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Turfgrass Growth Response Under Restricted Light: Growth Chamber Studies

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The light requirement of a turfgrass is interrelated to many other environmental factors influencing plant growth. Investigating the minimum light threshold begins with isolating light as a variable keeping other factors consistent.

The fraction of light used by plants is the *Photosynthetically Active Radiation* (PAR). PAR is measured as *Photosynthetic Photon Flux Density* (PPFD) and is reported as *micromoles per square meter per second* (μmol $m^{-2}s^{-1}$) or *mol per square meter per day* (mol $m^{-2}d^{-1}$). The PPFD falling on a surface such as a leaf is the *irradiance*. As a point of reference, on a bright mid-summer southern California day, the peak PPFD at noon is about 1900 μmol $m^{-2}s^{-1}$ and the irradiance accumulated for the total daylight hours is about 50 mol $m^{-2}d^{-1}$.

It was the objective of the following three studies to examine the irradiance threshold requirements for a blend of 'Rugby' and 'Classic' Kentucky bluegrass (*Poa pratensis* L.), 'Manhattan II' perennial ryegrass (*Lolium perenne* L.), and 'De Anza' zoysiagrass (*Zoysia* spp.).

Methods

Kentucky bluegrass and perennial ryegrass are two of the most widely used cool-season turfgrasses. Zoysiagrass is a warm-season grass not widely planted in southern California, but is of interest due to its high traffic tolerance. The shade tolerance of the three grasses varies widely with Kentucky bluegrass and perennial ryegrass to have medium shade tolerance, and zoysiagrass good shade tolerance (Beard, 1973). Perennial ryegrass showed to have good shade tolerance in a previous study (Cockerham, et al., 1994). In a study where perennial ryegrass and zoysiagrass were compared for shade tolerance, the perennial ryegrass failed and the zoysiagrass tolerated severe irradiance restriction (Cockerham, et al., 1997). Gaining knowledge of the irradiance threshold of the three grasses was important to the research on the use of turfgrass in low light sports facilities. Kentucky bluegrass had not been previously studied, but was of interest because of its use as a standard for quality turfgrass. Perennial ryegrass had both succeeded and failed in separate studies. Zoysiagrass had shown to be tolerant of low irradiance and have potential as a sports turf.

The grasses were studied in a growth chamber accumulating PPFD over 24 h and simultaneously compared with the grasses in unrestricted irradiance in a glasshouse. Grass response was measured as clipping yields and biomass dry weights.

The temperature and irradiance levels were held constant. Kentucky bluegrass received 11.1, 2.2, and 0.9 mol $m^{-2}d^{-1}$ over 24 h in a constant 23°C (73°F) temperature regime. These irradiance levels are 22%, 4%, and 2% of summer full daylight. The clipping dry weights and verdure dry weight were taken every two weeks. Verdure is the biomass of a turfgrass plant remaining after removal of mowed clippings and underground structures including roots and rhizomes.

The Kentucky bluegrass was the first experiment, the data from which suggested that the second study, which used perennial ryegrass, should be higher levels of irradiance. In the growth chamber, perennial ryegrass received 20.0, 11.1, and 4.1 mol $m^{-2}d^{-1}$ in a constant 23°C (73°F), which are equivalent to 40%, 22%, and 8% of summer full daylight. Along

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with clipping dry weight yield, the perennial ryegrass total biomass dry weight was measured, which included the roots.

Zoysiagrass received the same irradiance treatments as the perennial ryegrass, 20.0, 11.1, and 4.1 mol $m^{-2}d^{-1}$, but in a constant 30°C (86°F) with clipping yields and biomass data taken.

The final study was intended to simulate the effect of, as an example, the opening and closing periods of a retractable roof stadium. In the stadium, a turfgrass could be in the dark for several days and then, with the roof open, be in full sun for limited period of time each day. During the dark periods, if the application of artificial light were possible, the question arises: How much would be needed to get through the period to allow turf recovery when the roof opened? Even with the roof open, the grass would be in the shade for much of the day. To simulate this, zoysiagrass received 20.0, 11.1, and 4.1 mol $m^{-2}d^{-1}$ irradiance treatments in the growth chamber. The plants were then removed from the growth chamber and taken to an outdoor plot area where the grass was in shade for all but 6 h per day of direct sunlight providing approximately 20 mol $m^{-2}d^{-1}$ for recovery from the effects of the low irradiance.

