Tolerance of Seedling Bermudagrass to Postemergence Herbicides

J. H. McCalla, Jr., M. D. Richardson,* D. E. Karcher, and J. W. Boyd

ABSTRACT

The introduction of improved seeded cultivars of bermudagrass [*Cynodon dactylon* (L.) Pers.] has generated significant interest from the turfgrass industry. An important component of successfully establishing these new cultivars will be to develop effective weed control strategies for the critical establishment period. A field study and a greenhouse study were conducted to evaluate the tolerance of several seeded bermudagrasses to commonly used postemergence herbicides at different periods of establishment. In a field study, 'Princess' bermudagrass was seeded at a rate of 48 kg ha^{-1} during the early summer of 2000 and 2001. Postemergence herbicides were applied at either 1, 2, or 4 wk after emergence (WAE). Herbicide treatments included MSMA (monosodium salt of methylarsonic acid) at 1.12 kg ha^{-1}, metsulfuron (2[[[[(4-methoxy-6-methyl-1,3,5-triazin-2yl] amino] carboxyl] amino] sulfonyl]-2-benzoic acid) at 0.021 kg ha^{-1}, diclofop ((±)-2-[4-(2,4-dichlorophenoxy) phenoxy]propanoic acid) at 1.12 kg ha^{-1}, clopyralid (3,6 dichloro-2-pyridinecarboxylic acid) at 0.56 kg ha^{-1}, dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.56 kg ha^{-1}, 2,4-D amine D [(2,4- dichlorophenoxy) acetic acid at 0.56 kg ha^{-1}, and quinclorac (3, 7-dichloro-8-quinolinecarboxylic acid) at 0.842 kg ha^{-1}. Visual injury ratings were recorded at 3, 5, 7, 15, and 30 d after treatment (DAT) and percent turfgrass cover was recorded at 30 and 60 DAT. In the greenhouse study, the same herbicides and treatments were used with the cultivars Princess, Yukon, NuMex Sahara, Jackpot, and Mirage. In both the field and greenhouse studies, there was no clear effect of application timing on the tolerance of seedling bermudagrass to herbicides. Diclofop and metsulfuron caused the highest levels of injury in both years of the field study and in the greenhouse study. The other herbicides tested caused less injury. The bermudagrass recovered from all herbicide injury by 30 d after treatment. The results from this study indicate that seedling bermudagrass is relatively tolerant of many commonly used postemergence herbicides as soon as 1 WAE. These results will be useful to turfgrass managers who are considering use of improved cultivars in various turf situations.

Bermudagrass (*Cynodon* spp.) is a widely adapted warm season turfgrass and is used in numerous applications from transition zone to tropical regions of the world (Beard, 1973). Until recently, seeded bermudagrass cultivars have not offered the quality or performance that vegetatively propagated hybrids and selections have shown for many years. Although lower quality seeded cultivars provided a turf adequate for home lawns and utility areas, they did not produce an acceptable turf for golf course, sportsfields, or other high-quality applications. Several public and private turfgrass breeding programs began an aggressive search for new strains of seeded bermudagrass with improved qualities.

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The National Turfgrass Evaluation Program (NTEP) routinely conducts cultivar trials in which a number of different grasses are rated for quality and performance across a wide range of climatic zones. Hybrid and seeded bermudagrasses have been evaluated in NTEP trials for approximately 20 yr. In early NTEP trials, the quality of seeded cultivars was well below the vegetatively propagated standards 'Tifway' and Midlawn (Morris, 1993). Mirage and Yukon seeded bermudagrass were tested in the 1992 bermudagrass trial and showed improved quality over earlier seeded cultivars such as 'Arizona Common' but still produced inferior quality to the vegetative standards (Morris, 1997). Several seeded cultivars were entered into the 1997 NTEP bermudagrass test (Morris, 2002). A select few of these seeded cultivars not only performed much better than older seeded types, but also performed as well as the established vegetative hybrids. Of the seeded cultivars, Princess and Rivera showed exceptional quality relative to the hybrids with very high shoot densities and dark green color. After 4 yr of testing across North America, Riviera and Princess were equal to Tifway bermudagrass in overall turfgrass quality and also had higher ratings than older seeded types (Morris, 2002). These major improvements in turf quality have stimulated considerable interest from the turfgrass industry, as a high quality bermudagrass turf is now possible using seeded cultivars.

Weed control is often a major problem when seeding a turfgrass (Ross and Lembi, 1999). Weeds cause numerous problems during turfgrass establishment because they often grow more aggressively than seedling turf, which can lead to thin stands, reduced growth, and reduced turfgrass quality. Although numerous studies have evaluated weed control strategies for established bermudagrass turf, minimal work has been done with seeded bermudagrass, especially during the critical establishment period.

