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Research conducted on 'Champion' bermudagrass at the Clemson University Turfgrass Research Center determined (1) optimum nitrogen rates for 'Champion' growing under shade and full sunlight and (2) the effects of trinexapac-ethyl, various nitrogen rates, and iron on 'Champion' bermudagrass performance and thatch accumulation under shade over a two-year period. Among other results, researchers found that a 'Champion' bermudagrass putting green growing under shade requires about 40% less nitrogen than a green growing under full sunlight.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 400 projects at a cost of $30 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Nitrogen Management for 'Champion' Bermudagrass under Full Sun and Shade

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SUMMARY

Research conducted on 'Champion' bermudagrass (*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy) at the Clemson University Turfgrass Research Center determined (1) optimum nitrogen rates for 'Champion' growing under shade and full sunlight and (2) the effects of trinexapac-ethyl, various nitrogen rates, and iron on 'Champion' bermudagrass performance and thatch accumulation under shade over a two-year period. Their findings include:

- A 'Champion' bermudagrass putting green growing under shade requires about 40% less nitrogen than a green growing under full sunlight.
- Thatch accumulation under shade was 40% lower than under full sunlight. This suggests that bermudagrass greens under shade stress require less aggressive cultivation programs.
- Routine iron applications throughout the growing season had little effect on 'Champion' bermudagrass under shade or full sunlight.
- Applying trinexapac-ethyl every two weeks at 0.02 kg ha^{-1} improved turfgrass quality under shade of 'Champion'.
- This study implies that fertility programs should be adjusted if an ultradwarf bermudagrass putting green is under shade stress.

Nitrogen (N) is the most dynamic and important nutrient for turfgrasses. Turfgrass shoot tissue normally contains about 3 to 6% N of total dry weight. When nitrogen becomes deficient, a reduction in density, color, wear tolerance, shoot growth, and overall stress tolerance can occur. Depending on soil type, ultradwarf hybrid bermudagrass putting greens usually require approximately 250 to 450 kg N ha^{-1} to maintain an acceptable putting green standard (13).

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Previous research reports have noted morphological and physiological disadvantages of increasing nitrogen under full sunlight and shaded environments. Bunnell et al. (4) noted applying an additional 24 kg N ha^{-1} under shade reduced 'TifEagle' bermudagrass carbohydrate reservesby approximately 40%. Under full sunlight, Stanford et al. (20) observed an increase in leaf length, internode length, and shoot biomass when nitrogen was increased from 8.1 to 24.4 kg N ha^{-1}.

While N has major implications for plant health, plant growth regulators have become a routine management practice for superintendents, in particular, trinexapac-ethyl. Previous research has demonstrated the beneficial effects of applying plant growth regulators, including enhance chlorophyll concentration (6) and nutrient retention in bermudagrass putting greens (16). Trinexapac-ethyl has also been shown to improve the stress tolerance of turfgrasses, in particular, shade. Applying trinexapac-ethyl every three weeks (0.0393 kg a.i. ha^{-1}) increased 'TifEagle' bermudagrass turfgrass quality and chlorophyll concentration when grown under four hours of

Overview of the 'Champion' bermudagrass research project investigating various management practices to improve the performance of 'Champion' under shade.

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sunlight (4). Similar improvements have been noted for zoysiagrass following trinexapac-ethyl applications under shade stress (19).

While fertility and plant growth regulator use are key components of a successful management program, few published reports have investigated the response of 'Champion' bermudagrass under full sunlight and shade to various N rates and trinexapac-ethyl application regimes. This information will become increasingly important as the popularity of 'Champion' in the transition zone increases. Due to summer stress management challenges, superintendents in the transition zone are considering switching from creeping bentgrass to bermudagrass putting greens (9). While this switch will minimize summer stress management, new challenges will emerge, including winter color options, spring transition, thatch control, winter kill, and shade. Shade will be a particularly difficult stress to manage due to creeping bentgrass's greater shade tolerance compared to bermudagrass.

