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# Efficacy of Two Dithiopyr Formulations for Control of Smooth Crabgrass [*Digitaria ischaemum* (Schreb) Schreb. ex Muhl.] at Various Stages of Growth

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***Abstract*. Although dithiopyr has been used for smooth crabgrass [*Digitaria ischaemum* (Schreb) Schreb. ex Muhl.] control for many years, data describing the efficacy of a new, water-based formulation of dithiopyr for smooth crabgrass control are limited. Research was conducted in Knoxville, TN, and Griffin, GA, evaluating water-based and wettable powder dithiopyr formulations at 0.56 and 0.43 kg·ha$^{-1}$ for smooth crabgrass control when applied at the pre-emergence (PRE), one- to two-leaf (1LF), one- to two-tiller (1TL), and greater than three-tiller (3TL) stages of growth. These treatments were compared with quinclorac (0.84 kg·ha$^{-1}$) applied at the same POST timings (i.e., 1LF, 1TL, and 3TL). When applied PRE, all dithiopyr treatments provided greater than 85% smooth crabgrass control at the end of the trial in both locations. At the 1LF stage, both rates and formulations of dithiopyr provided greater than 93% smooth crabgrass control at 4 weeks after application and greater than 77% at the end of the trial. Applied at the 1TL stage in Tennessee, no differences in smooth crabgrass control were detected between quinclorac and any dithiopyr treatment at the end of the trial; when applied in Georgia at the 1TL stage, quinclorac provided greater smooth crabgrass control at the end of the trial than either rate or formulation of dithiopyr. Although no differences were detected between any dithiopyr treatment and quinclorac applied at the 3TL stage in Tennessee, smooth crabgrass control at the end of the trial measured less than 70% for all treatments. At the end of the trial in Georgia, smooth crabgrass control with quinclorac (91%) was greater than both formulations of dithiopyr. These findings suggest that both the wettable powder and water-based formulations of dithiopyr can be used to effectively control smooth crabgrass at the PRE and 1LF stages of growth, but quinclorac should be selected over dithiopyr for control of tillering smooth crabgrass plants. Turfgrass managers should implement smooth crabgrass control measures at PRE and 1LF timings, because erratic responses can be observed with both dithiopyr and quinclorac applications to smooth crabgrass after tillering. Chemical names used: dithiopyr (S,S-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinedicarbothioate); quinclorac (3,7-dichloro-8-quinolinecarboxylic acid).**

Smooth crabgrass [*Digitaria ischaemum* (Schreb) Schreb. ex Muhl.] infestations are common in golf course, athletic field, and landscape turf (McCarty et al., 2005). Smooth crabgrass is similar to large crabgrass (*Digitaria sanguinalis* L. Scop.); however, leaves of large crabgrass are densely covered in hairs (McCarty et al., 2005). A summer annual weed, smooth crabgrass exhibits a light green color, coarse leaf texture, and produces unsightly seed heads that reduce turfgrass aesthetic and functional quality (Hall et al., 1994). More importantly, in the transition zone and southern United States, smooth crabgrass aggressively competes with bermudagrass (*Cynodon* spp.) for light, water, and nutrients (Hall et al., 1994).

Commonly used herbicides for selective postemergence (POST) control of smooth crabgrass in bermudagrass include quinclorac and MSMA (McCarty et al., 2005). Quinclorac is a quinolinecarboxylic acid herbicide that causes cyanide accumulation in susceptible grasses, leading to phytotoxicity, root and shoot growth inhibition, and eventual necrosis (Ferrell et al., 2003; Grossman, 1998; Koo et al., 1994; Senseman, 2007). Quinclorac has been shown to provide effective POST control of smooth crabgrass in various cool- and warm-season turfgrasses (Chism and Bingham, 1991; Dernoeden et al., 2003; Enache and Ilnicki, 1991; Hart et al., 2004; Johnson, 1994a, 1994b, 1995, 1996; Reicher et al., 1999); however, turfgrass injury after treatment with quinclorac has been reported to vary considerably. For example, Johnson (1997) reported as high as 65% centipedegrass [*Eremochloa ophiuroides* (Munro) Hack] injury after treatment with quinclorac at 0.84 kg·ha$^{-1}$. Reicher et al. (2002) suggested that caution be exercised when applying quinclorac in regions where elevated air temperatures occur early in the growing season. Warm air temperatures could explain the increased levels of turf injury that have been observed with quinclorac applications to certain bermudagrass cultivars in the transition zone (Johnson, 1995, 1996; McElroy et al., 2005).