Numerous studies have investigated the efficacy and safety of postemergence herbicides on established bermudagrass turf and many postemergence strategies are available for control of major weed species common to bermudagrass (Johnson, 1975; McCarty, 1992; Murdoch and Ikeda, 1974; Reicher and Hardebeck, 2000). However, applications of postemergence herbicides may lead to turfgrass injury in seedling grasses, including retardation of growth, altered plant development and, ultimately, plant death (Millhollon, 1985). Therefore, finding appropriate postemergence herbicides and application timings that minimize injury to bermudagrass seedlings is important. Developing effective weed control strategies to aid establishment of these seeded grasses will be critical to their long-term success. The objective of this study was to evaluate the tolerance of a seeded bermudagrass during three stages of development to seven commonly used postemergence herbicides.

MATERIALS AND METHODS

Field Study

A field study was conducted over two growing seasons (2000 and 2001) at the University of Arkansas Research and Extension Center, Fayetteville, AR. The soil at the site is captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) with an average pH of 6.2. Before planting, the site was fumigated with methyl bromide (67%) and chloropicrin (33%) at 392 kg ha^{-1}. Sterilization of the soil provided a weed-free seed bed so injury effects of various herbicides could be more easily measured.

Princess bermudagrass was chosen for this study because of its high turf quality and commercial availability. Princess was seeded at 48 kg ha^{-1} on 31 May 2000 and 1 June 2001 using a 90 cm wide drop-seeder (Scotts Drop Spreader, The Scotts Company, Marysville, OH). The granular fungicide, Subdue [(R)-2-[(2,6-dimethylphenyl)-methoxyacetyl-amino]-propionic acid methyl ester, common name metalaxyl, Syngenta Crop Protection, Greensboro, NC] was applied at 76.4 kg ha^{-1} at planting to prevent development of any seedling pathogens and diseases such as *Pythium* spp. The site was irrigated with an automated irrigation system to provide optimum moisture conditions for germination and establishment of the seed and to prevent water stress. Plots were amended with phosphorous and potassium before planting according to soil test recommendations. Nitrogen was applied, beginning 5 d after first emergence, as urea (46-0-0) and reapplied every 2 wk during the test at a rate of 23.7 kg N ha^{-1}. Plots were mowed three times a week with a reel mower set to a bench height of 1.25 cm with clippings returned.

Seven herbicide treatments were applied at 1, 2, and 4 WAE. Full emergence was considered the point where 75% of seedlings had emerged based on a visual analysis. This was accomplished by conducting a seedling count within a 10 cm^2 area and comparing the count to the number of live seeds planted. Plot size for all treatments was 1.22 × 1.52 m. Herbicides included MSMA (monosodium salt of methylarsonic acid) at 1.12 kg a.i. ha^{-1}, metsulfuron (2[[[[(4-methoxy-6-methyl-1,3,5-triazin-2yl] amino] carboxyl] amino] sulfonyl]-2-benzoic acid) at 0.021 kg a.i. ha^{-1}, diclofop ((±)-2-[4-(2,4-dichlorophenoxy) phenoxy]propanoic acid) at 1.12 kg ha^{-1}, clopyralid (3,6 dichloro-2-pyridinecarboxylic acid) at 0.56 kg ha^{-1}, dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.56 kg ha^{-1}, 2,4-D amine D [(2,4- dichlorophenoxy) acetic acid at 0.56 kg ha^{-1}, and quinclorac (3, 7-dichloro-8-quinolinecarboxylic acid) at 0.842 kg ha^{-1}. All herbicides were applied in a spray volume of 374 L ha^{-1} with a CO_2 sprayer using a single nozzle spray wand with an 8001 flat fan nozzle and a spray shield to prevent drift between plots. Four untreated plots were maintained and rated as the control. In 2000, the 1 WAE application was made on 14 June, the 2 WAE was made on 21 June and the 4 WAE was applied on 5 July and in 2001 the 1 WAE application was made on 16 June, the 2 WAE was made on 23 June and the 4 WAE was made on 7 July (Fig. 1).

Visual injury ratings were taken on all plots at 3, 5, 7, 15, and 30 DAT and percentage turfgrass cover was assessed at 30 and 60 DAT by digital image analysis (Richardson et al., 2001). Visual injury ratings were taken using a scale from 0 through 9 with 0 being no injury and 9 being death of all plants. In this study, any injury of 3 or below was considered to be an acceptable level of injury (Johnson, 1996).

The experimental design was a randomized complete block design with four replications of each herbicide × timing treatment. All data were analyzed by analysis of variance procedures and mean separation tests were conducted using Fisher's Protected LSD ($P = 0.05$). Although the two years were considered repeats of an experiment, the original analysis investigated the main effects of year as well as all year interactions. Year × herbicide × timing interactions were significant for most evaluation periods (data not shown) and data were subsequently analyzed by year.