Unless tree thinning or removal is an option, a constraint for managing a bermudagrass putting will be shade. Bermudagrasses have long been noted for their poor performance under shade. Research at Clemson University and University of Florida suggests that 'TifEagle', 'Floradwarf', and 'Tifdwarf' bermudagrass require approximately 36 mol m^{-2} d^{-1} (about 8 hours) of sunlight for an acceptable appearance (3, 17). Also, zoysiagrass (*Zoysia matrella* (L.) Merr.) and seashore paspalum (*Paspalum vaginatum* Swartz.) have shown better shade tolerance than bermudagrass (2, 11).

Due to these management challenges, the research objectives of this project were to determine (1) 'Champion' bermudagrass performance under shade in the field, (2) optimum nitrogen rates when growing 'Champion' bermudagrass under shade, (3) interactive effects of trinexapac-ethyl, various N rates, and iron (Fe) in a reduced light environment, and (4) N rates, trinexapac-ethyl, Fe, and various light intensity effects on 'Champion' bermudagrass thatch accumulation over a two-year study period.

Materials and Methods

Research was conducted at the Turfgrass Research Center, Clemson University, Clemson, SC on 'Champion' bermudagrass field research plots established in July, 2003 with rootzone profile constructed to approximate United States Golf Association (USGA) recommendations (23). Shade treatments were initiated June 15, 2006 and terminated September 15, 2006 and repeated the subsequent summer. Shade treatments consisted of control (no shade) and 55% light reduction using a neutral density, polyfiber black shade cloth (Glenn Harp and Sons, Inc., Tucker, GA). Shade structures were 15 cm above the bermudagrass surface to reduce early morning and late afternoon sunlight encroachment, yet maintain adequate wind movement. All shade structures were placed on the bermudagrass surface at sunrise and removed at sunset.

Trinexapac-ethyl (Primo) was applied every two weeks from June 15 to August 31, 2006 and repeated the following year at 0.02 kg ha^{-1} using the emulsifiable concentrate (11.3% a.i.). Urea (46-0-0) was applied every two weeks at 147, 293, and 440 kg N ha^{-1} yr^{-1}. Both trinexapac-ethyl and urea were applied using a CO_2-pressurized backpack sprayer calibrated at 767 L ha^{-1}.

Plots were mowed daily at 3.2 mm throughout the study duration with clippings removed. Hollow tine aeration (1.3-cm diam. tines, 10 cm in length, with 5.0-cm spacing) occurred in June and August in both years. Irrigation was provided as needed to prevent wilt, while no fungicides, insecticides, or other pesticides were applied.

Data Collection

Data collected included microenvironment conditions, turfgrass quality, clipping yield, and shoot chlorophyll concentration. Microenvironmental parameters included canopy and soil temperature, wind movement, and light quality and quantity. Canopy and soil temperatures were recorded two to three times weekly at solar noon. Wind movement was recorded twice on days with

Light	Nitrogen (kg ha^{-1} yr^{-1})	Trinexapac-ethyl	Turfgrass quality†	Chlorophyll (mg g^{-1})	Clipping Yield (g m^{-2})
Shade	147		5.6	2.34	8.3
	293		4.8	1.97	18.8
	440		3.8	1.94	17.6
$LSD_{0.05}$			0.8	0.28	7.7
Full Sunlight	147		6.5	2.88	1.9
	293		7.4	3.02	4.2
	440		7.6	3.23	6.5
$LSD_{0.05}$			0.4	0.23	1.5
Shade		Yes	5.7	2.21	10.1
		No	3.8	1.95	14.6
$LSD_{0.05}$			0.5	0.22	ns
Full Sunlight		Yes	7.4	2.99	2.6
		No	7.0	3.09	4.4
$LSD_{0.05}$			0.3	ns	1.2

†Turfgrass quality based on a scale of 1-9, 1=brown, dead turfgrass, 6=minimally acceptable turfgrass, 9=healthy/green turfgrass.

