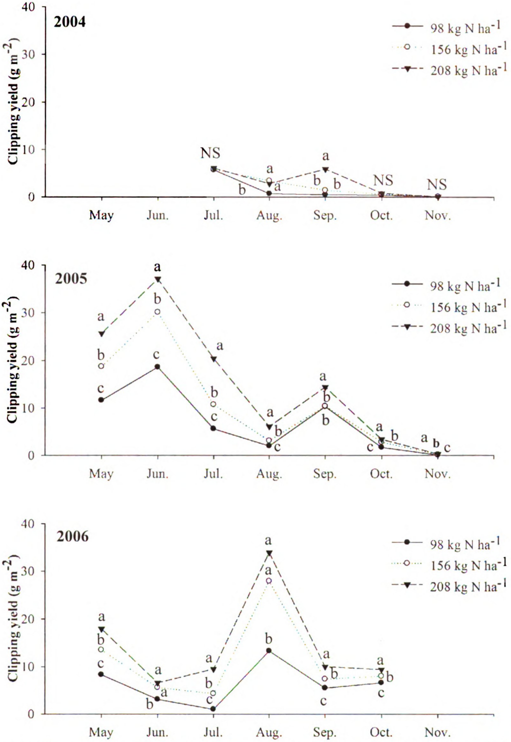

Figure 1-3. Mean turfgrass clipping yield for the nitrogen rate main effect for 2004 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05).

unscheduled fertilizer application. Bowman (2003) compared growth rate of perennial ryegrass (*Lolium perenne*) treated with a daily or periodic N application schedule. When comparing a 32 d interval of N applications to an 8 and 16 d interval of N applications, the growth rate of perennial ryegrass was greatly reduced after 30 days with the 32 d interval of N application.

Tissue N

There was a significant N rate main effect for tissue N concentration on 13 of 15 sampling dates. In 2004 there was a significant N rate main effect for tissue N concentration for the July, August, and September samplings (Figure 4). For the October sampling there was not a sufficient amount of clippings collected to conduct tissue nutrient analysis. For the July sampling date in 2004, the low N rate had the highest tissue N concentration but for the August and September samplings the low N rate had the lowest or equal to the lowest tissue N concentration. The high N rate had the highest or equal to the highest tissue N concentration for the August and September samplings.

In 2005, the low N rate treatment had the lowest tissue N concentration for all sampling dates except September. The high N rate treatment had the highest or equal to the highest tissue N concentration for all sampling dates. For the October sampling, there was no difference between the medium and high N rate treatments for tissue N concentration.

In 2006, there was a significant N rate main effect for tissue N concentration on five of six sampling dates. There were no significant differences among N rates for tissue

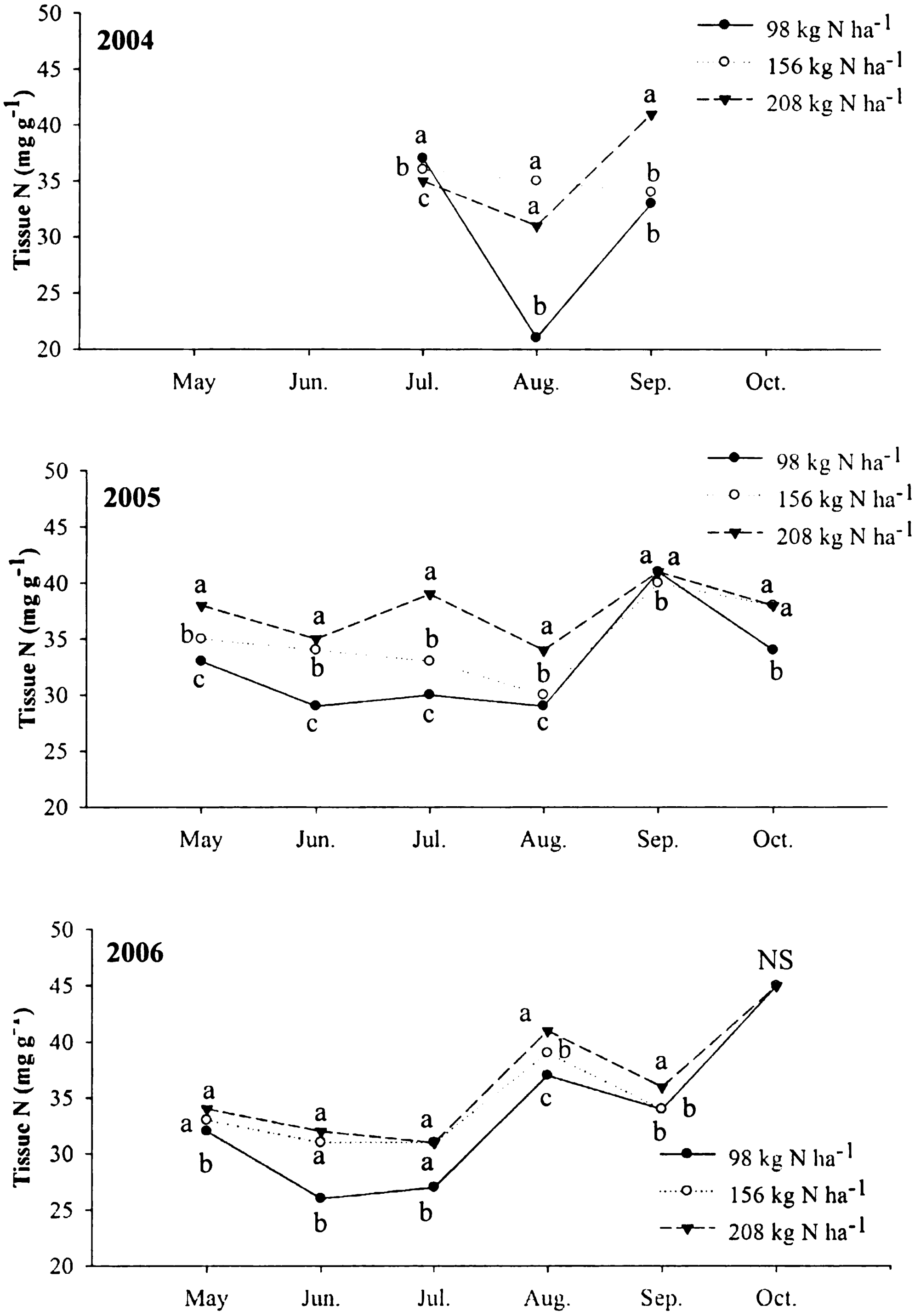

Figure 1-4. Mean turfgrass tissue nitrogen for the nitrogen rate main effect for 2004 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05).

N concentration for the October samplings. The low N rate treatment had the lowest or equal to the lowest tissue N concentration for all sampling dates. The high N rate treatment had the highest or equal to the highest tissue N concentration for all sampling dates. Tissue N concentration of Kentucky bluegrass for all N rate treatments ranged from 2.1 to 4.5 mg g^{-1} throughout the research. The range of tissue N concentration found during the three years of the research was within the sufficiency range for Kentucky bluegrass of 2.5 to 5.1 mg g^{-1} for all but one sampling date (Mills and Jones, 1996).

Tissue P

There was a significant N rate main effect for tissue P concentration on 8 of 15 sampling dates. For the August and September samplings in 2004 there was a significant N rate effect on tissue P concentration (Figure 5). For the August sampling, the medium and high N rate treatments had the highest tissue P concentration and the low N rate had the lowest tissue P concentration. For the September sampling, the high N rate had the highest tissue P concentration and the medium N rate had the lowest tissue P concentration.

For the May and July sampling dates in 2005, the high N rate had the highest tissue P concentration and low N rate had the lowest or equal to the lowest tissue P concentration. However, for the August and September sampling dates the low N rate had the highest tissue P concentration. Results for the August and September sampling dates were similar to results found by Rehm et al. (1977). They reported decreasing tissue P concentrations with increasing N fertilizer rates in mixed pastures containing

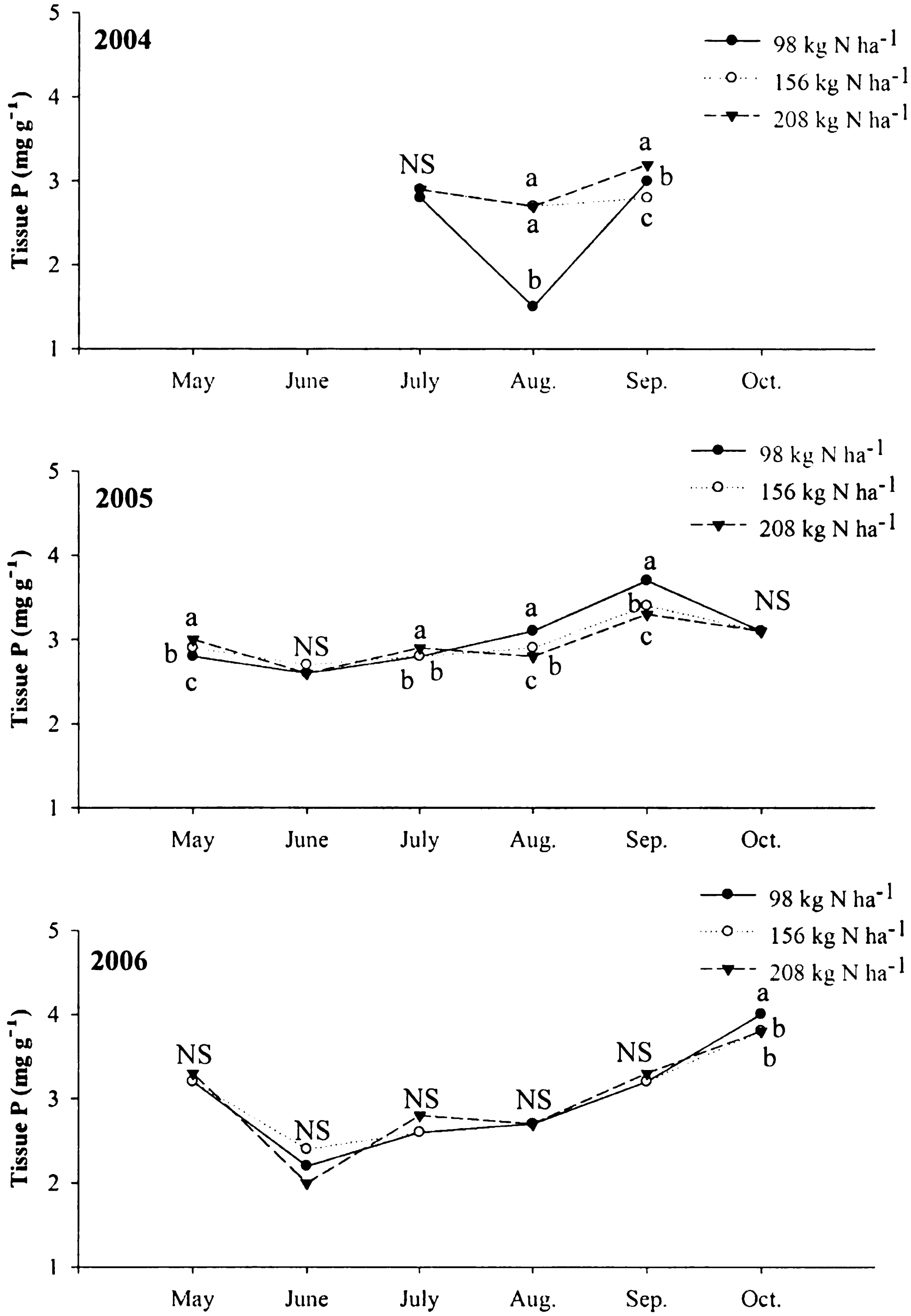

Figure 1-5. Mean turfgrass tissue phosphorus for the nitrogen rate main effect for 2004 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05).

Kentucky bluegrass. In 2006, tissue P concentration was significantly different among N treatments for only the October sampling date. For the October sampling date, the low N rate treatment had the highest tissue P concentration and the medium and high N rate treatments had the lowest tissue P concentration. Although there was a statistically significant difference for the October sampling, the difference in numerical values was small with 3.8 mg P g^{-1} for the medium and high N rates compared to 4.0 mg P g^{-1} for the low N rate (Figure 5).

In 2004, there was a significant P rate main effect on tissue P concentration for the July sampling. The medium and high P rate treatments had the highest tissue P concentration. In 2005, there was a significant P rate main effect on tissue P concentration for all sampling dates (Figure 6). The high P rate treatment had the highest tissue P concentration and the low P rate treatment had the lowest tissue P concentration on all sampling dates. In 2006, there was a significant P rate main effect on tissue P concentration on four of six sampling dates. Similar to 2005, for the majority of sampling dates the highest and lowest P rate treatments had the highest and lowest tissue P concentrations, respectively. Despite the fact that there were no P applications for the low P rate treatment for three years, tissue P concentration was within the sufficiency range for Kentucky bluegrass suggested by Mills and Jones (1996). Liu et al. (2008) observed P deficiency symptoms in St. Augustinegrass after one year with no P applications on a very low P soil. Dam et al. (1979) investigated tissue P concentration with various P rate applications on tall fescue. They found tissue P concentration increased with increasing P fertilization rate. Kruse et al (2005) evaluated responses of established creeping bentgrass to different P rates. They found P deficiency symptoms

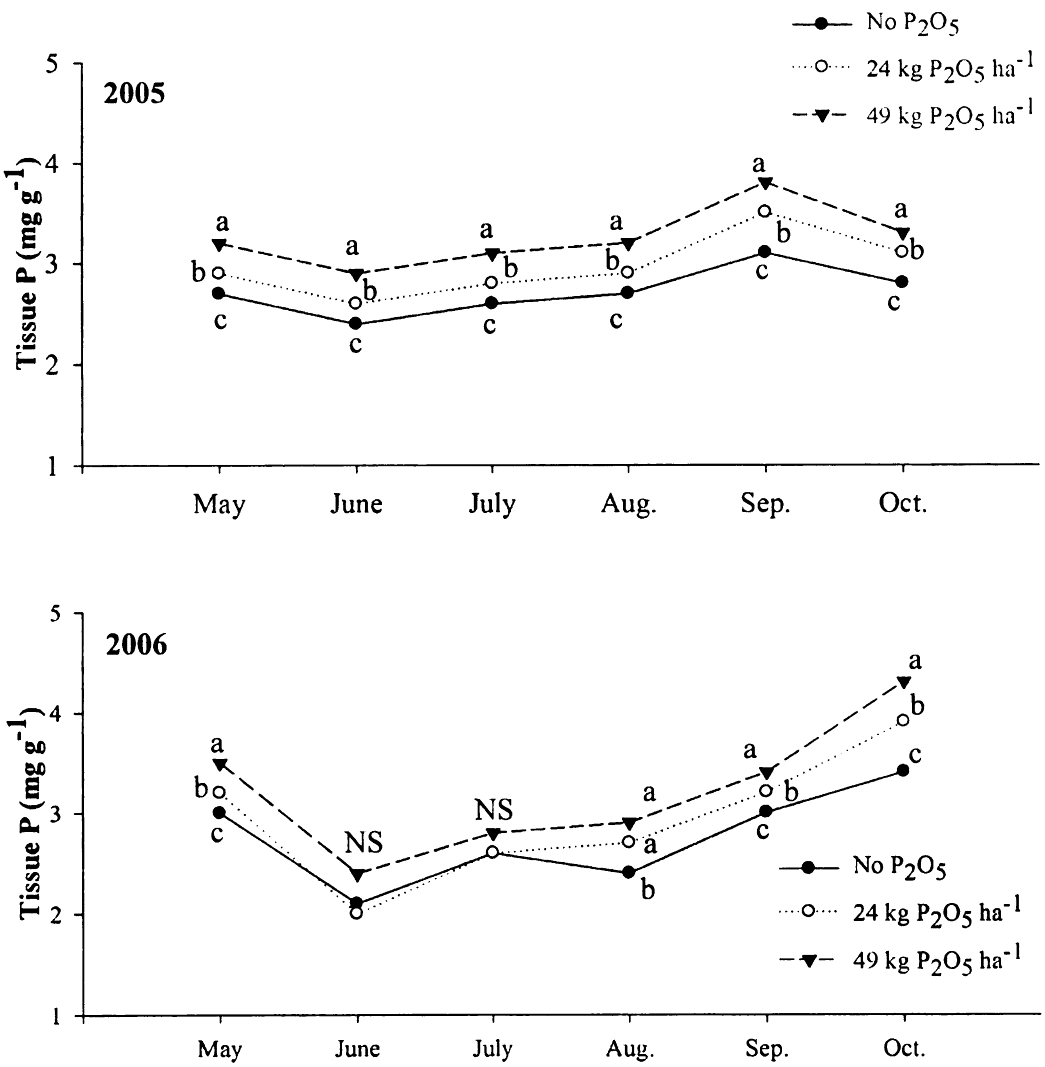

Figure 1-6. Mean turfgrass tissue phosphorus for the phosphorus rate main effect for 2005 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05).

with P rate application from 0 to 15 kg ha^{-1} after three years. In the present research, Kentucky bluegrass sod with a high soil P level that remained from the original soil thatch layer had no P deficiency symptoms over three years when planted on a soil with an initial soil P level of 7 mg kg^{-1}.

Amount of P removed in clippings

There was a significant N rate main effect for the amount of P removed in clippings for all sampling dates except July 2004. In 2004, the low N rate treatment had the lowest amount of P removed in clippings (Figure 7). The high N rate treatment had the highest or equal to the highest amount of P removed in clippings. In 2005, the low N rate treatment had the lowest amount of P removed in clippings except September when there was no difference between the low and medium N rate treatments. The high N rate treatment had the highest amount of P removed in clippings. In 2005, the mean clipping yield for the high N rate treatment for the May, June, and July samplings was 53% higher than the mean clipping yield for the September, October, and November samplings. The higher clipping yields early in 2005 resulted in more P removal and subsequently lower tissue P concentration later in the year. The amount of P removed in clippings from May through July for the low N rate ranged from 1.6 to 4.8 kg P ha^{-1}. The amount of P removed in clippings from May through July for the high N rate ranged from 6.0 to 9.5 kg P ha^{-1}. The amount of P removed in clippings was lower in August and September in comparison to May, June, and July.

In 2006, the low N rate treatment had the lowest amount of P removed in clippings except October when there was no difference between the low and medium N

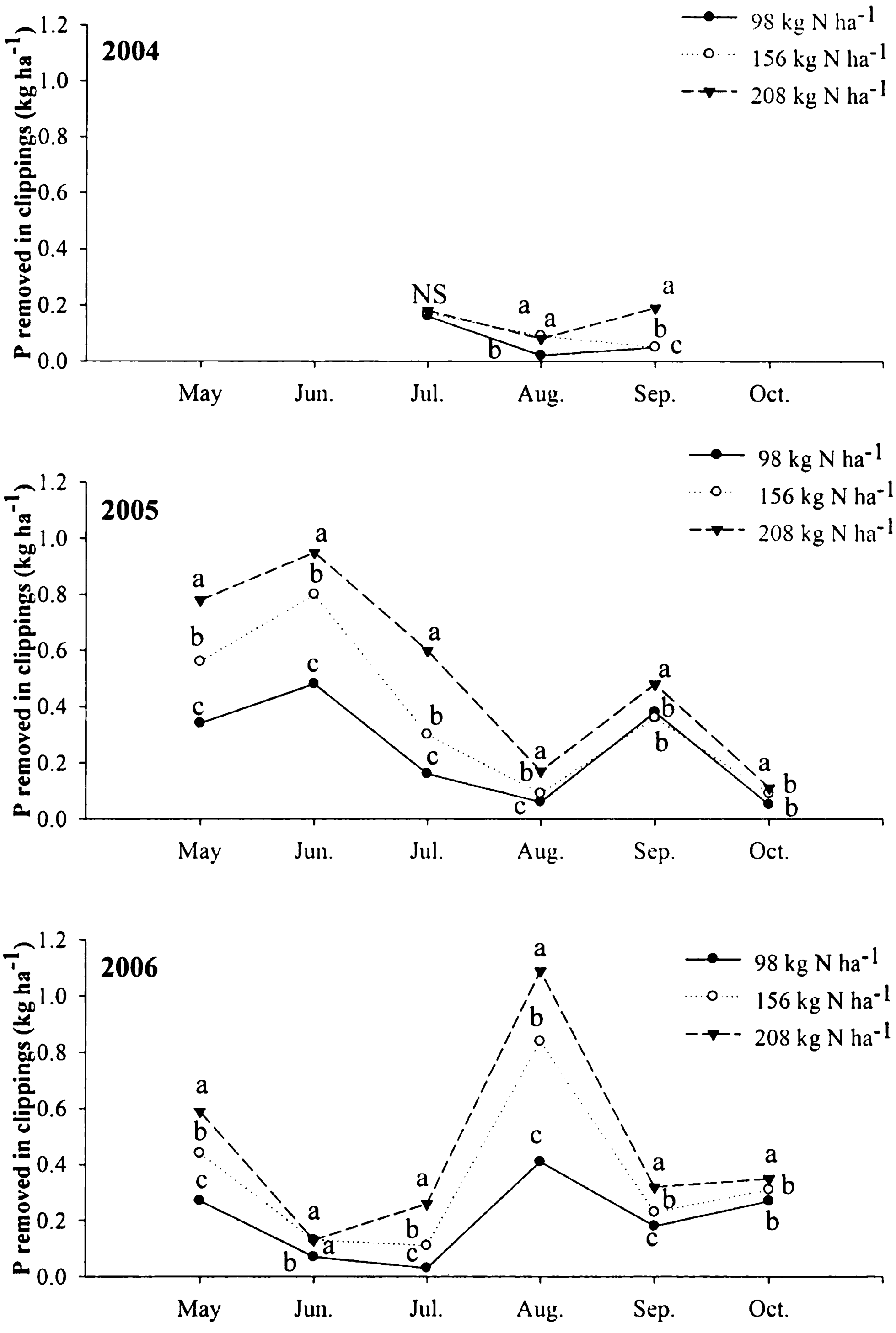

Figure 1-7. Mean phosphorus removed in clippings for the nitrogen rate main effect for 2004 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05).

rate treatment. The high N rate treatment had the highest or equal to the highest amount of P removed in clippings. The amount of P removed in clippings in August 2006 was high in comparison to 2004 and 2005 because of a large amount of clippings produced from an unscheduled N fertilizer application of 49 kg N ha^{-1} to the entire plot area two weeks prior to ratings.

