# **Determination of the Potential Impact from the Release of Glyphosate- and Glufosinate-Resistant *Agrostis stolonifera* L. in Various Crop and Non-Crop Ecosystems**

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## EXECUTIVE SUMMARY

The Weed Science Society of America (WSSA) was asked by the United States Department of Agriculture-Animal Plant Health Inspection Service (USDA-APHIS) to perform an analysis of the weed management implications associated with the potential deregulation and commercialization of glyphosate and glufosinate-resistant creeping bentgrass (*Agrostis stolonifera* L.) varieties. This analysis is needed to determine the current and potential significance of creeping bentgrass, and other species with which it can hybridize (several other *Agrostis* spp. and *Polypogon* spp.), as weeds in managed and non-managed ecosystems in the United States. The analysis deliberately focused exclusively on the weed management implications of the potential release of these creeping bentgrass varieties and did not attempt to assess other associated environmental and economic considerations. The Weed Science Society of America does not endorse or oppose the proposed deregulation of glyphosate- or glufosinate-creeping bentgrass. The information contained in this report does not represent a position for or against the technology and should not be interpreted as such. This work was done at the request of USDA/APHIS to provide science-based information for their use as a regulatory agency.

**Procedure.** To perform this analysis a team of distinguished weed scientists was assembled. The team was selected to include representation from the major geographical regions in the United States as well as a breadth of technical experience inclusive of all natural and managed terrestrial ecosystems where weed management is a concern (agronomic crops, horticultural crops, turf and nursery crops, range and pasture, natural areas, industrial sites and rights-of-way). Expertise on the occurrence of herbicide resistance, both natural and induced, was also included. The team members performed the analysis by drawing on their personal expertise, by conducting a comprehensive review of the pertinent literature and by personally surveying over ninety additional weed scientists and other experts familiar with specific areas of concern. The report prepared by this team was subsequently reviewed by an ad hoc review panel consisting of three members of the WSSA Board of Directors who also represent diverse geographical and technical backgrounds.

**Findings.** Creeping bentgrass, and the other *Agrostis* spp.and *Polypogon* spp. with which it can hybridize, are currently widespread throughout the United States. However, where these species occur, they are relatively non-aggressive, their presence is rarely considered a problem that warrants management and thus they are generally not managed as weeds. Despite the number of species and broad geographical distribution, they have no history as significant weeds of the principal crops in the U.S., other than as infestations in turf and grass seed crops. Overall, this indicates an inherent lack of weedy traits necessary for their adaptation and survival in crop culture. Several of these species have been reported as occasional weeds or as weeds of low importance in fruit, nuts, vegetables, ornamentals, pasture, range, rights-of-way or natural areas, but they were not identified as important, significant, or problem weeds in any of these environments.

All currently available information indicates that there is nothing about glyphosate- or glufosinate-resistant creeping bentgrass that will make these variants inherently more weedy than the existing non-resistant counterparts. No new weed management concerns were identified or anticipated except in situations where selection pressure is exerted by use of the respective herbicides. Due to the current minimal use of glufosinate in the U.S., there is no evidence that glufosinate-resistant creeping bentgrass will pose any additional weed management problems. However, glyphosate-resistant creeping bentgrass may create new weed management challenges in several specific and limited situations.

Treatment of resistant bentgrass or its hybrids will present a new challenge in grass seed and sod crops. Glyphosate is currently used to spot treat bentgrass if it is present in other grass seed or sod crops and it is used as a broadcast treatment when changing grass species or varieties within a field. This standard treatment will not be effective if glyphosate-resistant bentgrass varieties are present, therefore, alternative or additional herbicides will be needed. Several existing herbicides provide comparable levels of control. Some are currently labeled for this use while others would require additional registration approval before they could be used in these situations.

Glyphosate is also currently used in several other situations where the presence of resistant bentgrass species or its hybrids could complicate management. One of these situations is orchard floor management in perennial fruit, nut and vine crops. If resistant variants become established, and control of these species is warranted, alternative or additional herbicides will be needed. This is not a major concern, however, because numerous alternative herbicides that provide comparable levels of control are currently registered for this use.

Glyphosate is also a preferred herbicide for use in natural areas, public lands and rights-of-way environments. This herbicide is used for spot treatments and occasionally for total vegetation control and site preparation prior to renovation with desirable species. The presence of glyphosate-resistant creeping bentgrass or its hybrids would require the use of a different or an additional herbicide(s). There are several alternative herbicides that provide comparable levels of control of bentgrass species that are currently registered for use in non-crop or riparian environments, although some have limitations pertaining to the establishment of new vegetation.

Glyphosate is currently used on millions of acres of glyphosate resistant canola, corn, cotton and soybean crops. Bentgrass and related species have not been weed problems in conventional or modified versions of these crops. As additional glyphosate-resistant crops such as alfalfa, sugarbeets, potatoes and wheat are introduced there is potential for glyphosate-resistant bentgrass or its hybrids to become weedy in these crops due to recurrent selection pressure in the specific crop environments. However, bentgrass has not been an important weed problem in these crops when grown conventionally and several alternative herbicides that provide comparable levels of control of bentgrass species are currently registered for use in these crops.

A final concern is that the probable repeated use of glyphosate on resistant turf would increase selection pressure for the development of glyphosate-resistance in the targeted weed species. Usage of multiple applications per year over multiple years is similar to the use patterns in other perennial crops where glyphosate resistant grasses have previously developed. Should this occur, glyphosate resistant technology would be considerably less valuable in turf but in most other crops, alternative herbicides and management options are available for the control of these weed species.

**Conclusion.** Although the off-site movement of glyphosate- or glufosinate-resistant creeping bentgrass or their hybrids is likely over time, it is unlikely that deregulation and release of transgenic glyphosate- or glufosinate-resistant creeping bentgrass varieties will cause significant new weed problems in the principal crops or non-crop areas of the U.S. The strongest evidence supporting this conclusion are that these species have no history as important weeds of the principal U.S. crops, other than turf and grass seed crops; there is little evidence of active management of these species as weeds in non-crop situations; and alternative control methods (e.g., other herbicides, tillage, and crop rotation) exist for control of glyphosate or glufosinate-resistant creeping bentgrass in almost all crop and non-crop environments.

# INTRODUCTION

Glyphosate-resistant creeping bentgrass (*Agrostis stolonifera* L.)[2] has been developed and proposed for commercialization and use on golf courses in the United States. Glufosinate-resistant creeping bentgrass may also be proposed for commercialization (communication from USDA-APHIS). The introduction of glyphosate- or glufosinate-resistant creeping bentgrass for use on golf courses could improve the ability of managers to control weeds on fairways and tee boxes and on greens where few herbicides are currently registered for use. Weedy grasses such as annual bluegrass (*Poa annua* L.) and bermudagrass [*Cynodon dactylon* (L.) Pers.] could be effectively managed. Overall herbicide use on golf courses may be reduced by the introduction of glufosinate- or glyphosate-resistant creeping bentgrass. There also have been reports that when annual bluegrass is the predominate weedy grass in creeping bentgrass, fungicide use is much higher than in a pure sod of creeping bentgrass and that the use of glufosinate (chemical names for all herbicides mentioned are listed in Appendix 2) on glufosinate-resistant creeping bentgrass or velvet bentgrass may suppress the activity of some fungal pathogens (Wang et al. 2003). However, it is not the intent of this review to quantify how the introduction of herbicide resistant creeping bentgrass will affect overall pesticide use.

As with any herbicide-resistant crop introduction, the potential for the transgenic crop to become a weed is a possibility that must be evaluated. Herbicide-resistant creeping bentgrass is considerably different than transgenic grain, oil, and fiber crops previously introduced for use in that it is a perennial, it is more closely related to weedy relatives (with the exception of canola), and its intended use is not related to food or fiber production. The objective of this report was to determine if the approximately 34 *Agrostis* species and three cross-compatible *Polypogon* species (Table 1) found in the U.S. currently occur as weeds in any natural or managed ecosystems. If so, additional objectives were to document the importance of glyphosate and glufosinate herbicides in management of these species, to document alternatives to glyphosate and glufosinate for management of these species, and to document the presence or absence of natural or acquired herbicide resistance in these species. These objectives were accomplished by conducting a comprehensive review of the literature and surveying more than 90 weed scientists and other experts (Table 2) with experience in major and minor cropping situations as well as many with expertise on the management of invasive weeds in natural and managed ecosystems. These surveys (Table 3) were conducted by telephone, e-mail, and in person.