Although MSMA has been commonly used for POST smooth crabgrass control in bermudagrass turf, a U.S. Environmental Protection Agency (EPA) ruling determined that applications of MSMA for turfgrass weed control would not be legal after 2013 (U.S. EPA, 2009). Research investigating alternative smooth crabgrass control options is needed, because biotypes of quinclorac-resistant smooth crabgrass have been reported (Abdallah et al., 2006; Heap, 2010) and could become more widespread should practitioners rely solely on quinclorac for POST control of smooth crabgrass.

Dithiopyr is a pyridine herbicide labeled for pre-emergence (PRE) and early POST (from emergence until the one-tiller growth stage) control of smooth crabgrass in warm and cool-season turf (Anonymous, 2008a). Despite this labeling, turfgrass managers in the southeastern United States have recently reported that PRE applications of dithiopyr often fail to provide commercially acceptable smooth crabgrass control for an entire growing season (J.T Brosnan and P.E. McCullough, personal observation). From a POST perspective, researchers have reported dithiopyr efficacy against newly germinated smooth crabgrass seedlings (Enache and Ilnicki, 1991; Johnson, 1996, 1997; Reicher et al., 1999); however, the majority of data describing dithiopyr efficacy is specific to the emulsifiable concentrate and wettable powder (dithiopyr 40WP) formulations that have been used in the turfgrass industry for several years. A new, water-based formulation of dithiopyr (dithiopyr 2EW) received EPA labeling in May 2008 (Anonymous, 2008a). Published data describing the PRE and POST efficacy of this new formulation are limited.

Dithiopyr applications have been reported to negatively affect bermudagrass growth. Johnson (1995) reported severe reductions (greater than 20%) in the quality of the seeded bermudagrass cultivars Common, Cheyenne, Tropica, and Sahara treated with an older formulation of dithiopyr at 0.8 kg·ha$^{-1}$. Johnson (1997) observed greater than 15% bermudagrass injury 2 weeks after treatment with dithiopyr at 0.6 kg·ha$^{-1}$ as well. Although researchers have evaluated the effects of emulsifiable concentrate and wettable powder

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formulations of dithiopyr on the root development and establishment rate of hybrid bermudagrasses (Dernoeden et al., 1984; Fagerness et al., 2002; Ferrell et al., 2003; McCullough et al., 2007), data describing the tolerance of established common and hybrid bermudagrasses to the new, water-based formulation of dithiopyr are limited. Therefore, the objective of this research was to evaluate the efficacy and bermudagrass turf safety of a new, water-based formulation of dithiopyr applied for smooth crabgrass control at various stages of growth.

## Materials and Methods

*Research site.* Experiments were conducted on a mature stand of 'Yukon' seeded bermudagrass (*Cynodon dactylon* L.) from Mar. to Sept. 2009 at the University of Tennessee–Knoxville established on a Sequatchie loam soil (fine-loamy, siliceous, semiactive, thermic humic Hapludult) measuring 6.2 in soil pH and 2.1% in organic matter content. The experiment was replicated at the University of Georgia–Griffin on a mature stand of 'Tifsport' hybrid bermudagrass (*C. dactylon* × *C. transvaalensis* Burtt-Davy) established on a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) with 4.6% organic matter and a pH of 5.6. Irrigation at each location was applied to prevent wilt and both sites were mowed weekly at a 16-mm height with clippings returned.

