Management of Annual Bluegrass and Bermudagrass in Creeping Bentgrass Putting Greens

By

Floyd Tyler Cooper B.S.

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Approved

Dr. Gerald Henry
Chair of Committee

Dr. Peter Dotray

Dr. Robert Cox

Peggy Gordon Miller
Dean of the Graduate School

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Table of Contents

Abstract

Management of creeping bentgrass is relatively intense when maintained as a golf course putting green. The intense nature of the cultural practices required to maintain creeping bentgrass as a putting surface has a cumulative negative impact on this same environment. Aerification, verticutting, mowing, and topdressing open up the turfgrass canopy and cause significant wounding to creeping bentgrass plants. Voids in the canopy and reduced photosynthetic capability of desired turfgrass plants may shift the competitive edge to favor weed invasion.

Experiments were conducted at the Plant and Soil Science greenhouse facility in Lubbock, TX in 2011 and 2012 on ‘Riviera’ and ‘Savannah’ common bermudagrass. Herbicide treatments were applied on December 1, 2011 and February 8, 2012 and consisted of metamifop at 200, 300, 400, and 500 g ai ha^{-1}. A sequential application of each treatment was made on December 22, 2011 and February 29, 2012. An untreated check was included for comparison. The non-treated check pots exhibited 0% control and 0.59 to 0.83 g of biomass 3 weeks after initial treatment (WAIT), regardless of cultivar. Metamifop at 300 to 500 g ai ha^{-1} exhibited 96 to 100% bermudagrass control 3 WAIT, regardless of cultivar. Bermudagrass subjected to those same treatments exhibited 0.01 to 0.03 g of biomass 3 WAIT, regardless of cultivar. The 200 g ai ha^{-1} rate of metamifop exhibited 9% control of Savannah bermudagrass with 0.72 g of biomass collected, while Riviera was controlled 41% with 0.38 g of biomass collected. Sequential applications of metamifop at 300 to 500 g ai ha^{-1} completely controlled bermudagrass (100%) 6 WAIT, while a sequential

application at 200 g ai ha^{-1} controlled bermudagrass 8 to 19% 6 WAIT, regardless of cultivar. Bermudagrass subjected to 200 g ai ha^{-1} exhibited 0.48 to 0.56 g of biomass 6 WAIT, regardless of cultivar.

Experiments were conducted at the Plant and Soil Science greenhouse facility in Lubbock, TX in 2011 and 2012 on ‘Crystal Bluelinks’, ‘Penncross’, ‘Seaside II’, ‘Penn A-4’, ‘T-1’, and ‘L-93’ creeping bentgrass; and ‘SR 7200’ velvet bentgrass. Herbicide treatments were applied on December 1, 2011 and February 8, 2012 and consisted of metamifop at 200, 300, 400, and 500 g ai ha^{-1}. A sequential application of each treatment was made on December 22, 2011 and February 29, 2012. An untreated check was included for comparison. Metamifop at 200 to 300 g ai ha^{-1} exhibited 0 to 7% bentgrass phytotoxicity 3 WAIT, regardless of cultivar. Metamifop at 400 to 500 g ai ha^{-1} exhibited 12 to 18% phytotoxicity on L-93 and Penn A-4, while phytotoxicity on all other cultivars was ≤ 8% 3 WAIT. The phytotoxicity observed on L-93 and Penn A-4 in response to metamifop at 400 to 500 g ai ha^{-1} coincided with large reductions in biomass (72 to 91%) compared to the untreated checks 3 WAIT. All bentgrass cultivars exhibited ≤ 10% phytotoxicity in response to metamifop at 200 g ai ha^{-1} 6 WAIT. Bentgrass cultivars responded differently to applications of metamifop at 300 g ai ha^{-1} 6 WAIT. Phytotoxicity was only 10% for Crystal Bluelinks, 18% for Seaside II, 18% for SR 7200, and 26% for T-1. Phytotoxicity was 47 to 76% for the remaining cultivars 6 WAIT. Seaside II, SR 7200, T-1, and Crystal Bluelinks exhibited 24 to 36% phytotoxicity in response to metamifop at 400 g ai ha^{-1} 6 WAIT, while all other cultivars exhibited 70 to 86% phytotoxicity. Seaside II, SR 7200, and

Crystal Bluelinks exhibited 48 to 51% phytotoxicity in response to metamifop at 500 g ai ha^{-1} 6 WAIT, while all other cultivars exhibited 69 to 88% phytotoxicity. High levels of phytotoxicity 6 WAIT coincided with large amounts of biomass reduction when compared to the untreated check.

Three field experiments were conducted on creeping bentgrass greens at separate locations between the fall of 2011 and the spring of 2012 in Lubbock, TX. Herbicide treatments were initiated on October 10, 2011, November 10, 2011, or December 10, 2011 and consisted of single or sequential applications of methiozolin at 0.5 or 1.0 kg ai ha^{-1}. Sequential applications were made in one-month increments. Paclobutrazol at 0.28 kg ai ha^{-1} applied on October 10, 2011 with a sequential application on November 10, 2011 was evaluated as an industry standard. An untreated check was included for comparison. Minimal to no creeping bentgrass phytotoxicity (< 2.5%) was observed 28 DAIT in response to methiozolin, regardless of application rate or timing. Paclobutrazol treatments in our research exhibited 30% creeping bentgrass phytotoxicity 28 DAIT. However, phytotoxicity was reduced below acceptable levels (< 10%) by the following spring. Differences in annual bluegrass control were observed between locations. Methiozolin applications at the Rawls Golf Course exhibited 57 to 86% annual bluegrass control, regardless of application rate or timing. Control increased as applications were made later in the fall. Single applications of methiozolin applied in October exhibited 57 to 63% control, while applications made in December exhibited 65 to 73% control, regardless of rate. Annual bluegrass control in response to methiozolin at the Reese Golf Course ranged from 54 to 100%, regardless of application rate or timing. Control increased as applications were made later in the fall. Single applications of methiozolin applied in October exhibited 54 to 78% control, while applications made in November exhibited 78 to 88% control, regardless of rate. However, control was only 74% in response to single applications of methiozolin made in December, regardless of rate. The number of sequential applications of methiozolin significantly affected annual bluegrass control . Control was 63, 74, and 82% at the Rawls Golf Course in response to methiozolin applied 1, 2, and 3 times, respectively, regardless of application rate or application timing. Control was 75, 90 and 95% at the Reese Golf Course in response to methiozolin applied 1, 2, and 3 times, respectively, regardless of application rate or timing.

List of Tables

List of Figures

Chapter 1

Literature Review

Creeping bentgrass (*Agrostis stolonifera* L.) is a fine-textured, stoloniferous cool-season grass used primarily for golf course putting greens (Beard and Beard 2005; Christians 2011; Emmons 2000). Excellent heat and cold tolerance allow creeping bentgrass to grow in the northern U.S., transition zone, and several regions further south (Mazur 1986). When properly managed, creeping bentgrass can produce one of the finest putting surfaces in the world (Fry and Huang 2004).

Management of creeping bentgrass is relatively intense when maintained as a golf course putting green (Fry and Huang 2004). Heavy traffic and wear may compact the soil profile reducing water infiltration and root penetration. Aerification is often performed two to three times a year on bentgrass greens in early spring and fall to alleviate soil compaction, reduce thatch, and increase soil/air gas exchange (Brauen et al. 1998; Carrow et al. 1987; Erusha and Riordan 1989). Hollow tine aerification consists of removing 9.5 to 13 mm cores of soil to a maximum depth of 7.5 cm (McCarty 2008). Verticutting is employed to alleviate grain (the horizontal orientation of turfgrass shoots), reduce thatch, and breakup aerification cores. This process consists of slicing through the turf canopy to a depth of 2.5 cm with vertically oriented blades affixed to a horizontal shaft (McCarty 2008). Although both of these practices are conducted during vigorous turfgrass growth and low environmental stress, several negative impacts may occur. Wounding of bentgrass plants may make them more susceptible to disease infestation and soil cores (containing weed seed) (Brauen et al. 1998) brought to the surface may increase weed pressure (Youngner 1967).

Topdressing is often performed in conjunction with aerification to help increase water infiltration, amend soil profiles, and alleviate thatch accumulation (Beard and Beard 2005; McCarty 2008). Other benefits include enhanced turfgrass establishment, reduced winter desiccation, and improvement of the playing surface (Beard 1973; Emmons 2000; Karcher and Rieke 2005). Topdressing is the application of a thin layer of fine sand, soil, or other finely granulated material over the turf surface (Christians 2011; McCarty 2008). Careful attention is paid to apply equivalent materials to those already found in the rootzone. Applications may be made as infrequently as once or twice a year following aerification practices or every 10 to 14 days using reduced (1.6 mm depth) rates (Christians 2011; Emmons 2000). Drag mats are often employed to move topdressing material into aerification holes or below the playing surface (McCarty 2008). Mechanical damage caused from the abrasion of sand materials may increase disease infestation or reduce turfgrass photosynthetic capability (Fry and Huang 2004).

Mowing is the most basic cultural practice performed on turfgrass environments (Turgeon 2011). Creeping bentgrass putting greens are often mowed daily with reel mowers to heights ranging from 2.1 to 3.2 mm (Fry and Huang 2004; McCarty 2008). Frequent, low mowing is necessary to provide a dense, uniform playing surface. However, the periodic removal of a portion of shoot growth causes a lot of stress on a turfgrass environment (McCarty 2008). Mowing causes a temporary cessation of root growth, a reduction in carbohydrate production and storage, an increase in ports of entry for disease infestation, a temporary increase in water loss from cut leaf ends, and a reduction in water absorption by the root system (Fry and Huang 2004; McCarty 2008).

Irrigation is applied to bentgrass putting greens through an automated irrigation system or by hand through the practice of syringing (Christians 2011; Fry and Huang 2004; McCarty 2008). Irrigation frequency and amount is affected by the composition of the soil profile (Christians 2011). Watering deeply and infrequently is conducted on push-up greens that are comprised of native soils ranging from sandy loams to clay loams (Christians 2011). Creeping bentgrass greens established on sand-based rootzones often require daily applications of 5 mm of water during the summer and 2.5 mm during cooler months (Christians 2011). However, frequent irrigation may keep the upper soil surface wet and discourage roots from penetrating deeper in the soil profile (Christians 2011).

The intense nature of the cultural practices required to maintain creeping bentgrass as a putting surface has a cumulative negative impact on this same environment. Aerification, verticutting, mowing, and topdressing open up the turfgrass canopy and cause significant wounding to creeping bentgrass plants (Emmons 2000; Fry and Huang 2004; McCarty 2008). Voids in the canopy and reduced photosynthetic capability of desired turfgrass plants may shift the competitive edge to favor weed invasion (Emmons 2000; Fry and Huang 2004; McCarty 2008).

Annual bluegrass may be observed as a winter annual (*Poa annua* spp. *annua* L. Timm.) or perennial [*Poa annua* spp. *reptans* L. (Hauskins) Timm.] biotype in an array of turfgrass environments (Christians 2011). Tolerance to low mowing heights has led to its description as the most problematic weed in golf course putting greens (Lush 1989;

Sweeney and Danneberger 1997). Infestations are primarily due to improper management techniques and/or non-competitiveness of older creeping bentgrass cultivars (Beard 1970). Cultural practices such as irrigation, fertilization, mowing, and aerification intended to enhance the putting surface may promote annual bluegrass infestation (Sprague and Burton 1937). Large areas of turf may become infested during cooler weather as annual bluegrass begins to out-compete creeping bentgrass for light, water, and nutrients (Sprague and Burton 1937). The lime-green color of annual bluegrass creates a mottled appearance when grown among darker green turf such as creeping bentgrass (Lycan and Hart 2006). Abundant seedhead production and coarse texture of annual bluegrass cause the turf to appear tattered and reduces the playability of putting green surfaces (Beard et al. 1978; Engel and Illnicki 1969; McCarty 1999; Sprague and Burton 1937). The winter annual life cycle of annual bluegrass matches perfectly with the timing of aerification and verticutting typically conducted on bentgrass putting greens during spring and fall (Fry and Huang 2004; Turgeon 2011). Annual bluegrass grows readily in the shade, so openings in the turfgrass sward from shade intolerant species or seed brought to the surface through aerification or verticutting create opportunities for establishment (Emmons 2000; Fry and Huang 2004; McCarty 2008; Turgeon 2011).