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[2] Scientific names for all *Agrostis and Polypogon* species are listed in Table 1. Crop names are listed in Appendix 1.

***Table 1.* Summary of *Agrostis* (34 spp.) and relevant *Polypogon* (3 spp.) in temperate North America.**

| **Species / Taxa** | Common names | **O/IF, U** | **USA – Canada distribution** | **Native Rank** | **Hybrids with other species / comments on taxonomy &/or range** | **Hybrids with *A. stolonifera*** |
|---|---|---|---|---|---|---|
| 1 *Agrostis aequivalvis* (Trin.) Trin. | Arctic or northern bentgrass | Nv | AK-OR; Canada (BC) | G5? | | |
| 2 *Agrostis anadyrensis* Soczava | Anadyr bentgrass | Nv | AK | [G4?] | | |
| 3 *Agrostis avenacea* J.F. Gmel. | Pacific bentgrass | Nz | HI, CA, TX, OH, SC | [G5?] | Syn. of *Lachnagrostis filiformis*, *per* Jacobs 2001; Nv Polynesia, Australia | |
| 4 *Agrostis blasdalei* A.S. Hitchc. | Blasdale's or cliff bentgrass | Nv | CA endemic | G2 | | |
| 5 *Agrostis canina* L. | Velvet bentgrass | Nz, A | HI, many N states; Canada | G5 | sF1 with 21, and with 34 | vF1; rare? |
| 6 *Agrostis capillaris* L. | Colonial (or Rhode Island) bentgrass, (browntop) | Nz, A | Most states; Canada | [G5] | vF1 & vF2 with 7, and with 13, sF1? with 34, and F1 with probably 14 | vF1; frequent? |
| 7 *Agrostis castellana* Boiss. & Reuter | Dryland (incl. Highland) bentgrass | (Nz), A | WA, OR, AL, many states?; Canada? | [G4G5] | Confounded with 6, *q.v.* (& Table 2) | vF1; infreq.? |
| 8 *Agrostis clavata* Trin. | Clubbed bentgrass | Nv | AK; Canada (Yukon) | G4G5 | | |
| 9a *Agrostis clivicola* var. *clivicola* Crampton | Coastal bluff bentgrass | Nv | CA endemic | *G3?T3?* | *Syn. of 10* per *Harvey, but* ***not Kartesz*** | |
| 9b *Agrostis clivicola* var. *punta-reyesensis* Crampton | Point reyes bentgrass | Nv | CA endemic | [G3?T1Q] | *Syn. of 10* per *Harvey, but* ***not Kartesz*** | |
| 10 *Agrostis densiflora* Vasey | Dense-flowered bentgrass | Nv | CA-OR | G3G4 | F1? with 12 (Carlbom 1967, p. 88) | |
| 11 *Agrostis elliottiana* J.A. Schultes | Elliott's bentgrass | Nv | CA & mainly E US | G5 | | |
| 12 *Agrostis exarata* Trin. | Spike bentgrass | Nv | W US; W Canada | G5 | F1? with 10, F1 with 13? (Welsh) & 29 | sF1 with 30? |
| 13 *Agrostis gigantean* Roth | Redtop, black bentgrass | Nz, A | Nearly all states; Canada | [G5] | vF1 & vF2 with 6 (occasional?), sF1 with 21 (rare?), F1 with 13 or 30 (*i.e., A.s. s.l.*) (Welsh *et al*. 1993) | vF1; occasional? |
| 14 *Agrostis hallii* Vasey | Hall's bentgrass | Nv | CA-OR, & WA? | G4G5 | fF1 with 25, and F1 with probably 6 | |
| 15 *Agrostis hendersonii* A.S. Hitchc. | Henderson's bentgrass | Nv | CA-OR | [G1?] | Incl. *A. aristiglumis* (CA endemic) *per* Harvey 1999 | |
| 16 *Agrostis hooveri* Swallen | Hoover's bentgrass | Nv | CA endemic | [G2G3] | | |
| 17 *Agrostis howellii* Scribn. | Howell's bentgrass | Nv | OR endemic | G2 | | |
| 18 *Agrostis humilis* Vasey | Mountain or alpine bentgrass | Nv | W US (AK-CA-NM); W Canada | [G5] | Incl. *A. thurberiana* (W US, Can.) *per* Harvey 2001 (but not Harvey 1993, or Welsh *et al*. 1993, *q.v.*; *cf.* Biek 2000) | |
| 19 *Agrostis hyemalis* (Walt.) B.S.P. | Winter bentgrass | Nv | E US, especially SE; Canada | G5 | | |
| 20 *Agrostis idahoensis* Nash | Idaho bentgrass | Nv, (A) | W US; W Canada | [G5?] | Hybrid origin? (Welsh *et al*. 1993) | F1 |

*Table 1.* **(cont.) Summary of *Agrostis* (34 spp.) and relevant *Polypogon* (3 spp.) in temperate North America.**

| **Species / Taxa** | Common names | **O/IF, U** | **USA – Canada distribution** | **Native Rank** | **Hybrids with other species / comments on taxonomy &/or range** | **Hybrids with *A. stolonifera*** |
|---|---|---|---|---|---|---|
| 21 *Agrostis mertensii* Trin. | Northern or arctic bentgrass | Nv | AK-CO & TN-SC; Canada | G5 | F1 with 34; sF1 with 5, and 13 (rare?) | F1; rare |
| 22 *Agrostis microphylla* Steud. | Small-leavedbBentgrass | Nv | CA-WA & NV; Can. (SW BC) | G4 | | |
| 23 *Agrostis nebulosa* Boiss. & Reut. | Cloudgrass | I, (Nz) | Nz in OH, perhaps elsewhere | [G3G4] | Nv Iberian Peninsula | |
| 24 *Agrostis oregonensis* Vasey | Oregon redtop or bentgrass | Nv | W US (AK-CA-WY); W Can. | G4 | | |
| 25 *Agrostis pallens* Trin. | Leafy or dune bentgrass | Nv | CA-WA & MT; W Canada | G4G5 | Incl. *A. diegoensis* (*cf*. Harvey 1993, 2001; Biek 2000). Also fF1 with 14 | F1 |
| 26 *Agrostis perennans* (Walt.) Tuckerman | Upland bentgrass | Nv | E US & OR, WA; Canada | G5 | | |
| 27 *Agrostis rossiae* Vasey | Ross' bentgrass | Nv | WY endemic | **G1** | | |
| 28 *Agrostis sandwicensis* Hbd. | Hawaii bentgrass | Nv | HI endemic | **G3** | | |
| 29 *Agrostis scabra* Willd. | Rough bentgrass | Nv | Most states; Canada | G5 | F1 with 12, and F1? (≈ 20) with 33 (Welsh *et al.* 1993) | F1 |
| 30 *Agrostis stolonifera* L. | Creeping, spreading, carpet, and marsh bentgrass | Nz, Nv?, A | Nz all states, Nv? few N states; also Nz, Nv? in Canada | G5 | F1 with 13-15 other spp., incl. 10-12 other *Agrostis*; vF1, vF2; common? | |
| 31 *Agrostis tandilensis* (Kuntze) Parodi | Kennedy's bentgrass | Nz | CA | G3G5 | Nv Argentina, S Brazil | |
| 32 *Agrostis trinii* Turcz. | Trinius' bentgrass | Nv | AK | [G5?] | Syn. of 34 *per* Kartesz, but not Koyama | F1 |
| 33 *Agrostis variabilis* Rydb. | Alpine or mountain bentgrass | Nv | W US; W Canada (BC, AB) | G5 | F1? (≈ 20) with 29 (Welsh *et al*. 1993) | |
| 34 *Agrostis vinealis* Schreb. | Brown bentgrass | Nz, Nv | Nz many states?, Nv AK; Can.? | G5? | F1 with 21, sF1? with 6, sF1 with 5 | vF1; rare? |
| 1 *Polypogon fugax* Nees | Hill rabbit's-foot grass | (I?) | HI (old report) | [G?] | Nv Asia Minor | F1 |
| *2* Polypogon monspeliensis *(L.) Desf.* | Rabbitfoot polypogon or rabbits-foot grass | Nz | Most states (incl. HI, AK); Can. | [G5?] | | vF1; infreq.? |
| 3 *Polypogon viridis* (Gouan) Breistr. | Beardless rabbit's-foot grass | Nz | Scattered (16 states, incl. HI) | [G5?] | | sF1; rare? |

