Establishment of Seeded Zoysiagrass in a Perennial Ryegrass Sward: Effects of Soil-Surface Irradiance and Temperature

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ABSTRACT

Conversion from perennial ryegrass (*Lolium perenne* L.) to zoysiagrass (*Zoysia japonica* Steud.) in the transition zone of the USA may reduce irrigation and fungicide requirements. However, environmental conditions under perennial ryegrass canopies may inhibit establishment of seeded zoysiagrass. Our objectives were to quantify solar irradiance and temperatures at the soil surface and determine their effects on establishment of 'Zenith' zoysiagrass seeded into existing perennial ryegrass canopies. A 31-day shade study was conducted during 2002 near Manhattan, Kansas, USA. Zoysiagrass was seeded into bare-soil plots, each covered with shade cloth that blocked 40%, 65%, or 85% of solar irradiance. Additionally, two separate experiments were conducted in 1999-2000 (Study I) and 2002 (Study II) in which perennial ryegrass canopies were maintained at: 1) 1.4 cm (untreated); 2) 0.6 cm (scalped); or 3) treated with glyphosate (N-phosphonomethyl glycine [glyphosate-treated]). Irradiance below the canopy was modeled in both experiments and seedbed temperatures were measured with thermocouples in Study II. In the shade study, zoysiagrass seedling emergence and growth decreased as shade increased in bare-soil plots (r = -0.59 to -0.69). In perennial ryegrass, scalped and untreated turf shaded the seedbed surfaces by 36% and 72%, respectively, and soil temperatures averaged 1.1^{o}C cooler compared to glyphosate-treated turf. In scalped and glyphosate-treated plots, zoysiagrass seedling emergence was 90% greater the first year and coverage 59% greater the second year compared to untreated perennial ryegrass. Higher light penetration and seedbed temperatures during the initial 5 to 7 weeks after seeding contributed to higher zoysiagrass establishment in scalped and glyphosate-treated plots.

Keywords: glyphosate, shade, temperature, turfgrass.

Abbreviations: Day of year, DOY; Pure live seed, PLS; Soil encapsulated thermocouple, SET

There is increasing interest in the use of seeded zoysiagrass for golf courses in the transition zone of the USA. In many instances, the superintendent would prefer to convert a cool-season turfgrass stand to seeded zoysiagrass without closing the golf course. In a previous study, Zuk and Fry (2005) conducted multiple field evaluations and observed that zoysiagrass establishment occurred most rapidly when perennial ryegrass was treated with glyphosate prior to seeding, and to a lesser extent when perennial ryegrass was scalped during the first few weeks after seeding. Zoysiagrass failed to establish satisfactorily if seeded into an untreated perennial ryegrass stand.

Perennial ryegrass is competitive and has a fast vertical growth rate (Fry and Huang, 2004). The microclimate at the base of a living perennial ryegrass canopy is undoubtedly quite different than if the perennial ryegrass had been killed with glyphosate. Specifically, the soil surface under a living perennial ryegrass canopy will be more shaded and cooler than in a glyphosate-treated canopy. Furthermore, when perennial ryegrass is scalped, or mowed at a lower height, then leaf area is reduced which may allow more light penetration and result in higher seedbed temperatures than canopies maintained at fairway heights (e.g., 1.3 cm). Therefore, differences in microclimate at the soil surface among living perennial ryegrass canopies mowed at different heights and glyphosate-treated canopies may influence establishment of zoysiagrass seeded into perennial ryegrass. However, these differences have never been quantified.

Undoubtedly there are additional factors that may hinder zoysiagrass seed germination and subsequent growth under a perennial ryegrass canopy besides reduced light levels and temperatures. These include substandard seed-to-soil contact, potential allelopathic effects, and competition for nutrients and water between zoysiagrass seedlings and perennial ryegrass.

Therefore, our first objective was to evaluate the effects of seedbed irradiance and temperature on the establishment of zoysiagrass seeded into bare-soil plots. Bare-soil plots eliminated the additional, potentially deleterious, effects of an established perennial ryegrass stand on zoysiagrass establishment as listed above. These plots were covered with three thicknesses of shade cloth to allow differing levels of light penetration through to the seedbed surface. A second objective was to estimate soil-surface irradiance levels and measure seedbed temperatures under perennial ryegrass canopies mowed at different heights and under glyphosate-treated canopies. Our hypothesis was that lower light levels and temperatures in non-glyphosate treated perennial ryegrass canopies would reduce zoysiagrass emergence and coverage observed after seeding.

MATERIALS AND METHODS

Shade Study

This study was conducted to evaluate the effects of increasing shade levels on zoysiagrass seedling emergence and growth in bare-soil plots with similar seedbed properties. The study was located at the Rocky Ford Turfgrass Research Center near Manhattan, KS, USA (12^{o}N, 96.35^{o}W). The study area was a perennial ryegrass growing on a Chase silt loam (fine, montmorillonitic, mesic Aquic Arquidolls) (U.S.D.A. Soil Conservation Service, 1975) with a pH of 7.2 (Kansas State University Soil Testing Laboratory).

On 29 May, 2002, glyphosate at 3.4 kg a.i. ha^{-1} was applied to twelve individual treatment plots measuring 0.9 m x 0.9 m using a Solo backpack sprayer model no. 475 (Solo Inc., Newport News, VA) to eradicate all vegetation. On 1 August, shade frames measuring 0.9-m long x 0.9-m wide x 0.3-m tall were constructed of 2.5-cm diam. schedule 20 polyvinyl chloride irrigation pipe. Each frame was anchored to the ground with eight 0.3-m long cane-shaped pieces of 0.6-cm diam. concrete reinforcement bar.