Control of annual bluegrass often includes a combination of cultural and chemical approaches (Emmons 2000). The primary method of control is the prevention of new infestations. Turfgrass maintenance equipment including mowers, rollers, and aerifiers should be cleaned before moving from infested to non-infested sites (Emmons 2000; Fry and Huang 2004; Turgeon 2011). Single annual bluegrass plants should be removed before seed production begins and small areas of infestation may be isolated until control can be achieved (McCarty 2008). Creeping bentgrass should be maintained in a way that promotes maximum plant vigor in order to keep it competitive against annual bluegrass invasion (Fry and Huang 2004). Maintaining a dense turf helps shade the soil surface, creating difficulty for the establishment of annual bluegrass from seed (Emmons 2000; Fry and Huang 2004; Turgeon 2011). Overwatering, especially in shady areas, will predispose turfgrass to annual bluegrass invasion (Turgeon 2011). Applying irrigation deeply and infrequently will discourage the development of shallow-rooted annual bluegrass populations (Fry and Huang 2004). Aeration and other destructive cultural practices should be conducted during periods of low turfgrass stress and prior to annual bluegrass seed production (Fry and Huang 2004). Removal of grass clippings during mowing may help reduce the number of seeds that contribute to the weed seed bank in the soil profile (Emmons 2000; Fry and Huang 2004; Turgeon 2011).

Efficacy of preemergence herbicides can be erratic due to the ability of annual bluegrass to germinate from seed in a wide range of environments. In the past chemistries such as bensulide, dithiopyr, fenarimol, oxadiazon, pendimethalin, and prodiamine applied preemergence have all exhibited control of annual bluegrass (Bell et al. 1999; Callahan and McDonald 1992; Dernoeden 1998; Mueller-Warrant and Rosato 2002; Toler et al. 2003). However, only bensulide and fenarimol are labeled for use on creeping bentgrass greens. Postemergence control is difficult due to the limited number of labeled herbicides and presence of annual and perennial biotypes. There are no herbicides labeled for the selective, postemergence control of annual bluegrass in creeping bentgrass putting greens. Ethofumesate has been observed to provide some postemergence suppression, but it is not labeled for use on creeping bentgrass putting greens (Beam et al. 2003; Coats and Krans 1986; Hart and Lycan 2000). Bispyribac-sodium is registered for the control of annual bluegrass in creeping bentgrass fairways and roughs. Teuton et al. (2007) observed 86% annual bluegrass control 12 weeks after initial treatment (WAIT) in response to weekly applications of bispyribac-sodium at 12 or 24 g ai ha^{-1}. However, > 15% creeping bentgrass injury was observed 4 to 8 WAIT. Lycan and Hart (2006) observed reductions in annual bluegrass cover (14 to 42%) in response to bispyribac-sodium applied during the spring, summer, and fall. Summer treatments did not reduce creeping bentgrass turf quality, but spring and fall treatments caused reductions 3 weeks after treatment (WAT) (Lycan and Hart 2006). Sequential applications and tank-mixtures of plant growth regulators (paclobutrazol, trinexapac-ethyl, mefluidide, ethephon, and flurprimidol) have been shown to reduce annual bluegrass populations and/or prevent seedhead production (Beam et al. 2003; Eggens et al. 1989; Eggens and Wright 1985; Johnson and Murphy 1995; Kane and Miller 2003; Woosley et al. 2003). The greatest success has been observed with paclobutrazol. Woosley et al. (2003) observed > 85% annual bluegrass control in creeping bentgrass fairways with sequential applications of paclobutrazol at 0.14 and 0.28 kg ai ha^{-1}. McCullough et al. (2005) reported > 50% annual bluegrass control with applications of paclobutrazol at 0.14 kg ai ha^{-1} every two weeks or 0.56 kg ai ha^{-1} every six weeks.

Methiozolin [(5-(2,6-difluorobenzyl) oxymethyl-5-methyl-3-(3methylthiophen-2-yl)-1,2-isoxazoline)] is a preemergence and postemergence cell wall biosynthesis inhibitor used for the control of grass weeds in rice (Anonymous 2012; Johnson and Golob 2011). Recently, methiozolin has been registered for the control of annual bluegrass in creeping bentgrass greens due to low phytotoxicity (Anonymous 2012; Johnson and Golob 2011). Johnson and Golob (2011) observed 90 to 94% annual bluegrass control 3 WAIT in response to methiozolin at 1.48 kg ai ha^{-1} applied in the fall. Control remained at 90% through early spring. Similarly, Han and Kaminski (2011) reported nearly 100% control of 5 out of 6 annual bluegrass biotypes 3 WAIT in response to methiozolin at 2 kg ai ha^{-1}. High annual bluegrass efficacy combined with low creeping bentgrass phytotoxicity (Johnson and Golob 2011) may make methiozolin a viable altenative to plant growth regulators.

Bermudagrass (*Cynodon* spp. Rich.) is the primary warm-season turfgrass species utilized for home lawns, athletic fields, and golf courses. Bermudagrass is adapted to grow throughout the transition zone and further south (Christians 2011). It tolerates wear and recovers quicker from stress than cool-season grasses due to the abundant production of aggressive rhizomes and stolons (Beard 1973; Youngner 1961). However, this may make it a difficult to control weed in some turfgrass environments (Griffin et al. 1994; Johnson and Carrow 1993). In warm, temperate climates, creeping bentgrass is often utilized as a golf course putting surface. Optimum growth from June through August in these same climates enhances the ability of bermudagrass encroachment into putting greens from neighboring surrounds (Christians and Engelke 1994; Turgeon 2011). The presence of bermudagrass in bentgrass greens can disrupt the playing surface and reduce the aesthetic quality (Johnson and Carrow 1993; Lowe et al. 2000).

Limited options exist for the selective control of bermudagrass in managed turfgrass. The use of siduron for the control or suppression of bermudagrass in creeping bentgrass putting greens has been inconsistent. McMaugh (1971) reported complete control of bermudagrass in response to sequential applications of siduron at 45 kg ai ha^{-1} at 12 week (wk) intervals. Duble (1974) observed bermudagrass growth suppression with sequential (4- to 6-wk intervals) applications of siduron at 20 kg ai ha^{-1}, but suggested that additional applications would be needed to prevent further encroachment. No change or increased bermudagrass cover in response to single or sequential applications of siduron at 50 kg ai ha^{-1} was noted by Siviour and Schultz (1984). Johnson and Carrow (1993) reported 83 to 94% bermudagrass suppression by mid-June when tank-mixing siduron with flurprimidol at 54 + 0.8 kg ai ha^{-1} in March followed by (fb) 14 + 0.2 kg ai ha^{-1} in April and May. Single and sequential applications of ethofumesate (0.4 to 1.7 kg ai ha^{-1}) + flurprimidol (0.2 to 0.8 kg ai ha^{-1}) made from March until May exhibited 88 to 99% bermudagrass suppression by mid-June, regardless of cultivar. Sequential applications of fenoxaprop at 0.07 kg ai ha^{-1} in April, May, and June resulted in 75% suppression of ‘Common’ bermudagrass by mid-June, but only 14 and 26% suppression of ‘Tifway’ and ‘Tifgreen’ bermudagrass, respectively (Johnson and Carrow 1993). Doroh et al. (2011) observed similar control (32%) of Tifway bermudagrass 9 WAIT following sequential applications of fenoxaprop at 0.1 kg ai ha^{-1}, while sequential treatments of fenoxaprop alone or in combination with triclopyr resulted in the lowest percent cover of Common bermudagrass (3 to 19%) at the end of the growing season (Cudney et al. 1997).

Creeping bentgrass phytotoxicity is often observed in response to the herbicide rates required for bermudagrass control. Johnson and Carrow (1993) observed 50 to 77% and 23 to 45% phytotoxicity of 'Penncross' creeping bentgrass 10 days after treatment (DAT) of fenoxaprop at 0.13 kg ai ha^{-1} and ethofumesate + flurprimidol at 1.7 + 0.8 kg ai ha^{-1}, respectively. Fenoxaprop at 0.07 and 0.15 kg ai ha^{-1} exhibited bentgrass color ratings above acceptable levels (≥ 4.5) 14 DAT, while fluazifop at 0.1, 0.2, and 0.3 kg ai ha^{-1} exhibited bentgrass color ratings of 2.6 to 2.9 (Higgins et al. 1987). Henry and Hart (2004) observed a 20 and 40% reduction in clipping weight 4 WAT of L-93 creeping bentgrass in response to fenoxaprop at 0.07 and 0.15 kg ai ha^{-1}. Reductions in turfgrass quality not only affect creeping bentgrass aesthetic appearance, but may reduce its competition, making it more susceptible to invasion from other weeds [e.g. annual bluegrass (*Poa annua* L.)].

Metamifop, 2-[4-(6-chlorobenzooxazol-2-yloxy)phenoxy]-*N*-(2-fluorophenyl)-*N*-methylpropionamide, is a postemergence aryloxyphenoxypropionic acid herbicide (AOPP) used for the control of a wide range of annual and perennial grass weeds in cereal crops and rice (Moon et al. 2007). Cox and Askew (2011) observed similar control of bermudagrass (70 to 74%) with sequential applications of metamifop at 0.8 kg ai ha^{-1} as with fenoxaprop + triclopyr at 0.14 and 1.12 kg ai ha^{-1}, respectively. However, Doroh et al. (2011) observed only 36% bermudagrass control 9 WAIT in response to sequential applications of metamifop at 0.4 kg ai ha^{-1}. Tank-mixing metamifop at 0.4 kg ai ha^{-1} with triclopyr at 1.12 kg ai ha^{-1} increased bermudagrass control to 93% 9 WAIT. Single applications of metamifop at 200 and 300 g ai ha^{-1} exhibited ≤ 10% phytotoxicity of

‘Declaration’, ‘Penn A-4’, and L-93 creeping bentgrass 2 WAT (S.D Askew, personal communication). Metamifop could potentially be an alternative for the control of bermudagrass in cool-season turf without phytotoxicity concerns.

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Chapter II

Efficacy of Metamifop for the Control of Bermudagrass

Abstract

Experiments were conducted at the Plant and Soil Science greenhouse facility in Lubbock, TX in 2011 and 2012. ‘Riviera’ and ‘Savannah’ common bermudagrass were seeded at 244 kg ha^{-1} into 10.2 cm square pots containing a soilless potting media on August 26, 2011 and November 14, 2011. Pots were allowed to mature in the greenhouse over a three month period. Herbicide treatments were applied on December 1, 2011 and February 8, 2012 and consisted of metamifop at 200, 300, 400, and 500 g ai ha^{-1}. A sequential application of each treatment was made on December 22, 2011 and February 29, 2012. An untreated check was included for comparison. Visual ratings of percent bermudagrass control were recorded weekly on a scale of 0 (no control) to 100% (completely dead bermudagrass). Pots were cut to 0.6 cm after three weeks of growth (prior to sequential treatments), biomass was dried, and weighed. This procedure was conducted again three wks after sequential treatments. The non-treated check pots exhibited 0% control and 0.59 to 0.83 g of biomass 3 weeks after initial treatment (WAIT), regardless of cultivar. Metamifop at 300 to 500 g ai ha^{-1} exhibited 96 to 100% bermudagrass control 3 WAIT, regardless of cultivar. Bermudagrass subjected to those same treatments only exhibited 0.01 to 0.03 g of biomass 3 WAIT, regardless of cultivar. The 200 g ai ha^{-1} rate of metamifop exhibited only 9% control of Savannah bermudagrass with 0.72 g of biomass collected, while Riviera was controlled 41% with 0.38 g of biomass collected. Sequential applications of metamifop at 300 to 500 g ai ha^{-1}

completely controlled bermudagrass (100%) 6 WAIT, while a sequential application at 200 g ai ha^{-1} controlled bermudagrass 8 to 19% 6 WAIT, regardless of cultivar. Bermudagrass subjected to 200 g ai ha^{-1} exhibited 0.48 to 0.56 g of biomass 6 WAIT, regardless of cultivar.

Introduction

Bermudagrass (*Cynodon* spp. Rich.) is the primary warm-season turfgrass species grown in the United States (Christians 2011). Common to home lawns, athletic fields, and golf courses, bermudagrass is adapted to the southern and central regions of the transition zone (Christians 2011). The abundant production of aggressive rhizomes and stolons enables bermudagrass to tolerate wear and recover from stress quicker than cool-season turf (Beard 1973). However, this also may make it a difficult to control weed in some turfgrass environments (Griffin et al. 1994; Johnson and Carrow 1993). Creeping bentgrass (*Agrostis stolonifera* L.) is often utilized as a golf course putting surface in warm, temperate climates where bermudagrass is adapted to grow. Bermudagrass is capable of encroaching into putting greens from neighboring surrounds, because optimum bermudagrass growth occurs from June through August (Christians and Engelke 1994; Turgeon 2011) when creeping bentgrass is experiencing stress (Turgeon 2011). The presence of bermudagrass in bentgrass greens can disrupt the playing surface and reduce the aesthetic quality (Johnson and Carrow 1993; Lowe et al. 2000).