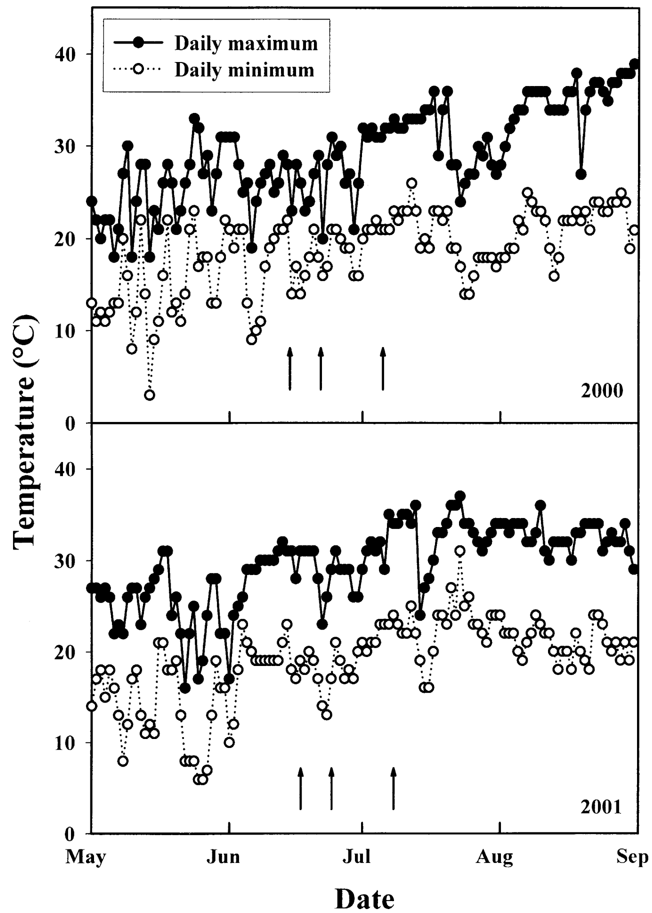

Fig. 1. Daily maximum and minimum temperatures for Fayetteville, AR, during the 2000 and 2001 growing seasons. Arrows indicate the 1, 2, and 4 wk after emergence herbicide application dates for each year.

Greenhouse Study

A greenhouse study was conducted to compare the tolerance of five seeded bermudagrass cultivars to the same herbicides used in the field study. The cultivars of seeded bermudagrass evaluated in the greenhouse were Princess, Yukon, NuMex Sahara, Mirage, and Jackpot.

All cultivars were seeded at a rate equivalent to 98 kg ha^{-1} into plastic growth trays containing 24, 7.62-cm^2 cells. The growth medium was 100% vermiculite and the seeds/seedlings were watered as needed during germination and throughout the study. Pots were drench-fertilized weekly using a soluble fertilizer (Miracle Gro, The Scotts Company) with an analysis of 15% N–30% P_2O_5–15% K_2O. The fertilizer solution was mixed to contain 100 mg N L^{-1}.

Herbicides were applied at either 1 or 2 WAE with a track-driven research spray chamber designed at the University of Arkansas (D. Oliver, personal communication) with a spray volume of 187 L ha^{-1}. Visual injury ratings were made at 3, 5, 7, 15, and 30 DAT. The same injury rating scale used in the field study was also used for the greenhouse study.

The experimental design was a completely randomized design with four replications of each cultivar × herbicide × timing treatment. All data were analyzed by analysis of variance procedures and mean separation tests were conducted by Fisher's Protected LSD ($P = 0.05$).

RESULTS AND DISCUSSION

Field Study

The analysis of variance indicated a significant effect of herbicide and timing and a herbicide × timing interaction on herbicide injury at most evaluation dates (Table 1). Although turfgrass establishment data was collected at 30 and 60 d after treatment, there was no significant herbicide or timing effect or interaction and all cover rates were in excess of 98% on both dates (data not shown). Because of the main effects interaction, the manuscript will primarily address those interactions between herbicide and application timing.

In 2000 and 2001, diclofop caused unacceptable injury to seedling turf, regardless of timing, with injury ratings approaching 6 to 7 in both years (Tables 2 and 3). The maximum effect of diclofop was observed between the 3 and 7 DAT timings for both seasons (Tables 2 and 3). Injury rating remained higher than the control at 15 DAT, but had declined to an acceptable level of injury at this rating in both seasons. Effects of application timing on herbicide injury were sporadic in both seasons. In 2000, the 1 and 2 WAE treatments caused more injury than the 4 WAE at 15 DAT but was not significant at other dates (Table 2). During the 2001 season, differences between the three timing treatments were not practically significant, although there were slight significant differences between timing treatments at some of the rating dates. In general, there was no specific trend that application timing date caused more injury than another.

Previous researchers have reported acceptable levels of injury when applying diclofop to established hybrid bermudagrass (McCarty et al., 1991; McCarty, 1991a; Murdoch and Nishimoto, 1982). Johnson (1996) reported that a single application of diclofop at 1.1 kg ha^{-1} was safe on established common bermudagrass. It is apparent from our study that seedling bermudagrass is more sensitive to diclofop than mature bermudagrass. Although the turf recovered from the diclofop injury within 60 d, the current recommendation would be to avoid applications of diclofop during establishment of bermudagrass unless goosegrass [*Eleusine indica* (L.) Gaertn.] was present in high concentrations. Goosegrass could be a significant competitor of seedling bermudagrass turf, leading to a significant reduction in turfgrass stand if left untreated. In cases with heavy infestations of goosegrass, the injury caused by diclofop would not be as damaging as the reduced stand caused by heavy competition from an aggressive weed such as goosegrass.

