Methiozolin [5-(2,6-difluorobenzyl)oxymethyl-5-methyl-3,3(3-methylthiophen-2-yl)-1,2-isoxazoline], a new annual bluegrass (*Poa annua* L.) herbicide for turfgrasses

Suk-Jin Koo,* Ki-Hwan Hwang, Man-Seok Jeon, Sung-Hun Kim, Jongsoo Lim, Dong-Guk Lee and Nam-Gyu Cho

Abstract

BACKGROUND: Selective control of annual bluegrass (*Poa annual* L.) has been difficult in turfgrasses. The potential of methiozolin in this area was investigated.

RESULTS: Methiozolin was safe on established zoysiagrass (*Zoysia japonica* Steud.), creeping bentgrass (*Agrostis palustris* Huds.), Kentucky bluegrass (*Poa pratensis* L.), and perennial ryegrass (*Lolium perenne* L.) at 1000 g ha$^{-1}$, and controlled annual bluegrass with GR$_{50}$ values of 23, 52, 104, and 218 g ha$^{-1}$ at PRE, two-, four- and eight-leaf stage, respectively, in the greenhouse. When applied at early flowering, methiozolin suppressed >80% of annual bluegrass seed heads at 2000 g ha$^{-1}$. $^{14}$C-Methiozolin was readily absorbed by both leaves and roots, but translocation was mainly acropetal. No herbicidal activity resulted from application to the leaf only; however, application to the soil surface only showed equivalent herbicidal activity to that of broadcast application to the leaf and soil. Methiozolin at 500 to 1000 g ha$^{-1}$ provided 80 to 100% control of annual bluegrass when applied in the fall with acceptable and temporary injury to creeping bentgrass, and about 60% control when applied in the spring with no bentgrass injury in the field.

CONCLUSION: Methiozolin is an excellent candidate for annual bluegrass management in turfgrasses.

Keywords: methiozolin; MRC-01; turf herbicide; annual bluegrass; creeping bentgrass

1 INTRODUCTION

Methiozolin is a new turf herbicide being developed by Moghu Research Center, Korea. The herbicide is in the isoxazoline chemical family and was first invented as a rice herbicide candidate. The molecule controlled barnyardgrass (*Echinochloa* spp.) and several other annual broadleaf and sedge weeds from 125 g ha$^{-1}$ in rice paddies while having good safety to transplanted rice up to 1.0 kg ha$^{-1}$. Koo and Hwang reported that the herbicide controlled annual bluegrass and large crabgrass (*Digitaria sanguinalis*) effectively in various cool and warm season turfgrasses. The mechanism of action of methiozolin and related chemistry is not thoroughly understood and appears to be novel. Lee et al. reported several morphological responses in germinating barnyardgrass including cessation of shoot and root growth without twisting, colour changes, burning and other symptoms associated with known modes of action. Further, they showed methiozolin inhibited root growth of corn, a susceptible grass, at a very low dose with a GR$_{50}$ of 0.03 µM. Using $^{14}$C-glucose incorporation into corn root cell wall constituents, Lee et al. showed methiozolin inhibited biosynthesis of both cellulose and hemicellulose fractions greatly from 0.1 µM after 24 h of exposure. However, the morphological symptoms did not resemble those of known cell wall synthesis inhibitors such as dichlobenil.

Recently, Grossmann et al. suggested methiozolin might inhibit tyrosine aminotransferase (TAT), an enzyme in the biosynthesis of plastoquinone, in duckweed (*Lemna paucicostata* L.). This suggestion was based on feeding of hydroxyphenylpyruvate, the product of TAT, to duckweed, which nullified growth inhibition of methiozolin. They also showed that methiozolin inhibited a recombinant TAT of *A. thaliana*, but with a very high IC$_{50}$ value (about 200 µM). Grossmann et al. further suggested that other TAT isoenzymes in *Arabidopsis* or from other plants could be more sensitive and the primary *in vivo* target of methiozolin. Although the mechanism of methiozolin was shown to involve inhibition of cell wall biosynthesis and potentially plastoquinone biosynthesis, the primary site of herbicidal action is still unclear.