Results

Kentucky bluegrass clipping yields increased at 11.1 mol $m^{-2}d^{-1}$ irradiance over a period of 29 d, as seen in Table 1. The clippings were greater in the high treatment than in the glasshouse. In the 2.2 and 0.9 mol $m^{-2}d^{-1}$ irradiance treatments, leaf extension nearly stopped.

Kentucky bluegrass continued to produce verdure biomass at 11.1 mol $m^{-2}d^{-1}$ for 29 d (Table 2). There was a steady decline in verdure biomass in the two lower irradiance treatments which suggested that carbohydrate depletion was occurring.

The development of the verdure biomass and clipping rate yield suggests that the minimum irradiance requirement for Kentucky bluegrass is below 11.1 mol $m^{-2}d^{-1}$ (Table 2).

Table 1. Kentucky bluegrass (23°C) clipping yield ($g\text{-}m^{-2}d^{-1}$).

Treatment mol $m^{-2}d^{-1}$ PPFD	T_0	T_{14}	T_{29}	LSD
11.1	1.1	2.7	3.9	3.3
2.2	1.1	0.8	0.5	0.6
0.9	1.1	0.5	0.1	0.3
glasshouse	1.1	1.5	3.3	2.4
LSD	*1.1*	*1.1*	*0.5*	

T_n = days after start

Table 2. Kentucky bluegrass (23°C) verdure ($g\ m^{-2}$).

Treatment mol $m^{-2}d^{-1}$ PPFD	T_0	T_{14}	T_{29}
11.1	133.2	184.2	124.2
2.2	133.2	105.6	88.6
0.9	133.2	116.2	54.1
glasshouse	133.2	165.1	166.7
LSD	*27.2*	*38.9*	*29.4*

T_n = days after start

Table 3. Perennial ryegrass clipping yield (25°C) g $m^{-2}d^{-1}$ dry weight.

Treatment mol $m^{-2}d^{-1}$ PPFD	T_0	T_7	T_{14}	T_{21}	T_{28}	T_{36}	T_{42}	LSD
20.0	5.0	5.7	6.2	2.7	1.6	0.5	0.5	2.27
11.1	5.0	8.2	7.7	2.8	1.1	0.1	0.1	1.05
4.1	5.0	2.9	2.0	1.7	0.8	0.7	0.5	0.43
Glasshouse	5.0	5.6	5.7	4.6	5.0	6.0	5.9	1.20
LSD		*1.28*	*2.82*	*1.74*	*0.82*	*0.37*	*0.61*	

T_n = days after start

Table 4. Perennial ryegrass total biomass (25°C) g m^{-2} dry weight.

Treatment mol $m^{-2}d^{-1}$ PPFD	T_0	T_{14}	T_{28}	T_{42}	LSD
20.0	730	717	858	795	237
11.1	730	613	516	463	140
4.1	730	554	442	453	82
Glasshouse	730	682	656	685	232
LSD		*111*	*185*	*199*	

T_n = days after start

Perennial ryegrass clipping yields at 11.1 and 20.0 mol $m^{-2}d^{-1}$ increased for 14 d and then quickly declined (Table 3). The 4.1 mol $m^{-2}d^{-1}$ irradiance treatment was insufficient for growth to occur as measured by clipping yields.

Total biomass of perennial ryegrass at 20.0 mol $m^{-2}d^{-1}$ was consistent over the 42 d of the study (Table 4). The total biomass of perennial ryegrass decreased significantly over time at irradiance levels of 11.1 and 4.1 mol $m^{-2}d^{-1}$.

Zoysiagrass clipping yields at 20.0 mol $m^{-2}d^{-1}$ at 30°C were fairly uniform during the 42 day period, although growth was slower in the growth chamber compared to that in the glasshouse as shown in Table 5. At 11.1 mol $m^{-2}d^{-1}$ clipping yields were consistent, though at a rate that was slower than that of the high irradiance treatment. At 4.1 mol $m^{-2}d^{-1}$ zoysiagrass leaf extension declined to a very low level.

