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Establishment of Bermudagrass and Zoysiagrass by Seed

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ABSTRACT

Bermudagrass [*Cynodon dactylon* var. *dactylon* (L.) Pers.] and zoysiagrass (*Zoysia japonica* Steud.) cultivars established by seed are desirable for golf and athletic turfs because of minimum establishment costs, but little is known about their management during establishment. Seeding dates, seeding rates, post-seeding N fertility, and herbicide safety on seedling 'Mirage' bermudagrass and 'Zenith' zoysiagrass were investigated in Indiana and Kentucky. Under the conditions of our studies, optimum bermudagrass establishment occurred when seeded 1 June to 15 July at 12 to 49 kg ha^{-1}, when >950 growing degree days (GDD, 5°C base) accumulated by first frost and when 49 kg ha^{-1} N mo^{-1} was applied. Earlier seeding dates provided more bermudagrass cover after the first winter. Optimum zoysiagrass establishment occurred when seeded from 1 to 15 June at 49 to 98 kg ha^{-1}, when > 1750 GDD accumulated by first frost, and when 49 kg ha^{-1} N mo^{-1} was applied. Increasing N from 49 kg ha^{-1} mo^{-1} to 98 kg ha^{-1} mo^{-1} did not hasten establishment of either species. Quinclorac applied at 0.84 kg ha^{-1} following seeding (PRE) or 0 to 28 wk after emergence (WAE) did not reduce bermudagrass and zoysiagrass coverage, but dithiopyr applied at 0.56 kg ha^{-1} before 1 WAE reduced coverage of both species. Siduron was not safe for use when seeding bermudagrass. Seeding bermudagrass or zoysiagrass instead of sprigging or sodding will allow managers to establish these turfs quickly and at minimal cost.

Bermudagrass and zoysiagrass are popular warm-season grasses in the transitional and warm climatic regions of the USA because they provide excellent golf and/or athletic turf, and can be maintained with minimal cost. Bermudagrass and zoysiagrass have historically been established vegetatively with sprigs or sod, which are relatively expensive. New cultivars of bermudagrass and zoysiagrass established by seed recently became commercially available and exhibit quality characteristics similar to vegetatively established cultivars (NTEP, 2001, 2002), but are up to \$30 000 ha^{-1} less expensive to establish depending upon species, cultivar, establishment method and seeding rate. Since improved bermudagrass and zoysiagrass cultivars available by seed are relatively new, little is known about their establishment.

Late spring to early summer plantings are preferred for warm-season grasses (Johnson and Thompson, 1961). This allows the longest period of warm soil temperatures necessary for adequate establishment of warm-season grasses (Beard, 1973). Ahring et al. (1975) reported that 'Arizona common' bermudagrass seeded after 9 May in Oklahoma resulted in greater freeze injury than when seeded earlier. Further research confirmed that seeded bermudagrass should be established as early as possible in late spring to increase winter survival (Munshaw et al., 1998; Hensler et al., 1999). However, Ahring et al. (1975) reported an experimental strain of bermudagrass was not affected by freezing when seeded as late as 21 July in Oklahoma, indicating potential improvements in cold hardiness through plant breeding. Portz et al. (1981) reported that zoysiagrass could be successfully established in Southern Illinois when seeded 1 July. Although seeded zoysiagrass cultivars are generally tolerant of winters in the transition zone (NTEP, 2001), no information exists on the effect of seeding date on establishment and winter survival. Thus, defining the optimum seeding dates for bermudagrass and zoysiagrass establishment and winter survival is important.

Earlier seeding date research focused on optimum calendar dates for seeding, but temperature varies by site and year and consequently these data are not always suitable to other locations. Given that temperature affects the growth of bermudagrass and zoysiagrass (Unruh et al., 1996), applying a GDD model to their establishment would be beneficial. Frank et al. (1998) used accumulated post-planting GDD to determine requirements for establishment and survival of buffalograss established by seed. A similar model would be useful for bermudagrass and zoysiagrass seeding date recommendations.

Rapid establishment is desired when establishing turf vegetatively or by seed. Nitrogen (N) fertilization is often increased to hasten vegetative establishment. Raising monthly N fertilization from 0 to 49 kg ha^{-1} during establishment increased coverage of 'Tifway' bermudagrass by 17% 18 wk after sprigging (Johnson, 1973). Richardson and Boyd (2001) reported 5 to 10% increase in coverage of 'Meyer' zoysiagrass 120 d after sprigging when monthly N was increased from 0 to 25 kg ha^{-1}. However, the effect of N fertilization on coverage has not been reported for bermudagrass and zoysiagrass establishment by seed.

