Control of Glyphosate-resistant Creeping Bentgrass with Postemergence Herbicides

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Creeping bentgrass (*Agrostis stolonifera* L.) is the primary turfgrass used on golf course putting greens and fairways in the temperate region of the United States. A cultivar that is resistant to glyphosate has recently been developed by the Scotts Company in partnership with the Monsanto Company. Establishment of golf course turf to glyphosate-resistant creeping bentgrass would improve weed control, in particular control of annual bluegrass (*Poa annua* L.). Creeping bentgrass is a stoloniferous grass that has the potential to move beyond golf course putting greens and fairways into areas where it is undesirable. Research was conducted at Iowa State University to evaluate herbicides for the control and removal of glyphosate-resistant creeping bentgrass from areas where it is undesirable

Materials and Methods
We removed plugs of glyphosate-resistant creeping bentgrass and 'Penncross' creeping bentgrass, measuring 4.25 inches in diameter, from an established native-soil putting green on 7 Nov. 2004. Plugs were placed in 5-inch diameter pots and allowed to acclimate to greenhouse conditions. Treatments included ten herbicides applied according to label directions (Table 1) and an untreated control. The study was a completely randomized design with four replications. Herbicides were applied to glyphosate-resistant creeping bentgrass and 'Penncross' creeping bentgrass on 28 Jan. 2005, in a spray booth using a total spray volume of 20 gallons per acre. Turf was fertilized and irrigated for optimal growth. Mowing occurred on a weekly basis before initiation of treatments and turf was maintained at a height of 0.5 inches.

Data collection and analysis
Turfgrass quality was recorded on a weekly basis using a scale of 1 to 9 with 1 = worst, 6 = acceptable, and 9 = excellent. Dry clipping weight was measured 14 and 42 days after treatment (DAT). Upon termination of the study (56 DAT), percent kill was documented. Data were analyzed by using the General Linear Model procedure of the Statistical Analysis System (SAS, 1999-2001). Mean comparisons for turfgrass quality, dry clipping weight, and percent kill were made using an *F*-protected least significant test. Contrasts were used to compare means for interactions of cultivar and herbicide. All tests of significance were made at the $P \leq 0.05$ level.

Results
All herbicides reduced turfgrass quality of glyphosate-resistant creeping bentgrass and 'Penncross' creeping bentgrass below levels of the untreated control 28 DAT with the exception of glyphosate applied to glyphosate-resistant bentgrass (Tables 2 and 3). Glufosinate reduced turfgrass quality of both cultivars to the worst quality rating (1) 14 days after treatment, however, the grass began to recover 28 DAT. Glyphosate applied to 'Penncross' creeping bentgrass reduced quality to a 1 at 14 DAT, but the grass began to recover 28 DAT and reached a quality rating of 3 by 56 DAT (Table 3). Both cultivars treated with imazapyr received the worst quality rating at 35 DAT and this was the only treatment to receive the worst rating at 56 DAT (Tables 2 and 3).

Percentage kill was the greatest when turfgrass was treated with imazapyr; 99% and 100% for glyphosate-resistant and 'Penncross' creeping bentgrass, respectively (Table 4). Glufosinate resulted in kill ≥ 75% for both cultivars and glyphosate killed 89% of 'Penncross' creeping bentgrass, but had no affect on bentgrass resistant to the herbicide (Table 4). All other herbicides provided varying control of both cultivars.

All herbicides reduced dry clipping weight of 'Penncross' creeping bentgrass below that of the control, 14 DAT (Table 5). This was also true for glyphosate-resistant creeping bentgrass with the exception of mesotrione and glyphosate. Imazapyr was the only herbicide that resulted in no clipping yield for both cultivars, 42 DAT (Table 5).

All of the herbicides provided similar control of both cultivars with the exception of quizalofop and glyphosate. Kill of glyphosate-resistant bentgrass treated with quizalofop was 65% compared with only 21% kill of 'Penncross' creeping bentgrass (Table 4). Glyphosate killed 89% of 'Penncross' creeping bentgrass, but glyphosate-resistant bentgrass was unaffected (Table 4).

Discussion
Imazapyr was the only herbicide evaluated that provided control ≥ 99% of both bentgrass cultivars. We feel that several of the herbicides evaluated, specifically fluazifop-P, glufosinate, and quizalofop, would provide complete control if two or more applications were made. Contrary to popular belief, we found that glyphosate did not completely control bentgrass susceptible to the herbicide. The label of Roundup Pro® (glyphosate) states that it only offers "partial control" of creeping bentgrass (Monsanto Corporation, 2003). We found that most of the herbicides resulted in control that was relatively similar between cultivars. This suggests that transformation of bentgrass does not confer resistance to other herbicides.