At both locations, the experimental design was a randomized complete block with three replications. Herbicide treatments included dithiopyr 2EW (0.56 and 0.43 kg·ha$^{-1}$) and dithiopyr 40WP (0.56 and 0.43 kg·ha$^{-1}$) applied at the pre-emergence (PRE), one- to two-leaf (1LF), one- to two-tiller (1TL), and greater than three-tiller (3TL) stages of smooth crabgrass growth. These treatments were compared with quinclorac (dry flowable formulation at 0.84 kg·ha$^{-1}$) applied at the same POST timings (i.e., 1LF, 1TL, and 3TL). Dithiopyr treatments were applied without a surfactant. In accordance with the product label, all quinclorac treatments were applied with a methylated seed oil surfactant at a rate of 1.5 L·ha$^{-1}$ (Anonymous, 2008b). Treatments were applied with a $CO_2$-powered boom sprayer calibrated to deliver 281 L·ha$^{-1}$ at the Tennessee location and 374 L·ha$^{-1}$ at the Georgia location. In the southeastern United States, practitioners commonly apply herbicides at carrier volumes ranging from 280 to 375 L·ha$^{-1}$ (J.T. Brosnan, personal observation). Sprayers in Georgia and Tennessee had 9504E and 8002 flat-fan nozzles, respectively (Tee Jet; Spraying Systems Co., Roswell, GA). Plots in Tennessee measured 1.5 × 3.0 m, whereas those in Georgia measured 1.0 × 3.0 m. Application dates and environmental conditions at application are presented in Table 1.

*Data collection.* Smooth crabgrass control and bermudagrass injury were assessed visually, because Yelverton et al. (2009) reported that visual ratings of herbicide responses in turf were significantly correlated with those quantified using the line intersect method or digital image analysis. Treated plots were rated relative to an untreated control on a percent scale, in which 0 equaled no smooth crabgrass control or turf injury and 100 equaled complete smooth crabgrass control or dead turf. Plots were evaluated every 2 weeks after application (WAA). For clarity, only evaluations made 4 WAA are presented here in addition to an end-of-trial rating made 10 weeks after the final application at each location. These data were selected to illustrate activity after application and season-long control.

*Statistical analysis.* Data from each location were subjected to arcsine square root transformations to stabilize variance (Ahrens et al., 1990). Interpretations were not different from nontransformed data; therefore, nontransformed means are presented here for clarity. Data from the untreated control were excluded from statistical analysis to stabilize variance as well (Corbett et al., 2004). Data were subjected to analysis of variance using the general linear model procedure in SAS (SAS Institute, 2006) with main effects and all possible interactions tested using the appropriate expected mean square values as described by McIntosh (1983). Single df contrasts ($\alpha = 0.05$) were used to evaluate preplanned comparisons embedded within the treatment structure. Significant location-by-treatment interactions were detected for smooth crabgrass control and bermudagrass injury; thus, data from each location were analyzed and are presented individually.

## Results and Discussion

*Control with pre-emergence applications.* No significant differences were reported between PRE treatments of dithiopyr in Tennessee. At the conclusion of the trial, all PRE treatments provided greater than 85% control of smooth crabgrass (Table 2). Similar control has been reported with older formulations of dithiopyr applied for large crabgrass (*Digitaria sanguinalis* L. Scop.) (Enache and Ilnicki, 1991; Reicher et al., 1999) and smooth crabgrass (Dernoeden, 2001). PRE treatments responded similarly in Georgia, because all treatments controlled smooth crabgrass greater than 86% at the end of the study (Table 2).

*Control with applications at the one-leaf growth stage.* In Tennessee, no differences were detected between dithiopyr treatments at the 1LF growth stage; all provided greater than 95% control of smooth crabgrass 4 WAA and greater than 83% control at the conclusion of the trial (Table 2). Enache and Ilnicki (1991) and Reicher et al. (1999) reported similar responses with older dithiopyr formulations applied for large crabgrass control in cool-season turf. Data collected in this study differ from those reported by Johnson (1997) for a 2-year study evaluating POST applications of dithiopyr (formulated as an emulsifiable concentrate) at 0.56 kg·ha$^{-1}$ for large crabgrass control in centipedegrass. Johnson (1997) reported greater than 82% large crabgrass control 4 weeks after treating plants at the three- to five-leaf stage of growth, but less than 21% control 15 WAA. The reduced level of season-long control reported with POST applications of dithiopyr in centipedegrass may be related to turf competition. Centipedegrass exhibits a slower growth habit than bermudagrass (Beard, 1973) and may have not been able to fill in the voids remaining after large crabgrass had been controlled, therefore allowing voids in the canopy for other large crabgrass seedlings to become established. In the same 2-year study, Johnson (1997) reported that quinclorac applied at 0.84 kg·ha$^{-1}$ provided less than 49% large crabgrass control 14 WAA and associated the poor control with the high degree of centipedegrass injury observed after application (greater than 50%).