Suggested seeding rates currently vary for bermudagrass. Seeding rates between 12 and 24 kg ha^{-1} increased stolon size and production and could increase winter hardiness of Mirage bermudagrass compared with higher seeding rates (Munshaw et al., 2001). Conversely, Brede (1994) found the greatest winter hardiness from seeding 150 kg ha^{-1} 'Cheyenne' bermudagrass, possibly because of an increase in the overall biomass of the stand. It is important to determine proper seeding rates to maximize winter hardiness since bermudagrass is often killed in the first winter after seeding (Philley and Krans, 1998). Suggested seeding rates also vary for zoysiagrass.

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Abbreviations: DAS, days after seeding; GDD, growing degree days; PRE, preemergence application immediately following seeding; WAE, weeks after emergence.

Portz et al. (1981) recommended seeding 38 to 98 kg ha^{-1} zoysiagrass, whereas Landry and Choi (1995) found 98 kg ha^{-1} produced the highest shoot and root growth in the greenhouse. It is necessary to determine the acceptable range of seeding rates, potential benefits of higher seeding rates for hastening bermudagrass and zoysiagrass establishment, and the effect of seeding rate on winter survival.

Summer annual grassy weeds such as crabgrass (*Digitaria* spp.) germinate in late spring to early summer at the same time that is recommended to establish warm-season turfgrasses by seed. Therefore, weed control is essential for establishment of bermudagrass or zoysiagrass since competition with summer annual grassy weeds will significantly reduce establishment rates (Carroll et al., 1996; Johnson, 1973). There is little data on the use of herbicides on seedling bermudagrass and zoysiagrass, and current label recommendations specify use on established bermudagrass or zoysiagrass turf only. The preemergence herbicides siduron [1-(2-methylcyclohexyl)-3-phenylurea], oxadiazon [3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethyl)-1,3,4-oxadiazol-2-(3*H*)-one], diuron [N'(3,4-dichlophenyl)-*N,N*-dimethylurea], and prodiamine [2,4 dinitro-N^3, N^3–dipropyl-6-(trifluoromethyl)-1,3-benzenediamine] are toxic to bermudagrass seedlings (Fermanian et al., 1980; McCalla and Richardson, 2002). Siduron applied at seeding of 'Korean common' zoysiagrass allowed the most zoysiagrass coverage (Portz et al., 1981). However, siduron provides poor long-term control of annual grasses (Dernoeden, 1984). For postemergence control of weeds in bermudagrass seedlings, quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) produced less herbicide injury than metsulfuron (methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino] sulfonyl]benzoate) and diclofop [(±)-2-{4-(2,4-dichlorophenoxy)-phenoxy]propanoic acid] (McCalla and Richardson, 2002). The preemergence herbicide dithiopyr [*S,S*-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(triflurormethyl)-3,5-pyridinedicarbothioate] and postemergence herbicide quinclorac are two herbicides that control crabgrass safely in spring-seeded cool-season turf (Reicher et al., 1999) and should be evaluated for use on bermudagrass or zoysiagrass seedlings.

Understanding these factors affecting establishment of bermudagrass and zoysiagrass is necessary to optimize establishment. The objectives of our research were to: (i) identify the optimum seeding dates for successful establishment and winter survival; (ii) identify the length of time and GDD requirements for producing 95% coverage; (iii) determine if additional post-seeding N fertilization would accelerate establishment; (iv) identify the range of acceptable seeding rates and determine if a relationship exists between winter survival and seeding rate; and (v) evaluate annual grassy weed herbicides for their safety on seedling bermudagrass and zoysiagrass.

MATERIALS AND METHODS

Seeding date, seeding rate, and herbicide safety experiments were conducted at the W.H. Daniel Turfgrass Research and Diagnostic Center, West Lafayette, IN. The seeding date experiment was also conducted at the University of Kentucky Agriculture Experimental Station, Lexington, KY. The Kentucky study also evaluated the influence of post-seeding N fertility treatments. Soil types were a Stark silt loam (fine-silty mixed mesic Aeric Ochraqualfs with a pH of 6.8, 224 kg ha^{-1} P, 639 kg ha^{-1} K, and 29 g kg^{-1} organic matter) in Indiana and a Maury silt loam (fine mixed mesic Typic Paleudalf with a pH of 6.3, 565 kg ha^{-1} P, and 391 kg ha^{-1} K) in Kentucky. Experimental areas were fumigated with methyl bromide before establishment to minimize weed competition. Seeding rates were calculated using pure live seed. Visual estimates of percent coverage were arcsine transformed before analysis to improve the homogeneity of the error variance and then backtransformed and presented as backtransformed means for easier interpretation (Steel et al., 1997). Data from each experiment were analyzed by PROC ANOVA (SAS Institute, Cary, NC). Data were combined across years if error variances were homogenous. Error variances for Indiana seeding date and seeding rate data were homogenous and combined across years when presented graphically. Means were separated using Fisher's protected least significant difference when *F* tests were significant at $\alpha = 0.05$.