There was a P rate main effect for the amount of P removed in clippings on 10 of 15 sampling dates (Figure 8). In 2004, there was only one sampling date where there was a significant P rate main effect. For the August 2004 sampling, the low P rate treatment had the lowest amount of P removed in clippings. The medium and high P rate treatment had the highest amount of P removed in clippings. In 2005, the low P rate treatment had the lowest or equal to the lowest amount of P removed in clippings. The high P rate treatment had the highest or equal to the highest amount of P removed in clippings. Similar to the N rate main effect for the amount of P removed in clippings, the higher clipping yield resulted in more P removal. The amount of P removed in clippings from May through July for the low P rate, 1.3 to 6.3 kg P ha^{-1}, was higher than the amount of P removed in clippings from August through October, 0.6 to 3.3 kg P ha^{-1}. The amount of P removed in clippings from May through July for the high P rate was 3.8 to 8.8 kg P ha^{-1} in comparison of the amount of P removed in clippings from August through October of 0.9 to 4.7 kg P ha^{-1}. In 2006, there was a significant P rate main effect for the amount of P removed in clippings on four of six samplings. The low P rate treatment had the lowest amount of P removed in clippings. There was no difference between the medium and high P rate treatments.

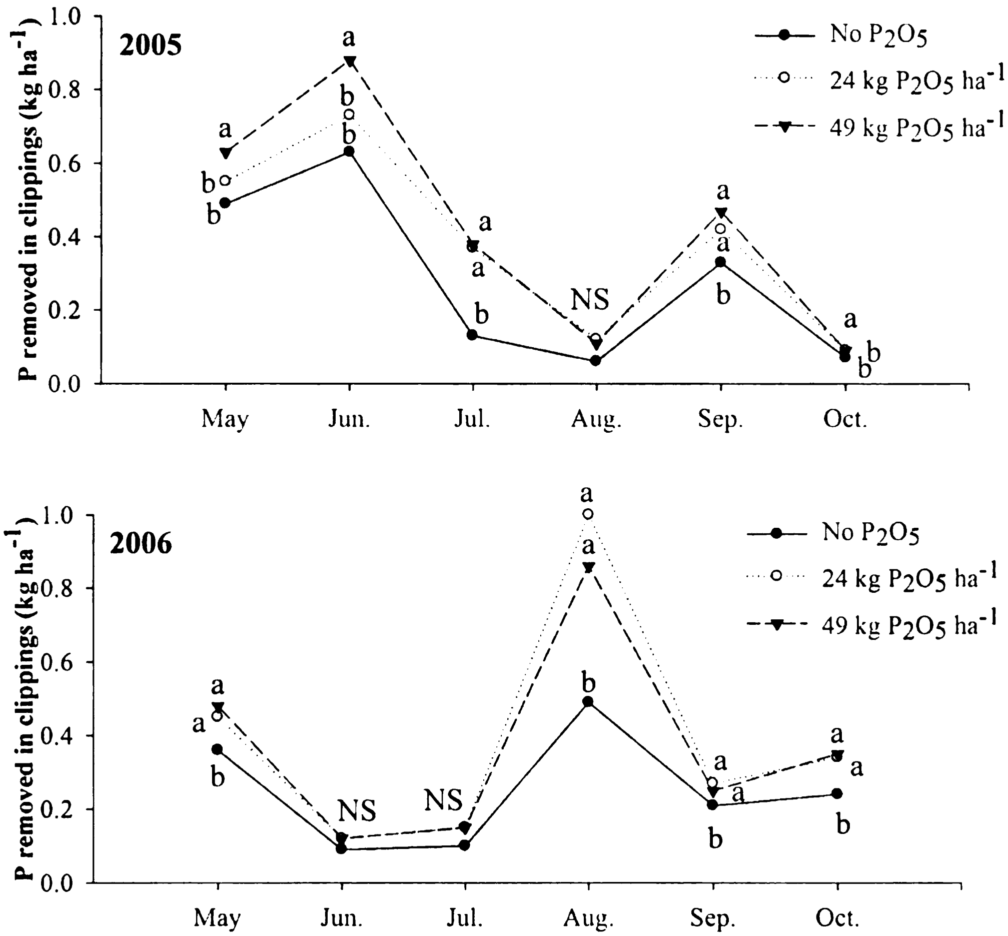

Figure 1-8. Mean phosphorus removed in clippings for the phosphorus rate main effect for 2005 to 2006. Means with the same letter within each date or denoted (NS) are not significantly different according to Fisher's LSD (P=0.05).

Soil P

There was a significant N rate main effect on soil P on one date and a P rate main effect on soil P on two dates during the three years of research. There was a significant difference in soil P levels for the two soil depths sampled for 13 of 17 sampling dates. The 0 to 5 cm soil depth had higher soil P concentration than the 5 to 10 cm soil depth on every sampling date when there was a significant difference (Table 4). The MSUSPNL does not recommend phosphate applications for Olsen P soil test values of greater than 23 mg kg^{-1} for a Kentucky bluegrass home lawn. The soil P level for either soil depth was less than or equal to 12 mg kg^{-1} for all sampling dates for three years. The MSUSPNL classify an Olsen soil P test value of less than 12 as low and recommend 98 kg P_2O_5 ha^{-1} annually. Soil P levels from 2004 to 2006 ranged from 2 to 12 mg kg^{-1} for the below thatch layer to 5 cm soil depth and ranged from 1 to 8 mg kg^{-1} for the 5 to 10 cm soil depth. Despite the low soil P levels and the recommendation from soil tests to apply phosphate, there were no P rate treatment effects for turfgrass color, quality, clipping yield, tissue N, or soil P. Christians (1996) also found that there were no significant turfgrass responses to additional phosphorus applications to Kentucky bluegrass grown on soil with P levels as low as 7 mg kg^{-1}. Liu et al. (2008) reported optimal growth of St. Augustinegrass can be achieved at soil P test levels below 10 mg kg^{-1}. Nus et al. (1993) applied 0 to 586 kg P ha^{-1} in a single application yearly for five years and then measured soil P level. Soil test levels ranged from 11 mg kg^{-1} for the no P treatment to 178 mg kg^{-1} for the highest P rate treatment. Nus et al. (1993) never observed any significant P rate effects on Kentucky bluegrass quality over five years of research. The soil P level in the sod thatch layer transplanted in 2004 was analyzed from the no P treatment plots in 2006.

Table 1-4. Mean soil phosphorus for soil depth main effect.

Soil depth†	May	June	July	Aug.	Sep.	Oct.	Nov.
		--------------------------------		2004	--------------------------------		
0 to 5‡	ND§	ND	12¶ a#	10 a	10 a	10 a	10 a
5 to 10	ND	ND	7 b	6 b	7 b	6 b	7 b
		--------------------------------		2005	--------------------------------		
0 to 5	2 a	4 a	3	2	2	9 a	9
5 to 10	1 b	2 b	2	2	1	6 b	7
		--------------------------------		2006	--------------------------------		
0 to 5	9 a	3 a	ND	9 a	9 a	10 a	ND
5 to 10	6 b	1 b	ND	7 b	8 b	8 b	ND

† Soil depth units are centimeter.

‡ Soil depth of 0 to 5 was measured below the thatch layer and the thatch layer was removed and not included in the soil analysis.

§ No data available.

¶ Soil phosphorus units are mg kg^{-1}.

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

The mean soil P level from the sod thatch layer was 58 mg kg^{-1}. The sod thatch layer with high soil P level may have resulted in the lack of turfgrass response to P applications in 2004 as the turfgrass root system developed and rooted into the underlying soil. However, by 2005 and 2006 it was observed that the sod had rooted into the underlying low P soil but the turfgrass was still not responsive to P applications. For turfgrass established from sod grown on a soil with a high soil P level, our research concludes that even when transplanting the sod to a low P soil, the turfgrass may not respond and P fertilizer applications may be unnecessary.

CONCLUSION

Nitrogen rate treatments had effects on turfgrass color and quality. Although the low N rate treatment had the lowest clipping yields, and color and quality ratings, it maintained acceptable color and quality ratings of six or above over the three years of research. The low N rate treatment had tissue N and P concentrations within cited sufficiency ranges and also had the lowest clipping yields among the N rate treatments. For a Kentucky bluegrass lawn established from sod where dark green turfgrass color is not important and lower clipping yields are desirable, the 98 kg N ha^{-1} yr^{-1} rate would be recommended. However, the low N rate treatment as applied with two applications spaced four months apart would not be recommended if maintaining consistent turfgrass color and quality throughout the growing season is desired. Applying lower amounts of N on a more frequent basis may result in more consistent growth and quality responses than observed from our two applications of 49 kg N ha^{-1} spaced four months apart. Overall, the medium and high N rate treatments had the highest turfgrass color and quality ratings with the highest clipping yield. If a dark green color is important and higher clipping yields which may result in more frequent mowing are not a problem, the high N rate treatment of 208 kg N ha^{-1} would be recommended.

Phosphorus rate treatments did not affect turfgrass color and quality from 2004 through 2006 even though the soil P test results would have recommended annual P applications of 98 kg P_2O_5 ha^{-1}. For turfgrass established from sod grown on a soil with a sufficient soil P level, our research concludes that even when transplanting sod to a low P soil, additional P applications are unnecessary.

REFERENCES CITED

Badra, A., L. E. Parent., Y. Desjardins, G. Allard, and N. Tremblay. 2005. Quantitative and qualitative responses of an established Kentucky bluegrass (Poa pratensis L.) turf to N, P, and K additions. Can. J. Plant Sci. 85:193-204.

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice-Hall. Eagle-wood Cliffs. NJ.

Beauchemin, S., R.R. Simard, and D. Cluis. 1998. Forms and concentration of phosphorus in drainage water of twenty-seven tile drained soils. J. Environ. Qual. 27:721–728.

Bigelow, C. A. K. S. Walker, and G. A. Hardebeck. 2007. Single fall applications of coated urea fertilizers produce a high quality Kentucky bluegrass turf. Applied Turfgrass Science. July. p.1-10.

Bowman, D. C. 2003. Daily vs. periodic nitrogen addition affects growth and tissue nitrogen in perennial ryegrass turf. Crop Sci. 43(2): p. 631-638.

Carpenter, P. J. and H. M, Meyer. 1999. Edina goes green part III: A survey of consumer lawn care knowledge and practices. HortTechnology. July-September. 9(3): p. 491-494.

Carrow, R. N., D. V. Waddington., and P. E. Rieke. 2001. Turfgrass soil fertility and chemical problems – Assessment and management. John Wiley & Sons, Inc., Hoboken, New Jersey. pp 170-171.

Carrow, R. N., D. V. Waddington., and P. E. Rieke. 2001. Turfgrass soil fertility and chemical problems – Assessment and management. John Wiley & Sons, Inc., Hoboken, New Jersey. pp 202.

Chichester, F. W. 1977. Effects of increased fertilizer rates on nitrogen content of runoff and percolate from monolith lysimeters. J. Environ. Qual. 6:211-217.

Christians, N. E. 1996. Phosphorus nutrition of turfgrass. Golf course management. John Wiley & Sons, Inc., Hoboken, New Jersey. 64(2):4-57.

Christians, N. E. 1996. Phosphorus nutrition of turfgrass. Golf course Manage. 64(2):54-57

Christians, N. E, D. P. Martin, and K. J. Karnok. 1979. Interrelationships among nutrient elements on calcareous sand greens. Agron. J. Abstracts. p. 120.

Cole, J. T., J.H. Baird, N. T. Basta, R. L. Huhnke, D. E. Storm, G. V. Johnson, M. E. Payton, M. D. Smolen, D. L. Martin, and J. C. Cole. 1997. Influence of Buffers on Pesticide and Nutrient Runoff from Bermudagrass Turf. J. Environ. Qual. 1997 26: 1589-1598.

Dam, J. V., R. Branson, and R. Strohman. 1979. Determining the need for phosphorus and potassium fertilization in a new turf planting. Calif. Turfgrass Culture. Vol. 29 (3) 17-18.

Edwards, D.R., P.A. Moore, Jr., and T.C. Daniel. 1996. Grassed filter strips can reduce losses of nitrogen and phosphorus in runoff. Better Crops with Plant Food. V80(4): 8-11.

Frank, K. W., K. M. O'Reilly, J. R. Crum, and R. N. Calhoun. 2006. The fate of nitrogen applied to a mature Kentucky bluegrass turf. Crop Science. 46(1): 209-215.

Gaudreau. J.E., D.M. Vietor, R.H. White, T.L. Provin, and C.L. Munster. 2002. Response of turf and quality of water runoff to manure and fertilizer. J. Environ. Qual. 31:1316-1322.

Johnson, P. G., R. T. Koenig, and K. L. KoppAgron. 2003. Nitrogen, Phosphorus, and Potassium Responses and Requirements in Calcareous Sand Greens. Agron J. 95:697–702.

Juska, F. V., A. A. Hanson. C. J. Erickson. 1965. Effects of phosphorus and other treatments on the development of red fescue, Merion, and common Kentucky bluegrass. Agron. J. 57(1): 75-78.

Kopp, K. L. and K. Guillard. 2002. Clipping management and nitrogen fertilization of turfgrass: Growth, nitrogen utilization, and quality. Crop Science. July/August. 42(4): 1225-1231.

Kruse, J. K, N. E. Christians, , and M. H. Chaplin. 2005. Remote sensing of phosphorus deficiencies in Agrostis stolonifera. International Turfgrass Society Research Journal. 10(Part 2): p. 923-928.

Kussow, W. 1995. Soil disturbance effects on nutrient losses from turf. Wisconsin Turf Research: Results of 1994 Studies. 22:95-100.

Linde, D. T., T. L. Watschke, and J. A. Borger. 1994. Nutrient transport in runoff from two turfgrass species. p. 489-496. In A.J. Cochran and M.R. Farrally (ed.) Science and golf II. Proc. of the 1994 World Scientific Congress of Golf. E & FN Spon, New York.

Liu, Min, J. B Sartain, L. E. Trenholm, and G. L. 2008. Phosphorus requirements of St. Augustinegrass grown in sandy soils. Crop Sci. 48(3):1178-1186.

Lowrance, R. and J.M. Sheridan, 2005. Surface runoff water quality in a manged three zone riparian buffer. J. Environ. Qual. 34:1851-1859.

Marschner, H. 1995. Mineral nutrition of higher plants. New York: Academic Press.

McVey, G. R. 1967. Response of Turfgrass Seedlings to Various Phosphorus Sources. Agron. J. Abstracts. 59: p. 53.

Mills, H. A. and J. B. Jones. 1996. Plant analysis handbook II. Micromacro publishing, Athens, GA, pp. 6-10, 112-118, 347-353.

Moss, J. Q., G. E. Bell, M. A. Kizer, M. E. Payton, H. Zhang, and D.L. Martin. 2006. Reducing nutrient runoff form golf course fairways using grass buffers of multiful heights. Crop Sci. 46:72-80.

Nemitz, J. R., C. A. Bigelow, V. A. Caceres, and D. S. Richmond. 2006. Survey of home lawn soil phosphorous levels in Tippecanoe County Indiana. 2006 Annual Report: Purdue University Turfgrass Science Program. p.1-3.

Nus, J. L, N. E. Christians, and K. L. Diesburg. 1993. High phosphorus applications influence soil-available potassium and Kentucky bluegrass copper content. HortScience. 28(6): p. 639-641.

Pritchett, W. L. and G. C. Horn. 1966. Fertilization fights turf disorders. Better Crops and Plant Food 50(3): 22–25.

Rehm, G. W., R. C. Sorensen, and W. J. Moline. 1977. Time and rate of fertilization on seeded warm-season and bluegrass pasture: II. Quality and nutrient content. Agron. J. 69:966-961.

Rosen, C. J. and B. P. Horgan. 2005. Regulation of phosphorus fertilizer application to turf in Minnesota: Historical perspective and opportunities for research and education. International Turfgrass Society Research Journal. 10(Part 1): 130-135.

SAS Institute Inc. 2001. The SAS system release 8.2 for Windows. SAS Inst., Cary, NC.

Sharpley, A.N. 1995. Identifying sites vulnerable to phosphorus loss in agricultural runoff. J. Environ. Qual. 24:947-951.

Sharpley, A. N., and S. Rekolainen. 1997. Phosphorus in agriculture and its environmental implications. P. 1-54. In H. Tunney, O. T. Carton,P. C. Brookes, and A. E.. Johnston (ed.) Phosphorus loss from soil water. CABI publ., Wallington, UK.

Soldat, D., A. M. Petrovic, and R. B Rao. 2005. Summary of soil test phosphorus results from home lawns and athletic fields in New York State: 2001 – 2005. 2005 Annual Meeting Abstracts. p.1.

Steinke, K., J. C. Stier, W. R. Kussow, and A. Thompson. 2007. Prairie and Turf Buffer Strips for Controlling Runoff from Paved Surfaces. J. Environ. Qual. 36:426–439 (2007).

Su, K., D. J. Bremer, S. J. Keeley, and J. D. Fry. 2007. Effects of high temperature and drought on a hybrid bluegrass compared with Kentucky bluegrass and tall fescue Crop Sci. 47(5): 2152-2161.

Stout, W.L., A.N. Sharpley, and J. Landa. 2000. Effectiveness of Coal Combustion By-Products in Controlling Phosphorus Export from Soils. J. Environ. Qual. 2000 29: 1239-1244.

Taiz, L. and E. Zeigler. 1991. Plant physiology. Benjamin/Cummings Publishing Co., San Francisco, CA, p 114.

Turner, T. R. 1980. Soil test calibration studies for turfgrass establishment. Ph.D dissertation. Pennsylvania State University, University Park, PA.

Turner, T. R. and N. W. Hummel. 1992. Nutritional requirements and fertilization. In D. V. Waddington, P. R. Carrow, and R. C. Shearman (Eds.), Turfgrass American Society of Agronomy, Madison, WI, pp. 385-430.

Turner, B. L. and P. H. Haygarth. 2000. Phosphorus forms and concentrations in leachate under four grassland soil types. Soil Sci. Soc. Am. J. 64:1090-1099.

Turtola, E. and A. Jaakkola. 1995. Loss of phosphorus by surface runoff and leaching from a heavy clay soil under barley and grass ley in Finland. Acta Agric. Scand. Sect. B, Soil and Plant Sci. 45:159-165.

Waddington, D. V, T. R. Turner, J. M. Duich, and E. L. Moberg. 1978. Effect of fertilization on Penncross creeping bentgrass. Agron. J. 70(5): 713-718.

Walker, K. S., C. A. Bigelow, D. R. Smith, G. E. Van Scoyoc, and Z. J. Reicher. 2007. Aboveground responses of three cool-season lawn species to varying annual nitrogen rates and application timings. Crop Sci. 47:1225-1236.

Warncke, D. and J.R. Brown. 1998. Potassium and other basic cations. p. 31-33. In Recommended Chemical Soil Test Procedures for the North Central Region; North Central Regional Research Publication No. 221; Revised January, 1998.

Watschke, T. L., D. V. Waddington, D. J. Wehner, and C. L. Forth. 1977. Effect of P, K, and lime on growth, composition, and ^{32}P absorption by Merion Kentucky bluegrass Agron. J. 69(5): 825-828.

Westfall, R. T. and J. A. Simmons. 1971. Germination and Seedling Development of Windsor Kentucky Bluegrass as Influenced by Phosphorus and Other Nutrients. Agron. J. Abstracts. 63: p. 52.

CHAPTER II

IRRIGATION AND NITROGEN AND POTASSIUM EFFECTS FOR TWO TURFGRASS SPECIES AND A COOMON LAWN MIXTURE

ABSTRACT

Turfgrass requires irrigation and fertilizer applications, and irrigation is often perceived to be a major fraction of the turfgrass maintenance budget when rainfall is insufficient and weather conditions are insufficient for turfgrass growth. Water requirements for turfgrass have been estimated on water use rates, and irrigation frequency and quantity. However, these parameters do not always provide adequate guidance for efficient irrigation management. Research was conducted for 2005 and 2006 to determine recommendations for irrigation and nitrogen and potassium program. The irrigation treatments were precipitation only, 0.5 cm of water every other day, and 1.8 cm of water once per week. The nitrogen (N) treatments were 98, 156, and 208 kg N ha^{-1} yr^{-1}. The low, medium, and high N treatments were applied over 2, 4, and 6 applications, respectively. All N treatments were a formulation containing 25% of slow and 75% of fast release nitrogen sources that are representative of typical home lawn fertilizers. Muriate of potash (0-0-60) was used as a source of potassium (K) and applied at a 2:1 N to K ratio. No phosphorus (P) was applied as a soil test indicated a high soil P level. Treatments were evaluated on Kentucky bluegrass, tall fescue, and the lawn mixture of Kentucky bluegrass, perennial ryegrass, creeping red fescue, Chewings fescue. Turfgrass color and quality ratings were taken every two weeks. Turfgrass clippings were collected every month and weighed. Soil volumetric water content (%) was

measured at 12 cm depth every two weeks. Research indicated that all turfgrass species without irrigation had turfgrass quality lower than the acceptable turfgrass quality rating of six during a portion of the growing season and significant differences were found among irrigation treatments. However, the precipitation only treatment had acceptable quality ratings on 8 of 12 sampling dates for two years. If water resource is limited, and turfgrass quality for low maintenance in July and August are not important, the precipitation only treatment would be accepted under the environmental conditions which occurred in regions similar to the area where the research was conducted.

INTRODUCTION

Appropriate water management is critical to maintain turfgrass quality especially during summer months. Common irrigation recommendations for turfgrass are to irrigate deep and infrequently in order to achieve a deep root system that will be better suited to endure prolonged drought conditions and maximize drought resistance (Qian and Fry, 1996).

Fry and Huang (2004) defined deep and infrequent irrigation as irrigation to furnish water for root zone when the first signs of leaf wilt appear. In general, deep and infrequent irrigation refers to applying large amounts of irrigation, 1.3 to 2.5 cm or more, in a single irrigation event. A number of research projects have been reported to support benefits of deep and infrequent irrigation. Bennett and Doss (1960) reported infrequent irrigation promoted better root development for both cool- and warm-season grasses. Medison and Hogan (1962) found better root growth with infrequent irrigation for warm-season grasses. Deeply and infrequently irrigated bentgrass produced higher levels of water soluble carbohydrate (Fu and Dernodeden, 2008). Jordan et al. (2003) investigated the responses of creeping bentgrass intensively managed to irrigation frequency of every four days and every day or every other day. They found creeping bentgrass with a frequency of every four days irrigation had greater turfgrass quality, shoot density, and root length than the other two irrigation frequencies. Johnson (2003) studied to compare irrigations with 2-, 4-, and 6-day interval for the response of Kentucky bluegrass (*Poa pratensis*), tall fescue (*Festuca arundinacea*), prairie junegrass (*Koeleria macrantha*), and buffalograss (*Buchloe dactyloides*). He reported that irrigation of 2-day interval produced greater turfgrass quality than irrigation of 4- or 6-day interval.

However, deep and infrequent irrigation is not recommended for all turfgrass situations. Turfgrass grown on sandy soils should be irrigated with smaller amounts of water more frequently as deep infrequent irrigations could potentially result in losses of irrigation water through leaching. Also, turfgrass grown on fine textured soils with low infiltration rates should be irrigated with smaller amounts of water more frequently to avoid run-off and puddling on the surface. The alternative to deep and infrequent irrigation is light and frequent irrigation. Light and frequent irrigation would be defined as maintaining soil at field capacity to apply irrigation when the first sign of leaf wilt is shown (Fry and Huang, 2004). Light and frequent irrigation is commonly used with small amounts of water, 0.3 to 0.6 cm, every day or every other day.