Smooth crabgrass control by the end of the study with dithiopyr applications at the 1LF and PRE stages were similar in Tennessee (Table 2). At the end of the trial, no differences in smooth crabgrass control were detected between dithiopyr formulations (2EW versus 40WP) applied at the 1LF stage in Tennessee; however, both rates of the wettable powder formulation and the 0.43 kg·ha$^{-1}$ rate of the

Table 1. Calendar dates and environmental conditions for herbicide applications for control of smooth crabgrass in Tennessee and Georgia in 2009.

| | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tennessee | | | | Georgia | | | |
| Smooth crabgrass growth stage | Date | Air temp[z] (°C) | Soil temp[y] (°C) | Relative humidity (%) | Date | Air temp (°C) | Soil temp (°C) | Relative humidity (%) |
| Pre-emergence (PRE) | 17 Mar. | 20 | 15 | 38 | 9 Mar. | 28 | 17 | 55 |
| 1- to 2-leaf stage (1LF) | 13 Apr. | 16 | 13 | 60 | 16 Apr. | 21 | 16 | 44 |
| 1- to 2-tiller stage (1TL) | 5 May | 17 | 16 | 88 | 27 May | 23 | 23 | 82 |
| Greater than 3 tillers (3TL) | 3 June | 35 | 31 | 60 | 17 June | 32 | 27 | 54 |

[z]Air temperature and relative humidity measured using a handheld weather meter (Kestrel 3000; Nielsen Kellerman Inc., Boothwyn, PA) immediately after herbicide application.
[y]Soil temperature measured at 2.54-cm depth using a handheld digital soil thermometer immediately after herbicide application.

Table 2. Smooth crabgrass control after herbicide applications at various stages of growth in Tennessee and Georgia in 2009.

| | | | Smooth crabgrass control | | | |
|---|---|---|---|---|---|---|
| | | | Tennessee | | Georgia | |
| | | Rate | 4 WAA[z] | End of trial[y] | 4 WAA | End of trial |
| Timing | Treatment | (kg·ha$^{-1}$) | (%) | | | |
| PRE[x] | Dithiopyr 2EW | 0.43 | 100 | 85 | 100 | 97 |
| | Dithiopyr 2EW | 0.56 | 100 | 92 | 100 | 98 |
| | Dithiopyr 40WP | 0.43 | 100 | 87 | 100 | 86 |
| | Dithiopyr 40WP | 0.56 | 100 | 92 | 100 | 91 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS[w] | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| 1LF[v] | Dithiopyr 2EW | 0.43 | 95 | 85 | 93 | 77 |
| | Dithiopyr 2EW | 0.56 | 97 | 91 | 97 | 86 |
| | Dithiopyr 40WP | 0.43 | 97 | 83 | 100 | 83 |
| | Dithiopyr 40WP | 0.56 | 98 | 90 | 100 | 93 |
| | Quinclorac 75DF[u] | 0.84 | 100 | 92 | 100 | 93 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.43) versus quinclorac | | NS | *[t] | NS | NS |
| | Dithiopyr 2EW (0.56) versus quinclorac | | NS | NS | NS | NS |
| | Dithiopyr 40WP (0.43) versus quinclorac | | NS | ** | NS | NS |
| | Dithiopyr 40WP (0.56) versus quinclorac | | NS | * | NS | NS |
| 1TL[s] | Dithiopyr 2EW | 0.43 | 88 | 90 | 65 | 76 |
| | Dithiopyr 2EW | 0.56 | 93 | 95 | 84 | 81 |
| | Dithiopyr 40WP | 0.43 | 88 | 87 | 55 | 73 |
| | Dithiopyr 40WP | 0.56 | 93 | 93 | 70 | 85 |
| | Quinclorac 75DF | 0.84 | 100 | 88 | 100 | 99 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.43) versus quinclorac | | * | NS | *** | * |
| | Dithiopyr 2EW (0.56) versus quinclorac | | ** | NS | *** | ** |
| | Dithiopyr 40WP (0.43) versus quinclorac | | * | NS | ** | * |
| | Dithiopyr 40WP (0.56) versus quinclorac | | ** | NS | *** | ** |
| 3TL[r] | Dithiopyr 2EW | 0.43 | 88 | 58 | 36 | 29 |
| | Dithiopyr 2EW | 0.56 | 85 | 65 | 51 | 41 |
| | Dithiopyr 40WP | 0.43 | 88 | 60 | 55 | 39 |
| | Dithiopyr 40WP | 0.56 | 88 | 67 | 80 | 70 |
| | Quinclorac 75DF | 0.84 | 100 | 68 | 99 | 91 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS | NS | * | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.43) versus quinclorac | | * | NS | ** | ** |
| | Dithiopyr 2EW (0.56) versus quinclorac | | ** | NS | *** | ** |
| | Dithiopyr 40WP (0.43) versus quinclorac | | ** | NS | *** | ** |
| | Dithiopyr 40WP (0.56) versus quinclorac | | * | NS | *** | *** |