Seeding Date and Nitrogen Fertility

Experimental design in Indiana was a randomized complete-block design with three replications and plot size was 1.5 by 1.5 m. In Kentucky, 2 by 2 m plots were arranged in a split-plot design with seeding date and species as whole plots and N treatments as sub-plots. Plots were seeded in 2000 and 2001 with Mirage bermudagrass at 24 kg ha^{-1} and Zenith zoysiagrass at 49 kg ha^{-1} on 1 and 15 June, 1 and 15 July, 1 and 15 August, and 1 September ± 2 d. Indiana plots received 49 kg ha^{-1} N from urea (46-0-0) at seeding and every 15 d after seeding (DAS) with the last application on 15 September while Kentucky plots received 49 kg ha^{-1} N from urea at seeding and applied every 15 or 30 DAS with the final application on 30 September. Before seeding, soil in the appropriate plots was prepared using a garden rake and hoe. Plots were lightly raked after seeding to improve seed-to-soil contact. The experimental areas were irrigated as needed to encourage germination and establishment, and mowed as needed at 2.5 cm with clippings removed. Percent coverage of bermudagrass and zoysiagrass were visually rated on a 0 to 100% linear scale every 2 wk after seeding.

Growing degree days (GDD) were calculated using the formula GDD = [(Max. Temp. °C + Min. Temp. °C)/2] − 5°C. Daily GDD were calculated from seeding until the final rating date for both sites by subtracting a 5°C species-specific base temperature from the mean daily temperature (Gilmore and Rogers, 1958; Pruess, 1983; Unruh et al., 1996).

Seeding Rate

Experimental design was a randomized complete-block design with six treatments and three replications, and separate experiments for each species. Mirage bermudagrass was seeded on 6 July 2001 and 22 June 2002 at 12, 24, 49, 73, 98, and 146 kg ha^{-1} and Zenith zoysiagrass was seeded on 22 June in 2001 and 2002 at 24, 49, 98, 146, 195, and 293 kg ha^{-1}. Plots were 1- by 2-m plots and were covered with AgroFabric Pro17 (American Agrifabrics, Alpharetta, GA) germination blanket for 2 wk after seeding to limit contamination on adjacent plots. Plots received 49 kg ha^{-1} N with urea once every month after seeding with the last application on 22 August in both years. The experimental area was irrigated as needed to encourage germination and establishment, and mowed as needed at 1.3 cm with a reel-type mower with clippings removed. Visual

Table 1. Seeding and application dates of quinclorac and dithiopyr on newly seeded Mirage bermudagrass and Zenith zoysiagrass in the herbicide safety study.

	2000		2001	
Application timing†‡	Bermudagrass	Zoysiagrass	Bermudagrass	Zoysiagrass
Seeding date	8 June	1 June	9 July	29 June
PRE	8 June	1 June	9 July	29 June
0 WAE	19 June	19 June	18 July	18 July
1 WAE	27 June	27 June	26 July	26 July
2 WAE	4 July	4 July	2 Aug.	2 Aug.
3 WAE	11 July	11 July	8 Aug.	8 Aug.
4 WAE	18 July	18 July	15 Aug.	15 Aug.

† PRE, preemergence application immediately following seeding.
‡ WAE, weeks after emergence.

estimates of percent coverage were collected every 14 d as previously described. Tiller density was determined every 14 d by counting the number of tillers in three 5.0-cm diameter plugs removed from each plot. A grid was used to collect subsamples from three preselected locations in each plot, and subsampling location was moved from left to right across the plot for each collection date to prevent sampling from the same location twice. A tiller was defined as the initial plant plus any aerial shoots emerging from axillary buds or a shoot emerging from stolons.

Herbicide Safety

A 2 by 2 by 6 factorial design was used with two turfgrass species, two herbicides, and six application timings. Herbicide treatments included 0.84 kg ha^{-1} quinclorac and 0.56 kg ha^{-1} dithiopyr with applications immediately following seeding (PRE) or 0, 1, 2, 3, or 4 wk after emergence (WAE) $\pm$ 1 d (Table 1). An untreated check and a PRE application of siduron at 6.7 kg ha^{-1} were included for comparison. Plots were seeded with 24 kg ha^{-1} Mirage bermudagrass on 6 July 2000 and 2001 and 49 kg ha^{-1} Zenith zoysiagrass on 22 June 2000 and 2001, and received 49 kg ha^{-1} N with urea every 2 wk after seeding. Seeding dates were offset to accommodate species germination differences and facilitate herbicide applications to both species on the same date. The experimental area was irrigated as needed to encourage germination and establishment, and mowed as needed at 2.5 cm. Emergence was defined as a uniform stand of 1.3-cm-tall seedlings. Herbicides were applied with a 1.5-m boom with three flat fan nozzles in 815 L ha^{-1} water with a CO_2–pressurized sprayer at 207 kPa. A split-plot design was used with species as main plots and herbicide treatments as subplots. Three replications of main plots were used, and subplots measured 1.5 by 1.5 m. Visual estimates of zoysiagrass and bermudagrass coverage were recorded weekly as previously described until 7 WAE. Phytotoxicity was rated weekly on a scale of 1 to 9, where 1 = brown turf, 5 = acceptable damage, and 9 = no visible phytotoxicity.