Limited options exist for the selective control of bermudagrass in managed turfgrass. The use of siduron for the control or suppression of bermudagrass in creeping bentgrass putting greens has been inconsistent. McMaugh (1971) reported complete control of bermudagrass in response to sequential applications of siduron at 45 kg ai ha^{-1} at 12-wk intervals. Although bermudagrass growth was suppressed with sequential (4- to 6-wk intervals) applications of siduron at 20 kg ai ha^{-1}, Duble (1974) suggested additional applications would be necessary to prevent further encroachment. Siviour and Schultz (1984) observed no change or increased bermudagrass cover in response to single or sequential applications of siduron at 50 kg ai ha^{-1}. Johnson and Carrow (1993) reported that tank-mixing siduron with flurprimidol at 54 + 0.8 kg ai ha^{-1} in March followed by (fb) 14 + 0.2 kg ai ha^{-1} in April and May exhibited 83 to 94% bermudagrass suppression by mid-June, regardless of cultivar. Single and sequential applications of ethofumesate (0.4 to 1.7 kg ai ha^{-1}) + flurprimidol (0.2 to 0.8 kg ai ha^{-1}) made from March until May exhibited 88 to 99% bermudagrass suppression by mid-June, regardless of cultivar. Sequential applications of fenoxaprop at 0.07 kg ai ha^{-1} in April, May, and June resulted in 75% suppression of 'Common' bermudagrass by mid-June, but only 14 and 26% suppression of 'Tifway' and 'Tifgreen' bermudagrass, respectively (Johnson and Carrow 1993). Doroh et al. (2011) observed similar control (32%) of Tifway bermudagrass 9 weeks after initial treatment (WAIT) following sequential applications of fenoxaprop at 0.1 kg ai ha^{-1}, while sequential treatments of fenoxaprop alone or in combination with triclopyr resulted in the lowest percent cover of Common bermudagrass (3 to 19%) at the end of the growing season (Cudney et al. 1997).

Herbicide rates required for bermudagrass control often exhibit unacceptable levels of creeping bentgrass phytotoxicity. Johnson and Carrow (1993) observed 50 to

77% and 23 to 45% phytotoxicity of ‘Penncross’ creeping bentgrass 10 days after treatment (DAT) with fenoxaprop at 0.13 kg ai ha^{-1} and ethofumesate + flurprimidol at 1.7 + 0.8 kg ai ha^{-1}, respectively. Higgins et al. (1987) reported that fenoxaprop at 0.07 and 0.15 kg ai ha^{-1} exhibited bentgrass color ratings above acceptable levels ($\geq$ 4.5) 14 DAT, while fluazifop at 0.1, 0.2, and 0.3 kg ai ha^{-1} exhibited bentgrass color ratings of 2.6 to 2.9. Henry and Hart (2004) observed a 20 and 40% reduction in clipping weight 4 weeks after treatment (WAT) of ‘L-93’ creeping bentgrass in response to fenoxaprop at 0.07 and 0.15 kg ai ha^{-1}. Reductions in turfgrass quality not only affect creeping bentgrass aesthetic appearance, but may reduce its competition, making it more susceptible to invasion from other weeds [e.g. annual bluegrass (*Poa annua* L.)].

Metamifop, 2-[4-(6-chlorobenzooxazol-2-yloxy)phenoxy]-*N*-(2-fluorophenyl)-*N*-methylpropionamide, is a postemergence aryloxyphenoxypropionic acid herbicide (AOPP) used for the control of a wide range of annual and perennial grass weeds in cereal crops and rice (Moon et al. 2007). Cox and Askew (2011) observed 70 and 74% bermudagrass control with sequential applications (3 weeks apart) of metamifop at 400 g ai ha^{-1} and fenoxaprop at 0.14 kg ai ha^{-1}, respectively. However, Doroh et al. (2011) observed only 36% bermudagrass control 9 WAIT in response to sequential applications of metamifop at 400 g ai ha^{-1}. Tank-mixing metamifop at 400 g ai ha^{-1} with triclopyr at 1.12 kg ai ha^{-1} increased bermudagrass control to 93% 9 WAIT. Single applications of metamifop at 200 and 300 g ha^{-1} exhibited < 10% phytotoxicity of ‘Declaration’, ‘Penn A-4’, and L-93 creeping bentgrass 2 WAT (A. D. Askew, personal communication). Metamifop could potentially be an alternative for the control of bermudagrass in cool-season turf with little to no phytotoxicity. Therefore, the objective of our research was to evaluate the efficacy of metamifop for postemergence control of common bermudagrass.

Materials and Methods

Experiments were conducted at the Plant and Soil Science greenhouse facility in Lubbock, TX in 2011 and 2012. 'Riviera' common bermudagrass (Johnston Seed Company, P.O. Box 1392, Enid, OK 73702) and 'Savannah' common bermudagrass (Turf Seed, 7644 Keene Rd NE, Gervais, OR 97026) were seeded at 244 kg ha^{-1} into 10.2 cm square pots containing a soilless potting media (Sun Gro Horticulture, 200 Burrard Street, Suite 1200, Vancouver, British Columbia, Canada) on August 26, 2011 and November 14, 2011. Fertilizer (7N – $7P_2O_5$ – $7K_2O$) (Green Spec Fertilizer, Grigg Brothers, P.O. Box 128, Albion, ID 83311) was applied at the time of seeding at a rate of 24.4 kg ha^{-1} N. Greenhouse temperatures were maintained at 34/26 C (day/night) with average midday (1200 and 1300 hr) solar radiation ranging from 636 to 754 µmol m^{-2} s^{-1}. Irrigation was supplied through an overhead irrigation system calibrated to deliver approximately 3.8 cm of water wk^{-1}. Pots were allowed to mature in the greenhouse over a three month period. Prior to herbicide application bermudagrass was mowed to 0.6 cm with hand-held, electric grass shearers (Oster Showmaster, Jarden Corporation, 555 Theodore Fremd Ave., Suite B-302, Rye, NY 10580). Treatments were arranged in a randomized complete block design with five replications. Herbicides were applied with a CO_2 backpack sprayer equipped with XR8004VS nozzle tips (Teejet, flat-fan extended range spray tips. Spraying Systems Co., North Ave. and Schmale Rd., Wheaton, IL

60129) calibrated to deliver 375 L ha^{-1} at 221 kPa. Herbicide treatments were applied on December 1, 2011 and February 8, 2012 and consisted of metamifop (32 F Dongbu Financial Center, 891-10-Daechi-Dong, Gangnam-Ga, Seoul, 135-523 Korea) at 200, 300, 400, and 500 g ai ha^{-1}. A sequential application of each treatment was made on December 22, 2011 and February 29, 2012. An untreated check was included for comparison.

Visual ratings of percent bermudagrass control was recorded weekly on a scale of 0 (no control) to 100% (completely dead bermudagrass). Pots were cut to 0.6 cm after three wks of growth (prior to sequential treatments), biomass was dried, and weighed. This procedure was conducted again three wks after sequential treatments. Data were subjected to analysis of variance (ANOVA) (P = 0.05) provided by SAS (SAS, Statistical Analysis Systems, 2002-2008, Release 9.2, Statistical Analysis Systems Institute, Cary, NC 27513) with sums of squares partitioned to reflect a split plot treatment structure. Bermudagrass cultivar was considered the main plot and metamifop rate was considered the subplot. Where main plot effects were significant, regressions were used to explain the relationship of measured responses to metamifop treatments. Effect of metamifop treatments were separated using Fisher's Protected Least Significant Difference (LSD) test at P = 0.05. The rate of metamifop required to reduce bermudagrass growth 50% (GR_{50}) was calculated.

Results and Discussion

The regression analysis of bermudagrass cultivar by metamifop rate adequately predicted biomass reduction 3 WAIT (Savannah R^2 = 0.80; Riviera R^2 = 0.90) (Figure 2.1). As metamifop rate increased, bermudagrass biomass decreased. The calculated GR_{50} 3 WAIT for Savannah and Riviera was 213 and 162 g ai ha^{-1}, respectively. The non-treated check pots exhibited 0% control and 0.59 to 0.83 g of biomass 3 WAIT, regardless of cultivar (Figure 2.1 and 2. 2). Metamifop at 300 to 500 g ai ha^{-1} exhibited 98 to 100% bermudagrass control 3 WAIT, regardless of cultivar. Similar control (88 to 99%) was observed with single and sequential applications of ethofumesate (0.4 to 1.7 kg ai ha^{-1}) + flurprimidol (0.2 to 0.8 kg ai ha^{-1}) (Johnson and Carrow 1993). Bermudagrass subjected to metamifop at 300 to 500 g ai ha^{-1} exhibited 0.01 to 0.03 g of biomass 3 WAIT, regardless of cultivar. The 200 g ai ha^{-1} rate of metamifop exhibited only 9% control of Savannah bermudagrass with 0.72 g of biomass collected, while Riviera was controlled 41% with 0.38 g of biomass collected.

The regression analysis of bermudagrass cultivar by metamifop rate adequately predicted biomass reduction 6 WAIT (Savannah R^2 = 0.95; Riviera R^2 = 0.94) (Figure 3). As metamifop rate increased, bermudagrass biomass decreased. The metamifop rate needed to control 50% of bermudagrass (GR_{50}) 6 WAIT for Savannah and Riviera was 147 and 158 g ai ha^{-1}, respectively. Sequential applications of metamifop at 300 to 500 g ai ha^{-1} completely controlled bermudagrass (100%) 6 WAIT, while a sequential application at 200 g ai ha^{-1} controlled bermudagrass 8 to 19% 6 WAIT, regardless of cultivar (Figure 4). Bermudagrass subjected to 200 g ai ha^{-1} exhibited 0.48 to 0.56 g of biomass 6 WAIT, regardless of cultivar. Cox and Askew (2011) observed 70% bermudagrass control with sequential applications (3 wks apart) of metamifop at 400 g ai ha^{-1}. However, Doroh et al. (2011) observed only 36% bermudagrass control 9 WAIT in response to sequential applications of metamifop at 400 g ai ha^{-1}.

Methods employed in this research may have accounted for greater bermudagrass control. Research conducted by Cox and Askew (2011) and Doroh et al. (2011) took place in the field, while our research was conducted in the greenhouse. Plants grown under greenhouse conditions are often more susceptible to herbicides, and therefore exhibit higher levels of phytotoxicity. Lingenfelter and Curran (2007) observed 98% control of wirestem muhly [*Muhlenbergia frondosa* (Poir.) Fern.] in the greenhouse in response to glyphosate (0.42 and 0.84 kg ai ha^{-1}) 4 WAT. The same applications made in the field only exhibited 60 to 87% control 4 WAT. Plant age and cultivar may have an effect on herbicide efficacy. Doroh et al. (2011) examined the effect of metamifop on 4-year-old bermudagrass, while bermudagrass utilized in our experiments were only 3 months old. Schuster et al. (2007) observed 80% control of 2.5-cm common lambsquarters (*Chenopodium album* L.) in response to glyphosate at 1.1 kg ae ha^{-1}, but only 55% control of 7.5- and 15-cm plants. Common bermudagrass cultivars were utilized in our research, while Tifway hybrid bermudagrass was evaluated in Doroh et al. (2011). Johnson and Carrow (1993) reported that sequential applications of fenoxaprop at 0.07 kg ai ha^{-1} in April, May, and June resulted in 75% suppression of Common bermudagrass by mid-June, but only 14 and 26% suppression of Tifway and Tifgreen bermudagrass, respectively.

Metamifop may be an alternative for the control of bermudagrass in cool-season turf. Excellent bermudagrass control (98 to 99%) was observed 3 WAIT in response to metamifop at 300 g ai ha^{-1}. Single applications of metamifop at 200 and 300 g ha^{-1} exhibited < 10% phytotoxicity of Declaration, PennA-4, and L-93 creeping bentgrass 2 WAT when examined in a field setting (A. D. Askew, personal communication). Higher application rates may cause unacceptable creeping bentgrass phytotoxicity and reduce its competition.