[z]Ratings made 4 weeks after treatments were applied at each growth stage.
[y]Ratings made 10 weeks after treatments were applied at the 3TL stage. Data were collected 12 Aug. in Knoxville, TN, and 31 Aug. in Griffin, GA.
[x]PRE = Smooth crabgrass plants had not emerged when treatments were applied on 17 Mar. in Knoxville, TN, and 9 Mar. in Griffin, GA.
[w]NS = No significant treatment differences at the $\alpha = 0.05$ level.
[v]1LF = Smooth crabgrass plants had one to two leaves when treatments were applied on 13 Apr. in Knoxville, TN, and 16 Apr. in Griffin, GA.
[u]Quinclorac 75DF applied with a methylated seed oil surfactant at a rate of 1.5 L·ha$^{-1}$.
[t]*,**,*** = Significant at the $P \leq 0.05$, 0.01, and 0.001 levels, respectively.
[s]1TL = Smooth crabgrass plants had 1 to 2 tillers when treatments were applied on 5 May in Knoxville, TN, and 27 May in Griffin, GA.
[r]3TL = Smooth crabgrass plants had more than 3 tillers when treatments were applied on 3 June in Knoxville, TN, and 17 June in Griffin, GA.

water-based formulation provided less smooth crabgrass control than quinclorac at 0.84 kg·ha$^{-1}$ by the end of the trial (Table 2). Responses of treatments applied at the 1LF stage in Georgia were similar to those observed in Tennessee, although no differences were detected between quinclorac and dithiopyr regardless of formulation (Table 2).

*Control with applications at the one-tiller growth stage.* No differences were detected between dithiopyr treatments in Tennessee at the 1TL stage; smooth crabgrass control exceeded 87% at 4 WAA and at the end of the trial (Table 2). Johnson (1997) also observed effective large crabgrass control (94%) 10 WAA with dithiopyr at 0.56 kg·ha$^{-1}$ applied to plants at a mid-postemergence (greater than three leaves but less than three tillers) growth stage; however, this response was not observed the second year that study was conducted.

Smooth crabgrass control 4 WAA in Tennessee with both formulations of dithiopyr was less than quinclorac at 0.84 kg·ha$^{-1}$ (Table 2), although at the end of the trial in Tennessee, no differences were detected between any dithiopyr treatment and quinclorac (Table 2). Smooth crabgrass control with quinclorac at the 1TL stage exceeded 88% at the end of this study in Tennessee. Johnson (1996) reported similar large crabgrass control with mid-postemergence (plants with at least three leaves but less than three tillers) applications of quinclorac at 0.84 kg·ha$^{-1}$ 10 WAA. Similarly, Dernoeden (2001) observed efficacy with mid-postemergence applications (plants with more than three leaves but less than four tillers) of quinclorac in two years of a 3-year study; in the third year, efficacy with quinclorac was not commercially acceptable. In another 3-year study, Dernoeden et al. (2003) observed variable control with mid-postemergence applications of quinclorac at 0.84 kg·ha$^{-1}$. The researchers suggested that poor performance observed on heavily infested sites might be the result of increased seed reservoirs in soil, rapid plant tillering, and dense mats of smooth crabgrass leaves protecting smaller plants in the canopy from contacting the spray solution.

Dithiopyr applications at the 1TL stage responded similarly in Georgia. Quinclorac applied at the 1TL stage in Georgia provided significantly greater smooth crabgrass control than all dithiopyr treatments at 4 WAA and the end of the trial (Table 2). This response was not observed in Tennessee. Site-to-site variability in quinclorac performance has been reported by other researchers (Dernoeden et al., 2003).