Annual bluegrass is a common and major weed species in both cool and warm season turfgrasses. Annual bluegrass usually behaves as a winter annual, germinating in the late summer to early fall when soil temperatures fall below 21°C, followed by prolific seed head.
production during the late winter and spring. In addition to the typical annual biotype, P. annua spp. reptans (Hausk.) Timm, a perennial subspecies of annual bluegrass, is commonly found in creeping bentgrass putting greens throughout most of the United States. The perennial biotype shows a stoloniferous prostrate growth habit and has been shown to be difficult to control by herbicides. Annual bluegrass is also managed by default as a turfgrass species in many golf courses, but is generally regarded as an undesirable species due to prolific seed head production, shallow root system, and susceptibility to many diseases and less tolerance to heat and cold. In a situation where annual bluegrass persists in more desirable turfgrasses, such as creeping bentgrass, it is very invasive yet relatively intolerant of most biotic and abiotic stresses, often dying unexpectedly, leaving surface voids, requiring higher cultural and chemical inputs to maintain it. Furthermore, it is considered to be the number one weed problem in turfgrass both in frequency of occurrence and difficulty of control.

Options for selective chemical control of annual bluegrass are limited, especially in cool season turfgrasses. A few herbicides, including bensulide and ethofumesate, or plant growth regulators (PGRs) such as ethephon, paclobutrazol or flurprimidol have traditionally been used for annual bluegrass suppression. Herbicides that have been introduced more recently include acetolactate synthase inhibitors, such as sulfosulfuron and bispyribac-sodium, which control annual bluegrass and/or roughstalk bluegrass (Poa trivialis L.). However, these options have had limitations in application timing, reliability or efficacy, possibly due to the wide genetic variability associated with annual bluegrass.

Methiozolin has been extensively evaluated in turf including annual bluegrass control in creeping bentgrass putting greens. McNulty et al. reported methiozolin at 0.5 and 0.75 kg ha$^{-1}$ applied in March 2009 reduced annual bluegrass cover by 77–80% at 2 months after treatment in creeping bentgrass putting greens. Methiozolin did not cause any injury on garden height (38–76 mm) perennial ryegrass, Kentucky bluegrass, or tall fescue, and suppressed seed head production of annual bluegrass 85% one week after application of >1500 g ha$^{-1}$. In the test, methiozolin at >3000 g ha$^{-1}$ controlled annual bluegrass and roughstalk bluegrass >80 and >90%, respectively, and was eventually superior to two applications of bispyribac-sodium at 74 g ha$^{-1}$. Methiozolin at 2000 g ha$^{-1}$ applied twice controlled 31 different annual bluegrass biotypes including 28 perennial biotypes in a pot test, and there was no biotype showing tolerance to methiozolin. Methiozolin did not injure several creeping bentgrass varieties such as A4, L-93 and Declaration when applied at 500–4000 g ha$^{-1}$ in two university trials; however, methiozolin at 2000–4000 g ha$^{-1}$ injured L-93 creeping bentgrass by 25–40% in hot and dry weather in a different location. Despite various research, little has been published to date on the whole picture of methiozolin as a turf herbicide. The objective of this research was to provide basic biological properties of methiozolin in terms of turfgrass safety, annual bluegrass rate responses in different growth stages, seed head suppression activity, site of uptake, and application window in the field.