Common perceptions of light and frequent irrigations are that they promote shallow rooting in turfgrass thereby making the turf more susceptible to dry soil conditions. Furthermore, frequent irrigation applications are often implicated in increased weed interference. Despite all the negative effects put forth for light frequent irrigation applications there are some positive effects reported. Melvin (1991) investigated effects of frequent and infrequent irrigation to turfgrass rooting depth and thatch thickness of Kentucky bluegrass. He found no differences between frequent and infrequent irrigation for rooting depth of Kentucky bluegrass although Smiley et al. (1980) reported that frequent irrigation results in shorter rooting depth of Kentucky bluegrass sod. Melvin also reported that daily irrigation treatments have also been shown to have a smaller thatch layer than weekly irrigation treatments. Research by Melvin and Vargas (1994) revealed that light and frequent irrigation treatments, 0.3 cm every day at 12 p.m., reduced the symptoms associated with necrotic ring spot (*Leptosphaeria korrae*). Jiang et al. (1998) also found that a light daily irrigation resulted in higher turfgrass quality, and reduced brown patch incidence when compared to deep infrequent irrigation based upon returning 80% of evapotranspiration weekly. Karnok and Tucker (1999) found that light and frequent irrigation decreased the symptoms of localized dry spot on creeping bentgrass (*Agrostis stolonifera*). Starrett et al. (1996) concluded that light and frequent irrigation had less pesticide leaching than deep and infrequent irrigation.

Although common irrigation recommendation for turfgrass is deep and infrequent irrigation, the recommendation is not proper for all turfgrass management. The objective of this study was to determine irrigation and nutrient recommendation for three turfgrass species.

LITERATURE REVIEW

Water is a necessary component for turfgrass growth. Water is usually limited in the arid areas and is a major fraction of turfgrass maintenance budget.

Irrigation is an artificial application of water to the soil and usually used to assist in growing crops in dry areas and during periods of inadequate rainfall (Beard, 2005). Irrigation requirements vary with turfgrass species, soil type, and weather condition (Beard, 1973). Turfgrass usually requires 2.5 to 3.8 cm of water per week for normal maintenance condition. This can come from rainfall, irrigation, or a combination of the two (Christians, 2004). Turfgrasses use only 1% of this amount water for growth and development (Shearman, 1988), while approximately 99% of water is lost through air or soil.

Factors affecting evapotranspiration (ET) rate

Total water used by turfgrass is defined as the total amount of water required for growth plus the sum of water loss from soil evaporation and plant transpiration referred to evapotranspiration (ET) (Beard, 1973). There are several factors that influence ET rate. Turfgrass species is one of the most important factors for ET rates. Average ET rates for warm-season grasses are 0.25 to 0.8 cm per day (Huang and Fry, 1999). Cool-season grasses have higher ET rates than warm-season grasses (Casnoff et al., 1989). Because warm-season grasses have a more efficient system of photosynthesis, cool-season grasses require more water to produce dry matter through photosynthesis (Hull, 1996). The turfgrass species categories with ET rates for cool-season grasses have been reported by previous researches. Tall fescue (*Festuca arundinacea Schreb.*), Kentucky bluegrass

(*Poa pratensis* L.), annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L.) had the highest ET rates. Rough bluegrass (*Poa trivialis* L.) and perennial ryegrass (*Lolium perenne* L.) were the middle group. Chewings fescue (*Festuca rubra* L. subsp. Fallax)), hard fescue (*Festuca brevipila* R.) and red fescue (*Festuca rubra* L. subsp. rubra) had the lowest ET rates (Minner, 1984; Aronson et al., 1987; Beard and Kim, 1989). Although turfgrass species is an important factor for ET rates, ET rates will vary under different environmental, climatic conditions, and cultural management (Aronson et al., 1987).

In addition to turfgrass species, environmental factors that include relative humidity, temperature, day length, wind, and soil water content have great influence on ET. Humidity is related to water loss from the surface of plant leaves due to the vapor pressure gradient between the plant leaf and atmosphere (Fry and Huang, 2004). Under dry conditions and low relative humidity, transpirational water loss is stimulated by a large vapor pressure gradient between the leaf and atmosphere. In this condition, the plant is efficient at cooling itself. In contrast, the vapor pressure between the leaf and atmosphere is diminished under high relative humidity. Thus, the plant has reduced ability for cooling itself under high relative humidity.

Wind is also a factor that affects ET rate. The plant leaf is surrounded by an air boundary layer of air and water vapor molecules that protect plant leaf from water loss. This air boundary is interrupted by wind which subsequently causes an increased ET rate. In high temperature areas like the southern United States, bentgrass putting greens can be located in low areas which are deficient in wind movement and result in increased air and soil temperature and heat stress (Fry and Huang, 2004). The critical effects of increasing temperature and heat stress have been reported to be shoot and root growth reduction with increasing air or soil temperatures above optimums (Huang and Gao, 2000; Xu and Huang, 2000). Fans and syringing are often used to promote ET rate and alleviate heat stress on bentgrass putting green. Guertal and Han (2002) reported that both the fan and syringe treatments had the effect of cooling soil temperature and the residual effects lasted four hours after fans had stopped running. However, the effects of fans and syringing was decreased when air temperature were lower than 32.2 °C.

Irrigation frequency

It has been suggested that both irrigation rate and timing can be determined through collecting meteorological data such as air temperature, vapor pressure, wind speed, and net radiation to estimate daily ET rate. Plant-based measurements that can be used to determine the water status of plants include leaf water potential, stomatal conductance, and canopy temperature (Brown et al., 2004; DaCosta and Huang, 2006). While these methods provide valuable information that can be used to determine the need for irrigation, they are time consuming and require numerous samples to characterize the variations across a site (Jackson, 1982). Appropriate water management is critical to retain turfgrass quality especially during summer months. The interest of developing water use efficiency has increased since water conservation has been mandated and if not managed well can cause reduction in turfgrass quality which is not desirable. The two most common irrigations during summer months are deep and infrequent and light and frequent irrigation. Light and frequent irrigation is common for most golf courses in order to minimize the time of wet soil and leaf wetness duration. In contrast, deep and infrequent irrigation is typically recommended to promote deeper root system and to tolerate drought stress.

Common irrigation recommendations for turfgrass are to irrigate deep and infrequently in order to achieve a deep root system that will be better suited to endure prolonged drought conditions and maximize drought resistance (Qian and Fry, 1996). Fry and Huang (2004) defined deep and infrequent irrigation as irrigation to furnish water for root zone when the first signs of leaf wilt appear. In general, deep and infrequent irrigation refers to applying large amounts of irrigation, 1.3 to 2.5 cm or more, in a single irrigation event. A number of researches have been reported to support the benefits of deep and infrequent irrigation. Bennett and Doss (1960) reported infrequent irrigation promoted better root development for both cool- and warm-season grasses. Medison and Hogan (1962) found better root growth with infrequent irrigation for warm-season grasses and deeply and infrequently irrigated bentgrass produced higher levels of water soluble carbohydrate (Fu and Dernodeden, 2008). Jordan et al. (2003) investigated the responses of creeping bentgrass that was intensively managed with irrigation frequencies of every four days, every day, or every other day, and found creeping bentgrass with every four days irrigation had greater turfgrass quality, shoot density, and root length. However, when Johnson (2003) compared irrigation with 2-, 4-, and 6-day intervals for Kentucky bluegrass (*Poa pratensis*), tall fescue (*Festuca arundinacea*), prairie junegrass (*Koeleria macrantha*), and buffalograss (*Buchloe dactyloides*), he reported that irrigation of 2-day interval produced greater turfgrass quality as compared to irrigation of 4- or 6-day intervals.

The effects of deep and infrequent irrigation on rooting depth have been well documented. Madison and Hagan (1962) found that Kentucky bluegrass maintained at a higher mowing height and infrequent irrigation had a deeper root system. They also found frequent irrigation resulted in shallower and sparser rooting. Mantell (1966) reported infrequent irrigation produced deeper root system of kikuyugrass (*Pennisetum clandestinum*). Doss et al. (1960) found that rooting depth for warm-season grasses was increased with longer interval of irrigation events. Qian and Fry (1996) found deep and infrequent irrigation to zoysiagrass decreased shoot growth, increased root elongation, and drought stress. Bennett and Doss (1960) found deeper tall fescue root length was promoted by reducing irrigation frequency that had longer periods of dry soil between irrigation events.

The relation between irrigation frequency and water use efficiency has been shown in the previous researches. Doss et al. (1964) reported ET rate was highest when water was unlimited but ET rate was reduced with increasing irrigation interval. Morgan et al. (1966) stated ET rate was higher when an irrigation program was used instead of tensiometer-guided irrigation because soil surface remained wetter. Brian et al. (1981) investigated growth rate of 11 turfgrasses including warm- and cool-season grasses with treatment of mowing height, irrigation frequency, and soil moisture. They found lower irrigation frequency reduced water use for both warm- and cool-season grasses. Peacock and Dudeck (1984) examined physiological response of St. Augustinegrass (*Stenotaphrum secundatum*). Peacock and Dudeck (1984) found less irrigation frequency reduced ET rate without a significant reduction in turfgrass quality.

Although the previous researches have shown the merits of deep and infrequent irrigation, deep and infrequent irrigation is not recommended for all turfgrass management systems. Turfgrass grown on sandy soils should be irrigated with smaller amounts of water more frequently as deep infrequent irrigations could potentially result in losses of irrigation water through leaching. Also, turfgrass grown on fine textured soils with low infiltration rates should be irrigated with smaller amounts of water more frequently to avoid run-off and puddling on the surface. The alternative to deep and infrequent irrigation is light and frequent irrigation. Light and frequent irrigation would be defined as applying small amounts of water, such as 0.3 to 0.6 cm, every day or every other day. Common perceptions of light and frequent irrigations are that they promote shallow rooting in turfgrass thereby making the turf more susceptible to dry soil conditions. Furthermore, frequent irrigation applications are often implicated in increased weed interference. Despite all the negative effects put forth for light frequent irrigation applications there are some positive effects. Research by Melvin and Vargas (1994) revealed that light and frequent irrigation treatments (0.3 cm every day at 12 p.m.) reduced the symptoms associated with Necrotic Ring Spot. Jiang et al. (1998) also found that a light daily irrigation resulted in higher turfgrass quality, and reduced brown patch incidence when compared to deep infrequent irrigation based upon returning 80% of evapotranspiration weekly. Turfgrass that received daily irrigation treatments have also been shown to have a smaller thatch layer than weekly irrigation treatments (Melvin, 1991). Karnok and Tucker (1999) found that light and frequent irrigation decreased the symptoms of localized dry spot on creeping bentgrass (*Agrostis stolonifera*). Starrett et al. (1996) concluded that light and frequent irrigation had less pesticide leaching ranged from 0 to 0.4 percent averaged than deep and infrequent irrigation that had 0.2 to 7.7 percent of pesticide leaching.

MATERIALS AND METHODS

In spring 2005, research was initiated at the Hancock Turfgrass Research Center on the campus of Michigan State University in East Lansing, Michigan. Each plot size for the study was 3.7 by 3.7 m. Irrigation and fertility treatments were initiated on Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea*), and a mixture of 40% Kentucky bluegrass, 25% creeping red fescue (*Festuca rubra* L.), 20% perennial ryegrass (*Lolium perenne* L.), and 15% Chewings fescue (*Festuca rubra* L. ssp. *Commutata*) on 25 April 2005. The three irrigation treatments were none (precipitation only), 0.5 cm applied every other day, and 1.8 cm applied once a week at one irrigation event. All irrigation treatments were applied at 6:00 a.m. The treatment list and application timing are listed in Table 1. The nitrogen (N) treatments were 98, 156, and 208 kg N ha^{-1} yr^{-1} for the low, medium, and high N rate treatments, respectively. The low, medium, and high N treatments were applied over 2, 4, and 6 applications, respectively. Nitrogen was applied using a mixture of sulfur coated urea (SCU) and urea at a ratio of 25% SCU to 75% urea. The potassium (K) applied from muriate of potash (0-0-60) at a ratio of 2:1 (N:K) for all treatments was applied. There was no phosphorus treatment for the study. All fertilizer was granular type and applied using a drop fertilizer spreader (Gandy 24H13, Gandy Company). Immediately following each fertilizer application, 1.3 cm of irrigation was applied.

The turfgrass was mowed weekly and clippings returned to the plots. Turfgrass color was measured by visual evaluation every two weeks from 2005 through 2006 using a scale of 1 to 9 (1=straw brown, 6=acceptable, and 9=dark green). Turfgrass quality ratings were measured by visual evaluation from 2005 and 2006 using a scale of 1 to 9

Table 2-1. Treatment list and application plan.

Irrigation	Species	N rate (kg ha^{-1} yr^{-1})	K_2O rate (kg ha^{-1} yr^{-1})	Application month‡						
				5	6	7	8	9	10	11
Precipitation only	Lawn mix†	98	49	×				×		
Precipitation only	Lawn mix	156	78	×	×			×	×	
Precipitation only	Lawn mix	208	104	×	×	×		×	×	×
Precipitation only	Tall fescue	98	49	×				×		
Precipitation only	Tall fescue	156	78	×	×			×	×	
Precipitation only	Tall fescue	208	104	×	×	×		×	×	×
Precipitation only	K. bluegrass	98	49	×				×		
Precipitation only	K. bluegrass	156	78	×	×			×	×	
Precipitation only	K. bluegrass	208	104	×	×	×		×	×	×
Every other day	Lawn mix	98	49	×				×		
Every other day	Lawn mix	156	78	×	×			×	×	
Every other day	Lawn mix	209	104	×	×	×		×	×	×
Every other day	Tall fescue	98	49	×				×		
Every other day	Tall fescue	156	78	×	×			×	×	
Every other day	Tall fescue	209	104	×	×	×		×	×	×
Every other day	K. bluegrass	98	49	×				×		
Every other day	K. bluegrass	156	78	×	×			×	×	
Every other day	K. bluegrass	209	104	×	×	×		×	×	×
Weekly	Lawn mix	98	49	×				×		
Weekly	Lawn mix	156	78	×	×			×	×	
Weekly	Lawn mix	209	104	×	×	×		×	×	×
Weekly	Tall fescue	98	49	×				×		
Weekly	Tall fescue	156	78	×	×			×	×	
Weekly	Tall fescue	209	104	×	×	×		×	×	×
Weekly	K. bluegrass	98	49	×				×		
Weekly	K. bluegrass	156	78	×	×			×	×	
Weekly	K. bluegrass	209	104	×	×	×		×	×	×

† Lawn mix is a turfgrass mixture of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Application schedule for 2006. In 2005, the first treatment was applied 25 April.

(1=poor, 6=acceptable, and 9=best). Turfgrass clippings were collected every two weeks from a 3.8 m^2 area of each plot, dried at 67 °C for 48 hours, weighed and analyzed for nitrogen, phosphorus, and potassium using Dumas method (AOAC 968.06). Soil samples were taken every month at the depth of 0 to 10 cm and analyzed for nitrate nitrogen, ammonium nitrogen, phosphorus and potassium levels. A cadmium reduction method was used to analyze nitrate nitrogen (Huffman and Barbarick, 1981) and the Salicylate Method was used for ammonium nitrogen (Nelson, 1983). The extractant of 1M NH_4OAc was used for soil K analysis (Warncke and Brown, 1998). Volumetric water content (%) in the soil was measured at the depth of 12 cm every two weeks by Time Domain Reflectometry (Field Scout TDR-300, Spectrum Technologies).

The experimental design was a randomized complete-block design with a split-plot arrangement and three replications. The irrigation, species, and N rate treatments were arranged in a 3^k factorial. Analysis of variance (ANOVA) was performed on transformed data using Statistical Analysis Systems design with k=3 (Montgomery, 1985). The following factors were used in the study.

1. Three irrigation treatments were precipitation only, 0.5 cm application every other day, and 1.8 cm application once a week

2. Turfgrass types were Kentucky bluegrass, tall fescue, and a lawn mix.

3. Fertilizer rates were 98, 156, and 208 kg N ha^{-1} yr^{-1} for the low, medium, and high nitrogen (N) rate treatments.

PROC MIXED was used for multiple factor analyses of variance (SAS Institute Inc., 2001). Fisher's least significant difference (LSD) was used for mean separation, when effects were significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

Turfgrass Color

There was a significant irrigation by species interaction for the September 2005 and August 2006 ratings (Table 2). For both rating dates, when irrigation was applied there was no significant difference in turfgrass color for any turfgrass species (Figure 1). When turfgrass received only precipitation, tall fescue and Kentucky bluegrass had higher turfgrass color ratings than the lawn mixture. The lawn mixture had the poorest turfgrass color without irrigation. When irrigation was applied, the lawn mixture had the greatest improvement in turfgrass color.

There was a significant species by N rate interaction for June and July in both 2005 and 2006. For these sampling dates, tall fescue had the highest or equal to the highest turfgrass color rating at any N rate (Figure 2). Tall fescue had an acceptable color rating of six for any N rate for June and July in both 2005 and 2006. Turfgrass color ratings less than six were found only for the low N rate treatment with the lawn mixture and for Kentucky bluegrass in July 2006. To produce acceptable turfgrass color, the medium or high N rates are required for the lawn mixture when species by N rate interactions were found.

There were significant irrigation, species, and N rate main effects for turfgrass color. In 2005, the weekly and every other day irrigation treatments had the highest turfgrass color ratings for the July, August, and September rating dates (Table 3). There were no significant differences between the weekly and every other day irrigation treatments for turfgrass color throughout the research. The weekly and every other day irrigation treatments had turfgrass color ratings greater than six throughout the research.

Table 2-2. Analysis of variance table for turfgrass color.

Source	df	May	June	July	Aug.	Sep.	Oct.
		----------------------------		2005	--------------------------------		
Irrigation (I)	2	NS	NS	*	*	**	NS
Species (S)	2	**	**	**	*	**	NS
I x S	4	NS	NS	NS	NS	*	NS
Nitrogen Rate (NR)	2	**	**	**	**	NS	**
I x NR	4	NS	NS	NS	NS	NS	NS
S x NR	4	NS	**	*	NS	NS	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS
		----------------------------		2006	--------------------------------		
Irrigation (I)	2	NS	NS	*	*	NS	NS
Species (S)	2	NS	**	**	**	**	**
I x S	4	NS	NS	NS	**	NS	NS
Nitrogen Rate (NR)	2	*	**	**	**	*	NS
I x NR	4	NS	NS	NS	NS	NS	NS
S x NR	4	NS	**	*	NS	NS	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

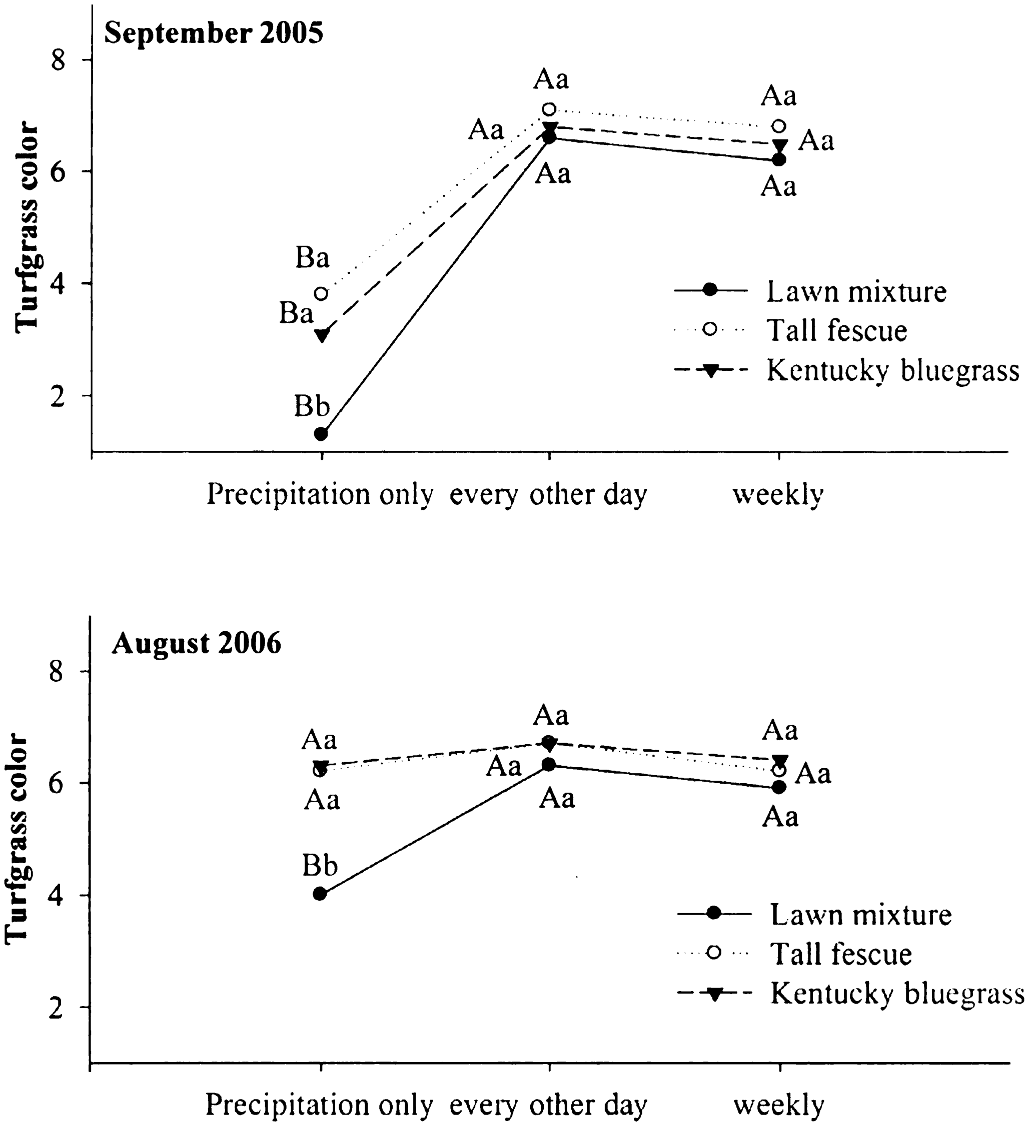

Figure 2-1. Irrigation × species interaction for turfgrass color for 2005 and 2006. Means with the same upper case letters are not significantly different among irrigation treatments according to Fisher's LSD test (P=0.05). Mean with the same lower case letters is not significantly different among species according to Fisher's LSD test (P=0.05).

