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dissertation entitled

The Effects of Plant Growth Regulators on Kentucky bluegrass (Poa pratensis L.) and Supina bluegrass (Poa supina Schrad.) in Reduced Light Conditions

presented by

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has been accepted towards fulfillment of the requirements for

Ph.D. degree in Crop & Soil Sciences

Major professor

Date 6 February 1997

THE EFFECTS OF PLANT GROWTH REGULATORS ON KENTUCKY BLUEGRASS (*POA PRATENSIS* L.) AND SUPINA BLUEGRASS (*P. SUPINA* SCHRAD.) IN REDUCED LIGHT CONDITIONS

By

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A DISSERTATION

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

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Sciences

1997

ABSTRACT

THE EFFECTS OF PLANT GROWTH REGULATORS ON KENTUCKY BLUEGRASS (*POA PRATENSIS* L.) AND SUPINA BLUEGRASS (*P. SUPINA* SCHRAD.) IN REDUCED LIGHT CONDITIONS

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Turfgrass management in reduced light conditions (RLC; < 30% full sunlight) is difficult because turf growth is affected by lack of sufficient light energy. Turf plants in RLC are relatively weak and cannot withstand traffic or other damage due to excessive shoot elongation, reduced tillering, and reduced root growth. In normal light conditions plant growth regulators which inhibit gibberellic acid (GA) biosynthesis are occasionally used on turfgrass to reduce mowing requirements by suppressing shoot growth. The objective of the research was to determine the effects of two GA-inhibitors (flurprimidol and trinexapac-ethyl) on turfgrass in RLC. The primary reason for the research was to develop a set of management strategies to maintain turfgrass in RLC for athletic events, e.g. athletic fields in covered stadia, although the results should be applicable to many turf situations. Three studies were conducted. In the first set of experiments, the effects of flurprimidol were tested at three nitrogen (N) rates (24, 48, and 96 kg ha^{-1} $month^{-1}$) on Kentucky bluegrass, with and without traffic, at two levels of RLC (approximately 1-2 and 8 mol photosynthetically active radiation (PAR) day^{-1}). A second study was undertaken to compare the relative shade tolerance of Supina bluegrass (*Poa supina* Schrad.) to Kentucky bluegrass (*P. pratensis* L.) with different combinations of trinexapac-ethyl and foliar-applied iron. In the third study the effects of trinexapac-ethyl on photosynthesis of Kentucky bluegrass and Supina bluegrass in RLC were assessed. The effects of trinexapac-ethyl on photosynthesis of Supina bluegrass maintained at low and high N rates (24 and 96 kg ha^{-1} $month^{-1}$) were also evaluated. Both flurprimidol and trinexapac-ethyl effectively suppressed shoot growth and enhanced turf quality in RLC. Supina bluegrass was significantly more tolerant of RLC compared to Kentucky bluegrass although neither grass prospered at 1-2 mol PAR day^{-1}. Supina bluegrass had greater rates of photosynthesis than Kentucky bluegrass on a turf area basis although this was related to the higher leaf area index (LAI) of Supina bluegrass. Trinexapac-ethyl did not affect photosynthetic rates in either species. Nitrogen rate had little effect on photosynthesis in RLC but the high N rate did reduce LAI.

Dedicated to my wife, Valerie Ann Stier

ACKNOWLEDGEMENTS

I would like to extend my deepest appreciation to Dr. John (Trey) N. Rogers, III, for his guidance, support, and the belief in me he has always held. I will forever consider myself the most fortunate of graduate students for all the wonderful opportunites Dr. Rogers has provided. My graduate committee also deserves special recognition for the time and efforts they have provided to me: Dr. James Flore, for the training and use of photosynthesis equipment and his lab space; Dr. Joseph Vargas, for his lab space and materials for identification of fungal pathogens as well as his insights on interacting with others; Dr. James Crum, for the special encouragement and wisdoms he shared with me. I am thankful for the help and friendship of T.J. Lawson, Richard Fogarsi, Thomas Nikolai, Mark Collins, and John C. Sorochan, as well as the myriad of student workers and golf course professionals with whom I have interacted, during the long, busy, and incredibly exciting days when we provided the world with the first indoor turfgrass athletic field at the Pontiac Silverdome for the 1993 U.S. Cup and 1994 World Cup.

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KEY TO SYMBOLS AND ABBREVIATIONS

CER, carbon exchange rate; PGR, plant growth regulator; GA, gibberellic acid; g_{max}, peak deceleration; TE, trinexapac-ethyl; PAR, photosynthetically active radiation; PPFD, photosynthetic photon flux density; Ly, langley; E, transpiration; g_s, stomatal conductance; g_m, mesophyll conductance; WUE, water use efficiency; LAI, leaf area index; N, nitrogen; P, phosphorus; K, potassium; CSSF, Covered Stadium Simulator Facility.

Chapter 1

INTERACTION OF NITROGEN AND FLURPRIMIDOL ON KENTUCKY BLUEGRASS (*POA PRATENSIS* L.) IN REDUCED LIGHT CONDITIONS

INTRODUCTION

Turfgrasses in intense shade have weak tissues, reduced root to shoot ratio, and reduced tillering resulting in a reduced quality turf which cannot withstand traffic (Beard, 1973; Wilkinson and Beard, 1975). Minimal nitrogen inputs are recommended to maintain a balance between shoot and root growth and to minimize the growth of excessively succulent tissue. Traffic is to be minimized or avoided (Dudeck and Peacock, 1992). Consequently, current recommendations for turf in shade do not allow for management techniques in which traffic is a factor. Yet golf courses often have areas subjected to both shade and traffic. In addition, recent interest in the use of turfgrass systems for covered stadia requires the development of new management techniques for turf subjected to traffic under intensely shaded conditions (Anonymous, 1995; Kierle, 1995; Rogers, 1994; Tracinski, 1993).

Plant growth regulators (PGRs) which are gibberellic acid biosynthesis-inhibitors (GA-inhibitors) have been used successfully to decrease vertical growth (i.e., clipping yields) (Dernoeden, 1984; Diesburg and Christians, 1989; Johnson, 1988) by inhibiting cell elongation (Kaufmann, 1986a). Side effects of GA-inhibitors include darker green color and increased turf density due to enhanced tillering, often following a transient phytotoxic response resulting in tip die back (Dernoeden, 1984; Watschke, 1981). In shade, excessive turfgrass shoot elongation leads to weak, traffic-intolerant turf (Beard, 1973). Preliminary research has proven the potential of GA-inhibitors to control shoot elongation and provide a higher quality turf compared to untreated turf in reduced light conditions although phytotoxicity can occur (Rogers et al., 1996; Rogers and Stier, 1993). In normal light situations multiple applications of GA-inhibitors increase the level of suppression but also increase the potential for phytotoxicity, especially when turf is grown under a stress condition (Dernoeden, 1984; Johnson, 1988; Vitolo et al., 1990). Nitrogen fertilization in concert with PGR application has been reported to successfully minimize or overcome the short-term deleterious effects of PGRs in normal light situations (Devitt and Morris, 1988). The effects of nitrogen rate on PGR-treated turf in reduced light conditions are unknown.

The primary objective of this research was to determine the appropriate rate of nitrogen to apply to flurprimidol-treated Kentucky bluegrass turf in reduced light conditions. Secondary objectives included determining the amount of light required to maintain turf in an enclosed environment, the effects of traffic, and turf response to flurprimidol in reduced light conditions.

MATERIALS AND METHODS

The research was conducted inside the Covered Stadium Simulator Facility (CSSF) at the Hancock Turfgrass Research Center between Dec. 1992 and April 1994. The CSSF was constructed to simulate the conditions inside the Pontiac Silverdome, a covered stadium (Stier et al., 1993). The CSSF was a 600 m^2 air-supported structure constructed of Sheerfill II®, a fiberglass fabric (Chemical Fabrics Corporation, Buffalo, NY) which transmitted approximately 11 ± 2% sunlight. Temperature and relative humidity were recorded daily with a sling psychrometer. Furnaces on the endwalls of the facility were used to maintain the temperature typically at 16.8 ± 0.9 sd °C. Actual temperatures occasionally ranged from 3 to 23 ° C due to the poor insulating characteristics of the fiberglass fabric, the inability of the furnaces to compensate for excessively low outdoor temperatures (e.g., -10 C), and lack of an active cooling mechanism. Relative humidity (RH) averaged 44.8 ± 6.2 sd % with a range of 24-70% RH.

Portable plots were established in wood boxes (1.2 x 1.2 x 0.15m depth) filled with a sand:peat mix (80:20 v/v) (Table 78, Appendix). The pH was 7.3 with initial P and K levels of 63 kg ha^{-1} and 30 kg ha^{-1}, respectively. Holes were drilled in the bottoms of the boxes for drainage. The sand:peat mixture was compacted using hand-held tampers. Starter fertilizer (13-25-12) was applied to the soil which supplied 7.6 g N m^{-2}, 6.4 g P m^{-2}, and 5.8 g K m^{-2}. On 30 Sept. 1992 the plots were sodded with a washed Kentucky bluegrass blend (20% each of 'Trenton', 'Midnight', 'Aspen', 'Rugby', and 'Kelly'). The plots were moved into the CSSF for testing on 7 Dec. 1992 through 10 April 1993. The experiments were repeated a second year (season). In 1993, plots were sodded 10 Sept. using a washed Kentucky bluegrass blend (20% each of 'Trenton', 'Midnight', 'Aspen', 'Glade', and 'Parade'). These plots were moved into the CSSF on 10 Dec. 1993 and maintained until 8 April or 23 August 1994 depending on the experiment. In both years plots were mowed once to twice weekly at 3.8 cm during establishment and irrigated as necessary to prevent moisture stress. Urea (2.4 g N m^{-2}) was applied to aid establishment at three weeks after sodding in 1992 and at two and five weeks after sodding in 1993.

Two experiments were conducted to assess the effects of nitrogen rate in PGR-treated turf. Experiment I was conducted in the ambient light conditions of the CSSF. Experiment II was conducted in the CSSF under supplemental lighting. Supplemental light was supplied by 430 W high pressure sodium (HPS) lamps suspended 2.7 m above the turf surface. An automatic timer controlled the lamps to provide a 12 hr photoperiod (0700 to 1900 hr). Reflective (metallic) mylar sheets were suspended in parallel along the two long sides of the rectangular plot area to separate the lighted plots from the unlighted plots and to reflect light from the lamps for increased uniformity of irradiance.

Radiation data outside the CSSF were collected with a LI-PY14226 pyranometer and integrated daily. Radiometric units (Ly day^{-1}) were converted to quantum units using the following equation based on conversion units from Thimijan and Heins (1983):

$$\text{Equation 1:} \quad ((\text{Ly day}^{-1}/1.05)*3600*24)/\ 10^{6} = \text{mol PAR day}^{-1}.$$

Radiation data for plots in ambient light conditions of the CSSF were estimated based on the percent transmission of photosynthetically active radiation (PAR) through the fabric, measured at the turf surface. Radiation data inside the CSSF from Dec. 1992 through April 1993 were determined at the turf surface weekly within one hour of the solar zenith using a hand-held photometer (Greenlee Inc., Rockford, IL). Occasionally a portable spectroradiometer (Li-Cor, Lincoln, NE) was used from Dec. 1992 to April 1993 to determine only photosynthetically active radiation (PAR), 400-700 nm. Starting

Dec.1993 radiation data inside the CSSF were collected weekly using only the spectroradiometer.

For plots in supplemental light conditions in 1992-1993, photometeric units (lux) were converted to quantum units (μmol m^{-2} s^{-1}) by multiplying against a conversion factor (0.2215) derived from data collected concurrently with the photometer and the spectroradiometer. Starting Dec. 1993 radiation data inside the CSSF were collected weekly using only the spectroradiometer. Based on measurements collected when ambient PAR inside the CSSF was low (e.g., 10 μmol m^{-2} s^{-1} during rainstorms, pre-dawn, or evening), the HPS lamps supplied approximately 173 $\pm$ 22 μmol PAR m^{-2} s^{-1}. The metallic mylar curtains on both sides of the plot area blocked much of the light transmitted into the CSSF. Measurements at different times of the day under a range of sunlight conditions (sunny, cloudy) showed approximately 10% of the sunlight transmitted into the CSSF impinged on the plots under supplemental light in the morning and late afternoon; at midday approximately 80% of the light transmitted into the CSSF fell on the plots under supplemental light. Because ambient light levels peaked at midday, it was estimated that approximately 50% of the daily ambient PAR inside the CSSF contributed to the total daily PPFD of plots under supplemental light. The total daily photosynthetic photon flux density (PPFD) of plots in supplemental light conditions was estimated as follows using the average PPFD (μmol m^{-2} s^{-1}) from all plots:

Equation 2: $(((173\ \mu\text{mol m}^{-2}\ \text{s}^{-1}\ \text{PAR}*60\ \text{sec min}^{-1})*60\ \text{min h}^{-1})*12\ \text{h})/1 \times 10^{6} =$

mol PAR day^{-1} from HPS lamps + $0.5\ \text{mol PAR day}^{-1}$ ambient light =

mol PAR day^{-1}, supplemental light plots

The experiments were arranged as randomized complete block, split plot designs with three replications. Treatments were arranged in a 3 x 2 x 2 factorial with nitrogen rate and flurprimidol as main plots. Simulated soccer traffic was applied as a sub-plot treatment split over the main plots. Nitrogen rates were 24, 48, and 96 kg ha^{-1} per treatment date. Urea nitrogen was applied with a drop spreader on the same dates as flurprimidol. Flurprimidol was applied at the label rate of 1.12 kg ha^{-1} in 1168 L H_2O ha^{-1} using a CO_2-powered backpack sprayer; control plots received no flurprimidol. Nitrogen and flurprimidol were applied on the following dates: 16 Dec., 21 Jan., and 26 Feb. (supplemental light study only) 1992-93, and 17 Dec., 4 Feb., and 21 Mar. 1993-94. The turf was irrigated with approximately 1.25 cm water immediately following fertilization and flurprimidol applications. Additional irrigation was supplied as necessary to prevent visible drought stress symptoms (blue-green turf color, footprinting, wilting). Plots in ambient light conditions received approximately 1.25 cm water at 14-21 day intervals, while plots in supplemental light conditions received approximately 1.25 cm at seven to 10 day intervals. Traffic was applied to one-half of each plot by having a person (approximately 75-115 kg) walk 50 passes while wearing molded soccer cleats on each of the following dates: 29 Dec., 14 Jan., 21 Jan., 29 Jan., 6 Feb., 20 Feb., 10 Mar., and 24 Mar. (supplemental lighted study only on latter two dates) 1992-93, and 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., 24 Mar., and 31 Mar. 1993-94. Traffic was applied immediately after mowing and prior to irrigation. Fungicides were applied at the onset of disease symptoms. On 9 Jan. 1993 and 14 Jan.

1994 chlorothalonil (tetrachloroisophthalonitrile; 16.5 kg ha^{-1}) was applied to control leafspot and melting out diseases caused by *Drechslera/Bipolaris* spp.

Plots were mowed once to twice weekly as needed to prevent removal of more than one-third of the leaf tissue. Clippings were collected, oven-dried at 60 °C for 48 h, and weighed. Turf quality was rated visually at five to 14 day intervals; ratings were conducted more frequently at the beginning of each year to assess rapid changes in turf quality and became less frequent as turf quality fluctuated less abruptly. Visual turf quality was based on a one to nine scale, with one representing completely necrotic turf or bare soil and nine representing dense, uniform turf with good color. A value of five was considered the minimum value for acceptable turf. Turf and rooting strength were evaluated periodically using an Eijkelkamp shear vane apparatus (Eijkelkamp, Giesbeek, The Netherlands) (Rogers and Waddington, 1990). The amount of force (torque) required to tear the turf was collected in two locations from each plot on every measurement date. Treatment effects on the turf surface hardness were periodically evaluated using a Clegg Impact Soil Tester (CIT) (Lafayette Instrument Co., Lafayette, IN). The CIT provided surface hardness values by measuring maximum deceleration of a 2.25 kg hammer when dropped from a 0.46 m height (Rogers and Waddington, 1990). Impact values were collected from three locations in each plot on each measurement date. On 23 August 1994, one core (10 cm diam) was collected for plant biomass estimates from each plot which had received supplemental light. Plant density was evaluated by counting the number of live plants in each core. Verdure was removed from each core, and all living tissue was oven-dried at 60° C for 48 h then weighed. The number of shoots per plant was determined by averaging the number of shoots from five plants selected at random from each plot.

Data were analyzed using MSTAT analysis of variance procedures for a 3-by-2 factorial experiment in a randomized complete block, split-plot design with three replications. The three nitrogen rates and two flurprimidol levels were split into trafficked and non-trafficked turf.

RESULTS AND DISCUSSION

Experiment I

Turf quality, growth, and other attributes declined over time. To document the trends data are presented for individual dates throughout the course of the experiment. Data are presented for each year due to different results between years. Although some of the differences could have been due to different cultivars in the second year, the differences were probably due to a longer and more favorable establishment period during the autumn 1993. Average daily PAR values of ambient light in the CSSF increased steadily from December through April from, ranging from approximately 1 mol PAR day^{-1} in December to approximately 3 mol PAR day^{-1} in April, but the turf did not respond (Table 1). Light quality transmitted through the fiberglass fabric of the CSSF mirrored the light quality of sunlight but light quantity was reduced approximately 90% (Figure 1).

Table 1. Photosynthetically active radiation (PAR) at the Hancock Turfgrass Research Center, East Lansing, MI.

Location	Dec. 1992	Jan. 1993	Feb. 1993	Mar. 1993	
Outside	mol PAR day^{-1} †				
average	7.5	12.6	23.2	21.1	
stnd deviation	3.9	5.4	3.1	12.2	
CSSF, ambient light ‡					
average	0.8	1.4	2.5	2.3	
stnd deviation	0.4	0.6	0.3	1.3	
CSSF, Supplemental light §					
average	7.9	8.2	8.7	8.6	
stnd deviation	1.2	1.2	1.1	1.6	
	Dec. 1993	Jan. 1994	Feb. 1994	Mar. 1994	Apr. 1994
Outside	mol PAR day^{-1}				
average	9.5	10.8	19.3	24.3	31.7
stnd deviation	4.9	5.0	7.0	9.9	14.5
CSSF, ambient light					
average	1.0	1.2	2.1	2.7	3.5
stnd deviation	0.5	0.6	0.8	1.1	1.6
CSSF, Supplemental light					
average	8.0	8.1	8.5	8.8	9.2
stnd deviation	1.2	1.2	1.4	1.5	1.8

† PAR was collected with a pyranomter (Li-Cor, model PY 14226, Lincoln NE) and integrated daily. Radiation units (Ly day^{-1}) were converted to quantum units (mol PAR day^{-1}) based on the conversion methods in Thimijan and Heins (1983).

‡ CSSF = Covered Stadium Simulator Facility. Ambient PAR inside the CSSF was estimated by measuring the percent PAR transmitted into the CSSF at turf levels with a photometer (Greenlee Inc., Rockford IL) or a portable spectroradiometer (Li-Cor, Lincoln NE).

§ Supplemental lighting was supplied by 400 W high pressure sodium lamps. Because reflective mylar curtains on two sides of the plots blocked an estimated 50% of the ambient light from plots which received supplemental light, 50% of the total daily PAR was added to the total daily PAR supplied by the lamps (5.4 mol m^{-2} day^{-1}) to estimate the total daily PAR received by turf under the supplemental light.

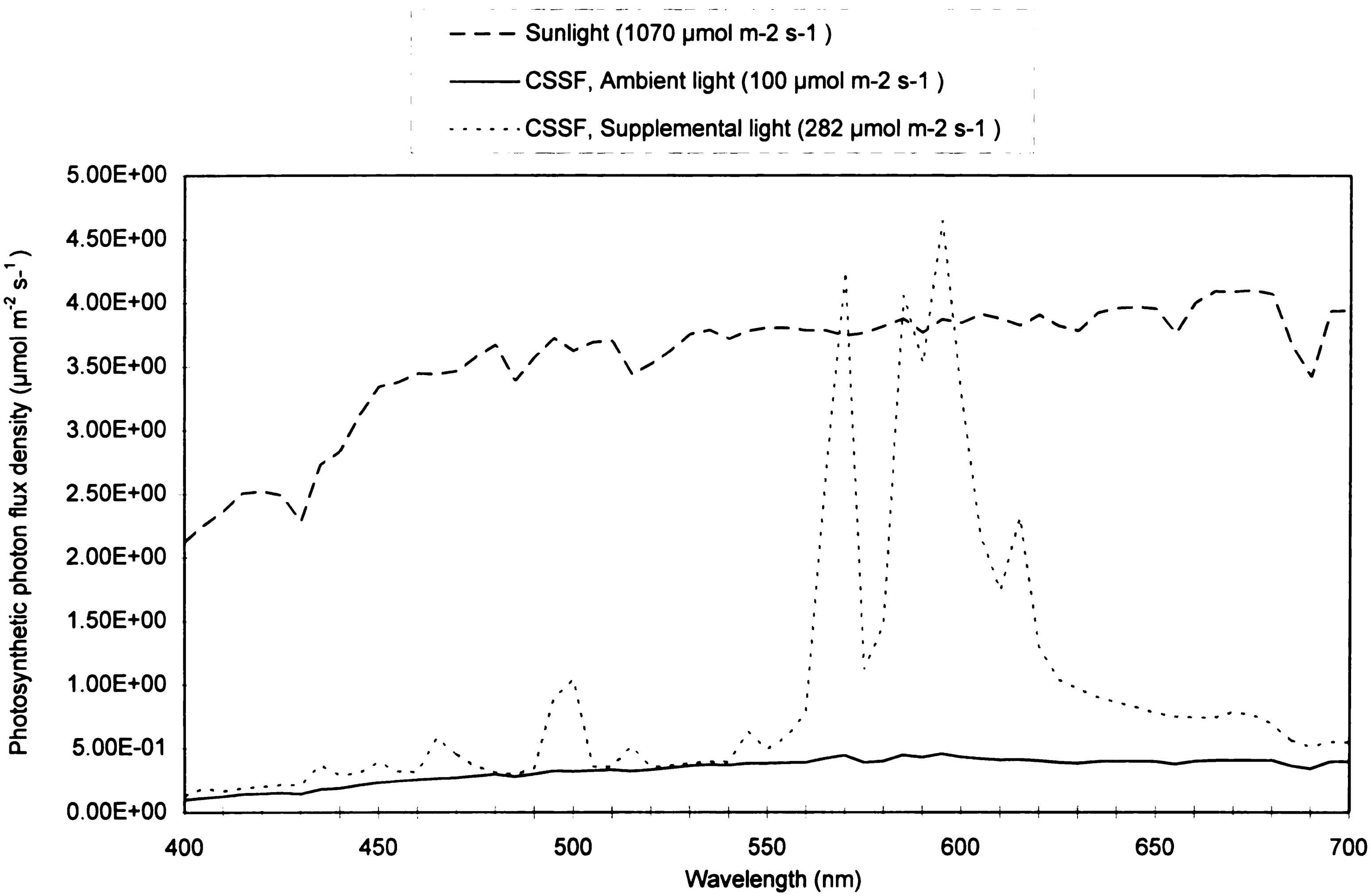

Figure 1. Photosynthetic photon flux density of sunlight, ambient light inside the Covered Stadium Simulator Facility (CSSF), and supplemental light inside the CSSF supplied by 400 W high pressure sodium lamps, 1515 h, 10 Feb. 1994.

Turf quality

Significant treatment effects on Kentucky bluegrass quality are shown in Table 2. In 1992-93 there were no interactions between treatments. In 1993-94 occasional interactions occurred between nitrogen-by-flurprimidol and nitrogen-by-traffic; a three-way interaction occurred on 22 Feb. 1994. In both 1992-93 and 1993-94 the turf recovered from winter dormancy once placed inside the CSSF, but did not survive well. Quality declined to unacceptable values (< 5.0) within 49 days after installation in the CSSF in 1993 and within 82 days in 1994 regardless of treatment. The turf became nearly completely necrotic within 72 days in 1993 although better quality was sustained for the entire trial (105 days) in 1994.

Traffic rapidly decreased turf quality and affected turf quality more often than nitrogen or flurprimidol (Table 2). Nitrogen rate did not affect turf quality in 1992-93; in 1993-94, the high rate (96 kg ha^{-1} $month^{-1}$) reduced turf quality within 74 days after installation in the CSSF (Table 3). High nitrogen rates are known to result in succulent tissues which render turf more susceptible to traffic and disease injury (Beard, 1973). High nitrogen rates have also been associated with decreased shoot density and root to shoot ratio in shaded conditions (Burton et al., 1959; Eriksen and Whitney, 1981; Schmidt and Blaser, 1967); flurprimidol did not alter this response at this level of light. Flurprimidol increased turf quality on two dates only after the second application in both seasons. Traffic began to decrease turf quality after one application (50 passes) in 1992 and after four applications (200 passes) in 1994. In 1993, the flurprimidol-by-traffic interaction on 3 Feb. showed flurprimidol increased turf quality in a non-trafficked

Table 2. Mean squares and treatment effects on the quality of Kentucky bluegrass maintained under ambient light conditions inside the Covered Stadium Simulator Facility, East Lansing, MI.