2 MATERIALS AND METHODS

2.1 Turfgrass safety

Turfgrass safety to methiozolin was evaluated during 2008–2009 in the greenhouse. Commercially available sod of zoysiagrass (cv. Samyeop-Jungji), creeping bentgrass (cv. Penncross), Kentucky bluegrass (mixture of cv. Tsunami, Midnight, Freedom III, and Brilliant), and perennial ryegrass (cv. Bright star II) was used to establish turf in 10 × 20 cm pots containing commercial compost (Bunong Horticulture Mix #5; Bunong Industry, Gyeongju, Korea) and a sandy loam (1:1, v/v). Pots were mowed at 1.0 cm once a week, and kept for 30 days in a greenhouse maintained at 25–30 °C (day) and 15–25 °C (night) prior to herbicide application. Methiozolin (25% EC) (Moghu Research Center Ltd, Daejeon, Korea) was applied at 500, 1000, 2000 and 4000 g a.i. ha$^{-1}$. For comparison, diethipyry (32% EC) (DongbuHannong, Seoul, Korea) was also applied at 480, 960 and 1920 g a.i. ha$^{-1}$. Applications were made using a CO$_2$ pressurised track sprayer (Korea Plant and Environmental Research Station, Suwon, Korea) equipped with a flat fan nozzle (Teejet 8002E; Spraying Systems Co., Roswell, USA) adjusted to deliver 300 L ha$^{-1}$ at 280 kPa. Turf phytotoxicity was visually evaluated after 2, 4 and 6 weeks based on a % scale (0 = no phytotoxic effect, 100 = completely killed). The experiment was conducted in a completely randomised design with three replications, and repeated.

2.2 Annual bluegrass growth stage

About 30 seeds of annual bluegrass were sown into 7-cm diameter pots containing the same soil mix described above. Seeds were then covered with finely sieved steam-sterilised sandy loam to a depth of 2 mm. Plants were maintained in a greenhouse at 17–20 °C at night and 25–30 °C during daytime. Seed was sown on 14-day intervals to obtain various growth stages from PRE to the two-, four- and eight-leaf stages before methiozolin application. Application rates were variable depending on the growth stage; the highest rates that each growth stage received were 250, 1000 and 2000 g ha$^{-1}$ for the PRE, two-, four- and eight-leaf stages, respectively. From the highest rates, six lower rates were applied using a two-fold serial dilution. The highest rate provided 100% control at each stage based on a preliminary study (data not shown). Pots were kept in a greenhouse and regularly watered for 4 weeks. Shoots were cut at the soil surface and the fresh weights measured.

Treatments were arranged in a completely randomised design with four replications and the experiment was repeated. Then mean fresh weight values were converted to percentage of the untreated control, and were subjected to a non-linear regression analysis using a logistic model.

2.3 Annual bluegrass seedhead suppression

Mature annual bluegrass turf was transplanted from a Kentucky bluegrass fairway at Castle Pine Country Club, Yeoju, Korea (37° N) on 25 February 2010 and moved to Moghu Research Center (Daejeon, Korea) (36° N). The turf was placed into 10 × 20 cm pots containing soil described above, mowed at 1.0 cm once or twice a week depending on growth rate and kept outside. Monthly average temperature during the test was 2.1, 5.3, 10.0, 17.8 and 23.4°C in February, March, April, May and June, respectively, based on the Daejeon Meteorological Center (22 Guseong, Yuseong, Daejeon, Korea) located <1 km away. On 10 May, when annual bluegrass was actively flowering, methiozolin was applied at 500, 1000, 1500 and 2000 g ha$^{-1}$. After application, annual bluegrass was not mowed in order to allow panicles to expand fully. After 25 days, shoots were harvested at 1 cm above the soil surface, and the numbers of panicles counted. Seedhead lengths were measured from 20 randomly chosen panicles. Treatments were arranged in a completely randomised design with three replications.
2.4 Site of uptake
Annual bluegrass was seeded and grown as described in the section 'Annual bluegrass growth stage' until the four-leaf stage and methiozolin was applied at 500, 1000 and 2000 g ha$^{-1}$ by the following three methods: (1) foliar and soil application; (2) foliar-only application, where to limit herbicide reaching the soil surface, the soil surface was covered with dry sand to a depth of 1.0 cm, plants were sprayed with the herbicide solutions, then immediately after the foliage had dried, sand was removed from the pots by careful shaking and brushing; and (3) soil-only application, the amount of the herbicide on the surface area of the pot was diluted in 5 mL of distilled water, then applied to the soil surface using a pipette without foliar contact. Six weeks after application, the remaining plants were cut at the soil surface, and the fresh weight was determined. The % control value was calculated based on the remaining fresh weight relative to that of the untreated control. Treatments were arranged in a completely randomised design with four replications and the experiment was repeated.