ORIGIN or INTEGRATION IN FLORA, and USE (O/IF, U): Nv = Native, Nz = Naturalized, I = Introduced, extent of naturalization unknown; A = Agronomic.
NATIVE RANK (TNC/NatureServe 2002, ranks in brackets by APHIS/BRS); in native range: G1 = critically rare, G2 = rare, G3 = vulnerable, G4 = apparently secure, G5 = widespread, abundant & secure; T = a ranking for subsp. or var. (trinomial); Q = a question/problem in taxonomy.
HYBRIDS: F1 = $F_1$ with sterility/fertility not given; f = fertile (without details), s = sterile, v = variable crossing behavior or reports (perhaps sterile and low or higher fertilities); species numbered in alphabetical order, so for example the number 30 = *Agrostis stolonifera*. See Table 2 for detailed information.

| *Table 2.* **Affiliation and Specialization of Survey Respondents and Other Expert Sources.** | | |
|---|---|---|
| **Name** | **Affiliation** | **Area of Specialization** |
| Ahrens, John | University of Rhode Island (retired) | Weed Science-horticulture, turf. |
| Allred, Kelly W. | New Mexico State University | Grass taxonomy. |
| Askew, Shawn | Virginia Polytechnic Institute and State University | Weed Science-turf. |
| Ball, Daniel A. | Oregon State University | Weed Science-grass seed crops, legumes, wheat. |
| Barker, Reed | USDA-ARS, Oregon | Grass genetics. |
| Bean, Brent | Texas A & M University | Weed Science-agronomic crops. |
| Beck, K. George | Colorado State University | Weed Science-rangeland, invasive weeds. |
| Becker, Roger | University of Minnesota | Weed Science-vegetables, non-cropland. |
| Bellinder, Robin | Cornell University | Weed Science-vegetables. |
| Bhowmik, Prasanta | University of Massachusetts | Weed Science-horticulture. |
| Boerboom, Chris | University of Wisconsin | Weed Science-agronomic crops. |
| Bonanno, A.Richard | University of Massachusetts | Weed Science-vegetables. |
| Boyd, John | University of Arkansas | Weed Science-turf, forages, forestry. |
| Boydston, Rick | Washington State University | Weed Science-horticulture, vegetables, agronomic crops. |
| Brecke, Barry | University of Florida | Weed Science-turf, agronomic crops. |
| Brede, Doug | Simplot Partners | Turfgrass breeding. |
| Brewster, Bill | Oregon State University | Weed Science-grass seed crops, specialty crops. |
| Byrd, John | Mississippi State University | Weed Science-turf, pasture, rights-of-way, agronomic crops. |
| Cacek, Terry | U.S. National Park Service | Weed Science-National IPM Program Leader |
| Carpinelli, Michael | USDA-ARS | Weed Science-Rangeland Ecology |
| Christians, Nick | Iowa State University | Weed Science-turf and ornamentals. |
| Cole, Liz | Oregon State University | Weed Science-forestry. |
| Curran, William | Penn State University | Weed Science-agronomic crops, forages. |
| Dernoeden, Peter | University of Maryland | Turfgrass. |
| Derr, Jeffrey F. | Virginia Tech | Weed Science-horticulture, turf. |
| Dewey, Steve | Utah State University | Weed Science-rangeland, natural areas, invasive weeds. |
| DiTomaso, Joe | University of California | Weed Science-rangeland, forestry, weed ecology, invasive weeds, taxonomy. |
| Doll, Jerry | University of Wisconsin | Weed Science - agronomic crops, noxious weeds. |
| Dunteman, Bob | | Sod farm owner. |
| Gardner, David | Ohio State University | Turfgrass Physiology. |
| Gaussion, Roch | University of Nebraska | Weed Science-Turfgrass. |
| Goerger, Richard | Delaware Department of Agriculture | Seed specialist. |
| Goss, Ryan M. | University of Nebraska | Turfgrass. |
| Hager, Aaron | University of Illinois | Weed Science -agronomic crops. |

| *Table 2.* **(cont.) Affiliation and Specialization of Survey Respondents and Other Expert Sources.** | | |
|---|---|---|
| **Name** | **Affiliation** | **Area of Specialization** |
| Hallett, Steve | Purdue University | Turfgrass. |
| Harper-Lore, Bonnie | Federal Highway Administration | Rights-of-Way-habitat restoration |
| Hart, Steve | Rutgers University | Weed Science-turf. |
| Hartzler, Bob | Iowa State University | Weed Science-agronomic crops, pastures. |
| Hagood, Scott | Virginia Polytechnic Institute and State University | Weed Science-agronomic crops. |
| Johnson, William G. | Purdue University | Weed Science-agronomic crops, forages, vegetables. |
| Jordan, Marilyn | The Nature Conservancy on Long Island, New York | Conservation Science. |
| Kenna, Mike | USGA, Research Director | Turfgrass. |
| Kopec, David | Karsten Turf Center | Turfgrass. |
| Lair, Kenneth | U.S. Bureau of Reclamation | Vegetation restoration-noxious weeds. |
| Lanini, Tom | University of California, Davis | Weed Science-horticulture, vegetables. |
| Lembi, Carole | Purdue University | Weed Science- aquatics. |
| Leslie, Andrew | Florida Department of Environmental Protection- Invasive Plant Management | Invasive species |
| Loux, Mark | Ohio State University | Weed Science-agronomic crops, forages. |
| Lym, Rod | North Dakota State University | Weed Science-rangeland, invasive weeds. |
| Lyon, Drew | University of Nebraska | Weed Science-agronomic crops, specialty crops. |
| MacDonald, Greg | University of Florida | Weed Science-turf, forages, small grains. |
| Mallory-Smith, Carol | Oregon State University | Weed Science-herbicide resistance, grass seed crops. |
| Martin, James R. | University of Kentucky | Weed Science-agronomic crops. |
| Mathers, Hannah | Ohio State University | Weed Science-ornamentals. |
| McCarty, L. Bert | Clemson University | Weed Science-turf. |
| McClosky, Bill | University of Arizona | Weed Science-agronomic crops, tree crops, alfalfa. |
| McGiffin, Milt | University of California | Weed Science-horticultural crops. |
| McNabb, Ken | Auburn University | Weed Science – forestry. |
| McNeel, Henry | U.S. Bureau of Land Management | Weed science- rangeland |
| Miller, Tim W. | Washington State University | Weed Science-horticultural crops, invasive weeds. |
| Minner, David | Iowa State University | Horticulture-turfgrass. |
| Morishita, Don | University of Idaho | Weed Science-small grains, sugarbeets. |
| Mueller-Warrant, George | Oregon State University | Weed Science-grass seed crops. |
| Murphy, Timothy R. | University of Georgia | Weed Science-turf. |
| Naczi, Robert | Delaware State Herbarium | Plant taxonomy. |
| Neal, Joe | North Carolina State University | Weed Science-turf, ornamentals. |
| Nelson, Larry | Clemson University | Forestry. |