*Control with applications at the greater than three-tiller growth stage.* At 4 WAA in Tennessee, quinclorac at the 3TL growth stage provided greater smooth crabgrass control than any rate or formulation of dithiopyr. For example, smooth crabgrass control with quinclorac measured 100% compared with 88% for dithiopyr 40WP at 0.56 kg·ha$^{-1}$ (Table 2). By the end of the study, smooth crabgrass recovery had occurred as the level of control provided by all rates and formulations of dithiopyr and quinclorac at the 3TL stage decreased to less than 70% (Table 2). Dernoeden et al. (2003) reported a similar response with quinclorac injuring multitiller smooth crabgrass plants for several weeks but failing to provide complete control. Although no differences were detected between either formulation of dithiopyr and quinclorac at the end of the study, smooth crabgrass control after these 3TL treatments would not be considered commercially acceptable.

Treatment responses observed after dithiopyr applications at the 3TL growth stage in Georgia were similar to those observed in Tennessee. A significant difference in smooth crabgrass control was detected between the water-based and wettable powder formulations of dithiopyr at 0.43 kg·ha$^{-1}$ at 4 WAA in Georgia; however, this difference was not present at the end of the trial (Table 2). No dithiopyr treatment applied at the 3TL growth stage provided greater than 70% smooth crabgrass control at the end of the trial in Georgia (Table 2). Quinclorac provided greater smooth crabgrass control than all dithiopyr treatments at 4 WAA and the end of the trial (Table 2). Although a direct statistical comparison could not be made, quinclorac tended to provide greater control at the 3TL stage in Georgia compared with Tennessee. A single application of quinclorac at the 3TL growth stage in Georgia provided greater than 90% smooth crabgrass control 4 WAA and at the end of the trial, whereas control at the end of the trial in

Table 3. Bermudagrass injury following herbicide applications at various stages of growth in Tennessee and Georgia in 2009.

| | | | Bermudagrass injury | | | |
|---|---|---|---|---|---|---|
| | | | 'Yukon' bermudagrass (Tennessee) | | 'Tifsport' hybrid bermudagrass (Georgia) | |
| | | | 4 WAA[z] | End of trial[y] | 4 WAA | End of trial |
| Timing | Treatment | Rate (kg·ha$^{-1}$) | (%) | | | |
| PRE[x] | Dithiopyr 2EW | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 2EW | 0.56 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.56 | 0 | 0 | 0 | 0 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS[w] | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| 1LF[v] | Dithiopyr 2EW | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 2EW | 0.56 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.56 | 0 | 0 | 0 | 0 |
| | Quinclorac 75DF[u] | 0.84 | 0 | 0 | 15 | 0 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.43) versus quinclorac | | NS | NS | ***[t] | NS |
| | Dithiopyr 2EW (0.56) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 40WP (0.43) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 40WP (0.56) versus quinclorac | | NS | NS | *** | NS |
| 1TL[s] | Dithiopyr 2EW | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 2EW | 0.56 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.56 | 0 | 0 | 0 | 0 |
| | Quinclorac 75DF | 0.84 | 0 | 0 | 21 | 0 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.43) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 2EW (0.56) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 40WP (0.43) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 40WP (0.56) versus quinclorac | | NS | NS | *** | NS |
| 3TL[r] | Dithiopyr 2EW | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 2EW | 0.56 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.43 | 0 | 0 | 0 | 0 |
| | Dithiopyr 40WP | 0.56 | 0 | 0 | 0 | 0 |
| | Quinclorac 75DF | 0.84 | 0 | 0 | 14 | 0 |
| | Dithiopyr 2EW (0.43) versus dithiopyr 40WP (0.43) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.56) versus dithiopyr 40WP (0.56) | | NS | NS | NS | NS |
| | Dithiopyr 2EW (0.43) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 2EW (0.56) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 40WP (0.43) versus quinclorac | | NS | NS | *** | NS |
| | Dithiopyr 40WP (0.56) versus quinclorac | | NS | NS | *** | NS |