Soil encapsulated thermocouple (SET) sensors were installed at the soil surface in each plot prior to seeding. The SET sensors were constructed following the technique used by Ham and Senock (1992). The sensors were used to record seedbed surface temperatures every 30 minutes. Data were collected using a CR10X datalogger (Campbell Scientific, Inc. Logan UT). Daytime seedbed temperatures are an average of all readings from 0800 to 1830 CST during the study.

The plot area under each frame was cultivated to a 2-cm depth with a common garden trowel before seeding, with care taken not to disturb the SET sensors. After the soil was cultivated, individual frames were covered with shade cloth (Cornelia Textiles, Cornelia, CA) that shaded 40, 65, and 85% of solar irradiance from the seedbed; untreated plots were not shaded. The shade cloth covering the frame was then fastened to the ground with twelve 10.1-cm long metal garden staples. Shade frames were placed in rows with 1.8 m between structures in a north-to-south direction and 0.7 m between structures in an east-to-west direction to avoid shading from adjacent frames. Diurnal measurements on 31 August (day of year [DOY] 231]) of intercepted photosynthetically active radiation below each shade cloth illustrated the effects of the three shade treatments on irradiance at the seedbed surface (Fig. 1). Photosynthetically active radiation was measured above and below the shade cloth with a ceptometer lightbar (Sunfleck Ceptometer, Decagon Devices, Pullman, WA). At dusk on 8 August, one portion of shade cloth on each frame was lifted and approximately 61 pure live seeds (PLS) of Zenith zoysiagrass were sown and left uncovered on cultivated soil in a 0.09 m^2 area in the center of the plot.

Pure live seed was determined by placing 20 seeds in each of three 100-mm diam. x 15-mm deep Petri dishes containing moist filter paper. Each dish was sealed with parafilm to prevent drying and contamination. Petri dishes were placed in a growth chamber with a 16 hour photoperiod at 30/25 ^{o}C (day/night) temperatures. Filter paper in each dish was rehydrated every 3 days with the same amount of water by injecting it through the parafilm seal with a syringe and hypodermic needle. After 28 days, average percentage germination was determined, and multiplied by percent purity on the seed container to determine PLS.

Each treatment plot was fertilized with a starter fertilizer (9-13-7) to provide P at 49 kg ha^{-1}. Water was applied 3 to 4 times daily through a spray nozzle attached to a garden hose. Water was applied over the top of the shade cloth (with the exception of the untreated plots which were not shaded) and then dripped down to the seedbed below. Weeds were eradicated from treatment plots by hand at dusk when required.

Data collection and analysis

Seedlings were harvested on 8 September, 2002 with a teaspoon to leave soil attached to the roots. Plants were placed in a freezer until measurements were made. Seedlings were rehydrated and roots separated from soil by soaking in tap water overnight on 11 September. Seedling number and the number of tillers on each seedling were counted. Root length and root and leaf area were determined using an Epson Expression 1680 Graphics Scanner and WinRHIZO 2002 root measurement software (Regents Instruments Inc., Quebec, Canada). Before scanning, all roots were dipped in methyl blue (5 g L^{-1} H_2O) to facilitate root measurement. The roots were placed in a transparent scanning tray containing water to facilitate root separation. After scanning, leaf and root biomass were determined by drying the plant tissue in a Blue M oven model no. OV-500B-1 (Blue M Electric Co., Blue Island, IL) at 65 ^{o}C for 48 hours and then weighing.

Experimental design was a randomized complete block design with three replicates of each of the three shade levels plus the full-sun control. Data were analyzed using the Statistical Analysis System (SAS, 2000). The analysis of variance (ANOVA) procedure was used to test for treatment effects and the correlation procedure for correlation values. Means were separated using the least significant difference (LSD) procedure.

Establishment of seeded zoysiagrass in a perennial ryegrass sward

Two separate experiments were conducted in adjacent areas in 1999-2000 (Study I), and in 2002 (Study II), using the same treatments at the Rocky Ford Turfgrass Research Center at Manhattan, KS. Each experimental area consisted of perennial ryegrass composed of equal parts of the cultivars ‘Roadrunner’, ‘Manhattan 3’, ‘Charger II’, and ‘Catalina’ that were 2-years old at the time each test was initiated. Soil characteristics were the same as described in the shade study above.

Immediately before seeding, the study area was core-aerified and verticut. Cores were removed using a 46-cm wide aerator with tines on 10-cm centers. The resulting holes measured 1.2-cm wide x 1.3 to 3.8-cm deep. After aerification, the test site was vertically mowed to a depth of 0.32 cm in four directions using a 46-cm wide vertical mower with a blade spacing of 9.5 cm to pulverize the cores and to improve seed to soil contact. Seeding was applied at 49 kg ha^{-1} in both evaluations, but reported as total PLS which was determined as described in the Shade Study.

The following seedbed preparation treatments were evaluated: 1) untreated; 2) scalped (plots were mowed at 0.6 cm three times weekly for seven weeks after seeding [five weeks in Study II] at which time tillering was observed); and 3) glyphosate at 3.4 kg a.i. ha^{-1} applied two weeks before seeding. Non-scalped turf was mowed at fairway height (1.4 cm) three times weekly. Plots were arranged in a randomized complete block design with three replications.

Study I

In Study I, Zenith zoysiagrass was seeded on 18 June, 1999 into plots measuring 1.2 x 2.4 m to provide PLS at 42 kg ha^{-1}. Seed was distributed using 946 ml shaker jars containing 60 g of a natural organic fertilizer 6-0-2 (24.5 kg N ha^{-1}) as a seed carrier. Seed was lightly raked in.