2.5 Uptake and translocation
2.5.1 Shoot application
Annual bluegrass was planted and grown as described in the section 'Annual bluegrass growth stage' until the 5th leaf started to emerge. At this stage, 0.8 µg of 14C-methiozolin (specific activity 4.55 MBq mg$^{-1}$; 14C-labelled at the isoxazoline ring carbon) dissolved in 5 µL of 50:50% (v:v) acetone–distilled water containing 0.1% Tween 20 was applied on the middle 5 mm of the 4th leaf blade of each plant using a micropipette. The treated leaf blade was then excised at 3, 6, 12, 24, 48, 72, 96, 120 and 168 h after application. The remaining plant parts were carefully removed from the soil and divided into the 5th leaf, 4th leaf sheath, the lower leaves, and the root. The treated 4th leaf blades were washed three times in 10 mL of 40% acetonitrile by shaking for 30 s in a glass tube. The washing solutions were combined and a 1 mL aliquot was taken for 14C quantification by liquid scintillation spectrometry (LSS) (Packard Tri-Carb Model 2100TR; Perkin Elmer, Waltham, MA, USA). The washed 4th leaf blade and other divided plant parts were dried in an oven at 60 °C for 24 h, combusted in a biological oxidiser (Packard Model No. 307; Perkin Elmer) and the 14C released was quantified by LSS. This experiment had three replicates, in which each replication consisted of three plants.

2.5.2 Root application
Annual bluegrass seedlings at the 4th leaf stage were carefully removed from pots after softening the soil with excessive water. Three seedlings were rolled up with a layer of cotton wool (about 3 mm thick, 1 cm wide) at the lower part of the shoot, and the cotton body containing the plants was inserted into the mouth of a 20 mL glass vial containing 17 mL of a full-strength Hoagland solution (Hoagland’s No. 2 Basal Salt Mixture; Sigma–Aldrich, Irvine, UK). Plants were allowed to adjust in the hydroponic culture condition for 3 days until reaching the 5th leaf stage. Then the Hoagland solution was replaced with fresh solution containing 0.1 µM 14C-methiozolin. Plants were exposed to the herbicide solution for 3, 6, 12, 24, 48, 72, 96, 120 and 168 h. At each measurement time, the plants were removed, roots were blotted on a cleaning tissue, and divided into the root and whole shoot, dried in an oven at 60 °C, combusted in a biological oxidiser, and the 14C released was quantified by LSS. Also, a 1 mL aliquot of the Hoagland solution in each vial was counted by LSS. This experiment had three replicates (vials), in which each vial had three individual plants at all the measurement times.

2.6 Field trial
A field trial was conducted from October 2008 to June 2009 on the practice putting greens and nursery greens at Daedeog Golf Course, Daejeon, Korea (36°N). The site was a typical sand-based creeping bentgrass (cv. Penncross) putting green with 20–40% annual bluegrass cover. Annual bluegrass populations were variable, from 1 cm to as large as 20 cm in diameter. Methiozolin (25% EC) at 500 and 1000 g a.i. ha$^{-1}$ was applied using 12 different timings from 21 October 2008 until 27 April 2009 in 3-week intervals. Applications were made with a handheld sprayer (Solo Sprayer Model 430-1G; Solo Sprayer Ltd., Newport, VA, USA) adjusted to deliver 1000 L ha$^{-1}$. The practice greens received regular mowing, fertilisation, irrigation and aeration practices by the management team. Herbicidal efficacy to annual bluegrass and phytotoxicity to creeping bentgrass were visually evaluated on a % scale of 0 (no efficacy or phytotoxicity) to 100 (complete plant death). The test was conducted in a randomised complete block design with three replicates.