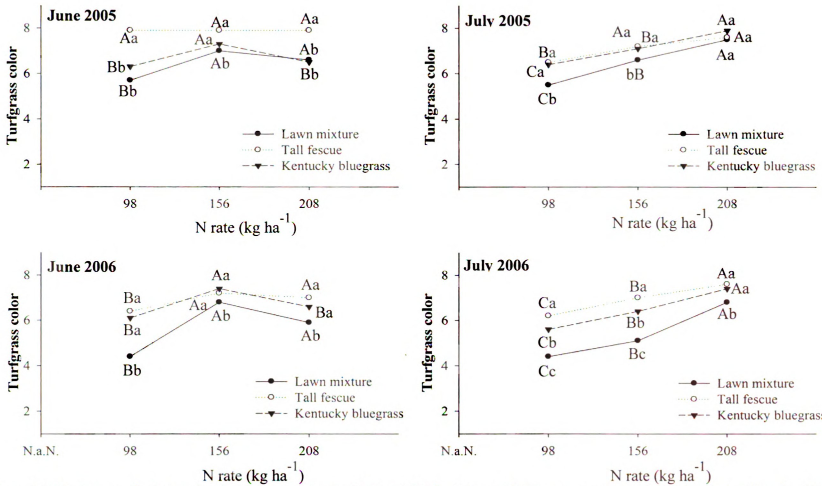

Figure 2-2. N rate × species interaction for turfgrass color for 2005 and 2006. Mean with the same upper case letters is not significantly different among N rate treatments according to Fisher's LSD test (P=0.05). Mean with the same lower case letters is not significantly different among species according to Fisher's LSD test (P=0.05).

Table 2-3. Mean turfgrass color for irrigation main effect.

Irrigation	May	June	July	Aug.	Sep.	Oct.
			2005			
Precipitation only	6.8†	6.7	6.5 b‡	5.8 b	2.7 b	7.5
0.5 cm every other day	6.8	7.2	7.1 a	6.9 a	6.8 a	7.5
1.8 cm weekly	6.9	7.1	7.1 a	7.0 a	6.5 a	7.4
			2006			
Precipitation only	7.4	6.2	5.5 b	5.5 b	6.1	6.7
0.5 cm every other day	7.1	6.6	6.7 a	6.6 a	6.4	7.0
1.8 cm weekly	7.5	6.5	6.7 a	6.2 a	6.3	7.3

† Tufgrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

For the precipitation only treatment in 2005, the turfgrass color rating in August and September was less than six. The turfgrass color rating for September 2005 was the lowest rating for any treatment during 2005 and 2006. The low turfgrass color rating was caused by a combination of low precipitation and high potential evaportranspiration (ETp). Precipitation for August 2005 was only 3.3 cm, the ETp was 11.0, and the water deficit was -7.7 cm (Figure 3). Under this dry condition and high ETp rate, proper turfgrass growth could not be expected and additional irrigation would be required to produce acceptable turfgrass color.

In 2006, both irrigation treatments had turfgrass color greater than six. However, the precipitation only treatment had unacceptable color ratings for the July and August rating dates. The precipitation only treatment had acceptable color ratings on eight of 12 rating dates for two years. The precipitation only treatment had less than acceptable ratings for turfgrass color on August 2005, September 2005, July 2006 and August 2006. The September 2005 rating was the lowest color rating for two years. Turfgrass color was rated on 6 September 2005, and thus was affected by weather conditions and treatment effects of August 2005. Total amount of water received for August 2005 was -7.7 due to lack of precipitation and high ETp rate of 11.0 cm. In addition to precipitation and ETp, turfgrass may need additional water when the high temperature exceeds optimum temperature for turfgrass growth during summer months. Fry and Huang (2004) reported high temperature stress can negatively affect turfgrass growth regarding transpiration and water use. The optimum temperature for shoot growth of cool-season turfgrasses is 15 to 23 °C (Beard, 1973). The maximum temperature for July and August in both 2005 and 2006 exceeded optimum temperature for turfgrass growth. The ETp for

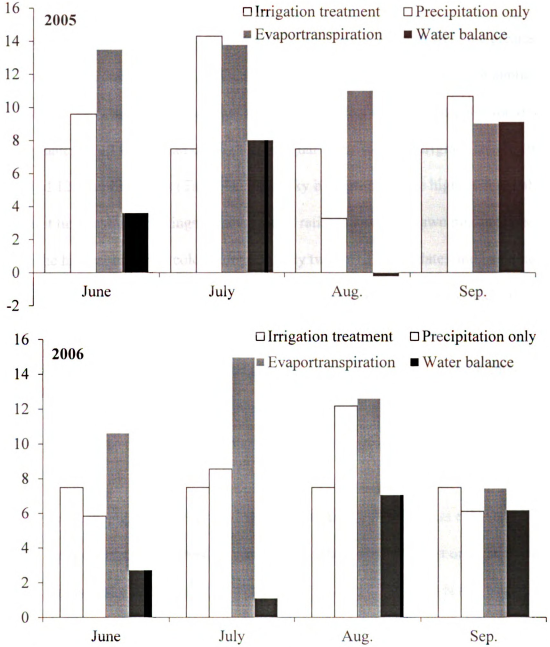

Figure 2-3. The amount of water received from precipitation and irrigation treatment. Evaportranspiration rate was included to caculate water balance. Irrigation treatment means either weekly and every other day treatments. The plots with weekly and every other day irrigation treatment received the same amount of water over time, only the application timing interval varied. Water balance was calculated from precipitaton, irrigation, and ETp (Water balance = precipitation + irrigation – ETp).

July and August in 2005 was 13.8 and 11.0 cm, respectively. The ETp for July and August in 2006 was 15.0 and 12.6 cm, respectively. These ETp rates were the greatest rate for each year, and indicate significant water stress when irrigation was not applied.

There was a significant turfgrass species main effect for turfgrass color for 10 of 12 rating dates. Tall fescue had the highest or equal to the highest turfgrass color ratings on eight of 12 sampling dates (Table 4). Kentucky bluegrass had the highest or equal to the highest turfgrass color ratings on seven of 12 rating dates. The lawn mixture was equal to the highest turfgrass color ratings on only two of 12 rating dates and had a rating less than six on four of 12 sampling dates. In contrast, Kentucky bluegrass and tall fescue had color ratings less than six on two and one of 12 rating dates, respectively. There were significant differences in turfgrass color between tall fescue and Kentucky bluegrass on May 2005, June 2005, September 2005, September 2006 and October 2006. Tall fescue had greater turfgrass color than Kentucky bluegrass on three of 12 rating dates.

There were significant N rate treatment main effects for turfgrass color on 10 of 12 rating dates (Table 5). The medium N rate treatment had the highest or equal to the highest turfgrass color ratings on four of 10 rating dates while the high N rate treatment had the highest or equal to the highest turfgrass color ratings on five of 10 rating dates. There were significant differences between the medium and high N rate treatments on seven of 12 rating dates. The high N rate treatment had higher turfgrass color ratings than the medium N rate treatment for the July and August ratings in both 2005 and 2006. The medium and high N rate treatments had color ratings greater than six on all rating dates except September 2005. The low turfgrass color rating for September 2005 may

Table 2-4. Mean turfgrass color for turfgrass type main effect.

Species	May	June	July	Aug.	Sep.	Oct.
			2005			
Lawn mixture†	7.3‡ a§	6.4 b	6.5 b	6.2 b	4.7 c	7.5
Tall fescue	7.8 a	7.9 a	7.1 a	6.8 a	5.9 a	7.3
Kentucky bluegrass	5.4 b	6.7 b	7.1 a	6.6 ab	5.5 b	7.6
			2006			
Lawn mixture	7.2	5.7 b	5.4 b	5.4 b	6.0 b	7.1 a
Tall fescue	7.6	6.9 a	6.9 a	6.4 a	6.1 b	6.5 b
Kentucky bluegrass	7.2	6.7 a	6.5 a	6.5 a	6.7 a	7.4 a

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Tufgrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

Table 2-5. Mean turfgrass color for nitrogen rate main effect.

N rate	May	June	July	Aug.	Sep.	Oct.
	------------------------------		2005	------------------------------		
98†	7.1‡ a§	6.6 c	6.1 c	6.1 c	5.3	7.3 b
156	6.8 b	7.4 a	7.0 b	6.4 b	5.4	7.7 a
208	6.6 b	7.0 b	7.7 a	7.2 a	5.4	7.4 b
	------------------------------		2006	------------------------------		
98†	7.5 a	5.7 c	5.4 c	5.8 b	6.1 b	7.0
156	7.3 b	7.1 a	6.2 b	6.0 b	6.3 a	7.1
208	7.3 b	6.5 b	7.3 a	6.5 a	6.4 a	7.0

† N rate units are kg ha^{-1} yr^{-1}.

‡ Tufgrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

have resulted from high ETp rate from the previous month. The total water balance for August 2005 was -7.7 cm (Table 19). In addition to high ETp rate, there were no N applications in August. The combination of weather condition and no N application affected turfgrass color rating for September 2005. In contrast, the water deficit for September 2006 was -0.4 cm (Table 19). Turfgrass color in September 2006 was greater than six due to an unscheduled fertilizer application of 49 kg N ha-1 to the entire plot area two weeks prior to ratings.

The low N rate treatment had turfgrass color ratings less than six on four of 12 rating dates. However, the low N rate treatment had the highest turfgrass color rating for the May 2005 and 2006 ratings. In June 2005 and 2006, the medium N rate had the highest turfgrass color. The high N rate had the highest turfgrass color for July and August for both 2005 and 2006. These results are due to the timing and amount of N applied per applications (Table 1). For the low, medium, and high N rate treatment each application was 49, 39, and 35 kg N ha^{-1}. For the turfgrass that received the greatest amount of N in a single application, the low N treatment had the highest turfgrass color for May 2005 and 2006. In June, the medium N rate treatment had the highest turfgrass color rating in June because of greater amount N of the single application than that of the high N rate treatment. There was no application of the low N rate treatment in June. In July, there was only the high N rate treatment. The difference in N application timing among the N rate treatments likely had significant effects on turfgrass color differences from May to August.

Turfgrass Quality

There was a significant species by N rate interaction for the June 2005 and 2006 rating dates (Table 6). Tall fescue had the highest or equal to the highest turfgrass quality for any N rate in June 2005 and 2006 (Figure 4). Tall fescue had turfgrass quality greater than six for both June 2005 and 2006. Turfgrass quality of the lawn mixture was improved from unacceptable to greater than acceptable turfgrass quality with an N rate increase from low to medium in June 2005 and 2006. The medium and high N rate treatments had turfgrass quality greater than six with all turfgrass types.

There was a significant irrigation by species interaction for the September 2005 and August 2006 ratings. In September 2005, none of the turfgrass species had acceptable quality ratings without irrigation (Figure 5). All species had turfgrass quality greater than six when irrigated. There were no differences between the every other day and weekly irrigation treatments. For the precipitation only treatment tall fescue had turfgrass quality greater than six in August 2006. This result is not unexpected because tall fescue has higher drought resistance and heat tolerance when compared to other commonly used cool-season turfgrasses (Beard, 1973). However, tall fescue had turfgrass quality less than six with the amount of precipitation of 3.3 cm in August 2005. In contrast to tall fescue, the lawn mixture had turfgrass quality less than six in August 2006.

Two way interactions were significant on only four of 12 rating dates. Throughout the research there were significant irrigation, species, and N rate main effects. There was an irrigation main effect on four of 12 rating dates (Table 7). In 2005, the weekly and every other day irrigation treatments had the highest turfgrass quality ratings for August and September. There were no significant differences between the weekly

Table 2-6. Analysis of variance table for turfgrass quality.

Source	df	May	June	July	Aug.	Sep.	Oct.
		2005					
Irrigation (I)	2	NS	NS	NS	*	**	NS
Species (S)	2	**	**	**	NS	**	NS
I x S	4	NS	NS	NS	NS	*	NS
Nitrogen Rate (NR)	2	**	**	**	**	NS	**
I x NR	4	NS	NS	NS	NS	NS	NS
S x NR	4	NS	*	NS	NS	NS	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS
		2006					
Irrigation (I)	2	NS	NS	*	*	NS	NS
Species (S)	2	**	**	**	**	**	**
I x S	4	NS	NS	NS	**	NS	NS
Nitrogen Rate (NR)	2	NS	**	**	**	NS	NS
I x NR	4	NS	NS	NS	NS	NS	NS
S x NR	4	NS	**	NS	NS	NS	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

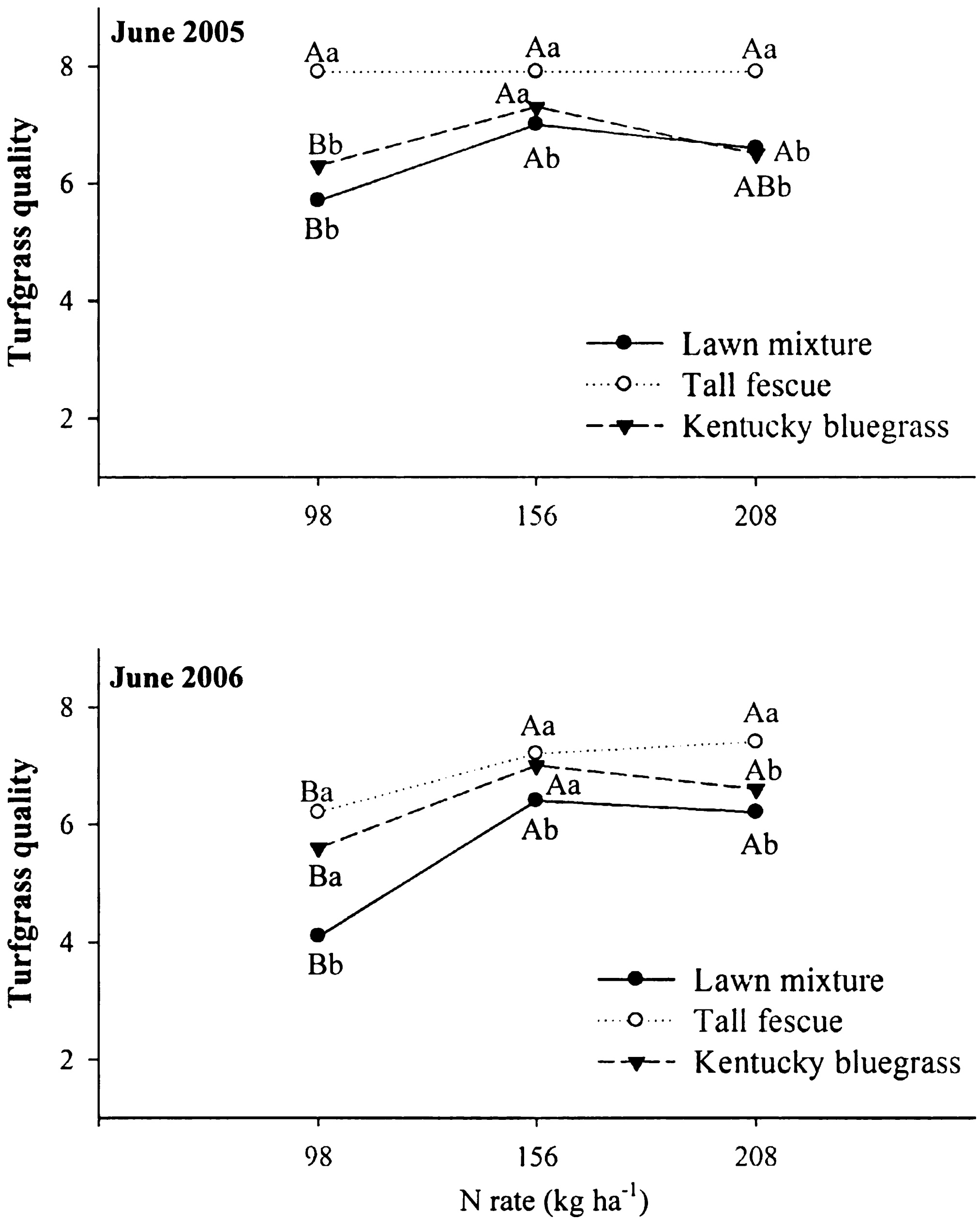

Figure 2-4. N rate × species interaction for turfgrass quality for 2005 and 2006. Mean with the same upper case letters is not significant among N rate treatments by Fisher's LSD test (P<0.05). Mean with the same lower case letters is not significant among species by Fisher's LSD test (P<0.05).

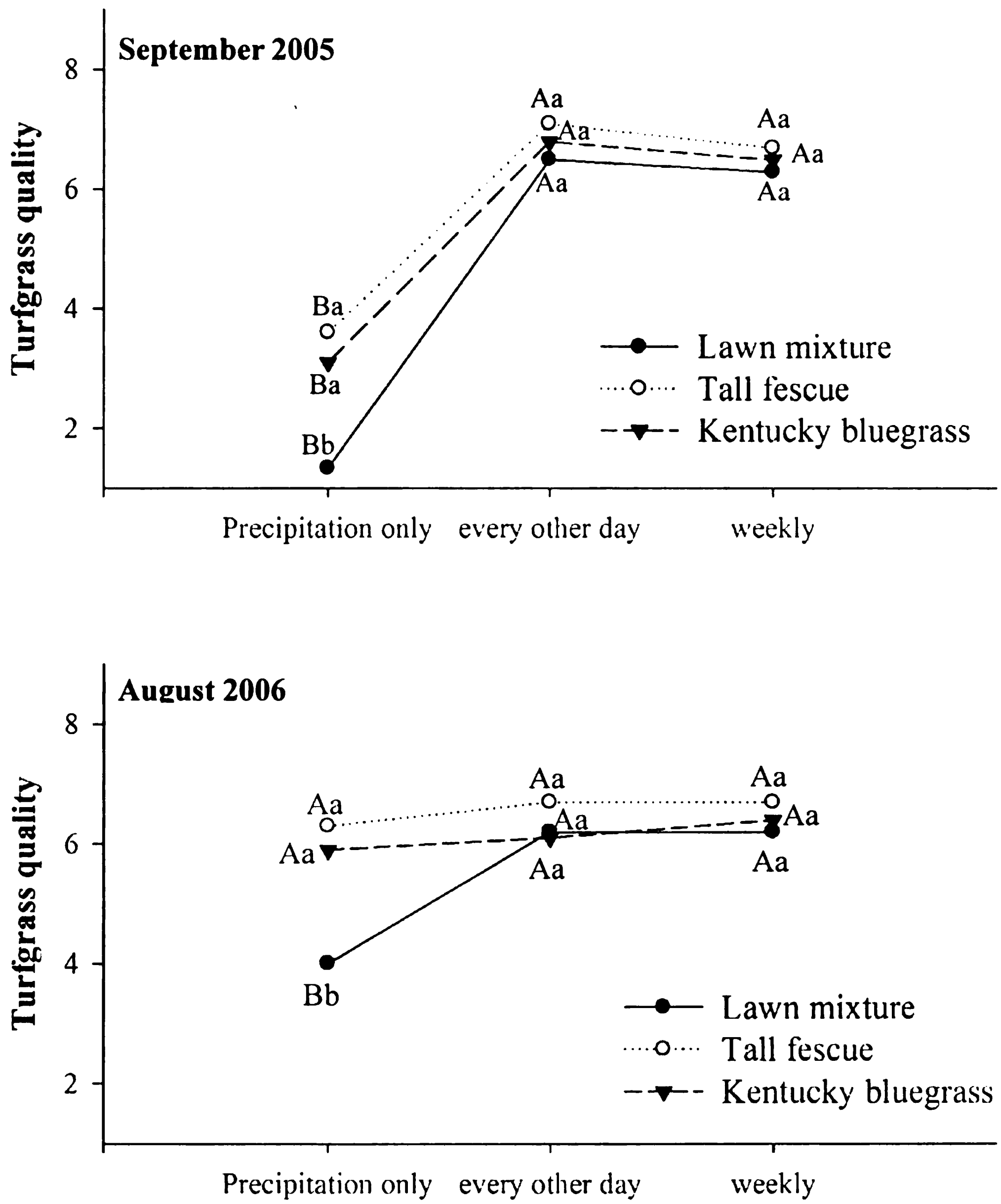

Figure 2-5. Irrigation × species interaction for turfgrass quality for 2005 and 2006. Mean with the same upper case letters is not significant among irrigation treatments by Fisher's LSD test ($P<0.05$). Mean with the same lower case letters is not significant among species by Fisher's LSD test ($P<0.05$).

Table 2-7. Mean turfgrass quality for irrigation main effect.

Irrigation	May	June	July	Aug.	Sep.	Oct.
	------------------------------		2005	-----------------------------------		
Precipitation only	6.2†	6.5	6.3	5.7 b‡	2.7 b	7.4
0.5 cm every other day	6.4	7.0	6.9	6.9 a	6.8 a	7.5
1.8 cm weekly	6.3	6.9	6.9	6.8 a	6.5 a	7.4
	------------------------------		2006	-----------------------------------		
Precipitation only	6.9	6.0	5.3 b	5.5 b	6.1	6.6
0.5 cm every other day	7.0	6.4	6.6 a	6.6 a	6.3	6.9
1.8 cm weekly	7.3	6.4	6.6 a	6.1 a	6.3	7.2

† Tufgrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

and every other day irrigation treatments on turfgrass quality throughout the research. For the precipitation only treatment, the turfgrass quality ratings in August and September were less than six.

In 2006, all irrigation treatments had turfgrass quality greater than six with the exception of the precipitation only treatment for July and August. The precipitation only treatment had acceptable quality ratings on eight of 12 rating dates during the research. If water resource is limited, and turfgrass quality for low maintenance in July and August are not important, the precipitation only treatment would be accepted for the area where the research was conducted. Richie et al. (2002) investigated the response of tall fescue to irrigation scheduling. They found plots irrigated with two irrigation events per week produced greater turfgrass quality than plots irrigated with three irrigation events per week. Johnson (2003) found that a two day irrigation interval produced greater turfgrass quality than four and six day irrigation intervals. Fry and Butler (1989) found similar results, tall fescue maintained high turfgrass quality by watering at 50 percent of estimated ETp every other day during summer months in Colorado, but weekly irrigation at this same level resulted in unacceptable turfgrass quality. However, we found no differences for turfgrass quality between every other day and weekly irrigation events. Qian and Fry (1996) concluded there were no differences on turfgrass quality between daily and infrequent irrigation at the first sign of leaf roll since the last irrigation.

There was a significant turfgrass species main effect on 10 of 12 rating dates (Table 8). Tall fescue had the highest or equal to the highest turfgrass quality ratings except for September and October 2006. The lawn mixture had the lowest or equal to the lowest turfgrass quality rating throughout the research. The water balance for August

Table 2-8. Mean turfgrass quality for species main effect.