| *Table 2.* **(cont.) Affiliation and Specialization of Survey Respondents and Other Expert Sources.** | | |
|---|---|---|
| **Name** | **Affiliation** | **Area of Specialization** |
| Newfield, Melanie | Dept. of Conservation, Wellington, New Zealand | Weed Ecology. |
| Nissen, Scott | Colorado State University | Weed Science-forages, vegetables. |
| Parker, Bob | Washington State University | Weed Science-agronomic crops, fruit and vegetables, non-cropland, forages. |
| Peterson, Dallas | Kansas State University | Weed Science-agronomic crops, pastures, rangeland. |
| Polster, David | Polster Environmental Services Ltd., Duncan, British Columbia | Plant Ecology. |
| Prostko, Eric | University of Georgia | Weed Science-agronomic crops. |
| Ransom, Corey | Oregon State University | Weed Science-agronomic crops, forages, mint. |
| Reichenbach, Roy | Wyoming Department of Agriculture | Weed Science-invasive weeds. |
| Reicher, Zachary | Purdue University | Weed Science-turfgrass. |
| Rose, Bill | Turf Seed & Pure Seed | Turfgrass Specialist |
| Rossi, Frank | Cornell University | Turfgass-Extension Specialist |
| Samson, John | Wyoming Department of Transportation | Vegetation restoration-rights-of-way |
| Schroeder, Jill | New Mexico State University | Weed Science-agronomic crops, vegetables. |
| Senesac, Andrew | Cornell University, Long Island | Weed Science-turf. |
| Sprague, Christy | Michigan State University | Weed Science-agronomic crops. |
| Stahlman, Phil | Kansas State University | Weed Science-small grains. |
| Tangren, Sara | Chesapeake Native Nursery, Tacoma Park, Maryland | Botany. |
| Thill, Donn | University of Idaho | Weed Science-herbicide resistance, agronomic crops. |
| Umeda, Kai | University of Arizona | Weed Science-horticultural crops, turf. |
| Van der Walle, Tom | Sunset Hills Country Club | Golf Course Superintendent |
| VanGessel, Mark | University of Delaware | Weed Science-vegetables, agronomic crops, turf. |
| Volk, William | U.S. Bureau of Land Management | Soil science |
| Warnke, Scott | USDA, Turf Breeding | Genetics and Plant Breeding. |
| Watrud, Lidia | U.S. EPA | |
| Westra, Philip | Colorado State University | Weed Science-agronomic crops, vegetables. |
| Wilson, Henry | Virginia Polytechnic Institute and State University | Weed Science-vegetables. |
| Yelverton, Fred | North Carolina State University | Weed Science-turf. |
| Yenish, Joe | Washington State University | Weed Science-small grains, specialty crops, forages. |
| Young, Brian | Southern Illinois University | Weed Science - agronomic crops. |
| Zedler, Joy | University of Wisconsin- Madison | Wetland Invasive Species |
| Zollinger, Richard | North Dakota State University | Weed Science-agronomic crops, small grains, turf, ornamentals. |

| *Table 3.* **Questionnaire used to solicit expert input pertaining to the release of glyphosate or glufosinate resistant creeping bentgrass.** |
|---|
| 1) If known, what *Agrostis* or *Polypogon* species (also *Agrostis*/*Polypogon* hybrids) have been identified in your area? |
| 2) Have any of the species above been identified as weeds? In what crops/ecosystems? |
| 3) Are glyphosate or glufosinate products used to control these species? If so, how are they used? |
| 4) What other products have been identified to control these species and how are they used? |
| 5) Have any of the *Agrostis* species been identified as being resistant or tolerant to glyphosate or glufosinate? |
| 6) In what crop/ecosystems would a glyphosate- or glufosinate-resistant creeping bentgrass or other *Agrostis* species/hybrids be a potential problem and why? |
| 7) What will be the effect of having an additional glyphosate or glufosinate resistant crop on weed management in the cropping system being reported? |
| 8) Will the introduction of glyphosate or glufosinate resistant creeping bentgrass exacerbate known or possible resistance in other weed species? |
| 9) What reports, bulletins, articles, surveys, or other published materials related to documentation of *Agrostis* species as weeds and their response to various product/management systems are available from your location? |
| 10) If introduced into your area, what is the overall potential of (herbicide)-resistant creeping bentgrass to directly or indirectly increase weed problems? Please indicate low, moderate, or high potential; and comment. |

***Agrostis* Taxonomy and Distribution in the United States.** The genus *Agrostis* is in the tribe Aveneae (including Agrostideae), which also contains oats (*Avena*) (Mabberley 1998; Watson & Dallwitz 1992, 1998, 1999; Clayton & Renvoize 1986; Phillips & Chen 2003; Jacobs 2001). In the U.S., 31 to 34 species of *Agrostis* are native or naturalized, with 17 to 19 of them also found in Canada (Table 1). There are 25 to 28 native species of *Agrostis* in the U.S., and 7 to 9 established introductions, mainly from Eurasia (7 to 8 of these species are entirely introduced, 1 or 2 mostly so). Some field grasses were called *Agrostis* by Theophrastus (370-*c.* 285 BC), director of Aristotle's garden in Athens (Greene 1909). The overall taxonomy of *Agrostis* is unsettled, difficult, and there is no comprehensive worldwide or definitive U.S. taxonomic treatment (Philipson 1937; Björkman 1960; Widén 1971; Tutin 1980; Romero García et al. 1988b; Koyama 1987; Rúgolo de Agrasar & Molina 1992, 1997; Edgar & Connor 2000; Soreng & Peterson 2003; and Hitchcock & Chase 1951; Carlbom 1967; Simpson 1967; Harvey 1993, 1999; Kartesz 2003). Consequently, the number of species stated above reflects different taxonomic judgments. The genus could include over 200 species, occurring primarily near their probable center of origin in Europe, along with some species native in the Southern Hemisphere or temperate to cold-temperate areas on tropical mountains. *Agrostis* is in the convenient grouping called cool-season grasses that posses a $C_3$ photosynthetic pathway (Campbell et al. 1999; Goverde et al. 2002).

Creeping bentgrass has become naturalized in temperate to cold-temperate regions throughout the world including New Zealand, southern Australia, South Africa, South America (including Tierra del Fuego, Patagonia and the Andes), North America, and remote islands such as Hawaii, the Juan Fernández Islands, the Falkland Islands, Gough Island, and Tristan da Cunha (Tompkins et al. 2000). Creeping bentgrass is native in Eurasia, Iceland and North Africa, and has ambiguous status, sometimes listed as a native, in the northern U.S. and/or in Canada at some salt marshes and freshwater lakes (Hitchcock & Chase 1951; Voss 1972; Dore & McNeill 1980; Harvey 1999). However, four close relatives (Table 1) are clearly native only in Eurasia or Europe (Widén 1971; Romero García et al. 1988a; Warnke et al. 1998; Vergara & Bughrara 2003). In the U.S., creeping bentgrass is mostly, if not entirely, naturalized probably arriving well before the 1750's (Sauer 1942, 1976; Richardson 1818; Odland 1930; Monteith 1930). It was likely introduced with seed or hay as forage for animals (as in other regions, *e.g.* Argentina – Rúgolo de Agrasar & Molina 1992). The species is naturalized in all states and recorded in the majority of counties, except for the warmer southern portions of states in the southeastern U.S. (Kartesz 2003; USGA 1922a; Moncrief 1964; Ferguson 1964; Xu & Huang 2001; Huang & Liu 2003; Pote & Huang 2003). The USDA/NRCS PLANTS database provides distribution maps for 31 *Agrostis* spp. based on herbarium records (http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=AGROS2). However, Kartesz (2003) is more complete. Both sources provide a general picture of the distribution of *Agrostis* in the U.S.