3 RESULTS AND DISCUSSION
3.1 Turfgrass safety
In the repeated experiments, no significant experimental run-by-treatment interactions were detected; thus, data from each run were combined. Data of each experiment were subjected to one-way ANOVA analysis. When the F-ratio was significant at the 5% level, Fisher’s protected LSD were calculated to separate the means.

3.2 Annual bluegrass growth stage
Methiozolin controlled annual bluegrass from PRE up to the eight-leaf stage (Fig. 1). GR50 values were 23, 52, 104 and 218 g ha$^{-1}$ at PRE and the two-, four- and eight-leaf stages, respectively, showing an increased herbicide rate to control developed annual bluegrass. However, methiozolin was capable of complete control at around 1000 g ha$^{-1}$ on all of the growth stages tested from PRE up to the eight-leaf stage. In combination with the turfgrass
safety in Table 1, methiozolin was shown to have a wide selectivity margin between turfgrasses and annual bluegrass.

### 3.3 Annual bluegrass seed head suppression

Methiozolin reduced both the number and length of panicles in a dose dependent manner (Fig. 2). The number of panicles decreased more than the length at a given rate. The number of panicles was reduced to less than 50% at 1000 g ha$^{-1}$, but there was no statistical difference in the length of the produced panicles at this rate. This suggests that methiozolin may interfere with seed head production at or before a certain developmental stage of panicle formation; the mature panicles after a critical stage may not be affected greatly by methiozolin.

### 3.4 Site of uptake

When methiozolin was applied only to the foliage, almost no herbicidal activity occurred at any rate tested. In contrast, when the herbicide was applied only to the soil, efficacy was statistically equivalent to the over-top spray (foliar and soil application) (Fig. 3). Therefore, herbicidal activity of methiozolin was clearly dependent on herbicide reaching the soil.

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**Table 1. Safety of methiozolin on various turf species in comparison with dithiopyr**

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate (g ha$^{-1}$)</th>
<th>Zoysiagrass (Z. japonica)</th>
<th>Creeping bentgrass</th>
<th>Kentucky bluegrass</th>
<th>Perennial ryegrass</th>
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<tbody>
<tr>
<td></td>
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<td>Week 4</td>
<td>Week 6</td>
<td>Week 2</td>
<td>Week 4</td>
</tr>
<tr>
<td>Methiozolin</td>
<td>250</td>
<td>0.0$^{ab}$</td>
<td>0.0$^{a}$</td>
<td>0.0$^{a}$</td>
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<td></td>
<td>500</td>
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<td>0.0$^{a}$</td>
<td>0.0$^{a}$</td>
<td>13.2$^{b}$</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>7.0$^{ab}$</td>
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<td>0.0$^{a}$</td>
<td>18.4$^{b}$</td>
</tr>
<tr>
<td></td>
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<td>2.1$^{b}$</td>
<td>0.0$^{a}$</td>
<td>22.8$^{b}$</td>
</tr>
<tr>
<td></td>
<td>4000</td>
<td>27.3$^{c}$</td>
<td>16.7$^{c}$</td>
<td>9.7$^{ab}$</td>
<td>22.7$^{bc}$</td>
</tr>
<tr>
<td>Dithiopyr</td>
<td>480</td>
<td>10.2$^{b}$</td>
<td>7.3$^{ab}$</td>
<td>15.1$^{b}$</td>
<td>3.4$^{a}$</td>
</tr>
<tr>
<td></td>
<td>960</td>
<td>23.3$^{c}$</td>
<td>15.1$^{b}$</td>
<td>13.3$^{b}$</td>
<td>23.3$^{c}$</td>
</tr>
<tr>
<td></td>
<td>1920</td>
<td>37.3$^{d}$</td>
<td>32.7$^{c}$</td>
<td>30.1$^{c}$</td>
<td>33.4$^{d}$</td>
</tr>
</tbody>
</table>

*All data points represent visual assessment (%): 0, no phytotoxic effect; 100, completely killed.*

*Means within a column followed by the same letter are not significantly different according to Fisher’s protected LSD at $P = 0.05$. 