Species	May	June	July	Aug.	Sep.	Oct.
	----------	----------	---------- 2005	----------	----------	----------
Lawn mixture†	7.0‡ b§	6.4 b	6.3 c	6.2	4.7 b	7.5
Tall fescue	7.9 a	7.9 a	7.1 a	6.7	5.8 a	7.3
Kentucky bluegrass	4.0 c	6.1 b	6.7 b	6.4	5.5 a	7.5
	----------	----------	---------- 2006	----------	----------	----------
Lawn mixture	6.8 b	5.3 b	5.3 c	5.4 b	5.9 b	6.9 b
Tall fescue	7.4 a	6.9 a	6.9 a	6.3 a	6.1 b	6.4 c
Kentucky bluegrass	7.0 b	6.7 a	6.3 b	6.4 a	6.7 a	7.4 a

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Tufgrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

2005 and July 2006 was low because of low precipitation (Figure 3). The ETp rate for August 2005 and July 2006 was 11.0 and 15.0 cm, respectively (Table 18 and Table 19). The water balance for August 2005 and July 2006 was -0.2 and 1.1 cm with irrigation, respectively. Without irrigation, the water balance for August 2005 and July 2006 were -7.7 and -6.4 cm, respectively. However, tall fescue had the highest quality for July 2006. The response of tall fescue to water deficit may result from deep rooting system of tall fescue that can reach water sources deeper in the soil profile (Qian et al., 1997). When performance of hybrid bluegrasses was compared with tall fescue and Kentucky bluegrass, tall fescue had the highest turfgrass quality without irrigation (Bremer et al., 2006). In the current research, there was a significant difference between tall fescue and Kentucky bluegrass on seven of 12 rating dates. Among these rating dates, tall fescue had greater turfgrass quality than Kentucky bluegrass on five of the seven rating dates. The lawn mixture had turfgrass quality less than six on five of 12 rating dates while tall fescue and Kentucky bluegrass had turfgrass quality ratings less than six on only one and two of 12 rating dates, respectively. Based on these results, regardless of irrigation treatments, tall fescue would be a better selection than lawn mixture to maintain high quality turfgrass.

There was a significant N rate main effect for turfgrass quality (Table 9). The medium N rate treatment had the highest or equal to the highest turfgrass quality rating on four of 12 rating dates. While the medium N rate treatment had the highest turfgrass quality on three rating dates during 2005, it had the highest turfgrass quality on only one date in 2006. The high N rate treatment had the highest turfgrass quality rating on four of 12 rating dates throughout the research. There were significant differences between the

Table 2-9. Mean turfgrass quality for nitrogen rate main effect.

N rate	May	June	July	Aug.	Sep.	Oct.
	------------------------------		2005	------------------------------		
98†	6.6‡ a§	6.5 b	6.0 c	6.1 c	5.3	7.2 b
156	6.3 ab	7.2 a	6.8 b	6.3 b	5.3	7.7 a
208	6.0 b	6.7 b	7.3 a	7.0 a	5.4	7.4 b
	------------------------------		2006	------------------------------		
98†	7.1	5.6 c	5.3 c	5.8 b	6.1	6.9
156	7.0	7.0 a	6.1 b	5.9 b	6.3	7.0
208	7.1	6.4 b	7.1 a	6.5 a	6.3	6.9

† N rate units are kg ha^{-1} yr^{-1}.

‡ Tufgrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

medium and high N rate on seven of 12 rating dates. The high N rate treatment had the highest turfgrass quality on July and August for both 2005 and 2006. The low N rate treatment had turfgrass quality less than six on four of 12 rating dates throughout the research. The medium and high N rate treatment produced turfgrass quality less than six on two and one of 12 rating dates for both 2005 and 2006, respectively. All N rate treatments had turfgrass quality ratings less than six on September 2005. Turfgrass quality for September 2005 was rated on 6 September 2005. Turfgrass quality for September 2005 should be affected from treatments and weather condition of the previous month. According to the application plan, there was no N application on August. In the case of low N rate treatment, there was a four month interval between applications because of two applications a year. In the case of the medium and high N rate treatments, there were three and two month intervals between applications because of four and six treatments per year, respectively. Acceptable turfgrass quality would not be expected with two to four month interval for N application.

In addition to no N application on August, the water balance was the lowest in August 2005 in both 2005 and 2006. Cool-season turfgrass during growing season under well-watered condition generally required average water use rate of 0.8 to 2.5 cm per day (Huang and Fry, 1999). However, the water balance calculated by precipitation and ETp was -0.2 cm per month with irrigation treatments and -7.7 cm per month without irrigation treatments in August 2005 (Figure 3). Additional irrigation is required for proper turfgrass growth under the condition. In September 2006, there was no significant difference among N rate treatments for turfgrass quality and all treatment had turfgrass quality greater than six because of an unscheduled fertilizer application of 49 kg N ha^{-1} to the entire plot area two weeks prior to ratings. Water balance was 7.1 cm per month with irrigation treatment and -0.4 cm per month without irrigation treatment for August 2006. Water balance was relatively higher in August 2006 than in August 2005. Based on the result of this study, the medium and high N rate would be recommended for higher turfgrass quality although there was turfgrass quality below acceptable rating of six with the medium and high N rate treatment.

Turfgrass clipping yields

There was a significant irrigation by species interaction for the August 2005, July, August, and October 2006 rating dates (Table 10). The precipitation only treatment had the lowest or equal to the lowest clipping yield for all species for these sampling dates except for October 2006 (Figure 6). In August 2005, the every other day irrigation treatment had higher clipping yields than the weekly irrigation treatment among all species. Qian and Fry (1996) reported clipping yield of zoysiagrass with daily irrigation was 30% higher than clipping yield with infrequent irrigation. However, there was no difference between the every other day and weekly irrigation treatment for clipping yield in August 2006. The precipitation amount in August 2006 was 12.2 cm while the plots received 3.3 cm of precipitation in August 2005. The every other day irrigation treatment had more effect on clipping yield than the weekly irrigation treatment under the weather condition of low precipitation level. With both every other day and weekly irrigation treatment, the lawn mixture had the highest clipping yields in August 2005. The lawn mixture had the highest or equal to the highest clipping yields with weekly irrigation treatment when irrigation by species interactions were found. There were no differences

Table 2-10. Analysis of variance table for clipping yield.

Source	df	May	June	July	Aug.	Sep.	Oct.	Total
		2005						
Irrigation (I)	2	NS	NS	*	**	*	NS	NS
Species (S)	2	**	**	**	**	**	**	**
I x S	4	NS	NS	NS	*	NS	NS	NS
Nitrogen Rate (NR)	2	**	**	**	**	**	**	**
I x NR	4	NS	NS	*	*	**	NS	NS
S x NR	4	NS	**	NS	NS	NS	*	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS	NS
		2006						
Irrigation (I)	2	ND†	NS	**	**	NS	NS	*
Species (S)	2	ND	**	**	**	**	**	**
I x S	4	ND	NS	*	*	NS	*	NS
Nitrogen Rate (NR)	2	ND	**	**	**	**	NS	**
I x NR	4	ND	NS	**	NS	**	NS	NS
S x NR	4	ND	NS	NS	*	NS	NS	NS
I x S x NR	8	ND	NS	NS	NS	NS	NS	NS

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

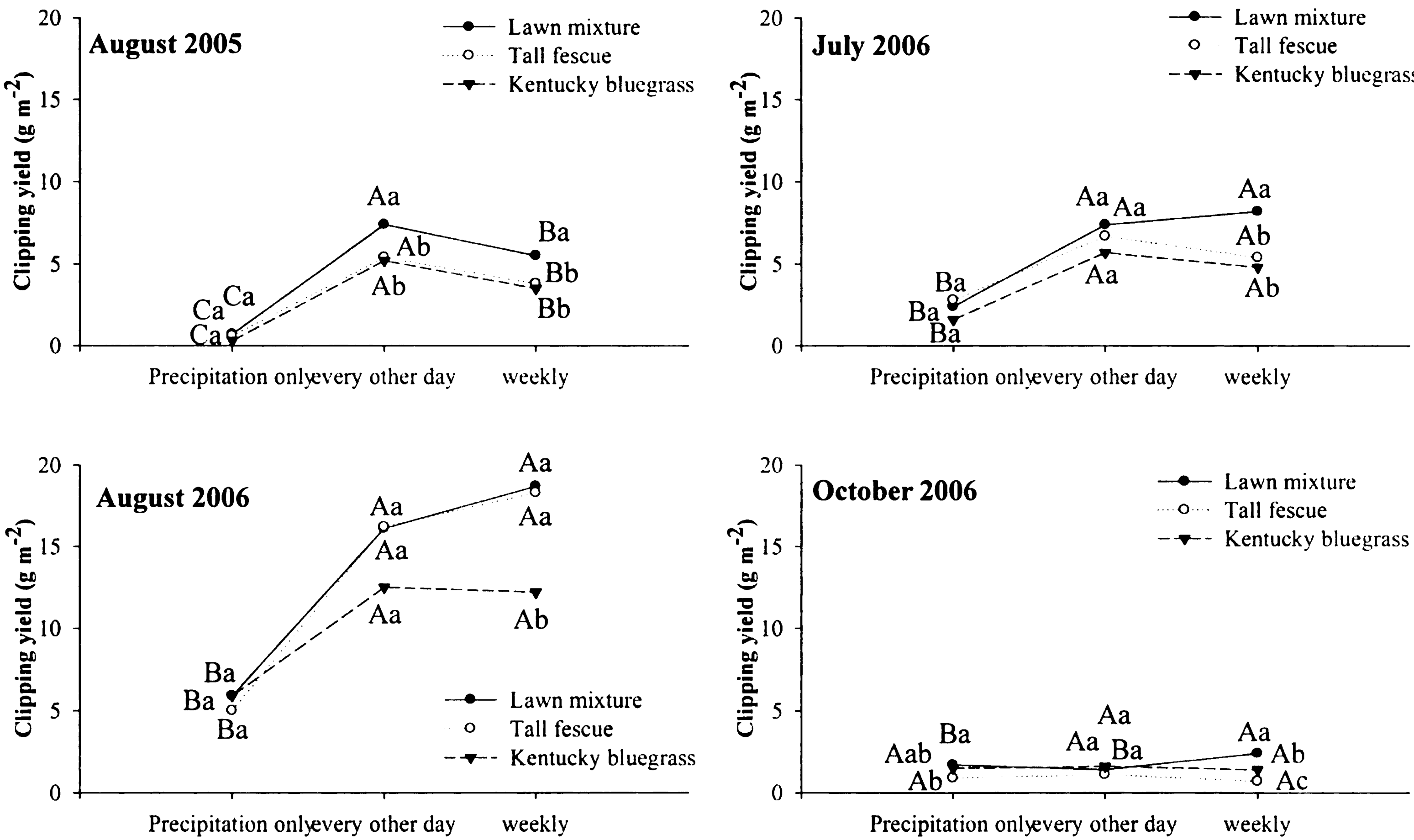

Figure 2-6. Irrigation × species interaction for clipping yield (g m^{-2}) for 2005 and 2006. Mean with the same upper case letters is not significantly different among irrigation treatments by Fisher's LSD test (P=0.05). Mean with the same lower case letters is not significantly different among species by Fisher's LSD test (P=0.05).

among species for clipping yields for the precipitation only treatment except for October 2006.

There was a significant species by N rate interaction on three of 12 sampling dates. Tall fescue had the highest or equal to the highest clipping yield at any N rate for June 2005 and August 2006 (Figure 7). Kentucky bluegrass had the lowest clipping yield at any N rate in June 2005 and the lowest or equal to the lowest clipping yield in October 2005 and August 2006. Overall, clipping yield was increased with N rate increase from the low to medium N rate.

There was a significant irrigation by N rate interaction on five of 11 sampling dates for turfgrass clipping yield. The precipitation only treatment had the lowest or equal to the lowest clipping yield at any N rate except for September 2005 and 2006 (Figure 8). The high N rate had the highest or equal to the highest amount of clipping yield at any irrigation treatment. Overall, clipping yields was increased with irrigation treatment and increase of N rate.

There was an irrigation main effect for clipping yield on five of 11 sampling dates (Table 11). The precipitation only treatment had the lowest or equal to the lowest clipping yield for all sampling dates when significant differences were found among irrigation treatments. The every other day and weekly irrigation treatments had the highest clipping yield on five and four of 11 sampling dates, respectively. There was only one sampling date when there was significant difference between the every other day and weekly irrigation treatments, August 2005. The every other day irrigation treatment had about 43 % more clipping yield than the weekly irrigation treatment in August 2005. The lowest water balance was in August 2005. The every other day

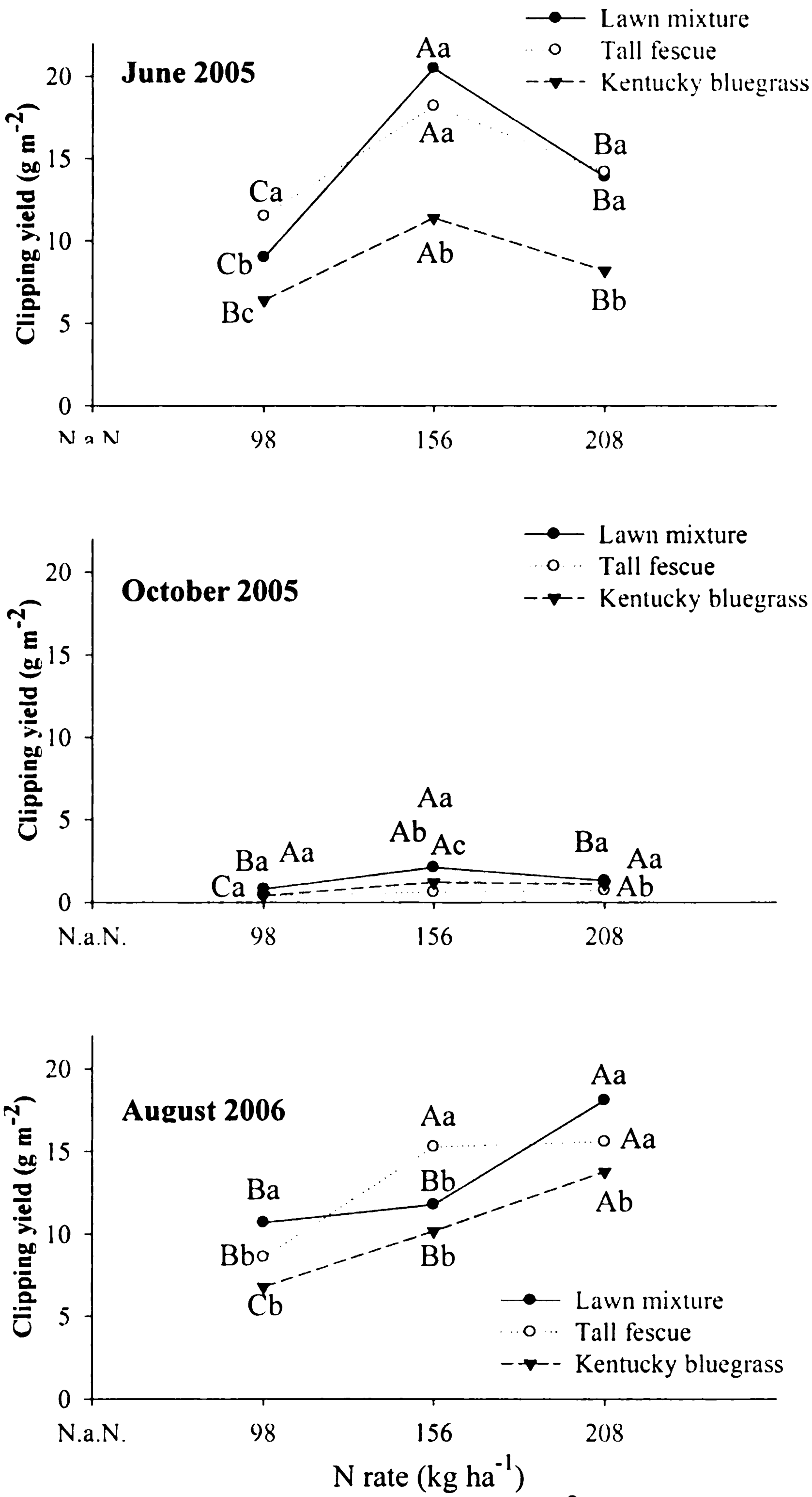

Figure 2-7. N rate × species interaction for clipping yield (g m^{-2}) for 2005 and 2006. Mean with the same upper case letters is not significant among N rate treatments by Fisher's LSD test ($P<0.05$). Mean with the same lower case letters is not significant among species by Fisher's LSD test ($P<0.05$).

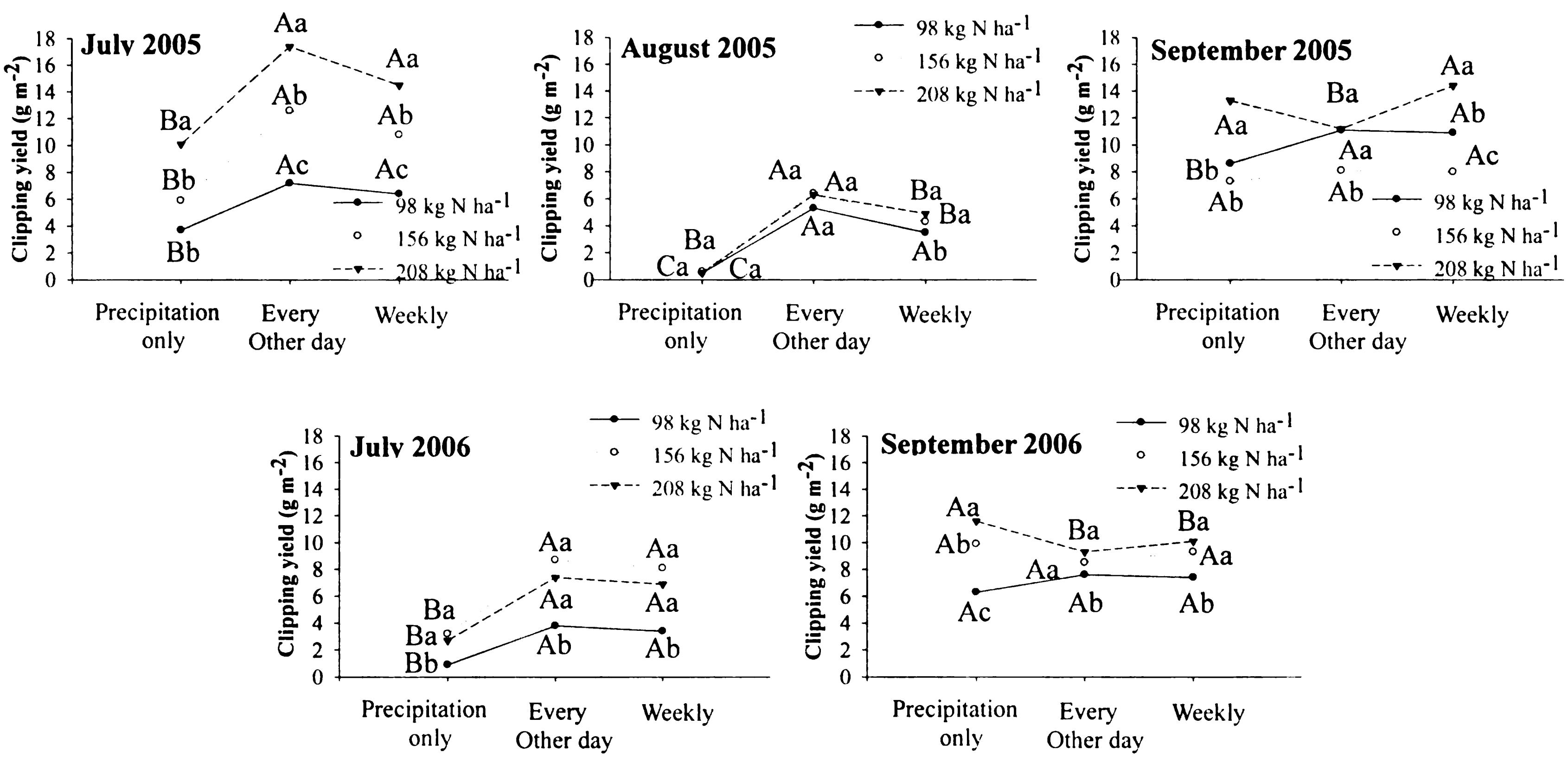

Figure 2-8. Irrigation × N rate interaction for clipping yield (g m^{-2}) for 2005 and 2006. Mean with the same upper case letters is not significantly different among irrigation treatments according to Fisher's LSD test (P=0.05). Mean with the same lower case letters is not significantly different among N rate treatments according to Fisher's LSD test (P=0.05).

Table 2-11. Mean turfgrass clipping yield for irrigation main effect.

Irrigation	May	June	July	Aug.	Sep.	Oct.	Total
				2005			
Precipitation only	23.7†	9.7	6.6 b‡	0.5 c	7.7 b	1.2	49.4
0.5 cm every other day	22.6	15.1	12.4 a	6.0 a	10.8 a	0.8	67.8
1.8 cm weekly	23.4	12.9	10.6 a	4.2 b	10.0 a	0.8	62.0
				2006			
Precipitation only	ND§	9.4	2.3 b	5.6 b	9.2	1.4	27.9 b
0.5 cm every other day	ND	12.5	6.6 a	14.9 a	8.5	1.4	43.9 a
1.8 cm weekly	ND	11.0	6.1 a	16.4 a	8.9	1.5	43.9 a

† Clipping yield units are g m^{-2}.

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

§ No data available.

irrigation was more effective for shoot growth than weekly irrigation when ETp replacement is insufficient to equal transpiration rate. According to Qian and Fry (1996), infrequent irrigation promotes faster shoot growth of turfgrass. They reported shoot growth of infrequently watered turfgrass was 24 % more than that of frequently watered turfgrass. There was no significant difference for total clipping yield in 2005. The every other day and weekly irrigation events had the highest total clipping yield in 2006. This result was probably due to an unscheduled fertilizer application of 49 kg N ha^{-1} to the entire plot area two weeks prior to ratings in August 2005.

There was a significant species main effect for clipping yield on all sampling dates (Table 12). The lawn mixture had the highest or equal to the highest clipping yield for all sampling dates. The highest total clipping yield was from the lawn mixture for two years. The lawn mixture had 110 and 26% more total clipping yield than Kentucky bluegrass in 2005 and 2006, respectively. The lawn mixture had 21 and 30% more total clipping yield than tall fescue in 2005 and 2006, respectively. The lawn mixture had a turfgrass quality rating of six on five of 12 rating dates while tall fescue and Kentucky bluegrass had turfgrass quality rating less than six on one and two of 12 sampling dates, respectively. The lawn mixture produced the lowest turf quality with the highest clipping yield which is undesirables for turfgrass management. Therefore, tall fescue or Kentucky bluegrass would be better selection than lawn mixture to promote turfgrass quality and reduce clipping yield.

There was a significant N rate main effect on 10 of 11 sampling dates (Table 13). The low N rate treatment had the highest or equal to the highest clipping yield on May and September 2005. These results were due to amount of applied per application

Table 2-12. Mean clipping yield for turfgrass type main effect.