		1992-93										
Source	df	18 Dec.	23 Dec.	30 Dec.	8 Jan.	15 Jan.	20 Jan.	25 Jan.	3 Feb.	17 Feb.		
Replication	2	0.167	1.764*	0.340	0.694	0.194	0.090	0.750	0.090	0.694		
Nitrogen (N)	2	0.125	0.389	0.215	0.007	0.340	0.299	1.188	0.632	0.090		
Flurprimidol (F)	1	0.056	0.056	0.250	1.174	0.174	1.361*	2.507	4.000**	0.340		
N x F	2	0.097	0.056	0.271	0.090	0.132	0.340	1.715	0.542	0.090		
Error	10	0.067	0.314	0.215	0.361	0.261	0.174	0.650	3.319	0.244		
Traffic (T) †	1	--	--	4.694*	0.563	5.840**	5.444**	25.840**	38.028**	11.674		
N x T	2	--	--	0.174	0.021	0.424	0.340	0.674	0.264	0.090		
F x T	1	--	--	0.111	0.340	0.007	0.250	0.340	1.778*	0.174		
N x F x T	2	--	--	0.090	0.049	0.049	0.021	0.340	0.097	0.090		
Error	12	--	--	0.097	0.194	0.153	0.132	0.514	2.833	0.389		
CV, %		5.00	9.70	5.79	8.04	7.09	7.11	16.70	18.41	39.04		
		1993-94										
		28 Dec.	5 Jan.	12 Jan.	24 Jan.	3 Feb.	10 Feb.	22 Feb.	3 Mar.	11 Mar.	18 Mar.	25 Mar.
Replication	2	0.097	0.681*	1.715	4.465*	4.882*	0.194	0.194	0.396	2.382	0.813	1.399
Nitrogen (N)	2	0.097	0.181	0.132	1.965	2.840	3.028	22.215**	17.646**	15.924*	7.521	12.603
Flurprimidol (F)	1	0.014	0.000	0.340	0.444	1.778	18.778*	25.840**	10.563**	11.111	11.674	10.070
N x F	2	0.014	0.042	0.632	0.049	0.257	0.528	2.424*	3.271*	1.090	2.007	2.281
Error	10	0.031	0.164	0.465	1.024	1.065	2.111	0.494	0.688	2.540	4.771	3.207
Traffic (T) ‡	1	--	--	0.007	0.028	0.250	7.111**	22.563**	14.063**	17.361**	25.840**	24.933**
N x T	2	--	--	0.007	0.090	0.146	1.361	1.896*	3.063**	1.715*	0.632	1.021
F x T	1	--	--	0.007	0.000	0.000	0.694	0.174	0.563	0.694	0.563	1.346
N x F x T	2	--	--	0.007	0.062	0.062	0.694	2.549*	0.771	0.965	1.396	0.168
Error	12	--	--	0.049	0.056	0.090	0.403	0.375	0.319	0.278	0.389	0.333
CV, %		3.16	6.81	3.63	4.44	5.78	13.21	14.18	14.59	14.60	18.03	17.30

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† Traffic was not started until 29 December 1992.

‡ Traffic was not started until 6 Jan. 1994.

Table 3. Main effects of nitrogen, flurprimidol, and traffic on the quality of Kentucky bluegrass maintained under ambient light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI. †

	1992-93‡								
Treatment	18 Dec.	23 Dec.	30 Dec.	8 Jan.	15 Jan.	20 Jan.	25 Jan.	3 Feb.	17 Feb.
Nitrogen (kg ha^{-1})§									
24	5.2	5.9	5.5	5.5	5.7	5.3	4.6	2.9	1.6
48	5.0	5.5	5.3	5.5	5.4	5.0	4.0	2.6	1.7
96	5.2	6.0	5.3	5.5	5.4	5.0	4.3	2.4	1.5
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Flurprimidol (kg ha^{-1})¶									
0.00	5.1	5.7	5.3	5.3	5.4	5.0	4.0	2.3	1.5
1.12	5.2	5.8	5.5	5.7	5.6	5.3*	4.6	3.0**	1.7
Traffic#									
without	--	--	5.8	5.6	5.9	5.5	5.1	3.7	2.2
with	--	--	5.0**	5.4	5.1**	4.7**	3.4**	1.6**	1.0**

	1993-94 ††										
Treatment	28 Dec.	5 Jan.	12 Jan.	24 Jan.	3 Feb.	10 Feb.	22 Feb.	3 Mar.	11 Mar.	18 Mar.	25 Mar.
Nitrogen (kg ha^{-1})‡‡											
24	5.5	6.0	6.0	5.0	4.7	4.8	5.0	4.3	4.1	3.7	3.5
48	5.7	6.1	6.1	5.2	5.3	5.3	5.2	4.8	4.4	4.1	4.3
96	5.4	5.8	6.2	5.8	5.6	4.3	2.8	2.5	2.3	2.6	2.2
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.6	0.7	1.4	ns	ns
Flurprimidol (kg ha^{-1})											
0.00	5.6	5.9	6.2	5.4	5.0	4.1	3.5	3.3	3.1	2.9	2.8
1.12	5.5	5.9	6.0	5.2	5.4	5.5*	5.2	4.4**	4.2	4.0	3.9
Traffic§§											
without	--	--	6.1	5.3	5.3	5.2	5.1	4.5	4.3	4.3	4.2
with	--	--	6.1	5.3	5.1	4.4**	3.5	3.2**	2.9**	2.6**	2.5**

Table 3 (cont'd.)

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Quality was evaluated on a 1-9 scale, 1= dead turf/bare soil and 9=dark green, dense, uniform turf.
‡ Plots were sodded 30 Sept. 1992, established outside, and moved inside the CSSF on 7 Dec. 1992.
§ Nitrogen was applied as urea on 16 Dec. 1992 and 18 Jan. 1993.
¶ Flurprimidol was applied on the same day as nitrogen; control plots were untreated.
# Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., and 6 Feb. 1993.
†† Plots were sodded 10 Sept. 1993, established outside, and moved inside the CSSF on 10 Dec. 1993.
‡‡ Nitrogen was applied as urea on 17 Dec. 1993, 4 Feb., and 21 Mar. 1994.
§§ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

situation but did not affect turf quality in a trafficked situation (Table 3). Flurprimidol-by-nitrogen and nitrogen-by-traffic interactions occurred in the second season (Table 4). In the flurprimidol-by-nitrogen interaction, flurprimidol increased turf quality at the low and medium nitrogen rates but did not affect quality at the high nitrogen rate because the high nitrogen rate decreased turf quality regardless of flurprimidol application. In the nitrogen-by-traffic interaction, traffic decreased turf quality at the medium and high nitrogen rates, but did not significantly affect turf quality at the low nitrogen rate. For the three-way interaction on turf quality, traffic did not affect quality at low or medium nitrogen rates when treated with flurprimidol, but did significantly reduce turf quality at the medium and high nitrogen rates in the absence of flurprimidol (Table 5).

Clipping yields

Weekly clipping yields were affected by flurprimidol and traffic in 1992-93 and by all three treatment groups individually in 1993-94 (Table 6). Data presented are intended to describe trends of main effects and interactions therefore interactions occurring only once were not discussed. Flurprimidol and traffic significantly reduced clipping yields beginning immediately after their first application (Table 7). The second application of flurprimidol inhibited vertical growth nearly completely, causing clipping yields to be at or near zero for the duration of the studies. Zero vertical growth is undesirable if it prevents turf recovery following damage. In this study flurprimidol did not appear to prevent recovery any more than untreated turf because the low light level was the limiting factor for growth. In 1994, high nitrogen rates resulted in decreased yields compared to

Table 4. Quality ratings for the significant flurprimidol-by-nitrogen and nitrogen-by-traffic interactions in Kentucky bluegrass turf maintained in ambient light conditions in the Covered Stadium Simulator Facility, East Lansing, MI, 1994.†

	Flurprimidol-by-nitrogen interaction					Nitrogen-by-traffic interaction					
	22 Feb.		3 Mar.			22 Feb.		3 Mar.		11 Mar.	
	Flurprimidol (kg ha^{-1}) ‡					Traffic ¶					
Nitrogen (kg ha^{-1}) §	0.00	1.12	0.00	1.12	Nitrogen (kg ha^{-1})	without	with	without	with	without	with
24	4.0	6.1	3.8	4.9	24	5.4	4.7	4.4	4.2	4.4	3.8
48	4.0	6.3	3.8	5.8	48	6.0	4.3	5.5	4.1	5.2	3.7
96	2.4	3.1	2.5	2.5	96	3.9	1.6	3.6	1.4	3.3	1.2
LSD (0.05)	0.9		1.1		LSD (0.05)	0.8		0.7		0.7	

† Quality was evaluated on a 1-9 scale, 1= dead turf/bare soil and 9= dark green, dense, uniform turf.
‡ Flurprimidol was applied 21 Dec. 1993 and 4 Feb. 1994.
§ Urea was the nitrogen source and was applied the same day as flurprimidol.
¶ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., and 2 Mar. 1994.

Table 5. Quality ratings for the significant nitrogen-by-flurprimidol-by-traffic interaction of Kentucky bluegrass turf maintained under ambient light conditions in the Covered Stadium Simulator Facility, 22 Feb. 1994.†

	Without traffic		With traffic‡			
	Flurprimidol (kg ha^{-1}) §					
Nitrogen (kg ha^{-1}) ¶	0.00	1.12	0.00	1.12	LSD (0.05)	
24	4.5	6.3	3.5	5.8		
48	5.3	6.7	2.7	6.0	between traffic	0.4
96	3.2	4.7	1.7	1.5	between N rate or flurprimidol	0.9

† Quality was evaluated on a 1-9 scale, 1= dead turf/bare soil and 9= dark green, dense, uniform turf.
‡ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., and 10 Feb. 1994.
§ Flurprimidol was applied 21 Dec. 1993 and 4 Feb. 1994.
¶ Urea was the nitrogen source and was applied the same days as flurprimidol.

Table 6. Mean squares and significance of treatment effects on clipping yields of Kentucky bluegrass maintained under ambient light conditions of Covered Stadium Simulator Facility, East Lansing, MI.

		1992	1993									
Source	df	29 Dec.	9 Jan.	15 Jan.	22 Jan.	29 Jan.	1 Feb.	8 Feb.	19 Feb.			
Replication	2	0.161	0.522	0.028	0.087	0.019	0.019	0.018	0.017	--†	--	--
Nitrogen (N)	2	0.293	0.340	0.136	0.045	0.006	0.069	0.023	0.019	--	--	--
Flurprimidol (F)	1	6.242**	36.603**	5.214**	4.658**	0.903**	1.210**	1.969**	4.767**	--	--	--
N x F	2	0.181	0.360	0.002	0.019	0.016	0.069	0.028	0.009	--	--	--
Error	10	0.152	0.410	0.062	0.106	0.022	0.052	0.086	0.077	--	--	--
Traffic (T) ‡	1	--	4.767**	4.340**	2.377**	0.934**	1.210**	1.203**	5.680**	--	--	--
N x T	2	--	0.120	0.005	0.019	0.010	0.069	0.019	0.030	--	--	--
F x T	1	--	2.834**	1.138**	1.342**	0.667**	1.210**	0.993**	3.868**	--	--	--
N x F x T	2	--	0.037	0.044	0.007	0.021	0.069	0.019	0.006	--	--	--
Error	12	--	0.036	0.039	0.057	0.025	0.047	0.034	0.037	--	--	--
CV, %		27.77	11.82	28.78	53.65	86.00	118.09	73.14	44.19	--	--	--
		1994										
		4 Jan.	11 Jan.	18 Jan.	24 Jan.	30 Jan.	10 Feb.	15 Feb.	22 Feb.	2 Mar.	16 Mar.	30 Mar.
Replication	2	1.062	0.432	0.588	0.024	0.754	0.151	0.521	0.896	0.198	1.646	0.029
Nitrogen (N)	2	3.022*	0.949	3.115	0.129	0.037	0.233*	1.059	4.648*	2.254**	3.327*	3.082**
Flurprimidol (F)	1	24.036**	55.007**	148.840**	3.967**	38.906**	14.440**	30.158**	95.714**	65.340**	77.001**	74.103**
N x F	2	0.284	0.293	3.115	0.003	0.087	0.233*	0.931	4.648*	2.342**	3.327*	3.082**
Error	10	0.555	0.552	1.039	0.174	0.456	0.044	0.333	0.635	0.109	0.549	0.322
Traffic (T) §	1	--	4.562**	0.810	0.051	1.059**	0.160	2.176**	2.300**	3.802**	1.891**	6.545**
N x T	2	--	0.211	0.143	0.023	0.007	0.006	0.004	0.094	0.051	0.404*	0.049
F x T	1	--	3.738**	0.810	0.051	0.788**	0.160	1.800**	2.300**	3.802**	1.891**	6.545**
N x F x T	12	--	0.163	0.143	0.070	0.015	0.006	0.006	0.094	0.051	0.404*	0.049
Error		--	0.089	0.194	0.030	0.054	0.036	0.041	0.052	0.036	0.101	0.106
CV, %		28.65	15.41	21.64	15.78	17.96	29.80	19.94	13.93	13.94	21.77	22.65

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 7. Effect of nitrogen rate, flurprimidol, and traffic on clipping yields of Kentucky bluegrass maintained under ambient light conditions in the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

Treatment	yield (g 0.5 m^{-2})							
	1992	1993						
Nitrogen (kg ha^{-1})‡	29 Dec.	9 Jan.	15 Jan.	22 Jan.	29 Jan.	1 Feb.	8 Feb.	19 Feb.
24	1.2	1.6	0.8	0.5	0.2	0.1	0.2	0.4
48	1.6	1.8	0.7	0.5	0.2	0.2	0.3	0.5
96	1.4	1.4	0.6	0.4	0.2	0.2	0.3	0.4
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns
Flurprimidol (kg ha^{-1})								
0.00	2.0	2.6	1.1	0.8	0.3	0.4	0.5	0.8
1.12 §	0.8**	0.6**	0.3**	0.1**	0.0**	0.0**	0.0**	0.1**
Traffic								
without	--	2.0	1.0	0.7	0.3	0.4	0.4	0.8
with ¶	--	1.2**	0.3**	0.2**	0.0**	0.0**	0.1**	0.0**

	1994										
Nitrogen (kg ha^{-1}) #	4 Jan.	11 Jan.	18 Jan.	24 Jan.	30 Jan.	10 Feb.	15 Feb.	22 Feb.	2 Mar.	16 Mar.	30 Mar.
24	1.8	1.7	1.8	1.0	1.3	0.8	1.2	2.1	1.8	2.0	1.9
48	2.8	1.9	1.6	1.1	1.2	0.6	1.1	1.9	1.4	1.4	1.6
96	3.2	2.2	2.6	1.2	1.4	0.5	0.7	0.9	0.9	1.0	0.9
LSD (0.05)	0.7	ns	ns	ns	ns	ns	ns	0.7	0.3	0.7	0.5
Flurprimidol (kg ha^{-1})											
0.00	3.8	3.2	4.1	1.4	2.3	1.3	1.9	3.3	2.7	2.9	2.9
1.12 ††	1.4**	0.7**	0.0**	0.8**	0.3**	0.0**	0.1**	0.0**	0.0**	0.0**	0.0**
Traffic											
without	--	2.4	2.2	1.1	1.5	0.7	1.3	1.9	1.7	1.7	1.9
with ‡‡	--	1.5**	1.9	1.1	1.1**	0.6	0.8**	1.4**	1.0**	1.2**	1.0**

*, ** Significant at the 0.05 and 0.01 probability levels, respectively; ns = not significant at p=0.05.

† Plots were established outside in the autumn and moved into the CSSF on 7 Dec. 1992 and 10 Dec. 1993.

Table 7 (cont'd.)

‡ Nitrogen was supplied as urea on 16 Dec. 1992 and 18 Jan. 1993.
§ Flurprimidol was applied on the same day as nitrogen.
¶ Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., and 6 Feb. 1993.
# Nitrogen (urea) was applied 17 Dec. 1993, 4 Feb., and 21 Mar. 1994.
†† Flurprimidol was applied on the same day as nitrogen.
‡‡ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

medium and low nitrogen rates. The adverse response to high nitrogen has been reported previously for bermudagrass and forage grasses in reduced light conditions (Burton et al., 1959; Eriksen & Whitney 1981). More importantly, nitrogen and flurprimidol interacted on clipping yields in the second season. Nitrogen did not affect clipping yields when flurprimidol was applied (which resulted in zero yield for all nitrogen rates) while clipping yields were decreased proprotionally to increased nitrogen rates in the absence of flurprimidol (Table 8). This is in contrast to Devitt and Morris (1988) who reported high nitrogen rates reduced the effects of GA-inhibitors, although Johnson (1988) found higher nitrogen rates (25 vs. 50 kg ha^{-1}) did not decrease the effectiveness of flurprimidol on bermudagrass in full sun. Traffic and flurprimidol also interacted in both seasons with flurprimidol decreasing clipping yields more than traffic (Table 9).

Surface characteristics

Shear resistance of turf was most affected by traffic and only minimally affected by nitrogen or flurprimidol. No interactions occurred (Table 10). Traffic consistently decreased shear resistance values. High nitrogen rates decreased shear resistance compared to low nitrogen rates (Table 11). Low shear resistance values due to traffic and high nitrogen rates were probably due to reduced turf cover and possibly reduced root structure although rooting was not measured. Flurprimidol had little effect, causing an increase on one date in 1994. Shear resistance declined over time regardless of treatment due to lack of sufficient light energy to sustain growth, particularly rooting.

Table 8. Values for the significant nitrogen-by-flurprimidol interaction on clipping yields of Kentucky bluegrass turf maintained under ambient light conditions in the Covered Stadium Simulator Facility (CSSF), East Lansing, MI. †

	1994									
	10 Feb.		22 Feb.		2 Mar.		16 Mar.		30 Mar.	
	Flurprimidol (kg ha^{-1}) ‡									
Nitrogen (kg ha^{-1})§	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12
	yield (g 0.5 m^{-2})									
24	1.6	0.0	4.2	0.0	3.6	0.0	4.1	0.0	3.7	0.0
48	1.2	0.0	3.7	0.0	2.7	0.0	2.7	0.0	3.1	0.0
96	1.0	0.0	1.9	0.0	1.8	0.0	2.0	0.0	1.8	0.0
LSD (0.05)	0.3		1.0		0.4		1.0		0.7	

† Plots were established outside during autumn 1993 and moved into the CSSF on 10 Dec. 1993.
‡ Flurprimidol (1.12 kg ha^{-1}) was applied on 17 Dec. 1993, 4 Feb. and 21 Mar. 1994.
§ Nitrogen was applied as urea on the same dates as flurprimidol.

Table 9. Values for the significant flurprimidol-by-traffic interactions on clipping yields of Kentucky bluegrass turf maintained under ambient light conditions in the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	Yield (g 0.5 m^{-2})													
	1993													
	9 Jan.		15 Jan.		22 Jan.		29 Jan.		1 Feb.		8 Feb.		19 Feb.	
	Flurprimidol (kg ha^{-1})‡													
Traffic	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12
without	3.2	0.7	1.6	0.4	1.3	0.2	0.6	0.1	0.7	0.0	0.8	0.0	1.5	0.1
with §	2.0	0.5	0.5	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
LSD(0.05)	0.2		0.2		0.2		0.2		0.2		0.2		0.2	

	1994													
	11 Jan.		30 Jan.		15 Feb.		22 Feb.		2 Mar.		16 Mar.		30 Mar.	
	Flurprimidol (kg ha^{-1})#													
Traffic	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12	0.00	1.12
without	4.0	0.8	2.7	0.3	2.4	0.1	3.8	0.0	3.4	0.0	3.4	0.0	3.7	0.0
with ††	2.4	0.6	2.0	0.2	1.5	0.1	2.8	0.0	2.1	0.0	2.5	0.0	2.0	0.0
LSD (0.05)	0.3		0.2		0.2		0.2		0.2		0.3		0.3	

† Plots were established during autumn of both years and moved into the CSSF on 7 Dec. 1992 and 10 Dec. 1993.
‡ Flurprimidol (1.12 kg ha^{-1}) was applied 16 Dec. 1992 and 18 Jan. 1993.
§ Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., and 6 Feb. 1993.
# Flurprimidol (1.12 kg ha^{-1}) was applied 17 Dec. 1993, 4 Feb., and 21 Mar. 1994.
†† Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

Table 10. Mean squares and significance of treatment effects on the shear resistance of Kentucky bluegrass maintained under ambient light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.

		Shear resistance (N•m)				
		1992-93			1993-94	
Source of variation	df	22 Dec.	11 Jan.	3 Feb.	28 Dec.	8 Apr.
Replication	2	22.028	2.507	9.299	9.528	1.021
N rate (N)	2	5.778	21.049*	5.132	0.778	37.646*
Flurprimidol (F)	1	23.361	0.563	10.028	0.028	30.250*
N x F	2	0.444	5.063	1.799	8.778	3.771
Error	10	8.828	4.724	3.624	4.828	5.738
Traffic (T)†	1	-----	25.840*	40.111	-----	20.250*
N x T	2	-----	4.215	4.090	-----	2.146
F x T	1	-----	2.007	4.000	-----	0.250
N x F x T	2	-----	7.340	0.896	-----	0.187
Error	12	-----	3.993	1.681	-----	2.507
CV, %		0.00	10.74	8.38	0.00	15.97

* Significant at the 0.05 probability level.

† Traffic applications were not started until 29 Dec. 1992 and 6 Jan. 1994.

Table 11. Main effects of nitrogen, flurprimidol, and traffic on the shear resistance of Kentucky bluegrass turf maintained under ambient light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.

	Shear resistance (N•m)				
	1992-93			1993-94	
Treatment	22 Dec.	11 Jan.	3 Feb.	28 Dec.	8 Apr.
Nitrogen (kg ha^{-1}) †					
24	20.9	20.1	16.2	22.6	11.7
48	19.9	18.2	15.0	22.8	10.0
96	21.2	17.5	15.2	22.5	8.1
LSD (0.05)	ns	2.0	ns	ns	3.1
Flurprimidol (kg ha^{-1})					
none	19.9	18.7	15.0	22.5	9.0
1.12 ‡	21.5	18.5	16.0	22.6	10.8*
Traffic					
without	----	19.4	16.5	22.5	10.7
with §	----	17.7*	14.4**	22.5	9.2*

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† Nitrogen was applied as urea on 16 Dec. 1992, 18 Jan., 17 Dec. 1993, 4 Feb., and 21 Mar. 1994.

‡ Flurprimidol was applied on the same days as nitrogen.

§Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., and 6 Feb. 1993, and 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

Treatment effects on surface hardness were not consistent between years (Table 12). Relative differences in g_{max} values between years were probably due to the use of different accelerometers in the CIT equipment following a repair in 1993. In the first season (1992-93) traffic treatments appeared to reduce surface hardness, while in the second season traffic treatments increased surface hardness (Table 13). Generally traffic will increase surface hardness by compaction and reduction of thatch and turf cover (Rogers and Waddington, 1990). Surface hardness is also affected by soil moisture with higher soil moisture providing lower g_{max} values (Rogers and Waddington, 1992), however, soil moisture was not determined in this study. In Feb. 1993 most turf in trafficked areas was dead although a thick (approximately 1.5 cm) mat layer remained which may have retained sufficient moisture to cause a decrease in g_{max}. Compaction in the mat layer by the traffic may also have caused decreased water infiltration. Non-trafficked areas may have had lower soil moisture values due to water uptake by the turf and increased infiltration rates. In Feb. and Apr. 1994 turf cover was higher than in 1993 and soil moisture values may have been more equivalent between trafficked and non-trafficked turf.

Experiment II

Supplemental lighting supplied approximately 8.4 ± 1.4 mol PAR day^{-1} (Table 1). The HPS lamps emitted a significant portion of their light in the yellow, orange, and red wavelengths (Figure 1). Ambient light in the CSSF was minimal and contributed little to the PAR on plots under supplemental light.

Table 12. Mean squares and the significance of treatment effects on the surface hardness of Kentucky bluegrass turf maintained in ambient light conditions of the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.

		1993	1994	
Source of variation	df	3 Feb.	3 Feb.	8 Apr.
Replication	2	99.750	398.401*	240.465
N rate (N)	2	1226.750	33.347	106.747
Flurprimidol (F)	1	205.444	31.923	30.988
N x F	2	196.861	143.191	37.814
Error	10	78.783	93.879	130.947
Traffic (T)	1	3211.111**	753.503**	1497.690**
N x T	2	206.194	57.341	116.328
F x T	1	225.000	9.714	124.695
N x F x T	2	37.750	6.930	45.859
Error	12	157.333	18.056	50.820
CV, %		9.09	6.23	9.48

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 13. Effects of traffic on Clegg Impact Values of Kentucky bluegrass turf maintained in reduced light conditions inside the Covered Stadium Simulator Facilty (CSSF), East Lansing, MI.†

	g_{max}					
	Ambient light			Supplemental light ‡		
	1993	1994		1993	1994	
Treatment	Feb. 3	3 Feb.	8 Apr.	3 Feb.	3 Feb.	8 Apr.
Nitrogen (kg ha^{-1}) §						
24	141.3	66.5	72.2	156.0	74.4	83.5
48	134.8	69.8	75.4	146.6	69.2	79.0
96	134.8	68.2	78.1	147.2	71.0	79.2
LSD (0.05)	ns	ns	ns	ns	ns	ns
Flurprimidol (kg ha^{-1})						
0.00	139.8	67.2	74.3	144.3	72.6	82.9
1.12 ¶	134.1	69.1	76.2	155.6	70.5	78.2
Traffic						
without	147.4	63.6	68.8	154.9	66.4	73.8
with #	128.6**	72.8**	81.7**	145.0	76.7**	87.3**

*, ** Significant at the 0.05 and 0.01 probability levels, respectively; ns = not significant at p=0.05.

† Plots were established outside during autumn of each year and moved into the CSSF on 7 Dec. 1992 and on 10 Dec. 1993.

‡ Supplemental light was supplied from 400 W high pressure sodium lamps.

§ Nitrogen was applied as urea on 16 Dec. 1992, 18 Jan., 26 Feb., 21 Dec. 1993, and 4 Feb., 21 Mar. 1994.

¶ Flurprimidol was applied on the same dates as nitrogen fertilizer.

Traffic was applied on 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., 6 Feb., 20 Feb., 10 Mar., 24 Mar. 1993, and 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., 24 Mar., and 31 Mar. 1994.

Turf quality remained relatively stable under the supplemental light conditions. Traffic had more of an effect on the turf in the first year than in the second year for probably two reasons: 1) shorter period of establishment in the first year, and 2) a heavier person (approximately 115 kg) applied the traffic the first year while a lighter person (approximately 75 kg) applied the traffic the second year. The turf responded significantly to flurprimidol applications in most cases although surface characteristics (shear resistance, surface hardness) were not greatly affected.