After seeding, siduron [N- (2-methylcyclohexyl)-N-phenylurea] was applied at 5.6 kg a.i. ha^{-1} for preemergence weed control; a 12-30-7 (N-P-K) fertilizer was blended with the siduron to deliver N at 18 kg ha^{-1}. The study area was watered immediately after the herbicide was applied.

Irrigation was applied through a hose-end sprinkler two to three times daily for the first four weeks after seeding in 1999 to provide 2 mm of water in each session. On 18 July, irrigation was applied twice daily to provide 3 mm of water in each session. Beginning on 31 August, irrigation was applied only to prevent zoysiagrass wilt.

Urea (46-0-0) was applied to provide N at 49 kg ha^{-1} on 12 July, 1999; 15 June and 20 July, 2000. A single application of N from urea at 73 kg ha^{-1} was also made on 9 Aug., 1999.

The following broadleaf herbicides were applied to all treatment plots with a Terra Master 160 boom sprayer (Broyhill Co., Dakota City, NE) at 138 kPa and 561 L water ha^{-1}: 2,4-D (2, 4-dichlorophenoxyacetic acid, 1.1 kg a.i. ha^{-1}) + mecoprop (dimethylamine salt of 2-(2-methyl-4-chlorophenoxy) propionic acid, 0.3 kg a.i. ha^{-1}) + dicamba (3, 6-dichloro-o-anisic acid, 0.1 kg a.i ha^{-1}) on 1 May and 22 October, 1999; and 13 March and 24 Nov., 2000. For preemergence control of grassy weeds, prodiamine [N^3, N^3-Di-n-propyl-2, 4-dinitro-6-(trifluoromethyl)-m-phenylenediamine] was applied at 1 kg a.i. ha^{-1} on 13 March, 2000.

Study II

Study II was conducted from 19 June to 11 October, 2002 (DOY 170 to 284). Zenith zoysiagrass was seeded on 19 June, 2002 into plots measuring 0.9 m x 0.9 m at 21 kg ha^{-1} PLS. Seed distribution was as described for Study I.

Irrigation was applied through a hose-end sprinkler two to three times daily during the first four weeks after seeding to provide a total of 2 mm of water per application. After four weeks, irrigation was applied twice daily every one to two days to provide a total of 3.8 mm of water in each application. After eight weeks, irrigation was applied solely to prevent zoysiagrass wilt.

Nitrogen from urea (46-0-0) was applied at 49 kg ha^{-1} on 20 June and 4 and 21 August, 2002. No herbicides, other than siduron as described above, were applied in Study II.

Data collection and analysis

Data were collected on solar radiation, soil surface temperature (Study II only), zoysiagrass seedling emergence (Study I only), and zoysiagrass coverage. Solar irradiance at the seedbed surface was modeled using measurements of leaf area index and estimates of percent canopy coverage in each treatment. Each perennial ryegrass plot had different fractions of its surface covered by green leaves (i.e., canopy), bare soil, or dead biomass. In glyphosate-treated plots there were essentially no green leaves early in the study. After aeration and four passes with the vertical mower, the dead biomass was pulverized and within a short time had degraded to where very little intact canopy remained. Thus, when modeling irradiance at the seedbed surface it was assumed that areas not covered with green leaves were bare soil. Although the small amount of dead biomass present may have initially shaded the soil surface, its effect was likely negligible when estimating irradiance at the soil surface, particularly when compared with areas covered with green leaves. Thus, total irradiance at the seedbed surface was calculated as the sum of irradiance: 1) penetrating through the canopy portion; and 2) falling on bare soil. Total irradiance at the seedbed surface on each plot (I_{plot}; W m^{-2}) was determined using equation 1:

$$I_{plot} = a_c I + a_s I_o \qquad [1]$$

where a_c is the fraction of area covered by canopy or green leaves, I is the attenuated radiant flux density under the canopy, a_s is the fraction of area covered by bare soil, and I_o is the unattenuated flux density of solar irradiance. The sum of areas covered by canopy and bare soil was defined as unity (equation 2):

$$a_c + a_s = 1 \qquad [2]$$

In Study II, the coefficients a_c and a_s were estimated from images collected weekly using an agricultural digital infrared camera (Dycam ADC model 4, Dycam, Inc. Woodland Hills, CA). The camera was positioned 2.2 meters above each plot when collecting data and provided estimates of canopy coverage. In Study I, no infrared images were collected. However, both Study I and II were conducted in the same area of turfgrass that included the same cultivars of perennial ryegrass and similar soil properties and cultural practices. Furthermore, Study I and II were conducted during the same time of year, albeit in different years. Therefore, we assumed that weekly canopy coverages (i.e., a_c and a_s) were the same among treatments in Study I and II between seeding and the beginning of tillering (when scalping was terminated).

Solar irradiance at the seedbed surface under the canopies in each plot (Study II) or treatment (Study I) was estimated using the Bouguer-Lambert Law (Eq. 3) (Loomis and Conner, 1992; Cambell and Norman, 1998):

$$I = I_o \exp\left(-k_{LAI} LAI\right) \qquad [3]$$

where k_{LAI} is the extinction coefficient, which relates to the fraction of light intercepted per unit leaf area index (LAI; m^2 leaves m^{-2} ground). Leaf area index averaged 3.3 m^2 m^{-2} in untreated plots and 1.45 m^2 m^{-2} in scalped plots; LAI was measured from perennial ryegrass samples harvested from this study area and measured using the Epson scanner previously described in the Shade Study. The k_{LAI} for perennial ryegrass was estimated empirically as 0.41 (Loomis and Conner, 1992). Weather data from a local station (Weather Data Library, Kansas State University, Manhattan, KS) provided measurements of I_o during the study periods in 1999 and 2002.