RESULTS AND DISCUSSION

Seeding Date and Nitrogen Fertility

Bermudagrass coverage in October was greatest (>95%) when seeded as late as 1 Aug. 2000 and 15 July 2001 in Indiana and 1 July 2000 and 1 Aug. 2001 in Kentucky (Table 2). The seeding window for acceptable zoysiagrass establishment was narrower. Zoysiagrass seeded before 1 July in Indiana, 1 July 2000 and 15 June 2001 in Kentucky produced the highest coverage by first frost in October (Table 2). The question remained if bermudagrass and zoysiagrass seeded earlier than 1 June will provide adequate coverage by the first frost. An additional seeding date was added in Indiana in 2001, and both species seeded May 15 reached 98% coverage by first frost and were not significantly different than plots seeded 1 or 15 June (data not shown).

No bermudagrass survived either winter in Indiana, but bermudagrass survived both winters in Kentucky (Table 3). Bermudagrass seeded before 15 July 2000 in Kentucky provided the most coverage after winter when rated 10 May 2001 (Table 3), suggesting more winterkill from later seeding dates. Additionally, bermudagrass coverage in plots seeded before 15 Aug. 2001 was highest when rated 10 June 2002. Data from both years suggest that earlier seeding dates provide more bermudagrass cover after the first winter. This agrees with previous work suggesting planting bermudagrass earlier in summer increases winter hardiness (Ahring et al., 1975; Munshaw et al., 1998; Hensler et al., 1999; Richardson et al., 2003). Mirage bermudagrass produces few rhizomes during the initial year of planting (Munshaw et al., 2001)

Table 2. Effects of seeding date on coverage of Mirage bermudagrass and Zenith zoysiagrass rated before the first frost after seeding, and post seeding accumulated growing degree days (GDD) (5°C base) from planting date to the final rating date.

	Indiana		Kentucky	
Seeding date	2 Oct. 2000	2 Oct. 2001	22 Sep. 2000	3 Oct. 2001
	Backtransformed bermudagrass, % coverage			
1 June	99†a‡	98a	100§a	100a
15 June	99a	99a	100a	100a
1 July	99a	98a	100a	100a
15 July	98a	97a	95b	100a
1 Aug.	96a	94b	79c	100a
15 Aug.	91b	82c	17d	68b
1 Sept.	14c	8d	18d	28c
	Backtransformed zoysiagrass, % coverage			
1 June	100a	92a	91a	100a
15 June	97a	96a	96a	96b
1 July	79b	75b	80b	90b
15 July	33c	64b	44c	60c
1 Aug.	37c	28c	14d	47d
15 Aug.	6d	7d	2e	16e
1 Sept.	1e	1e	0f	7f
	Post seeding accumulated GDD			
1 June	1976	1971	2006	2172
15 June	1759	1773	1755	1947
1 July	1494	1498	1459	1663
15 July	1235	1275	1186	1413
1 Aug.	968	940	894	1067
15 Aug.	733	676	631	778
1 Sept.	436	388	323	462

† Means over three replications.
‡ Means over two nitrogen regimes and three replications.
§ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 3. Effects of seeding date on survival of Mirage bermudagrass evaluated the spring following establishment.

	Indiana		Kentucky	
Seeding date	15 June 2001	15 June 2002	10 May 2001	10 June 2002
	Backtransformed % coverage			
1 June	0†	0	89‡a§	89a
15 June	0	0	81b	75b
1 July	0	0	71c	82ab
15 July	0	0	56d	82ab
1 Aug.	0	0	70c	85ab
15 Aug.	0	0	0e	27c
1 Sept.	0	0	1e	0d

† Means over three replications.
‡ Means over two nitrogen regimes and three replications.
§ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

and stolons are the principal overwintering storage organ for bermudagrass (Dunn and Nelson, 1974). Therefore, winterkill in later seeding dates was most likely due to inadequate stolon fitness. Conversely, zoysiagrass survived both winters in Indiana and Kentucky regardless of seeding date (Table 4), which was expected given the increased winter tolerance of zoysiagrass relative to bermudagrass (Rogers et al., 1977).

Bermudagrass reached 95% coverage in 30 to 60 d after seeding when seeded from 1 June to 1 August in Indiana (Fig. 1a). Bermudagrass produced 95% coverage or more when accumulating >950 post-planting GDD (Table 2). In contrast to bermudagrass, zoysiagrass took 90 to 105 d to reach 95% coverage when seeded from 1 June to 15 June (Fig. 1b). This agrees with earlier research in Illinois showing zoysiagrass could reach 90% coverage 84 d after seeding (Portz et al., 1981). Zoysiagrass establishment was slower than bermudagrass to establish, requiring >1750 accumulated post-planting GDD to produce 95% coverage.