Table 5. Zoysiagrass (30°C) clipping yields (g $m^{-2}d^{-1}$) dry weight.

Treatment mol $m^{-2}d^{-1}$ PPFD	T_0	T_7	T_{14}	T_{21}	T_{28}	T_{35}	T_{42}	LSD
20.0	8.0	9.4	9.8	8.5	8.6	8.2	7.1	1.97
11.1	8.0	6.4	5.8	4.9	4.7	6.4	5.2	1.44
4.1	8.0	3.1	2.0	1.7	1.8	1.1	0.8	0.73
Glasshouse	8.0	---	9.8	8.8	12.9	10.4	11.0	1.95
LSD		*1.55*	*1.54*	*2.17*	*1.21*	*1.55*	*1.43*	

T_n = days after start

Table 6. Zoysiagrass (30°C) total biomass (g m^{-2}) dry weight.

Treatment mol $m^{-2}d^{-1}$ PPFD	T_0	T_{14}	T_{28}	T_{42}	LSD
20.0	1009	994	1043	931	267
11.1	1009	1077	1017	977	184
4.1	1009	826	859	778	157
Glasshouse	1009	1025	1066	1170	174
LSD		*180*	*196*	*217*	

T_n = days after start

Zoysiagrass produced comparable amounts of total biomass in the glasshouse and in the growth chamber at 20.0 and 11.1 mol $m^{-2}d^{-1}$ for 42 d as shown in Table 6. At 4.1 mol $m^{-2}d^{-1}$ less total biomass was produced in comparison to the higher light treatments.

In the roof opening simulation study, the zoysiagrass from all treatments was slow to respond to the change in environment. Clipping yields decreased for several days following location change, before starting recovery. All showed good recovery after 21 d as shown in Table 7.

Conclusions

The clipping yield and production of verdure biomass indicate that the irradiance threshold for Kentucky bluegrass was below 11.1 mol $m^{-2}d^{-1}$. The consistent yield in perennial ryegrass total biomass suggested that irradiance of 20.0 mol $m^{-2}d^{-1}$ would provide for basic plant maintenance requirements, however, the large clipping yield decreases at lower irradiance levels indicated insufficient irradiance to sustain growth. It was concluded, therefore, that the perennial ryegrass threshold was above 20.0 mol $m^{-2}d^{-1}$.

Zoysiagrass growth at irradiance levels of 20.0 and 11.1 mol $m^{-2}d^{-1}$ produced consistent clipping yields and total biomass, with the rate of growth slower at the lower treatment level. At 4.1 mol $m^{-2}d^{-1}$ clipping production stopped but total biomass was retained, suggesting that the threshold was below 11.1 mol $m^{-2}d^{-1}$, but above 4.1 mol $m^{-2}d^{-1}$.

The zoysiagrass response to restricted irradiance followed by moving to limited full sun was slow, but recovery did occur.

Irradiance as µmol $m^{-2}s^{-1}$ is often used in calculations for lighting to provide the accumulated PPFD as mol $m^{-2}d^{-1}$. Kentucky bluegrass at 23°C (73°F), and zoysiagrass at 30°C (86°F), continued growth at 11.1 mol $m^{-2}d^{-1}$ which required 128 µmol $m^{-2}s^{-1}$ over the 24-h period in the growth chamber. The 11.1 mol $m^{-2}d^{-1}$ irradiance accumulation can be provided at 515 µmol $m^{-2}s^{-1}$ for 6 h per day or 770 µmol $m^{-2}s^{-1}$ for 4 h per day. Zoysiagrass needed over 185 µmol $m^{-2}s^{-1}$ but less than 515 µmol $m^{-2}s^{-1}$ for 6 h per day or over 277 µmol $m^{-2}s^{-1}$ but less than 770 µmol $m^{-2}s^{-1}$ for 4 h per day.

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Table 7. Clipping yields (g-$m^{-2}d^{-1}$) of Zoysiagrass (30°C) with recovery at 6 h d^{-1} sun.