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**Figure 1.** Dose responses of annual bluegrass to methiozolin at various growth stages. Each data point is the mean ± SD. Fresh weight of the untreated control was 4.87, 7.77, 9.68 and 10.27 g per pot, for PRE, the two-, four- and eight-leaf stages, respectively. In each equation, $X$ is represents the rate (g ha$^{-1}$).

**Figure 2.** Seedhead suppression activity of methiozolin on annual bluegrass. Each data point is the mean ± SD. Untreated control produced 807 panicles in a pot of 14 × 21 cm$^2$ with an average panicle length of 15.5 mm.

### 3.5 Uptake and translocation

When administered to the leaf, methiozolin was readily absorbed, reaching a maximum of approximately 60% after 4 days (96 h) (Fig. 4A). However, translocation to the other tissues was limited. At 168 h, translocation to the upper leaf, lower leaves, and root were 1.8, 0.4 and 0.5%, respectively. Of the translocated radioactivity, the majority migrated to the upper 5th leaf, and showed a pattern of pseudo-linear increase over time in the 5th leaf. These data suggest that methiozolin has limited phloem mobility. At the later measurement time, there was some decrease in overall recovery (about 20%). It is possible to hypothesise this loss might be due to plant metabolism and/or other chemical loss such as vapourisation or photodegradation; however, a study is needed to confirm the hypothesis.

When administered hydroponically to roots, absorption reached about 20% of the total applied after 48 h, with most of this in the shoot after 72 h (Fig. 4B). This pattern suggests methiozolin is readily absorbed by the root followed by acropetal translocation to the shoot. In terms of absorption kinetics, a pseudo-linear increase in tissue radiolabel occurred in 2 days in the root and 3 days in the shoot, followed by a small residual uptake until 7 days after application. Sterling summarised that lipophilic neutral herbicide molecules were thought to passively diffuse into plant cells across
the plasma membrane, because the lipophilic nature of such molecules allows them to diffuse across the lipid bilayer of plant membranes down their concentration gradient.\textsuperscript{25} Methiozolin is a neutral lipophilic molecule having log \( P \text{octanol/water} \) of 3.9 (Moghu Research Center, unpublished data), and may be absorbed by a simple diffusion model. However, in the kinetics studies with a lipophilic herbicide, for example ametryn and atrazine, an equilibrium was reached very rapidly in about 10 min.\textsuperscript{26} In the case of methiozolin, uptake continued for a much longer period until at least 48 h; and the overall kinetic pattern over the 168 h appeared to be biphasic, which is a typical kinetics of an active absorption system involving a transporter.\textsuperscript{27} A calculated theoretical tissue concentration of \( ^{14}\text{C} \) was much higher than the external solution (data not shown), further suggesting methiozolin absorption might not be a simple diffusion but involve an active transport system or other factors such as cell wall deposition. Therefore, a detailed investigation is needed to understand the precise absorption mechanism of methiozolin in plant roots. Nevertheless, the data in Fig. 4A and B suggest that the translocation path is predominantly xylem.

In Fig. 3, methiozolin was shown to be herbicidal by soil application. This aspect can be understood from the result in Fig. 4 showing that, although methiozolin can be absorbed readily by both the leaf and root, whole tissue distribution is largely due to root absorption.

Lycan and Hart showed that bispyribac-sodium absorption and translocation was greater in root application than foliar application.\textsuperscript{28} Inhibitory activity was also greater with foliar and root administration than foliar only; however, the difference was small. Therefore, it appeared that the root absorption did not contribute greatly to the whole plant activity in the case of bispyribac-sodium. In the case of methiozolin, the whole plant activity was entirely based on the root absorption, but foliar-absorbed methiozolin did not contribute significantly.