Table 1. Turfgrass quality, chlorophyll concentration, and clipping yield of ‘Champion’ bermudagrass following 12-weeks of various light environments, nitrogen rates, and trinexapac-ethyl applications at Clemson University.

a consistent breeze. Light quality was measured on a clear, cloudless day at solar noon using a spectroradiameter (Model LI-1800; LiCor, Inc., Lincoln, NE), while photon flux density (micromol m^{-2} s^{-1}) was recorded two to three times weekly at solar noon using a quantum radiometer (Model LI-250, LiCor, Lincoln, NE).

Visual turf quality ratings were recorded at 4, 8, and 12 weeks based on color, density, texture, and uniformity of the bermudagrass surface. Quality was visually evaluated from 1 to 9 where 1 = brown, dead turfgrass, 6 = minimal acceptable quality, and 9 = ideal green, healthy turfgrass.

Clipping yield (g m^{-2}, oven-dry wt.) was collected at weeks 6 and 12 for both years. Shoot tissue was collected using a Toro® walk behind greens mower following one day of growth. Following clipping collection, clippings were oven-dried at 80^{o} C for 48 hours and weighed to quantify clipping production.

Shoot chlorophyll (mg g^{-1}) was collected on same dates as clipping yield. Fresh clippings were collected from each plot and immediately placed in a plastic bag inside a covered bucket to prevent sunlight degradation. Clippings were weighed (0.1g) and placed in a glass test tube with 10 mL of dimethyl sulfoxide (10). Samples were incubated in 65^{o} C water on a hot plate for 1.5 hours and continuously shaken. Upon completion, samples were passed through filter paper and remaining extract (2 mL) transferred into cuvettes. Absorbance values were recorded at 663 nm and 645 nm wavelengths using a spectrophotometer (GenesysTM 20, ThermoSpectronic, Rochester, NY) and chlorophyll content was assessed (1).

Thatch accumulation (g m^{-2}) and depth (cm) were measured at week 12 for both years. A bulk density sampler extracted one 206-cm^3 core from each plot. Roots were clipped at the base of