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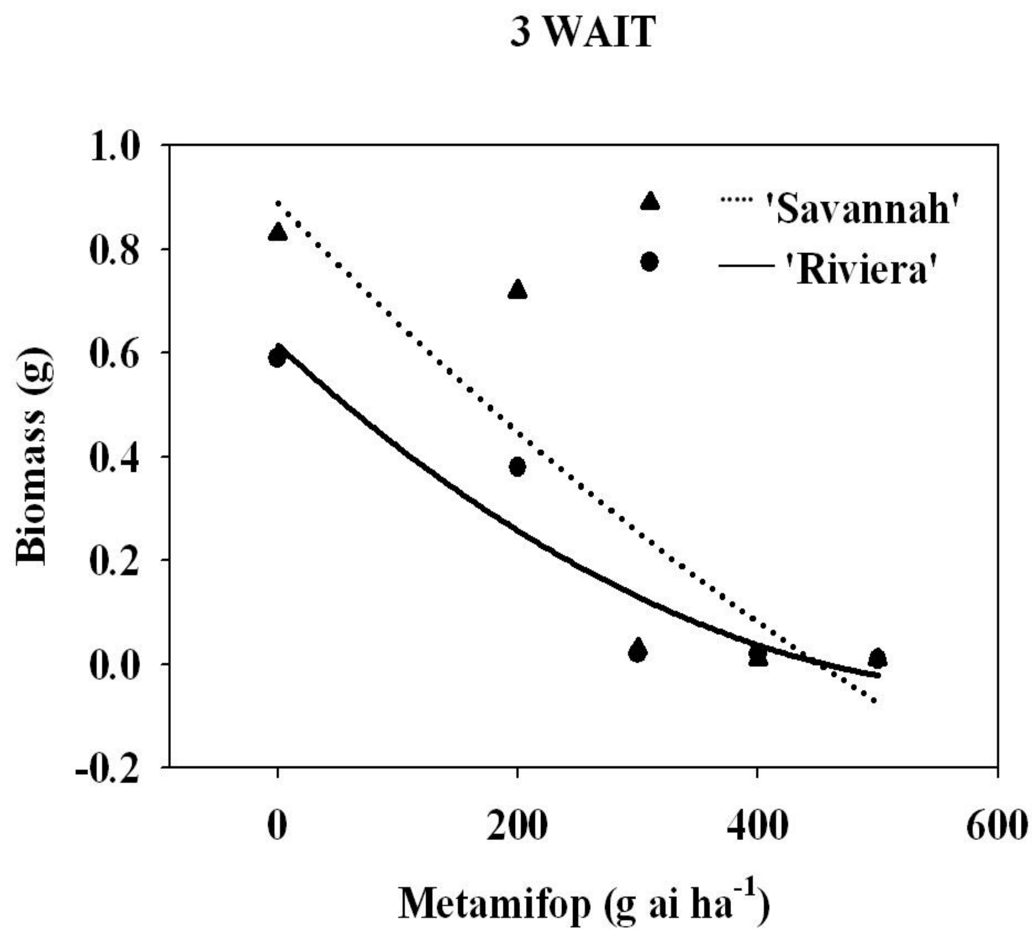

Figure 2.1. Above-ground biomass of 'Savannah' and 'Riviera' common bermudagrass 3 WAIT in response to metamifop. Quadratic equations: 'Savannah', $y = 0.01x^2 – 0.12x + 3.27$, $R^2 = 0.80$; 'Riviera', $y = 0.01x^2 – 0.11x + 2.26$, $R^2 = 0.90$. The calculated GR_{50} for Savannah and Riviera was 213 and 162 g ai ha^{-1}, respectively.

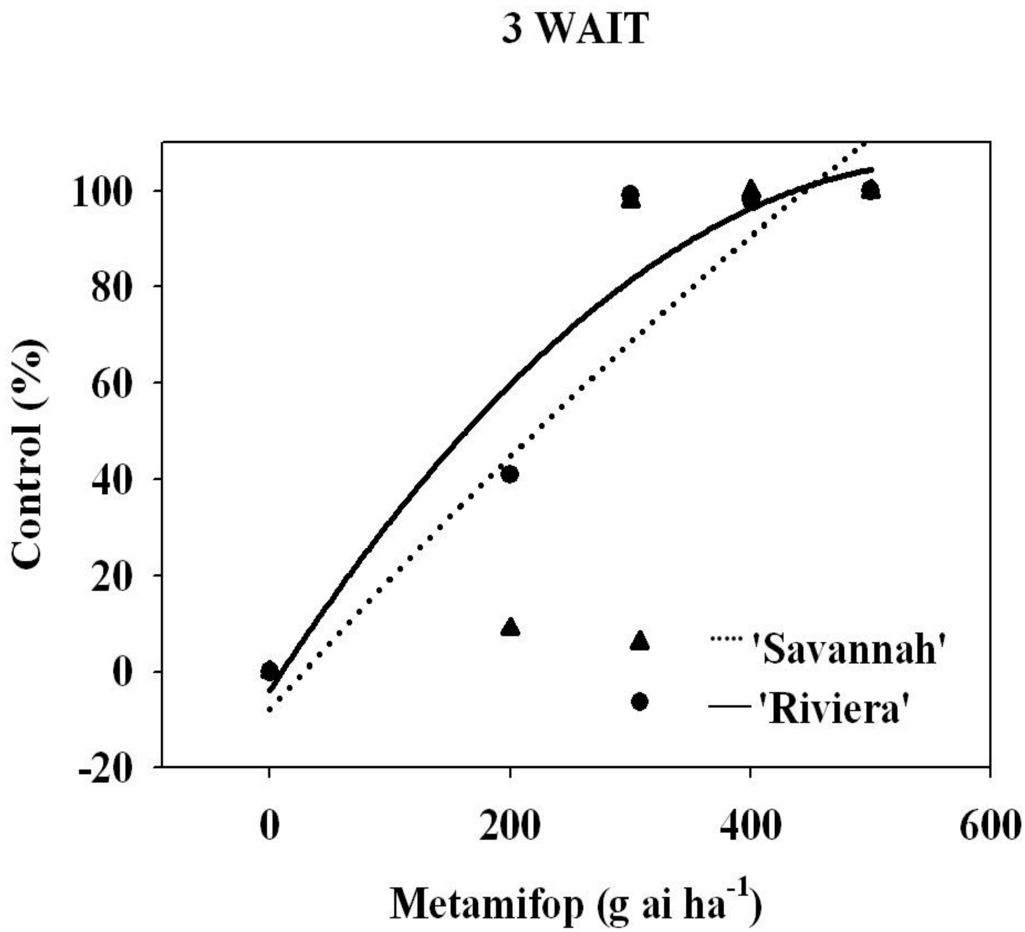

Figure 2.2. Percent control of ‘Savannah’ and ‘Riviera’ common bermudagrass 3 WAIT in response to metamifop. Quadratic equations: ‘Savannah’, $y = -0.06x^2 + 1.02x – 7.78$, $R^2 = 0.78$; ‘Riviera’, $y = -0.06x^2 + 1.42x – 3.86$, $R^2 = 0.92$.

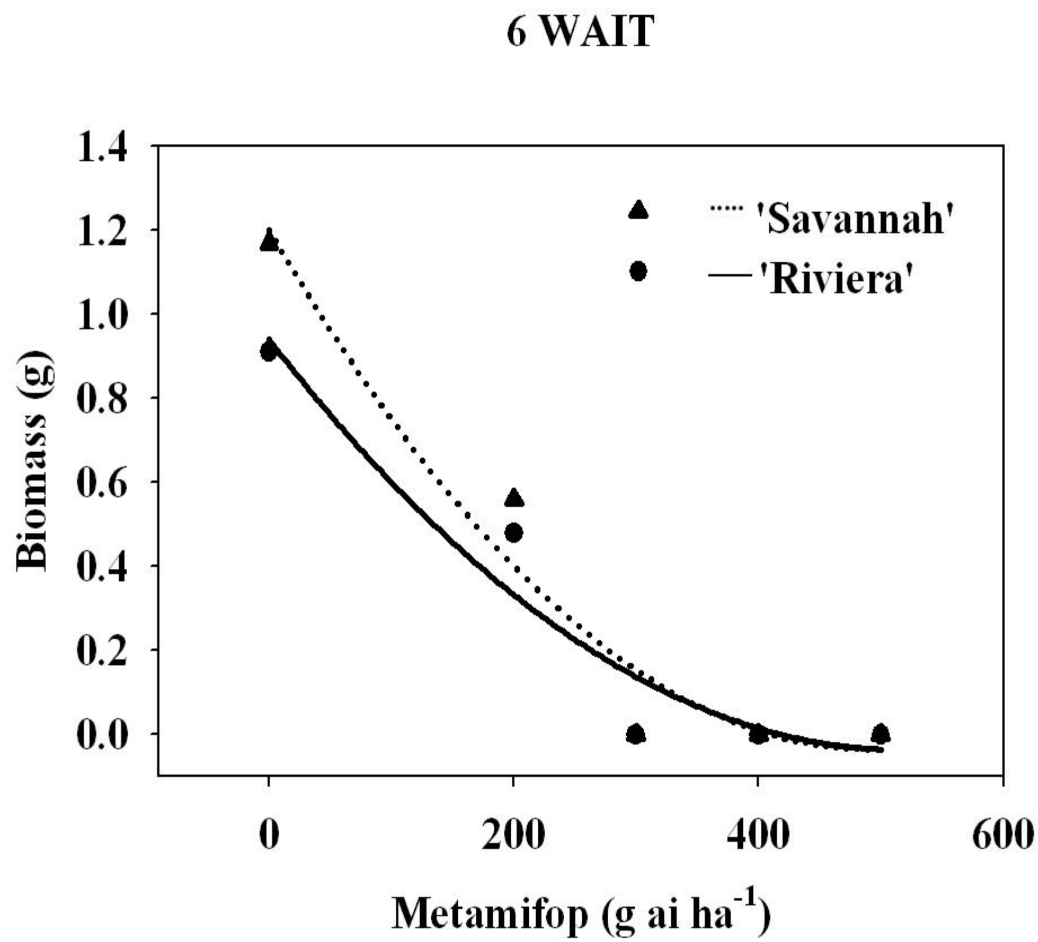

Figure 2.3. Above-ground biomass of ‘Savannah’ and ‘Riviera’ common bermudagrass 6 WAIT in response to metamifop. Quadratic equations: ‘Savannah’, $y = -0.01x^2 – 0.25x – 1.20$, $R^2 = 0.95$; ‘Riviera’, $y = 0.01x^2 – 0.19x – 3.46$, $R^2 = 0.94$. The calculated GR_{50} for Savannah and Riviera was 147 and 158 g ai ha^{-1}, respectively.

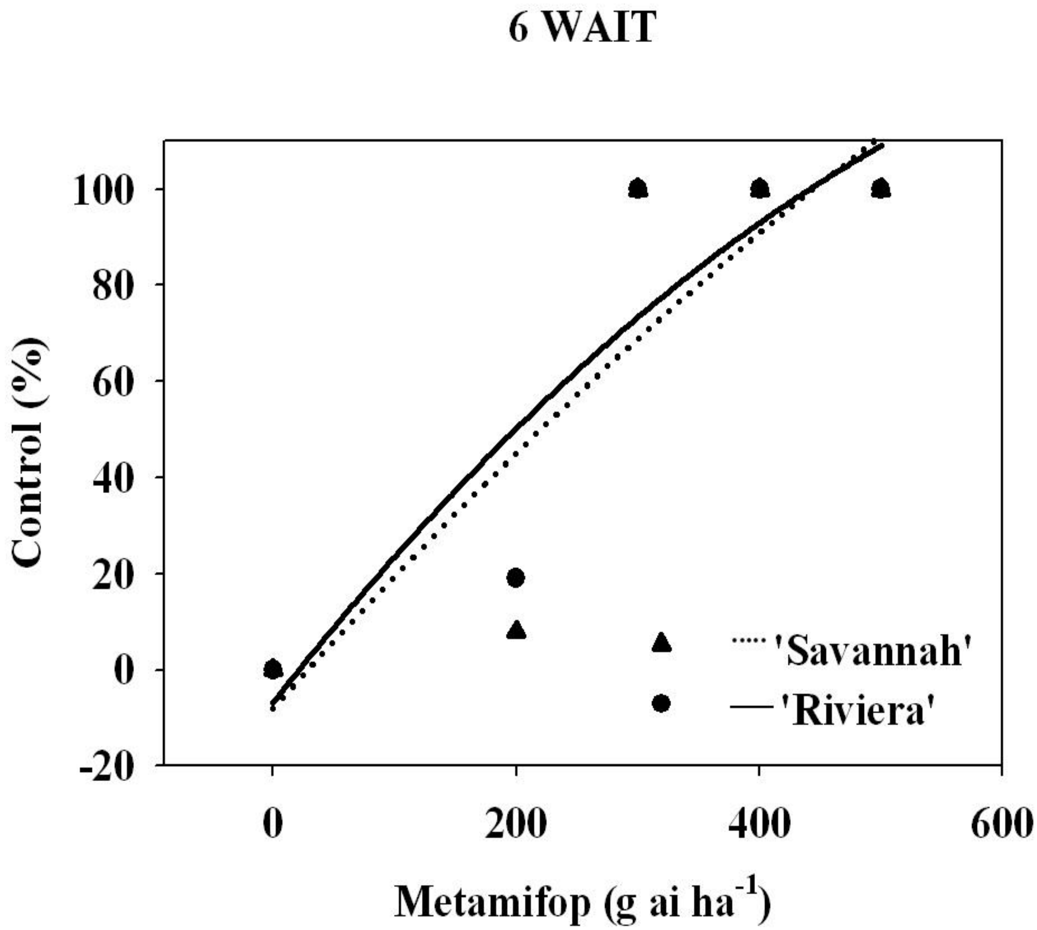

Figure 2.4. Percent control of ‘Savannah’ and ‘Riviera’ common bermudagrass 6 WAIT in response to metamifop. Quadratic equations: ‘Savannah’, $y = -0.06x^2 + 1.05x - 8.03$, $R^2 = 0.77$; ‘Riviera’, $y = -0.03x^2 + 1.18x - 6.72$, $R^2 = 0.82$.