The turfgrass industry in the U.S. frequently equates creeping bentgrass with *Agrostis palustris* or sometimes *A. stolonifera* var. *palustris*, but this usage does not agree with the detailed botanical concepts of Hubbard (1984) or Sell & Murrell (1996) where the plants are native or utilized. This U.S. convention may in part reflect the continuing influence of the manual by Hitchcock & Chase (1905, 1935,1951) and Piper (1918), instead of recognizing newer taxonomic benchmarks such as *Flora Europaea* (Tutin 1980) and *The Jepson Manual* (Harvey

1993). Because the introduction of creeping bentgrass into the U.S. came from various European countries over an extended period of time and due to the subsequent adaptation, selection and breeding programs, the U.S. creeping bentgrass germplasm is a rich and heterogeneous mixture quite unlike the native ecotype in Europe (Sell & Murrell1996; Rozema & Blom 1977; Davies & Singh 1983; Winkler et al. 2003; Panter & May 1997; Aston & Bradshaw 1966; Olff et al. 1993; Ahmad & Wainwright 1976; McNeilly et al. 1987; Misra & Tyler 2000b, 2000a; Kik 1987; Kik et al. 1990a, 1990b, 1992). Another legacy problem lingering in the U.S. and Canada is an overly broad scope in use of the name *A. stolonifera* (or *A. alba*) (Malte 1928; Gleason 1952; Gleason & Cronquist 1963; Steyermark 1963; Munz 1968; Cronquist et al. 1977; Stubbendieck et al. 1982; Welsh et al. 1993), and sometimes the name *A. stolonifera* var. *stolonifera* was used rather than *A. stolonifera* var. *major* to name the plants usually called redtop and well accepted now as *A. gigantea* (Tutin 1980; Sell & Murrell 1996; and North America, Fassett 1951; Voss 1972; Bailey et al. 1976; McNeill & Dore 1976; Dore & McNeill 1980; Pohl 1978; Gleason & Cronquist 1991; Harvey 1993, 1999, 2001; Yatskievych 1999).

Creeping bentgrass has a "competitive-ruderal" ecological strategy in the well-known C-S-R (competition–stress–ruderality) system of plant strategies or functional types (Grime 1977, 1988, 2001), which thus includes weedy characteristics (Schippers et al. 2001; Hill et al. 2002; Wilcox 1998; Marshall 1990; Goldsmith 1978; Booth et al. 2003; Baker 1965, 1972, 1974; Keeler 1985, 1989). The plant's roots (Fitts 1925a; Murphy et al. 1994; Boeker 1974; Lehman & Engelke 1991; Steer & Harris 2000; Beard & Daniel 1966; Ralston & Daniel 1972; Krans & Johnson 1974; Bowman et al. 1998) and stolons actively forage in space, exploiting pockets of nutrient enrichment and vegetation gaps (Crick & Grime 1987; Hunt et al. 1987; Grime et al. 1988; Glimskär & Ericsson 1999; Glimskär 2000). Being a clonal perennial, the plant functions in a modular way, and the leafy plantlets (rooted tillers) along a stolon are able to become nutritionally independent (Jónsdóttir 1991b, 1991a; Marshall & Anderson-Taylor 1992). Consequently, severed stolons or dispersed pieces of stolons with nodes are readily able to establish new plants (Boedeltje et al. 2003; Widén 1971; Fitts 1925b; Carrier 1923, 1924).

Of the 10 to 12 species of *Agrostis* in the U.S. with which it is known that creeping bentgrass can hybridize (Table 1 & Appendix 3), the most likely hybridization is with colonial bentgrass, forming *A. murbeckii*. It probably also hybridizes to a lesser extent with redtop. Colonial bentgrass is most likely to cross with dryland bentgrass, forming *A. fouilladei*, which can backcross into colonial bentgrass, and for some years all of these were imported unknowingly from New Zealand as colonial bentgrass (*A. capillaris*) and widely distributed. Colonial bentgrass is also likely to cross with redtop, forming *A. bjoerkmanii*, as found in Rhode Island. Creeping bentgrass has also been reported to hybridize with three *Polypogon* species. The various hybrids are for the most part sterile or with very low fertility, but could be vegetatively vigorous. Hybridization and introgression have always been aspects of the domestication and improvement of crops and ornamentals (Gepts 2002; Anderson 1961). Various new laboratory techniques facilitate working with hybrid turfgrasses (Brilman 2001; Ovesná et al. 2002), and efforts are underway to hybridize *Agrostis* species for traditional reasons such as developing disease resistance (Belanger et al. 2003c, 2003b).

**Current Uses of *Agrostis* spp. in the U.S.** Once a popular pasture grass in the U.S., creeping bentgrass has been suggested for reseeding on some western grasslands (USDA Forest Service 1940; Davis 1952; Fransen & Chaney 2002). However, the current major use of bentgrasses in the U.S. is as a turfgrass on golf courses. Turfgrass is a large crop in the U.S.; however, little published information exists on the economic value of this industry. The USDA Agricultural Research Service does not track home lawn or turf hectareage, and no published value is currently available. The U.S. Environmental Protection Agency estimated that there are between 6.5 and 9.7 million hectares of maintained turfgrass in the United States, with 7.16 million hectares cited as a conservative estimate (Liskey 1997).

Golf courses make up a very small percentage of total U.S. turf hectareage; however, they are presently considered the only potential market for glyphosate- or glufosinate-resistant creeping bentgrass. As of January 2003, there were 15,827 golf course facilities in the United States (National Golf Foundation). Florida has the most golf courses with 1,073, followed by California (912), Michigan (854), and Texas (838). There is the equivalent of 14,725 eighteen-hole golf courses in the U.S., with the discrepancy due to a significant number of nine-hole golf facilities. A typical eighteen-hole golf course averages 60 hectares: however, only a fraction of that total is highly-maintained turf. On average, an eighteen-hole golf course will have 0.8 to 1.2 hectares of putting greens, 1.2 to 2 hectares as tees, and 8 to 12 hectares as fairway (Beard 2002). In the cool-season turfgrass region of the U. S. (Turgeon 2002), creeping bentgrass is commonly used on golf courses for putting greens, tees, and fairway turf. Because of its excellent characteristics as a putting green turf, creeping bentgrass use has also extended into the northern portion of the warm-season grass-growing region but high maintenance is needed in this environment. Other grasses such as bermudagrass or zoysiagrass (*Zoysia* spp.) are better adapted for use on fairways and tees in this area. Occasionally, creeping bentgrass is also used for playing surfaces such as croquet, lawn bowling, home lawn putting greens, and very rarely (due to the intensive inputs and management that are needed), as an ornamental lawn.

Creeping bentgrass is the most widely used of the bentgrasses for golf courses and forms a turf of exceptionally high shoot density when mown at heights of 2 cm or less. Creeping bentgrass spreads by stolons that can form new plants wherever they are deposited. Bentgrass stolons can be transported on shoes, golf equipment, tires, flowing water, etc. and as such, bentgrass established on golf courses can become a weed in home lawns and other turfs even when these areas are not directly adjacent to a golf course.

While there are approximately 34 (Table 1) bentgrass species found in the U.S., only four to five are intentionally planted in turfgrass systems (Turgeon 2002). Colonial bentgrass is not widely used in golf courses because it does not have the high quality of creeping bentgrass. Conventional breeding is being utilized to improve the turf performance of colonial bentgrass due to this species' high degree of resistance to dollar spot (*Lanzia* spp. and *Moellerodiscus* spp.), the primary disease problem in creeping bentgrass. However, resistance to dollar spot is offset by a greater propensity to infection from brown patch (*Rhizoctonia solani*).

Velvet bentgrass is used principally as a turf on golf course putting greens. It forms exceptionally high quality putting greens, but is considered a specialty turfgrass that is adapted primarily to cool, coastal zones.

Redtop is a low maintenance turfgrass species that is often included in seed mixtures in very low maintenance plantings such as pastures, highway roadsides, parks, cemeteries, airports and mine tailings (Archer and Bunch 1953). The use of redtop in these mixtures is declining, but conventional practice has been to plant 8 to 12 different grass species and the most adapted would survive and flourish. Redtop can be a weed in pastures because it persists with few cultural inputs and spreads by rhizomes; however, it can also be utilized as a forage grass as well. Other bentgrass species such as Idaho and dryland bentgrass have recently been tested for golf course use but have not been commercially adopted by turf managers.

## WEEDINESS OF *AGROSTIS* SPECIES AND CURRENT MANAGEMENT IN U.S. CROPPED AND NON-CROPPED SYSTEMS

**Turf.** As previously mentioned, of the 34 species of bentgrass native or naturalized in the U.S., several have been evaluated for use on golf courses but only creeping bentgrass is widely utilized, mainly in the northern parts of the U.S. Only creeping bentgrass and redtop are reported as weeds of significance in other turfgrasses (Table 4). Other species of bentgrass that are used in turf were routinely mentioned as being present in survey responses from turfgrass scientists, however, they were not considered as weeds since there was no attempt at removal.