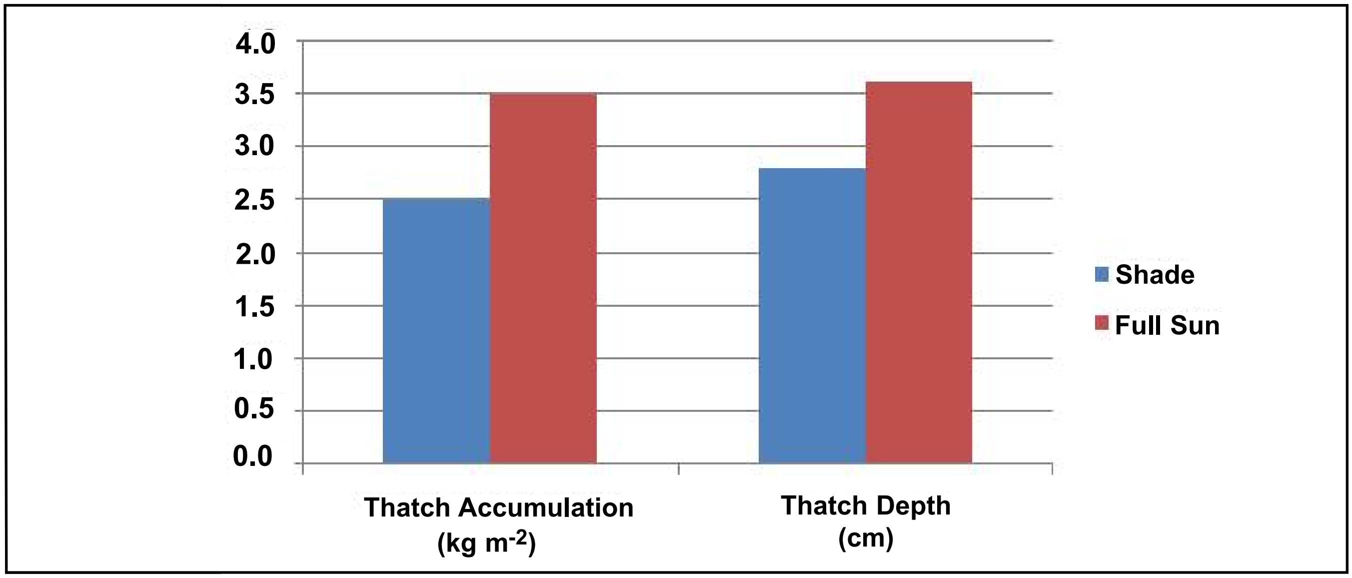

Figure 1. Thatch accumulation (kg m^{-2}) and thatch depth (cm) of 'Champion' bermudagrass grown under full sunlight or 55% shade for 12 weeks at Clemson University, Clemson, SC.

the thatch layer and the remaining thatch sample was placed in an 80º C oven for 96 hours and weighed. Samples were then placed in a muffle furnace at 525º C for three hours to provide ash-free weight. Samples were weighed again and then subtracted from the original dry weight, which was used to determine thatch accumulation (g m^{-2}). Thatch depth (cm) was measured from five points on the soil core and averaged. Following oven drying, measurements were taken from the top of the turfgrass surface to the base of the thatch layer.

Treatments were arranged in a split-block design with three replications. Management practices were arranged in a randomized complete block design, while shade was the split-plot factor. Treatment effects were evaluated using analysis of variance techniques. No meaningful year by treatment interaction was noted for all responses measured, so data for the two years were pooled. Means separation was analyzed using Fisher's protected least significant difference (LSD) test with alpha = 0.05.

Results

Shade cloth reduced canopy temperature up to 7.8º C and soil temperature up to 2.2º C compared to full sunlight (data not presented). Shade cloth reduced light intensity 55% (1891.4 micromol m^{-2} s^{-1} full sunlight versus 833.9 micromol m^{-2} s^{-1} 55% shade), however, no differences in light quality or wind movement were detected.

Turfgrass Quality

After three months of 55% shade, applying N at 147 kg ha^{-1} yr^{-1} resulted in the greatest turfgrass quality compared to N at 293 and 440 kg ha^{-1} yr^{-1} (Table 1). However, even with the adjustment in N rates, turfgrass quality scores remained below an acceptable threshold. Other researchers have also noted the decline of bermudagrass turfgrass quality below acceptable standards in other field shade trials (3, 11).

In full sunlight, N applied at 147 kg ha^{-1} yr^{-1} had lower turfgrass quality scores compared to N rates of 293 and 440 kg ha^{-1} yr^{-1}, but all turfgrass quality scores remained above the acceptable threshold (Table 1). Applying N at 147 kg ha^{-1} yr^{-1} provided acceptable turfgrass quality in full sunlight by week 12. However, Long (14) noted N applied as ammonium sulfate at 488 kg ha^{-1} yr^{-1} was insufficient for acceptable turfgrass quality. This discrepancy between these studies may be due to the different N source (ammonium sulfate) compared to urea used in this study. Also,