Chapter III

Tolerance of Bentgrass (*Agrostis* spp.) to Metamifop

Abstract

Experiments were conducted at the Plant and Soil Science greenhouse facility in Lubbock, TX in 2011 and 2012. ‘Crystal Bluelinks’, ‘Penncross’, ‘Seaside II’, ‘Penn A-4’, ‘T-1’, and ‘L-93’ creeping bentgrass; and ‘SR 7200’ velvet bentgrass were seeded at 147 kg ha^{-1} into 10.2 cm square pots containing a soilless potting media on August 26, 2011 and November 14, 2011. Pots were allowed to mature in the greenhouse over a three month period. Herbicide treatments were applied on December 1, 2011 and February 8, 2012 and consisted of metamifop at 200, 300, 400, and 500 g ai ha^{-1}. A sequential application of each treatment was made on December 22, 2011 and February 29, 2012. An untreated check was included for comparison. Visual ratings of percent bentgrass phytotoxicity were recorded weekly on a scale of 0 (no phytotoxicity) to 100% (completely dead bentgrass). Pots were cut to 0.6 cm after three weeks of growth (prior to sequential treatments), biomass was dried, and weighed. This procedure was conducted again three weeks after sequential treatments. Metamifop at 200 to 300 g ai ha^{-1} exhibited 0 to 7% bentgrass phytotoxicity 3 weeks after initial treatment, regardless of cultivar. Metamifop at 400 to 500 g ai ha^{-1} exhibited 12 to 18% phytotoxicity on L-93 and Penn A-4, while phytotoxicity on all other cultivars was ≤ 8% 3 WAIT. The phytotoxicity observed on L-93 and Penn A-4 in response to metamifop at 400 to 500 g ai ha^{-1} coincided with large reductions in biomass (72 to 91%) compared to the untreated check 3 WAIT. All bentgrass cultivars exhibited ≤ 10% phytotoxicity in response to metamifop

at 200 g ai ha^{-1} 6 WAIT. Bentgrass cultivars responded differently to applications of metamifop at 300 g ai ha^{-1} 6 WAIT. Phytotoxicity was only 10% for Crystal Bluelinks, 18% for Seaside II, 18% for SR 7200, and 26% for T-1. Phytotoxicity was 47 to 76% for the remaining cultivars 6 WAIT. Seaside II, SR 7200, T-1, and Crystal Bluelinks exhibited 24 to 36% phytotoxicity in response to metamifop at 400 g ai ha^{-1} 6 WAIT, while all other cultivars exhibited 70 to 86% phytotoxicity. Seaside II, SR 7200, and Crystal Bluelinks exhibited 48 to 51% phytotoxicity in response to metamifop at 500 g ai ha^{-1} 6 WAIT, while all other cultivars exhibited 69 to 88% phytotoxicity. High or severe levels of phytotoxicity 6 WAIT coincided with large amounts of biomass reduction when compared to the untreated check.

Introduction

Creeping bentgrass (*Agrostis stolonifera* L.) is a fine-textured, stoloniferous cool-season grass primarily used for golf course putting greens (Beard and Beard 2005; Christians 2011; Emmons 2000). Excellent heat and cold tolerance allow creeping bentgrass to grow in the northern U.S., the transition zone, and several regions further south (Mazur 1986). When properly managed, creeping bentgrass can produce one of the finest putting surfaces in the world (Fry and Huang 2004). However, the intense nature of the cultural practices required to maintain creeping bentgrass as a putting surface has a cumulative negative impact on this same environment. Aerification, verticutting, mowing, and topdressing open up the turfgrass canopy and may cause significant wounding to creeping bentgrass plants (Emmons 2000; Fry and Huang 2004; McCarty

2008). Voids in the canopy and reduced photosynthetic capability of desired turfgrass plants may shift the competitive edge to favor weed invasion (Emmons 2000; Fry and Huang 2004; McCarty 2008).

Bermudagrass (*Cynodon* spp. Rich.) is the primary warm-season turfgrass species adapted to growth in the southern and central regions of the transition zone (Christians 2011). The presence of aggressive rhizomes and stolons enables bermudagrass to tolerate wear and recover from stress quicker than cool-season turf (Beard 1973; Youngner 1961). However, this may also make it a difficult to control weed in certain turfgrass environments (Griffin et al. 1994; Johnson and Carrow 1993). Bermudagrass is often observed encroaching into creeping bentgrass (*Agrostis stolonifera* L.) putting greens from neighboring surrounds. This primarily occurs from June through August when bermudagrass is vigorously growing (Christians and Engelke 1994; Turgeon 2011) and creeping bentgrass is under environmental stress (Turgeon 2011). The presence of bermudagrass in bentgrass greens disrupts the playing surface and reduces its aesthetic quality (Johnson and Carrow 1993; Lowe et al. 2000).

Limited options exist for the selective control of bermudagrass in managed turfgrass. Siduron, ethofumesate, and fenoxaprop have all exhibited control of bermudagrass (Cudney et al. 1997; Doroh et al. 2011; Duble 1974; Johnson and Carrow 1993; McMaugh 1971). However, herbicide rates required for bermudagrass control often exhibit unacceptable levels of creeping bentgrass phytotoxicity. Johnson and Carrow (1993) observed 50 to 77% and 23 to 45% phytotoxicity of ‘Penncross’ creeping bentgrass 10 days after treatment (DAT) with fenoxaprop at 0.13 kg ai ha^{-1} and ethofumesate + flurprimidol at 1.7 + 0.8 kg ai ha^{-1}, respectively. Higgins et al. (1987) reported that fenoxaprop at 0.07 and 0.15 kg ai ha^{-1} exhibited bentgrass color ratings above acceptable levels ($\geq$ 4.5) 14 DAT, while fluazifop at 0.1, 0.2, and 0.3 kg ai ha^{-1} exhibited bentgrass color ratings of 2.6 to 2.9. Henry and Hart (2004) observed a 20 and 40% reduction in clipping weight 4 weeks after treatment (WAT) of 'L-93' creeping bentgrass in response to fenoxaprop at 0.07 and 0.15 kg ai ha^{-1}. Reductions in turfgrass quality not only affect creeping bentgrass aesthetic appearance, but may reduce its competition, making it more susceptible to invasion from other weeds [e.g. annual bluegrass (*Poa annua* L.)].

Metamifop, 2-[4-(6-chlorobenzooxazol-2-yloxy)phenoxy]-*N*-(2-fluorophenyl)-*N*-methylpropionamide, is a postemergence aryloxyphenoxypropionic acid herbicide used for the control of a wide range of annual and perennial grass weeds in cereal crops and rice (Moon et al. 2007). Cox and Askew (2011) observed 70 and 74% bermudagrass control with sequential applications (3 wks apart) of metamifop at 400 g ai ha^{-1} and fenoxaprop at 0.14 kg ai ha^{-1}, respectively. However, Doroh et al. (2011) observed only 36% bermudagrass control 9 WAIT in response to sequential applications of metamifop at 400 g ai ha^{-1}. Tank-mixing metamifop at 400 g ai ha^{-1} with triclopyr at 1.12 kg ai ha^{-1} increased bermudagrass control to 93% 9 WAIT. Single applications of metamifop at 200 and 300 g ha^{-1} exhibited < 10% phytotoxicity of 'Declaration', 'Penn A-4', and L-93 creeping bentgrass 2 WAT (S. D. Askew, personal communication). Metamifop could potentially be an alternative for the control of bermudagrass in cool-season turf with little to no phytotoxicity. Therefore, the objective of our research was to evaluate the tolerance of bentgrass spp. to metamifop.

Materials and Methods

Experiments were conducted at the Plant and Soil Science greenhouse facility in Lubbock, TX in 2011 and 2012. ‘Crystal Bluelinks’ (Tee 2 Green, P.O. Box 250, Hubbard, OR 97032), Penncross (Tee 2 Green, P.O. Box 250, Hubbard, OR 97032), ‘Seaside II’ (Tee 2 Green, P.O. Box 250, Hubbard, OR 97032), Penn A-4 (Tee 2 Green, P.O. Box 250, Hubbard, OR 97032), ‘T-1’ (J. R. Simplot Company, P.O. Box 27, Boise, ID 83707), and L-93 (J. R. Simplot Company, P.O. Box 27, Boise, ID 83707) creeping bentgrass; and ‘SR 7200’ (Seed Research of Oregon, 27630 Llewellyn Rd., Corvallis, OR 97333) velvet bentgrass were seeded at 147 kg ha^{-1} into 10.2 cm square pots containing a soilless potting media (Sun Gro Horticulture, 200 Burrard Street, Suite 1200, Vancouver, British Columbia, Canada) on August 26, 2011 and November 14, 2011. Fertilizer (7N – $7P_2O_5$ – $7K_2O$) (Green Spec Fertilizer, Grigg Brothers, P.O. Box 128, Albion, ID 83311) was applied at the time of seeding at a rate of 24.4 kg ha^{-1} N. Greenhouse temperatures were maintained at 34/26 C (day/night) with average midday (1200 and 1300 hr) solar radiation ranging from 636 to 754 µmol m^{-2} s^{-1}. Irrigation was supplied through an overhead irrigation system calibrated to deliver approximately 3.8 cm of water wk^{-1}. Pots were allowed to mature in the greenhouse over a three month period. Prior to herbicide application bermudagrass was mowed to 0.6 cm with hand-held, electric grass shearers (Oster Showmaster, Jarden Corporation, 555 Theodore Fremd Ave., Suite B-302, Rye, NY 10580). Treatments were arranged in a randomized complete block design with five replications. Herbicides were applied with a CO_2 backpack sprayer equipped with XR8004VS nozzle tips (Teejet, flat-fan extended range spray tips. Spraying Systems Co., North Ave. and Schmale Rd., Wheaton, IL 60129) calibrated to deliver 375 L ha^{-1} at 221 kPa. Herbicide treatments were applied on December 1, 2011 and February 8, 2012 and consisted of metamifop (32 F Dongbu Financial Center, 891-10-Daechi-Dong, Gangnam-Ga, Seoul, 135-523 Korea) at 200, 300, 400, and 500 g ai ha^{-1}. A sequential application of each treatment was made on December 22, 2011 and February 29, 2012. An untreated check was included for comparison.

Visual ratings of percent bentgrass phytotoxicity was recorded weekly on a scale of 0 (no phytotoxicity) to 100% (completely dead bentgrass). Pots were cut to 0.6 cm after three weeks of growth (prior to sequential treatments), biomass was dried, and weighed. This procedure was conducted again three weeks after sequential treatments. Data were subjected to analysis of variance (ANOVA) ($P = 0.05$) provided by SAS (SAS, Statistical Analysis Systems, 2002-2008, Release 9.2, Statistical Analysis Systems Institute, Cary, NC 27513) with sums of squares partitioned to reflect a split plot treatment structure. Bentgrass cultivar was considered the main plot and metamifop rate was considered the subplot. Where main plot effects were significant, regressions were used to explain the relationship of measured responses to metamifop treatments. Effect of metamifop treatments were separated using Fisher's Protected Least Significant Difference (LSD) test at $P = 0.05$. The rate of metamifop required to reduce bentgrass growth 50% (GR_{50}) was calculated.

Results and Discussion

The regression analysis of bentgrass cultivar by metamifop rate adequately predicted biomass reduction 3 WAIT (L-93 R^2 = 0.92; Penn A-4 R^2 = 0.72; Penncross R^2 = 0.94; Seaside II R^2 = 0.64; Crystal Bluelinks R^2 = 0.82; T-1 R^2 = 0.65; SR 7200 R^2 = 0.92) (Figure 3.1). As metamifop rate increased, bentgrass biomass decreased. The calculated GR_{50} 3 WAIT for L-93, Penn A-4, and Penncross was 268, 388, and 467 g ai ha^{-1}, respectively. The GR_{50} for Seaside II, Crystal Bluelinks, T-1, and SR 7200 could not be determined within our range of metamifop rates. Metamifop at 200 to 300 g ai ha^{-1} exhibited 0 to 7% bentgrass phytotoxicity 3 WAIT, regardless of cultivar (Figure 3.2). Similar observations (< 10% phytotoxicity) were reported at Virginia Tech on Declaration, PennA-4, and L-93 creeping bentgrass 2 WAT in response to single applications of metamifop at 200 and 300 g ha^{-1} (S. D. Askew, personal communication). Metamifop at 400 to 500 g ai ha^{-1} exhibited 12 to 18% phytotoxicity on L-93 and Penn A-4, while phytotoxicity on all other cultivars was ≤ 8% 3 WAIT. The phytotoxicity observed on L-93 and Penn A-4 in response to metamifop at 400 to 500 g ai ha^{-1} coincided with large reductions in biomass (72 to 91%) compared to the untreated check 3 WAIT (Figure 3.3).