### 3.6 Field trial

The average temperature of the test site was typical of a northern continental climate. The temperature remained below freezing for most of the winter, from December to February, and creeping bentgrass was dormant during this time and until mid-March. Methiozolin at 500 g ha\(^{-1}\) applied in the fall (October to November) provided about 90\% annual bluegrass control when observed in June of the following year. Winter application initially appeared to control annual bluegrass when observed in March; however, this was the poorest timing when observed in June due to recovery of the plants. Spring application in late March to April provided 40–50\% control of annual bluegrass (Fig. 5A). Methiozolin at 1000 g ha\(^{-1}\) showed a similar trend, showing best efficacy by fall to early winter application, poorest during mid-winter application, and a lower level control (about 60\%) during spring application. The higher rate (1000 g ha\(^{-1}\)) was more persistent in maintaining efficacy compared to the lower rate (500 g ha\(^{-1}\)). Fall application provided better efficacy than spring in the study; but the longer
Methiozolin, a new bluegrass herbicide

A: Efficacy

![Herbicidal efficacy graph](image1)

<table>
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<tr>
<td>15-Jun-09</td>
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Evaluated on 30-Mar-09
Evaluated on 15-Jun-09

B: Phytotoxicity

![Phytotoxicity graph](image2)

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<tr>
<td>21-Oct-08</td>
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</tr>
<tr>
<td>15-Jun-09</td>
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Evaluated on 30-Mar-09
Evaluated on 15-Jun-09

Figure 5. Herbicidal efficacy on annual bluegrass, and phytotoxicity to creeping bentgrass of methiozolin by different application time. Each bar is the mean ± SD.

Annual bluegrass is the most important weed problem in golf turf, and herbicide options have been limited due to poor control, inconsistency, and lack of turf safety. Golf courses usually consist of multiple turfgrass species and annual bluegrass can persist as a weed in any species and location. Therefore, a herbicide with limited turf selectivity is inconvenient in a multiple turf species system. Methiozolin was shown to have broad safety to the tested turf species, including zoysiagrass, creeping bentgrass, Kentucky bluegrass, perennial ryegrass. Methiozolin was also safe on bermudagrass (Cynodon dactylon (L.) Pers.) (Dr Robert H. Walker, Auburn University, unpublished field test), seashore paspalum (Paspalum vaginatum L.) (Dr Barry J. Brecke, University of Florida, unpublished field test), and kikuyugrass (Pennisetum clandestinum Hochst. Ex Chiov.) (Dr James H. Baird, University of California, Riverside, unpublished field test). Although detailed variety tests are needed, preliminary screening tests with different creeping bentgrass cultivars showed little varietal differences in
sensitivity (data not shown), suggesting further flexibility in uses of methiozolin in a golf turf situation.

Herbicidal activity of typical POST herbicides such as acetolactate synthase inhibitors or ACCase inhibitors is largely due to foliar activity. Increased foliar uptake tended to provide better weed control in the case of bispyribac-sodium, which is a well-investigated herbicide for annual bluegrass control in turf. An adjuvant increased herbicidal activity of bispyribac-sodium. Pyribenoxim, another acetolactate synthase inhibitor, showed loss of herbicidal activity by interference of foliar uptake and/or translocation such as leaf removal within 5 days after application, or application of another herbicide that inhibited phloem flow. Bispyribac-sodium was shown to lose herbicidal activity in cool temperatures. These findings demonstrate the sensitivity of a foliar herbicide to factors such as adjuvants, mowing, rain fastness, or temperature. By contrast, methiozolin activity depends on root uptake and acropetal mobility, which means adjuvants and mowing are less likely to affect performance. Therefore, methiozolin possesses favourable characteristics as a turf herbicide. Collectively, these results suggest that methiozolin is a new turf herbicide candidate potentially providing an excellent solution for annual bluegrass control in various turfgrasses.

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REFERENCES