Turf quality

Nitrogen rate and flurprimidol generated main effects on turf quality throughout the study in both seasons (Table 14). Turf quality increased in proportion to nitrogen rate (Table 15). Flurprimidol significantly enhanced turf quality in both seasons. Interactions between nitrogen and flurprimidol in both seasons showed higher nitrogen rates particularly enhanced turf quality when treated with flurprimidol (Table 16). Traffic decreased turf quality in season one but had little effect in season two. A three-way interaction occurred on turf quality 91 days after installation in the CSSF in both seasons: Traffic decreased turf quality of flurprimidol-treated turf only at the low nitrogen rate; otherwise traffic had no effect. Flurprimidol was responsible for most of the three-way interaction as it enhanced the effects of nitrogen at each successive nitrogen rate (Table 17).

Table 14. Mean squares for the effects of nitrogen rate, flurprimidol, and traffic on the quality of Kentucky bluegrass maintained under supplemental light conditions inside the Covered Stadium Simulator Facility, East Lansing, MI.

		1992-93										
Source	df	18 Dec	30 Dec	8 Jan	15 Jan	20 Jan	25 Jan	3 Feb	17 Feb	8 Mar	21 Mar	10 Apr
Replication	2	1.361	0.924	1.396*	1.188*	0.111	0.021	0.215	1.049	0.000	0.965	1.194
N rate (N)	2	0.861	1.924*	2.771**	0.438	1.215	0.813**	3.882*	4.715*	3.521*	5.715	6.361
Flurprimidol (F)	1	2.778*	0.028	0.063	10.028**	14.063**	24.174**	53.778**	14.694**	41.174**	30.250**	47.840**
N x F	2	0.028	0.007	0.271	0.132	0.146	1.215**	3.215*	6.674**	2.424*	1.271	1.361
Error	10	0.361	0.282	0.313	0.271	0.561	0.079	0.657	0.690	0.500	1.482	2.803
Traffic (T) †	1	-	1.778**	1.174**	0.250	0.063	3.063**	9.000**	18.778**	3.063**	11.111**	3.674*
N x T	2	-	0.090	0.049	0.063	0.021	0.063	0.188	0.715	0.146	0.090	0.111
F x T	1	-	0.028	0.007	0.111	0.174	0.174	0.111	0.250	0.063	0.111	0.174
N x F x T	2	-	0.007	0.132	0.007	0.007	0.049	0.299	1.562	0.438*	0.090	0.194
Error	12	-	0.042	0.090	0.063	0.069	0.056	0.347	0.597	0.111	0.243	0.493
CV, %		6.91	3.19	4.32	3.66	4.06	3.80	10.20	14.64	5.52	8.25	13.85
		1993-94										
		28 Dec	5 Jan	12 Jan	24 Jan	3 Feb	10 Feb	22 Feb	3 Mar	11 Mar	17 Mar	25 Mar
Replication	2	0.361	0.861*	0.111	0.632	0.861	0.146	0.090	0.396	1.674*	0.271	0.361
N rate (N)	2	0.444	0.528	7.694**	6.132**	14.111**	2.896**	2.299**	9.333**	7.528**	13.271**	1.340*
Flurprimidol (F)	1	0.000	1.000*	5.444*	7.111**	21.778**	41.174**	72.250**	87.111**	84.028**	62.674**	55.007**
N x F	2	0.333	1.750**	2.528	1.799	4.111**	3.340**	3.146**	1.694*	1.194*	1.132*	0.549
Error	10	0.161	0.161	0.811	0.524	0.228	0.313	0.157	0.229	0.240	0.229	0.178
Traffic (T) ‡	1	-	-	0.000	0.000	0.000	0.007	0.028	0.250*	0.028	0.174	0.063
N x T	2	-	-	0.000	0.021	0.000	0.049	0.049	0.083	0.028*	0.090	0.021
F x T	1	-	-	0.000	0.000	0.000	0.063	0.250*	0.111	0.028	0.174	0.007
N x F x T	2	-	-	0.000	0.021	0.000	0.021	0.063	0.028	0.028*	0.090	0.007
Error	12	-	-	0.000	0.014	0.000	0.035	0.021	0.035	0.007	0.097	0.042
CV, %		5.15	5.32	0.00	1.74	0.00	3.00	2.16	2.90	1.29	4.89	3.09

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† Traffic was not started until 29 Dec. 1992
‡ Traffic was not started until 6 Jan. 1993.

Table 15. Main effects of nitrogen rate and flurprimidol on the quality of Kentucky bluegrass maintained under supplemental light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	1992-93 ‡										
Treatment	18 Dec.	30 Dec.	8 Jan.	15 Jan.	20 Jan.	25 Jan.	3 Feb.	17 Feb.	8 Mar.	21 Mar.	10 Apr.
Nitrogen (kg ha^{-1}) §											
24	5.3	6.0	6.4	6.7	6.2	6.1	5.9	4.9	5.5	5.2	4.5
48	5.8	6.8	7.0	6.8	6.4	6.0	5.2	5.0	6.0	6.0	4.9
96	5.7	6.5	7.4	7.0	6.8	6.5	6.3	6.0	6.6	6.6	5.9
LSD (0.05)	ns	0.5	0.5	ns	ns	0.3	0.7	0.8	0.6	ns	ns
Flurprimidol (kg ha^{-1})											
0.00	5.8	6.4	6.9	6.3	5.9	5.4	4.6	4.6	5.0	5.1	3.9
1.12 ¶	5.3*	6.4	7.0	7.4*	7.1*	7.0**	7.0**	5.9**	7.1**	6.9**	6.2**
Traffic											
without	--	6.6	7.1	6.9	6.5	6.5	6.3	6.0	6.3	6.5	5.4
with #	--	6.2*	6.8*	6.7	6.4	5.9**	5.3**	4.6**	5.7**	5.4**	4.8**
	1993-94 ††										
	28 Dec.	5 Jan.	12 Jan.	24 Jan.	3 Feb.	10 Feb.	22 Feb.	3 Mar.	11 Mar.	17 Mar.	25 Mar.
Nitrogen (kg ha^{-1})											
24	5.8	6.2	5.4	6.1	5.2	5.7	6.2	5.4	5.7	5.2	6.2
48	6.2	6.4	6.4	6.7	6.3	6.3	7.1	6.8	6.5	6.5	6.6
96	6.2	6.6	7.0	7.5	7.3	6.6	6.7	7.1	7.2	7.3	6.9
LSD (0.05)	ns	ns	0.8	0.7	0.4	0.5	0.4	0.4	0.4	ns	0.4
Flurprimidol (kg ha^{-1})											
0.00	6.1	6.3	5.9	6.3	5.5	5.1	5.3	4.9	4.9	5.1	5.4
1.12	6.1	6.6	6.7**	7.2**	7.1**	7.3**	8.1**	8.0**	8.0**	7.7	7.8**

Table 15 (cont'd.)

Traffic											
without	--	--	6.3	6.8	6.3	6.2	6.7	6.5	6.5	6.4	6.6
with §§	--	--	6.3	6.8	6.3	6.2	6.7	6.3*	6.4	6.3	6.5

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† Supplemental lighting (approximately 8.4 mol PAR day^{-1}) was supplied by 400 W high pressure sodium lamps.

‡ Plots were established outside in the autumn (sodded 30 Sept.) and moved inside 7 Dec. 1992.

§ Nitrogen was supplied as urea at 24, 48, or 96 kg ha^{-1} at four to six week intervals.

¶ Plots were treated with flurprimidol (1.12 kg ha^{-1}) in conjunction with fertilizer applications.

Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., 6 Feb., 20 Feb., 10 Mar., and 24 Mar. 1993.

†† Plots were established outside in the autumn (sodded 10 Sept.) and moved inside 10 Dec. 1993.

§§ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

Table 16. Values for the significant interactions of nitrogen rate and flurprimidol treatment on the quality of Kentucky bluegrass maintained under supplemental light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	1993							
	25 Jan.		3 Feb.		17 Feb.		8 Mar.	
	flurprimidol							
Nitrogen (kg ha^{-1})	No	Yes	No	Yes	No	Yes	No	Yes
24	5.6	6.7	5.2	6.5	4.7	5.1	4.8	6.2
48	5.3	6.8	3.7	6.7	4.8	5.2	5.2	6.9
96	5.3	7.7	4.8	7.8	4.5	7.5	5.0	8.2
LSD (0.05)	0.4		1.0		1.1		0.9	

	1994													
	5 Jan.		3 Feb.		10 Feb.		22 Feb.		3 Mar.		11 Mar.		17 Mar.	
	flurprimidol													
Nitrogen (kg ha^{-1})	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
24	6.5	6.0	5.0	5.3	5.2	6.2	5.4	7.1	4.2	6.6	4.5	6.8	4.2	6.3
48	6.2	6.7	5.5	7.2	5.2	7.5	5.5	8.7	5.2	8.3	4.8	8.2	5.3	7.8
96	6.2	7.2	6.0	8.7	5.1	8.2	4.9	8.5	5.2	9.0	5.5	9.0	5.7	9.0
LSD (0.05)	0.5		0.6		0.7		0.5		0.6		0.6		0.6	

† Supplemental lighting (approximately 8.4 mol PAR day^{-1}) was supplied with 400 W high pressure sodium lamps.
‡ Nitrogen was supplied as urea at four to six week intervals.
§ Flurprimidol (1.12 kg ha^{-1}) was applied in conjunction with fertilizer applications.

Table 17. Quality ratings for the significant nitrogen-by-flurprimidol-by-traffic interactions in Kentucky bluegrass turf under supplemental light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	8 March 1993				11 March 1994			
	No Traffic		Traffic‡		No Traffic		Traffic§	
Nitrogen rate (kg ha^{-1})¶	No PGR	PGR#	No PGR	PGR	No PGR	PGR	No PGR	PGR
24	4.8	6.5	4.7	6.0	4.5	7.0	4.5	6.7
48	5.3	7.5	5.0	6.3	4.8	8.2	4.8	8.2
96	5.5	8.3	4.5	8.0	5.5	9.0	5.5	9.0
LSD (0.05)								
between traffic		0.2				0.1		
between N rates or flurprimidol		0.9				0.6		

† Supplemental lighting (approximately 8.4 mol PAR day^{-1}) was supplied from 400 W high pressure sodium lamps.
‡ Traffic was applied 29 Dec. 1992; 14 Jan., 21 Jan., 29 Jan., 6 Feb., 20 Feb., 10 Mar., and 24 Mar. 1993.
§ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994
¶ Nitrogen was supplied as urea at four to six week intervals.
# Flurprimidol (1.12 kg ha^{-1}) was applied in conjunction with nitrogen fertilizer.

Clipping yields

Treatments indicated significant main effects and two-way interactions between nitrogen and flurprimidol and between flurprimidol and traffic on clipping yields in both seasons (Table 18). Clipping yields were proportional to nitrogen rates while flurprimidol and traffic both significantly decreased clipping yields (Table 19). The nitrogen-by-flurprimidol interactions showed flurprimidol negated the effects of nitrogen on clipping yields while increasing nitrogen rates significantly increased clipping yields in the absence of flurprimidol (Table 20). The flurprimidol-by-traffic interaction showed traffic did not reduce clipping yields when flurprimidol was applied because flurprimidol acutely reduced clipping yields compared to traffic (Table 21).

Surface characteristics

Treatments affected turf shear strength in both seasons (Table 22). No interactions occurred. Traffic and higher nitrogen rates decreased turf shear strength. Unlike the results in experiment one, the lower shear resistance values were probably due to reduced rooting and increased turf succulence as turf cover was not significantly diminished by either treatment. Flurprimidol did not affect shear strength in season one but caused a slight decline in season two (Table 23).

Treatment effects on surface hardness (CIT values) were inconsistent between seasons. In season one only the flurprimidol-by-traffic interaction was significant, while in season two the nitrogen-by-flurprimidol interaction was significant plus flurprimidol and traffic main effects (Table 24). In season one, traffic apparently decreased surface

Table 18. Mean squares and significance of treatment effects on clipping yields of Kentucky bluegrass maintained under supplemental light conditions of Covered Stadium Simulator Facility, East Lansing, MI.

		Yield (g 0.5 m^{-2})									
		1992	1993								
Source	df	29 Dec.	9 Jan.	15 Jan.	22 Jan.	29 Jan.	1 Feb.	8 Feb.	19 Feb.	12 Mar.	27 Mar.
Replication	2	3.648	12.852	2.154	0.751	0.452	5.653	1.144	38.640	30.579	13.562
Nitrogen (N)	2	80.367*	132.253*	17.2240**	3.807**	0.886	7.538	0.838	38.494	12.366	5.763
Flurprimidol (F)	1	1386.889**	2370.067**	307.126**	149.247**	40.853**	74.837**	34.028*	280.004*	131.676**	82.810**
N x F	2	51.573*	98.574*	1.729	0.468	1.380	7.538	5.038	3.205	5.476	5.763
Error	10	12.228	18.119	1.335	0.494	1.424	3.512	6.381	45.224	8.197	5.655
Traffic (T)	1	--	31.174*	28.712**	9.507**	9.558**	10.568*	19.068**	35.204**	18.562**	0.034
N x T	2	--	1.670	1.707	0.225	0.227	0.885	0.558	7.179	2.474	0.102
F x T	1	--	15.867	7.067*	4.067**	3.516*	10.568*	1.103	11.111	0.627	0.034
N x F x T	2	--	0.227	0.205	0.075	0.407	0.885	0.046	4.160	1.761	0.102
Error	12	--	3.730	0.965	0.405	0.548	1.268	0.663	3.726	0.776	0.219
CV, %		31.07	18.71	19.94	22.05	34.49	78.09	34.68	38.35	30.51	30.87

		1994									
Source	df	4 Jan.	11 Jan.	18 Jan.	24 Jan.	2 Feb.	9 Feb.	15 Feb.	22 Feb.	16 Mar.	30 Mar.
Replication	2	26.968	6.341	8.297*	0.710	6.847*	1.600*	0.527	2.351	5.353	0.181
Nitrogen (N)	2	40.417*	32.744**	23.908**	12.054**	37.376**	4.827**	13.293**	7.552*	33.100**	22.555
Flurprimidol (F)	1	315.005**	454.400**	331.847**	148.028**	408.377**	84.334**	514.156**	802.778**	239.218**	1070.380**
N x F	2	8.847	20.596**	18.860**	10.455**	24.377**	3.040**	5.473**	7.552*	2.003	9.137
Error	10	8.299	2.293	1.283	0.701	1.614	0.374	0.347	1.543	3.434	5.930
Traffic (T)	1	--	15.210**	1.734	0.780	3.706	0.490	3.770**	0.250	0.234	12.250**
N x T	2	--	0.875	0.357	0.241	1.204	0.016	0.223	0.040	2.347	0.527
F x T	1	--	8.218**	0.250	0.047	0.856	0.063	2.176**	0.250	5.444	11.222**
N x F x T	2	--	0.283	0.136	0.068	0.758	0.126	0.056	0.040	0.301	0.332
Error	12	--	0.609	0.487	0.180	1.178	0.110	0.169	0.203	1.934	0.545
CV, %		32.94	12.95	14.67	14.47	22.50	15.60	9.06	9.53	34.74	12.01

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 19. Effect of nitrogen rate, flurprimidol, and traffic on clipping yields of Kentucky bluegrass maintained under supplemental light conditions of the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	Yield (g 0.5 m^2)									
	1992 ‡	1993								
Treatment	29 Dec.	9 Jan.	15 Jan.	22 Jan.	29 Jan.	1 Feb.	8 Feb.	19 Feb.	12 Mar.	27 Mar.
Nitrogen rate (kg ha^{-1})§										
24	7.4	6.9	3.9	2.4	1.9	0.6	2.1	3.5	1.8	0.7
48	11.6	10.5	4.7	2.8	2.2	1.5	2.3	4.8	3.1	1.9
96	14.7	13.6	6.2	3.5	2.4	2.2	2.6	6.9	3.8	1.9
LSD (0.05)	4.5	3.9	1.0	0.6	ns	ns	ns	ns	ns	ns
Flurprimidol (kg ha^{-1})¶										
none	20.033	18.4	7.8	4.9	3.2	2.9	3.3	7.8	4.8	3.0
1.12	2.478**	2.2*	2.0**	0.8**	1.1**	0.0**	1.4*	2.2*	1.0**	0.0**
Traffic										
without	--	11.3	5.8	3.4	2.7	2.0	3.1	6.0	3.6	1.5
with #	--	9.4**	4.0**	2.4**	1.6**	0.9*	1.6**	4.0**	2.2**	1.5
	1994 ††									
Treatment	4 Jan.	11 Jan.	18 Jan.	24 Jan.	2 Feb.	9 Feb.	15 Feb.	22 Feb.	16 Mar.	30 Mar.
Nitrogen rate (kg ha^{-1})‡‡										
24	5.8	4.2	3.3	1.9	3.0	1.5	3.3	3.8	2.3	4.7
48	9.6	6.3	4.9	3.1	4.9	2.2	5.1	5.2	4.0	6.4
96	10.8	7.5	6.1	3.9	6.6	2.7	5.1	5.1	5.6	7.4
LSD (0.05)	3.7	1.4	1.0	0.8	1.2	0.6	0.5	1.1	1.7	ns
Flurprimidol (kg ha^{-1})										
none	12.9	9.6	7.8	5.0	8.2	3.7	8.3	9.4	6.6	11.6
1.12	4.6**	2.5**	1.7**	0.9**	1.5**	0.6**	0.8**	0.0**	1.4**	0.7**
Traffic										
without	--	6.7	5.0	3.1	5.1	2.2	4.9	4.8	4.1	6.7
with §§	--	5.4**	4.5	2.8	4.5	2.0	4.2**	4.6	3.9	5.6**

Table 19 (cont'd.)

*, ** Significant at the 0.05 and 0.01 probability levels, respectively; ns = not significant at p=0.05.
† Supplemental light was supplied by 400 W high pressure sodium lamps.
‡ Plots were established outside during autumn 1992 and moved into the CSSF on 7 Dec. 1992.
§ Nitrogen was applied as urea on 16 Dec. 1992, 18 Jan., and 26 Feb. 1993.
¶ Flurprimidol was applied on the same date as nitrogen in both years.
# Traffic was applied 29 Dec. 1992; 14 Jan., 21 Jan., 29 Jan., 6 Feb., 20 Feb., 10 Mar., and 24 Mar. 1993.
†† Plots were established outside during autumn 1993 and moved into the CSSF on 10 Dec. 1993.
‡‡ Nitrogen was applied as urea on 17 Dec. 1992; 4 Feb.,and 21 Mar. 1994.
§§ Traffic was applied 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

Table 20. Clipping yields for the significant nitrogen-by-flurprimidol interactions in Kentucky bluegrass turf maintained under supplementary light conditions in the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

Nitrogen	Yield (g 0.5 m^{-2})																	
	1992 ‡		1993		1994§													
	29 Dec.		9 Jan.		11 Jan.		18 Jan.		24 Jan.		2 Feb.		9 Feb.		15 Feb.		22 Feb.	
	Flurprimidol ¶																	
($kg\ ha^{-1}$)#	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
24	13.0	1.9	11.9	2.0	6.9	1.6	5.5	1.1	3.2	0.6	5.4	0.7	2.6	0.3	6.3	0.3	7.6	0.0
48	21.2	2.0	19.3	1.7	9.3	3.4	7.4	2.4	4.8	1.3	7.6	2.1	3.5	0.9	9.4	1.0	10.5	0.0
96	25.9	3.5	24.1	3.0	12.5	2.4	10.6	1.6	6.9	0.8	11.6	1.6	4.8	0.6	9.3	1.0	10.2	0.0
LSD (0.05)	6.4		5.5		1.9		1.5		1.1		2.1		0.8		0.8		1.6	

† Supplemental lighting was supplied from 400 W high pressure sodium lamps.
‡ Plots were established outside during autumn 1992 and moved into the CSSF on 7 Dec. 1992.
§ Plots were established outside during autumn 1993 and moved into the CSSF on 10 Dec. 1993.
¶ Flurprimidol (1.12 $kg\ ha^{-1}$) was applied on 16 Dec. 1992, 18 Jan., 26 Feb., and 21 Dec. 1993, 4 Feb., and 21 Mar. 1994.
# Nitrogen was applied as urea on the same dates as flurprimidol.

Table 21. Clipping yields for the significant flurprimidol-by-traffic interactions in Kentucky bluegrass turf maintained under supplementary light conditions in the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	Yield (g 0.5 m^{-2})													
	1993 ‡								1994 §					
	15 Jan.		22 Jan.		29 Jan.		1 Feb.		11 Jan.		15 Feb.		30 Mar.	
	Traffic ¶													
Flurprimidol ($kg\ ha^{-1}$) #	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
0.00	9.2	6.5	5.7	4.1	4.0	2.4	4.0	0.0	10.7	8.4	8.9	7.8	12.7	10.5
1.12	2.5	1.6	1.0	0.7	1.3	0.9	1.8	0.0	2.6	2.3	0.8	0.7	0.7	0.7
LSD (0.05)	1.0		0.6		0.8		1.2		0.8		0.4		0.8	

† Supplemental light was supplied with 400 W high pressure sodium lamps.
‡ Plots were established outside during autumn 1992 and moved into the CSSF on 7 Dec. 1992.
§ Plots were established outside during autumn 1993 and moved into the CSSF on 10 Dec. 1993.
¶ Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., and 29 Jan. 1993 and 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.
# Flurprimidol (1.12 kg ha^{-1}) was applied 16 Dec. 1992, 18 Jan., 26 Feb., 21 Dec. 1993, and 4 Feb., 21 Mar. 1994.

Table 22. Mean squares and significance of treatment effects on the shear resistance of Kentucky bluegrass maintained under supplemental light conditions inside the Covered Stadium Simulator Facility, East Lansing, MI.

		Shear resistance (N•m)					
		1992-93				1993-94	
Source	df	22 Dec.	11 Jan.	3 Feb.	20 May	28 Dec.	8 Apr.
Replication	2	50.361**	10.896	10.882	5.027	23.083	5.090
N rate (N)	2	0.528	6.813	12.340	127.823**	5.250	281.757**
Flurprimidol (F)	1	1.000	16.000	16.000	15.867	8.028	20.250*
N x F	2	19.083	10.146	3.271	3.151	0.861	6.896
Error	10	5.828	6.929	8.315	3.643	9.083	3.599
Traffic (T)†	1	------	12.250	4.000	125.814**	------	20.250*
N x T	2	------	2.021	4.146	2.014	------	10.021
F x T	1	------	0.694	0.111	1.914	------	2.778
N x F x T	2	------	1.882	1.549	0.034	------	0.632
Error	12	------	4.604	7.271	2.537	------	3.764
CV, %		0.00	9.61	12.87	12.82	0.00	10.95

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† Traffic was not started until 29 Dec. 1992 the first year and 6 Jan. 1994 the second year.

Table 23. Effects of nitrogen, flurprimidol, and traffic on the shear resistance of Kentucky bluegrass maintained under supplemental light conditions inside the Covered Stadium Simulator Facility (CSSF), East Lansing, MI.†

	Shear resistance (N•m)					
	1992-93				1993-94	
Treatment	22 Dec.	11 Jan.	3 Feb.	20 May	28 Dec.	8 Apr.
Nitrogen (kg ha^{-1}) ‡						
24	21.8	23.1	22.0	16.1	23.7	22.2
48	21.5	22.2	20.0	11.5	24.7	18.4
96	21.9	21.6	20.8	9.7	24.9	12.6
LSD (0.05)	ns	ns	ns	1.7	ns	2.4
Flurprimidol (kg ha^{-1})						
none	21.9	21.7	20.8	11.8	24.9	18.5
1.12 §	21.6	23.0	21.6	13.1	23.9	17.0*
Traffic						
without	----	22.9	21.3	14.3	----	18.5
with ¶	----	21.8	20.6	10.6	----	17.0*

* Significant at the 0.05 probability level; ns=not significant at p=0.05.

† Supplemental light (approximately 8.4 mol day^{-1}) was supplied by 400 W high pressure sodium lamps.

‡ Nitrogen was applied as urea on 16 Dec. 1992, 18 Jan., 17 Dec. 1993, 4 Feb., and 21 Mar. 1994.

§ Flurprimidol was applied on the same days as nitrogen.

¶ Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., 29 Jan., and 6 Feb. 1993, and 6 Jan., 11 Jan., 25 Jan., 1 Feb., 10 Feb., 22 Feb., 2 Mar., 17 Mar., and 24 Mar. 1994.

Table 24. Mean squares and significance of treatment effects on the surface hardness of Kentucky bluegrass turf maintained under supplemental light conditions in the Covered Stadium Simulator Facility, East Lansing, MI.

		1993	1993-94	
Source	df	3 Feb.	3 Feb.	8 Apr.
Replication	2	2762.861**	85.343	146.551*
N rate (N)	2	331.361	84.010	77.048
Flurprimidol (F)	1	1156.000	37.414	198.810*
N x F	2	245.583	109.471	214.666**
Error	10	316.228	35.931	23.308
Traffic (T)	1	880.111	945.563**	1653.778**
N x T	2	525.194	2.843	0.564
F x T	1	2177.778**	0.122	17.921
N x F x T	2	739.528	9.880	41.792
Error	12	195.889	19.469	30.086
CV, %		9.33	6.17	6.81

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 25. Clegg Impact Values (g_{max}) for the flurprimidol-by-traffic interaction (3 Feb. 1993) and flurprimidol-by-nitrogen interaction (8 Apr. 1994) in Kentucky bluegrass turf maintained under supplemental light conditions in the Covered Stadium Simulator Facilty, East Lansing, MI.†

	g_{max}				
	3 Feb. 1993		8 Apr. 1994		
	flurprimidol (kg ha^{-1})‡			flurprimidol (kg ha^{-1})§	
Traffic¶	0.00	1.12	Nitrogen (kg ha^{-1})#	0.00	1.12
	g			g	
without	157.0	152.8	24	83.2	83.8
with	131.6	158.4	48	86.3	71.8
			96	79.3	79.0
LSD (0.05)	14.4			6.2	

† Supplemental light (approximately 8.4 mol day^{-1}) was supplied by 400 W high pressure sodium lamps.
‡ Flurprimidol was applied 16 Dec. 1992 and 18 Jan. 1993
§ Flurprimidol was applied 21 Dec. 1992 and 4 Feb. 1993.
¶ Traffic was applied 29 Dec. 1992, 14 Jan., 21 Jan., and 29 Jan. 1993
# Nitrogen was applied on the same dates as flurprimidol.

hardness in the absence of flurprimidol; traffic did not affect surface hardness of turf treated with flurprimidol (Table 25). Untreated turf was flaccid and traffic caused a prostrate growth (grain), forming a cushion on the surface which absorbed the impact of the CIT hammer. Turf treated with flurprimidol remained rigid and had an upright growth which resulted in similar amounts of foliage removal during mowing, thus providing similar cushioning, regardless of traffic. The flurprimidol-by-nitrogen interaction was more difficult to decipher. CIT values were inconsistent among treatments and did not indicate an orderly or meaningful response (Table 25).