The regression analysis of bentgrass cultivar by metamifop rate adequately predicted biomass reduction 6 WAIT (L-93 R^2 = 0.99; Penn A-4 R^2 = 0.84; Penncross R^2 = 0.74; Seaside II R^2 = 0.96; Crystal Bluelinks R^2 = 0.79; T-1 R^2 = 0.98; SR 7200 R^2 = 0.80) (Figure 3.3). As metamifop rate increased, bentgrass biomass decreased. The calculated GR_{50} 6 WAIT for L-93, Penn A-4, Penncross, Crystal Bluelinks, and T-1 was

155, 261, 396, 428, and 302 g ai ha^{-1}, respectively. The GR_{50} for Seaside II and SR 7200 could not be determined within our range of metamifop rates. All bentgrass cultivars exhibited ≤ 10% phytotoxicity in response to metamifop at 200 g ai ha^{-1} 6 WAIT (Figure 4). Bentgrass cultivars responded differently to applications of metamifop at 300 g ai ha^{-1} 6 WAIT. Phytotoxicity was only 10% for Crystal Bluelinks, 18% for Seaside II, 18% for SR 7200, and 26% for T-1. Phytotoxicity was 47 to 76% for the remaining cultivars 6 WAIT. Similar phytotoxicity (50 to 77%) of Penncross creeping bentgrass was reported by Johnson and Carrow (1993) 10 DAT of fenoxaprop at 0.13 kg ai ha^{-1}. Seaside II, SR 7200, T-1, and Crystal Bluelinks exhibited 24 to 36% phytotoxicity in response to metamifop at 400 g ai ha^{-1} 6 WAIT, while all other cultivars exhibited 70 to 86% phytotoxicity. Seaside II, SR 7200, and Crystal Bluelinks exhibited 48 to 51% phytotoxicity in response to metamifop at 500 g ai ha^{-1} 6 WAIT, while all other cultivars exhibited 69 to 88% phytotoxicity. Severe levels of phytotoxicity 6 WAIT coincided with large amounts of biomass reduction when compared to the untreated check (Figure 3.3).

Methods employed in this research may have accounted for greater bentgrass phytotoxicity. Research conducted at Virginia Tech on Declaration, PennA-4, and L-93 creeping bentgrass (S. D. Askew, personal communication) took place in the field, while our research was conducted in the greenhouse. Plants grown under greenhouse conditions are often more susceptible to herbicides, and therefore exhibit higher levels of phytotoxicity. Lingenfelter and Curran (2007) observed 98% control of wirestem muhly [*Muhlenbergia frondosa* (Poir.) Fern.] grown in the greenhouse in response to glyphosate (0.42 and 0.84 kg ai ha^{-1}) 4 WAT. The same applications made in the field exhibited 60 to 87% control 4 WAT. Plant age may have an effect on herbicide efficacy. Putting surfaces examined in research at Virginia Tech where > 10 yrs old (S. D. Askew, personal communication), while bermudagrass utilized in our experiments were only 3 months old. Schuster et al. (2007) observed 80% control of 2.5-cm common lambsquarters (*Chenopodium album* L.) in response to glyphosate at 1.1 kg ae ha^{-1}, but 55% control of 7.5- and 15-cm plants.

Metamifop may be an alternative for the control of bermudagrass in cool-season turf. However, this may be cultivar dependent. Seaside II, Crystal Bluelinks, and SR 7200 exhibited good tolerance (≤ 18%) to sequential applications of metamifop at 300 g ai ha^{-1}. The same applications caused ≥ 26% phytotoxicity to the remaining cultivars. Higher application rates (> 300 g ai ha^{-1}) may cause unacceptable bentgrass phytotoxicity and reduce its competition.

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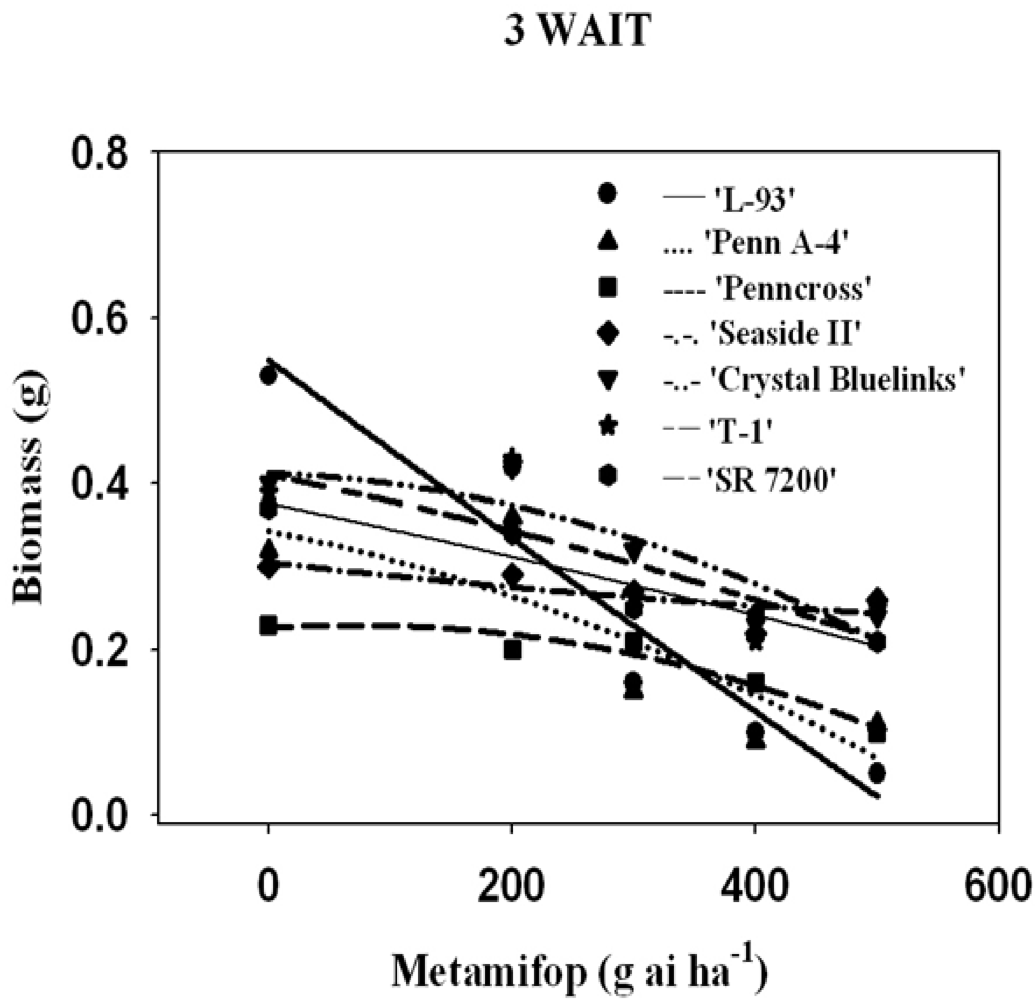

Figure 3.1. Above-ground biomass of several bentgrass cultivars 3 WAIT in response to metamifop. Quadratic equations: L-93, $y = 0.01x^2 – 0.05x + 2.02$, $R^2 = 0.92$; Penn A-4, $y = -0.01x^2 – 0.05x + 1.26$, $R^2 = 0.72$; Penncross, $y = -0.01x^2 + 0.07x + 0.83$, $R^2 = 0.94$; Seaside II, $y = 0.01x^2 – 0.03x + 1.12$, $R^2 = 0.64$; Crystal Bluelinks, $y = -0.01x^2 – 0.04x + 1.52$, $R^2 = 0.82$; T-1, $y = -0.01x^2 + 0.05x + 1.51$, $R^2 = 0.65$; SR 7200, $y = -0.01x^2 – 0.06x + 1.38$, $R^2 = 0.92$. The calculated GR_{50} for L-93, Penn A-4, and Penncross was 268, 388, and 467 g ai ha^{-1}, respectively. The GR_{50} for Seaside II, Crystal Bluelinks, T-1, and SR 7200 could not be determined within our range of metamifop rates.

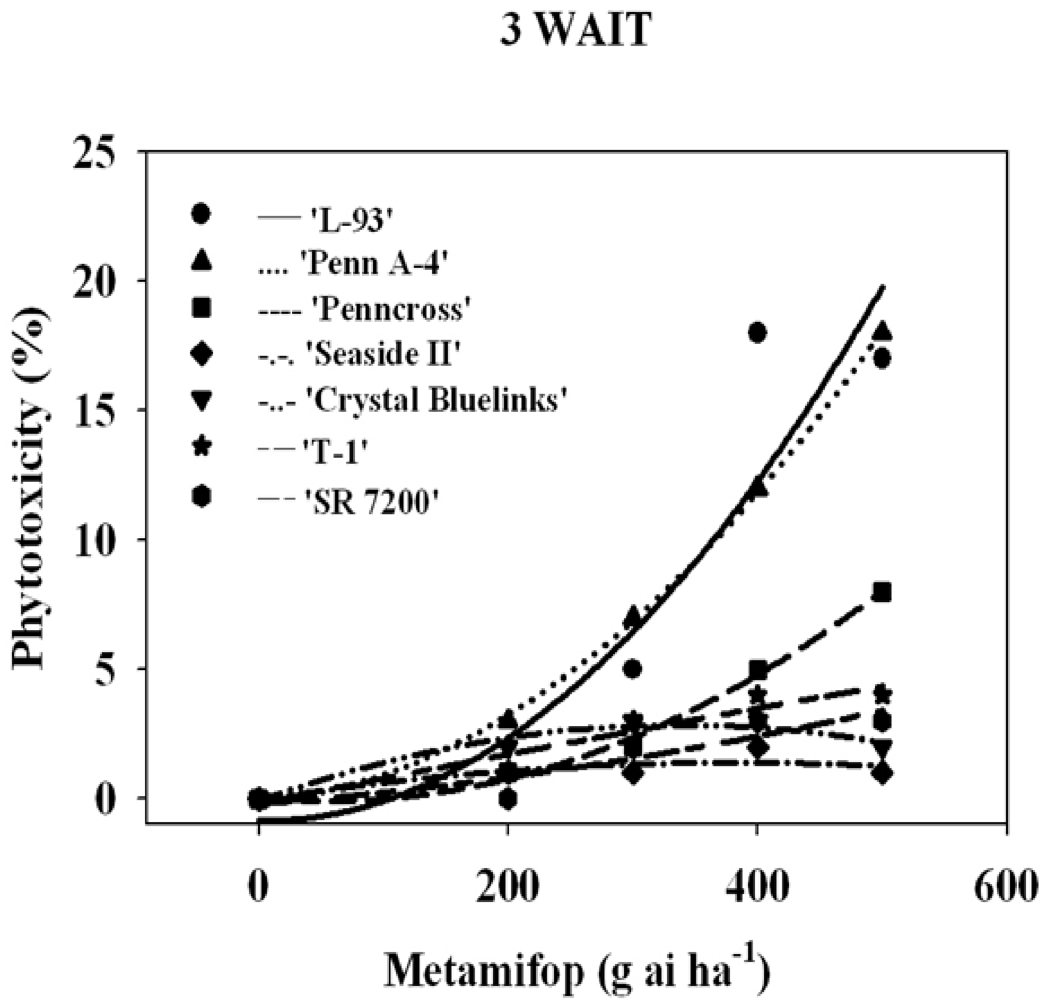

Figure 3.2. Percent phytotoxicity of several bentgrass cultivars 3 WAIT in response to metamifop. Quadratic equations: L-93, $y = 0.06x^2 - 0.15x - 3.13$, $R^2 = 0.85$; Penn A-4, $y = 0.04x^2 + 0.16x - 0.80$, $R^2 = 0.99$; Penncross, $y = 0.03x^2 - 0.23x + 0.44$, $R^2 = 0.99$; Seaside II, $y = -0.01x^2 + 0.38x - 0.74$, $R^2 = 0.73$; Crystal Bluelinks, $y = 0.02x^2 + 0.24x - 1.19$, $R^2 = 0.96$; T-1, $y = -0.01x^2 + 0.49x - 0.65$, $R^2 = 0.92$; SR 7200, $y = 0.02x^2 + 0.19x - 0.76$, $R^2 = 0.84$.