Metsulfuron also caused unacceptable levels of injury to the seedling bermudagrass in both seasons and the injury was generally most severe at 3 DAT (Tables 2 and 3). By 15 DAT, the seedlings had recovered to minimal levels of injury and the injury was almost completely dissipated by 30 DAT. In 2000, the 2 and 4 WAE timing treatments caused more injury than the 1 WAE treatment (Table 2). The 4 WAE treatments showed slightly higher levels of injury in 2000 possibly because of an increase in air temperature immediately following treatment (Fig. 1). However, in 2001, the 1 and 2 WAE treatments caused the most injury during the same pe-

Table 1. Analysis of variance testing the effects of herbicide and timing on the herbicide injury of seedling bermudagrasses.

	Days after treatment					
Source	3	5	7	15	30	Avg. injury
			2000			
Block	†NS	NS	NS	NS	NS	NS
Herbicide (H)	***	***	***	***	NS	***
Timing (T)	***	***	***	***	***	***
H × T	***	**	*	NS	*	NS
			2001			
Block	NS	NS	NS	NS	NS	NS
Herbicide (H)	***	***	***	***	NS	***
Timing (T)	***	***	NS	*	NS	***
H × T	NS	***	***	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant at the 0.05 level.

Table 2. Herbicide injury on 'Princess' seeded bermudagrass, as affected by seven postemergence herbicides applied at either 1, 2, or 4 wk after emergence (WAE) (2000).

	Days after treatment				
Timing	3	5	7	15	30
(WAE)	herbicide injury†				
			Diclofop		
1	5.5	4.5	5.5	2.8	0.5
2	6.3	5.5	3.8	1.8	0.0
4	5.3	3.5	2.8	0.0	0.0
LSD (0.05)	0.8	2.4	1.8	1.7	0.5
			Metsulfuron		
1	2.3	1.5	2.5	2.0	1.0
2	5.3	3.0	1.8	2.0	0.5
4	6.0	4.0	3.0	0.0	0.0
LSD (0.05)	1.6	1.6	1.8	2.2	1.4
			2,4-D		
1	0.4	2.0	3.3	2.0	0.0
2	1.3	2.0	3.0	1.5	1.0
4	4.3	3.0	0.0	0.0	0.0
LSD (0.05)	1.0	1.1	1.6	1.2	0.0
			Dicamba		
1	1.1	1.5	3.0	2.0	0.8
2	1.0	1.8	1.3	1.5	0.5
4	3.3	2.8	2.8	1.0	0.0
LSD (0.05)	1.7	0.8	1.3	3.4	0.7
			MSMA		
1	0.8	1.3	2.0	1.5	0.3
2	1.0	1.5	1.0	1.3	0.3
4	2.0	2.3	1.8	0.0	0.0
LSD (0.05)	1.1	0.8	1.2	0.9	0.7
			Clopyralid		
1	0.5	1.3	2.3	1.8	0.5
2	1.3	2.0	1.5	1.5	0.0
4	1.8	1.5	2.3	1.0	0.0
LSD (0.05)	1.1	1.0	1.4	0.9	0.5
			Quinclorac		
1	0.9	1.8	2.3	1.8	0.8
2	1.5	3.5	1.5	2.0	0.0
4	2.0	3.0	3.3	0.0	0.0
LSD (0.05)	1.2	1.5	1.6	0.6	0.5

† Herbicide injury was rated visually on a scale of 0 through 9, with 0 = no injury and 9 = complete death.

riod, even though temperature again increased at the 4 WAE treatment. The injury observed with metsulfuron in this study is slightly more severe than what had been observed on mature Tifway and 'Tifdwarf' bermudagrass (McCarty, 1991b). No strong conclusion could be stated that the timings we investigated had a predictable influence on the injury (Tables 2 and 3). However, injury observed in this study indicated that seedling turf has less tolerance to metsulfuron than previously reported for mature turf. Nonetheless, the turf recovered quickly from the injury and metsulfuron should not cause a serious problem during establishment.