Plant density

By August 1994 all turf was maintaining fair to excellent quality and had completely recovered from traffic. Plant biomass data showed flurprimidol significantly affected turf growth five months after the final treatment had been applied. While the number of plants per unit area was less in plots treated with flurprimidol compared to control plots, the number of shoots per plant was nearly double, and verdure mass was approximately 25% greater (Table 26).

CONCLUSIONS

Kentucky bluegrass turf in the early stages of winter dormancy recovered sufficiently within two weeks at approximately 1 mol PAR m^{-2} day^{-1} and temporarily provided acceptable quality. However, this level of light was insufficient to maintain acceptable Kentucky bluegrass turf for periods of longer than eight weeks. At 1-3 mol m^{-2} day^{-1} PAR the best nitrogen rates were a low or medium rate (24 and 48 kg ha^{-1} $month^{-1}$).

Table 26. Plant density, shoot density, and verdure weight of Kentucky bluegrass maintained under supplemental light in the Covered Stadium Simulator Facility, 10 Dec. 1993 to 23 August 1994.†

Treatment	No. of plants m^{-2} ‡	No. of shoots $plant^{-1}$ §	Verdure (g m^{-2}) ¶
Nitrogen rate (kg ha^{-1}) #			
24	8885	2.8	60.8
48	8144	3.2	60.7
96	7095	3.5	49.1
LSD (0.05)	ns	ns	ns
Flurprimidol rate (kg ha^{-1}) ††			
0.00	9474	2.2	49.7
1.12	6609 **	4.0 *	64.1

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† Supplemental light, approximately 8.4 mol PAR day^{-1}, was supplied from 400 W high pressure sodium lamps.

‡ Plants were counted from a 10 cm diam core extracted from each plot.

§ Five randomly selected plants from each plot were used for analysis.

¶ Verdure was collected from a 10 cm diam core extracted from each plot and included all living above ground plant tissue.

Nitrogen was applied as urea on 21 Dec. 1993, 4 Feb. 1994, 21 March 1994.

†† Flurprimidol was applied on the same dates as nitrogen fertilizer.

Traffic and high nitrogen rates (e.g., 96 kg ha^{-1}) hastened demise of the turf, while flurprimidol extended the period of acceptable quality for a short period (e.g., two weeks). Two or more full rate applications of flurprimidol at four to six weeks halted the turf vertical growth rate which may have reduced the potential for recovery from damage (Stier et al., 1994), although lack of sufficient light would probably have been the limiting factor for recovery.

Kentucky bluegrass turf recovered from winter dormancy within two weeks when placed in supplemental light conditions. Reduced light of approximately 8.4 mol PAR m^{-2} day^{-1} was sufficient to maintain high quality turf indefinitely, even in trafficked conditions. The medium nitrogen rate (48 kg ha^{-1} mo^{-1}) was considered optimal as it provided the most desirable combination of quality, yield, hardness, and shear resistance. Flurprimidol significantally improved turf quality throughout the study and was paramount for maintaining high turf quality. Timing of flurprimidol applications and rates need to be further assessed as turf vertical growth was nearly totally halted following the second application. Flurprimidol rates and application intervals should be determined that allow a steady suppression of growth without inhibiting turf recovery from traffic and other damages. Diesburg and Christians (1989) reported the combination of growth phase and season affected turf response to PGRs. Since the environment of indoor stadia is moderated, long-term or permanent use of turf in covered stadia or other reduced light conditions may require unique rates and application intervals due to the lack of seasonal changes.

Chapter 2

THE EFFECTS OF TRINEXAPAC-ETHYL AND FOLIAR IRON ON SUPINA BLUEGRASS (*POA SUPINA* SCHRAD.) AND KENTUCKY BLUEGRASS (*P. PRATENSIS* L.)

INTRODUCTION

Commonly used cool-season turfgrasses are thought to have evolved near the margins of forests in Eurasia where light would not have been limited (Beard, 1973). Consequently, most commonly used cool-season turfgrass species have relatively poor shade tolerance with the exception of the fine fescues (e.g., *Festuca rubra* L., *F. rubra* var. *commutata* Gaud.). As a turf, fine fescues perform best in conditions of well-drained soil and low fertility but have poor traffic tolerance due in part to a slow recuperative rate (Beard, 1973). Kentucky bluegrass (*Poa pratensis* L.) is the most commonly used cool-season turfgrass but its growth can be severely limited in the shade due to insufficient light and enhanced disease susceptibility (Beard, 1973; Vargas and Beard, 1981). Rough bluegrass (*Poa trivialis* L.) has better shade tolerance than Kentucky bluegrass but lacks traffic tolerance. A relatively shade and traffic tolerant cool-season turfgrass species is desirable for golf courses, lawns, and athletic fields.

Supina bluegrass (*P. supina* Schrad.) has been cultivated as a cool-season turfgrass in Germany for over 20 years (Berner, 1984). Supina bluegrass is a stoloniferous turfgrass capable of forming a dense turf at low mowing heights suitable for lawns, athletic fields, and golf course fairways, tees, and putting greens (Berner, 1980; Nonn, 1994; Pietsch, 1989). The stolons are significantly more robust and have shorter internodes compared to rough bluegrass (personal observation). Supina bluegrass is found naturally in high traffic areas (e.g., human and cattle paths) and in moist, shaded areas in woods near the Alps (Berner, 1984; Pietsch, 1989). Supina bluegrass is well adapted to cold weather and is common even in the sub-alpine regions of the Alps (Berner, 1984; Köck and Walch, 1977; Skirde, 1971). In Germany, Supina bluegrass often encroaches and fills in high wear areas on sports fields (Köck and Walch, 1977); subsequent testing documented the high wear tolerance which is at least partly due to a rapid recuperative rate (Berner, 1980; Berner 1984). In addition, Supina bluegrass has been observed to have a high level of shade tolerance on golf courses, lawns, and in controlled tests in Germany although the actual data have not been reported (Pietsch, 1989). The ability to persist in moist, shaded, high traffic environments makes Supina bluegrass a suitable candidate for use as a turf for shaded golf course or athletic field situations (e.g., partially or wholly covered stadia). Drawbacks to the production and use of Supina bluegrass are its poor seed yield (hence, high cost), poor drought tolerance, undefined management schemes, and light green leaf color (Berner, 1980; Leinauer et al., 1991). The development of management schemes requires controlled investigation. While seed yield and drought tolerance are characteristics not easily altered, leaf color is an adjustable parameter which could increase the acceptablity of Supina bluegrass if a darker color can be easily obtained.

Plant growth regulators (PGRs) and foliar applications of iron have been used successfully to enhance (darken) turf foliage in normal field conditions (Brueninger et al., 1983; Freeborg, 1983; Glinski et al., 1992; Yust et al., 1984). Foliar applications of iron have also been useful to negate the transient phytotoxicity which can result from a PGR (Carrow & Johnson, 1990). Recent reports indicate PGRs can also significantly enhance turf color and quality in reduced light conditions (RLC) (< 30% full sunlight) (Rogers et al., 1996; Stier et al., 1994) although the effects of iron are relatively unknown. Although moderate RLC result in increased chlorophyll content, extreme RLC reduce chlorophyll content resulting in a lighter green color (Beard, 1973). In our research we have found chlorophyll levels in Kentucky bluegrass decline at less than approximately 10 mol photosynthetically active radiation (PAR) day^{-1}, equivalent to approximately 20% full summer sunlight (*unpublished data*).

The objectives of this research were to: 1) Compare the shade tolerance of Supina bluegrass and Kentucky bluegrass under a defined light regime, and 2) Determine the effects of multiple applications of trinexapac-ethyl (below label rates) and foliar applications of iron on the growth and quality of Supina bluegrass and Kentucky bluegrass in RLC.

MATERIALS AND METHODS

Experimental environment

The research was conducted inside the Covered Stadium Simulator Facility (CSSF) at the Hancock Turfgrass Research Center from Dec. 1994 through May 1996. Constructed initially in 1992 with a fiberglass fabric (Sheerfill IV, Chemical Fabrics Corporation, Buffalo, NY) which transmitted 11 ± 2% sunlight, the fabric was replaced in late October

1994. The new fiberglass fabric, Sheerfill IV®, transmitted approximately 10.5 ± 1.4% solar radiation from Nov. 1994 through April 1995. After being bleached by the sun in the spring and summer of 1995, the fabric transmitted approximately 15.5 ± 3.0 % solar radiation from Dec. 1995 through May 1996. Quality of the light transmitted through the Sheerfill IV® was equivalent to that transmitted by Sheerfill II® (Figure 1, Chapter 1). Temperature and relative humidity were recorded daily with a sling psychrometer. Temperature was maintained typically at 16.6 C using furnaces. Actual temperatures ranged from 12.2 to 24.4 C due to the inability of the furnaces to compensate for extremely low outdoor temperatures (e.g., -10 C) and due to the lack of an active cooling system as outdoor air temperatures rose during the spring. Relative humidity averaged 45.6 ± 12.5 % with a range of 28-63%.

Daily totals of photosynthetically active radiation (PAR) in the CSSF were determined based on the percent of PAR transmitted through the fabric onto the turf surface inside the CSSF. To determine percentage of light transmission, data were collected weekly from each plot inside the CSSF within one hour of the solar zenith using a Li-Cor 1800 portable spectroradiometer (Li-Cor, Lincoln, NE). Two to four measurements were collected outside the CSSF with the spectroradiometer immediately before and immediately after collecting data inside the CSSF. Daily solar radiation data outside the CSSF were collected with a Li-Cor PY 14226 pyranometer (Li-Cor, Lincoln, NE) located approximately 15 m away from the CSSF. Pyranometer data were integrated hourly and daily through a Maxi weather station (Rain Bird Sales, Inc., Glendora, CA). Radiometric units from the pyranometer were converted to quantum units using the following equation which was based on conversion units from Thimijan and Heins (1983):

$$\text{Equation 1:} \quad ((\text{Ly day}^{-1}/1.05)*3600*24)/10^6 = \text{mol PAR day}^{-1}.$$

The average percentage of light transmitted into the CSSF was used to determine the daily PAR inside the CSSF based on the data recorded outside with the pyranometer.

Plot construction and maintenance

Portable plots were established in wood boxes (1.2 x 1.2 x 0.15m depth) filled with a sand:peat mix (80:20 v/v) (Table 78, Appendix). The pH was 7.3 with initial P and K levels of 85 and 90 kg ha^{-1}, respectively, in 1994. In 1995, the pH was 7.7 with initial P and K levels of 131 and 85 kg ha^{-1}, respectively. Sixteen holes (0.6 cm diam) were drilled in the bottoms of each box to provide drainage. The sand:peat mixture was compacted using hand-held tampers. Starter fertilizer (13-25-12 in 1994) was added to the sand:peat mixture surface prior to sodding to supply 66 kg P ha^{-1} and 58 kg K ha^{-1} in 1994. The plots were sodded 28 September 1994 and 28 August 1995. Additional fertilizer was applied twice in 1994 (24, 20, and 18.5 kg N, P, K ha^{-1}, respectively, on 29 Sept. and 36, 30, and 28 kg N, P, K ha^{-1}, respectively, 13 Oct.) and once in 1995 (24, 20, and 18.5 kg N, P, K ha^{-1}, respectively, on 29 Sept.) prior to moving the plots into the CSSF. Supina bluegrass 'Supranova' and Kentucky bluegrass 'Victa'/'Abbey' (50:50 v/v) were used both years. In 1994 the Supina bluegrass sod had been raised in a woody yard waste compost media while in 1995 washed Supina bluegrass sod grown in a sandy loam soil was used for establishment (sod raised in the woody compost was not available). In both 1994 and 1995 washed Kentucky bluegrass sod grown in an organic soil was used for establishment. Plots were mowed once to twice weekly depending on height of cut and growth rate. During establishment (approximately three weeks) plots were mowed with a rotary mower set at 5 cm height. The height was gradually lowered to 3 cm; a reel mower was used once a 3 cm cutting height was achieved. Plots were irrigated as necessary to prevent visible drought stress (bluish-green color, footprinting, wilting). Trinexapac-ethyl (0.19 kg ha^{-1}, approximately two-thirds the full label rate for Kentucky bluegrass) was applied to six plots each of Supina bluegrass and Kentucky bluegrass on 3 Oct. 1994 and 9 Oct. 1995. A CO_2-powered backpack sprayer with 8002 flat fan nozzles was used to apply the trinexapac-ethyl in 896 L H_2O ha^{-1}. Plots were moved into the CSSF for testing from 12 Dec. 1994 through 12 April 1995 and from 8 Dec. 1995 through 11 June 1996.

The plots were arranged in the CSSF in a completely randomized design with three replications per treatment. Two experiments were designed to determined treatment effects in both non-trafficked (Experiment I) and trafficked (Experiment II) conditions. Traffic was applied by having a person (approximately 70-75 kg) jog 50 passes each week. Traffic was applied 28 Dec. 1994 through 16 Mar. 1995 (total of 144 passes) and 26 Jan. 1995 through 26 Apr. 1996 (total of 168 passes). Additional trinexapac-ethyl (0.08 kg ha^{-1}, approximately one-quarter the full label rate for Kentucky bluegrass, diluted in 896 L H_2O ha^{-1}) was applied on 21 Dec. 1994, 20 Jan., 18 Feb., and 16 Mar. 1995 for the first year's testing and on 31 Jan., 15 Mar., and 26 Apr. 1996 for the second year's testing. Iron (1.14 kg ha^{-1} as $FeSO_4 \cdot 7H_2O$) was applied to foliage using Ferromec

AC (PBI Gordon Corp., Kansas City, MO) on the following dates: 10 Jan., 14 Feb., and 17 Mar. 1995; 28 Feb. and 13 May 1996.

Plots were fertilized monthly with 24, 2, and 20 kg ha^{-1} N, P, and K, respectively (18-3-18). Approximately 1.25 cm water was applied immediately following fertilizer application. Additional irrigation was applied as necessary to prevent drought stress (approximately 1.25 cm at seven to 14 day intervals). Industrial fans were occasionally used for 24-72 h periods to dry the turf surface following irrigation to discourage fungal pathogen activity. Iprodione (3-(3,5-Dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboximide) was applied to all plots on 23 Dec. 1994 (3 kg ha^{-1}), 6 Mar. (6 kg ha^{-1}) and 14 Apr. (6 kg ha^{-1}), 1995 to control Microdochium patch (*Microdochium nivale*), primarily on the Supina bluegrass.

Data collection

A reel mower was used to maintain turf height at 3 cm. The turf was mowed once to twice weekly to prevent removal of more than one-third of the leaf tissue. Mowing was always performed immediately preceding data collection or fertilizer, trinexapac-ethyl, or traffic application. Clippings were generally collected for clipping yield determination except occasionally when time limits precluded clipping collection. Clippings were collected from a 41 x 117 cm strip through the center of each trafficked and non-trafficked plot. Clippings were dried in a forced-air oven at 60 C for 48 h then weighed.

Turf color and quality were evaluated visually on a one to nine scale. A one rating represented 100% necrotic turf/bare soil, while a nine rating represented dark green or ideal turf, respectively. A value of five was considered the minimum acceptable unit.

Turf rooting and strength were evaluated periodically using an Eijkelkamp shear vane apparatus (Eijkelkamp, Giesbeek, The Netherlands). The torque required to tear the turf with the shear vane was recorded as an average of two measurements per plot (Rogers and Waddington, 1990). On 24 March 1995 and 30 May 1996, plant densities were determined by counting the number of plants in eight random squares (32.7 cm^2 each) of a 0.4 m quadrat (Skogley and Sawyer, 1992). Leaf samples from 10 randomly selected plants were collected from each non-trafficked plot for chlorophyll analysis on 4 Apr. 1995 and 29 May 1996 (trafficked plots were not sampled because adequate plant material was often not available). A 10 mm segment from the youngest fully expanded leaf of each plant was excised starting 5 mm above the leaf collar. The leaf portion next to the shoot (< 5 mm distant) was avoided due to possible physiological differences compared to the more mature leaf region (Skinner and Nelson, 1995). Chlorophyll was extracted in three ml *N,N*-dimethlyformamide (DMF) incubated in the dark at 4 C for 48 h (Moran and Porath, 1980). A double-beam spectrophotometer was used to determine absorbances and the extinction coefficients described by Inskeep and Bloom (1985) were used to calculate levels of chlorophyll *a*, *b*, and total chlorophyll. On 12 Apr. 1995 and 31 May 1996 samples of ten randomly selected plants were collected from each plot for biomass assessments. Average leaf number shoot^{-1}, average shoot number plant^{-1}, and average oven-dry weight plant^{-1} were determined for each sample.

Data were analyzed using MSTAT analysis of variance procedures. Data were analyzed as a 2x2x2 factorial in a completely randomized design with three replications.

RESULTS AND DISCUSSION

Temperature inside the CSSF averaged 16.6 C ± 1.5 C with a range of 12-24 C. Relative humidity averaged 46% ± 12% with a range of 28-63%. Photosynthetically active radiation inside the CSSF ranged from approximately 1 mol PAR day^{-1} during December 1994 to approximately 5 mol PAR day^{-1} in May 1996 (Table 27). The Supina bluegrass responded to the increased PAR in the spring more than did Kentucky bluegrass. In general, quality of the Supina bluegrass in 1995-96 was superior to that in 1994-95, probably largely due to the higher light transmittance of the Sheerfill IV fabric due to bleaching by the sun during the summer of 1995.

Turf color and quality

Experiment I: Turf not subjected to traffic

Turf color and quality was affected by both species and trinexapac-ethyl as soon as observations began once inside the CSSF (Tables 28 and 29). The turf was dormant when it was brought into the CSSF and recovered quickly the first year (1994) but slowly the second year (1995). In 1995 the weather had become quite cold in early November without an appropriate transition ("hardening-off") period between growing and non-growing conditions which probably caused the delay in recovery inside the CSSF. The extra N application in autumn 1994 may also have contributed to faster green-up of turf inside the CSSF. Turf treated with trinexapac-ethyl was particularly slow to recover inside the CSSF during the second year (Tables 30 and 31). Once recovered from

Table 27. Photosynthetically active radiation (PAR) at the Hancock Turfgrass Research Center, East Lansing, MI.

Location	Dec. 1994	Jan. 1995	Feb. 1995	Mar. 1995	Apr. 1995	
	mol PAR day^{-1} †					
average	8.4	9.4	19.2	24.8	26.9	
stnd deviation	3.9	6.5	6.6	10.4	12.8	
CSSF ‡, Ambient light						
average	0.9	1.0	2.0	2.6	2.8	
stnd deviation	0.4	0.7	0.7	1.1	1.4	
	Dec. 1995	Jan. 1996	Feb. 1996	Mar. 1996	Apr. 1996	May 1996
	mol PAR day^{-1}					
average	9.5	10.6	14.6	27.8	29.0	34.1
stnd deviation	4.4	4.7	7.6	10.2	14.6	14.5
CSSF, Ambient light						
average	1.5	1.6	2.3	4.3	4.5	5.3
stnd deviation	0.7	0.7	1.2	1.6	2.3	2.2

† PAR was collected with a pyranomter (Li-Cor, model PY 14226, Lincoln NE) and integrated daily. Radiation units (Ly day^{-1}) were converted to quantum units (mol PAR m^{-2} day^{-1}) based on the conversion methods in Thimijan and Heins (1983).

‡ CSSF = Covered Stadium Simulator Facility. Ambient PAR inside the CSSF was estimated by measuring the percent PAR transmitted into the CSSF at turf level with a photometer (Greenlee Inc., Rockford IL) or a portable spectroradiometer (Li-Cor, model LI-1800, Lincoln NE).

Table 28. Mean squares and treatment effects on quality ratings of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

1994-1995

Source of variation	df	20 Dec.	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species (S)	1	11.344	8.167**	7.594**	0.010	0.260	6.000**	27.094**
Trinexapac-ethyl (TE)	1	2.344	3.375**	25.010**	23.010**	27.094**	32.667**	44.010**
S x TE	1	0.260	2.667**	5.510**	12.760**	14.260**	9.375**	0.094
Iron (Fe)	1	0.844	0.667*	0.510	0.010	0.094	0.167	0.844*
S x Fe	1	0.844	0.042	0.260	0.844*	0.010	0.375	0.094
TE x Fe	1	0.010	0.167	0.844	0.010	0.260	0.042	1.260*
S x TE x Fe	1	0.094	0.042	0.094	0.010	0.510	0.000	0.260
Error	16	12.667	1.833	0.302	0.156	4.500	0.240	0.240
CV, %		14.38	5.05	9.26	7.81	11.21	12.37	10.63

1995-1996

Source of variation	df	20 Dec.	5 Jan.	26 Jan.	19 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species (S)	1	1.500	0.167	2.344	4.594**	7.594*	41.344**	58.594**	71.760**	104.167**	82.510**
Trinexapac-ethyl (TE)	1	12.042**	26.042**	3.760*	1.260**	8.760**	12.760**	38.760**	17.510**	15.042**	12.760**
S x TE	1	3.375**	28.167**	5.510**	0.010	3.760**	3.010	11.344**	14.260**	16.667**	21.094**
Iron (Fe)	1	0.042	0.167	0.010	1.260**	1.760*	0.510	0.844	0.510	0.000	0.844
S x Fe	1	1.042	0.042	0.094	0.510*	0.010	0.510	0.510	0.010	0.042	0.010
TE x Fe	1	0.000	0.167	0.010	0.010	0.010	0.094	1.260	0.010	0.000	0.510
S x TE x Fe	1	1.500	0.042	0.010	0.260	0.510	0.094	0.094	0.510	0.042	0.094
Error	16	0.313	0.146	0.500	0.115	0.396	0.760	0.615	0.427	0.135	0.396
CV, %		15.97	7.83	12.52	5.09	10.45	15.56	18.91	19.73	11.78	20.54

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 29. Mean squares and treatment effects on color ratings of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

Source of variation	df	1994-1995						
		20 Dec.	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species (S)	1	31.510**	12.042**	3.375*	2.344*	10.667**	7.594**	5.042**
Trinexapac-ethyl (TE)	1	5.510**	12.042**	28.167**	33.844**	57.042**	68.344**	40.042**
S x TE	1	4.594**	1.042**	1.500**	17.510**	3.375**	1.760**	0.375
Iron (Fe)	1	0.010	0.042	0.042	1.260*	2.042**	0.260	0.042
S x Fe	1	0.094	0.042	3.375**	0.510	0.042	0.010	0.042
TE x Fe	1	0.260	0.042	0.667*	0.260	0.167	0.844	2.042*
S x TE x Fe	1	0.094	0.042	0.000	0.510	0.667	0.844	2.042*
Error	16	0.104	0.115	0.115	0.229	0.146	0.125	0.302
CV, %		5.25	6.02	6.40	10.21	7.16	6.98	9.92

Source of variation	df	1995-1996										
		20 Dec.	5 Jan.	26 Jan.	19 Feb.	28 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species (S)	1	6.000**	0.094	5.510*	12.042**	21.094**	6.000*	14.260**	16.667*	100.042**	165.375**	119.260**
Trinexapac-ethyl (TE)	1	20.167**	38.760**	5.510**	5.042**	12.760**	6.000**	11.344**	32.667**	13.500**	8.167**	3.760**
S x TE	1	2.667*	36.260**	10.010**	0.000	0.260	0.000	0.260	0.667	13.500**	8.167**	3.760**
Iron (Fe)	1	0.667	1.260	0.260	0.667	3.760*	3.375**	0.510	1.500	0.167	0.667**	0.010
S x Fe	1	0.167	0.510	0.094	1.042	0.094	0.042	0.510	1.500	0.000	0.667**	0.010
TE x Fe	1	0.167	0.510	0.010	1.042	1.260	2.042*	0.260	1.500	0.042	0.375**	0.010
S x TE x Fe	1	0.667	0.010	0.510	0.667	1.260	0.042	0.010	0.167	0.042	0.375**	0.010
Error	16	0.396	0.490	0.302	0.333	0.469	0.271	0.240	0.552	0.073	0.021	0.104
CV, %		21.57	15.62	9.73	9.12	11.86	8.22	9.07	18.58	7.62	3.98	9.99

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 30. Effect of species, trinexapac-ethyl, and iron on quality† of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1994-1995						
Treatment	20 Dec.	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species							
Supina bluegrass	6.9	7.3	6.5	5.0	4.8	4.5	5.7
Kentucky bluegrass	5.5	6.1	5.4**	5.1	4.6	3.5**	3.5**
Trinexapac-ethyl							
no	5.9	6.3	4.9	4.1	3.7	2.8	3.2
yes‡	6.5	7.1	7.0**	6.0**	5.8**	5.1**	6.0**
Iron							
no	6.4	6.9	6.1	5.0	4.8	4.0	4.8
yes§	6.0	6.5	5.8	5.1	4.7	3.9	4.4*

	1995-1996									
Treatment	20 Dec.	5 Jan.	26 Jan.	19 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species										
Supina bluegrass	3.2	4.8	6.0	7.1	6.6	6.9	5.7	5.0	5.2	4.9
Kentucky bluegrass	3.8	5.0	5.3	6.2**	5.5*	4.3**	2.6**	1.6**	1.0**	1.2**
Trinexapac-ethyl										
no	4.2	5.9	6.0	6.4	5.4	4.9	2.9	2.5	2.3	2.3
yes¶	2.8**	3.8**	5.2*	6.9**	6.6**	6.3**	5.4**	4.2**	3.9**	3.8**

Table 30. Effect of species, trinexapac-ethyl, and iron on quality† of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1994-1995						
Treatment	20 Dec.	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species							
Supina bluegrass	6.9	7.3	6.5	5.0	4.8	4.5	5.7
Kentucky bluegrass	5.5	6.1	5.4**	5.1	4.6	3.5**	3.5**
Trinexapac-ethyl							
no	5.9	6.3	4.9	4.1	3.7	2.8	3.2
yes‡	6.5	7.1	7.0**	6.0**	5.8**	5.1**	6.0**
Iron							
no	6.4	6.9	6.1	5.0	4.8	4.0	4.8
yes§	6.0	6.5	5.8	5.1	4.7	3.9	4.4*

	1995-1996									
Treatment	20 Dec.	5 Jan.	26 Jan.	19 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species										
Supina bluegrass	3.2	4.8	6.0	7.1	6.6	6.9	5.7	5.0	5.2	4.9
Kentucky bluegrass	3.8	5.0	5.3	6.2**	5.5*	4.3**	2.6**	1.6**	1.0**	1.2**
Trinexapac-ethyl										
no	4.2	5.9	6.0	6.4	5.4	4.9	2.9	2.5	2.3	2.3
yes¶	2.8**	3.8**	5.2*	6.9**	6.6**	6.3**	5.4**	4.2**	3.9**	3.8**

Table 31. Effect of species, trinexapac-ethyl, and iron on turfgrass color† in reduced light conditions under non-trafficked conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1994-1995						
Treatment	20 Dec.	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species							
Supina bluegrass	5.0	4.9	4.9	4.4	4.7	4.5	5.1
Kentucky bluegrass	7.3**	6.3**	5.7*	5.0*	6.0**	5.6**	6.0**
Trinexapac-ethyl							
no	5.7	4.9	4.2	3.5	3.8	3.4	4.2
yes‡	6.6**	6.3**	6.4**	5.9**	6.9**	6.8**	6.8**
Iron							
no	6.1	5.6	5.2	4.5	5.0	5.0	5.5
yes§	6.2	5.7	5.3	4.9	5.6	5.2	5.6

	1995-1996										
Treatment	20 Dec.	5 Jan.	26 Jan.	19 Feb.	28 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species											
Supina bluegrass	2.4	6.1	5.6	4.9	4.8	5.8	6.2	4.8	5.6	6.2	5.5
Kentucky bluegrass	3.4**	5.2**	6.8**	6.4**	6.7**	6.8*	4.6**	3.2*	1.5**	1.0**	1.0**
Trinexapac-ethyl											
no	3.8	6.1	5.7	5.0	5.0	5.8	4.7	2.8	2.8	3.0	2.8
yes¶	2.0**	5.2**	6.8*	6.4*	6.5**	6.8**	6.1**	5.2**	4.3**	4.2**	3.6**

Table 31 (cont'd.)