Species	May	June	July	Aug.	Sep.	Oct.	Total
	2005						
Lawn mixture†	32.9‡ a§	14.5 a	11.9 a	4.5 a	12.9 a	1.4 a	78.0 a
Tall fescue	28.2 b	14.6 a	8.8 b	3.3 b	8.6 b	0.6 b	64.0 b
Kentucky bluegrass	8.6 c	8.7 b	8.9 b	3.0 b	7.0 c	0.9 b	37.1 c
	2006						
Lawn mixture	ND¶	12.9 a	6.0 a	13.6 a	10.9 a	1.8 a	45.2 a
Tall fescue	ND	8.7 b	4.9 b	13.2 a	7.0 c	0.9 b	34.7 b
Kentucky bluegrass	ND	11.3 a	4.1 c	10.2 b	8.7 b	1.5 a	35.8 b

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Clipping yield units are g m^{-2}.

§ Means in a column within a year followed by the same letter are not significant different according to Fisher's LSD ($P<0.05$).

¶ No data available.

Table 2-13. Mean clipping yield for nitrogen rate main effect.

N rate	May	June	July	Aug.	Sep.	Oct.	Total
				2005			
98†	24.9‡ a§	8.9 c	5.8 c	3.1 b	10.5 a	0.6 c	53.8 c
156	23.1 b	16.7 a	9.8 b	3.8 a	10.2 a	1.3 a	64.9 a
208	21.7 b	12.1 b	14.0 a	3.9 a	7.8 b	1.0 b	60.5 b
				2006			
98†	ND¶	10.1 b	2.7 c	8.7 c	7.1 c	1.3	29.9 c
156	ND	10.6 b	6.7 a	12.4 b	9.2 b	1.4	40.3 b
208	ND	12.1 a	5.7 b	15.8 a	10.3 a	1.6	45.5 a

† N rate units are kg ha^{-1} yr^{-1}.

‡ Clipping yield units are g m^{-2}.

§ Means in a column within a year followed by the same letter are not significant different according to Fisher's LSD (P<0.05).

¶ No data available.

because the single application of the low N rate treatment had the largest amount of N. However, the result in 2006 is different because of an unscheduled fertilizer application of 49 kg N ha^{-1} to the entire plot area two weeks prior to ratings. The low N rate treatment had the lowest clipping yield on August 2005 and 2006. The low N rate treatment had two applications per year with a four month interval between applications. The N source is 75% urea and 25% SCU which would not be expected to last four months. Therefore, the lowest clipping yield with the low N rate treatment would be expected.

Both the medium and high N rate treatment had the highest or equal to the highest clipping yield on five of 11 sampling dates, respectively. There were significant differences between the medium and high N rate treatments except the sampling date on August 2005 when significant differences were found among N rate treatments. While no significant difference was found on August 2005, there was a difference in August 2006. Water balance in August 2005 was -0.2 cm compared to 7.1 cm in August 2006. The medium N rate treatment had the highest amount of total clipping yield in 2005 while the high N rate treatment had the highest total clipping yield in 2006. When weather condition is dry, there was no significant difference between the medium and high N rate treatments.

Research has shown that clipping yield is increased with N application (Teutsch et al., 2005; Kopp and Guillard, 2002; Starr and Deroo, 1981). When clippings are returned, additional N contained in clippings will be added. Heckman et al. (2000) returned Kentucky bluegrass clippings to turf using a mulching mower. They found turfgrass clippings improved the color and quality compared to removing clippings and reducing

N rate by 50% did not affect turfgrass color when clippings were returned. Although both the medium and high N rate treatment produced the highest amount of total clipping yield on most sampling dates, the medium N rate would be recommended to maintain turfgrass quality with lower clipping yield.

Soil moisture content

There was an irrigation by species interaction on only one of nine rating dates for 2005 and 2006 (Table 14). There were significant main effects for irrigation, species, and N rate. In 2005, the every other day irrigation treatment had the highest or equal to the highest soil moisture content throughout the research (Table 15). There were significant differences between the weekly and the every other day irrigation treatments for the July 2005 rating. Despite the difference in soil moisture content in July 2005, there were no differences in turfgrass color and quality between the irrigation treatments in July 2005. These results of turfgrass color and quality was probably due to relatively high precipitation rate of 14.3 cm in July 2005 (Table 18). It is two times greater amount of water than that of water from irrigation treatment and the greatest amount of precipitation for the year. This amount of precipitation in July 2005 was sufficient for acceptable color and quality rating. The precipitation only treatment had the lowest soil moisture content during 2005. Water balance was -0.2 cm in August 2005 due to the 11 cm ETp and low precipitation (Figure 3). Under the weather condition, turfgrass can be stressed and result in limiting growth without additional irrigation when ETp replacement is insufficient to equal transpiration rate. In the result of this study, turfgrass quality treated by precipitation only in August and following September 2005 was less than

Table 2-14. Analysis of variance table for soil moisture content

Source	df	May	June	July	Aug.	Sep.	Oct.
		------------------------------		2005	------------------------------		
Irrigation (I)	2	ND†	**	**	**	ND	ND
Species (S)	2	ND	**	**	**	ND	ND
I x S	4	ND	NS	NS	NS	ND	ND
Nitrogen Rate (NR)	2	ND	NS	NS	NS	ND	ND
I x NR	4	ND	NS	NS	NS	ND	ND
S x NR	4	ND	NS	NS	NS	ND	ND
I x S x NR	8	ND	NS	NS	NS	ND	ND
		------------------------------		2006	------------------------------		
Irrigation (I)	2	**	**	**	**	**	**
Species (S)	2	**	**	**	**	**	**
I x S	4	NS	NS	NS	*	NS	NS
Nitrogen Rate (NR)	2	NS	**	NS	*	**	NS
I x NR	4	NS	NS	NS	NS	NS	NS
S x NR	4	NS	NS	NS	NS	NS	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table 2-15. Mean soil moisture content for irrigation main effect.

Irrigation	May	June	July	Aug.	Sep.	Oct.
			2005			
Precipitation only	ND†	9.5‡ b§	18.7 c	6.9 b	ND	ND
0.5 cm every other day	ND	20.6 a	26.8 a	23.1 a	ND	ND
1.8 cm weekly	ND	17.5 a	21.4 b	18.0 a	ND	ND
			2006			
Precipitation only	26.2 b	11.3 c	13.3 b	22.1 c	26.3 b	25.7 b
0.5 cm every other day	32.3 a	26.9 a	21.5 a	30.5 a	32.2 a	30.9 a
1.8 cm weekly	32.0 a	22.4 b	19.0 a	28.4 b	31.0 a	30.0 a

† No data available.

‡ Soil moisture content units are percent.

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

acceptable turfgrass quality of six.

In 2006, the every other day irrigation treatment had the highest or equal to the highest soil moisture content. The precipitation only treatment had the lowest soil moisture content for the year. With the lowest soil moisture content, the precipitation only treatment had the lowest turfgrass quality and ratings lower than six in July and August. There were no differences between the every other day and weekly irrigation treatment for turfgrass quality in July and August. Weather condition in July and August was 15.0 and 12.6 cm ETp, respectively. Water balance in July and August was 1.1 and 7.0 cm, respectively. Under this condition, soil moisture content of 22.1% was insufficient level to generate acceptable turfgrass quality without irrigation treatments. Acceptable turfgrass quality was not produced without irrigation treatment. Watson (1950) investigated the response of turfgrass consisting of mixed bentgrass, red fescue, and Kentucky bluegrass to four levels of soil moisture content and five soil compaction levels. He reported the average soil moisture content for the growing season is about 16 to 18 %. Although soil moisture content was higher than 18 % in August, acceptable turfgrass quality was not produced. It may result from relatively high ETp of 12.6 cm and high mean temperature of 27.3 C.

There was a significant turfgrass species main effect for soil moisture content. Tall fescue had the highest or equal to the highest soil moisture content throughout the research (Table 16). With the highest soil moisture content, tall fescue had the highest or equal to the highest turfgrass quality throughout the research except for September and October 2006 when significant differences were found among species. There were significant differences between tall fescue and Kentucky bluegrass for soil moisture

Table 2-16. Mean soil moisture content for species main effect.

Species	May	June	July	Aug.	Sep.	Oct.
			------------------------------ 2005 ------------------------------			
Lawn mixture†	ND‡	14.6§b¶	22.0 b	15.0 b	ND	ND
Tall fescue	ND	17.9 a	24.3 a	18.6 a	ND	ND
Kentucky bluegrass	ND	15.2 b	20.5 b	14.5. b	ND	ND
			------------------------------ 2006 ------------------------------			
Lawn mixture	29.3 b	19.4 b	17.7 b	25.7 b	28.9 b	28.2 b
Tall fescue	31.4 a	22.8 a	19.3 a	29.4 a	31.7 a	30.5 a
Kentucky bluegrass	29.8 b	18.3 b	16.8 b	25.8 b	29.0 b	28.0 b

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ No data available.

§ Soil moisture content units are percent.

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

content throughout the research except for June and August 2005. The lawn mixture had the lowest or equal to the lowest soil moisture content for 2005 and the lowest soil moisture content during 2006.

There was a significant turfgrass N rate main effect for soil moisture content for 2006. The high N rate had the lowest soil moisture content when there were significant differences among N rate treatments for soil moisture content (Table 17). Higher N rate promote turfgrass growth and water use. The relation between N rate and water use of turfgrass was reported by Barton et al. (2009). They concluded that turfgrass ETp rate was significantly affected by turfgrass growth, which was largely promoted by N application rate. In the results of this study, the highest total clipping yield was produced by the high N rate treatment in 2006. However, there was no difference between the low and medium N rate treatment for soil moisture content. In spite of no difference, the medium N rate had acceptable turfgrass quality for two years except two of 12 rating dates. Based on these results, the medium N rate would be recommended to maintain acceptable quality of turfgrass under the conditions of the research area.

Table 2-17. Mean soil moisture content for nitrogen rate main effect for 2006.

N rate	May	June	July	Aug.	Sep.	Oct.
98†	30.5‡	20.7 a§	18.2	27.4 a	30.6 a	29.2
156	30.1	20.4 a	18.2	27.2 a	30.0 a	28.9
208	29.9	19.4 b	17.3	26.4 b	29.0 b	28.6

† N rate units are kg ha^{-1} yr^{-1}.

‡ Soil moisture content units are percent.

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

Table 18. Weather data for 2005.

Month	Min. Temp.	Max. Temp.	Relative Humidity	Solar Radiation	Wind Run	Precipitation	ETp
Jan.	-8.58†	-0.42	97.10‡	141.67§	187.76¶	2.01#	1.30††
Feb.	-5.55	2.77	97.81	191.39	138.09	4.34	1.70
Mar.	-4.45	5.10	94.67	323.61	213.44	1.57	4.42
Apr.	4.04	17.56	83.21	462.09	233.55	1.68	10.39
May	7.37	19.34	92.95	467.20	182.98	4.17	10.49
June	17.23	28.72	97.32	532.34	130.49	9.60	13.49
July	17.50	28.80	102.89	554.01	97.73	14.30	13.77
Aug.	17.43	28.58	100.88	445.84	105.91	3.28	11.00
Sep.	13.33	26.37	99.94	381.48	119.88	10.67	9.04
Oct.	7.27	17.46	97.71	246.16	121.67	0.69	4.75
Nov.	1.54	10.89	92.72	154.93	282.81	10.01	3.18
Dec.	-5.51	-0.91	100.23	93.09	155.56	2.97	0.51

† Temperature units are Celsius.

‡ Relative humidity units are percent.

§ Solar radiation units are Langleys.

¶ Wind run units are km d^{-1}.

Precipitation units are centimeter.

†† ETp units are centimeter.

Table 19. Weather data for 2006.

Month	Min. Temp.	Max. Temp.	Relative Humidity	Solar Radiation	Wind Run	Precipitation	ETp
Jan.	-0.99†	5.09	99.43‡	111.30§	240.02¶	10.39#	1.35††
Feb.	-5.67	2.19	94.22	228.50	229.15	3.25	2.36
Mar.	-0.38	9.79	89.06	294.16	256.20	5.94	3.00
Apr.	4.63	18.39	85.46	433.36	121.44	6.05	7.01
May	17.92	35.72	90.60	441.24	0.27	17.93	4.17
June	20.59	42.79	84.59	579.78	135.93	5.84	10.62
July	17.79	28.98	86.62	535.50	162.63	8.56	14.96
Aug.	16.43	27.27	88.96	454.91	160.08	12.17	12.60
Sep.	11.06	20.98	90.27	293.26	175.67	6.12	7.44
Oct.	3.98	14.26	84.16	208.84	210.07	7.90	5.49
Nov.	1.73	10.23	83.64	130.52	171.18	8.53	3.25
Dec.	-0.71	5.65	82.42	101.58	261.90	5.03	2.95

† Temperature units are Celsius.

‡ Relative humidity units are percent.

§ Solar radiation units are Langleys.

¶ Wind run units are km d^{-1}.

Precipitation units are centimeter.

†† ETp units are centimeter.

CONCLUSION

We found that different timing of irrigation applications had effects on clipping yield and soil moisture content. However, there were no differences on turfgrass color and quality between the every other day and the weekly irrigation treatments. Both the every other day and weekly irrigation treatments had turfgrass quality greater than acceptable quality of six throughout the study. Precipitation only treatment had turfgrass quality less than six on four of 12 rating dates. Most of these ratings occurred during the summer months from July to September with dry weather conditions. If water resource is limited, and turfgrass quality for low maintenance from July to September are not important, precipitation only treatment would be accepted under the weather conditions of the research area. If maintaining turfgrass quality in summer months is important for the turfgrass manager, then either the every other day or the weekly irrigation treatment would be acceptable.

Although the lawn mix had the greatest shoot growth for most sampling dates, tall fescue had the highest turfgrass quality on eight of 12 rating dates. The highest soil moisture content was also found in the tall fescue plots. Tall fescue maintained acceptable turfgrass quality for two years except one rating date while the lawn mixture had turfgrass quality less than six on five rating dates for two years. Compared to tall fescue, Kentucky bluegrass had turfgrass quality greater than six on five rating dates for the study. Based on the results of the study, tall fescue would be recommended to maintain turfgrass quality, soil moisture content, and less clipping yield. Although Kentucky bluegrass had less turfgrass quality than tall fescue during spring and summer months, Kentucky bluegrass was still acceptable to maintain acceptable turfgrass quality for home lawn area.

There were significance differences between the medium and high N rate treatments for turfgrass quality. Although both the medium and high N rate treatments maintained acceptable turfgrass quality throughout the study except for two and one rating date, respectively, the high N rate treatment had greater turfgrass quality than the medium N treatment for July and August in both 2005 and 2006. The medium N rate treatment had turfgrass quality less than six on September 2005 and August 2006. During the summer months, the high N rate produced better turfgrass quality than the medium N rate treatment. Overall, the medium N rate treatment would be accepted for acceptable turfgrass quality. If high maintenance turfgrass quality is required, then the high N rate is needed to maintain high turfgrass quality.

REFERENCES CITED

Aronson, L. J., A. J. Gold, R. J. Hull, and J. L. Cisar. 1987. Evapotranspiration of cool-season turfgrasses in the humid Northeast. Agron. J. 79:901-905.

Barton, L., G. G. Y. Wan, R. P. Buck, and T. D. Colmer. 2009. Nitrogen increases evapotranspiration and growth of a warm-season turfgrass. Agron. J. 101:17-24.

Beard, J. B. 1973. Turfgrass: Science and culture. Prentice-Hall. Eagle-wood Cliffs. NJ.

Beard, J. B. and K. S. Kim. 1989. Low-water-use turfgrasses USGA Green Sect. Rec. 27:12-13.

Beard, James B; Harriet J. Beard. 2005. Beard's Turfgrass Encyclopedia for Golf Courses, Grounds, Lawns, Sports Fields. Michigan State University Press. p. 231.

Bennett, O. and B. Doss. 1960. Effect of soil moisture level on root distribution of cool-season species. Agron. J. 52:204-7.

Biran, I., B. Bravdo, I. Bushkin-Harav, and E. Rawitz. 1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. Agron. J. 73:85-90.

Bremer, D.J., K. Su, S.J. Keeley, and J.D. Fry. 2006. Performance in the transition zone of two hybrid bluegrasses compared with Kentucky bluegrass and tall fescue. Available at: Appl. Turfgrass Sci., p. 1–9. DOI: 10.1094/ATS-2006-0808-02-RS.

Brown, R. H., D. A. Devitt, and R. L. Morris. 2004. Water use and physiological response of tall fescue turf to water deficit irrigation in an arid environment. HortScience 39:388-393.

Casnoff, D. M., R. L. Green, and J. B. Beard. 1989. Leaf blade stomatal densities often warm-season perennial grasses and their evapotranspiration rates. *Proc. Of the 6th int. Turfgrass Res. Conf.*, Tokyo, Japan, Vol 6, pp. 129-131. Inter. Turfgrass Soc.

Christians, N. E. 2004. Fundamental of turfgrass management. John Wiley & Sons, Inc., Hoboken, New Jersey.

DaCosta, M. and B. Huang. 2006. Minimum water requirements for creeping, colonial and velvet bentgrasses under fairway conditions. Crop Sci. 46: 81-89.

Doss, B. D., D. A. Ashley, and O. L. Bennett. 1960. Effect of soil moisture regime on root distribution of warm season forage species. Agron. J. 52: 569-572.

Doss, B. D., O. L. Bennett, and D. A. Ashley. 1964. Moisture use by forage species as related to pan evaporation and net radiation. Soil Sci. 98:322-327.

Fry, J.D., and J.D. Butler. 1989. Responses of tall and hard fescue to deficit irrigation. Crop Sci. 29:1536–1541.

Fry, J and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Inc., Hoboken, New Jersey.

Fu, J. and P. H. Dernoeden. 2008. Carbohydrate metabolism in creeping bentgrass as influenced by two summer irrigation practices. J. Am. Soc. Hort Sci. 133(5): p. 678-683.

Guertal, E. and D. Han. 2002. Fans and syringing for cooling creeping bentgrass putting greens: Using both fans and syringing was most effective in cooling air and soil temperatures of creeping bentgrass putting greens. Golf Course Management. July. 70(7): p. 57-60.

Heckman, J. R., H. Liu, W. Hill, M. DeMilia, and W. L. Anastasia. 2000. Kentucky bluegrass responses to mowing practice and nitrogen fertility management. J. Sustain. Agric. Environ. 15: 25-33.

Hull, R. J. 1996. Managing turf for minimum water use. *TurfGrass Trends* 5(10):1-9.

Huang, B. and J. Fry. 1999. Turfgrass evapotranspiration. J. Crop Prod. 2:317-33.

Huang, B. and H. Gao. 2000. Growth and carbohydrate metabolism of creeping bentgrass cultivars in response to increasing temperatures. Crop Sci. 40:1115-1120.

Huffman, S.A. and K.A. Barbarick, 1981. Soil nitrate analysis by cadmium reduction. Comm Soil Sci Plant Anal. 12(1): 79-89.

Jackson, R. D. 1982. Canopy temperature and crop water stress. Adv. Irrig. 1:43-85.

Jiang, H., J. Fry, and N. Tisserat. 1998. Assessing irrigation management for its effects on disease and weed levels in perennial ryegrass. Crop Sci. 38:440-445.

Johnson, P. G. 2003. The influence of frequent or infrequent irrigation on turfgrasses in the cool-arid west. USGA Turfgrass and Environmental Research Online. March 15. 2(6): p. 1-8.

Jordan, J., R. White, D. Vietor, T. Hale, J. Thomas, and M. Engelke. 2003. Effect of irrigation frequency on turf quality, shoot density, and root length density of five bentgrass cultivars. Crop Sci. 43:282-87.

Karnok, Keith J., and Kevin A. Tucker. 1999. Dry spots return with summer. Golf Course Management. 67(5):49-52.

Kopp, K. L. and K. Guillard. 2002. Clipping management and nitrogen fertilization of turfgrass: Growth, nitrogen utilization, and quality. Crop Science. July/August. 42(4): 1225-1231.

Madison, J. and R. Horgan. 1962. Extraction of soil moisture by Merion and other cultural operations. Agron. J. 54;157-60.

Mantell, A. 1966. Effect of irrigation frequency and nitrogen fertilization on growth and water use of a kikuyugrass lawn (*Pennisetum clandestinum* Hochst.). Agron. J. 58: 559-561.

Melvin, B.P. 1991. Biological and cultural management of summer patch and necrotic ring spot. Ph.D. Dissertation p179: Michigan State University. East Lansing, MI.

Melvin, B. P. and J. M. Vargas. 1994. Irrigation frequency and fertilizer type influence necrotic ring spot of Kentucky Bluegrass. HortScience. September. 29(9): p. 1028-1030.

Minner, D. D. 1984. Cool-season turfgrass quality as related to evapotranspiration and drought. Ph.D. Dissertation. Colorado Sate University., Fort Collins (Diss. Abstr. 45-1345)

Montgomery, D. C. 1985. The Effect of Non-normality on Variables Sampling Plans. Naval Research Logistics Quarterly, Vol. 32, No. 1.

Morgan, W. C., J. Letey, S. J. Richards and N. Valoras. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass Management I. Effects on compactability, water infiltration rates, evapotranspiration, and number of irrigations. Agron. J. 58:525-528.

Nelson, Darrell W., 1983. Determination of Ammonium in KCl Extracts of Soils by the Salicylate Method. Comm Soil Sci Plant Anal. 14(11) 1051-1062.

Peacock, C. H.; Dudeck, A. E. 1984. Physiological response of St. Augustinegrass to irrigation scheduling. Agron. J. 76:275-279.Qian, Y. L., and J. D. Fry. 1996. Irrigation frequency affects zoysiagrass rooting and plant water status. HortSci. 31:234-237.

Qian, Y. and J. Fry. 1996. Irrigation frequency and turfgrass performance: Studies find advantages to deep, infrequent irrigation of zoysiagrass. Golf Course Management. 64(5): p. 49-51.

Qian, Y. L., J. D. Fry, and W. S. Upham. 1997. Rooting and drought avoidance of warm-season turfgrasses and tall fescue in kansas. Crop Sci. 37:905-910.

Richie, W.E., R. L. Green, G.J. Klein, and J.S. Hartin. 2002. Tall Fescue Performance Influenced by Irrigation Scheduling, Cultivar, and Mowing Height. Crop Sci. 42:2011–2017.

SAS Institute Inc. 2001. The SAS system release 8.2 for Windows. SAS Inst., Cary, NC.

Shearman, R. 1988. Turfgrass water use, Part IV. Lansdscape Manage. 27(3):30-31.

Smiley, R. W., M. M. Craven, and J. A. Bruhn. 1980. Fusarium blight and physical, chemical, and microbial properties of Kentucky bluegrass sod. Plant Disease 64:60-62

Starr, J. L and H. C. DeRoo. 1981. The fate of nitrogen fertilizer applied to turfgrass. Crop Sci. 21: 531-536.