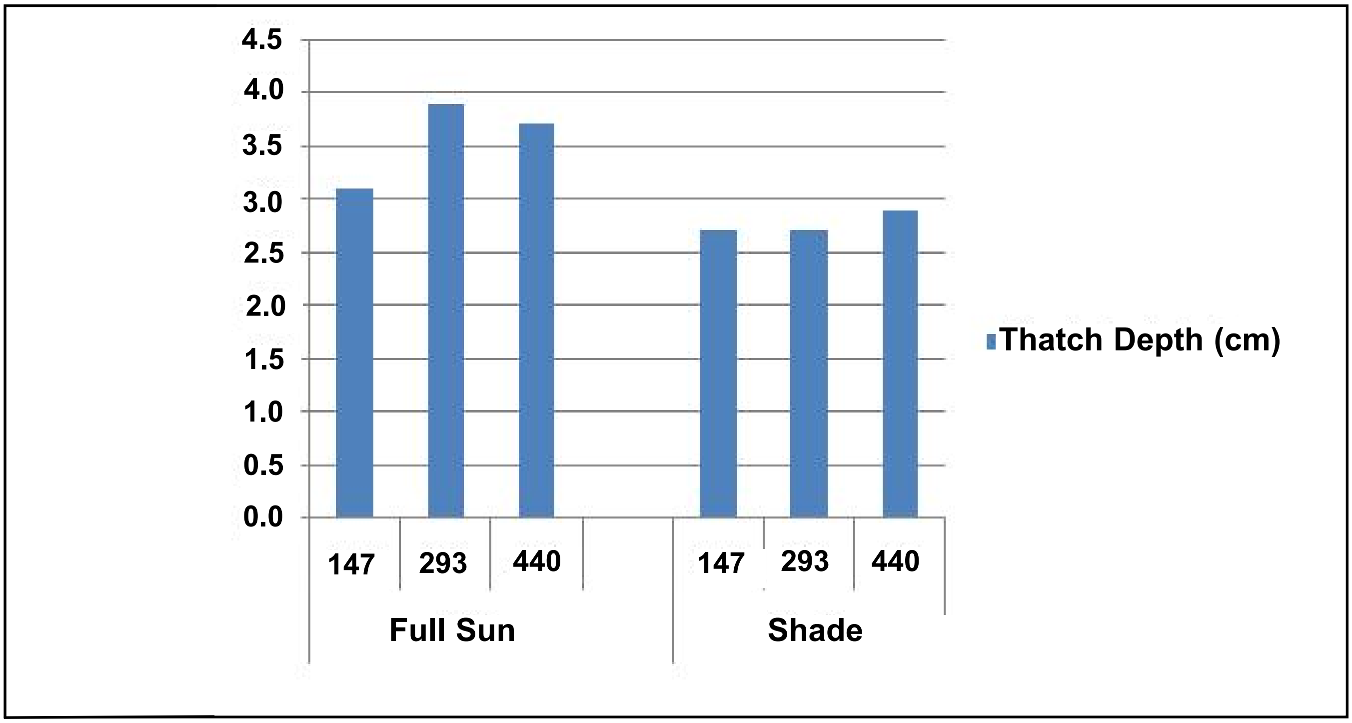

Figure 2. Thatch depth (cm) of 'Champion' bermudagrass grown under full sunlight or 55% shade for 12 weeks in response to three N rates of 147, 293, and 440 kg N ha^{-1} yr^{-1} at Clemson University, Clemson, SC.

'Champion' bermudagrass used by Long (14) was still in a grow-in phase and may have required a higher annual N input than the established bermudagrass green used in the present study. Regardless of light environment, by the end of the study, trinexapac-ethyl increased turfgrass quality, which has been noted in previous field studies (4, 16).

Adjusting N rates and applying trinexapac-ethyl significantly impacted the performance of 'Champion' bermudagrass under full sunlight and shade. Meanwhile, Fe did not influence turfgrass quality under full sunlight or shade (data not presented). Previous research at Virginia Tech also found Fe was ineffective in consistently enhancing bermudagrass color and quality (18). Iron's ineffectiveness may be related to daily clipping removal because symptoms of Fe deficiency are often linked to sites where daily mowing occurs (22). Also, Fe is quickly converted to insoluble forms in the soil, which typically results in short-term visual responses following Fe applications (18).