To determine seedbed temperatures in each treatment in Study II, SET sensors were installed at the soil surface in each plot on 29 June, 2002 and data collection began on 5 July, 2002 (DOY 186); data were collected as previously described in the Shade Study. Average daytime seedbed temperatures were calculated between 1000 and 1600 h (CST).

On 8 Aug., 1999, percent germination was determined in each seedbed treatment in Study I. The number of seedlings was counted within a 10 x 10-cm template that was randomly tossed three times per plot, and percentage emergence was calculated by dividing this number by the number of PLS that had been applied and multiplying by 100.

Zoysiagrass coverage was measured on 25 Aug. and 19 Sept. 1999, and 25 Sept., 2000 in Study I and 27 July and 11 October, 2002 in Study II using a vertical point quadrant described by Gaussoin and Branham (1989). The vertical point quadrant was constructed of a PVC frame with an internal monofilament grid spaced on 100-mm centers. The grid was placed over each plot to estimate zoysiagrass coverage. The presence of any part of a zoysiagrass seedling under an intersection was recorded as a hit. To determine percent coverage, the number of hits was divided by the number of intersections on the grid and multiplied by 100.

Data were analyzed using the Statistical Analysis System (SAS, 2000). The analysis of variance (ANOVA) procedure was used to test for treatment effects and the correlation procedure for correlation values. Means were separated using the least significant difference (LSD) procedure.

RESULTS AND DISCUSSION

Shade Study

Seedbed drying was more rapid in unshaded plots because the soil surface was exposed to higher solar irradiance than in shaded plots (Fig.1). Although the seedbeds of all plots were irrigated by hand three to four times per day, irrigation frequency was inadequate to maintain sufficient soil moisture levels in unshaded plots for optimal establishment of zoysiagrass seedlings. Conversely, shade cloth prevented total drying among shaded plots between irrigations. Furthermore, seedbeds in unshaded plots were exposed to erosive effects of rainfall, whereas those in shaded plots were protected. As a result, establishment of zoysiagrass was generally hindered in unshaded plots compared to 40% shaded plots (Table 1). Therefore, statistical analyses are presented and discussion in this section focused only on data among shaded plots to illustrate the effect of irradiance levels on zoysiagrass establishment in bare plots.

Zoysiagrass seedling number and growth declined as shade increased (Table 1). For example, correlation coefficients of -0.59 to -0.69 were observed between increasing shade levels and zoysiagrass seedling and tiller numbers, leaf area, leaf dry weight, root length, and root dry weight. For unknown reasons, a lower correlation coefficient ($r = -0.20$) occurred between shade level and root area. Growth parameters of zoysiagrass decreased more between 40 and 65% than between 65 and 85% shade treatments, and differences were generally significant between 40% shade and the higher shade levels ($P < 0.05$). These data suggest a non-linear relationship between light levels and zoysiagrass germination and growth, with the greatest deleterious effects on zoysiagrass growth parameters occurring as shade increased from 40 to 65%. During the study, daily irradiance at the soil surface averaged 9.4, 5.5, and 2.3 MJ m^{-2} in 40, 65, and 85% shaded plots, respectively.

Daytime seedbed temperatures were consistently lower in 65 and 85% than in 40% shaded plots although differences were not significant among plots on a day by day basis ($P <$ 0.05). However, average seedbed temperatures during the entire study, which reflect the potential cumulative effects of seedbed temperatures on zoysiagrass growth, were significantly lower in 65 and 85% (mean=27.3^{o}C) than in 40% (mean=28.7 ^{o}C) shaded plots. Yeam and Portz (1980) and Yeam et al. (1985) observed lower zoysiagrass germination rates with decreasing temperature. In our study, zoysiagrass seedling number and growth were substantially lower in 65 and 85% than in 40% shaded plots. Therefore, the cumulative effects of cooler soils in 65 and 85% shaded plots may have contributed to lower zoysiagrass germination and thus, to the observed reduction in seedling number and growth.

Results from this shade study indicate that lower surface irradiance and to a lesser extent, lower seedbed temperatures, resulted in lower zoysiagrass seedling emergence and growth given that all other seedbed surface properties were similar.

Establishment of Seeded Zoysiagrass in a Perennial Ryegrass Sward

In Studies I and II, daily irradiance at the seedbed surface was greatest in glyphosate-treated plots throughout the experiment, followed by the scalped treatment (Fig. 2). Seedbed irradiance was lowest in the untreated plots. Average daily irradiance in the 5 to 7 weeks following seeding (until tillering was observed/scalping was terminated) was similar in 1999 and 2002, and averaged 19.1 MJ m^{-2} in glyphosate-treated, 12.4 MJ m^{-2} in scalped, and 5.3 MJ m^{-2} in untreated plots; differences in daily irradiance were statistically significant among all treatments during both periods ($P < 0.0001$). Irradiance was greatest in glyphosate-treated plots because of increased exposure of bare soil. The lower mowing height of the scalped plots during that time allowed more light to penetrate to the seedbed than in untreated plots.