Starrett, S. K., N. E. Christians, and T. A. Austin. 1996. Movement of pesticides under two irrigation regimes applied to turfgrass. J. Environ. Qual. 25:566–571.

Teutsch, C. D., J. H. Fike, H. John, and W. M. Tilson. 2005. Yield, digestibility, and nutritive value of crabgrass as impacted by nitrogen fertilization rate and source. Agron. J. 97:1640-1646

Warncke, D. and J.R. Brown. 1998. Potassium and other basic cations. P. 31-33. In Recommended Chemical Soil Test Procedures for the North Central Region; North Central Regional Research Publication No. 221; Revised January, 1998.

Watson, J. R. 1950. Irrigation and compaction on established fairway turf. USGA Journal and Turf Management. 3: 25-29.

Xu, Q. and B. Huang. 2000. Growth and physiological responses of creeping bentgrass to changes in air and soil temperatures. Crop Sci. 40:1363-1368.

APPENDIX

Table A1-1. Analysis of variance table for turfgrass color.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
		2004										
Treatments	9	NS	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	NS	NS	**	**	**	**	**	*	NS	**	**
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2005										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	**	**
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2006										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	NS	NS	**	**	**	**	**	**	NS	NS	NS
P rate (PR)	2	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	**	NS	*	NS	NS	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

Table A1-2. Analysis of variance table for turfgrass quality.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
		2004										
Treatments	9	*	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	NS	NS	**	**	**	**	**	NS	NS	**	**
P rate (PR)	2	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2005										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	**	**	**	**	**	**	**	**	NS	*	**
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2006										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	NS	NS	**	**	**	**	**	**	NS	NS	NS
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

Table A1-3. Analysis of variance table for clipping yield.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
		2004										
Treatments	9	NS	*	**	**	**	**	**	**	*	NS	ND†
N rate (NR)	2	NS	NS	**	**	**	**	**	**	NS	NS	ND
P rate (PR)	2	NS	NS	*	*	NS	NS	NS	**	NS	NS	ND
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	ND
		2005										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	**	**
P rate (PR)	2	NS	NS	NS	*	NS	NS	NS	*	NS	*	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2006										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	**	**
P rate (PR)	2	NS	NS	*	NS	NS	*	NS	NS	NS	**	**
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table A1-4. Analysis of variance table for turfgrass tissue phosphorus.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
		2004										
Treatments	9	NS	**	**	**	**	**	**	ND†	ND	ND	ND
N rate (NR)	2	NS	NS	**	**	**	**	**	ND	ND	ND	ND
P rate (PR)	2	NS	NS	**	*	NS	NS	NS	ND	ND	ND	ND
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	ND	ND	ND	ND
		2005										
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	**	**
P rate (PR)	2	**	**	**	**	**	NS	NS	*	**	**	**
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2006										
Treatments	9	**	**	**	**	**	**	**	**	**	ND	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	ND	**
P rate (PR)	2	**	*	NS	*	NS	**	NS	**	*	ND	**
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	ND	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table A1-5. Analysis of variance table for turfgrass tissue potassium.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
		2004										
Treatments	9	NS	**	**	**	**	NS	NS	ND†	ND	ND	ND
N rate (NR)	2	NS	NS	NS	**	**	**	**	ND	ND	ND	ND
P rate (PR)	2	NS	**	NS	NS	NS	NS	NS	ND	ND	ND	ND
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	ND	ND	ND	ND
		2005										
Treatments	9	**	**	**	**	**	NS	**	**	**	**	**
N rate (NR)	2	**	*	**	**	**	NS	NS	NS	**	NS	NS
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2006										
Treatments	9	*	**	NS	**	NS	**	NS	NS	NS	NA	**
N rate (NR)	2	**	NS	NS	**	NS	**	NS	*	**	NA	NS
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NA	**
NR×PR	4	NS	NS	NS	*	NS	NS	NS	NS	NS	NA	NS

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table A1-6. Analysis of variance table for phosphorus removed in clippings.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
2004												
Treatments	9	NS	**	**	**	**	**	**	ND[†]	ND	ND	ND
N rate (NR)	2	NS	NS	**	**	**	**	**	ND	ND	ND	ND
P rate (PR)	2	NS	NS	**	*	NS	NS	NS	ND	ND	ND	ND
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	ND	ND	ND	ND
2005												
Treatments	9	**	**	**	**	**	**	**	**	**	**	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	**	**
P rate (PR)	2	**	**	**	**	**	NS	NS	*	**	**	**
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2006												
Treatments	9	**	**	**	**	**	**	**	**	**	ND	**
N rate (NR)	2	**	**	**	**	**	**	**	**	**	ND	**
P rate (PR)	2	**	*	NS	*	NS	**	NS	**	*	ND	**
NR×PR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	ND	NS

* indicates significance at $P = 0.05$.

** indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table A1-7. Analysis of variance table for soil phosphorus.

Source	df	May	June	July	Aug.	Sep.	Oct.	Nov.
		-------------------------			2004	-------------------------		
Treatments	9	ND†	ND	NS	NS	NS	NS	NS
N rate (NR)	2	ND	ND	NS	NS	NS	NS	NS
P rate (PR)	2	ND	ND	NS	NS	NS	NS	NS
NR×PR	4	ND	ND	NS	NS	NS	NS	NS
Soil Depth (SD)	1	ND	ND	**	NS	**	NS	**
NR×SD	2	ND	ND	NS	NS	NS	NS	NS
PR×SD	2	ND	ND	NS	NS	NS	NS	NS
NR×PR×SD	4	ND	ND	NS	NS	NS	NS	NS
		-------------------------			2005	-------------------------		
Treatments	9	NS	*	NS	NS	NS	NS	NS
N rate (NR)	2	NS	*	NS	NS	NS	*	NS
P rate (PR)	2	NS	NS	NS	NS	NS	NS	NS
NR×PR	4	NS	NS	NS	NS	NS	NS	NS
Soil Depth (SD)	1	NS	*	**	**	NS	**	NS
NR×SD	2	NS	NS	NS	NS	NS	NS	NS
PR×SD	2	NS	NS	NS	NS	NS	NS	NS
NR×PR×SD	4	NS	NS	NS	NS	NS	NS	NS
		-------------------------			2006	-------------------------		
Treatments	9	NS	NS	ND	NS	*	NS	ND
N rate (NR)	2	NS	NS	ND	NS	**	NS	ND
P rate (PR)	2	NS	NS	ND	NS	NS	NS	ND
NR×PR	4	NS	NS	ND	NS	NS	NS	ND
Soil Depth (SD)	1	NS	**	ND	**	**	NS	ND
NR×SD	2	NS	NS	ND	NS	NS	NS	ND
PR×SD	2	NS	NS	ND	NS	NS	NS	ND
NR×PR×SD	4	NS	NS	ND	NS	NS	NS	ND

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available

Table A1-8. Mean turfgrass color for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
					2004						
98	7.9‡	8.0	7.3 b§	6.6 b	6.7 c	6.6 c	7.3 c	7.3 b	7.1	5.8 b	6.0 b
156	7.7	8.0	8.0 a	7.8 a	7.5 b	7.3 b	7.7 b	7.2 b	7	6.5 a	6.7 a
208	7.7	8.0	8.0 a	8.0 a	8.2 a	8.3 a	8.3 a	7.6 a	7.3	6.6 a	6.6 a
					2005						
98	7.6 b	6.9 c	6.8 b	6.6 a	6.0 c	5.9 c	5.7 c	5.2 c	6.8 b	6.8 b	7.0 b
156	8.0 ab	7.2 b	7.9 a	8.0 a	7.1 b	6.9 b	7.0 b	6.3 b	7.4 a	7.4 a	7.8 a
208	8.1 a	7.4 a	7.9 a	8.0 a	8.0 a	8.0 a	8.0 a	7.6 a	7.8 a	7.8 a	7.8 a
					2006						
98	7.9	7.0	6.4 b	5.3 b	5.3 c	5.4 c	5.7 b	7.3 c	6.4	7.8	7.1
156	8.0	7.0	8.0 a	7.0 a	7.2 b	7.0 b	6.8 a	7.8 b	6.7	7.8	7.1
208	8.0	7.0	7.8 a	6.8 a	9.0 a	8.0 a	7.4 a	8.6 a	6.7	7.9	7.0

† N rate units are kg ha^{-1}

‡ Kentucky bluegrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

Table A1-9. Mean turfgrass color for phosphorus rate main effect.

P_2O_5 rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
0	7.8‡	7.9	7.8	7.4	7.5	7.4	7.7	7.3	7.1	6.2	6.5
24	7.8	8.0	7.8	7.6	7.4	7.4	7.8	7.3	7.0	6.2	6.3
49	7.6	8.0	7.8	7.5	7.5	7.4	7.9	7.4	7.2	6.4	6.5
						2005					
0	7.8	7.2	7.7	7.5	7.0	6.8	6.8	6.3	7.3	7.5	7.5
24	7.9	7.2	7.6	7.6	7.0	7.0	7.0	6.3	7.2	7.7	7.6
49	7.9	7.1	7.4	7.5	7.0	7.0	6.8	6.5	7.4	7.7	7.5
						2006					
0	7.9	7.0	7.3	6.2	7.2	6.8 ab§	6.2	7.9	6.6	8.0	7.2
24	8.0	7.0	7.4	6.6	7.3	7.0 a	7.2	7.9	6.6	7.8	7.0
49	8.0	7.0	7.5	6.3	7.1	6.6 b	6.6	7.8	6.6	7.7	7.0

† P_2O_5 rate units are kg ha^{-1}.

‡ Kentucky bluegrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

Table A1-10. Mean turfgrass quality for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
98	7.9‡	8.0	7.5 b§	6.8 b	6.7 c	6.9 c	7.3 c	7.0	6.9	6.0 b	5.8 b
156	7.8	8.0	8.0 a	7.8 a	7.6 b	7.5 b	7.6 b	7.0	6.9	6.5 a	6.4 a
208	7.6	8.0	8.0 a	7.9 a	8.3 a	8.3 a	8.4 a	7.3	7.2	6.6 a	6.5 a
						2005					
98	7.3 b	6.8 b	6.7 b	6.7 b	6.7 c	5.8 c	5.9 c	5.2 c	7.0	7.2 b	7.0 b
156	7.9 a	7.0 a	7.8 a	8.0 a	7.0 b	6.8 b	6.9 b	6.0 b	7.3	7.8 a	7.8 a
208	8.0 a	7.1 a	7.7 a	8.0 a	8.0 a	8.0 a	7.3 a	7.3 a	7.4	7.6 ab	7.7 a
						2006					
98	7.7	7.0	6.1 b	4.7 c	4.7 c	5.2 c	5.4 b	6.9 b	6.3	7.5	7.0
156	7.8	7.0	7.0 a	6.8 a	6.8 b	6.8 b	6.8 a	7.4 b	6.7	7.6	7.1
208	7.9	6.9	6.9 a	6.3 b	7.7 a	7.8 a	7.3 a	8.4 a	6.7	7.5	6.9

† N rate units are kg ha^{-1}.

‡ Kentucky bluegrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

Table A1-11. Mean turfgrass quality for phosphorus rate main effect.

P_2O_5 rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
					2004						
0	7.7‡	7.9	7.7	7.4	7.4 b§	7.5	7.8	7.1	7.0	6.3	6.3
24	7.8	8.0	7.9	7.5	7.5 ab	7.5	7.8	7.0	6.9	6.3	6.1
49	7.8	8.0	7.8	7.5	7.8 a	7.7	7.9	7.3	7.2	6.5	6.3
					2005						
0	7.8	7.0	7.3	7.6	7.0	6.8	6.9	6.0	7.2	7.4	7.3
24	7.8	7.0	7.5	7.6	7.0	7.0	7.0	6.2	7.1	7.5	7.6
49	7.8	7.0	7.3	7.5	7.0	8.6	6.9	6.3	7.4	7.7	7.4
					2006						
0	7.9	6.9	6.6	5.8	6.3	6.5	6.0	7.6	6.5	7.6	7.0
24	7.6	7.0	6.8	6.1	6.8	6.8	6.0	7.6	6.6	7.7	7.0
49	7.6	7.0	6.7	6.0	6.2	6.6	6.4	7.6	6.6	7.3	7.0

† P_2O_5 rate units are kg ha^{-1}.

‡ Kentucky bluegrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

Table A1-12. Mean turfgrass clipping yield for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
98	7.8‡	5.7	6.3 c§	0.7 b	1.1 c	0.5 b	1.6 c	0.2 b	0.4	0.1	ND¶
156	7.3	5.8	9.3 a	3.4 a	3.9 b	1.4 b	3.2 b	0.2 b	0.6	0.1	ND
208	7.6	6.1	9.0 b	2.8 a	6.0 a	5.9 a	6.3 a	0.5 a	0.8	0.1	ND
						2005					
98	11.6 c	36.9 c	18.6 c	8.1 c	5.6 c	1.6 c	2.0 c	2.1 c	10.3 b	4.6 b	1.7 c
156	18.7 b	44.4 b	30.1 b	12.9 b	10.7 b	3.0 b	3.1 b	3.4 b	10.4 b	4.2 b	2.8 b
208	25.7 a	52.6 a	37.1 a	15.5 a	20.4 a	5.6 a	6.1 a	6.4 a	14.4 a	5.7 a	3.4 a
						2006					
98	8.3 c	7.7 c	3.1 b	0.7 b	1.0 c	4.3 c	13.3 b	8.9 c	5.5 c	6.6 c	6.6 c
156	13.5 b	9.8 b	5.6 a	2.8 a	4.3 b	12.7 b	27.9 a	13.6 b	7.4 b	8.0 b	8.0 b
208	17.9 a	11.9 a	6.6 a	2.9 a	9.5 a	22.4 a	33.9 a	17.5 a	10.0 a	9.4 a	9.4 a

† N rate units are kg ha^{-1}.

‡ Clipping dry weight units are g m-2.

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

¶ No data available.

Table A1-13. Mean turfgrass clipping yield for phosphorus rate main effect.

P_2O_5 rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2004										
0	7.1‡	4.7	7.1 b§	1.6 b	3.0	2.1	3.6	0.2 b	0.5	0.1	ND¶
24	8.8	6.8	9.3 a	2.8 a	4.1	3.1	3.6	0.3 ab	0.6	0.1	ND
49	6.7	6.1	8.2 ab	2.4 ab	3.8	2.5	4.0	0.4 a	0.6	0.1	ND
	2005										
0	17.8	41.9	26.4	11.9 ab	11.6	3.1	3.4	3.6 b	10.6	4.4 b	2.4
24	18.8	45.1	28.5	13.1 a	12.9	3.8	4.1	4.5 a	12.1	5.2 a	2.8
49	19.5	47.0	31.0	11.5 b	12.2	3.3	3.7	3.7 ab	12.4	4.9 ab	2.8
	2006										
0	12.2	9.6	4.5 b	1.8	4.0	11.0 b	19.4	11.9	7.1	ND	7.0
24	13.9	10.6	6.1 a	2.6	5.6	14.8 a	28.9	14.9	8.4	ND	8.7
49	13.5	9.2	4.7 ab	2.0	5.1	13.6 ab	26.9	13.2	7.4	ND	8.3

† P_2O_5 rate units are kg ha^{-1}.

‡ Clipping dry weight units are g m^{-2}.

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

¶ No data available.

Table A1-14. Mean turfgrass tissue phosphorus for the nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
					2004						
98	0.24‡	0.28	0.28 a§	0.15 b	0.16 c	0.30 b	0.26	ND¶	ND	ND	ND
156	0.24	0.29	0.29 a	0.27 a	0.25 b	0.28 c	0.28	ND	ND	ND	ND
208	0.24	0.29	0.27 b	0.27 a	0.28 a	0.32 a	0.30	ND	ND	ND	ND
					2005						
98	0.28 c	0.27	0.26	0.25	0.28 b	0.18	0.31 a	0.29	0.37 a	0.38 a	0.31
156	0.29 b	0.28	0.27	0.26	0.28 b	0.21	0.29 b	0.27	0.34 b	0.36 b	0.31
208	0.30 a	0.28	0.26	0.26	0.29 a	0.24	0.28 c	0.28	0.33 c	0.35 c	0.31
					2006						
98	0.32	0.28	0.22	0.24	0.26	0.30	0.27	0.33	0.32	ND	0.40 a
156	0.32	0.27	0.24	0.24	0.26	0.30	0.27	0.32	0.32	ND	0.38 b
208	0.33	0.26	0.20	0.23	0.28	0.30	0.27	0.33	0.33	ND	0.38 b

† N rate units are kg ha^{-1}.

‡ The unit of tissue phosphorus is percent (%)

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

¶ No data available.

Table A1-15. Mean turfgrass tissue phosphorus for phosphorus rate main effect.

P_2O_5 rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
0	0.24‡	0.28 b§	0.25 c	0.23	0.23	0.30	0.27	ND¶	ND	ND	ND
24	0.25	0.29 a	0.27 b	0.23	0.24	0.29	0.29	ND	ND	ND	ND
49	0.25	0.29 a	0.32 a	0.23	0.23	0.30	0.28	ND	ND	ND	ND
						2005					
0	0.27 c	0.26 c	0.24 c	0.24 c	0.26 c	0.20	0.27 c	0.26 c	0.31 c	0.33 c	0.28 c
24	0.29 b	0.28 b	0.26 b	0.25 b	0.28 b	0.20	0.29 b	0.27 b	0.35 b	0.37 b	0.31 b
49	0.32 a	0.30 a	0.29 a	0.27 a	0.31 a	0.24	0.32 a	0.30 a	0.38 a	0.40 a	0.33 a
						2006					
0	0.30 c	0.24 c	0.21	0.22 c	0.26	0.28 b	0.24 b	0.31 c	0.30 c	ND	0.34 c
24	0.32 b	0.27 b	0.20	0.23 b	0.26	0.29 b	0.27 a	0.33 b	0.32 b	ND	0.39 b
49	0.35 a	0.29 a	0.24	0.26 a	0.28	0.33 a	0.29 a	0.34 a	0.34 a	ND	0.43 a

† N rate units are kg ha^{-1}.

‡ The unit of tissue phosphorus is percent (%).

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

¶ No data available.

Table A1-16. Mean turfgrass tissue potassium for the nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
98	1.8‡	2.0	2.0	0.9 b§	1.1 b	1.9 ab	1.3 b	ND¶	ND	ND	ND
156	1.8	2.0	2.1	1.7 a	1.9 a	1.8 b	1.6 ab	ND	ND	ND	ND
208	1.7	2.0	2.1	1.7 a	1.9 a	2.1 a	1.8 a	ND	ND	ND	ND
						2005					
98	1.74 c	1.74 a	1.86 b	1.58 c	1.88 c	1.04	2.09	1.78	2.17 a	2.49	1.94
156	1.84 b	1.68 b	1.95 a	1.69 b	2.04 b	1.39	2.08	1.81	2.08 b	2.44	1.98
208	1.95 a	1.78 a	1.94 a	1.75 a	2.17 a	1.56	2.05	1.81	1.98 c	2.43	1.97
						2006					
98	1.97 b	2.18	1.81	1.48 b	1.60	1.89 b	1.62	2.41 ab	2.09 b	ND	2.62
156	2.10 a	2.21	1.90	1.77 a	1.64	2.01 a	1.73	2.39 b	2.17 b	ND	2.62
208	2.09 a	2.27	1.74	1.72 a	1.76	2.09 a	1.77	2.50 a	2.28 a	ND	2.66

† N rate units are kg ha^{-1}.

‡ The unit of tissue potassium is percent (%)

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

¶ No data available.

Table A1-17. Mean turfgrass tissue potassium for phosphorus rate main effect.

P_2O_5 rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
0	1.80‡	1.9 b§	2.00	1.40	1.60	2.00	1.60	ND¶	ND	ND	ND
24	1.80	2.1 a	2.10	1.50	1.70	1.90	1.60	ND	ND	ND	ND
49	1.80	2.1 a	2.10	1.40	1.60	1.90	1.50	ND	ND	ND	ND
						2005					
0	1.85	1.71	1.96 a	1.66	2.01	1.38	2.05	1.78	2.04	2.44	1.92
24	1.83	1.72	1.88 b	1.69	2.03	1.24	2.08	1.82	2.09	2.46	1.99
49	1.84	1.76	1.92 ab	1.68	2.05	1.37	2.10	1.79	2.10	2.46	1.99
						2006					
0	2.02	2.16	1.84	1.64	1.71	1.95	1.60	2.42	2.16	ND	2.57 b
24	2.08	2.24	1.73	1.66	1.58	2.01	1.76	2.44	2.19	ND	2.65 a
49	2.06	2.27	1.89	1.66	1.70	2.04	1.76	2.44	2.20	ND	2.69 a

† N rate units are kg ha^{-1}.

‡ The unit of tissue potassium is percent (%)

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

¶ No data available.

Table A1-18. Mean phosphorus removed in clippings for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
98	0.19‡	0.16	0.18 b§	0.02 b	0.03 c	0.01 c	0.05 c	ND¶	ND	ND	ND
156	0.18	0.17	0.27 a	0.09 a	0.18 b	0.05 b	0.09 b	ND	ND	ND	ND
208	0.19	0.18	0.25 a	0.08 a	0.18 a	0.19 a	0.18 a	ND	ND	ND	ND
						2005					
98	0.34 c	1.01 c	0.48 c	0.20 c	0.16 c	0.03 c	0.06 c	0.06 c	0.38 b	0.18 b	0.05 c
156	0.56 b	1.25 b	0.80 b	0.33 b	0.30 b	0.07 b	0.09 b	0.09 b	0.36 b	0.15 c	0.09 b
208	0.78 a	1.49 a	0.95 a	0.40 a	0.60 a	0.14 a	0.17 a	0.18 a	0.48 a	0.20 a	0.11 a
						2006					
98	0.27 c	0.21 c	0.07 b	0.02 b	0.03 c	0.13 c	0.41 c	0.30 c	0.18 c	ND	0.27 b
156	0.44 b	0.26 b	0.13 a	0.07 a	0.11 b	0.37 b	0.84 b	0.44 b	0.23 b	ND	0.31 b
208	0.59 a	0.31 a	0.13 a	0.07 a	0.26 a	0.66 a	1.09 a	0.57 a	0.32 a	ND	0.35 a

† N rate units are kg ha^{-1}.

‡ The unit of phosphorus removed in clippings is kg ha^{-1}.

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

¶ No data available.