Nitrogen treatments did not affect establishment or winter survival of bermudagrass or zoysiagrass (data not shown). For each species, N effects were significant on only 1 of 14 rating dates, and N effects on coverage were inconsistent. Our results on Mirage bermudagrass were similar to those reported for 'Tifway' bermudagrass sprigs where establishment was not encouraged by increasing the monthly post-planting N applications from 49 to 98 kg ha^{-1} (Johnson, 1973). To maximize winter survival during the first winter following seeding of

Table 4. Effects of seeding date on survival of Zenith zoysiagrass evaluated the spring following establishment.

	Indiana		Kentucky	
Seeding date	15 June 2001	15 June 2002	10 May 2001	10 June 2002
	Backtransformed percent coverage			
1 June	84†a‡	95a	91§a	100a
15 June	88a	97a	89a	100a
1 July	63b	72b	78b	99a
15 July	37c	67b	34c	76b
1 Aug	23d	16c	1d	72b
15 Aug	0e	1d	0d	14c
1 Sept	1e	0d	0d	0d

† Means over three replications.
‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
§ Means over two nitrogen regimes and three replications.

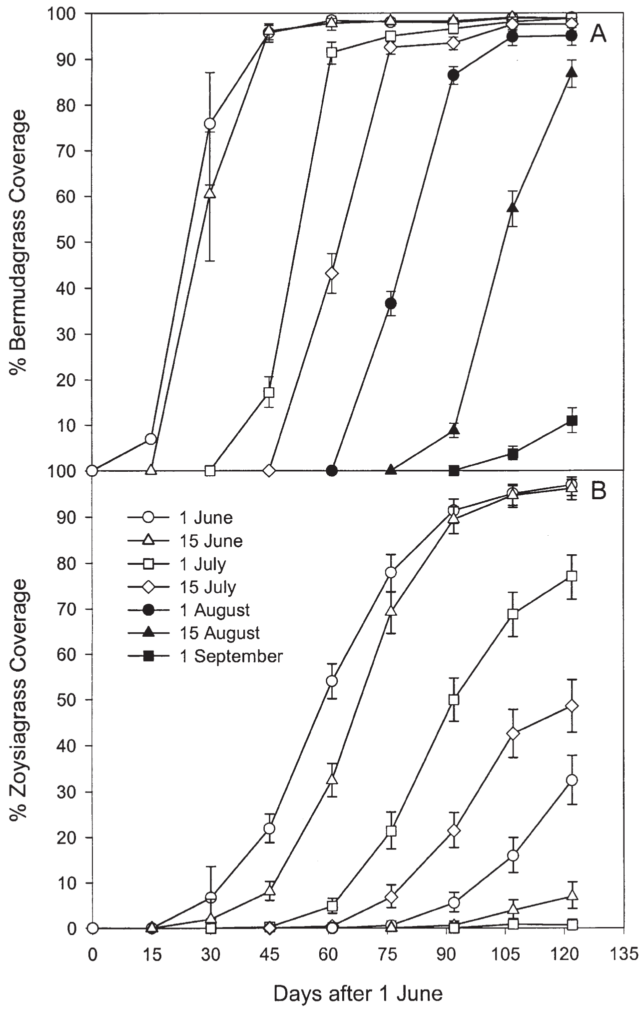

Fig. 1. Effects of seeding date on coverage of Mirage bermudagrass (A) and Zenith zoysiagrass (B) averaged over 2000 and 2001. Error bars equal one-half of the least significant difference (P = 0.05). Means are significantly different where error bars do not overlap.

bermudagrass, Munshaw et al. (2001) recommends using 49 kg ha^{-1} N twice monthly early in the growing season, then once monthly starting 1 July, and terminating N applications by the end of August. However, bermudagrass coverage following winter in May or June was not affected by the N fertility regime used in our study.

Results of this study indicate that increasing monthly N fertilization from 49 kg ha^{-1} to 98 kg ha^{-1} does not improve Zenith zoysiagrass establishment by seed. This is consistent with results of Richardson and Boyd (2001) who reported that increasing N from 25 to 50 kg ha^{-1} mo^{-1} did not significantly improve Meyer zoysiagrass coverage 120 d after sprigging. Fry and Dernoeden (1987) also found that increasing annual N rates from 48 kg ha^{-1} to 196 kg ha^{-1} or more during the initial growing season will not hasten establishment of Meyer sprigs. Most reports agree that some N fertilization is beneficial for zoysiagrass establishment, but applications should be kept to a minimum and not exceed 49 kg ha^{-1} mo^{-1}.