In conclusion, imazapyr killed creeping bentgrass in one application and would be an excellent alternative to glyphosate. Research conducted at Iowa State University has also shown that mesotrione provides effective control of creeping bentgrass in the field, but is ineffective in greenhouse studies. Future research should be conducted to evaluate these herbicides in the field. All of the herbicides evaluated have potential to control bentgrass with multiple applications, and this should be the target of future research. Although glyphosate-resistant creeping bentgrass may move into areas where it is undesirable, alternative herbicides are available that will provide control of bentgrass at levels similar to that of glyphosate.

Table 1. Herbicides evaluated for control of glyphosate-resistant and 'Penncross' creeping bentgrass. All herbicides were applied per label directions.

Trade Name	Active ingredient	Rate	Adjuvant	Rate
		lb·acre^{-1}		volume/volume
Untreated control	---	---	---	---
Fusilade DX	Fluazifop-P	0.38	NIS	0.25%
Revolver	Foramsulfuron	0.04	---	---
Finale	Glufosinate	1.5	Ammonium Sulfate	17 lb per 100 gal
Roundup Pro	Glyphosate	1.5	---	---
Raptor	Imazamox	0.05	NIS	0.25%
Arsenal	Imazapyr	0.75	NIS[z]	0.25%
Callisto	Mesotrione	0.3	NIS	0.25%
Assure II	Quizalofop	0.08	NIS	0.25%
Poast Plus	Sethoxydim	0.28	COC[y]	32 oz·acre^{-1}
Outrider	Sulfosulfuron	0.09	NIS	0.25%

[z]Non-ionic surfactant
[y]Crop oil concentrate

Table 2. Turfgrass quality of glyphosate-resistant creeping bentgrass treated with several herbicides. Turfgrass quality was rated on 1-9 scale with 1 = worst, 6 = acceptable, and 9 = excellent. Values are means from four replications.

Active Ingredient	Time after treatment (days)							
	7	14	21	28	35	42	49	56
	Turfgrass quality							
Untreated control	9	9	8	9	8	6	7	6
Fluazifop-P	6	5	3	3	3	2	3	4
Foramsulfuron	5	5	4	4	3	4	4	4
Glufosinate	1	1	1	2	2	2	2	3
Glyphosate	9	9	8	9	7	6	6	5
Imazamox	6	5	5	5	4	6	6	6
Imazapyr	5	4	3	2	1	2	1	1
Mesotrione	8	7	4	4	3	3	4	5
Quizalofop	6	5	4	3	3	4	3	3
Sethoxydim	5	4	4	3	4	4	5	4
Sulfosulfuron	7	8	6	7	6	5	6	6
$LSD_{0.05}$	1	1	1	1	1	2	1	1

Table 3. Turfgrass quality of 'Penncross' creeping bentgrass treated with several herbicides. Turfgrass quality was rated on 1-9 scale with 1 = worst, 6 = acceptable, and 9 = excellent. Values are means from four replications.

Active Ingredient	Time after treatment (days)							
	7	14	21	28	35	42	49	56
	Turfgrass quality							
Untreated control	9	9	9	8	9	8	8	7
Fluazifop-P	6	4	3	3	3	3	4	4
Foramsulfuron	6	5	5	5	4	5	5	4
Glufosinate	1	1	1	2	2	2	2	3
Glyphosate	2	1	1	2	2	2	2	3
Imazamox	5	5	4	4	4	5	5	6
Imazapyr	5	4	3	2	1	2	1	1
Mesotrione	9	5	3	3	4	4	5	5
Quizalofop	5	4	3	3	3	3	4	5
Sethoxydim	5	4	3	4	4	4	4	4
Sulfosulfuron	6	8	8	6	5	7	6	5
$LSD_{0.05}$	1	1	1	1	1	2	1	1

Table 4. Percentage kill of glyphosate-resistant and 'Penncross' creeping bentgrass treated with several herbicides. Percentage kill was recorded 56 days after treatment. Values are means from four replications.

Active ingredient	Glyphosate-resistant creeping bentgrass	'Penncross' creeping bentgrass
	Percentage kill	
	%	
Untreated control	0	4
Fluazifop-P	59	44
Foramsulfuron	20	36
Glufosinate	79	75
Glyphosate	0	89
Imazamox	16	26
Imazapyr	99	100
Mesotrione	9	11
Quizalofop	65	21
Sethoxydim	23	23
Sulfosulfuron	10	8
$LSD_{0.05}$	20	19

Table 5. Clipping dry weight of glyphosate-resistant and 'Penncross' creeping bentgrass treated with several herbicides. Turf was maintained at 13 mm. Clippings were collected for each pot, dried, and weighed. Values are means from four replications.