Herbicide injury on plots treated with 2,4-D were highest between 3 and 5 DAT for timings across both years (Tables 2 and 3). Unacceptable levels of injury were observed at various times after treatment and varied according to timing. However, effect of timing was not consistent from year to year or within years, suggesting that most of the variability in the 2,4-D injury was attributable to random error. In 2000, an increase in air temperature following the 4 WAE treatments may have led to a slight increase in injury for the 3 and 5 DAT rating periods (Fig. 1). It should be noted that unacceptable levels of injury were only observed for short periods of time each year and were never considered a serious problem. Coats et al. (1985) found similar results on mature common bermudagrass, with injury from 2,4-D temporary and lasting only 2 wk. Much of the recent research involving 2,4-D has focused on its use in three-way herbicide combinations with dicamba and mecoprop. In those studies, it was found that the three way combinations caused more severe injury than 2,4-D alone but injury was also temporary (Bell et al., 2000; Coats et al., 1985; Johnson, 1995). Bermudagrass seedlings response to 2,4-D alone was similar to that reported for established bermudagrass. Injury was acceptable when 2,4-D was applied at 0.56 kg ha^{-1} but more research needs to be conducted to evaluate the response of seedling bermudagrass to different rates of 2,4-D and the response to three way combinations of 2,4-D, dicamba, and mecoprop.

Table 3. Herbicide injury on 'Princess' seeded bermudagrass, as affected by seven postemergence herbicides applied at either 1, 2, or 4 wk after emergence (WAE) (2001).

	Days after treatment				
Timing	3	5	7	15	30
(WAE)	herbicide injury†				
			Diclofop		
1	6.8	6.0	3.3	1.5	0.0
2	5.3	3.8	2.0	1.5	0.0
4	5.0	5.3	4.0	1.8	0.0
LSD (0.05)	2.2	1.8	0.9	0.9	0.0
			Metsulfuron		
1	6.0	5.0	2.5	1.8	0.0
2	5.3	2.5	1.5	1.8	0.0
4	3.3	3.3	2.0	1.3	0.0
LSD (0.05)	1.2	1.3	0.8	0.8	0.0
			2,4-D		
1	2.7	3.7	3.0	1.3	0.0
2	2.8	2.3	1.8	1.3	0.0
4	3.5	3.5	2.8	1.0	0.0
LSD (0.05)	3.4	3.6	3.6	3.6	0.0
			Dicamba		
1	2.3	2.3	2.0	1.5	0.0
2	1.8	1.8	1.0	1.5	0.0
4	2.0	1.8	1.0	1.0	0.0
LSD (0.05)	3.4	0.8	3.6	0.8	0.0
			MSMA		
1	2.0	1.0	1.3	1.5	0.0
2	1.0	1.3	2.3	2.8	0.0
4	2.0	2.0	1.0	0.8	0.0
LSD (0.05)	0.6	0.5	2.0	2.2	0.0
			Clopyralid		
1	2.8	1.3	1.0	1.3	0.0
2	1.0	1.0	2.5	2.3	0.0
4	2.0	2.0	1.5	1.0	0.0
LSD (0.05)	0.6	0.9	1.3	2.4	0.0
			Quinclorac		
1	2.8	2.0	1.5	1.3	0.0
2	1.5	1.3	1.3	1.5	0.0
4	3.0	3.0	2.5	1.3	0.0
LSD (0.05)	1.4	1.2	1.2	0.8	0.0

† Herbicide injury was rated visually on a scale of 0 through 9, with 0 = no injury and 9 = complete death.

Applications of dicamba generally caused minimal levels of injury to bermudagrass seedlings in both years, but unacceptable levels were observed at a few evaluation dates in 2000 (Tables 2 and 3). In 2000, the 4 WAE treatment caused more injury at 3 and 5 DAT than the other two timings, but there was no difference in treatment timing by 15 DAT (Table 2). In 2001, all injury was considered acceptable and there was no difference in the timing treatments (Table 3). These results are consistent with Johnson (1995) who found that four established seeded cultivars were tolerant to dicamba at the 0.6 kg ha^{-1} rate and that common bermudagrass was more susceptible than the improved seeded cultivars at that application rate. As with 2,4-D, the majority of recent research done with dicamba has focused on three-way combinations of dicamba with 2,4-D and mecoprop.

MSMA caused similar levels of injury in both 2000 and 2001, with injury levels ranging form 0.7 to 2.8 (Tables 2 and 3). Timing had no consistent effect on injury levels in either season, but there was a slight increase in injury in 2000 following the 4 WAE treatment. These results are similar to those of Bell et al., (2000), where MSMA was found to cause minimal injury on established Yukon bermudagrass. Injury caused by MSMA subsided completely by 30 DAT (Tables 2 and 3), similar to earlier reports (Nishimoto and Murdoch, 1994; Lowe et al., 2000). Collectively, these data suggest that MSMA can be safely used on seedling bermudagrass during establishment to control problematic weeds such as crabgrass (*Digitaria* spp).

Clopyralid caused minimal levels of injury to the seedling bermudagrass in both 2000 and 2001 (Tables 2 and 3). In addition, there were no significant affects of application timing on herbicide injury in either year (Tables 2 and 3). Observed injury was considered to be in the tolerable range for this herbicide. Johnson (2001) reported that clopyralid caused moderate discoloration to established common bermudagrass but full recovery occurred within 1 wk. In the present study, recovery was not complete until 15 DAT in 2000 and 30 DAT in 2001, suggesting that clopyralid injury is similar on

Table 4. Analysis of variance testing the effects of cultivar, herbicide, and timing on the herbicide injury of seedling bermudagrass in a greenhouse study.