[z]Ratings made 4 weeks after treatments were applied at each growth stage.
[y]Ratings made 10 weeks after treatments were applied at the 3TL stage. Data were collected 12 Aug. in Knoxville, TN, and 31 Aug. in Griffin, GA.
[x]PRE = Smooth crabgrass plants had not emerged when treatments were applied on 17 Mar. in Knoxville, TN, and 9 Mar. in Griffin, GA.
[w]NS = No significant treatment differences at the $\alpha = 0.05$ level.
[v]1LF = Smooth crabgrass plants had 1 to 2 leaves when treatments were applied on 13 Apr. in Knoxville, TN, and 16 Apr. in Griffin, GA.
[u]Quinclorac 75DF applied with a methylated seed oil surfactant at a rate of 1.5 L·ha$^{-1}$.
[t]*** = Significant at the $P \leq 0.001$ level.
[s]1TL = Smooth crabgrass plants had 1 to 2 tillers when treatments were applied on 5 May in Knoxville, TN, and 27 May in Griffin, GA.
[r]3TL = Smooth crabgrass plants had more than 3 tillers when treatments were applied on 3 June in Knoxville, TN, and 17 June in Griffin, GA.

Tennessee was only 68% (Table 2). Site-to-site variability in multitiller smooth crabgrass control with quinclorac has been reported by other researchers (Dernoeden et al., 2003).

*Turfgrass injury.* Bermudagrass injury was not detected for any treatment applied in Tennessee (Table 3). This response differs from that reported by Johnson (1997) who observed greater than 30% injury on an unnamed bermudagrass cultivar 2 weeks after treatment with quinclorac at 0.8 $kg \cdot ha^{-1}$. Similarly, McElroy et al. (2005) reported that quinclorac injured 'Yukon' bermudagrass 20% when applied 4 to 6 weeks after seedling emergence. The lack of injury detected in this research suggests that 'Yukon' bermudagrass tolerance to quinclorac may increase as the turf stand matures over time.

Although no dithiopyr treatment induced injury in Georgia, every application of quinclorac significantly injured 'TifSport' hybrid bermudagrass. Bermudagrass injury measured 15%, 21%, and 14% 4 WAA at the 1LF, 1TL, and 3TL growth stages, respectively (Table 2); however, no injury was observed for any quinclorac treatment at the end of the trial. Chism and Bingham (1991) and Johnson (1997) observed similar injurious responses with quinclorac applied at 1.12 $kg \cdot ha^{-1}$ and 0.8 $kg \cdot ha^{-1}$, respectively, to unnamed bermudagrass cultivars.

Differences in quinclorac tolerance observed between locations may be the result of environmental conditions when treatments were applied. Air temperatures were greater in Georgia than Tennessee on the first three application dates of the growing season (Table 1). Reicher et al. (2002) noted that quinclorac injury could be significant when applied under conditions of elevated air temperature early in the growing season. Differences in 'Yukon' and 'TifSport' tolerance to quinclorac in this research may also be genetic, because triploid hybrid bermudagrasses like 'TifSport' have been shown to be more sensitive to herbicides than tetraploid common bermudagrasses (Webster et al., 2003).

## Conclusion

This field investigation suggests that either formulation of dithiopyr can be used to effectively control smooth crabgrass when applied at the PRE and 1LF stages of growth. Neither formulation of dithiopyr injured 'Yukon' or 'Tifsport' bermudagrass at any timing. Once smooth crabgrass plants begin to tiller, dithiopyr efficacy may vary with POST applications; however, acceptable smooth crabgrass control (80% or greater) at the end of the trial was achieved with the high rate of dithiopyr (0.56 $kg \cdot ha^{-1}$) applied at the 1TL stage in both Tennessee and Georgia. Quinclorac (0.84 $kg \cdot ha^{-1}$) tended to provide greater control of 1TL and 3TL smooth crabgrass than either rate or formulation of dithiopyr in this study, suggesting that practitioners should rely on quinclorac rather than dithiopyr for control of tillering smooth crabgrass plants.

Efficacy of dithiopyr for POST control of smooth crabgrass could increase with higher application rates, adjuvants, or tank mixtures of dithiopyr with other herbicides, all of which warrant further investigation. Models predicting smooth crabgrass germination and emergence based on heat accumulation units (i.e., growing degree-days) and soil temperature have been developed (Fidanza et al., 1996). Future research is needed to address how these models could also be used to schedule PRE and 1LF applications of dithiopyr for smooth crabgrass control.

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