Zoysiagrass seedling emergence seven weeks after seeding in Study I was significantly different ($P < 0.05$) among all treatments: glyphosate-treated (7.1 seedlings dm^{-2}) > scalped (3.6 seedlings dm^{-2}) > untreated (0.1 seedlings dm^{-2}). Presumably, greater irradiance on the seedbed surface in glyphosate-treated and scalped perennial ryegrass provided more light for zoysiagrass emergence. Other factors may have contributed to higher zoysiagrass seedling emergence in glyphosate-treated plots, such as the potential for better seed-to-soil contact than in scalped and untreated perennial ryegrass plots. However, as indicated in our shade study where all seedbeds were similar, zoysiagrass emergence and growth in bare, shaded plots was negatively correlated with increasing shade levels ($r = -0.59$ to -0.69, excluding zoysiagrass root area; Table 1). This indicates a substantial effect of light on zoysiagrass emergence and growth. Yeam et al. (1985) reported that zoysiagrass germination increased as light energy increased because of the photodormancy of zoysiagrass seed. In their study, zoysiagrass coverage decreased when seed was planted too deep; the authors attributed this decreased germination to lower light interception by seeds.

Coverage in Study I was also higher in glyphosate-treated than in untreated plots seven weeks after seeding, reflecting the higher seedling emergence observed in glyphosate-treated plots (Fig. 3). However, coverage in scalped plots was not significantly different than in untreated perennial ryegrass despite higher seedling emergence in scalped plots. In Study II, the trends in coverage at the end of five weeks were comparable to Study I, with glyphosate-treated plots being greater than scalped and untreated perennial ryegrass but no significant differences observed between scalped and untreated plots (Fig. 3; $P<0.05$). Similarly, no statistical differences in zoysiagrass coverage were observed between scalped and untreated perennial ryegrass by September of the first year of establishment in both Study I (8.3 % in scalped and 5

% in untreated) and Study II (0.6 % in scalped and 0 % in untreated); however, zoysiagrass coverage in scalped and untreated was still significantly lower than in glyphosate-treated perennial ryegrass (75% in Study I and 19.3% in Study II). By September of the second season of establishment in Study I, zoysiagrass coverage differed significantly ($P < 0.05$) among all treatments and reflected the same statistical ranking observed for seedling emergence: glyphosate-treated (99%) > scalped (59%) > 0% (untreated). Hence, the nominal differences in zoysiagrass seedling emergence among treatments at seven weeks after seeding resulted in more dramatic differences in coverage at the end of the second year of establishment.

Our results from the Shade Study indicated that some zoysiagrass seedlings germinate and grow even at 85% shade; however, shoot and root growth is greatly impaired compared to plants growing at higher light levels (Table 1). Although some zoysiagrass seeds germinate at the base of an untreated perennial ryegrass canopy, reduced vigor resulting from 72% shade (as calculated from aforementioned irradiance levels), coupled with the need to compete with the faster-growing, mature perennial ryegrass, lead to essentially no zoysiagrass coverage after the second year of establishment.

Seedbed temperatures in Study II were generally greatest in glyphosate-treated plots, followed by scalped and untreated plots (Fig. 4). Although average daytime temperatures did not appear substantially different among plots, temperatures were significantly greater in glyphosate-treated than in untreated plots (Fig. 5; $P < 0.05$). Higher daytime temperatures were likely caused by the warming effect of the highest irradiances on the seedbeds of glyphosate-treated plots (Fig. 3), and may have further contributed to higher zoysiagrass germination and coverage by the end of the initial 5-week period in glyphosate-treated plots. Yeam and Portz, (1980) and Yeam et al. (1985) observed zoysiagrass germination at 30 ^{o}C, but increased amounts as seedbed temperatures reached 35 °C. In Study II, seedbed temperatures were above 35 °C on 15 days in glyphosate-treated plots compared with only 4 days in scalped and 2 days in untreated plots (data not shown). However, the effect of seedbed temperature on zoysiagrass coverage was not as pronounced as the effect of solar irradiance (Figs. 3 and 4). For example, one scalped plot and two glyphosate-treated plots all averaged approximately the same daytime seedbed temperature (~31 °C; 1000 to 1600 CST) early in the study, but resultant zoysiagrass coverage was negligible in the scalped plot, whereas coverage was significantly higher (14 and 18%) in the glyphosate-treated plots. The latter indicates that higher levels of irradiance at the seedbed may contribute more to zoysiagrass establishment than higher seedbed temperatures.

It is likely that other factors besides reduced surface irradiance and temperatures contribute to lower zoysiagrass seedling emergence, and ultimately lower coverage, in a perennial ryegrass canopy. These include substandard seed to soil contact, potential allelopathic effects of the perennial ryegrass on zoysiagrass seedlings (Zuk and Fry, 2002), and competition for nutrients and water between zoysiagrass seedlings and perennial ryegrass. Further research may be needed to investigate the effects of these factors on zoysiagrass germination and seedling growth at specific light levels.

CONCLUSIONS

Seeded zoysiagrass emergence and growth in bare-soil plots decreased as shade increased from 40 to 85% ($r = -0.59$ to -0.69). Daytime seedbed temperatures (0800 to 1830 h, CST) averaged about 1.4 °C lower in 65 and 85% shade than in 40% shade. This indicated that lower light levels, and to a lesser extent, lower seedbed temperatures, reduced zoysiagrass establishment given similar seedbed properties among plots. In perennial ryegrass plots, seeded zoysiagrass emergence was greater where more significant perennial ryegrass suppression techniques were employed, i.e., more seedlings emerged in glyphosate-treated plots, followed by scalped perennial ryegrass, and then by untreated turf. Concomitant measurements of surface irradiance and soil temperatures in each of these perennial ryegrass canopies suggested that higher surface irradiance and temperatures in glyphosate-treated and scalped perennial ryegrass likely contribute to improved zoysiagrass emergence five to seven weeks after seeding and greater coverage after the second season of establishment. Additional, potentially confounding effects may need to be evaluated, such as seed to soil contact in bare versus scalped and untreated plots.