Treatment	Days recovery (outdoor facility)								
mol $m^{-2}d^{-1}$ PPFD	T_0	T_7	T_{14}	T_{21}	T_{28}	T_{35}	T_{42}	T_{49}	LSD
14 d gr.chamb.									
20.0	10.5	2.7	-	8.2	6.4	8.4	7.2	11.6	5.45
11.1	5.7	2.2	-	7.0	7.7	8.4	7.5	12.3	3.27
4.1	1.4	1.2	-	5.0	5.5	8.6	8.1	8.5	1.63
28 d gr.chamb.									
20.0	-	4.3	6.3	8.0	6.6	7.7	-	-	1.87
11.1	-	2.7	4.0	5.6	7.4	6.7	-	-	1.98
4.1	-	1.7	3.3	5.0	5.9	6.6	-	-	1.83
LSD	*9.00*	*1.15*	*2.77*	*4.29*	*1.55*	*3.76*	*3.50*	*4.32*	

T_n = days after placing in outdoor restricted irradiance facility

Turfgrass Growth Response Under Restricted Light: Artificial Irradiance Studies

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Practical use of artificial irradiance for turf growth in a sports facility has been considered a key to some sports field development. It was the objective of this work to evaluate the response of artificial irradiance on turfgrass growth.

Methods

Two approaches to illuminating turf were investigated. First, very intense light sources were moved across the grass providing brief but high-irradiance pulses of light and, second, similar light sources were placed in fixed positions on the field with the output uniformly distributed across the turf.

Artificial Light Source Study. The testing of the response of the grass to the mobile irradiance source was conducted by moving the grass back and forth on an automated trolley beneath fixed sources of light. 'Manhattan II' perennial ryegrass (*Lolium perenne* L.) and 'De Anza' zoysiagrass (*Zoysia* spp.) were evaluated. Turf used in these experiments was established from washed sod plugs in pots filled with medium sand (Davis and Paul, 1985). Each treatment in the experiments consisted of 20 pots held in a rack approximately 12 in x 12 in. A preplant fertilizer (15-15-15) was applied beneath the plugs at a rate of 1.0 lb N 1000 ft^{-2}. Irrigation of the pots was adequate to provide non-limiting water.

Three xenon arc spotlights (Xenontech, Inc., North Hollywood, CA) were arranged to provide illuminated spots on a bench in a darkened building. PPFD in the spots was 800 to 1000 $\mu mol\ s^{-1}m^{-2}$. The trolley moved pots of grass in and out of the spots for 12 h d^{-1}. Although the building was ventilated, temperature and humidity were not controlled.

Pots spent 14 to 19 seconds in each illuminated spot per pass (the longer period being while the trolley reversed direction). The first group of 20 pots moved sequentially through all three illuminated spots resulting in approximately four times the exposure of the last pots entering, which were positioned on the trolley to reach only the first illuminated position. The cumulative irradiances reported are the sums of the exposure pulses. Cumulative daily irradiances for the three positions on the trolley were 10.3, 6.0, and 2.5 mol $m^{-2}d^{-1}$.

Ten 'Manhattan II' perennial ryegrass pots were harvested on the day treatments began (T_0). Half of the pots on the trolley were randomly selected and harvested for total biomass at 14 d (T_{14}) after beginning treatments. The final 10 pots on the trolley were harvested after 28 d. At each harvest an equal number of pots were harvested from those kept in the glasshouse. Biomass was harvested by removing the plants from the pots and washing sand from the roots over a fine mesh screen, oven drying, and weighing.

'De Anza' zoysiagrass (Gibeault and Cockerham, 1997; Youngner, 1980) pots were randomly selected from the 20 per irradiance treatment for harvests at 7, 14, and 21 (T_7, $T_{14,}$ and T_{21}, respectively) days after treatment began. Six pots were harvested for biomass at each harvest.

Spectral Quality Study. The importance of spectral quality of potential light sources was tested with three different lamp types. A xenon arc lamp provided a pure white light, but with considerable output in the near infrared (heat). High pressure sodium (GE Lucalox™) vapor lamps provided a very unbalanced spectrum with most of their radiance in several peaks between 560-620 nm. A sulfur/microwave lamp (Fusion Lighting, Rockville, MD) provided a smooth, broad spectrum output slightly skewed to the blue end, but with none of the infrared peaks of the xenon lamp.