Active ingredient	Glyphosate-resistant creeping bentgrass		'Penncross' creeping bentgrass	
	Time after treatment (days)			
	14	42	14	42
	Clipping dry weight			
	$mg \cdot pot^{-1}$			
Untreated control	79	81	94	147
Fluazifop-P	14	23	24	104
Foramsulfuron	15	22	15	63
Glufosinate	4	33	8	35
Glyphosate	94	105	15	25
Imazamox	10	53	15	57
Imazapyr	11	0	23	0
Mesotrione	59	90	54	99
Quizalofop	15	30	15	66
Sethoxydim	6	70	15	72
Sulfosulfuron	31	146	13	68
$LSD_{0.05}$	31	42	17	54

Fig. 1. Glyphosate-resistant and 'Penncross' creeping bentgrass 56 days after treatment with imazapyr.

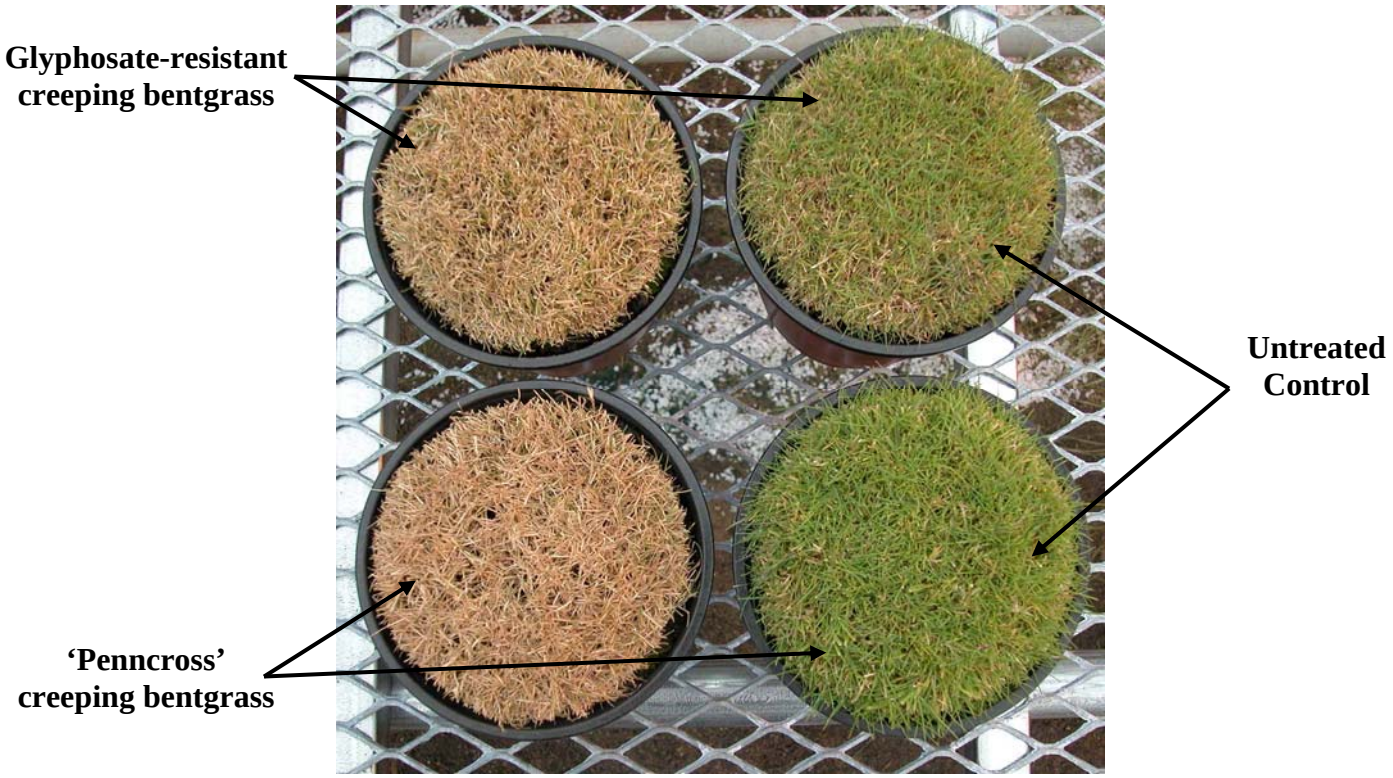

Fig. 2. Glyphosate-resistant and 'Penncross' creeping bentgrass 56 days after treatment with glyphosate.