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Table 1. Shade impact on seedling morphology of zoysiagrsss four weeks after seeding on bare soil on 8 August, 2002 in Manhattan, KS.

Morphology[†]	Untreated	% Shade 40	% Shade 65	% Shade 85	Correlation Coefficients[‡] (Among 40, 65, & 85% Shaded Plots)
Seedlings (no. m^{-2})	55.6	138.9a*	44.4b	36.7b	-0.59
Tillers (no. $plant^{-1}$)	18.8	31.0a	6.0b	4.8b	-0.63
Leaf Area (cm^2)	18.2	52.9a	13.6ab	5.9b	-0.65
Root Area (cm^2)	261	252a	202a	204a	-0.20
Root Length (cm)	59.3	84.0a	30.6b	24.8b	-0.69
Leaf Dry Wt. (g)	0.037	0.044a	0.009ab	0.004b	-0.66
Root Dry Wt. (g)	0.008	0.008a	0.002ab	0.001b	-0.64

*Means followed with the same letter within a row are not significantly different ($P < 0.05$).

†Plots were seeded at 678 PLS m^2.

‡Correlation coefficients are presented only on data from shaded plots because establishment in untreated plots was deleteriously affected by significant soil-drying between irrigations.

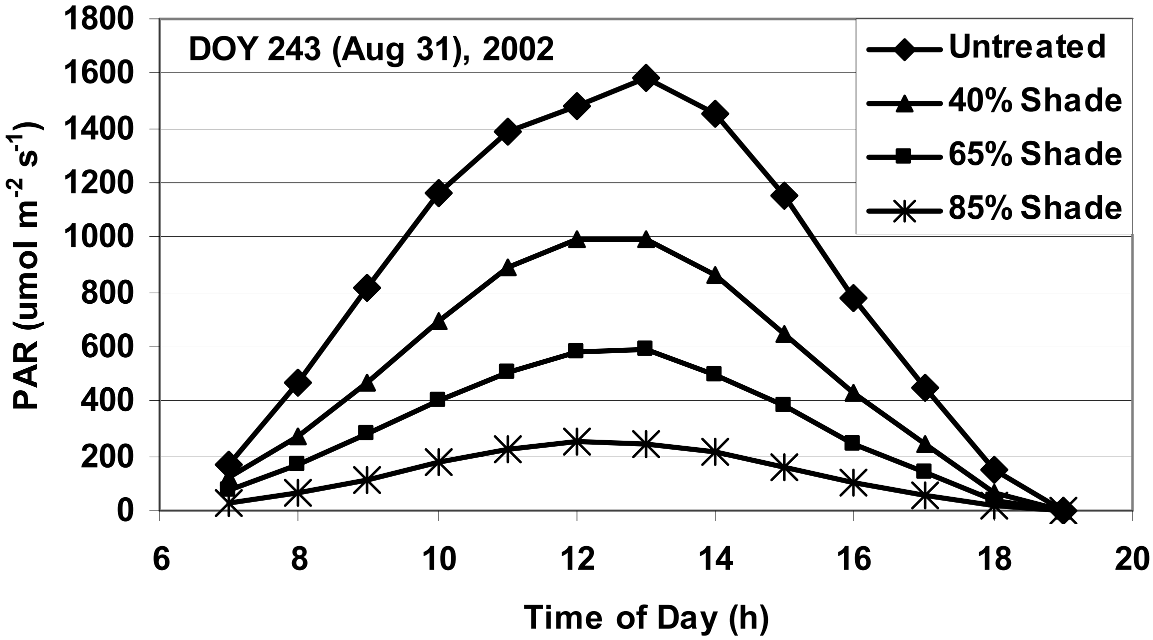

Figure 1. Diurnal light levels above and below shade cloths blocking 40%, 65%, and 85% of photosynthetically active radiation (PAR) to the seedbed surface in bare-soil plots seeded with zoysiagrass in the Shade Study.