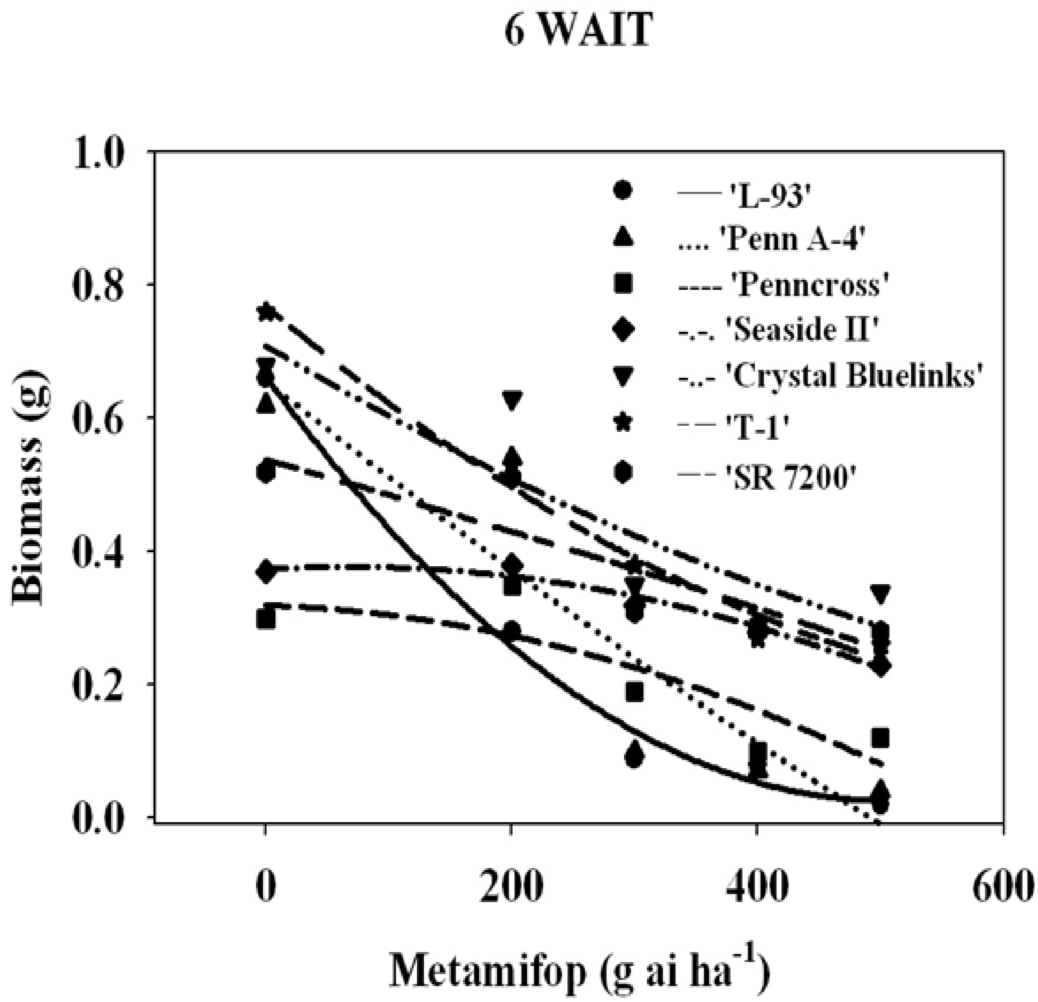

Figure 3.3. Above-ground biomass of several bentgrass cultivars 6 WAIT in response to metamifop. Quadratic equations: L-93, $y = -0.01x^2 – 0.13x + 2.44$, $R^2 = 0.99$; Penn A-4, $y = 0.01x^2 – 0.07x + 2.41$, $R^2 = 0.84$; Penncross, $y = -0.01x^2 – 0.04x + 1.17$, $R^2 = 0.74$; Seaside II, $y = -0.01x^2 + 0.02x + 1.38$, $R^2 = 0.96$; Crystal Bluelinks, $y = 0.01x^2 – 0.06x + 2.61$, $R^2 = 0.79$; T-1, $y = 0.01x^2 – 0.08x + 2.83$, $R^2 = 0.98$; SR 7200, $y = -0.01x^2 – 0.09x + 1.98$, $R^2 = 0.80$. The calculated GR_{50} for L-93, Penn A-4, Penncross, Crystal Bluelinks, and T-1 was 155, 261, 396, 428, and 302 g ai ha^{-1}, respectively. The GR_{50} for Seaside II and SR 7200 could not be determined within our range of metamifop rates.

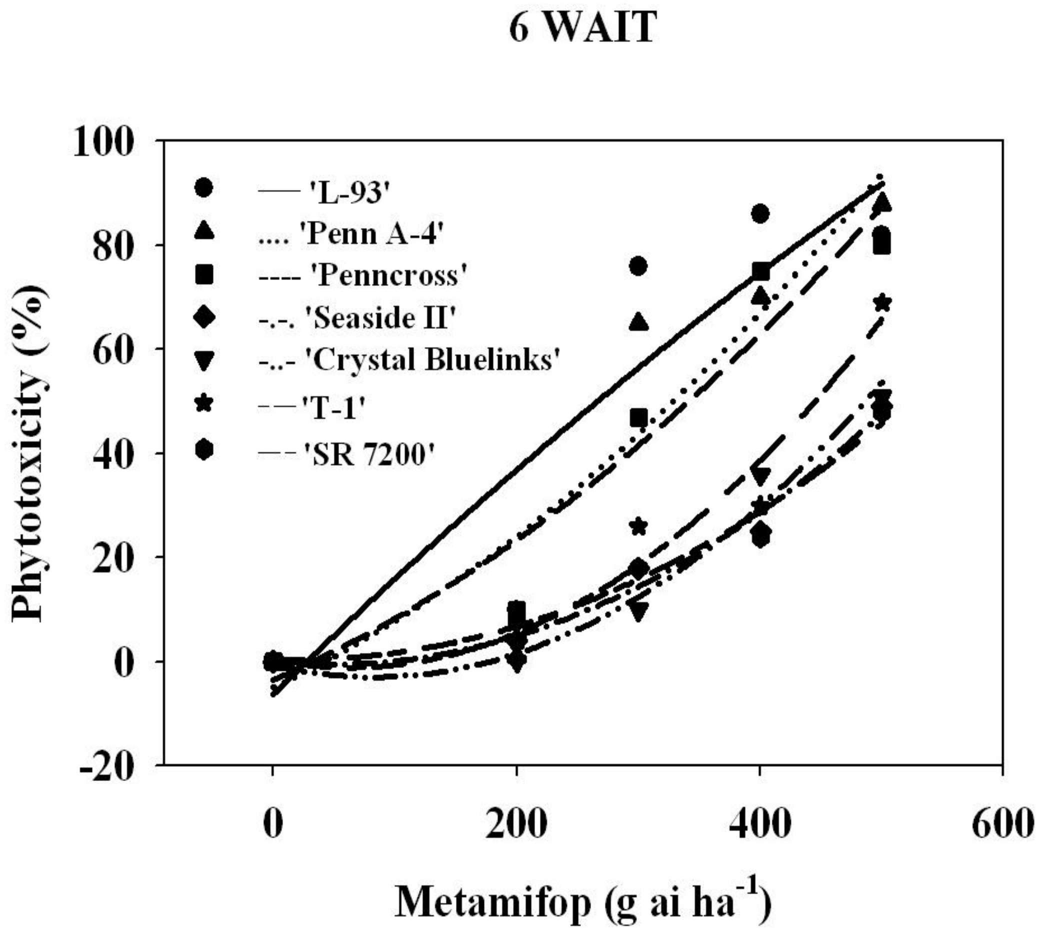

Figure 3.4. Percent control of several bentgrass cultivars 6 WAIT in response to metamifop. Quadratic equations: L-93, $y = -0.04x^2 + 0.84x – 6.13$, $R^2 = 0.81$; Penn A-4, $y = 0.03x^2 + 0.40x – 4.82$, $R^2 = 0.85$; Penncross, $y = 0.03x^2 + 0.38x – 3.48$, $R^2 = 0.92$; Seaside II, $y = 0.04x^2 – 0.30x + 0.72$, $R^2 = 0.98$; Crystal Bluelinks, $y = 0.06x^2 – 0.72x – 2.67$, $R^2 = 0.97$; T-1, $y = 0.06x^2 – 0.59x + 1.01$, $R^2 = 0.96$; SR 7200, $y = 0.04x^2 – 0.40x + 2.05$, $R^2 = 0.97$.

Chapter IV

Annual Bluegrass Control with Fall Applications of Methiozolin

Abstract

Three field experiments were conducted on creeping bentgrass greens at separate locations between the fall of 2011 and the spring of 2012 in Lubbock, TX. Herbicide treatments were initiated on October 10, 2011, November 10, 2011, or December 10, 2011 and consisted of single or sequential applications of methiozolin at 0.5 or 1.0 kg ai ha^{-1}. Sequential applications were made in one-month increments. Paclobutrazol at 0.28 kg ai ha^{-1} applied on October 10, 2011 with a sequential on November 10, 2011 was evaluated as an industry standard. An untreated check was included for comparison. Minimal to no creeping bentgrass phytotoxicity (< 2.5%) was observed 28 days after initial treatment (DAIT) in response to methiozolin, regardless of application rate or timing. Paclobutrazol treatments in our research exhibited 30% creeping bentgrass phytotoxicity 28 DAIT. However, phytotoxicity was reduced below acceptable levels (< 10%) by the following spring. Differences in annual bluegrass control were observed between locations. Methiozolin applications at the Rawls Golf Course exhibited 57 to 86% annual bluegrass control, regardless of application rate or timing. Control increased as applications were made later in the fall. Single applications of methiozolin applied in October exhibited 57 to 63% control, while applications made in December exhibited 65 to 73% control, regardless of rate. Annual bluegrass control in response to methiozolin at the Reese Golf Course ranged from 54 to 100%, regardless of application rate or timing. Control increased as applications were made later in the fall. Single applications of

methiozolin applied in October exhibited 54 to 78% control, while applications made in November exhibited 78 to 88% control, regardless of rate. However, control was only 74% in response to single applications of methiozolin made in December, regardless of rate. The number of sequential applications of methiozolin significantly affected annual bluegrass control. Control of annual bluegrass was 63, 74, and 82% at the Rawls Golf Course in response to methiozolin applied 1, 2, and 3 times, respectively, regardless of application rate or application timing. Control of annual bluegrass was 75, 90, and 95% at the Reese Golf Course in response to methiozolin applied 1, 2, and 3 times, respectively, regardless of application rate or timing.

Introduction

Creeping bentgrass (*Agrostis stolonifera* L.) is a fine-textured, stoloniferous cool-season grass primarily used for golf course putting greens (Beard and Beard 2005; Christians 2011; Emmons 2000) in the northern U.S., transition zone, and several regions further south (Mazur 1986). When properly managed, creeping bentgrass can produce one of the finest putting surfaces in the world (Fry and Huang 2004). Management of creeping bentgrass is relatively intense when maintained as a golf course putting green (Fry and Huang 2004). The intense nature of the cultural practices required to maintain creeping bentgrass as a putting surface has a cumulative negative impact on this same environment. Aerification, verticutting, mowing, and topdressing open up the turfgrass canopy and cause significant wounding to creeping bentgrass plants (Emmons 2000; Fry and Huang 2004; McCarty 2008). Voids in the canopy and reduced photosynthetic capability of desired turfgrass plants may shift the competitive edge to favor weed invasion (Emmons 2000; Fry and Huang 2004; McCarty 2008).

Tolerance to low mowing heights has led to annual bluegrass (*Poa annua* spp.) being described as the most problematic weed in golf course putting greens (Lush 1989; Sweeney and Danneburger 1997). Infestations are primarily due to improper management techniques and/or non-competitiveness of older creeping bentgrass cultivars (Beard 1970). Cultural practices such as irrigation, fertilization, mowing, and aerification intended to enhance the putting surface may promote annual bluegrass infestation (Sprague and Burton 1937). During cooler weather, large areas of turf may become infested as annual bluegrass begins to out-compete creeping bentgrass for light, water, and nutrients (Sprague and Burton 1937). The lime-green color of annual bluegrass reduces the aesthetics of golf greens when grown as a mixed stand with the darker green foliage of creeping bentgrass (Lycan and Hart 2006). The production of numerous seedheads during cool weather and coarse texture of annual bluegrass causes the turf to appear tattered and reduces the playability of putting green surfaces (Beard et al. 1978; Engel and Illnicki 1969; McCarty 1999; Sprague and Burton 1937).