Clipping Yield

Under full sunlight, increasing N from 147 to 440 kg ha^{-1} yr^{-1} led to a 3.4 times greater clipping yield (Table 1). Two weeks after the final trinexapac-ethyl application, treated plots under full sunlight had 69% fewer clippings compared to plots not treated with trinexapac-ethyl. Previous studies have also noted trinexapac-ethyl's ability to reduce ultradwarf bermudagrass clipping yield in full sunlight and shade (4, 16).

Chlorophyll

Under shade, increasing N rates to 293 and 440 kg ha^{-1} yr^{-1} decreased chlorophyll concentration by approximately 20% compared to the 147 kg ha^{-1} yr^{-1} N rate (Table 1). However, under full sunlight, 'Champion' fertilized with 147 kg ha^{-1} yr^{-1} of N had a 12% chlorophyll decrease compared to 440 kg ha^{-1} yr^{-1} of N. A chlorophyll concentration increase (13%) was noted for trinexapac-ethyl-treated plots compared to untreated plots under shade. Chlorophyll levels increased because trinexapac-ethyl favorably alters anatomical development of plant cells (7).

Under full sunlight, trinexapac-ethyl minimally influenced 'Champion' bermudagrass chlorophyll concentrations in full sunlight. Bunnell et al. (4) also noted trinexapac-ethyl did not increase chlorophyll concentration of sun-grown 'TifEagle' bermudagrass at a 3.2 mm mowing height. However, McCullough et al. (16) noted trinexapac-ethyl applied in three week intervals at 0.05 kg a.i. ha^{-1} increased 'TifEagle' bermudagrass chlorophyll concentration by 18% early in the growing season compared to untreated 'TifEagle'.

While N and trinexapac-ethyl played keys roles in chlorophyll production of 'Champion', Fe did not impact chlorophyll concentration (data not presented). Similar results were noted by Stier and Rogers (21) when Kentucky bluegrass (*Poa pratensis* L.) and supine bluegrass (*Poa supina* Schrad.) were subjected to shade stress. Previous investigations have noted increased Fe availability in a nutrient solution medium enhanced chloroplast development of Kentucky bluegrass, which increased chlorophyll b production (12).

Thatch

Under shade, 'Champion' had 40% less thatch accumulation than 'Champion' bermudagrass grown in full sun (Figure 1). This suggests a less aggressive cultivation approach is needed to control thatch buildup in a shaded ultradwarf bermudagrass putting green.

Increasing N to 147 kg ha^{-1} yr^{-1} increased thatch depth 26% in full sunlight (Figure 2). Similar to thatch accumulation, full-sun plots had 29% greater thatch depth than shade-grown plots (Figure 2). Applying trinexapac-ethyl resulted in slightly greater thatch depth compared to untreated and lower-N plots. However, Fagerness et al. (8) indicated repeated trinexapac-ethyl applications (0.11 kg a.i. ha^{-1}) did not affect thatch development, but increased shoot density and percent green canopy tissue.

Conclusions

Growing an ultradwarf bermudagrass putting green under shade will become a major challenge for superintendents who switch from creeping bentgrass putting green grasses. However, adjusting management practices, in particular N management, can significantly improve bermudagrass quality under shade. Using 147 kg N ha^{-1} yr^{-1}, which is approximately 40% lower than the recommended N requirements for ultradwarf bermudagrass putting greens (15), significantly improved 'Champion' turfgrass quality under reduced light compared to higher N rates. Low N reduced vertical shoot growth, thereby, minimizing shoot tissue removed from daily mowing.

Although 'Champion' bermudagrass quality was enhanced by reduced N rates and routinely applying trinexapac-ethyl, turfgrass quality will inevitably decline if shade intensity is too great or shade duration is too long. It has been suggested that ultradwarf bermudagrass greens require approximately 36 mol m^{-2} d^{-1} of sunlight (3, 17). Also, time of shading is a relevant consideration when establishing a bermudagrass green (3). Selective tree thinning or removal, along with traffic reduction, should also be considered in attempting to prolong 'Champion' bermudagrass turfgrass quality under reduced light (5).

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