Iron											
no	2.8	4.7	5.5	6.2	5.4	6.0	5.2	3.8	3.5	3.5	3.2
yes#	3.1	4.2	5.8	6.5	6.2*	6.7**	5.5	4.2	3.6	3.8**	3.2

*,** Significant at 0.05 and 0.01 probability levels, respectively.

† Color was rated visually on a one to nine scale; one = 100% chlorotic turf/necrotic turf, nine=dark green turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., and 17 Mar. 1995.

¶ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

dormancy, Supina bluegrass turf quality was superior to that of Kentucky bluegrass (Table 30). Turf density, uniformity, and overall appearance contributed to the quality ratings. Kentucky bluegrass turf density declined over time and the turf died in 1996 due in part to powdery mildew (*Erysiphe graminis*). No powdery mildew was observed on Supina bluegrass although Microdochium patch (*Microdochium nivale*) occasionally occurred. The Microdochium patch was controlled by using fans to dry the turf and with fungicide. Supina bluegrass had a lighter green color than Kentucky bluegrass except towards the end of the second year when the Kentucky bluegrass became necrotic (Table 31). Iron had negligible effect on either color or quality of turf in either year except for minor, transient (< 4 wks) increases in turf color which, while statistically significant, were not as dramatic as those caused by trinexapac-ethyl.

Interactions between species and trinexapac-ethyl occurred frequently (Tables 32 and 33). Supina bluegrass was more sensitive to trinexapac-ethyl than Kentucky bluegrass. Trinexapac-ethyl usually increased the turf quality and enhanced the color of Supina bluegrass compared to Kentucky bluegrass except at the beginning of the second year when trinexapac-ethyl delayed recovery from winter dormancy.

Experiment II: Turf subjected to traffic

Treatment effects on the quality and color of turf subjected to traffic were similar to those of untrafficked turf although actual values differed (Tables 34 and 35). Traffic treatments resulted in unacceptable turf quality and color (rating values < 5) two to three weeks after traffic applications began in 1994-1995 and three to five weeks after traffic applications began in 1996 (Tables 36 and 37). Traffic killed most of the turf within

Table 32. Quality rating values† for the significant species-by-trinexapac-ethyl interactions on non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1995									
	6 Jan.		26 Jan.		9 Feb.		24 Feb.		17 Mar.	
	trinexapac-ethyl ‡									
Species	no	yes	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	6.6	8.0	5.0	8.0	3.3	6.8	3.0	6.7	2.7	6.2
Kentucky bluegrass	6.1	6.2	4.8	5.9	4.8	5.3	4.3	4.9	2.9	4.0
LSD (0.05)	0.4		0.7		0.5		0.6		0.6	

	1995-96													
	20 Dec.		26 Jan.		8 Mar.		26 Apr.		13 May		29 May		11 June	
	trinexapac-ethyl §													
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	4.3	2.2	6.8	5.1	5.6	7.6	3.8	7.7	3.4	6.7	3.6	6.8	3.2	6.6
Kentucky bluegrass	4.1	3.4	5.2	5.4	5.2	5.7	2.0	3.2	1.5	1.7	1.1	1.0	1.4	1.0
LSD (0.05)	0.7		0.9		0.8		1.0		0.8		0.5		0.8	

† Quality was rated visually on a one to nine scale; 1=100% dead turf/bare soil, 9=dense, uniform turf; 5 was the minimum value for acceptable turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 33. Color rating values† for the significant species-by-trinexapac-ethyl interaction on non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1994-1995											
	20 Dec.		6 Jan.		26 Jan.		9 Feb.		24 Feb.		17 Mar.	
	trinexapac-ethyl ‡											
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	4.1	5.9	4.0	5.8	3.6	6.2	2.3	6.4	2.8	6.6	3.1	5.9
Kentucky bluegrass	7.2	7.3	5.8	6.8	4.8	6.5	4.7	5.3	4.8	7.2	3.7	7.6
LSD (0.05)	0.4		0.4		0.4		0.6		0.5		0.4	

	1995-1996											
	20 Dec.		5 Jan.		26 Jan.		13 May		29 May		11 June	
	trinexapac-ethyl §											
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	3.7	1.2	6.9	1.9	7.2	5.0	4.1	7.1	1.8	6.4	4.7	6.2
Kentucky bluegrass	4.0	2.8	4.6	4.5	5.0	5.3	1.5	1.5	1.0	1.0	1.0	1.0
LSD (0.05)	0.8		0.9		0.7		0.3		0.2		0.4	

† Color was rated visually on a one to nine scale; one = 100% chlorotic turf/necrotic turf, nine=dark green turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 34. Mean square and treatment effects on quality of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1995					
Source of variation	df	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species (S)	1	0.667	0.375	5.510*	0.000	0.167	2.667
Trinexapac-ethyl (TE)	1	9.375**	32.667**	2.344*	1.500**	2.042*	2.667*
S x TE	1	8.167**	18.375**	3.760**	0.667*	0.375	1.500
Iron (Fe)	1	0.167	0.167	0.010	0.042	0.042	0.375
S x Fe	1	0.042	1.042	0.010	0.042	0.042	2.042
TE x Fe	1	0.000	0.167	0.010	0.042	0.167	0.042
S x TE x Fe	1	0.375	0.042	0.260	0.042	0.167	0.375
Error	16	6.167	8.167	4.833	0.260	0.458	0.646
CV, %		10.28	15.04	21.80	34.02	42.76	40.18

		1996						
Source of variation	df	19 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species (S)	1	4.594*	3.010	2.344*	3.375**	25.010**	27.094**	25.010**
Trinexapac-ethyl (TE)	1	1.260*	7.594*	1.760*	3.375**	19.260**	15.844**	11.344**
S x TE	1	0.260	3.760	1.760*	2.667**	17.510**	15.844**	15.844**
Iron (Fe)	1	0.844	3.010	0.844	1.042**	0.844	0.844	0.260
S x Fe	1	0.010	0.260	0.010	0.667**	0.510	0.844	1.260
TE x Fe	1	0.094	0.010	0.094	0.667**	0.260	0.260	0.510
S x TE x Fe	1	1.260*	2.344	0.094	0.375*	0.094	0.260	0.010
Error	16	0.229	1.094	0.240	0.042	0.292	0.479	0.625
CV, %		7.69	25.48	29.74	14.41	26.18	33.56	36.84

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 35. Mean square and treatment effects on color of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1995					
Source of variation	df	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species (S)	1	12.760**	4.568*	9.413*	0.680	0.010	0.844
Trinexapac-ethyl (TE)	1	12.760**	27.158**	4.192**	23.920*	1.260	1.260
S x TE	1	1.260**	1.274**	4.142**	0.000	1.260	1.260
Iron (Fe)	1	0.010	0.012	0.039	0.045	0.510	0.844
S x Fe	1	0.010	3.032**	0.044	0.038	0.510	0.844
TE x Fe	1	0.094	0.502*	0.000	0.045	0.844	1.260
S x TE x Fe	1	0.094	0.012	1.515*	0.045	0.844	1.260
Error	16	0.104	0.126	0.415	3.098	0.781	1.052
CV, %		5.25	6.78	21.78	78.17	58.12	60.78

		1996							
Source of variation	df	19 Feb.	28 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species (S)	1	8.760*	13.500*	0.510	1.500	9.375**	71.760**	57.042**	130.667**
Trinexapac-ethyl (TE)	1	6.510**	12.042**	7.594	2.667*	5.042**	38.760**	32.667**	2.667**
S x TE	1	0.094	1.042	1.260	2.667*	4.167*	36.260**	32.667**	2.667**
Iron (Fe)	1	0.844	2.042	3.010	2.042*	2.042	0.010	8.167	0.000
S x Fe	1	1.260	0.042	0.260	0.375	1.500	0.010	8.167	0.000
TE x Fe	1	1.760	4.167*	0.010	0.375	0.667	0.010	1.042	0.000
S x TE x Fe	1	1.260	2.667	3.760	0.375	0.375	0.010	1.042	0.000
Error	16	0.500	0.771	2.021	0.271	0.354	0.760	2.229	0.021
CV, %		11.35	15.49	31.44	32.87	35.71	31.47	58.74	4.33

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 34. Mean square and treatment effects on quality of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1995						
Source of variation	df	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.	
Species (S)	1	0.667	0.375	5.510*	0.000	0.167	2.667	
Trinexapac-ethyl (TE)	1	9.375**	32.667**	2.344*	1.500**	2.042*	2.667*	
S x TE	1	8.167**	18.375**	3.760**	0.667*	0.375	1.500	
Iron (Fe)	1	0.167	0.167	0.010	0.042	0.042	0.375	
S x Fe	1	0.042	1.042	0.010	0.042	0.042	2.042	
TE x Fe	1	0.000	0.167	0.010	0.042	0.167	0.042	
S x TE x Fe	1	0.375	0.042	0.260	0.042	0.167	0.375	
Error	16	6.167	8.167	4.833	0.260	0.458	0.646	
CV, %		10.28	15.04	21.80	34.02	42.76	40.18	
		1996						
Source of variation	df	19 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species (S)	1	4.594*	3.010	2.344*	3.375**	25.010**	27.094**	25.010**
Trinexapac-ethyl (TE)	1	1.260*	7.594*	1.760*	3.375**	19.260**	15.844**	11.344**
S x TE	1	0.260	3.760	1.760*	2.667**	17.510**	15.844**	15.844**
Iron (Fe)	1	0.844	3.010	0.844	1.042**	0.844	0.844	0.260
S x Fe	1	0.010	0.260	0.010	0.667**	0.510	0.844	1.260
TE x Fe	1	0.094	0.010	0.094	0.667**	0.260	0.260	0.510
S x TE x Fe	1	1.260*	2.344	0.094	0.375*	0.094	0.260	0.010
Error	16	0.229	1.094	0.240	0.042	0.292	0.479	0.625
CV, %		7.69	25.48	29.74	14.41	26.18	33.56	36.84

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 36 (cont'd.)

Iron							
no	6.0	3.8	1.5	1.2	1.9	1.9	2.0
yes#	6.4	4.5	1.8	1.6**	2.2	2.2	2.2

*,** Significant at 0.05 and 0.01 probability levels, respectively.

† Quality was rated visually on a one to nine scale; 1=100% dead turf/bare soil, 9=dense, uniform turf; 5 was the minimum value for acceptable turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., and 17 Mar. 1995.

¶ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

Table 37. Effect of species, trinexapac-ethyl, and iron on color† of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1995					
Treatment	6 Jan.	26 Jan.	9 Feb.	24 Feb.	17 Mar.	6 Apr.
Species						
Supina bluegrass	4.9	4.8	2.3	2.1	1.5	1.9
Kentucky bluegrass	6.3**	5.7*	3.6*	2.4	1.5	1.5
Trinexapac-ethyl						
no	4.9	4.2	2.5	1.3	1.3	1.5
yes‡	6.3**	6.3**	3.4**	3.2*	1.8	1.9
Iron						
no	5.6	5.2	3.0	2.2	1.7	1.9
yes§	5.6	5.2	2.9	2.3	1.4	1.5

	1996							
Treatment	19 Feb.	28 Feb.	8 Mar.	29 Mar.	26 Apr.	13 May	29 May	11 June
Species								
Supina bluegrass	5.6	4.9	4.4	1.8	2.3	4.5	4.1	5.7
Kentucky bluegrass	6.8*	6.4*	4.7	1.3	1.0**	1.0**	1.0**	1.0**
Trinexapac-ethyl								
no	5.7	5.0	4.0	1.2	1.2	1.5	1.4	3.0
yes¶	6.8**	6.4**	5.1	1.9*	2.1**	4.0**	3.7**	3.7**

Table 37 (cont'd.)

Iron								
no	6.0	5.4	4.2	1.3	1.4	2.8	2.0	3.3
yes#	6.4	6.0	4.9	1.9*	2.0	2.8	3.1	3.3

*,** Significant at 0.05 and 0.01 probability levels, respectively.

† Color was rated visually on a one to nine scale; one = 100% chlorotic turf/necrotic turf, nine=dark green turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., and 17 Mar. 1995.

¶ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

eight to nine weeks in both years. Supina bluegrass showed signs of recovery, however, within three weeks after traffic treatments were ended; Kentucky bluegrass did not recover. Trinexapac-ethyl treatments resulted in superior recovery of Supina bluegrass compared to untreated turf (Tables 38 and 39) while Kentucky bluegrass was unaffected. As with non-trafficked turf, iron had little or no effect.

Clipping yields

Experiment I: Turf not subjected to traffic

Clipping yields of Kentucky bluegrass were significantly different compared to Supina bluegrass yields throughout the study (Table 40). Kentucky bluegrass clipping yields were greater than those of Supina bluegrass for the first two to three months inside the CSSF after which they were either no different (1995) or significantly less as the Kentucky bluegrass died (1996) (Table 41). In this study clipping yield data was only partly indicative of the turf's response to RLC; Supina bluegrass has a creeping growth habit which can be expected to result in less clipping yield compared to Kentucky bluegrass in even normal sunlight (Berner, 1980). Trinexapac-ethyl treatments significantly reduced clippings of both species on most dates. As with the effect on color and quality, Supina bluegrass was more sensitive to trinexapac-ethyl than Kentucky bluegrass in terms of clipping yield reduction (Table 42).

Lack of PGR efficacy after the first application and the rapid growth flushes following growth suppression commonly documented in non-RLC were not observed (Cooper et al., 1985; Shearing and Batch, 1982). The potential decline in turf color and quality observed due to the potential for retention of senescent foliage/suppression of new growth

Table 38. Quality ratings† for the significant species-by-trinexapac-ethyl interactions on turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1995					
	6 Jan.		26 Jan.		9 Feb.	
	trinexapac-ethyl ‡					
Species	no	yes	no	yes	no	yes
Supina bluegrass	5.0	7.4	2.6	6.7	1.3	2.8
Kentucky bluegrass	5.8	5.9	4.6	5.1	3.1	2.9
LSD (0.05)	0.8		0.9		0.7	

	1996									
	29 Mar.		26 Apr.		13 May		29 May		11 June	
	trinexapac-ethyl §									
Species	no	yes	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	1.4	2.5	1.1	2.5	3.4	6.7	1.5	4.8	1.7	4.7
Kentucky bluegrass	1.3	1.3	1.0	1.1	1.5	1.7	1.0	1.0	1.2	1.0
LSD (0.05)	0.6		0.3		0.7		0.9		1.1	

† Quality was rated visually on a one to nine scale; 1=100% dead turf/bare soil, 9=dense, uniform turf; 5 was the minimum value for acceptable turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 39. Color ratins† for the signifcant species-by-trinexapac-ethyl interactions on turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1995					
	6 Jan.		26 Jan.		9 Feb.	
	trinexapac-ethyl ‡					
Species	no	yes	no	yes	no	yes
Supina bluegrass	3.9	5.8	3.5	6.1	1.5	3.2
Kentucky bluegrass	5.8	6.8	4.8	6.5	3.6	3.6
LSD (0.05)	0.4		0.4		0.8	

	1996									
	29 Mar.		26 Apr.		13 May		29 May		11 June	
	trinexapac-ethyl §									
Species	no	yes	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	1.2	2.5	1.4	3.2	2.0	7.0	1.8	6.4	5.0	6.3
Kentucky bluegrass	1.3	1.3	1.0	1.1	1.0	1.1	1.0	1.0	1.0	1.0
LSD (0.05)	0.6		0.7		1.1		2.2		0.2	

† Color was rated visually on a one to nine scale; one = 100% chlorotic turf/necrotic turf, nine=dark green turf.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 40. Mean squares and significance of treatment effects on clipping yields of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1995										
Source	df	13 Jan.	18 Jan.	25 Jan.	1 Feb.	8 Feb.	15 Feb.	22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.
Species (S)	1	99.145**	21.376**	66.234**	15.089**	21.774**	16.401**	17.086**	10.760**	6.121*	0.360	6.334
TE	1	148.106**	11.999	19.929**	14.994**	14.727**	24.442**	44.363**	33.820**	24.321**	36.162*	9.464
S x TE	1	2.018	0.663	2.477**	0.502	3.227*	0.341	0.760	1.088	0.005	3.466	3.018
Iron (Fe)	1	0.976	0.293	0.048	0.172	0.002	0.000	0.909	0.158	0.141	4.699	5.235
S x FE	1	0.499	3.643	0.324	0.026	0.052	0.459	0.088	0.002	0.191	9.627	0.537
TE x FE	1	1.782	0.222	0.338	0.219	0.043	0.859	0.162	1.029	0.322	3.713	2.179
S x TE x FE	1	3.315	5.694	0.725	0.105	0.066	2.148*	1.122	2.106	2.458	0.004	1.922
Error	16	1.735	1.474	0.287	0.483	0.496	0.370	1.263	0.822	0.780	3.744	5.897
CV, %		18.96	37.86	16.48	28.34	34.75	27.64	47.19	55.14	42.18	46.70	53.12

		1996								
Source	df	8 Mar.	12 Mar.	24 Mar.	1 Apr.	15 Apr.	29 Apr.	3 May	8 May	17 May
Species (S)	1	12.630	156.417**	24.120	46.621**	129.596*	2.815	19.530	20.888*	24.080**
TE	1	5.539	45.733*	503.617**	108.758**	264.737**	12.702	24.261*	11.579**	11.620**
S x TE	1	5.539	48.082*	227.058	36.680*	60.579**	75.828**	25.113*	19.639**	14.727**
Iron (Fe)	1	4.395	100.409**	35.722	10.415	10.494	48.906*	13.878*	0.393	0.037
S x FE	1	0.980	20.739	31.740	0.158	0.005	1.530	0.044	0.081	0.056
TE x FE	1	1.990	3.519	90.171	0.644	0.105	12.702	4.762	0.435	1.017
S x TE x FE	1	0.803	35.893*	194.712	5.616	2.071	13.954	0.419	1.378	3.168*
Error	16	1.490	5.495	51.336	4.192	3.078	6.379	2.863	0.662	0.430
CV, %		28.07	18.55	54.11	29.59	19.35	29.67	40.19	38.98	36.64

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 41. Effects of species, trinexapac-ethyl, and iron on clipping yields of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI..

Treatment	1995										
	13 Jan.	18 Jan.	25 Jan.	1 Feb.	8 Feb.	15 Feb.	22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.
Species	$g\ m^{-2}$										
Supina bluegrass	4.9	2.3	1.6	1.7	1.1	1.4	1.5	1.0	1.6	4.0	4.1
Kentucky bluegrass	9.0**	4.2**	4.9**	3.2**	3.0**	3.0**	3.2	2.3	2.6	4.3	5.1
Trinexapac-ethyl											
no	9.4	3.9	4.2	3.2	2.8	3.2	3.7	2.8	3.1	5.4	5.2
yes†	4.5**	2.5*	2.3**	1.7**	1.2**	1.2**	1.0**	0.5**	1.1**	2.9*	3.9
Iron											
no	6.7	3.1	3.2	2.4	2.0	2.2	2.2	1.6	2.0	3.7	4.1
yes‡	7.1	3.3	3.3	2.5	2.0	2.2	2.6	1.7	2.2	4.6	5.0

Treatment	1996								
	8 Mar.	12 Mar.	24 Mar.	1 Apr.	15 Apr.	29 Apr.	3 May	8 May	17 May
	$g\ m^{-2}$								
Species									
Supina bluegrass	3.6	10.1	12.2	5.5	6.7	8.2	5.1	3.0	2.8
Kentucky bluegrass	5.1	15.2**	14.2	8.3**	11.4*	8.8	3.3	1.2*	0.8**
Trinexapac-ethyl									
no	4.8	14.0	17.8	9.0	12.4	9.2	5.2	2.8	2.5
yes	3.9	11.3*	8.7*	4.8*	5.7*	7.8	3.2*	1.4**	1.1**

Table 41 (cont'd.)

Iron									
no	3.9	10.6	14.5	6.3	8.4	7.1	3.5	2.2	1.8
yes¶	4.8	14.6**	12.0	7.6	9.7	9.9*	5.0*	2.0	1.8

*,** Significant at 0.05 and 0.01 probability levels, respectively.

† Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., and 17 Mar. 1995.

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

¶ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

Table 42. Values for significant interactions of trinexapac-ethyl and species on clipping yields of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1995															
	18 Jan.		25 Jan.		1 Feb.		8 Feb.		15 Feb.		22 Feb.		1 Mar.		8 Mar.	
	trinexapac-ethyl†															
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
	$g\ m^{-2}$															
Supina bluegrass	2.8	1.7	2.2	1.0	2.3	1.0	1.5	0.7	2.5	0.2	3.1	0.0	1.9	0.0	2.6	0.6
Kentucky bluegrass	5.0	3.3	6.1	3.7	4.2	2.3	4.1	1.8	3.9	2.1	4.4	2.0	3.7	0.9	3.6	1.6

	1996															
	12 Mar.		24 Mar.		1 Apr.		15 Apr.		29 Apr.		3 May		8 May		17 May	
	trinexapac-ethyl‡															
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
	$g\ m^{-2}$															
Supina bluegrass	12.9	7.3	20.0	4.6	8.9	2.2	11.7	1.8	10.7	5.7	7.1	3.1	4.6	1.4	4.3	1.3
Kentucky bluegrass	15.2	15.2	15.8	12.7	9.2	7.4	13.1	9.7	7.8	9.9	3.3	3.3	0.9	1.4	0.7	0.9

† Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

resulting from long-term PGR applications was also not observed (Watschke, 1976; Kaufmann, 1986b). Apparently the successive low rate (0.08 kg ha^{-1}) applications of trinexapac-ethyl suppressed growth only to the point where carbohydrates may have been shifted to enhance tillering without causing growth cessation (Hanson and Branham, 1987). For practical use it may be important to be able to monitor the level of active PGR in the turf if PGRs are to be used on a continuous basis to maintain turf in RLC. Immunological techniques may prove to be the most expedient method for determining the amount of active ingredient in the plant.

Experiment II: Turf subjected to traffic

Treatment effects on the clipping yields of trafficked turf were similar to non-trafficked turf (Table 43) but actual yields were much lower than those from non-trafficked turf (Table 44). Trinexapac-ethyl continued to affect Supina bluegrass more significantly compared to Kentucky bluegrass (Table 45). In 1995 yields of Supina bluegrass were zero after Feb. 1 although turf yields in 1996 indicated continued growth throughout the trial. Since total inhibition of growth will slow or eliminate turf recovery it is important to match timing and rates of application of PGRs to maintain acceptable turf cover.