Postemergence control of annual bluegrass is difficult due to the limited number of labeled herbicides and the presence of annual (*Poa annua* spp. *annua* L. Timm.) and perennial [*Poa annua* spp. *reptans* L. (Hauskins) Timm.] biotypes. There are no herbicides labeled for the selective, postemergence control of annual bluegrass in creeping bentgrass putting greens. Certain herbicides have successfully controlled annual bluegrass infestations on creeping bentgrass greens, but associated injury is often considered unacceptable. Ethofumesate may provide some postemergence suppression, but it is not labeled for use on creeping bentgrass putting greens (Beam et al. 2003; Coats and Krans 1986; Hart and Lycan 2000). Bispyribac-sodium is registered for the control of annual bluegrass in creeping bentgrass fairways and roughs. Teuton et al. (2007) observed 86% annual bluegrass control 12 weeks after initial treatment (WAIT) in response to weekly applications of bispyribac-sodium at 12 or 24 g ai ha^{-1}. However, >15% creeping bentgrass injury was observed 4 to 8 WAIT. Lycan and Hart (2006) observed reductions in annual bluegrass cover (14 to 42%) in response to bispyribac-sodium applied during the spring, summer, and fall. Summer treatments did not reduce creeping bentgrass turf quality, but spring and fall treatments caused reductions 3 weeks after treatment (WAT) (Lycan and Hart 2006). Sequential applications and tank-mixtures of plant growth regulators (paclobutrazol, trinexapac-ethyl, mefluidide, ethephon, and flurprimidol) have been shown to reduce annual bluegrass populations and/or prevent seedhead production (Beam et al. 2003; Eggens et al. 1989; Eggens and Wright 1985; Johnson and Murphy 1995; Kane and Miller 2003; Woosley et al. 2003). Woosley et al. (2003) observed > 85% annual bluegrass control in creeping bentgrass fairways with sequential applications of paclobutrazol at 0.14 and 0.28 kg ai ha^{-1}. McCullough et al. (2005) reported > 50% annual bluegrass control with applications of paclobutrazol at 0.14 kg ai ha^{-1} every two wks or 0.56 kg ai ha^{-1} every six wks.

Methiozolin [(5-(2,6-difluorobenzyl) oxymethyl-5-methyl-3-(3methylthiophen-2-yl)-1,2-isoxazoline)] is a preemergence and postemergence cell wall biosynthesis inhibitor used for the control of grass weeds in rice (Anonymous 2012; Johnson and

Golob 2011). Recently, methiozolin was registered for the control of annual bluegrass in creeping bentgrass greens due to low phytotoxicity (Anonymous 2012; Johnson and Golob 2011). Johnson and Golob (2011) observed 90 to 94% annual bluegrass control 3 WAIT in response to methiozolin at 1.48 kg ai ha^{-1} applied in the fall. Control remained at 90% through early spring. Similarly, Han and Kaminski (2011) reported nearly 100% control of 5 out of 6 annual bluegrass biotypes 3 WAIT in response to methiozolin at 2 kg ai ha^{-1}. Brosnan and Breeden (2012) reported > 90% annual bluegrass control and no creeping bentgrass phytotoxicity 28 WAIT in response to sequential fall applications of methiozolin at 0.5 to 1.0 kg ai ha^{-1}. High annual bluegrass efficacy combined with low creeping bentgrass phytotoxicity (Johnson and Golob 2011) may make methiozolin a viable altenative to plant growth regulators. Therefore, the objective of our research was to evaluate single and sequential applications of methiozolin applied in the fall for annual bluegrass control in creeping bentgrass putting greens.

Materials and Methods

Three field experiments were conducted at separate locations between the fall of 2011 and the spring of 2012 in Lubbock, TX. Two trials were located at the Rawls Golf Course on 'Dominant Plus' creeping bentgrass greens grown on a USGA spec soil profile. The practice pitching green had a soil particle size analysis of 96.5% sand, 2.3% silt, and 1.2% clay with organic matter content of 0.7%. The practice putting green had a soil particle size analysis of 95.4% sand, 3.7% silt, and 0.9% clay with organic matter content of 0.7%. The trial located at Reese Golf Course was conducted on a push-up style

'Penncross' green with a soil particle analysis of 89.9% sand, 5.9% silt, and 4.2% clay with organic matter content of 2.2%. Natural infestations of annual bluegrass were historically present in each of the three locations. Plots, 1.5 x 1.5 m, were arranged in a randomized complete block design with four replications per treatment. Annual bluegrass cover was determined at the time of initial herbicide application through grid counts using a 0.3 m^2 grid (25 intersecting points) tossed into each plot. Each putting green was maintained at approximately 3.2 mm and irrigation was applied to maintain adequate soil moisture.

Herbicide treatments were initiated on October 10, 2011, November 10, 2011, or December 10, 2011 and consisted of single or sequential applications of methiozolin (POA-BAKSA, Moghu Research Center Ltd., BVC 311, KRIBB, Yuseong, Daejeon, 305-333, Korea) at 0.5 or 1.0 kg ai ha^{-1}. Sequential applications were made in one-month increments. Paclobutrazol (Trimmit 2SC, Syngenta Crop Protection, LLC., P.O. Box 18300, Greensboro, NC 27419-8300) at 0.28 kg ai ha^{-1} applied on October 10, 2011 with a sequential on November 10, 2011 was evaluated as an industry standard. An untreated check was included for comparison (Table 1). Herbicides were applied with a CO_2 backpack sprayer equipped with XR8003VS nozzle tips (Teejet, flat-fan extended range spray tips. Spraying Systems Co., North Ave. and Schmale Rd., Wheaton, IL 60129) calibrated to deliver 305 L ha^{-1} at 275 kPa.

Data collected included creeping bentgrass phytotoxicity and annual bluegrass control based on digital image analysis and grid counts, respectively. Digital photographs were taken 1 and 2 weeks after each application with a Nikon (Coolpix P5000, Nikon Inc.

USA, Melville, NY) camera capable of capturing 10 million pixels per image mounted on a 0.28 m^2 light box equipped with four compact florescent light bulbs (N:Vision 14-Watt (60W) Daylight CFL Light Bulbs, N:Vision, Atlanta, GA) each with a light output of 172 $\mu mol\ m^{-2}\ s^{-1}$. Digital images were analyzed using WinCam 2007 software to determine percent creeping bentgrass leaf firing (i.e., chlorotic and/or necrotic tissue). Percent creeping bentgrass leaf firing was converted to percent creeping bentgrass phytotoxicity by comparing each plot to the untreated check within each experimental replication. Grid counts were taken 119, 137, and 164 DAIT using a 0.3 m^2 grid (25 intersecting points) tossed into each plot. Plants directly under each line intersection were identified and totaled for each plot. Grid counts were converted to percent annual bluegrass control by comparing each plot to the cover recorded at initial herbicide application.

Percent creeping bentgrass phytotoxicity and percent annual bluegrass control data were arc-sin square root transformed prior to analysis. Transformation did not improve variance homogeneity; therefore, nontransformed data were used in analysis and presentation. There was a significant treatment by location interaction. Data from both locations at the Rawls Golf Course were combined and an ANOVA was performed. A separate ANOVA was performed on data from the Reese Golf Course which will be presented separately. Means were separated using Fisher's protected LSD test ($\alpha = 0.05$). Single, double, and triple applications of methiozolin were averaged across methiozolin rates (0.5 and 1.0 kg ai ha-1) and timings (October, November, and December) and evaluated by a separate ANOVA in order to compare single vs. sequential applications.

Results and Discussion

Minimal to no creeping bentgrass phytotoxicity (< 2.5%) was observed 28 DAIT in response to methiozolin, regardless of application rate or timing (data not shown). Askew et al. (2012) observed no creeping bentgrass injury in response to sequential applications of methiozolin totaling 2.0 and 4.0 kg ai ha^{-1}. However, Venner et al. (2012) reported 60 to 80% bentgrass injury in response to sequential methiozolin applications of 2.0 kg ai ha^{-1} in September through November. Paclobutrazol treatments in our research exhibited 30% creeping bentgrass phytotoxicity 28 DAIT (data not shown). However, phytotoxicity was reduced below acceptable levels (< 10%) by the following spring. Johnson and Murphy (1995) observed 20 to 32% creeping bentgrass phytotoxicity 2 WAT creeping in response to sequential applications of paclobutrazol at 0.3 or 0.6 kg ai ha^{-1}.

Differences in annual bluegrass control were observed between locations. Methiozolin applications at the Rawls Golf Course exhibited 57 to 86% annual bluegrass control, regardless of application rate or timing (Table 1). Control increased as applications were made later in the fall. Single applications of methiozolin applied in October exhibited 57 to 63% control, while applications made in December exhibited 65 to 73% control, regardless of rate. Annual bluegrass control in response to methiozolin at the Reese Golf Course ranged from 54 to 100%, regardless of application rate or timing (Table 1). Control increased as applications were made later in the fall. Single applications of methiozolin applied in October exhibited 54 to 78% control, while applications made in

November exhibited 78 to 88% control, regardless of rate. However, control was only 74% in response to single applications of methiozolin made in December, regardless of rate. Brosnan and Breeden (2012) observed similar control (> 73%) 25 WAIT with single applications of methiozolin at 0.5 and 1.0 kg ai ha^{-1} applied in the fall to push-up style bentgrass greens.

The number of sequential applications of methiozolin significantly affected annual bluegrass control (Table 2). Control of annual bluegrass was 63, 74, and 82% at the Rawls Golf Course in response to methiozolin applied 1, 2, and 3 times, respectively, regardless of application rate or application timing. Control of annual bluegrass was 75, 90, and 95% at the Reese Golf Course in response to methiozolin applied 1, 2, and 3 times, respectively, regardless of application rate or timing. Brosnan and Breeden (2012) reported > 90% annual bluegrass control 28 WAIT in response to sequential fall applications of methiozolin at 0.5 to 1.0 kg ai ha^{-1}. Askew et al. (2012) observed 61, 87, and 93% annual bluegrass control when methiozolin was applied 2, 4, or 6 times per year at a total of 4.0 kg ai ha^{-1}.

Increased annual bluegrass efficacy at the Reese Golf Course may be associated with soil characteristics and management practices. The soil at Reese Golf Course consisted of 89.9% sand, 5.9% silt, and 4.2% clay with organic matter content of 2.2%, while the soil at the Rawls Golf Course was ≥ 95.4% sand, ≤ 1.2% clay with an organic matter content of 0.7%. Reduced methiozolin efficacy at the Rawls Golf Course may be attributed to increased herbicide mobility through the sand-based rootzone. Stougaard et al. (1990) reported that imazethapyr and imazaquin were least mobile in a silty clay loam with clay content of 30% and organic matter content of 2.5% compared to a silt loam soil with 19% clay and 1.5 % organic matter or a sandy loam with 15% clay and 1.0% organic matter. Sand-based rootzones often require more frequent irrigation applications due to quicker infiltration rates and poor water-holding capacity. Efficacy of methiozolin applications at the Rawls Golf Course may have been affected by irrigation practices. Futch and Singh (1999) observed an increase in mobility of bromacil, diuron, norflurazon, oryzalin, oxyfluorfen, simazine, and thiazopyr as irrigation was increased from 3.2 to 12.8 cm applied at a rate of 2.5 cm hr^{-1}.

These trials suggest that methiozolin applied in the fall can effectively reduce annual bluegrass populations in creeping bentgrass greens with minimal phytotoxicity. Sequential applications may be necessary to provide the greatest amount of control. Soil type effects methiozolin efficacy and may warrant lower application rates made at shorter intervals.

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Table 4.1. Annual bluegrass control with fall 2011 applications of methiozolin 164 DAIT[a] at Rawls Golf Course and Reese Golf Course in Lubbock, TX in 2012[b].

			Rawls GC	Reese GC
Treatment	Rate	App. Timing	Control 164 DAIT	
	— kg ai ha^{-1} —		— % control —	
Untreated Check	—	Oct. 10, 2011	0	0
Methiozolin[c]	0.5	Oct. 10, 2011	57	54
Methiozolin	1.0	Oct. 10, 2011	63	79
Methiozolin	0.5	Nov. 10, 2011	56	78
Methiozolin	1.0	Nov. 10, 2011	64	88
Methiozolin	0.5	Dec. 10, 2011	65	74
Methiozolin	1.0	Dec. 10, 2011	73	74
Methiozolin	0.5 fb 0.5	Oct. fb Nov.	58	87
Methiozolin	1.0 fb 1.0	Oct. fb Nov.	73	88
Methiozolin	0.5 fb 0.5	Nov. fb Dec.	76	85
Methiozolin	1.0 fb 1.0	Nov. fb Dec.	86	100
Methiozolin	0.5 fb 0.5 fb 0.5	Oct. fb Nov. fb Dec.	80	92
Methiozolin	1.0 fb 1.0 fb 1.0	Oct. fb Nov. fb Dec.	83	97
Paclobutrazol	0.28 fb 0.28	Oct. fb Nov.	79	93
LSD (P = 0.05)	—	—	16.8	22.1

[a] Abbreviations: days after initial treatment, DAIT; followed by, fb.

[b]Data were pooled over Rawls GC locations, but data from Reese GC is presented separately.

[c] Single or sequential applications were made with each application within a treatment receiving the same herbicide rate.

Table 4.2. Effect of single vs. sequential applications of methiozolin on the control of annual bluegrass 164 DAIT[a] at Rawls GC and Reese GC in Lubbock, TX in 2012[b].

		Rawls GC	Reese GC
Treatment[c]	# of Applications	Control 164 DAIT	
		—— % control ——	
Methiozolin	1	63	75
Methiozolin	2	74	90
Methiozolin	3	82	95
LSD (P = 0.05)	—	10.4	11.8

[a]Abbreviations, days after initial treatment, DAIT.

[b]Data were pooled over Rawls GC locations, but data from Reese GC is presented separately.

[c]Treatments were averaged across methiozolin rates and application dates.