The standard recommendation to kill patches of creeping bentgrass in another type of turf, is to use glyphosate and then to reseed or resod the treated areas (University of Minnesota 2004; Colorado State University 2004). However, this approach is often ineffective for two reasons. First, unless the killed turf is removed and sod replaced, creeping bentgrass control with glyphosate is rarely 100% (Hart et al. 2002). A small percentage of stolons, or stolon sections, survive and the grass reestablishes. Second, when spot treating patches in an existing turf, it is highly unlikely that all bentgrass will be observed and treated. In a dense turf, it is difficult to see recently established stolons and small bentgrass patches. For these two reasons, creeping bentgrass control in other turfgrasses is not commonly attempted. Most homeowners and professional turf managers generally either keep the creeping bentgrass-infested turf or destroy the entire turf and reseed or place new sod.

Recently discovered herbicide chemistries offer the prospect for selective control of creeping bentgrass growing in Kentucky bluegrass turf (Table 5) (Askew et al. 2003). Mesotrione is a new product that has been reported to selectively control creeping bentgrass in Kentucky bluegrass. Mesotrione and isoxaflutole [also reported to control creeping bentgrass in other turf (Bhowmik and Drohen 2001 )] have the same mode of action, inhibition of the enzyme 4-hydroxyphenyl-pyruvate-dioxygenase (4-HPPD) (Vencill 2002). Currently, neither product is labeled for use on turf. The possibility that one of these products may be labeled for bentgrass removal in turfgrass would simultaneously aid in the selective control of creeping bentgrass (glyphosate-resistant, glufosinate-resistant, or conventional) while offering a tool to control the spread of glyphosate- or glufosinate-resistant creeping bentgrass from the intended site of use.

| *Table 4. Agrostis* or *Polypogon* species that have been reported as weeds. | | | | |
|---|---|---|---|---|
| **Species** | **States** | **Crop** | **Level of Importance (none, low, moderate, high)** | **Comments** |
| **A. stolonifera** | All | Turfgrass | Moderate to high | Major turfgrass species used in all states in US; less of a problem in southern states. |
| *A. stolonifera* | OR | Fruit crops | Low | |
| *A. stolonifera* | ID, OR | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| *A. capillaris* | All | Turfgrass | Low | Secondary turfgrass species; not widely utilized; not a weed problem in turf. |
| *A. capillaris* | OR | Fruit crops | Low | |
| *A. capillaris* | ID, OR | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| *A. canina* | States in northern US | Turfgrass | Low | Secondary turfgrass species; not widely utilized; not a weed problem in turf |
| *A. castellana* | States in Northern US | Turfgrass | Very Low | Evaluated as a potential turfgrass in most states, rarely planted in commercial turf. |
| *A. gigantea* | IL, IN, OH, NE | Turfgrass | Low | Rarely utilized as turf, can become a weed in turf. |
| *A. gigantea* | OR | Fruit crops | Low | |
| *A. gigantea* | ID, OR | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| *A. gigantea* | OH | Pastures and hayfields | Low | |
| *A. gigantea* | NY, MD | Meadows | Not reported | Wildland areas. |
| *A. exarata* | ID, OR | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| *A. humilis* | ID | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| *A. idahoensis* | ID | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| *A. scabra* | ID | Pastures, hayfields, non-crop areas, ornamentals, grass seed fields | Low to moderate | Greatest concern in grass seed fields. |
| **P. monspeliensis** | CA | Asparagus, cole crops, citrus, grape, kiwi, olive, pear, peppers, walnut | Low | |
| *P. monspeliensis* | AZ | Alfalfa | Low | Irrigation ditch banks |
| *P. monspeliensis* | ID | Potato, sugarbeet, corn, alfalfa | Low to moderate | |
| *P. monspeliensis* | OR | Corn, wheat, edible legumes, seed alfalfa | Low | Ditchbank weed |

| *Table 5.* **Herbicides[1] used for the management of *Agrostis* or *Polypogon* species.** | | | | |
|---|---|---|---|---|
| **Species** | **Crop or Area** | **Product Common Name** | **Level of Control (fair, good, excellent)** | **Comments** |
| ***A. stolonifera*** | Turfgrass | Glyphosate | Good to excellent | Provides non-selective control; requires 2-3 applications for complete control. |
| *A. stolonifera* | Turfgrass | Pronamide | Excellent | Seedlings only. |
| *A. stolonifera* | Turfgrass | Foramsulfuron | Fair to excellent | |
| *A. stolonifera* | Turfgrass | Hexazinone | Good to excellent | |
| *A. stolonifera* | Soybean | Clethodim | Fair to good | |
| *A. stolonifera* | Corn | Nicosulfuron | Fair to good | |
| *A. stolonifera* | Corn | Atrazine | Fair to good | Postemergence. |
| *A. stolonifera* | Fruits | Glyphosate, Glufosinate | Good | Foliarly applied. |
| *A. stolonifera* | Hayfields and Pastures | Glyphosate | Not reported | Spot application or renovation. |
| *A. stolonifera* | Riparian Zones | Imazapyr | Good to excellent | Not selective. |
| *A. stolonifera* | Riparian Zones | Glyphosate (contains no surfactant) | Excellent | Not selective and needs repeated applications. |
| *A. stolonifera* | Rangeland, Pasture, Public Lands, National Parks | Glyphosate | Excellent | Repeated applications required for control. |
| *A. stolonifera* | Rangeland, Pasture, Public Lands, National Parks | Imazapic | Good | Higher rates on established perennials. |
| *A. stolonifera* | Rangeland, Pasture, Public Lands, National Parks | Sethoxydim, Clethodim, Fluazifop | Good | Complete control on seedlings. Repeated applications needed for established plants. |
| *A. stolonifera* | Rights-of-Way | Imazapic | Good to excellent | Selective at lower rates; higher rates on established grasses; split applications needed for perennials. |
| *A. stolonifera* | Rights-of-Way | Glyphosate | Excellent | Not selective. |
| *A. stolonifera* | Rights-of-Way | Bromacil | Excellent | Some selectivity when grasses are dormant. |
| *A. stolonifera* | Rights-of-Way | Hexazinone | Excellent | |
| *A. stolonifera* | Forests | Hexazinone | Excellent | Pines and firs have good tolerance; lower rates selective. |
| *A. stolonifera* | Forests | Imazapyr | Excellent | Not selective. |
| *A. stolonifera* | Forests | Sulfometuron | Good | Multiple applications in established grasses. |

| *Table 5.* (cont.) Herbicides[1] used for the management of *Agrostis* or *Polypogon* species. | | | | |
|---|---|---|---|---|
| *A. stolonifera* | Forests | Glyphosate | Excellent | |
| *A. stolonifera* | Non-crop Areas | Fluazifop, Quizalofop, other ACCase inhibitors | Fair to excellent | Not selective in turfgrass. |
| *A. stolonifera* | Non-crop Areas | Glyphosate | Fair | For turfgrass renovation; requires multiple applications; spring application for powerline vegetation management. |
| *A. stolonifera* | Non-crop Areas | Glufosinate | Not reported | For turfgrass renovation. |
| *A. stolonifera* | Non-crop Areas | Glufosinate | Good | On glyphosate-resistant creeping bentgrass. |
| *A. stolonifera* | Non-crop Areas | Isoxaflutole | Good to excellent | Partially selective turfgrass weed control. |
| *A. stolonifera* | Non-crop Areas | Mesotrione | Excellent | Partially selective turfgrass weed control. |
| *A. gigantea* | Turfgrass | Bromacil | Good to excellent | |
| *A. gigantea* | Pastures | Imazapic | Good | Used in conservation areas and pastures in the west to control redtop; would also control *A. stolonifera.* |
| *A. gigantea* | Hayfields and Pastures | Glyphosate | Excellent | For pasture and hayfield renovation. |
| *A. gigantea* | Fruits | Glyphosate, Glufosinate | Good | Foliarly applied. |
| *A. gigantea* | Non-crop Areas | Fluazifop, Quizalofop, other ACCase inhibitors | Fair to good | |
| *A. gigantea* | Non-crop Areas | Glyphosate, Glufosinate | Not reported | For turfgrass renovation. |
| *A. capillaris* | Fruits | Glyphosate, Glufosinate | Good | Foliarly applied. |
| *A. capillaris* | Non-crop Areas | Fluazifop, other ACCase inhibitors | Excellent | Not selective in turfgrass. |
| *A. capillaris* | Non-crop Areas | Isoxaflutole | Excellent | Partially selective turfgrass weed control. |
| *A. capillaris* | Non-crop Areas | Mesotrione | Excellent | Partially selective turfgrass weed control. |
| *A. capillaris* | Non-crop Areas | Glyphosate | Fair | For turfgrass renovation; requires multiple applications. |
| *A. canina* | Non-crop Areas | Fluazifop, other ACCase inhibitors | Excellent | Not selective in turfgrass. |
| *A. canina* | Non-crop Areas | Isoxaflutole | Excellent | Partially selective turfgrass weed control. |
| *A. canina* | Non-crop Areas | Mesotrione | Excellent | Partially selective turfgrass weed control. |
| *A. canina* | Non-crop Areas | Glyphosate | Fair | For turfgrass renovation; requires multiple applications. |