	Days after treatment				
Source	3	5	7	15	30
Cultivar (C)	*	†NS	NS	*	***
Herbicide (H)	***	***	***	***	***
Timing (T)	***	***	***	***	***
C × H	NS	NS	**	NS	***
C × T	*	**	**	***	NS
H × T	***	***	***	***	***
C × H × T	NS	NS	NS	NS	*

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant at the 0.05 level.

both seedling and mature turf, but it took seedling turf longer to recover from the injury.

Quinclorac caused injury to the turf in both 2000 and 2001, especially at the early rating dates (Tables 2 and 3). In both years, injury had returned to acceptable levels by 15 DAT. A previous study demonstrated that seedling bermudagrass had good tolerance of quinclorac (Reicher and Hardebeck, 2000). Tifway bermudagrass has shown excellent tolerance to quinclorac and exhibited minimal phytotoxicity when applied at 4.48 kg ha^{-1} (McCarty, 1992). Johnson (1995,1996) reported that quinclorac caused significant injury on common bermudagrass when applied at 0.84 kg ha^{-1}. However, in that study, injury observed was ephemeral and was gone 2 wk after application. Results seen in this study and those of previous studies (McCarty, 1992; Johnson, 1995; Reicher and Hardebeck, 2000) demonstrate that quinclorac can be safely used on bermudagrass turf during the establishment stage.

Table 5. Herbicide injury, as affected by five seeded bermudagrass cultivars, averaged across seven postemergence herbicides in a greenhouse study. Herbicides were applied at either 1 or 2 wk after emergence (WAE).

	Days after treatment				
Timing	3	5	7	15	30
(WAE)			herbicide injury†		
			'Jackpot'		
1	1.8	1.5	1.6	1.9	1.9
2	1.7	2.3	2.1	2.1	2.1
LSD (0.05)	0.4	0.5	0.6	1.0	1.0
			'Mirage'		
1	1.4	1.5	1.6	2.2	1.8
2	2.0	2.7	2.3	2.4	2.2
LSD (0.05)	0.4	0.4	0.6	1.1	0.9
			'NuMex Sahara'		
1	1.3	1.6	1.8	2.2	1.6
2	1.9	2.3	2.1	2.2	2.3
LSD (0.05)	0.4	0.7	0.5	1.0	0.9
			'Princess'		
1	1.3	1.4	1.5	2.1	2.0
2	2.1	2.4	2.2	2.4	2.3
LSD (0.05)	0.4	0.5	0.6	1.2	1.2
			'Yukon'		
1	1.6	1.6	1.8	2.6	2.5
2	2.4	2.6	2.6	2.9	3.0
LSD (0.05)	0.5	0.5	0.6	1.2	1.5

† Herbicide injury was rated visually on a scale of 1 through 9, with 1 = no injury and 9 = complete death.

Greenhouse Study

Analysis of variance indicated a significant effect of herbicide, timing, and cultivar (Table 4). In addition, a significant cultivar × timing and herbicide × timing interaction was observed at all but one date that was rated. A significant cultivar × herbicide interaction was observed at the 7 and 30 DAT rating periods. The three-way interaction of cultivar × herbicide × timing was significant at the $P = 0.05$ level of probability at the 30 DAT rating only (Table 4). On the basis of the minimal effects of the three-way interaction, the data are presented as the cultivar × timing, herbicide × timing, and cultivar × herbicide interactions (Tables 5–7).

When averaged across herbicides, all cultivars responded similarly to the herbicides evaluated in this study (Table 5). Yukon showed a slightly higher injury response to the various herbicides than the other cultivars, but the injury level remained at or below acceptable levels (Table 5). Effects of timing on herbicide injury were similar across all cultivars, in that the 2 WAE treatment produced slightly higher injury ratings than the 1 WAE treatment (Table 5). Jackpot and NuMex Sahara had the fewest evaluation dates where timing was significant, while all of the other cultivars had differences due to timing on three evaluation dates. It is unclear why seedlings treated at 2 WAE would be more susceptible to herbicide injury than the 1 WAE treat-

Table 6. Herbicide injury, as affected by seven postemergence herbicides, averaged across all five seeded bermudagrass cultivars in a greenhouse study. Herbicides were applied at either 1 or 2 wk after emergence (WAE).