The lamps provided irradiance of 970 $\mu mol\ m^{-2}s^{-1}$ at the turf surface onto pots fixed in position. Irradiance from each lamp was 14 mol $m^{-2}d^{-1}$ over a 4 h period. Pots were rotated daily to minimize any variation in irradiance among positions under the lamps.

Results

Artificial Light Source Study. After 14 d of 10.3 mol $m^{-2}d^{-1}$ from the xenon lamps, perennial ryegrass total biomass had not decreased and there were no significant difference between the 10.3 mol $m^{-2}d^{-1}$ and non-limited irradiance (glasshouse) treatments as shown in Table 1. Total biomass at 6.0 mol $m^{-2}d^{-1}$ level was lower than that grown in the glasshouse. After 28 d perennial ryegrass biomass was significantly less at all levels of irradiance under artificial

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Table 1. Perennial ryegrass total biomass ($g\ m^{-2}$) under xenon arc lamps.

Irradiance ($mol\ m^{-2}\ d^{-1}$)	T_0	T_{14}	T_{28}	LSD
10.3	676	673	510	118
6.0	676	539	427	75
2.5	676	465-	319	92
Glasshouse	676	790	996	231
LSD		*190*	*140*	

Table 3. Effect of irradiance source on De Anza zoysiagrass total biomass ($g\ m^{-2}$) at 14 $mol\ m^{-2}\ d^{-1}$.

Source	T_0	T_7	T_{14}	T_{21}	T_{28}
High Pressure Sodium	111.8	92.0	103.4	100.8	87.1
Xenon	111.8	96.2	92.1	86.0	83.3
Sulfur microwave	111.8	94.8	98.6	88.3	89.0
LSD		*22.5*	*27.2*	*13.0*	*26.9*

light relative to the glasshouse treatment. Perennial ryegrass maintained its original biomass under 10.3 $mol\ m^{-2}d^{-1}$ after 14 d and increased biomass in the full sun treatment in the glasshouse.

'De Anza' zoysiagrass increased biomass after 7 d at 10.3 $mol\ m^{-2}d^{-1}$, then decreased biomass over the next 7 d to be stable with the 6.0 and 2.5 $mol\ m^{-2}d^{-1}$ treatments as seen in Table 2. Zoysiagrass performed well under reduced irradiance levels, maintaining 88% of its original biomass after 21 d at 10.3 $mol\ m^{-2}d^{-1}$. At 6.0 $mol\ m^{-2}d^{-1}$ biomass was reduced less than 25% after 21 d. At each of these irradiances, there was a non-significant trend of increasing biomass from T_{14} to T_{21}. This trend suggests that the grass may have begun to acclimate to the reduced irradiance conditions. At the minimum, no further decrease in biomass occurred after 14 d with 'De Anza' zoysiagrass.

Table 2. De Anza zoysiagrass total biomass ($g\ m^{-2}$) under xenon arc lamps.

Irradiance ($mol\ m^{-2}\ d^{-1}$)	T_0	T_7	T_{14}	T_{21}	LSD
10.3	925	1427	732	819	198
6.0	925	778	663	717	176
2.5	925	758	754	--	197
LSD		*192*	*190*	*152*	

Spectral Quality Study. There were no significant differences in biomass when grown under the different sources of artificial irradiance for the duration of the study as given in Table 3. The source of the irradiance and its spectral distribution did not appear to be as important as the amount of irradiance. In regard to plant growth, any of the sources evaluated would be satisfactory to use, based on the results of this study. Also, no discoloration or other deleterious effect of any of the irradiance sources was noted throughout the study.

The spectral quality study results showed that any of the artificial irradiance lamps tested would be acceptable in terms of grass performance; the relatively inexpensive and efficient Na-vapor lamps would serve as well as the much more expensive lamps with balanced spectra.

Conclusions

'Manhattan' perennial ryegrass and 'De Anza' zoysiagrass produced biomass under artificial light at 10.3 $mol\ m^{-2}d^{-1}$. The zoysiagrass lost biomass, but stabilized under irradiance as low as 6.0 $mol\ m^{-2}d^{-1}$. Under the conditions of the studies, the irradiance source did not make a difference for the zoysiagrass performance.