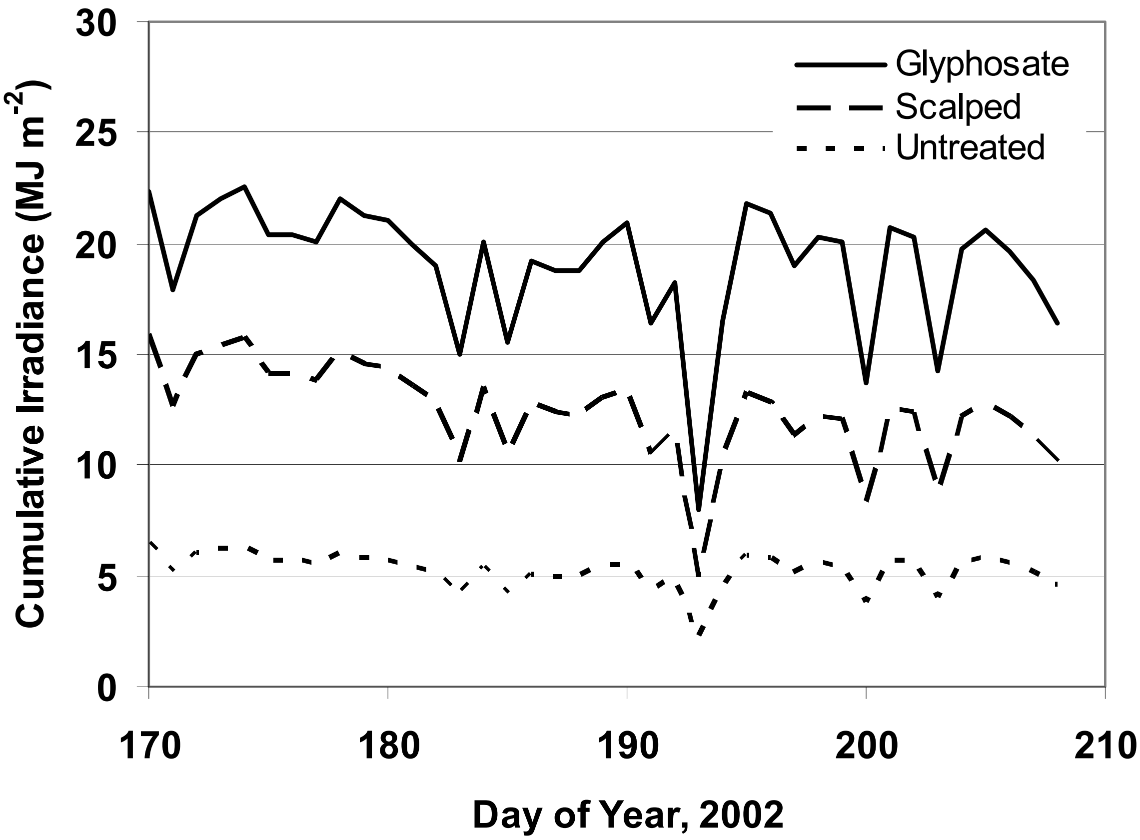

Figure 2. Daily seedbed-surface irradiance within glyphosate-treated, scalped, and untreated perennial ryegrass plots during the first five weeks (19 June to 27 July, 2002) of Study II in which zoysiagrass was seeded into an existing perennial ryegrass sward.

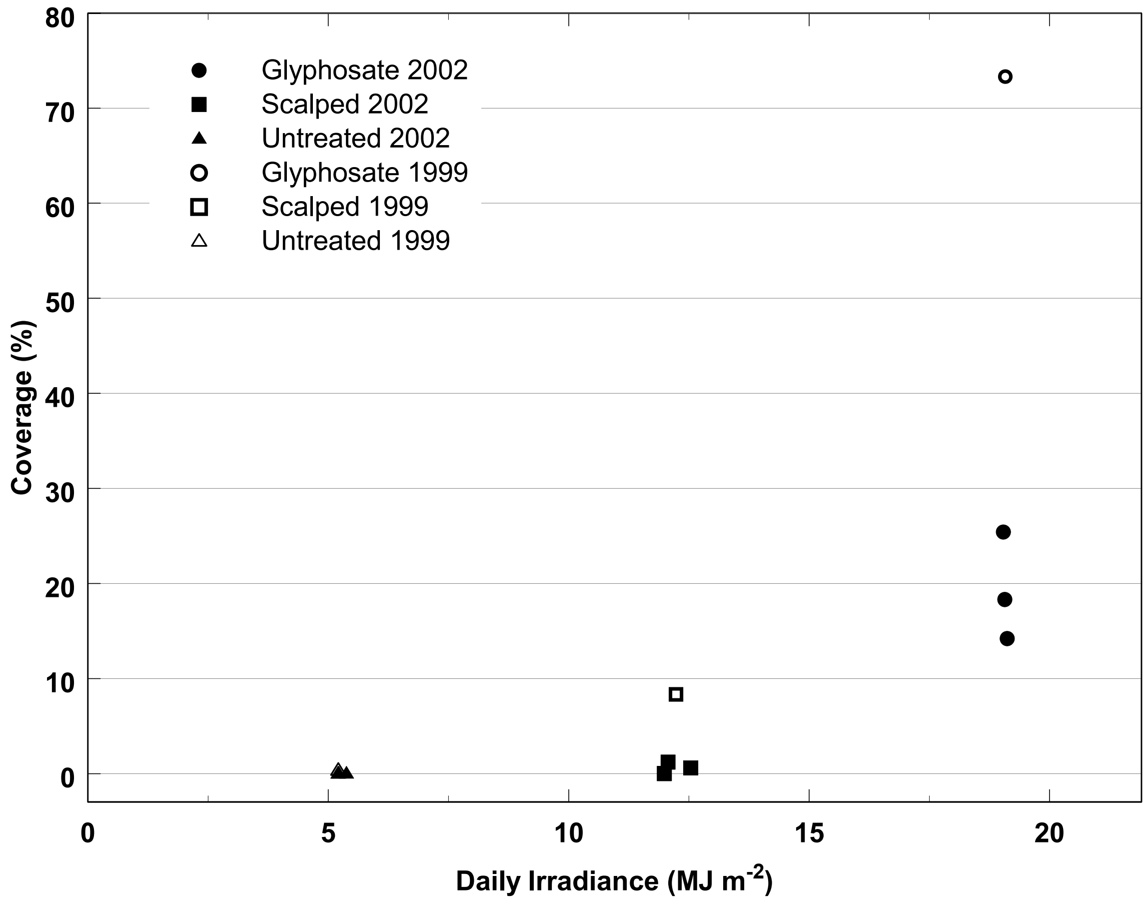

Figure 3. Percent zoysiagrass coverage in relation to average daily irradiance from 18 June to 8 Aug, 1999 (DOY 169 to 220; Study I) and 19 June to 27 July, 2002 (DOY 170 to 208; Study II) in which zoysiagrass was seeded into an existing perennial ryegrass swards. Individual data points represent replicates in 2002 and treatment averages in 1999; replicates of seedbed irradiances were not available in 1999 because canopy cover and bare soil components of individual plots were not measured but rather estimated from 2002 data.