Turf shear resistance

Experiment I: Turf not subjected to traffic

Turf species and trinexapac-ethyl consistently affected turf shear resistance while other treatment effects were rare and inconsistent (Table 46). Shear resistance declined

Table 43. Mean squares and significance of treatment effects on clipping yields of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1995										
Source	df	13 Jan.	18 Jan.	25 Jan.	1 Feb.	8 Feb.	15 Feb.	22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.
Species (S)	1	152.158**	40.951**	51.656**	24.020**	6.912**	9.920*	9.946*	1.233*	1.500	2.561	3.053
TE	1	88.974**	13.515**	4.887**	3.596**	1.826**	6.314**	6.500**	4.150**	2.600**	0.882	0.874
S x TE	1	7.718**	0.098	1.670*	1.184**	1.033*	5.088**	4.655**	1.233*	0.821**	0.331	0.459
Iron (Fe)	1	1.038**	0.158	0.000	0.000	0.056	0.100	0.020	0.002	0.003	1.344	0.844
S x FE	1	2.516	4.533	0.003	0.000	0.010	0.329	0.016	0.785	0.427*	2.030	1.144
TE x FE	1	1.515	1.071	0.041	0.189	0.094	0.293	0.732	0.002	0.070	1.033	0.010
S x TE x FE	1	14.586**	0.105	0.001	0.219	0.001	0.637	0.760	0.785	0.944**	0.564	0.602
Error	16	1.675	1.126	0.250	0.101	0.134	0.451	0.490	0.208	0.111	0.752	1.209
CV, %		22.12	38.72	25.48	27.33	60.41	96.61	96.76	109.68	84.39	136.36	122.72
		1996										
		8 Mar.	12 Mar.	24 Mar.	1 Apr.	15 Apr.	29 Apr.	3 May	8 May	17 May		
Species (S)	1	0.002	66.334**	18.288	21.603	15.456	5.597	7.820	11.166**	6.668*		
TE	1	4.043	0.029	50.489**	15.026**	12.877**	0.050	11.399	4.603	5.714**		
S x TE	1	0.146	9.004	12.892	4.310	6.998**	8.202	16.500*	8.509	6.563**		
Iron (Fe)	1	0.219	11.179	1.038	0.200	0.714	14.493	1.316	0.116	0.072		
S x FE	1	0.525	0.118	0.175	0.000	0.073	3.060	0.829	0.008	0.009		
TE x FE	1	0.657	0.184	0.111	0.168	1.685	3.368	0.647	0.186	0.061		
S x TE x FE	1	1.140	30.106**	23.781	7.628*	2.344	2.768	0.213	0.739	0.580		
Error	16	1.718	2.311	8.442	2.067	1.144	2.951	2.961	0.504	0.165		
CV, %		77.57	31.94	53.02	43.06	42.11	45.95	74.14	53.41	41.39		

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 44. Effects of species and trinexapac-ethyl on clipping yields of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1995										
Treatment	13 Jan.	18 Jan.	25 Jan.	1 Feb.	8 Feb.	15 Feb.	22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.
Species	$g\ m^{-2}$										
Supina bluegrass	3.3	1.4	0.5	0.2	0.1	0.1	0.1	0.2	0.1	0.3	0.5
Kentucky bluegrass	8.4**	4.0**	3.4**	2.2**	1.1**	1.3*	1.4*	0.6*	0.6	1.0	1.3
Trinexapac-ethyl											
no	7.8	3.5	2.4	1.6	0.9	1.2	1.2	0.8	0.7	0.8	1.1
yes †	3.9**	2.0**	1.5**	0.8**	0.3**	0.2**	0.2**	0.0**	0.1**	0.4	0.7
Iron											
no	5.6	2.7	2.0	1.2	0.6	0.8	0.7	0.4	0.4	0.4	0.7
yes ‡	6.1	2.8	2.0	1.2	0.7	0.6	0.8	0.4	0.4	0.9	1.1

	1996								
Treatment	8 Mar.	12 Mar.	24 Mar.	1 Apr.	15 Apr.	29 Apr.	3 May	8 May	17 May
Species	$g\ m^{-2}$								
Supina bluegrass	1.7	3.1	4.6	2.4	1.7	4.2	2.9	2.0	1.5
Kentucky bluegrass	1.7	6.4	6.4	4.3	3.3	3.3	1.8	0.6**	0.5*
Trinexapac-ethyl									
no	2.1	4.7	6.9	4.1	3.3	3.7	3.0	1.8	1.5
yes §	1.3	4.8	4.0**	2.5**	1.8**	3.8	1.6	0.9*	0.5**

Table 44 (cont'd.)

Iron									
no	1.6	4.1	5.3	3.2	2.4	3.0	2.1	1.4	1.0
yes ¶	1.8	5.4	5.7	3.4	2.7	4.5	2.6	1.3	0.9

*,** Significant at 0.05 and 0.01 probability levels, respectively.

† Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., and 17 Mar. 1995.

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

¶ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

Table 45. Values from significant interactions of trinexapac-ethyl and species on clipping yields of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

Treatment	1995															
	13 Jan.		25 Jan.		1 Feb.		8 Feb.		15 Feb.		22 Feb.		1 Mar.		8 Mar.	
	trinexapac-ethyl †															
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
	$g\ m^{-2}$															
Supina bluegrass	4.7	2.0	0.7	0.3	0.3	0.0	0.1	0.0	0.1	0.0	0.2	0.0	0.4	0.0	0.3	0.0
Kentucky bluegrass	10.9	5.9	4.1	2.7	2.8	1.6	1.6	0.7	2.3	0.4	2.3	0.4	1.3	0.0	1.2	0.1
LSD (0.05)	1.0		0.6		0.4		0.5		0.8		0.8		0.6		0.3	

	1996															
	12 Mar.		24 Mar.		1 Apr.		15 Apr.		29 Apr.		3 May		8 May		17 May	
	trinexapac-ethyl ‡															
Species	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
	$g\ m^{-2}$															
Supina bluegrass	3.7	2.5	6.8	2.4	3.6	1.2	3.0	0.5	4.8	3.7	4.4	1.4	3.0	1.0	2.5	0.5
Kentucky bluegrass	5.8	7.1	7.1	5.6	4.6	3.9	3.5	3.2	2.6	3.9	1.6	1.9	0.5	0.8	0.4	0.5
LSD (0.05)	ns		ns		ns		0.8		ns		2.0		0.9		0.4	

† Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 46. Mean square and significance of treatment effects on shear resistance of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1994-1995			
Source of variation	df	20 Dec.	20 Jan.	22 Feb.	31 Mar.
Species (S)	1	369.094**	2.344	546.260**	240.667**
Trinexapac-ethyl (TE)	1	0.010	94.010**	0.260	20.167*
S x TE	1	3.760	10.010	1.760	3.375
Iron (Fe)	1	3.760	15.844	3.760	2.042
S x Fe	1	0.010	17.510	0.260	2.667
TE x Fe	1	0.010	36.260	1.260	32.667**
S x TE x Fe	1	7.594*	0.094	0.010	15.042*
Error	16	1.042	17.760	2.271	3.219
CV, %		5.57	25.77	10.17	14.08

		1996		
Source of variation	df	17 Jan.	12 Mar.	31 May
Species (S)	1	121.500**	48.167*	28.711**
Trinexapac-ethyl (TE)	1	1.500	18.375	5.753*
S x TE	1	7.042	15.042	6.773*
Iron (Fe)	1	4.167	5.042	0.023
S x Fe	1	2.042	30.375	0.315
TE x Fe	1	7.042	16.667	0.003
S x TE x Fe	1	0.667	32.667	0.065
Error	16	2.281	8.000	0.815
CV, %		7.29	16.80	10.31

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

over time in both years regardless of treatment (Table 47). The decline in shear resistance indicated a lack of sufficient turf growth and rooting probably due to insufficient light energy to sustain turf permanently. In the first year Kentucky bluegrass had higher shear resistance than Supina bluegrass probably due to the presence of rhizomes in Kentucky bluegrass which added stability to the turf (McNitt, 1994). Shear resistance values of Kentucky bluegrass were significantly lower than those of Supina bluegrass in 1996, perhaps due to increased root growth of Supina bluegrass during the longer establishment period in autumn of 1995 compared to autumn 1994. However the practical significance of such a difference in shear resistance may not be important as values were still relatively close. In addition, a desirable value for shear resistance using the Eijkelkamp shear vane has not been established despite previous attempts (Liesecke and Schmidt, 1978) . Shear resistance values are generally important for their ability to indicate relative turf strength and rooting differences. In 1996 the shear resistance of Supina bluegrass was significantly increased by trinexapac-ethyl while Kentucky bluegrass shear resistance was unchanged (Table 48). Trinexapac-ethyl enhanced Supina bluegrass growth and development more than Kentucky bluegrass, which resulted in more biomass aboveground which enhanced the shear resistance of the Supina bluegrass.

Experiment II: Turf subjected to traffic

Treatment effects on turf shear resistance were similar to those on non-trafficked turf (Table 49). Shear values declined over time due to loss of turf density and actual values were lower than for non-trafficked turf (Table 50). Supina bluegrass continued to be

Table 47. Effect of species, trinexapac-ethyl, and iron on shear resistance values (N•m) of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1994-1995			
Treatment	20 Dec.	20 Jan.	22 Feb.	31 Mar.
Species	N m			
Supina bluegrass	14.2	16.0	10.0	9.0
Kentucky bluegrass	22.4**	16.7	19.6**	15.3**
Trinexapac-ethyl				
no	18.3	14.4	14.7	11.2
yes†	18.3	18.3**	14.9	13.0*
Iron				
no	18.7	15.5	15.2	12.4
yes‡	17.9	17.2	14.4	11.8

	1996		
Treatment	17 Jan.	12 Mar.	31 May
Species	N m		
Supina bluegrass	23.0	18.2	9.9
Kentucky bluegrass	18.5**	15.4*	7.7**
Trinexapac-ethyl			
no	20.5	16.0	8.3
yes§	21.0	17.7*	9.2*
Iron			
no	20.3	16.4	8.7
yes¶	21.1	17.3	8.8

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

†Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., 17 Mar 1995.

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

¶ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

Table 48. Shear resistance values (N•m) for the significant species-by-trinexapac-ethyl interaction on non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	31 May 1996	
	------------------------------ trinecapac-ethyl† ------------------------------	
Species	no	yes
	---------------------------------------N m ---------------------------------------	
Supina bluegrass	8.8	10.9
Kentucky bluegrass	7.7	7.6
LSD (0.05)	1.1	

† Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 49. Mean square and significance of treatment effects on shear resistance of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		1994-1995		
Source of variation	df	20 Jan.	22 Feb.	31 Mar.
Species (S)	1	8.167	546.260**	152.510**
Trinexapac-ethyl (TE)	1	60.167	10.010	15.844**
S x TE	1	12.042	1.260	8.760*
Iron (Fe)	1	4.167	8.760	10.010*
S x Fe	1	18.375	6.510	4.594
TE x Fe	1	22.042	1.760	0.844
S x TE x Fe	1	1.500	0.260	25.010**
Error	16	15.010	3.083	1.948
CV, %		25.62	13.57	15.47

		1996	
Source of variation	df	12 Mar.	31 May
Species (S)	1	45.375*	19.260**
Trinexapac-ethyl (TE)	1	5.042	16.667**
S x TE	1	2.667	24.000**
Iron (Fe)	1	5.042	2.344
S x Fe	1	6.000	0.094
TE x Fe	1	6.000	0.667
S x TE x Fe	1	15.042	0.167
Error	16	6.667	1.255
CV, %		18.33	15.86

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 50. Effect of species, trinexapac-ethyl, and iron on shear resistance values (N•m) of turfgrass subjected to traffic† in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	1994-1995		
Treatment	20 Jan.	22 Feb.	31 Mar.
Species	N m		
Supina bluegrass	14.5	8.2	6.5
Kentucky bluegrass	15.7	17.7**	11.5**
Trinexapac-ethyl			
no	13.5	12.3	8.2
yes‡	16.7*	13.6	9.8**
Iron			
no	14.7	12.3	9.7
yes§	15.5	13.5	8.4*

	1996	
Treatment	12 Mar.	31 May
Species	N m	
Supina bluegrass	15.5	8.0
Kentucky bluegrass	12.7	6.2**
Trinexapac-ethyl		
no	13.6	6.2
yes¶	14.5	7.9**
Iron		
no	13.6	7.4
yes#	14.5	6.8

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† Traffic was applied by persons who jogged on the turf 50 passess each week while wearing molded soccer cleats on the following dates: 28 Dec. 1994 through 16 Mar. 1995 and 26 Jan. through 26 Apr. 1996.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., 17 Mar 1995.

¶ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

more sensitive to trinexapac-ethyl applications in both 1995 and 1996 compared to Kentucky bluegrass (Table 51).

Plant density and biomass

Experiment I: Turf not subjected to traffic

Species, trinexapac-ethyl, and species-by-trinexapac-ethyl interactions existed for specific plant weight, plant density, tiller, and leaf counts (Table 52). The turf density of Supina bluegrass was much greater than Kentucky bluegrass and positively influenced quality ratings. Supina bluegrass had more tillers and leaves per plant plus a higher specific plant weight (Table 53). Plant density (number plants per unit area) was either the same or greater than Kentucky bluegrass.

Trinexapac-ethyl increased turf density by increasing the plant density, number of tillers and leaves per plant, and specific plant weight. Apparently trinexapac-ethyl was effective at repartitioning carbohydrates in the plant to produce axillary tillers and more leaves per plant similar to the effects of paclobutrazol and flurprimidol (Hanson and Branham, 1987). Turf left untreated, particularly Kentucky bluegrass, exhibited a spindlier, more upright growth habit and may have exhausted carbohydrate reserves by cell and shoot elongation without benefitting from an increased leaf area index (LAI) resulting from the trinexapac-ethyl application. As with color, quality, and clipping yields, Supina bluegrass was more sensitive to trinexapac-ethyl than Kentucky bluegrass and exhibited a strong positive response while Kentucky bluegrass was largely unaffected (Table 54).

Table 51. Shear resistance values (N•m) for the significant species-by-trinexapac-ethyl interactions on turfgrass subjected to traffic† in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	31 March 1995		31 May 1996	
	trinexapac-ethyl			
Species	no	yes‡	no	yes§
	N m			
Supina bluegrass	5.1	7.9	6.1	9.8
Kentucky bluegrass	11.3	11.8	6.3	6.0
LSD (0.05)	1.6		1.0	

† Traffic was applied by persons who jogged on the turf 50 passess each week while wearing molded soccer cleats on the following dates: 28 Dec. 1994 through 16 Mar. 1995 and 26 Jan. through 26 Apr. 1996.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 52. Mean squares and treatment effects on plant density and biomass of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		12 April 1995			
Source of variation	df	Plant density (No. plants m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species (S)	1	1695697.630	15.360**	180.950*	94.169**
Trinexapac-ethyl (TE)	1	13834140.784**	2.667*	34.800*	143.277**
S x TE	1	749137.231	3.227*	33.844*	48.053*
Iron (Fe)	1	4924.957	0.202	3.300	1.242
S x Fe	1	60.805	0.135	1.170	0.814
TE x Fe	1	102207.627	0.375	13.650	14.291
S x TE x Fe	1	572082.701	0.482	3.920	2.857
Error	16	610266.411	0.400	4.872	7.807
CV, %		13.71	33.27	30.82	29.72
		31 May 1996			
Source of variation	df	Plant density (No. plants m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species (S)	1	20665817.941**	10.402**	388.815**	2061.277**
Trinexapac-ethyl (TE)	1	832314.080**	0.807**	12.042*	10.010
S x TE	1	1208798.011**	0.807**	1.500	2.306
Iron (Fe)	1	26813.528	0.240	2.282	58.033
S x Fe	1	32164.085	0.240	8.167	191.648
TE x Fe	1	1520.039	0.082	1.500	198.490
S x TE x Fe	1	547.217	0.082	0.015	220.584
Error	16	28759.193	0.087	2.187	66.212
CV, %		15.79	17.84	20.17	33.78

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 53. Effect of species, trinexapac-ethyl, and iron on plant density and biomass of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	12 April 1995			
Treatment	Plant density (No. plnts m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species				
Supina bluegrass	5430.8	2.7	9.9	11.4
Kentucky bluegrass	5962.4	1.1**	4.4*	7.4**
Trinexapac-ethyl				
no	4937.4	1.6	6.0	7.0
yes†	6455.8**	2.2*	8.4**	11.9**
Iron				
no	5710.9	1.8	6.8	9.2
yes‡	5682.2	2.0	7.5	9.6

	31 May 1996			
Treatment	Plant density (No. plnts m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species				
Supina bluegrass	1990.	2.3	11.4	33.4
Kentucky bluegrass	134**	1.0**	3.3**	14.8**
Trinexapac-ethyl				
no	875	1.5	6.6	23.4
yes§	1248**	1.8**	8.0*	24.8
Iron				
no	1028	1.6	7.0	22.5
yes¶	1095	1.8	7.6	25.6

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

†Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., 17 Mar 1995.

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

¶ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

Table 54. Plant density and biomass values for the significant species-by-trinexapac-ethyl interactions on non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	12 April 1995							
	Plant density (no. plants m^{-2})		Tillers $plant^{-1}$		Leaves $plant^{-1}$		Specific plant weight (mg)	
	trinexapac-ethyl†							
Species	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	49370	6366	2.0	3.4	7.5	12.3	7.5	15.2
Kentucky bluegrass	5379	6544	1.1	1.1	4.4	4.4	6.4	8.4
LSD (0.05)	ns		0.8		2.7		3.4	

	31 May 1996							
	Plant density (no. plants m^{-2})		Tillers $plant^{-1}$		Leaves $plant^{-1}$		Specific plant weight (mg)	
	trinexapac-ethyl‡							
Species	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	1579	2400	2.0	2.7	10.4	12.3	33.0	33.7
Kentucky bluegrass	172	96	1.0	1.0	2.8	3.8	13.9	15.8
LSD (0.05)	208		0.4		ns		ns	

† Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Experiment II: Turf subjected to traffic

Trinexapac-ethyl had less effect on the biomass of turf subjected to traffic compared to non-trafficked turf (Table 55). Supina bluegrass continued to exhibit a higher plant density, more tillers and leaves per plant, and higher specific plant weight compared to Kentucky bluegrass (Table 56). In addition, both species exhibited a higher specific plant weight compared to untrafficked turf apparently due to less competition for light and perhaps water and nutrients. Unlike non-trafficked turf, trinexapac-ethyl had little effect on response to traffic between species (Table 57).

Chlorophyll concentration

Experiment I: Turf not subjected to traffic

Species and trinexapac-ethyl significantly affected chlorophyll *a* and *b* levels and total chlorophyll (Table 58). The greater levels of chlorophyll *a*, *b*, and total chlorophyll in Kentucky bluegrass compared to Supina bluegrass were consistent with the darker green color of Kentucky bluegrass but were not effective in providing superior shade tolerance (Table 59). Trinexapac-ethyl also enhanced chlorophyll concentration (leaf area basis) in both turf species probably due to decreased cell enlargement. Trinexapac-ethyl cannot be expected to affect chlorophyll synthesis directly since its known modes of action have been described as blocking gibberellic acid (GA) biosynthesis only at the end of the pathway, primarily by preventing 3-β hydroxylation of the biologically inactive GA_{20} to the biologically active GA_1 (Rademacher, 1991). Since carotenoids and GA_1 have a common precursor, geranylgernalypyrophosphate (GGPP), it is possible GA inhibition

Table 55. Mean squares and treatment effects on plant density and biomass of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Resarch Center, East Lansing, MI.

Source of variation	df	Plant density (No. plnts m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
		12 April 1995			
Species (S)	1	1368037.471	15.844**	301.750**	193.007**
Trinexapac-ethyl (TE)	1	5113419.885*	0.260	9.004	9.805
S x TE	1	107254.135	0.304	3.450	1.540
Iron (Fe)	1	8755.448	0.000	0.120	4.200
S x Fe	1	190673.985	0.020	2.100	1.101
TE x Fe	1	117712.025	0.004	0.454	1.224
S x TE x Fe	1	78798.975	0.000	2.220	1.325
Error	16	689430.079	0.293	4.807	8.944
CV, %		39.94	26.78	25.16	21.78
		31 May 1996			
Source of variation	df	Plant density (No. plnts m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species (S)	1	5545355.292**	6.934**	320.470**	2058.869*
Trinexapac-ethyl (TE)	1	818147.252**	0.350	6.720	110.039
S x TE	1	934886.447**	0.510	4.420	98.537
Iron (Fe)	1	41101.925	0.070	1.450	5.482
S x Fe	1	107254.140	0.020	0.400	31.763
TE x Fe	1	35021.756	0.034	0.634	0.196
S x TE x Fe	1	0.000	0.004	0.034	224.298
Error	16	94729.003	0.125	2.390	125.984
CV, %		50.62	22.59	22.95	39.29

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 56. Effect of species, trinexapac-ethyl, and iron on plant density and biomass of turfgrass subjected to traffic† in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	12 April 1995			
Treatment	Plant density (No. plnts m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species				
Supina bluegrass	1840	2.8	12.3	16.6
Kentucky bluegrass	2317	1.2**	5.2**	10.9**
Trinexapac-ethyl				
no	1617	1.9	8.1	13.1
yes‡	2540*	2.1	9.3	14.4
Iron				
no	2098	2.0	8.8	14.1
yes§	2060	2.0	8.6	13.3

	31 May 1996			
Treatment	Plant density (No. plnts m^{-2})	Tillers $plant^{-1}$	Leaves $plant^{-1}$	Specific plant weight (mg)
Species				
Supina bluegrass	1089	2.1	10.4	37.8
Kentucky bluegrass	127**	1.0**	3.1**	19.3**
Trinexapac-ethyl				
no	423	1.4	6.2	26.4
yes¶	793**	1.7	7.3	30.7
Iron				
no	649	1.5	6.5	28.1
yes#	567	1.6	7.0	29.0

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† Traffic was applied by persons who jogged on the turf 50 passes each week while wearing molded soccer cleats on the following dates: 28 Dec. 1994 through 16 Mar. 1995 and 26 Jan. through 26 Apr. 1996.

†Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., 17 Mar 1995.

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

¶ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

Table 57. Plant density and biomass values for the species-by-trinexapac-ethyl interactions on turfgrass subjected to traffic† in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	12 April 1995							
	Plant density (no. plants m^{-2})		Tillers $plant^{-1}$		Leaves $plant^{-1}$		Specific plant weight (mg)	
	trinexapac-ethyl‡							
Species	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	1445	2234	2.6	3.0	11.3	13.2	16.2	17.0
Kentucky bluegrass	1789	2846	1.2	1.2	4.9	5.4	10.0	11.8
LSD (0.05)	ns		ns		ns		ns	

	31 May 1996							
	Plant density (no. plants m^{-2})		Tillers $plant^{-1}$		Leaves $plant^{-1}$		Specific plant weight (mg)	
	trinexapac-ethyl§							
Species	no	yes	no	yes	no	yes	no	yes
Supina bluegrass	707	1471	1.8	2.4	9.4	11.4	33.7	42.0
Kentucky bluegrass	140	114	1.0	1.0	3.0	3.2	19.2	19.4
LSD (0.05)	377		ns		ns		ns	

† Traffic was applied by persons who jogged on the turf 50 passes each week while wearing molded soccer cleats on the following dates: 28 Dec. 1994 through 16 Mar. 1995 and 26 Jan. through 26 Apr. 1996.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

Table 58. Mean squares and treatment effects on chlorophyll of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		4 April 1995			
Source of variation	df	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Chlorophyll *a:b*
Species (S)	1	238.644**	30.173**	435.968**	0.029
Trinexapac-ethyl (TE)	1	314.071**	47.124**	601.301**	0.163*
S x TE	1	1.815	0.008	2.227	0.000
Iron (Fe)	1	5.587	0.980	10.921	0.000
S x Fe	1	4.267	0.022	5.125	0.035
TE x Fe	1	11.289	1.701	21.263	0.001
S x TE x Fe	1	19.802	1.071	30.759	0.009
Error	16	13.265	2.285	26.225	0.027
CV, %		15.21	19.45	16.16	5.25
		29 May 1996			
Source of variation	df	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Chlorophyll *a:b*
Species (S)	1	32.109	2.734	55.937*	0.029
Trinexapac-ethyl (TE)	1	121.590**	10.935**	200.797**	0.020
S x TE	1	8.592	0.680	15.360	0.029
Iron (Fe)	1	19.911	2.257	33.844	0.032
S x Fe	1	13.681	1.344	22.042	0.000
TE x Fe	1	0.341	0.070	1.033	0.022
S x TE x Fe	1	0.928	0.109	1.288	0.034
Error	16	4.710	0.470	7.887	0.043
CV, %		10.03	9.78	9.79	6.70

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 59. Effect of species, trinexapac-ethyl, and iron on chlorophyll content of non-trafficked turfgrass in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

	4 April 1995			
Treatment	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Chlorophyll *a:b*
	----------μg cm^{-2} leaf tissue----------			
Species				
Supina bluegrass	20.8	6.7	27.4	3.1
Kentucky bluegrass	27.1**	8.9**	36.0**	3.1
Trinexapac-ethyl				
no	20.3	6.4	26.7	3.2
yes†	27.6**	9.2**	36.7**	3.0*
Iron				
no	24.4	8.0	32.4	3.1
yes‡	23.5	7.6	31.0	3.1

	29 May 1996			
Treatment	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Chlorophyll *a:b*
	----------μg cm^{-2} leaf tissue----------			
Species				
Supina bluegrass	20.5	6.7	27.1	3.1
Kentucky bluegrass	22.8*	7.3	30.2*	3.1
Trinexapac-ethyl				
no	19.4	6.3	25.8	3.1
yes§	23.9**	7.7**	31.6**	3.1
Iron				
no	20.7	6.7	27.5	3.1
yes¶	22.5	7.3*	29.9	3.1

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

†Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

‡ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., 17 Mar 1995.

§ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 9 Oct. 1995 (0.19 kg ha^{-1}), 31 Jan., 15 Mar., 26 Apr. 1996 (0.08 kg ha^{-1} each date).

¶ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 28 Feb. and 13 May 1996.

could cause a feedback mechanism to shunt additional GGPP to carotenoid production. Current evidence does not support the existence of such a feedback mechanism as typically non-active gibberellins(GA_1 precursors) continue to accumulate in the presence of a (GA_1) biosynthetic inhibitor (Rademacher, 1991).

Iron application caused only minor, temporary darker green turf color. Chlorophyll levels were relatively unaffected within two weeks following an application of iron. This result suggests the plants were already at their maximum capacity for using iron for chlorophyll production or else energy levels within the turfgrass plants were too low to utilize the iron. Auxiliary studies showed that while foliar applications of iron failed to enhance turf color or chlorophyll levels in Kentucky bluegrass, iron levels in plant tissues were increased threefold following an application of iron sulfate at the same rate used in the current study (*unpublished data*). Another possible explanation for the inconsistency between color enhancement and lack of effect on chlorophyll content is that the leaves used for chlorophyll analysis might have been partially unexpanded at the time of the iron application thus the effect would have been seen particularly on older leaves.