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Turfgrass Growth Response Under Restricted Light: Nitrogen and Height of Cut Effect on Turfgrass Injury

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The game of baseball played on natural turf surfaces inevitably results in damage to the grass. Generally with the batted ball, only the leaves are sheared and the stems are left intact. Ball mark injury is different from divoting, yet it is an important source of baseball infield damage. Injury recovery is a matter of topgrowth recuperation rather than filling in a hole.

Turf observations from restricted irradiance research indicated that the turf density was reduced and the stems were softer in the turf grown under limited irradiance compared to that in non-limiting irradiance. This is consistent with observations of other grasses (McBee and Holt, 1966). It was thought that batted baseball injury would be more severe in restricted irradiance and could be exacerbated by certain cultural practices so it was the objective of this work to evaluate the effect of nitrogen and height of cut on injury and recovery of zoysiagrass turf.

Methods

The work was in part conducted in a specially constructed field facility at UC Riverside. The irradiance restriction facility was a sand rootzone media (Davis and Paul, 1985) turfgrass plot, 16 in (40 cm.) deep with perforated drain lines (Table 1). The plot was bordered on 4 sides with canvas walls. A superstructure of opaque, vertically-oriented louvers ran North-South above the plot. The louvers were 2 ft (0.6 m) tall, positioned with their lower edge 6 ft (1.8 m) above the turf. The louvers allowed sunlight to the turf in a seasonal time-pattern of shade and full sun at 4.5 h d^{-1} in early spring to 6.5 h d^{-1} in mid-summer. The plot received 6.5 h d^{-1} during the June-July period of the study in 1997.

'De Anza' zoysiagrass turf (Gibeault and Cockerham, 1997) was established in May 1997 from sod in the irradiance restriction facility. At the same time, an unshaded plot of 'De Anza' zoysiagrass was established to allow comparison of turf performance under full sunlight conditions. Louvers were placed in the irradiance restriction facility in early June 1997.

Table 1. Sand particle size specifications for sports field research facility.*

Description	Particle size	Sieve	% by wt.	
Gravel/fine gravel	>2.0 mm	10	0	
Very coarse sand	1-2 mm	18	<5.0 (max.)	
Coarse sand	0.5-1.0 mm	35	<40.0 (max.)	0.05-1.0 >90%
Medium sand	0.25-0.5 mm	60	>40.0 (max.)	
Fine sand	0.05-0.25 mm	270	<20.0 (max.)	
Very fine material	<0.05 mm		<2.0 (max.)	

*Davis and Paul, 1985

Mowing height of cut (HOC) treatments were 0.5, 0.75, and 1.0 in (0.3, 1.9 and 2.5 cm). Nitrogen was applied biweekly as 15-15-15 at 1.0, 2.0, 3.0 lbs 1000 ft^{-2} mo^{-1} (53, 106 and 159 kg N ha^{-1} mo^{-1}), beginning in early May. Treatments were replicated four times in a randomized complete block design. All treatments received simulated sports traffic with a Brinkman Traffic Simulator (Cockerham and Brinkman, 1989) throughout the study. Turf quality ratings were made throughout the study.

Scuffing from a baseball was produced with a Juggs™ baseball pitching machine with the speed set at the maximum (90 mph). The balls were released from the machine 5 ft above the ground and 16 ft from the impact area. The balls were thrown at a downward angle of 12 - 14°. At this velocity and angle, the most susceptible turf was subject to significant injury including divoting in which verdure was completely torn loose (stems cut at the crown of the plant).

Table 2. Effect of nitrogen (N) and height of cut (HOC) on viual quality of De Anza zoysiagrass under limited irradiance. Turf Scores 1=poor turf; 9=excellent turf.