Seeding Rate

Higher seeding rates of bermudagrass or zoysiagrass initially produced higher tiller densities and coverage

(Fig. 2 and 3), which is similar to cool-season grasses (Madison, 1966; Parr, 1982). Tiller densities from higher seeding rates decreased for both species as the stand approached full coverage. This occurred 42 DAS for bermudagrass (Fig. 2) and 70 DAS for zoysiagrass (Fig. 3). The downward trend of tiller density was most likely due to an increased competition among plants resulting in self-thinning (Danneberger, 1993). Although tiller weights were not recorded in our study, our anecdotal observations agree with Lush (1990) who reported higher seeding rates result in stands with higher densities and low plant biomass, but eventually all seeding rates will produce similar biomass.

Seeded bermudagrass had strong stoloniferous growth during establishment that facilitated rapid turf coverage. Bermudagrass coverage 14 DAS was not enhanced by seeding more than 49 kg ha^{-1}, and all seeding rates produced similar coverage after 42 DAS (Fig. 2b). Tiller density from 49 kg ha^{-1} was similar to that of 73, 98, and 146 kg ha^{-1} 28 DAS and this continued through 84 DAS (Fig. 2a). If rapid coverage and higher densities are desired, seeding 49 kg ha^{-1} will provide coverage similar to higher seed rates 14 DAS and will provide significantly higher tiller densities than either 12 or 24 kg ha^{-1} until 70 DAS. Conversely, if budget is more important than rapid coverage, seeding 12 to 24 kg ha^{-1} is adequate since there was no difference in coverage among seeding rates 56 DAS, and no difference in tiller density between 12, 24, or 49 kg ha^{-1} 70 DAS or later.

Only 2% or less bermudagrass survived the winters in the seeding rate study (data not shown) indicating no clear relationship between seeding rate and winter survival in Indiana. Munshaw et al. (2001) recommend seeding 12 to 24 kg ha^{-1} to maximize stolon size and production and possibly reduce winterkill, but Brede (1994) found the greatest winter survival occurred when seeding 150 kg ha^{-1}. The winters during our study were too extreme for Mirage bermudagrass to survive, and we were unable to determine if seeding rate affects bermudagrass winter survival.

Zoysiagrass produces stolons and rhizomes similar to

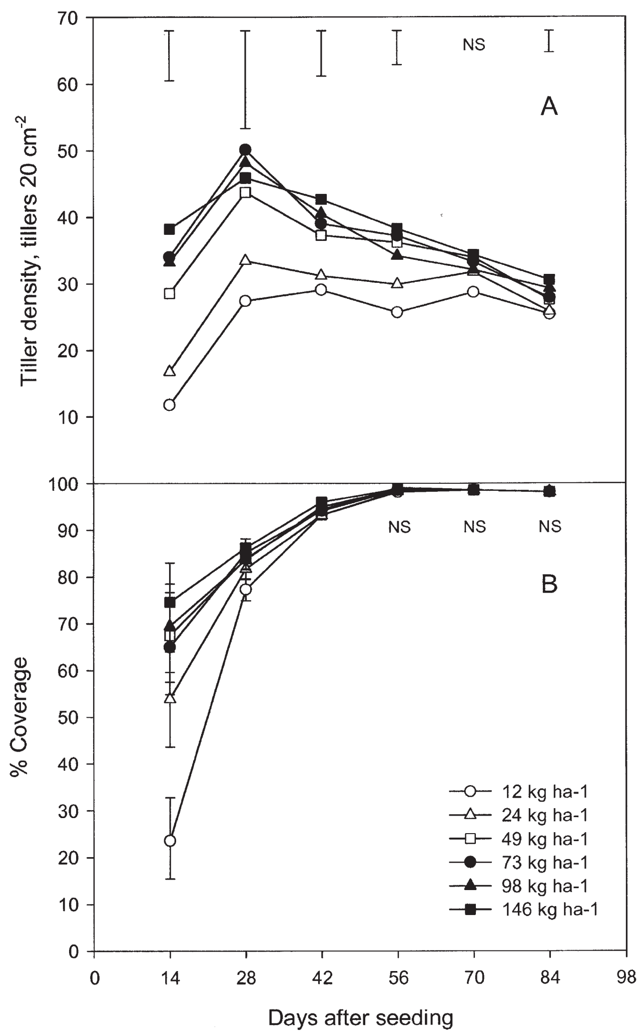

Fig. 2. Effects of seeding rate on Mirage bermudagrass tiller density (A) and backtransformed coverage (B) averaged over 2001 and 2002. Error bars equal one-half of the least significant difference (P = 0.05). Means are significantly different where error bars do not overlap.