Chlorophyll *a:b* ratios were relatively unaffected by any treatment. Chlorophyll *a:b* ratios were approximately 3:1 which is equivalent to the ratio of approximately 3:1 observed for sun plants (Nobel, 1991). This indicates Supina bluegrass is not a "shade" plant *per se* but apparently has mechanisms for shade tolerance which are lacking in Kentucky bluegrass.

Experiment II: Turf subjected to traffic

Treatment effects on chlorophyll quality and quantity were similar between trafficked and untrafficked turf in 1995 (Table 60). As expected, data from 1995 indicated traffic did not affect chlorophyll content (Table 61). Data were not collected in 1996 due to insufficient plant material (the youngest fully matured leaves were consistently too short from mowing to use in analysis).

CONCLUSIONS

Supina bluegrass was more tolerant of RLC than Kentucky bluegrass. The light conditions tested were too low to sustain Supina bluegrass permanently in a trafficked conditions and were marginal for non-trafficked conditions. The enhanced growth of Supina bluegrass due to increasing light levels and photoperiod in the spring indicated the actual light requirement to sustain Supina bluegrass under traffic was greater than the test conditions generally provided.

Iron had negligible effect on any characteristic of either turfgrass species. Trinexapac-ethyl treatments provided superior enhancement of color and quality compared to iron. In addition, iron did not provide the enhanced biomass associated with trinexapac-ethyl treatments.

Supina bluegrass was consistently more responsive to trinexapac-ethyl than Kentucky bluegrass. Trinexapac-ethyl may have helped to increase the turf quality in RLC by shifting carbohydrate partitioning away from primary shoots to stimulate tillering with a subsequent increase in the LAI in addition to promoting a more prostrate

Table 60. Mean squares and treatment effects on chlorophyll of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI.

		4 April 1995			
Source of variation	df	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Chlorophyll *a*:*b*
Species (S)	1	104.125**	14.774**	278.734**	0.077*
Trinexapac-ethyl (TE)	1	179.252**	23.108**	328.486**	0.027
S x TE	1	0.017	0.134	4.708	0.010
Iron (Fe)	1	5.636	0.485	12.600	0.007
S x Fe	1	0.956	0.002	5.180	0.020
TE x Fe	1	24.990	3.190	52.896*	0.000
S x TE x Fe	1	13.395	3.046	4.797	0.056
Error	16	7.701	1.048	11.416	0.013
CV, %		10.98	12.94	10.18	3.54

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 61. Effect of species, trinexapac-ethyl, and iron on chlorophyll content of turfgrass subjected to traffic in reduced light conditions, Hancock Turfgrass Research Center, East Lansing, MI. †

	4 April 1995			
Treatment	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Chlorophyll *a*:*b*
	----------------------μg cm^{-2} leaf tissue------------------------			
Species				
Supina bluegrass	23.2	7.1	29.8	3.3
Kentucky bluegrass	27.4**	8.7**	36.6**	3.2*
Trinexapac-ethyl				
no	22.5	6.9	29.5	3.3
yes‡	28.0**	8.9**	36.7**	3.2
Iron				
no	24.8	7.8	32.5	3.2
yes§	25.8	8.1	33.9	3.2

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† Traffic was applied by persons who jogged on the turf 50 passes each week while waring molded soccer cleats from 28 Dec. 1994 through 16 May 1995.

‡ Trinexapac-ethyl was applied on the following dates; rates are shown in parentheses: 3 Oct. 1994 (0.19 kg ha^{-1}), 20 Jan., 18 Feb., 16 Mar. 1995 (0.08 kg ha^{-1} each date).

§ Iron (1.14 kg ha^{-1}) was applied as $FeSO_4$ on 10 Jan., 14 Feb., 17 Mar 1995.

and compact growth. These attributes could be expected to enhance net photoassimilation on a turf area basis, creating a favorable cycle as more carbohydrates can be produced to regenerate tissues damaged by traffic or disease.

Supina bluegrass was superior to Kentucky bluegrass in RLC due in part to an apparent resistance to powdery mildew. Supina bluegrass was more susceptible to pink snow mold in RLC compared to Kentucky bluegrass. This problem was partly controlled by providing wind movement over the turf with portable fans although occasional fungicide applications were still necessary to prevent noticeable disease damage.

Chapter 3

PHOTOSYNTHESIS OF SUPINA BLUEGRASS (*POA SUPINA* SCHRAD.) AND KENTUCKY BLUEGRASS (*P. PRATENSIS* L.) IN REDUCED LIGHT CONDITIONS AS AFFECTED BY NITROGEN AND TRINEXAPAC-ETHYL

INTRODUCTION

Turfgrass performance in reduced light conditions (RLC; < 30% sunlight) is often poor due to insufficient light for photosynthesis and normal turf growth. Turfgrass species and cultivars may vary widely in their tolerance to RLC although all may exhibit reduced tillering, reduced rooting, and an upright spindly growth (Beard, 1973). Supina bluegrass (*Poa supina* Schrad.), a stoloniferous grass native to the sub-alpine regions of Europe, has been developed in Germany as a turfgrass with purportedly good to excellent shade and traffic tolerance (Berner, 1984; Nonn, 1994; Pietsch, 1989; Skirde, 1971). Preliminary research supports the hypothesis that Supina bluegrass is more tolerant of RLC than Kentucky bluegrass (*P. pratensis* L.) (Stier and Rogers, 1995) which is commonly used in the United States but has poor shade tolerance (Beard, 1973). The mechanism(s) for the apparent shade tolerance of Supina bluegrass is/are unknown.

In addition to the use of shade-tolerant turfgrasses proper management techniques are also important for turf performance in RLC. Previous research has indicated the potential for plant growth regulators (PGRs) which inhibit gibberellic acid (GA) biosynthesis to improve turf quality in reduced light conditions (Rogers et al., 1996; Stier and Rogers, 1995). Turf treated with GA-inhibitors in RLC was more uniform with darker color and increased density compared to untreated turf. While the GA-inhibitors effectively suppressed shoot elongation, other mechanisms by which the GA-inhibitors improved turf quality were unknown. Possibilities range from enhanced photosynthetic rates (Gausman et al., 1991), increased carbohydrate production or partitioning (Hanson and Branham, 1987; Wang et al. 1985), increased chlorophyll levels (Wang et al 1985, Archbold and Houtz, 1988), increased protein/enzyme levels and/or activity (Wang et al. 1985), altered hormonal levels affecting foliar production (Gausman et al., 1991), to gene expression (Gausman et al., 1991). Conversely, Archbold and Houtz (1988) reported flurprimidol and paclobutrazol decreased photosynthetic rates and Rubisco activities in strawberry plants. DeJong and Doyle (1984) found paclobutrazol reduced shoot growth of nectarine trees but did not affect photosynthesis. Mefluidide, generally considered a mitotic inhibitor which also may inhibit GA-biosynthesis (Wilkenson, 1982), consistently reduced photosynthetic rates of 'Baron' Kentucky bluegrass while amidochlor occasionally enhanced photosynthesis (Spokas and Cooper, 1991).

In the early 1990's a new GA-inhibitior, trinexapac-ethyl (TE), was labeled for use on turfgrasses, primarily to decrease mowing requirements by suppressing shoot growth (Vitolo et al., 1990). The potential side effects of TE on plant physiology are relatively unknown due to its recent release but may be different than other turf GA-inhibitors. TE apparently blocks 3-β oxidation of the biologically inactive GA_{20} to form the biologically active GA_1 as opposed to flurprimidol and paclobutrazol which inhibit ent-kaurene oxidation oxidative steps earlier in the biosynthetic pathway (Coolbaugh et al., 1982; Rademacher, 1991).

In normal (full sun) conditions GA-inhibitor effects on turfgrass can vary with nitrogen (N) rate and turf species or cultivars. Watschke (1981) found differences in responses of two Kentucky bluegrass culitivars ('Merion' and 'Pennstar') to paclobutrazol and flurprimidol. Other studies showed high N rates reduced the effects of flurprimidol on common bermudagrass [*Cynodon dactylon* (L.) Pers.] (Devitt and Morris, 1988) but not on 'Tifway' hybrid bermudagrass [*Cynodon transvaalensis* Burtt-Davy x *C. dactylon* (L.) Pers.] (Johnson, 1988). Johnson (1994) corroborated the differences in response to trinexapac-ethyl between common bermudagrass and 'Tifway' hybrid bermudagrass. In RLC of approximately 5-6 mol photosynthetically active radiation (PAR) day^{-1}, medium to high N rates (48 and 96 kg ha^{-1} at four to six week intervals) resulted in significantly better quality Kentucky bluegrass compared to low N rates (24 kg ha^{-1} at four to six week intervals) when flurprimidol was applied, although low and medium N rates provided superior turf in the absence of flurprimidol (Chapter 1).

Due to the demand for improved turfgrasses and management schemes for turf in RLC, studies were initiated to examine the effects of N rate, trinexapac-ethyl, and species on turf photosynthesis in RLC. Two hypotheses were tested: 1) Supina bluegrass was more tolerant of RLC compared to Kentucky bluegrass due to a greater carbon exchange rate (CER), i.e., enhanced photosynthetic rate, and 2) Trinexapac-ethyl improved turfgrass quality in RLC by enhancing CER. The objectives of this research were to determine if differences in CER existed between Supina bluegrass and Kentucky bluegrass and to determine the effects of trinexapac-ethyl on CER of the two species. A second set of objectives were to determine the influence of nitrogen rate and trinexapac-ethyl on the CER of Supina bluegrass.

MATERIALS AND METHODS

Plot establishment and testing

Experiment I: Species x PGR study

Portable plots were established outside in full sun conditions. Wooden boxes (1.2 x 1.2 x 0.15 m depth) were filled with a sand:peat mixture (80:20 v/v) (Table 78, Appendix). The pH was 7.8 with initial P and K levels of 85 kg ha^{-1} and 90 kg ha^{-1}, respectively. Sixteen holes (0.6 cm diam) were drilled on approximately 23 cm spacings in the bottom of each box to provide drainage. Starter fertilizer (13-25-12) was applied to the soil and supplied 76 kg N ha^{-1}, 64 kg P ha^{-1}, and 58 kg K ha^{-1}. Ten plots each were sodded in Sept. 1995 with Supina bluegrass 'Supra' or Kentucky bluegrass 'Blacksburg'. The sod had been grown in a composted wood mulch on polyethylene sheeting during the summer of 1995 (Cairol and Chevallier, 1981). Plots were mowed two to three times weekly to 3 cm height and irrigated as necessary to prevent moisture stress. Plots were fertilized bimonthly with 48 kg ha^{-1} N, 3 kg ha^{-1} P, and 40 kg ha^{-1} K. To prepare plots for testing in reduced light conditions (RLC), plots were fertilized with 48 kg N ha^{-1}, 41 kg P ha^{-1}, and 38 kg K ha^{-1} on 26 Aug. 1996. Plots were fertilized thereafter on a biweekly basis with 37 kg N ha^{-1}, 3 kg P ha^{-1}, and 30 kg K ha^{-1}.

On 18 Sept. 1996 trinexapac-ethyl (0.19 kg ha^{-1}) was applied to five plots each of Supina bluegrass and Kentucky bluegrass. Plots were moved into the Covered Stadium Simulator Facility (CSSF) on 4 October 1996 and arranged in a randomized complete block (RCB) design with five replications. Air temperature was maintained at 15.9 C ± 2.9 C (range was 10-20 C). Relative humidity was 55.4 ± 8.7%.

High pressure sodium lamps (400 W), suspended 2.7 m above the turf surface, provided a steady but reduced light condition of approximately 100 ± 9 μmol m^{-2} s^{-1} on a 12 h photoperiod (ppd) and provided approximately 4.3 mol PAR m^{-2} day^{-1}, not including ambient light (Table 62). Iprodione (3-(3,5-dichlorophenyl)-N-(1-methethyl)-2,4-dioxo-1-imidazolidinecarboximide), 5.93 kg ha^{-1}, was applied with a CO_2-powered backpack sprayer on 2 November 1996 to control Microdochium patch (*Microdochium nivale*). An open gas exchange system was used to determine photosynthetic rates (Sams and Flore, 1982) using a polycarbonate chamber (4.9 cm^2, approximately 24 cm^3) secured over the turf surface. Gas exchange measurements, foliar characteristics, and chlorophyll concentrations were determined 23-25 Nov. 1996 approximately seven weeks after the turf was moved into the CSSF. Carbon exchange rates (CERs) were collected on 23 Nov. between 1200-1600 h after CO_2 levels in ambient air had stabilized following large fluctuations earlier in the day. Data were analyzed as a 2 x 2 factorial in a RCB design with two species (Supina bluegrass and Kentucky bluegrass) and TE treatments (0.00 and 0.19 kg ha^{-1} trinexapac-ethyl) as main plots with five replications.

Table 62. Photosynthetically active radiation (PAR) of plots in the Covered Stadium Simulator Facility (CSSF), Hancock Turfgrass Research Center, East Lansing, MI.

Location	1996 October	1996 November
	---------------------mol PAR day^{-1} -------------------	
Outside†		
average	15.5	9.8
standard deviation	9.4	4.3
CSSF, ambient light ‡		
average	2.4	1.5
standard deviation	1.5	0.7
CSSF, supplemental light §		
average	5.5	5.1
standard deviation	1.1	0.7

† PAR was integrated daily using a pyranometer (Li-Cor, model PY 14226, Lincoln NE). Radiometric units (Ly day^{-1}) were converted to quantum units (mol PAR m^{-2} day^{-1}) based on the conversion units published by Thimijan and Heins (1983).

‡ PAR inside the CSSF was determined by measuring the percent of PAR transmitted into the CSSF at turf level with a portable spectroradiometer (Li-Cor, model LI-1800, Lincoln NE).

§ Supplemental light (approximately 100 μmol m^{-2} s^{-1}; 12 h photoperiod) was supplied with 400 W high pressure sodium lamps.

Experiment II: Nitrogen x PGR study

Portable plots were established outside in full sun conditions. Wooden boxes (1.2 x 1.2 x 0.15 m depth) were filled with sand (Table 79, Appendix). Sixteen holes (0.6 cm diam) were drilled on approximately 23 cm spacings in the bottom of each box to provide drainage. Starter fertilizer (13-25-12) was raked into the upper 2 cm of the sand surface to provide 76 kg N ha^{-1}, 64 kg P ha^{-1}, and 58 kg K ha^{-1}. Sixteen plots were sodded 29 August 1996 with Supina bluegrass 'Supranova' washed sod. Plots were irrigated as necessary to prevent moisture stress. Plots were mowed at 5 cm height at seven day intervals for the first 14 days, after which mowing height was gradually reduced to 3 cm height during the following 21 days. Thereafter, plots were mowed two to three times weekly to 3 cm height. Beginning 18 Sept. 1996 plots were fertilized with either a low N rate, 24 kg N ha^{-1} month^{-1}, or a high N rate, 96 kg N ha^{-1} month^{-1} applied in split applications biweekly at 48 kg N ha^{-1}. Potassium was applied biweekly at 48 kg K ha^{-1} to all plots.

On 18 Sept. 1996 trinexapac-ethyl (0.19 kg ha^{-1}) was applied to four plots each fertilized with low or high N rates. Plots were moved into the CSSF on 4 October 1996 and arranged in a randomized complete block (RCB) design with four replications. High pressure sodium lamps (400 W) were suspended 2.7 m above the turf surface and provided a steady but reduced light condition of approximately 100 ± 9 μmol m^{-2} s^{-1}. The lamps were on a 12 h photoperiod (ppd) which totalled approximately 5 mol PAR m^{-2} day^{-1}, including ambient light (Table 62). Iprodione (3-(3,5-dichlorophenyl)-N-(1-methethyl)-2,4-dioxo-1-imidazolidinecarboximide), 5.93 kg ha^{-1}, was applied with a

CO_2-powered backpack sprayer on 2 November 1996 to control Microdochium patch (*Microdochium nivale*). Carbon exchange rates were determined 15 and 16 Nov. 1996 (one and two days after mowing, respectively) using an open gas exchange system with a polycarbonate chamber (surface area = 27 cm^2; volume approximately 200 cm^3). The same location on each plot was assayed on both dates. Leaf areas from CER sampling areas were determined 16 Nov. 1996. Samples for chlorophyll analysis were collected 18 Nov. and analyzed 20 Nov. 1996. Carbon exchange rates were determined again on 26 Nov. (1 day after mowing) using a smaller polycarbonate chamber (surface area = 4.9 cm^2; volume approximately 24 cm^3) to determine the effects of a greater flow rate:surface area on the CER. Leaf areas were determined from the sample areas the same day. Samples for chlorophyll analysis were collected 25 Nov. and analyzed 27 Nov. Photosynthetic measurements were collected between 0900-1200 h on all dates.
Gas exchange and foliar data were analyzed as a 2 x 2 factorial with N rate (24 and 96 kg ha^{-1} $month^{-1}$) and TE (0.00 and 0.19 kg ha^{-1}) as main plots with four replications.

<u>Gas exchange measurements</u>

Carbon dioxide assimilation and related parameters were measured using an open system. The system was comprised of an ADC LCA2 infrared gas analyzer (IRGA), an air supply unit (ASU) capable of delivering up to 600 ml min^{-1} flow, a Parkinson leaf chamber (PLC) (Analytical Development Co. Ltd., Hoddesdon, England), and a polycarbonate assimilation chamber (PLC). Semi-flexible polyethylene tubing was used to connect the system components. Ambient air inside the CSSF was used as the air source and was drawn from a distance of at least 4 m away from the experimental site to minimize CO_2 fluctuations due to the investigator. Air was drawn from approximately 0.3 m above the asphalt floor from a corner of the facility subject to little air movement which minimized CO_2 fluctuation. Air drawn from a height of 4 m inside the facility, or from outside the facility, had serious CO_2 fluctuations due apparently to furnace-emitted (heated) air. The CO_2 fluctuations prevented accurate measurements even when the air was passed through containers up to 250 L in attempts to dampen the CO_2 fluctuations. Ambient air (approximately $CO_2 = 349 \pm 5$ $\mu L\ L^{-1}$ except on 26 Nov. when $CO_2 = 427 \pm 11$ $\mu L\ L^{-1}$) was passed into the ASU which pumped at a flow rate of 500 ml min^{-1}. The air was passed into a dome-shaped polycarbonate chamber (either 4.91 cm^2 opening, volume approximately 24 cm^3, or 27.3 cm^2 opening, volume approximately 200 cm^3) through in inlet port midway at or slightly below the turf surface. The chamber was secured over the turf surface using wire which was hooked over bolts at the chamber base and inserted into the turf. An exit port near the top of the chamber passed air into the IRGA for analysis of CO_2 concentration. Steady readings of CO_2 differential between the chamber and ambient air were achieved within one to two minutes. Immediately following gas exchange determination, a PLC was connected between the outlet port of the assimilation chamber and the IRGA for temperature and relative humidity measurements. The temperature and relative humidity of the ambient air were then measured. The photosynthetic photon flux density (PPFD) was determined during assimilation using a Li-Cor 190S quantum sensor (LiCor, Lincoln, NE). Photosynthetic parameters were calculated on both a turf surface area and leaf area basis using a BASIC computer program (Moon and Flore, 1986). No attempt was made to inhibit the effects of soil respiration on CER.

Leaf area analysis

Leaf area of the turf was determined using a Li-Cor 300 leaf area meter (Li-Cor, Lincoln, NE). Leaf blades were excised from shoots and placed flat on sheet of clear contact paper. The contact paper was taped inside a folded piece of transparency paper; the sheets were then passed through the leaf area meter. The average of three readings were collected for each sample and the "blank" area of the contact paper plus tape was subtracted.

Chlorophyll analysis

Sections (1 cm length) were collected from the middle of the youngest, fully expanded leaf blades of 10 plants per plot. Leaf widths were measured for leaf area determination. The mass of each 10 segment sample was determined to evaluate fresh leaf weight. Chlorophyll was extracted according to the methods of Moran and Porath (1980) using the extinction coefficients and formulae determined by Inskeep and Bloom (1985). Chlorophyll was extracted from each 10 leaf segment sample in 3 ml *N,N*-Dimethylformamide during incubation in the dark for 48 h at 4 °C. Absorbance values were measured using a UV-Vis spectrophotometer to determine chlorophyll *a*, chlorophyll *b*, and total chlorophyll concentrations.

RESULTS

Experiment I: Species x PGR study

Species significantly affected CER, E, and g_s on a turf surface basis while trinexapac-ethyl did not affect gas exchange parameters (Table 63). No interactions occurred between species and TE on any gas exchange parameters. Supina bluegrass CER on a turf surface area basis was over 50% greater than CER of Kentucky bluegrass and significantly different at $p=0.05$ (Table 64). Higher transpiration rate and stomatal conductance of Supina bluegrass corresponded with the greater CER compared to lower values observed from Kentucky bluegrass. Trinexapac-ethyl did not significantly enhance CER although CER was 36% greater in treated versus control plots. On a leaf area basis neither species or TE affected CER (Table 65). Values of gas exchange parameters were quite similar between the two species on a leaf area basis (Table 66).

Species and TE both significantly affected LAI, fresh leaf weight, and chlorophyll levels (Table 67). There were no significant interactions between species and TE. Supina bluegrass turf had a greater LAI and lower fresh leaf weight but less chlorophyll compared to Kentucky bluegrass (Table 68). Trinexapac-ethyl resulted in greater LAI and increased chlorophyll levels in both species. Chlorophyll a:b was not affected by any treatment.

Experiment II: Nitrogen x PGR study

Nitrogen and trinexapac-ethyl did not have a significant effect on CER or other gas exchange parameters of Supina bluegrass when evaluated on a turf area basis (Table 69). A higher than normal (approximately 350 $\mu L\ L^{-1}\ CO_2$) ambient CO_2 level and decreased

Table 63. Mean squares and treatment effects of species and trinexapac-ethyl on photosynthetic parameters† of turfgrass maintained in reduced light conditions (approximately 5 mol PAR day^{-1}), turf surface area basis, 23 November 1996.

Source	CER (μmol CO_2 m^{-2} s^{-1})	E (mmol m^{-2} s^{-1})	g_s (mmol m^{-2} s^{-1})	Ci (μmol CO_2 mol CO_2^{-1})	g_m (mmol m^{-2} s^{-1})	WUE, 1 x 10^{-3} (mol CO_2 mol H_2O^{-1})
Replication	0.313	0.124	226.552	1062.181	5.603	1.841
Species (S)	1.331*	0.522*	883.253*	1504.765	10.382	0.538
Trinexapac-ethyl (TE)	0.677	0.033	39.340	131.687	6.555	1.342
S x TE	0.246	0.043	74.846	571.594	1.255	0.050
Error	0.274	0.102	174.425	1026.379	4.879	1.098
CV, %	43.08	47.46	51.88	10.98	51.46	50.60

* Significant at the 0.05 probability level.

† CER, carbon exchange rate; E, transpiration; g_s, stomatal conductance; Ci, internal leaf CO_2 , g_m , mesophyll conductance; WUE, water use efficiency.

Table 64. Photosynthetic differences between Supina bluegrass and Kentucky bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), turf surface area basis, 23 November 1996.

Treatment	CER † (μmol m^{-2} s^{-1})	E (mmol m^{-2} s^{-1})	C_i (μmol mol^{-1})	g_s (mmol mol^{-1})	g_m (mmol mol^{-1})	WUE, 1 x 10^{-3} (mol CO_2 mol H_2O^{-1})
Species						
Supina bluegrass	1.47	0.84	300.33	32.10	5.01	1.91
Kentucky bluegrass	0.96*	0.51*	282.98	18.81*	3.57	2.24
Trinexapac-ethyl (kg ha^{-1})						
0.00	1.03	0.72	294.22	26.86	3.72	1.82
0.19 ‡	1.40	0.63	289.09	24.06	4.86	2.33

* Significant at the 0.05 probability level.

† CER, carbon exchange rate; E, transpiration; g_s, stomatal conductance; Ci, internal leaf CO_2, g_m, mesophyll conductance; WUE, water use efficiency.

‡ Applied 18 Sept. 1996.

Table 65. Mean squares and treatment effects of species and trinexapac-ethyl on photosynthetic parameters† of turfgrass maintained in reduced light conditions (approximately 5 mol PAR day^{-1}), leaf area basis, 23 November 1996.

	CER	E	g_s	Ci	g_m	WUE, 1 x 10^{-3}
Source	(µmol CO_2 m^{-2} s^{-1})	(mmol m^{-2} s^{-1})	(mmol m^{-2} s^{-1})	(µmol CO_2 mol CO_2^{-1})	(mmol m^{-2} s^{-1})	(mol CO_2 mol H_2O^{-1})
Replication	0.055*	0.012	19.793	1062.181	1.000	1.870
Species (S)	0.003	0.005	11.674	1504.765	0.000	0.522
Trinexapac-ethyl (TE)	0.001	0.030	41.876	131.687	0.001	1.316
S x TE	0.000	0.000	0.242	571.594	0.017	0.055
Error	0.014	0.015	23.974	1026.379	0.266	1.103
CV, %	35.11	63.08	67.69	10.98	43.47	50.65

* Significant at the 0.05 probability level.

† CER, carbon exchange rate; E, transpiration; g_s, stomatal conductance; Ci, internal leaf CO_2 , g_m , mesophyll conductance; WUE, water use efficiency.

Table 66. Photosynthetic differences between Supina bluegrass and Kentucky bluegrass in reduced light conditions (approximately 5mol PAR day^{-1}), leaf area basis, 23 November 1996.