N (lb/M/mo)	HOC (in)	Jun 16	Jun 30	July 14	Aug 10	mean
3.0	1.0	6.2	5.8	6.0	6.0	6.0
	0.75	5.8	6.0	5.7	5.8	5.8
	0.5	4.7	4.3	4.3	4.5	4.5
2.0	1.0	6.2	5.8	6.0	6.0	6.0
	0.75	5.8	5.7	5.7	5.8	5.8
	0.5	5.2	4.7	4.7	5.2	4.9
1.0	1.0	6.2	5.8	5.8	5.8	5.9
	0.75	6.0	5.5	5.5	5.5	5.6
	0.5	4.7	4.2	4.5	4.7	4.5
LSD		*0.5*	*0.4*	*0.5*	*0.6*	*0.4*
N effect						
3.0 lb/M		5.6	5.4	5.3	5.4	5.4
2.0		5.7	5.4	5.4	5.7	5.6
1.0		5.6	5.2	5.3	5.3	5.3
LSD		*0.6*	*0.5*	*0.6*	*0.7*	*0.5*
HOC effect						
1.0 in		6.2	5.8	5.9	5.9	6.0
0.75		5.9	5.7	5.6	5.7	5.7
0.5		4.8	4.4	4.5	4.8	4.6
LSD		*0.3*	*0.3*	*0.4*	*0.5*	*0.3*

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Scuffing injury was applied June 5 and July 1, 1997. Scuffing damage was visually rated on a 1 to 5 scale at three dates after treatment for injury and rate of recovery. Recovery rate was defined as the improvement in rating from 7 to 14 d following injury (T_7 to T_{14}).

Data of the field studies were analyzed by Analysis of Variance Procedure (ANOVA) of SAS statistical software (SAS Institute Inc., 1988) and means were separated according to Fisher's protected LSD. Differences were considered significant at P=0.05.

Table 3. Effect of nitrogen (N) and height of cut (HOC) on baseball scuffing injury to De Anza zoysiagrass under limited irradiance. Scuffing applied June 5 and July 1. Injury ratings 1 (no injury) to 5 (bare soil).

N (lb/M/mo)	HOC (in)	Jun 8 (T_3)	Jun 15 (T_{10})	Jun 23	1-week Recovery (T_3 – T_{10})	Jul 2 (T_1)	Jul 8 (T_8)	Jul 15	1-week Recovery (T_1-T_8)
3.0	1.0	3.1	1.9	1.0	1.3	4.1	3.2	1.7	0.9
	0.75	3.7	2.8	1.5	0.8	4.3	3.8	2.6	0.5
	0.5	2.9	3.0	1.0	-0.1	5.0	4.8		0.3
2.0	1.0	3.1	1.9	1.0	1.2	3.8	2.9	1.5	0.9
	0.75	2.3	2.5	1.2	0.6	4.2	3.3	2.0	0.8
	0.5	3.0	3.1	1.0	-0.1	4.8	4.3	3.0	0.5
1.0	1.0	2.4	1.8	1.0	0.6	4.1	3.7	2.2	0.4
	0.75	3.2	2.5	1.2	0.7	4.3	3.6	2.1	0.7
	0.5	3.0	2.7	1.0	0.3	4.8	4.8		-0.1
LSD		*0.9*	*1.0*	*0.4*	*0.5*	*0.4*	*0.7*	*0.7*	*0.6*
N effect									
3.0 lb/M		3.3	2.0	1.3	0.6	4.5	4.0	2.2	0.5
2.0		2.8	2.6	1.1	0.7	4.3	3.5	1.9	0.8
1.0		2.8	2.6	1.1	0.5	4.4	4.0	2.2	0.3
LSD		*0.9*	*0.8*	*.04*	*0.3*	*0.3*	*0.3*	*0.4*	*0.3*
HOC effect									
1.0 in		2.8	2.4	1.0	1.0	4.0	3.3	1.8	0.7
0.75		3.1	2.3	1.3	0.7	4.3	3.6	2.2	0.7
0.5		3.0	2.4	1.0	0.1	4.9	4.6	3.0	0.2
LSD		*0.5*	*0.3*	*0.4*	*0.3*	*0.3*	*0.5*	*0.9*	*0.5*

Results

The optimum height of cut for 'De Anza' zoysiagrass grown in full sun, non-limiting irradiance is 0.3 - 0.75 in. (Cockerham, et al., 1997). Under conditions of limited irradiance, turfgrass quality declined significantly at the HOC of 0.5 in. for all N treatments. The 'De Anza' zoysiagrass with 6.5 h d^{-1} of full sun and simulated sports traffic did not respond to N greater than 1 lb per month as can be seen in Table 2.