	Days after treatment				
Timing	3	5	7	15	30
(WAE)			herbicide injury†		
			Quinclorac		
1	1.3	1.4	1.5	1.1	1.1
2	1.7	1.9	1.5	1.3	1.4
LSD (0.05)	0.4	0.4	0.4	0.3	0.4
			Metsulfuron		
1	1.3	1.4	1.6	2.8	2.5
2	2.0	2.8	2.9	3.0	2.6
LSD (0.05)	0.5	0.4	0.5	0.6	0.6
			Diclofop		
1	2.3	2.7	2.7	6.7	6.0
2	2.5	3.9	4.9	6.5	6.8
LSD (0.05)	0.5	0.4	0.5	1.0	1.5
			Dicamba		
1	1.3	1.5	1.5	1.3	1.0
2	2.2	2.2	1.8	1.7	1.7
LSD (0.05)	0.5	0.6	0.6	0.6	0.4
			2,4-D		
1	1.2	1.1	1.2	1.4	1.1
2	1.2	2.3	2.1	2.0	1.7
LSD (0.05)	0.4	0.5	0.5	0.8	0.4
			MSMA		
1	1.5	1.4	1.6	1.2	1.1
2	1.9	2.5	1.6	1.3	1.2
LSD (0.05)	0.4	0.5	0.4	0.3	0.2
			Clopyralid		
1	1.4	1.2	1.5	1.1	1.0
2	1.9	1.9	1.3	1.2	1.4
LSD (0.05)	0.4	0.4	0.4	0.2	0.3

† Herbicide injury was rated visually on a scale of 1 through 9, with 1 = no injury and 9 = complete death.

Table 7. Herbicide × cultivar effects on herbicide injury of seedling bermudagrass at the 7 and 30 d after treatment (DAT) evaluation dates.

Herbicide	Jackpot	Mirage	NuMex Sahara	Princess	Yukon	LSD (0.05)	Jackpot	Mirage	NuMex Sahara	Princess	Yukon	LSD (0.05)
	herbicide injury† at 7 DAT						herbicide injury at 30 DAT					
2,4-D	1.3	1.8	1.8	1.5	2.2	NS‡	1.1	1.4	1.1	1.4	2.2	NS
Clopyralid	1.3	1.4	1.5	1.4	1.4	NS	1.0	1.1	1.3	1.5	1.4	NS
Dicamba	1.1	1.3	1.6	1.4	2.6	0.7	1.3	1.1	1.1	1.1	2.4	NS
Diclofop	3.8	3.6	3.5	4.0	3.4	NS	5.5	5.6	5.3	6.9	4.9	2.1
MSMA	1.7	1.8	1.9	1.3	1.6	NS	1.4	1.0	1.0	1.1	1.6	NS
Metsulfuron	2.3	2.5	2.0	2.0	2.1	NS	2.6	2.5	2.9	1.9	2.4	NS
Quinclorac	1.4	1.4	1.5	1.4	1.9	NS	1.0	1.1	1.0	1.2	1.6	NS
LSD (0.05)	0.8	0.9	2.0	0.8	1.0		0.9	0.8	1.0	1.1	0.7	

† Herbicide injury was visually rated on a scale of 1–9 with 9 being total death and 1 being no injury.
‡ NS, nonsignificant at the 0.05 level.

ment, but it was consistent across most cultivars. Differences due to timing were not consistent in the field study (Table 2 and 3), which suggests these results could be an anomaly of greenhouse-grown plants. One hypothesis is that herbicide absorption is somehow limited soon after emergence because of limited leaf development. Another hypothesis is that the increased amount of leaf area observed in the later treatments may lead to higher herbicide absorption and subsequently more injury. From a practical standpoint, it can be concluded that herbicide injury is level for all cultivars and both timing periods and timing should not be considered a great concern.

When averaged across cultivars, all herbicides produced noticeable levels of injury on the seedling turf, regardless of timing (Table 6). Diclofop caused the highest level of injury in the greenhouse study, similar to what was observed under field conditions. However, in the greenhouse, diclofop actually caused some plant death in individual plots and caused very high levels of injury across cultivars (Table 6). The greenhouse environment may have caused a slight change in seedling development, which predisposed it to more herbicide injury than in the field study. However, the conclusion remains that diclofop should only be used on seedling bermudagrass under severe pressure from goosegrass. Metsulfuron was the only other herbicide that caused injury levels in the unacceptable range, which is similar to field results.

A significant timing effect was observed at specific observation dates for all of the herbicides (Table 6). In most cases, the 2 WAE treatment again caused slightly more injury than the 1 WAE treatment. However, there were no clear cases where application timing of a specific herbicide made a large biological impact on the degree of turf injury.

The herbicide by cultivar interaction was only significant at the 7- and 30-DAT evaluation periods (Table 7). At 7 DAT, the primary difference between cultivars was the response to dicamba, with Yukon being slightly more susceptible than the other cultivars. At 30 DAT, the only significant differences were observed with diclofop, where Princess was more sensitive than Yukon, with all other cultivars having an intermediate response (Table 7). While these differences may be statistically significant at these single dates, it is doubtful they have great practical significance, since there were not observed at any other rating date.