Treatment	CER † ($\mu mol\ m^{-2}\ s^{-1}$)	E ($mmol\ m^{-2}\ s^{-1}$)	C_i ($\mu mol\ mol^{-1}$)	g_s ($mmol\ mol^{-1}$)	g_m ($mmol\ mol^{-1}$)	WUE, 1 x 10^{-3} ($mol\ CO_2\ mol\ H_2O^{-1}$)
Species						
Supina bluegrass	0.35	0.21	300.33	8.00	1.18	1.91
Kentucky bluegrass	0.32	0.18	282.98	6.50	1.19	2.24
Trinexapac-ethyl (kg ha^{-1})						
0.00	0.33	0.23	294.22	8.68	1.18	1.82
0.19‡	0.34	0.16	289.09	5.79	1.20	2.33

† CER, carbon exchange rate; E, transpiration; g_s, stomatal conductance; Ci, internal leaf CO_2 , g_m , mesophyll conductance; WUE, water use efficiency.
‡ Applied 18 Sept. 1996.

Table 67. Mean squares and significance of treatment effects on leaf area index (LAI), fresh leaf weight, and chlorophyll concentration of turfgrasses in reduced light conditions (approximately 5 mol PAR day^{-1}), 24 Nov. 1996.

		Fresh leaf wt.	chlorophyll (µg cm^{-2} leaf tissue)			
Source	LAI	(µg cm^{-2})	Chl *a*	Chl *b*	Chl total	Chl a:b
Replication	1.984	2.513**	23.547*	2.924*	41.765*	0.040
Species (S)	7.308**	2.537*	404.011**	42.166**	706.860**	0.009
Trinexapac-ethyl (TE)	5.629*	9.098**	196.753**	23.285**	354.987**	0.014
S x TE	0.981	0.035	6.555	3.329†	19.247	0.136
Error	0.696	0.347	5.120	0.710	7.985	0.06
CV, %	22.21	6.64	9.12	10.39	8.58	7.97

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 68. Effects of species and trinexapac-ethyl on foliage and chlorophyll of turfgrasses in reduced light conditions, approximately 5 mol PAR day^{-1}, 24 Nov. 1996.

			chlorophyll (μg cm^{-2} leaf tissue)			
Treatment	LAI	Fresh leaf wt. (μg cm^{2})	Chl *a*	Chl *b*	Chl total	Chl *a*:*b*
Species						
Supina bluegrass	4.36	8.52	20.32	6.66	29.98	3.10
Kentucky bluegrass	3.15**	9.23*	29.31**	9.56**	38.87**	3.06
Trinexapac-ethyl (kg ha^{-1})						
0.00	3.22	8.20	21.68	7.03	28.71	3.11
0.19 †	4.29*	9.55**	27.95**	9.19**	37.13**	3.06

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† Applied 18 Sept. 1996.

Table 69. Mean squares and treatment effects of photosynthetic characteristics† of Supina bluegrass affected by trinexapac-ethyl and nitrogen rate in reduced light conditions (approximately 5 mol PAR day^{-1}), turf surface area basis.

Source	CER ($\mu mol\ m^{-2}\ s^{-1}$)	E ($mmol\ m^{-2}\ s^{-1}$)	C_i ($\mu mol\ mol^{-1}$)	g_s ($mmol\ mol^{-1}$)	g_m ($mmol\ mol^{-1}$)	WUE, 1×10^{-3} ($mol\ CO_2\ mol^{-1}\ H_2O$)
			27.3 cm^2 assimilation chamber			
			15 Nov. 1996, 24 h after mowing			
Replication	0.662*	0.004	9171.106*	0.687	117.530	6.188
Nitrogen (N)	0.010	0.000	62.450	0.526	24.182	0.366
Trinexapac-ethyl (TE)	0.028	0.009	395.513	10.049	18.512	0.286
N x TE	0.089	0.032*	4293.853	37.454*	21.414	5.244
Error	0.162	0.004	1573.685	6.951	45.771	1.786
CV, %	43.23	32.55	19.45	37.31	109.51	28.95
			16 Nov. 1996, 48 h after mowing			
Replication	0.122	0.006	3298.292	7.419	27.152	4.588
Nitrogen (N)	0.476	0.004	13825.645	4.233	109.412	18.041
Trinexapac-ethyl (TE)	0.010	0.001	9.938	1.594	8.851	0.069
N x TE	0.245	0.058	7578.136	84.502	5.546	7.385
Error	0.153	0.012	4470.106	16.822	24.036	5.111
CV, %	35.29	45.45	36.62	49.01	63.84	42.67
			4.9 cm^2 assimilation chamber			
			26 Nov. 1996, 24 h after mowing			
Replication	0.727	0.169	232.507	1074.779	8.948	4.679
Nitrogen (N)	0.086	0.014	34.486	156.688	1.600	0.222
Trinexapac-ethyl (TE)	0.092	0.012	42.935	573.004	2.117	2.415
N x TE	0.086	0.042	81.406	14.119	0.766	0.065

Table 69 (cont'd.)

Error	0.500	0.084	218.729	574.758	3.077	1.228
CV, %	30.68	40.98	44.61	6.98	25.99	30.84

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† CER, carbon exchange rate; E, transpiration; g_s, stomatal conductance; Ci, internal leaf CO_2; $g_{m'}$, mesophyll conductance; WUE, water use efficiency.

assimilation area:flow rate ratio (smaller versus larger chamber) did not result in different treatment effects although the CER, E, and g_s rates were higher than on previous dates at a "typical" ambient CO_2 level (Table 70). Small and large chamber sizes (flow rate approximately 500 ml min^{-1}) resulted in similar values when compared between the species x PGR and nitrogen x PGR studies.

Carbon exchange rates on a turf area basis were lower at the high N rate compared to the low N rate although treatment effects were not significant at p=0.05 (Table 70). Carbon exchange rates 48 h after mowing were slightly greater compared to 24 h after mowing but there were still no significant differences among treatments. An interaction occurred on 15 Nov. 1996 between species and TE on E and g_s when gas exchange parameters were determined on a turf area basis. Twenty-four hours after mowing, E and g_s of turf maintained at high N and treated with TE were significantly greater than untreated, high N turf or low N turf regardless of treatment (Table 71). This interaction was not significant on a leaf area basis and was not observed when the experiment was repeated on 26 Nov. 1996.

On a leaf area basis nitrogen was the only treatment effect to produce any significant effects (Table 72). TE had no effect and there were no interactions. The high nitrogen rate increased CER, E, g_s, and g_m although the results were only significant for CER (p=0.10), E, and g_s on one date 24 h after mowing and were not significant 48 h after mowing (Table 73).

Both nitrogen rate and TE significantly affected LAI and chlorophyll content of Supina bluegrass (Table 74). There were no significant interactions on foliage or

Table 70. Effects of nitrogen and trinexapac-ethyl on photosynthetic parameters‡ of Supina bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), turf surface area basis.

Treatment	CER ($\mu mol\ m^{-2}\ s^{-1}$)	E ($mmol\ m^{-2}\ s^{-1}$)	C_i ($\mu mol\ mol^{-1}$)	g_s ($mmol\ mol^{-1}$)	g_m ($mmol\ mol^{-1}$)	WUE, 1×10^{-3} ($mol\ CO_2\ mol^{-1}\ H_2O$)
	27.3 cm^2 assimilation chamber §					
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)¶	15 Nov. 1996, 24 h after mowing, 346 ± 3 $\mu L\ L^{-1}$ ambient CO_2, 148 ± 18 $\mu mol\ m^{-2}\ s^{-1}$ PAR					
24	0.96	0.20	201.94	6.88	4.95	4.77
96	0.91	0.20	205.90	7.25	7.41	4.47
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	0.89	0.18	198.95	6.27	7.25	4.75
0.19 #	0.97	0.22	208.89	7.86	5.10	4.48
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)	16 Nov. 1996, 48 h after mowing, 347 ± 2 $\mu L\ L^{-1}$ ambient CO_2, 162 ± 19 $\mu mol\ m^{-2}s^{-1}$ PAR					
24	1.28	0.23	153.16	7.86	10.29	6.36
96	0.94	0.26	211.95	8.88	5.06	4.24†
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	1.08	0.23	183.34	8.05	6.94	5.23
0.19	1.13	0.25	181.76	8.68	8.42	5.36
	4.9 cm^2 assimilation chamber					
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)	26 Nov. 1996, 24 h after mowing, 427 ± 11 $\mu L\ L^{-1}$ ambient CO_2, 166 ± 13 $\mu mol\ m^{-2}\ s^{-1}$ PAR					
24	2.38	0.74	340.09	34.62	7.06	3.71
96	2.23	0.68	346.35	31.68	6.43	3.48
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	2.23	0.73	349.21	34.79	6.38	3.20
0.19	2.38	0.68	337.24	31.51	7.11	3.98

Table 70 (cont'd).

† Significant at the 0.10 probability level.
‡ CER, carbon exchange rate; E, transpiration; g_s, stomatal conductance; Ci, internal leaf CO_2; g_m,, mesophyll conductance; WUE, water use efficiency.
§ Flow rate was 0.5 L min^{-1} through both chambers on all dates.
¶ Nitrogen was supplied as urea. The low rate was applied at four week intervals, the high rate was split into two biweekly applications each month.
# Applied 18 Sept. 1996.

Table 71. Interaction of N rate and trinexapac-ethyl on transpiration (E) and stomatal conductance (g_s) of Supina bluegrass maintained in reduced light conditions of approximately 5 mol PAR day^{-1}.

	ambient CO_2 = 346 ± 3 $\mu L\ L^{-1}$			
	E		g_s	
	trinexapac-ethyl (kg ha^{-1}) †			
N rate (kg ha^{-1})	0.00	0.19	0.00	0.19
24	0.22	0.18	7.62	6.15
96	0.13	0.27	4.92	9.57
LSD (0.05)	0.10		4.2	

† Applied 18 Sept. 1996.

Table 72. Mean squares and treament effects of photosynthetic characteristics† of Supina bluegrass affected by trinexapac-ethyl and nitrogen rate in reduced light conditions (approximately 5 mol PAR day^{-1}), leaf area basis.

Source	CER ($\mu mol\ m^{-2}\ s^{-1}$)	E ($mmol\ m^{-2}\ s^{-1}$)	C_i ($\mu mol\ mol^{-1}$)	g_s ($mmol\ mol^{-1}$)	g_m ($mmol\ mol^{-1}$)	WUE, 1 x 10^{-3} ($mol\ CO_2\ mol^{-1}\ H_2O$)
27.3 cm^2 assimilation chamber						
15 Nov. 1996, 24 h after mowing, 346 ± 3 $\mu L\ L^{-1}$ ambient CO_2, 148 ± 18 $\mu mol\ m^{-2}\ s^{-1}$ PAR						
Replication	0.072*	0.000	9171.106*	0.546	15.871	6.188
Nitrogen (N)	0.053†	0.005**	62.450	6.337*	10.808	0.366
Trinexapac-ethyl (TE)	0.004	0.000	395.513	0.025	5.748	0.286
N x TE	0.00	0.001	4293.853	1.160	5.653	5.244
Error	0.015	0.000	1573.685	0.663	6.228	1.786
CV, %	37.16	27.21	19.45	30.92	110.58	28.95
16 Nov. 1996, 48 h after mowing, 347 ± 2 $\mu L\ L^{-1}$ ambient CO_2, 162 ± 19 $\mu mol\ m^{-2}\ s^{-1}$ PAR						
Replication	0.012	0.000	3298.292	1.766	1.116	4.588
Nitrogen (N)	0.010	0.012	13825.645	13.268	1.300	18.041
Trinexapac-ethyl (TE)	0.016	0.001	9.938	0.870	0.133	0.069
N x TE	0.002	0.002	7578.136	2.814	0.828	7.385
Error	0.007	0.004	4470.106	5.661	1.299	5.111
CV, %	21.68	68.17	36.62	72.20	46.07	42.67
4.9 cm^2 assimilation chamber						
26 Nov. 1996, 24 h after mowing, 427 ± 11 $\mu L\ L^{-1}$ ambient CO_2, 166 ± 13 $\mu mol\ m^{-2}\ s^{-1}$ PAR						
Replication	0.079	0.007	1074.779	10.435	0.872*	4.681
Nitrogen (N)	0.034	0.003	156.688	7.426	0.187	0.221
Trinexapac-ethyl (TE)	0.022	0.008	573.004	20.521	0.101	2.418
N x TE	0.017	0.004	14.119	8.702	0.114	0.065
Error	0.022	0.003	574.758	9.071	0.138	1.227

Table 72 (cont'd.)

CV, %	33.37	43.28	6.98	46.98	28.23	30.83

*, ** Significant at the 0.10, 0.05 and 0.01 probability levels, respectively.

† CER, carbon exchange rate; E, transpiration rate; g_s, stomatal conductance; Ci, internal leaf CO_2; g_m, mesophyll conductance; WUE, water use efficiency.

Table 73. Effects of nitrogen and trinexapac-ethyl on photosynthetic parameters‡ of Supina bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), leaf area basis.

Treatment	CER ($\mu mol\ m^{-2}\ s^{-1}$)	E ($mmol\ m^{-2}\ s^{-1}$)	C_i ($\mu mol\ mol^{-1}$)	g_s ($mmol\ mol^{-1}$)	g_m ($mmol\ mol^{-1}$)	WUE, 1×10^{-3} ($mol\ CO_2\ mol^{-1}\ H_2O$)
	$27.3\ cm^2$ assimilation chamber †					
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)	15 Nov. 1996, 24 h after mowing, 346 ± 3 $\mu L\ L^{-1}$ ambient CO_2, 148 ± 18 $\mu mol\ m^{-2}\ s^{-1}$ PAR					
24	0.28	0.06	201.945	2.00	1.44	4.77
96	0.39†	0.09**	205.896	3.26*	3.08	4.47
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	0.35	0.07	198.949	2.59	2.86	4.75
0.19 §	0.32	0.08	208.893	2.67	1.66	4.84
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)	16 Nov. 1996, 48 h after mowing, 347 ± 2 $\mu L\ L^{-1}$ ambient CO_2, 162 ± 19 $\mu mol\ m^{-2} s^{-1}$ PAR					
24	0.37	0.07	153.156	2.38	2.76	6.36
96	0.42	0.12	211.948	4.21	2.19	4.24†
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	0.42	0.10	183.340	3.53	2.56	5.23
0.19	0.36	0.09	181.764	3.06	2.38	5.36
	$4.9\ cm^2$ assimilation chamber					
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)	26 Nov. 1996, 24 h after mowing, 427 ± 11 $\mu L\ L^{-1}$ ambient CO_2, 166 ± 13 $\mu mol\ m^{-2}\ s^{-1}$ PAR					
24	0.40	0.12	340.09	5.73	1.21	3.71
96	0.50	0.15	346.35	7.09	1.43	3.48
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	0.49	0.16	349.21	7.54	1.40	3.20
0.19	0.41	0.11	337.24	5.28	1.24	3.98

Table 73 (cont'd.)

†, *, ** Significant at the 0.10, 0.05. and 0.01 probability levels, respectively.
‡ CER, carbon exchange rate; E, transpiration rate; g_s, stomatal conductance; Ci, internal leaf CO_2; g_m, mesophyll conductance; WUE, water use efficiency.

Table 74. Mean squares and significance of treatment effects on leaf area index (LAI), fresh leaf weight, and chlorophyll concentration of Supina bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), 17 Nov. 1996.

		Fresh leaf wt.	Chlorophyll (μg cm^{-2})			
Source	LAI	(μg cm^{-2})	Chl a	Chl b	Chl Total	Chl a:b
Replication	1.943	0.819	16.305*	1.843*	29.105*	0.004
Nitrogen (N)	5.736**	0.148	93.364**	6.799**	150.492**	0.017
Trinexapac-ethyl (TE)	2.190†	6.945*	47.163**	3.851**	77.925**	0.002
N x TE	0.040	0.805	2.273	0.473	4.785	0.013
Error	0.504	0.938	3.261	0.337	5.611	0.005
CV, %	26.33	9.94	6.61	7.08	6.67	2.06

*, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

chlorophyll content. The high nitrogen rate significantly reduced LAI although chlorophyll content was increased (Table 75). Trinexapac-ethyl significantly increased LAI, fresh leaf weight, and chlorophyll concentration. The ratio of chlorophyll *a:b* was not affected by any treatment.

Although it was not a planned component of the study, N rate was observed to affect Microdochium patch (*Microdochium nivale*) (Table 76). Microdochium patch severely damaged turf maintained at high N rates while turf at low N rates sustained significantly less damage (Table 77).

DISCUSSION

Carbon exchange rates (approximately 1 μmol CO_2 m^{-2} s^{-1}, turf area basis) were comparable to results obtained using an open system to determine CER of Kentucky bluegrass during sod establishment in similarly reduced light conditions of 150 μmol m^{-2} s^{-1} PAR (Karnok and Augustin, 1981). Karnok and Augustin (1981) reported increasing assimilation rates on a sward area basis with increasing days after mowing which corresponded to increased shoot height. Since fine turf is normally mowed frequently (e.g., one or two day intervals) the photosynthetic rate within one to two days following mowing was deemed important in the current study.

Morgan and Brown (1983) concluded the optimal LAI of bermudagrass for photosynthesis was approximately 4.7 at 1600-2000 μmol m^{-2} s^{-1} PAR while lesser LAIs resulted in significantly lower CER. The optimal LAI for cool-season turfgrasses in reduced light conditions is unknown but the higher LAI of Supina bluegrass was

Table 75. Effects of nitrogen rate and trinexapac-ethyl on leaf area index (LAI), fresh leaf weight, and chlorophyll concentration of Supina bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), 17 Nov. 1996.

Treatment	LAI	Fresh leaf wt: ($\mu g\ cm^{-2}$)	Chlorophyll ($\mu g\ cm^{-2}$) Chl a	Chl b	Chl total	Chl a:b
Nitrogen ($kg\ ha^{-1}\ month^{-1}$)						
24	3.3	9.64	24.92	7.55	32.46	3.30
96	2.1**	9.84	29.75**	8.86**	38.59**	3.36
Trinexapac-ethyl ($kg\ ha^{-1}$)						
0.00	2.3	9.1	25.61	7.71	33.32	3.32
0.19‡	3.1†	10.4*	29.05**	8.69**	37.73**	3.34

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
‡ Applied 18 Sept. 1996.

Table 76. Mean squares and treatment effects on Microdochium patch (*Microdochium nivale*) effects on Supina bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), 18 Nov. 1996.

	Turfgrass		
Source of variation	Color	Density	Quality
Replication	0.099	421.229	1.307
Nitrogen rate (N)	0.391	6123.063**	62.106**
Trinexapac-ethyl (TE)	8.266**	742.563	8.266
N x TE	0.391	60.063	2.641
Error	0.488	175.229	5.307
CV, %	9.35	18.690	45.23

** Significant at the 0.01 probability level.

Table 77. Effects of nitrogen rate and trinexapac-ethyl on Microdochium patch (*Microdochium nivale*) damage to Supina bluegrass in reduced light conditions (approximately 5 mol PAR day^{-1}), 18 Nov. 1996.

	Turfgrass		
Treatment	Color†	Density‡	Quality§
Nitrogen rate (kg ha^{-1} $month^{-1}$)¶			
24	7.3	90.4	7.1
48	7.6	51.2**	3.1**
Trinexapac-ethyl (kg ha^{-1})			
0.00	6.8	64.0	4.4
0.19 ††	8.2**	77.6	5.8

** Significant at the 0.01 probability level.

† Color was rated visually on a one to nine scale, one = chlorotic, yellow turf, nine= dark green turf color with 5 a minimum rating for acceptable color.

‡ Percent turf cover, visual estimate.

§ Quality was rated visually on a one to nine scale, one=100% necrotic turf, nine=dense, uniform, ideal turf with 5 a minimum rating for acceptable turf.

¶ Nitrogen was applied as urea

†† Applied 18 Sept. 1996.

apparently responsible for most or all of the difference in CER between the two species a sward area basis. There were no significant gas exchange differences between species on a leaf area basis. Supina bluegrass plants have a prostrate growth habit and stolons with short internodes and numerous tillers which apparently provided a greater leaf area for photon capture and gas exchange compared to Kentucky bluegrass which exhibits an increasingly more vertical growth habit as PPFD declines (Wilkinson and Beard, 1973).

The high N rate did not increase photosynthesis on a turf area basis because the amount of foliage was significantly decreased. High disease incidence associated with the high N rate may have caused a reduction in foliage although areas which appeared to be relatively unaffected by disease were chosen for CER measurements. The direct relationship between N rate and photosynthesis in non light-limiting situations appears to be largely dependent on the increased leaf biomass stimulated by higher N rates which affect carbon partitioning (Belanger et al., 1994; Gastal and Belanger, 1993; Nelson et al., 1993; Walker and Ward, 1973). In the current study, the high N rate may have stimulated excessive shoot growth early on after being placed in the reduced light conditions and depleted the carbohydrate pool necessary to sustain foliar growth and development. The high N rate may also have stimulated respiration which would have depleted the pool of nonstructural carbohydrates and resulted in reduced tillering.

On a leaf area basis, the high N rate had a tendency to increase photosynthesis although this was significant only on one of the three dates. This result concurs with Walker and Ward (1973) who reported photosynthetic rates of centipedegrass [*Eremochloa ophiuroides* (Munro.) Hack.] were directly dependent on N rate. The higher

N rate may have resulted in greater enzyme, particularly Rubisco, production (Ogata et al., 1983; Stitt and Schulze, 1994) and/or greater mesophyll conductance (g_m) (Bolton and Brown, 1980).

The lack of significant effect of TE on photosynthesis in RLC is not surprising. GA-inhibitors (paclobutrazol, flurprimidol) which act to inhibit *ent*-kaurene oxidation to *ent*-kaurenoic acid have been associated with both increases and decreases in photosynthetic rates in strawberries (Archbold and Houtz, 1988). Trinexapac-ethyl, however, inhibits the latter stages of GA biosynthesis, primarily by inhibiting hydroxylation at the 3ß position of $GA_{20}$to produce a biologically active GA_1 (Rademacher, 1991). Several other differences exist between trinexapac-ethyl and other GA-inhibitors commonly used on turf which may influence their effects on plant physiology: 1) trinexapac-ethyl is foliar-absorbed (Vitolo et al., 1990), while paclobutrazol and flurprimidol are drenched into the ground for root uptake (Watschke et al., 1992), and 2) trinexapac-ethyl may be less phytotoxic than paclobutrazol and flurprimidol (Watschke and DiPaola, 1995).

It is important to understand the mechanism(s) by which trinexapac-ethyl affects turfgrass growth and physiology in order to successfully use trinexapac-ethyl to maintain high quality turf in RLC. Green et al. (1990) reported flurprimidol significantly reduced the ET rate of St. Augustinegrass for 5 weeks after application. Although the ET components were not split into the respective components of evaporation and transpiration, it was implied the reduced leaf extension rate was responsible for lowering the ET. Such data are important as decreased transpiration in RLC will further inhibit photosynthate production, an undesirable effect.

TE did significantly enhance leaf area and chlorophyll concentrations of both species and of Supina bluegrass across nitrogen rates but did not signficantly affect CER, even on a sward area basis. The effects of TE on photosynthesis may have been complicated by reduced senescence and increased LAI since increased leaf age and greater canopy development have been reported to reduce individual leaf photosynthetic rate (Morgan and Brown 1983).

The improved turf quality associated with TE on turf in RLC may be related only to darker green leaf color and increased leaf area and/or tillering. Reduced leaf senescence rate and additional tillering could have been stimulated by TE side effects on other hormones or by TE altering carbohydrate levels and partitioning in the plants. GA-inhibitors have been shown to affect levels of other hormones such as abscisic acid in wheat (Buta and Spaulding, 1990) but their effects on hormones in turf is not known. Research on PGR effects on carbohydrate partitioning in turf is scarce. The key publication in the area, produced prior to the release of TE, indicates even GA-inhibitors with similar modes of action (paclobutrazol and flurprimidol) vary in their effect on assimilate partitioning (Hanson and Branham 1987). It is interesting to note that both paclobutrazol and flurprimidol did significantly decrease photoassimilate partitioning to roots four weeks after treatment (Hanson and Branham, 1987) although this may have been a transient response and not resulted in long-term effects. In the long term, reduced photoassimilate partitioning to roots could decrease turf quality and growth due to reduced root production. Studies on root growth of turf treated with flurprimidol or TE indicated these compounds had either no effect or had a beneficial effect on root growth

(Dernoeden, 1984; Elam, 1993; McCarty et al., 1990). Studies on the effects of GA-inhibitors on photosynthate partitioning and hormone levels in turfgrass in RLC are warranted.

Chlorophyll concentration did not affect photosynthetic rates ($r^2 = 0.07$). Differences in chlorophyll concentration were often statistically significant at $p=0.05$ when analyzed between species, between N rates, and between TE and untreated plots, but were not great enough to result in different photosynthetic rates. The quantity of photosynthetically active radiation, not chlorophyll, limited the CER. Species and TE did have a significant role in turf color (Ch. 2), however, and for practical reasons species and TE must be considered when managing turf in reduced light conditions. Chlorophyll *a:b* ratios were typical of "sun" plants, approximately 3 (Nobel, 1991), and were not affected by any treatments.

CONCLUSION

The relative shade tolerance of Supina bluegrass compared to Kentucky bluegrass appeared to be related to a greater LAI and not to superior gas exchange properties (e.g. CER, transpiration, stomatal resistance). The high N rate did not sufficiently enhance Supina bluegrass photosynthetic rates to offset problems associated with the lower LAI compared to the low N rate or the problem of the increased Microdochium patch incidence (*Microdochium nivale*). Trinexapac-ethyl did not seem to affect gas exchange parameters of photosynthesis. It is likely TE improved turf quality in RLC by mechanisms other than enhanced photosynthesis, possibly by altering photosynthate partitioning.

APPENDIX

Table 78. Particle size analysis of sand used in sand:peat mixture (80:20) .

Description						
Gravel	Very coarse	Coarse	Medium	Fine	Very fine	Silt & clay
diameter (mm)						
> 2	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	< 0.05
Percent (%)						
1.5	1.3	11.6	70.8	14.4	0.35	0.05
2.8		82.4		14.8		

Table 79. Particle size analysis of sand used in Experiment II: Nitrogen x PGR study (Chapter 3).

Description						
Gravel	Very coarse	Coarse	Medium	Fine	Very fine	Silt & clay
diameter (mm)						
> 2	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	< 0.05
Percent (%)						
0.9	6.7	32.0	40.0	16.2	1.6	0.5
7.6		72.0		18.3		

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