In the limited irradiance facility there was no scuffing injury response of the turf to N alone, as the damage from the baseball was the same in all of the treatments. Turf recovery was significantly greater when mowed at 1.0 in. and 0.75 in. than at 0.5 in. Injury was greater in July than June. The recovery rate was the same for each month, which left the turf injury greater a week after the second scuffing treatment than it was a week after the first treatment as shown in Table 3.

In the non-limiting irradiance study, N treatments had a greater effect on injury susceptibility of the zoysiagrass turf than HOC. Nitrogen at 3.0 lbs per 1000 ft^2 per month had lower injury than 2.0 or 1.0 lb after 7 and 14 d as shown in Table 4, but turf recovery from injury was not affected by the HOC. The 0.75 in. HOC and 3.0 lb N 1000 ft^{-2} mo^{-1} treatment gave significantly lower scuffing injury than most of the other treatments.

Table 4. Affect of nitrogen (N) and height of cut (HOC) on baseball scuffing injury to De Anza zoysiagrass under non-limited irradiance. Scuffing applied June 1. Injury ratings 1 (no injury) to 5 (bare soil).

N (lb/M/mo)	HOC (in)	T_7	T_{14}	Recovery (T_7 – T_{14})
3.0	1.0	2.9	2.3	0.7
	0.75	2.4	1.8	0.6
	0.5	2.8	2.0	0.8
2.0	1.0	2.8	2.4	0.4
	0.75	3.3	2.8	0.5
	0.5	3.2	2.8	0.4
1.0	1.0	3.3	2.7	0.7
	0.75	2.8	2.4	0.4
	0.5	3.3	2.5	0.8
LSD		*0.6*	*0.6*	*0.5*
N effect				
3.0 lb/M		2.7	2.0	0.7
2.0		3.1	2.6	0.4
1.0		3.2	2.5	0.6
LSD		*0.4*	*0.3*	*0.4*
HOC effect				
1.0		3.0	2.4	0.6
0.75		2.8	2.3	0.5
0.5		3.1	2.4	0.6
LSD		*0.4*	*0.4*	*0.3*

Conclusion

The 'De Anza' zoysiagrass under conditions of limited irradiance was better able to withstand scuffing injury and recover from the injury at the higher mowing heights and higher N application rates. A mowing height of 0.5 in. was too low for turf performance under the condition of limited irradiance. In non-limiting irradiance mowing the turfgrass at 0.75 in. with 3.0 lb N ft^{-2} mo^{-1} provided the greater tolerance to scuffing injury than most of the other treatment combinations.

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WARNING ON THE USE OF CHEMICALS

Pesticides are poisonous. Always read and carefully follow all precautions and safety recommendations given on the container label. Store all chemicals in their original labeled containers in a locked cabinet or shed, away from food or feeds and out of the reach of children, unauthorized persons, pets, and livestock.

Recommendations are based on the best information currently available, and treatments based on them should not leave residues exceeding the tolerance established for any particular chemical. Confine chemicals to the area being treated. THE GROWER IS LEGALLY RESPONSIBLE for residues on his crops as well as for problems caused by drift from his property to other properties or crops.

Consult your County Agricultural Commissioner for correct methods of disposing of leftover spray material and empty containers. **Never burn pesticide containers.**

PHYTOTOXICITY: Certain Chemicals may cause plant injury if used at the wrong stage of plant development or when temperatures are too high. Injury may also result from excessive amounts of the wrong formulation or from mixing incompatible materials. Inert ingredients, such as wetters, spreaders, emulsifiers, diluents and solvents, can cause plant injury. Since formulations are often changed by manufacturers, it is possible that plant injury may occur, even though no injury was noted in previous seasons.

NOTE: Progress reports give experimental data that should not be considered as recommendations for use. Until the products and the uses given appear on a registered pesticide label or other legal, supplementary direction for use, it is illegal to use the chemicals as described.

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