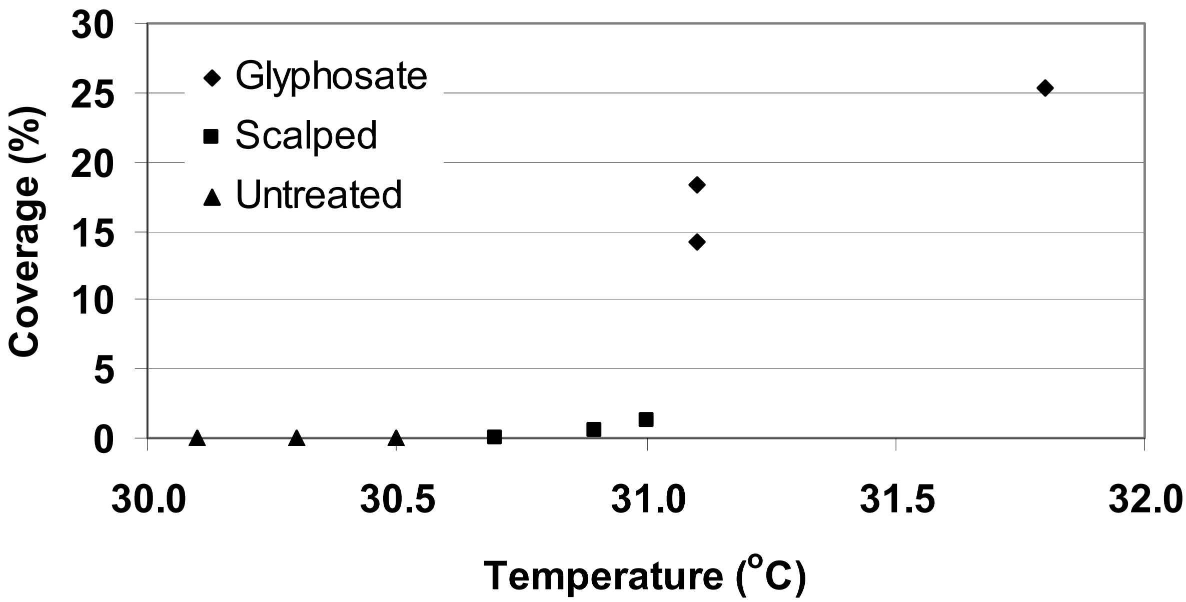

Figure 4. Percent zoysiagrass coverage in relation to average daytime seedbed surface temperature (1000 to 1600 CST) during the period 5 to 27 July, 2002 (DOY 186 to 208) in Study II in which zoysiagrass was seeded into an existing perennial ryegrass sward. Coverage in glyphosate-treated perennial ryegrass was significantly ($P < 0.05$) greater than that in scalped or untreated turf.

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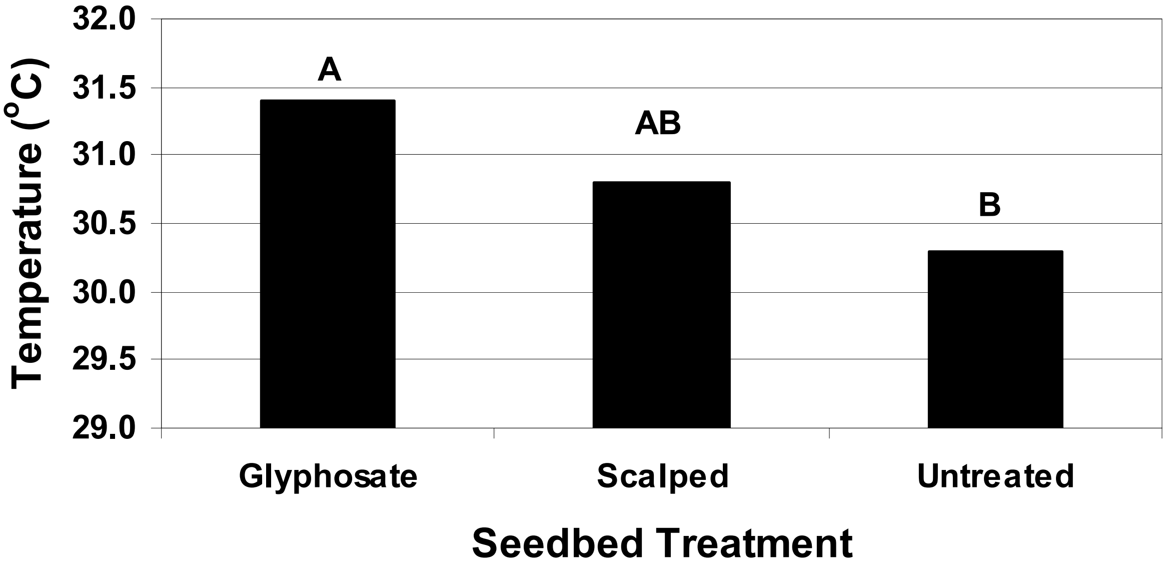

Figure 5. Average daytime seedbed surface temperature within each treatment plot during the period 5 July to 27 July, 2002 (DOY 186 to 208; 1000 to 1600 CST) in Study II in which zoysiagrass was seeded into an existing perennial ryegrass sward. Treatments labeled with the same letters are not significantly different ($P < 0.05$).