| *Table 5.* (cont.) **Herbicides[1] used for the management of *Agrostis* or *Polypogon* species.** | | | | |
|---|---|---|---|---|
| *A. hyemalis* | Non-crop Areas | ACCase inhibitors | Not reported | |
| *A. hyemalis* | Non-crop Areas | Glyphosate | Not reported | Spring application for powerline vegetation management. |
| *A. perennans* | Non-crop Areas | ACCase inhibitors | Not reported | |
| *A. perennans* | Non-crop Areas | Glyphosate | Not reported | Spring application for powerline vegetation management. |
| *A.* spp. | Hayfields and Pastures | Glyphosate | Not reported | Spot application or renovation.. |
| *A.* spp. | Temporary soil sterilant | Dazomet | Excellent | Expensive; difficult to apply. |
| *A.* spp. | Various | Imazaquin | Fair | |
| *A.* spp. | Various | Paraquat | Fair | |
| *A.* spp. | Various | Sulfosulfuron | Good | |
| *A.* spp. | Various | Trifloxysulfuron | Good | |
| *A.* spp. | Ornamentals | Clethodim, Sethoxydim, Fluazifop | Good to excellent | Foliarly applied. |
| *A.* spp. | Grass seed crops | Pendimethalin | Good | Seedling control only. |
| *A.* spp. | Grass seed crops | Metolachlor | Good | Seedling control only. |
| *A.* spp. | Grass seed crops | Dimethenamid | Good | Seedling control only. |
| *A.* spp. | Grass seed corps | Oxyfluorfen | Good | Seedling control only. |
| *A.* spp. | Grass seed crops | Diuron | Good | Seedling control only. |
| *A.* spp. | Grass seed crops | Metribuzin | Good | Seedling control only. |
| *A.* spp. | Grass seed crops | Pronamide | Good | Seedling control only. |
| *A.* spp. | Grass seed crops | Ethofumesate | Good | Seedling control only. |
| *P. monspeliensis* | Most Vegetables, Cotton, Fruits, and Nuts | Clethodim, Sethoxydim, Fluazifop | Excellent | Foliarly applied. |
| *P. monspeliensis* | Cotton | Trifluralin, Pendimethalin | Excellent | Soil applied. |
| *P. monspeliensis* | Fruits and nuts | Trifluralin, Pendamethalin, Oryzalin, Diuron, Norflurazon | Excellent | Soil applied. |
| *P. monspeliensis* | Fruits and nuts | Glyphosate, Glufosinate, Clethodim, Sethoxydim, Fluazifop | Excellent | Foliarly applied. |
| *P. monspeliensis* | Potato, sugarbeet, corn, alfalfa | Glyphosate | Not reported | Spot application. |

[1]The herbicide names in this list are Weed Science Society of America common names. Specific information pertaining to these herbicides can be found in the *Herbicide Handbook* (Vencill 2002). Each of the herbicides shown may be available under a number of different Trade Names. Product labels may vary for the specific situations the product can be used

Glyphosate- or glufosinate-resistant creeping bentgrass is not considered to present a greater problem in managed turfgrass systems than non-transformed bentgrass. Glyphosate is the best control option currently available for the management of creeping bentgrass in other types of turf but requires multiple applications usually combined with physical removal (Koski 2002; Anonymous 1998).

**Landscape and Ornamental Cropping Systems**. Ornamental plants for use in home and commercial landscaping is an economically important business and nurseries produce large quantities of annual and herbaceous perennial plants that are sold to homeowners and professionals for landscape installation. In 1998, sales of landscape plant materials exceeded 2.3 billion dollars in the U.S. (U.S. Department of Agriculture, 1998 Census of Horticultural Specialties).

Many gardens, home landscapes, and commercial gardens contain beds of annual or herbaceous and woody perennials, ornamental grasses, or combinations of both. These landscape beds require weed control programs that differ from those typically used for turfgrass weed control. Regardless of whether landscape plantings consist of annual flowers, herbaceous and woody perennials, or ornamental grasses, bentgrass species are rarely reported as weeds in these settings except in and around golf courses where creeping bentgrass is being used. Questionnaire responses from weed scientists working with ornamentals reported either no, or occasional, presence of bentgrasses as weeds in ornamentals. None of the respondents considered creeping bentgrass a problem weed. None of the respondents reported creeping bentgrass to be a weed in commercial landscape plant production operations. Weed scientists in Michigan, New York, and Virginia have observed creeping bentgrass as an occasional weed problem in home landscape beds. They noted that creeping bentgrass can encroach from lawns that contain creeping bentgrass in a mixed turf, however, it was not considered a problem weed in these settings. One weed scientist working with ornamentals believed that glyphosate-resistant creeping bentgrass could become a more troublesome weed in landscapes if the technology is commercialized. The most commonly used herbicide in most landscapes is glyphosate as a spot treatment. There are a number of herbicides such as clethodim, fluazifop, and sethoxydim that can be used selectively for annual and perennial grass control in most ornamentals (Table 5).

**Grass Seed Production.** The Pacific Northwest has a long history of grass seed production including various bentgrasses (Schoth 1939). Seeds from natural stands of seaside bentgrass (*Agrostis* spp.) were first harvested in 1924 for use on golf courses, parks, recreation fields, lawns and cemeteries. Astoria colonial bentgrass (*Agrostis capillaris*, formerly *A. tenuis*) was first harvested from natural stands in northwestern Oregon in 1926. Highland colonial bentgrass (reported as *Agrostis tenuis* now recognized as *A. castellana*) was first harvested in 1928 from natural stands near Yoncalla, Oregon. Most of the production of bentgrass seed prior to 1934 was from natural stands. Bentgrass seed production shifted to the use of cultivated stands, primarily in the Lower Colombia River and Klamath Lake regions of Oregon after 1934.

By 1936, over 200,000 kg of *Agrostis* spp. seed were being produced. *Agrostis* seed production has rarely occurred east of the Cascade mountains due to long winter dormancy, and susceptibility to snowmold diseases. The Willamette Valley of Oregon produces the majority of *Agrostis* spp. seed grown in the U.S., producing approximately 628,000 kg of colonial bentgrass and 1.5 million kg of creeping bentgrass seed in 2002 (Young 2003) which is 0.2 and 0.44 %, respectively, of the total grass seed production in Oregon. The predominate grass species grown for seed in Oregon are annual and perennial ryegrasses (198 million kg) and tall fescue (115 million kg).

There are at least 24 *Agrostis* spp. and two *Polypogon* spp. that occur in the Pacific Northwest, the majority of which are best adapted to the wetter regions west of the Cascade mountains in Oregon and Washington. Many are natives to the region in addition to the many commercial varieties that have been grown in this region over the past 50 years. The most prominent of these species in the Pacific Northwest include creeping bentgrass, redtop, dryland bentgrass, velvet bentgrass, colonial bentgrass, spike bentgrass, and rabbitfoot polypogon.