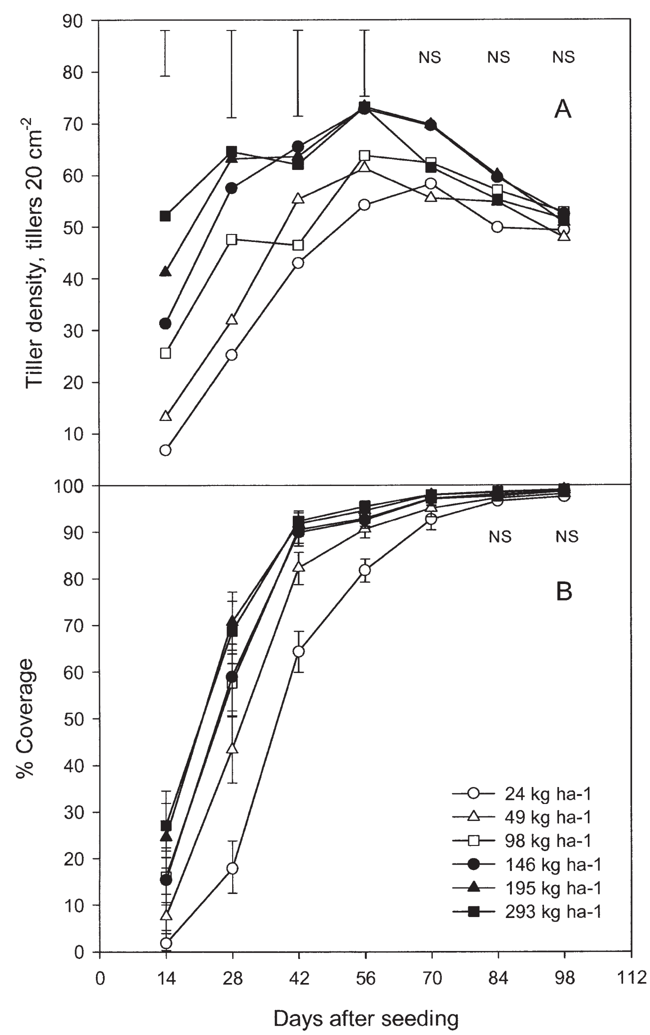

Fig. 3. Effects of seeding rate on Zenith zoysiagrass tiller density (A) and backtransformed coverage (B) averaged over 2001 and 2002. Error bars equal one-half of the least significant difference (P = 0.05). Means are significantly different where error bars do not overlap.

bermudagrass, but establishment is slower than bermudagrass. By 42 DAS, there was no improvement in coverage by seeding more than 98 kg ha^{-1} (Fig. 3b). Zoysiagrass seeded at 24 kg ha^{-1} produced significantly less coverage than 48 kg ha^{-1} until 70 DAS, therefore seeding 24 kg ha^{-1} should not be used where rapid establishment is required. This is in agreement with Portz et al. (1981) who recommended using 38 kg ha^{-1} or more when seeding zoysiagrass. Similarities in zoysiagrass coverage among all seeding rates did not occur until 84 DAS. Tiller density at 28 DAS was similar between 98 and 293 kg ha^{-1} (Fig. 3a). By 56 DAS, all seeding rates greater than 24 kg ha^{-1} produced similar tiller densities. Similar to Portz et al. (1981) and Landry and Choi (1995), zoysiagrass seeding rates of 49 to 98 kg ha^{-1} were optimum in our experiments. Zoysiagrass survived both winters without damage regardless of seeding rate.

Herbicide Safety

Bermudagrass coverage 3 wk after emergence (WAE) in 2000 was reduced by a PRE application of quinclorac, but this effect was short term (Table 5). Quinclorac had no negative effect on bermudagrass coverage regardless of application timing in 2001. Therefore, quinclorac can be applied to bermudagrass at 0 WAE or later without risk of damage, which agrees with recent greenhouse and field studies (Bayrer et al., 2002; McCalla and Richardson, 2002). Since quinclorac controls crabgrass (Enache and Ilnicki, 1991) as well as many broadleaf weeds (Neal, 1990), it is a useful establishment tool for practitioners.

Bermudagrass coverage 3 WAE was reduced when dithiopyr was applied PRE or 0 WAE in both years of the study (Table 5). However, by 7 WAE only the PRE treatment of dithiopyr reduced bermudagrass coverage. Therefore, dithopyr can be safely applied to bermudagrass seedlings 1 WAE or later. As was reported by others (Fermanian et al., 1980), the siduron standard treatment reduced bermudagrass coverage by 32% or more 3 WAE when compared to the untreated control.