Table A1-19. Mean phosphorus removed in clippings for phosphorus rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2004					
98	0.17	0.13	0.18 b	0.04 b	0.08	0.07	0.10	ND¶	ND	ND	ND
156	0.22	0.20	0.25 a	0.07 a	0.12	0.10	0.10	ND	ND	ND	ND
208	0.17	0.18	0.26 a	0.07 a	0.11	0.08	0.13	ND	ND	ND	ND
						2005					
98	0.49 b	1.07 b	0.63 b	0.28 b	0.13 b	0.06	0.06	0.09 b	0.33 b	0.14 b	0.07 b
156	0.55 b	1.25 b	0.73 b	0.33 a	0.37 a	0.09	0.12	0.13 a	0.42 a	0.19 a	0.09 a
208	0.63 a	1.42 a	0.88 a	0.32 a	0.38 a	0.09	0.11	0.11 ab	0.47 a	0.20 a	0.09 a
						2006					
98	0.36 b	0.23 a	0.09	0.04 b	0.10	0.29 b	0.49 b	0.37 b	0.21 b	ND	0.24 b
156	0.45 a	0.28 a	0.12	0.06 a	0.15	0.43 a	1.00 a	0.49 a	0.27 a	ND	0.34 a
208	0.48 a	0.26 ab	0.12	0.05 ab	0.15	0.44 a	0.86 a	0.45 a	0.25 a	ND	0.35 a

† N rate units are kg ha^{-1}.

‡ The unit of phosphorus removed in clippings is kg ha^{-1}.

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

¶ No data available.

Table A1-20. Mean soil phosphorus for nitrogen rate main effect.

N rate†	Month						
	May	June	July	Aug.	Sep.	Oct.	Nov.
				2004			
98	ND‡	ND	9.3§	7.3	8.3	7.9	7.9
156	ND	ND	9.9	8.5	8.8	9.0	8.6
208	ND	ND	9.7	8.5	8.5	7.3	8.7
				2005			
98	1.6	3.2	2.5	1.7	1.4	7.6	7.8 ab¶
156	1.0	2.1	1.8	1.5	1.1	8.1	6.7 b
208	2.1	3.5	2.0	1.7	1.5	6.8	9.6 a
				2006			
98	8.0	1.6	ND	7.9	8.1	9.3	ND
156	7.6	1.5	ND	7.9	8.6	9.1	ND
208	6.2	2.4	ND	7.9	9.0	8.5	ND

† N rate units are kg ha^{-1}.

‡ No data available

§ Soil phosphorus units are ppm.

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

Table A1-21. Mean soil phosphorus for phosphorus rate main effect.

N rate†	Month						
	May	June	July	Aug.	Sep.	Oct.	Nov.
				2004			
98	ND‡	ND	9.1§	7.5	8.2	7.5	8.2
156	ND	ND	9.9	8.7	8.7	8.1	8.5
208	ND	ND	9.8	7.9	8.7	8.5	8.5
				2005			
98	1.2	2.4	1.9	1.4	1.2	6.5	8.2
156	2.0	3.3	2.5	2.0	1.6	8.1	7.0
208	1.5	3.2	1.9	1.7	1.2	8.0	8.8
				2006			
98	6.3 b¶	1.5	ND	6.9	7.3 b	8.6	ND
156	6.7 b	1.9	ND	8.2	8.7 a	9.4	ND
208	8.8 a	2.0	ND	8.6	9.7 a	5.9	ND

† N rate units are kg ha^{-1}.

‡ No data available.

§ Soil phosphorus units are ppm.

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

Table A1-22. Mean soil phosphorus for soil depth main effect.

Depth†	Month						
	May	June	July	Aug.	Sep.	Oct.	Nov.
				2004			
5	ND‡	ND	11.8§ a¶	9.9 a	10.1 a	9.9 a	9.6 a
10	ND	ND	7.4 b	6.2 b	6.9 b	6.2 b	7.2 b
				2005			
5	2.1 a	3.8 a	2.5	1.8	1.6	9.0 a	8.7
10	1.0 b	2.1 b	1.7	1.5	1.1	6.1 b	7.3
				2006			
5	8.8 a	2.5 a	ND	8.7 a	9.3 a	9.8 a	ND
10	5.8 b	1.1 b	ND	7.1 b	7.8 b	8.1 b	ND

† Depth units are centimeter.

‡ No data available.

§ Soil phosphorus units are ppm.

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

Table A2-1. Analysis of variance table for turfgrass color.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
		2005										
Irrigation (I)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	2	NS	NS	NS	NS	*	NS	*	**	**	**	NS
I x S	4	**	**	**	**	**	**	*	*	**	**	NS
Nitrogen rate (NR)	2	NS	NS	NS	NS	NS	NS	NS	NS	*	**	NS
I x NR	4	**	**	**	**	**	**	**	**	NS	**	**
S x NR	4	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS
I x S x NR	8	NS	NS	**	NS	*	**	NS	NS	NS	*	NS
		2006										
Irrigation (I)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	2	NS	NS	NS	*	*	*	*	NS	NS	NS	NS
I x S	4	NS	**	**	**	**	*	**	*	**	**	**
Nitrogen rate (NR)	2	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS
I x NR	4	*	**	**	**	**	**	**	*	*	NS	NS
S x NR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x S x NR	8	NS	NS	**	NS	*	NS	NS	NS	NS	NS	NS

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

Table A2-2. Analysis of variance table for turfgrass quality.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
2005												
Irrigation (I)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	2	NS	NS	NS	NS	NS	NS	*	**	**	**	NS
I x S	4	**	**	**	*	**	*	NS	*	**	**	NS
Nitrogen rate (NR)	2	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS
I x NR	4	**	NS	**	**	**	**	**	**	NS	**	**
S x NR	4	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
I x S x NR	8	NS	NS	*	NS	NS	**	NS	NS	NS	*	NS
2006												
Irrigation (I)	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	2	NS	NS	NS	*	*	*	*	NS	NS	NS	NS
I x S	4	**	**	**	**	**	*	**	*	**	**	**
Nitrogen rate (NR)	2	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS
I x NR	4	NS	NS	**	**	**	**	**	*	NS	NS	NS
S x NR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
I x S x NR	8	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

Table A2-3. Analysis of variance table for clipping yield.

Source	df	Week after treatment						
		May	June	July	Aug.	Sep.	Oct.	Total
		2005						
Irrigation (I)	2	NS	NS	NS	NS	NS	NS	NS
Species (S)	2	NS	NS	*	**	*	NS	NS
I x S	4	**	**	**	**	**	**	**
Nitrogen rate (NR)	2	NS	NS	NS	*	NS	NS	NS
I x NR	4	**	**	**	**	**	**	**
S x NR	4	NS	NS	*	*	**	NS	NS
I x S x NR	8	NS	**	NS	NS	NS	*	NS
		2006						
Irrigation (I)	2	ND†	NS	NS	NS	NS	NS	ND
Species (S)	2	ND	NS	**	**	NS	NS	ND
I x S	4	ND	**	**	**	**	**	ND
Nitrogen rate (NR)	2	ND	NS	*	*	NS	*	ND
I x NR	4	ND	**	**	**	**	NS	ND
S x NR	4	ND	NS	**	NS	**	NS	ND
I x S x NR	8	ND	NS	NS	*	NS	NS	ND

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table A2-4. Analysis of variance table for soil water content.

Source	df	Week after treatment										
		2	4	6	8	10	12	14	16	18	20	22
2005												
Irrigation (I)	2	ND[†]	ND	ND	**	**	**	**	**	ND	ND	ND
Species (S)	2	ND	ND	ND	**	**	**	**	**	ND	ND	ND
I x S	4	ND	ND	ND	NS	NS	NS	*	NS	ND	ND	ND
Nitrogen rate (NR)	2	ND	ND	ND	NS	NS	*	NS	NS	ND	ND	ND
I x NR	4	ND	ND	ND	NS	**	NS	NS	NS	ND	ND	ND
S x NR	4	ND	ND	ND	NS	NS	NS	NS	NS	ND	ND	ND
I x S x NR	8	ND	ND	ND	NS	*	NS	NS	NS	ND	ND	ND
2006												
Irrigation (I)	2	**	**	**	**	**	**	**	**	**	**	**
Species (S)	2	**	**	**	**	**	**	**	**	**	**	**
I x S	4	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*
Nitrogen rate (NR)	2	NS	NS	**	NS	NS	NS	*	NS	**	NS	NS
I x NR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x NR	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x S x NR	8	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Indicates significance at $P = 0.05$.

** Indicates significance at $P = 0.01$.

NS indicates not significant at $P = 0.05$.

† No data available.

Table A2-5. Mean turfgrass color for irrigation main effect.

Irrigation	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2005										
Precipitation only	6.8†	7.1	6.7	6.6	6.5 b‡	6.7	5.8 b	4.8 b	2.7 b	4.7 b	7.5
Every other day	6.8	7.0	7.2	6.9	7.1 a	6.9	6.9 a	7.0 a	6.8 a	7.1 a	7.5
Weekly	6.9	7.0	7.1	6.9	7.1 a	7.1	7.0 a	6.9 a	6.5 a	6.9 a	7.4
	2006										
Precipitation only	7.4	6.8	6.2	5.4 b	5.5 b	6.1 b	5.5 b	6.2	6.1	6.7	6.6
Every other day	7.1	6.9	6.6	6.9 a	6.7 a	7.0 a	6.6 a	6.4	6.4	7.0	6.7
Weekly	7.5	6.9	6.5	6.8 a	6.7 a	6.9 a	6.2 a	6.3	6.3	7.3	6.7

† Turfgrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

Table A2-6. Mean turfgrass color for species main effect.

Species	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2005					
Lawn mixture†	7.3‡ a§	7.3 a	6.4 b	6.5 b	6.5 b	6.8 b	6.2 b	5.9 b	4.7 c	5.6 b	7.5
Tall fescue	7.8 a	7.9 a	7.9 a	7.2 a	7.1 a	6.7 b	6.8 a	6.5 a	5.9 a	6.5 a	7.3
Kentucky bluegrass	5.4 b	6.0 b	6.7 b	6.6 b	7.1 a	7.3 a	6.6 ab	6.4 a	5.5 b	6.7 a	7.6
						2006					
Lawn mixture	7.2	6.3 b	5.7 b	5.6 c	5.4 b	6.3 b	5.4 b	5.8 b	6.0 b	7.1 a	7.0 a
Tall fescue	7.6	7.1 a	6.9 a	7.3 a	6.9 a	6.9 a	6.4 a	6.3 ab	6.1 b	6.5 b	5.9 b
Kentucky bluegrass	7.2	7.1 a	6.7 a	6.3 b	6.5 a	6.9 a	6.5 a	6.8 a	6.7 a	7.4 a	7.0 a

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Turfgrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

Table A2-7. Mean turfgrass color for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2005										
98	7.1‡ a§	7.3 a	6.6 c	6.1 c	6.1 c	6.2 c	6.1 c	5.9 c	5.3	6.4 a	7.3 b
156	6.8 b	7.0 b	7.4 a	7.3 a	7.0 b	6.7 b	6.4 b	6.2 b	5.4	6.4 b	7.7 a
208	6.6 b	6.9 b	7.0 b	6.9 b	7.7 a	7.8 a	7.2 a	6.6 a	5.4	5.9 b	7.4 b
	2006										
98	7.5 a	7.1 a	5.7 c	5.6 c	5.4 c	6.1 c	5.8 b	6.0 b	6.1 b	7.0	6.7
156	7.3 b	6.7 b	7.1 a	7.0 a	6.2 b	6.6 b	6.0 b	6.4 a	6.3 a	7.1	6.6
208	7.3 b	6.7 b	6.5 b	6.6 b	7.3 a	7.3 a	6.5 a	6.5 a	6.4 a	7.0	6.6

† N rate units are kg ha^{-1}

‡ Turfgrass color was rated from 1 to 9 (1 = straw brown, 9 = dark green, and 6 = acceptable).

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

Table A2-8. Mean turfgrass quality for irrigation main effect.

Irrigation	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2005					
Precipitation only	6.2†	6.7	6.5	6.4	6.3	6.5	5.7 b‡	4.8 b	2.7 b	4.7 b	7.4
Every other day	6.4	6.9	7.0	6.9	6.9	7.0	6.9 a	7.1 a	6.8 a	7.1 a	7.5
Weekly	6.3	6.8	6.9	7.0	6.9	7.0	6.8 a	6.8 a	6.5 a	6.9 a	7.4
						2006					
Precipitation only	6.9	6.7	6.0	5.3 b	5.3 b	6.1 b	5.5 b	6.1	6.1	6.6	6.4
Every other day	7.0	6.8	6.4	6.9 a	6.6 a	7.0 a	6.6 a	6.4	6.3	6.9	6.6
Weekly	7.3	6.9	6.4	6.7 a	6.6 a	6.8 a	6.1 a	6.3	6.3	7.2	6.6

† Turfgrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

Table A2-9. Mean turfgrass quality for species main effect.

Species	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2005										
Lawn mixture†	7.0‡b§	7.3 b	6.4 b	6.7 b	6.3 c	6.7 b	6.2	5.8 b	4.7 b	5.6 b	7.5
Tall fescue	7.9 a	8.0 a	7.9 a	7.2 a	7.1 a	6.6 b	6.7	6.5 a	5.8 a	6.4 a	7.3
Kentucky bluegrass	4.0 c	5.3 c	6.1 b	6.5 b	6.7 b	7.1 a	6.4	6.4 a	5.5 a	6.7 a	7.5
	2006										
Lawn mixture	6.8 b	6.1 b	5.3 b	5.4 b	5.3 c	6.2 b	5.4 b	5.8 b	5.9 b	6.9 b	6.9 a
Tall fescue	7.4 a	7.1 a	6.9 a	7.3 a	6.9 a	6.9 a	6.3 a	6.3 ab	6.1 b	6.4 c	5.8 b
Kentucky bluegrass	7.0 b	7.1 a	6.7 a	6.2 b	6.3 b	6.9 a	6.4 a	6.8 a	6.7 a	7.4 a	6.9 a

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Turfgrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

Table A2-10. Mean turfgrass quality for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2005										
98	6.6‡a§	7.0	6.5 b	6.1 c	6.0 c	6.1 c	6.1 c	5.9 c	5.3	6.5 a	7.2 b
156	6.3 ab	6.8	7.2 a	7.6 a	6.8 b	6.6 b	6.3 b	6.2 b	5.3	6.4 a	7.7 a
208	6.0 b	6.7	6.7 b	6.7 b	7.3 a	7.7 a	7.0 a	6.5 a	5.4	5.9 b	7.4 b
	2006										
98	7.1	6.9	5.6 c	5.6 c	5.3 c	6.1 c	5.8 b	6.0 b	6.1	6.9	6.5
156	7.0	6.7	7.0 a	6.9 a	6.1 b	6.6 b	5.9 b	6.3 ab	6.3	7.0	6.6
208	7.1	6.7	6.4 b	6.5 b	7.1 a	7.3 a	6.5 a	6.5 a	6.3	6.9	6.5

† N rate units are kg ha^{-1}

‡ Turfgrass quality was rated from 1 to 9 (1 = worst, 9 = excellent, and 6 = acceptable).

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

Table A2-11. Mean turfgrass clipping yield for irrigation main effect.

Irrigation	Month						
	May	June	July	Aug.	Sep.	Oct.	Total
	2005						
Precipitation only	23.7†	9.7	6.6 b‡	0.5 c	7.7 b	1.2	49.4
Every other day	22.6	15.1	12.4 a	6.0 a	10.8 a	0.8	67.8
Weekly	23.4	12.9	10.6 a	4.2 b	10.0 a	0.8	62.0
	2006						
Precipitation only	ND§	9.4	2.3 b	5.6 b	9.2	1.4	27.9 b
Every other day	ND	12.5	6.6 a	14.9 a	8.5	1.4	43.9 a
Weekly	ND	11.0	6.1 a	16.4 a	8.9	1.5	43.9 a

† Clipping dry weight units are g m^{-2}.

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

§ No data available.

Table A2-12. Mean turfgrass clipping yield for species main effect.

Species	Month						
	May	June	July	Aug.	Sep.	Oct.	Total
	---- 2005 ----						
Lawn mixture†	32.9‡ a§	14.5 a	11.9 a	4.5 a	12.9 a	1.4 a	78.0 a
Tall fescue	28.2 b	14.6 a	8.8 b	3.3 b	8.6 b	0.6 b	64.0 b
Kentucky bluegrass	8.6 c	8.7 b	8.9 b	3.0 b	7.0 c	0.9 b	37.1 c
	---- 2006 ----						
Lawn mixture	ND¶	12.9 a	6.0 a	13.6 a	10.9 a	1.8 a	45.2 a
Tall fescue	ND	8.7 b	4.9 b	13.2 a	7.0 c	0.9 b	34.7 b
Kentucky bluegrass	ND	11.3 a	4.1 c	10.2 b	8.7 b	1.5 a	35.8 b

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ Clipping dry weight units are g m^{-2}.

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

¶ No data available.

Table A2-13. Mean turfgrass clipping yield for nitrogen rate main effect.

N rate†	Month						
	May	June	July	Aug.	Sep.	Oct.	Total
	2005						
98	24.9‡ a§	8.9 c	5.8 c	3.1 b	10.5 a	0.6 c	15.6 c
156	23.1 b	16.7 a	9.8 b	3.8 a	10.2 a	1.3 a	18.9 a
208	21.7 b	12.1 b	14.0 a	3.9 a	7.8 b	1.0 b	17.6 b
	2006						
98	ND¶	10.1 b	2.7 c	8.7 c	7.1 c	1.3	29.9 c
156	ND	10.6 b	6.7 a	12.4 b	9.2 b	1.4	40.3 b
208	ND	12.1 a	5.7 b	15.8 a	10.3 a	1.6	45.5 a

† N rate units are kg ha^{-1}

‡ Clipping dry weight units are g m^{-2}.

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

¶ No data available.

Table A2-14. Mean soil water content for irrigation main effect.

Irrigation	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2005										
Precipitation only	ND[†]	ND	ND	9.5[‡] b[§]	14.6 c	18.7 c	9.3 c	6.9 b	ND	ND	ND
Every other day	ND	ND	ND	20.6 a	30.3 a	26.8 a	26.9 a	23.1 a	ND	ND	ND
Weekly	ND	ND	ND	17.5 a	22.6 b	21.4 b	20.6 b	18.0 a	ND	ND	ND
	2006										
Precipitation only	26.2 b	8.5 b	11.3 c	17.1 c	13.3 b	6.1 c	22.1 c	28.6 b	26.3 b	25.7 b	23.9 b
Every other day	32.3 a	26.1 a	26.9 a	32.3 a	21.5 a	19.2 a	30.5 a	34.5 a	32.2 a	30.9 a	29.8 a
Weekly	32.0 a	24.3 a	22.4 b	26.5 b	19.0 a	16.2 b	28.4 b	33.0 a	31.0 a	30.0 a	27.4 a

† No data available.

‡ The units of soil water content are percent (%).

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

Table A2-15. Mean soil water content for species main effect.

Species	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
	2005										
Lawn mixture†	ND‡	ND	ND	14.6§b¶	22.0 b	22.0 b	17.7 b	15.0 b	ND	ND	ND
Tall fescue	ND	ND	ND	17.9 a	24.7 a	24.3 a	22.0 a	18.6 a	ND	ND	ND
Kentucky bluegrass	ND	ND	ND	15.2 b	20.8 b	20.5 b	17.0 b	14.5. b	ND	ND	ND
	2006										
Lawn mixture	29.3 b	18.4 b	19.4 b	24.1 b	17.7 b	12.8 b	25.7 b	30.9 b	28.9 b	28.2 b	26.1 b
Tall fescue	31.4 a	22.4 a	22.8 a	27.1 a	19.3 a	15.6 a	29.4 a	33.6 a	31.7 a	30.5 a	28.7 a
Kentucky bluegrass	29.8 b	18.1 b	18.3 b	24.6 b	16.8 b	13.1 b	25.8 b	31.5 b	29.0 b	28.0 b	26.4 b

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ No data available.

§ The units of soil water content are percent (%).

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

Table A2-16. Mean soil water content for nitrogen rate main effect.

N rate†	Week after treatment										
	2	4	6	8	10	12	14	16	18	20	22
						2005					
98	ND‡	ND	ND	16.2§	22.4	22.8 a¶	19.3	16.0	ND	ND	ND
156	ND	ND	ND	15.9	22.5	22.1 b	19.0	15.9	ND	ND	ND
208	ND	ND	ND	15.4	22.7	21.9 b	18.4	16.2	ND	ND	ND
						2006					
98	30.5	19.8	20.7 a	25.6	18.2	14.0	27.4 a	32.0	30.6 a	29.2	27.0
156	30.1	19.8	20.4 a	25.3	18.2	13.9	27.2 a	32.1	30.0 a	28.9	27.2
208	29.9	19.4	19.4 b	25.0	17.3	13.6	26.4 b	31.9	29.0 b	28.6	26.9

† N rate units are kg ha^{-1}.

‡ No data available.

§ The units of soil water content are percent (%).

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

Table A2-17. Mean soil phosphorus for irrigation main effect.

Irrigation	Month						
	May	June	July	Aug.	Sep.	Oct.	Nov.
				2005			
Precipitation only	ND†	30.6‡	24.2	23.6	23.3	22.1	24.8
Every other day	ND	31.9	24.5	25.0	23.1	24.6	25.3
Weekly	ND	28.7	28.1	24.8	20.0	21.9	20.8
				2006			
Precipitation only	26.9	26.5	ND	ND	24.7	22.4	23.4
Every other day	29.9	30.9	ND	ND	27.5	26.0	26.7
Weekly	27.7	28.7	ND	ND	24.7	21.9	22.8

† No data available.

‡ Soil phosphorus units are ppm.

Table A2-18. Mean soil phosphorus for species main effect.

Species	Month						
	May	June	July	Aug.	Sep.	Oct.	Nov.
				2005			
Lawn mixture[†]	ND[‡]	31.4[§]	27.3	25.0	23.2	22.6	23.9
Tall fescue	ND	30.3	25.7	24.3	20.4	24.3	24.4
Kentucky bluegrass	ND	29.5	23.8	24.2	19.9	21.6	22.5
				2006			
Lawn mixture	28.3	28.0	ND	ND	25.8	23.9	24.0
Tall fescue	29.3	30.3	ND	ND	26.7	24.0	25.0
Kentucky bluegrass	26.9	27.7	ND	ND	24.3	22.4	23.9

† Lawn mixture is a combination of Kentucky bluegrass, perennial ryegrass, creeping red fescue, and Chewings fescue.

‡ No data available.

§ The units of soil water content are percent (%).

Table A2-19. Mean soil phosphorus for nitrogen rate main effect.

N rate†	Month						
	May	June	July	Aug.	Sep.	Oct.	Nov.
				2005			
98	ND‡	30.8§	25.2	23.3	21.4	22.4	23.3
156	ND	30.3	26.1	25.9	20.0	23.4	23.3
208	ND	30.2	25.4	24.3	22.0	22.7	24.2
				2006			
98	26.6	27.4	ND	ND	25.1	22.4	23.9
156	29.7	29.1	ND	ND	26.2	24.5	24.5
208	28.1	29.5	ND	ND	25.2	23.4	24.5

† N rate units are kg ha^{-1}.

‡ No data available

§ Soil phosphorus units are ppm.

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