CONCLUSIONS

Herbicide injury was observed on seedling bermudagrass turf using several postemergence herbicides, including diclofop, metsulfuron, 2, 4-D, and dicamba. However, all plots recovered fully from herbicide injury by 30 DAT, indicating that the injury will not prevent establishment of the turf. Diclofop caused injury to seedling bermudagrass in both field and greenhouse studies and even caused some plant death in greenhouse work. However, this injury was temporary in field situations and had largely disappeared by 30 DAT. Since this herbicide is one of the most widely used postemergence goosegrass control materials, managers should be aware that temporary injury will occur if this herbicide is used on seedling bermudagrass.

Results from the greenhouse study firmly support the field studies. Responses to these seven herbicides are consistent across at least five other seeded cultivars, demonstrating that all of these herbicides could be used to control weeds in seedling bermudagrass. Future studies should investigate other aspects of weed control for seedling bermudagrass including repeat applications of herbicides, dose–response issues, and tank-mixes of herbicides. In addition, more field data should be collected with these and other herbicides on a broad range of cultivars in field situations.

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REFERENCES

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice Hall Publishing, Englewood Cliffs, NJ.

Bell, G.E., D.L. Martin, R.M. Kuzmic, M.L. Stone, and J.B. Solie. 2000. Herbicide tolerance of two cold resistant bermudagrass (*Cynodon* spp.) cultivars determined by visual assessment and vehicle-mounted optical sensing. Weed Technol. 14:635–641.

Coats, G.E., J.H. Jordah Jr., and J.T. McGregor, Jr. 1985. Field evaluation of postemergence herbicides for Virginia buttonweed control in turf. Bull. Miss. Agric. For. Exp. Stn.: The Station. Apr. (937).

Johnson, B.J. 1975. Effects of herbicide treatments on the establishment of 'Tifway' bermudagrass. Agron. J. 23:462–464.

Johnson, B.J. 1995. Frequency of Drive (quinclorac) treatments on common bermudagrass tolerance on large crabgrass. J. Environ. Hortic. 13:104–108.

Johnson, B.J. 1996. Tank-mixed herbicides for large crabgrass (*Dig-*

itaria sanguinalis) and goosegrass (*Eleusine indica*) control in bermudagrass (*Cynodon dactylon*) turf. Weed Technol. 10:716–721.
Johnson, B.J. 2001. Effects of herbicide treatments on suppression of seashore paspalum (*Paspalum vaginatum*) in bermudagrass (*Cynodon* spp.). Weed Technol. 15:63–169.
Lowe, D.B., T. Whitwell, S.B. Martin, and L.B. McCarty. 2000. Yellow nutsedge (*Cyperus esculentus*) management and tuber reduction in bermudagrass (C*ynodon dactylon* × *C. transvaalensis*) turf with selected herbicide programs. Weed Technol. 14:72–76.
McCarty, L.B., L.C. Miller, and D.L. Colvin. 1991. Bermudagrass (*Cynodon* spp.) cultivar response to diclofop, MSMA, and metribuzin. Weed Technol. 5:27–32.
McCarty, L.B. 1991a. Goosegrass (*Eleusine indica*) control in bermudagrass (*Cynodon* spp.) turf with diclofop. Weed Sci. 21:537–541.
McCarty, L.B. 1991b. Metsulfuron for prostrate spurge control in bermudagrass. Proc. South Weed Soc. 44:180.
McCarty, L.B. 1992. Quinclorac evaluations in warm-season turfgrasses. Proc. South Weed Soc. 45:136.
Millhollon, R.W. 1985. Progressive kill of rhizomatous johnsongrass (*Sorghum halepense*) from repeated treatment with dalapon, MSMA, or asulam. Weed Sci. 33:216–221.
Morris, K.N. 1993. National Turfgrass Evaluation Program. 1986 National Bermudagrass Test. NTEP No. 93–1. USDA, Beltsville, MD.
Morris, K.N. 1997. National Tufgrass Evaluation Program. 1992 National Bermudagrass Test. NTEP No. 97–9. USDA, Beltsville, MD.
Morris, K.N. 2002. National Turfgrass Evaluation Program. 1997 National Bermudagrass Test. NTEP No. 02–7. USDA, Beltsville, MD.
Murdoch, C.L., and D. Ikeda. 1974. Goosegrass control in bermudagrass turf with combinations of MSMA and s-triazines. Agron. J. 66:712–714.
Murdoch, C.L., and R.K. Nishimoto. 1982. Diclofop for goosegrass control in bermudagrass putting greens. HortScience 17:914–915.
Nishimoto, R.K., and C.L. Murdoch. 1994. Smutgrass (*Sporobolus indicus*) control in bermudagrass (*Cynodon dactylon*) turf with triazine-MSMA applications. Weed Technol. 8:836–839.
Reicher, Z., and G. Hardebeck. 2000. Safety of Drive and Dimension on newly seeded bermudagrass and zoysiagrass. 2001 Annual Report-Purdue University Turfgrass Science Program: 59–65.
Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888.
Ross, M.A., and C.A. Lembi. 1999. Applied weed science. Prentice Hall, Upper Saddle River, NJ.