Quinclorac had no effect on zoysiagrass in 2000. In 2001, quinclorac applied PRE reduced zoysiagrass coverage 3 WAE, but zoysiagrass recovered and was not affected 5 WAE or later (Table 6). Quinclorac can be safely applied 0 WAE to zoysiagrass seedlings. Conversely, dithiopyr applied PRE allowed a maximum of 5% coverage by the end of the experiments. Dithiopyr applied 0 WAE also reduced zoysiagrass coverage, allowing only 50% coverage by 7 WAE in 2000 and 87% coverage by 7 WAE in 2001. Coverage was not affected by dithiopyr applied 1 WAE or later. The effects of the siduron treatment were not different than that of the untreated control. This was expected since siduron is commonly used for preemergence weed control in zoysiagrass seedings (Portz et al., 1981; Maki et al., 1989; Zuk and Fry, 2002). Since weed competition was intentionally eliminated in our study, effects of early herbicide applications on bermudagrass or zoysiagrass coverage may be even more positive under weed pressure.

Seeding bermudagrass or zoysiagrass instead of sprigging or sodding will allow managers to establish these turfs quickly and at minimal cost. Under the conditions of our studies, optimum bermudagrass establishment occurs when seeded 1 June to 15 July at 12 to 49 kg ha^{-1}, when >950 GDD accumulate by first frost and when applying 49 kg ha^{-1} N mo^{-1}. Earlier seeding dates provide more bermudagrass cover after the first winter. For weed control in bermudagrass seedlings, quinclorac is safe on bermudagrass seedlings at 0 WAE or later,

Table 5. Backtransformed percent coverage of Mirage bermudagrass treated with quinclorac or dithiopyr at various times before and after seeding.

Herbicide	Application timing	2000 3 WAE	2000 5 WAE	2000 7 WAE	2001 3 WAE	2001 5 WAE	2001 7 WAE
		Backtransformed percent coverage					
Quinclorac	PRE†	98b‡	99a	100a	91a	94a	97a
	0 WAE§	100a	100a	100a	97a	96a	99a
	1 WAE	100a	100a	100a	94a	97a	100a
	2 WAE	98ab	99a	100a	94a	94a	98a
	3 WAE		100a	100a		95a	99a
	4 WAE		100a	100a		95a	99a
	Mean	99	99	100	94	95	99
Dithiopyr	PRE	1c	7c	45b	0c	4b	26b
	0 WAE	73b	93b	98a	82b	91	99a
	1 WAE	97a	98a	99a	94a	95a	100a
	2 WAE	99a	99a	100a	93a	95a	98a
	3 WAE		98a	100a		94a	98a
	4 WAE		98a	99a		97a	100a
	Mean	68	82	90	67	79	86
Siduron control		4	60	94	64	89	98
Untreated control		99	100	100	96	98	100
		ANOVA					
Source of variation							
Herb (H)		**	**	**	**	**	**
Timing (T)		**	**	**	**	**	**
H × T		**	**	**	**	**	**

** Significant at the 0.01 probability level.
† PRE, preemergence application immediately following seeding.
‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
§ WAE, weeks after bermudagrass seedling emergence.

Table 6. Backtransformed percent coverage of Zenith zoysiagrass treated with quinclorac or dithiopyr at various times before and after seeding.

Herbicide	Application timing	2000 3 WAE	2000 5 WAE	2000 7 WAE	2001 3 WAE	2001 5 WAE	2001 7 WAE
		Backtransformed percent coverage					
Quinclorac	PRE†	61a‡	89a	98a	82b	91a	98a
	0 WAE§	58a	88a	98a	84ab	92a	99a
	1 WAE	79a	95a	98a	91a	95a	99a
	2 WAE	68a	95a	97a	87ab	92a	100a
	3 WAE		97a	98a		94a	100a
	4 WAE		96a	99a		91a	97a
	Mean	67	93	98	86	93	99
Dithiopyr	PRE	0b	0c	5c	0c	1c	3c
	0 WAE	2b	9b	50b	66b	76b	87b
	1 WAE	72a	95a	97a	80a	93a	97a
	2 WAE	60a	93a	95a	83a	93a	98a
	3 WAE		95a	98a		90a	96a
	4 WAE		93a	95a		93a	99a
	Mean	34	64	73	57	74	80
Siduron control		82	92	98	88	94	99
Untreated control		84	98	98	84	93	99
		ANOVA					
Source of variation							
Herb (H)		**	**	**	**	**	**
Timing (T)		**	**	**	**	**	**
H × T		**	**	**	**	**	**

** Significant at the 0.01 probability level.
† PRE, preemergence application immediately following seeding.
‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
§ WAE, weeks after zoysiagrass seedling emergence.

and dithiopyr is safe when applied 1 WAE or later. Siduron is not safe when seeding bermudagrass. Optimum zoysiagrass establishment occurs when seeding from 1 to 15 June, seeding 49 to 98 kg ha^{-1}, when >1750 GDD accumulate by first frost, and when applying 49 kg ha^{-1} N mo^{-1}. For weed control in seedling zoysiagrass, applications of siduron PRE, quinclorac 0 WAE or later, or dithiopyr 1 WAE or later can be used safely.

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