*Agrostis* species are rarely reported as weeds in most crops, other than grass seed crops, in this region while rabbitfoot polypogon is considered to be an occasional weed in irrigated crops. Of the 26 species known to occur in the region, the species that present the greatest problem in grass seed production are creeping bentgrass, velvet bentgrass, spike bentgrass, redtop, dryland bentgrass, colonial bentgrass, rough bentgrass, and rabbitfoot polypogon. Where *Agrostis* species have historically been grown for seed, they routinely occur as weeds in other grass seed crops, including perennial ryegrass, orchardgrass, tall fescue, and fine fescues (Table 4). A number of herbicides are registered for use in grass seed production for grass control (Colquhoun et al. 2001). Glyphosate and glufosinate are registered for all of these crops and can be used as spot treatments for bentgrass management. Other herbicides registered for use in various grass seed crops for the control of grass weeds are: pendimethalin, metolachlor, dimethenamid, flufenacet, metribuzin, oxyfluorfen, diuron, pronamide, terbacil, and ethofumesate. These herbicides are not registered on all grass seed crops and are primarily used for management of grasses (including bentgrasses with the exception of terbacil) prior to or shortly after emergence.

**Agronomic Crops.** A review of the literature revealed that *Agrostis* and *Polypogon* species are rarely cited as weeds of cropland. To supplement the literature review a questionnaire (Table 3) was sent to weed scientists and other experts in 23 states with direct knowledge of weed management in 28 crops.

Although *Agrostis* species are widely distributed throughout the U.S., the occurrence of *Agrostis* or *Polypogon* spp. as cropland weeds was reported to be relatively low. Respondents from Arizona, California, Oregon, Ohio, and Idaho listed *Agrostis* or *Polypogon* spp. as occasional cropland weeds, but most respondents considered these species to be of no significant importance as weeds of agronomic cropland (Table 4). Rabbitfoot polypogon has been reported as a weed in Arizona (Parker 1990), California, Idaho, and Oregon (Table 4), and is present in Texas and Louisiana (www.csdl.tamu.edu/FLORA)], and most likely is present in several other states. In Arizona, it was reported as an occasional problem in alfalfa. None of the respondents were aware of *Agrostis x Polypogon* hybrids present in their area. There are no *Agrostis* or *Polypogon* species on the U.S. Federal Noxious Weed List (Anonymous 2000). At the state level, *Agrostis gigantea* and *Agrostis* spp. (which includes creeping, colonial, and velvet bentgrasses) are on the Delaware, Maryland, Pennsylvania, Virginia, and West Virginia Noxious Weed Seed Lists which prohibits their presence in commercial seed, but no states list *Agrostis* or *Polypogon* species as noxious terrestrial or aquatic weeds. The significance of *Agrostis* spp. as important weeds of food, feed, or fiber crops appears to be minimal and limited to pastures (Schulte and Neuteboom 2002). Due to the minimal importance of these species in agronomic crops, little specific information on their management has been written or published. However, several herbicides that have activity on *Agrostis* and *Polypogon* species (Table 5) are currently registered for use in these types of crops.

**Vegetables, Fruits and Nuts.** Vegetables (over 50 different commodities) and fruit and nut crops are produced in all states with California being the largest producer for most (National Agricultural Statistics Service, www.usda.gov/nass). These crops are quite diverse in where they are grown and the types of weed management systems that are used. All are considered high value crops and weed management inputs generally do not account for a significant portion of the total production costs, but if ignored can significantly affect yield and quality of the harvested crop. At present, no vegetable, fruit or nut crops are commercially available with resistance to herbicides.

In fruit and nut crops, there were no reports of *Agrostis* species as weeds with the exception of Oregon where three (creeping bentgrass, colonial bentgrass, and redtop) have occasionally been reported in raspberry, blueberry, apple, and grape (Table 4). Rabbitfoot polypogon was reported as a weed in citrus, grape, kiwi fruit, olive, pear and walnut in California (Univ. CA IPM Online, www.imp.ucdavis.edu). In all instances, the level of concern was rated as low. Glyphosate and glufosinate are used to control these weeds in fruit and nut crops as are many other herbicides. These include soil applications of pendimethalin, trifluralin, oryzalin, diuron, napropamide and foliar applications of clethodim, sethoxydim and fluazifop. These products are listed by the Univ. of California IPM Online (www.ipm.ucdavis.edu/PMG/r1700999.html) as providing excellent control of rabbitfoot polypogon. Tillage can also be used effectively since rabbitfoot polypogon is an annual. After establishment of most fruit and nut trees, high rates of diuron, norflurazon, oryzalin, and bromacil (in citrus) can be used and are effective on annual and perennial grasses. It is not expected that the introduction of glyphosate- or glufosinate-resistant creeping bentgrass or hybrids of this species would pose a problem in fruits and nuts. Of note, it has been reported that repeated use of glyphosate on orchard crops in California (Heap 2004) and Oregon (Perez-Jones et al. 2004) has resulted in the development of glyphosate-resistant rigid ryegrass (*Lolium rigidum* Gaudin) and Italian ryegrass (*Lolium multiflorum* Lam.), respectively.

Vegetable production is quite varied across the United States and weed management practices may include soil fumigation (usually for disease or nematode management but also reduces weed infestations of many species), extensive tillage, hand weeding, and use of soil and foliar active herbicides. The high cash value of vegetables generally allows producers the economic flexibility to use some or all of the practices noted above. The USDA IR-4 program (ir4.rutgers.edu) ) is actively working to register new uses of existing herbicides and has expanded the list of herbicides available for control of weeds in vegetable crops. None of the *Agrostis* species were listed or reported as weeds in vegetables, however, it was noted that in the Pacific Northwest, several of the species may occur at very low levels but growers have not reported them. Rabbitfoot polypogon has been reported as a weed in California in asparagus, cole crops, and peppers (Univ. of California, IPM Online). Glyphosate can be used in these crops as preplant or spot treatment for the control of this species. Selective herbicides such as sethoxydim, fluazifop, clethodim are also available for use as preplant, spot treatment or over the top foliar applications and are reported to give excellent control..

The introduction of an *Agrostis* species or hybrid that is resistant to glyphosate or glufosinate would have little impact on the weed management programs in vegetable, fruit or nut crops. There are no reports of significant problems with any of the *Agrostis* or *Polypogon* species and there are several options available for their management.

**Commercial Forestry Production.** In commercial forestry situations of the Pacific Northwest, no problems were reported from infestations of *Agrostis* spp. or *Polypogon* spp. in either first year tree establishment or in established tree stands. Although one respondent was concerned that the introduction of glyphosate-resistant creeping bentgrass could cause future changes in species diversity, no details were given for this opinion. The herbicides commonly used for weed control in forestry in the Pacific Northwest are glyphosate, sulfometuron, and triclopyr. These are typically used for site preparation prior to planting but can be used selectively at different growth stages for Douglas fir and other evergreen species. Glyphosate, without a surfactant, is often sprayed at low application rates over trees as an aerial application to control competing vegetation.

In the southeastern U.S., no *Agrostis* spp., no *Polypogon* spp.*,* nor any other cool season grasses were reported as problems in commercial pine production. The grasses of most concern are bermudagrass and cogongrass [*Imperata cylindrical* (L.) Beauv.]. Herbicides most commonly used are glyphosate, sulfometuron, imazapyr, triclopyr, and hexazinone. No weeds in forestry production areas have been reported to be resistant to glyphosate or glufosinate, however, resistance to ALS inhibitor herbicides has been reported.

**Pastures, Rangeland, Rights-of-way, and Public Lands**. Many *Agrostis* and *Polypogon* species were listed by respondents and various other reports as occurring in pasture and rangeland situations (Table 4). However, respondents did not consider the presence of these species to be weeds of high importance since they are utilized by livestock, no deleterious effects were identified, and few efforts are currently being made to control or manage them on rangeland or in improved pastures. Creeping bentgrass rarely occurs in rangeland and pastures and is usually found only in riparian areas. Two species, rough bentgrass and redtop, were reported as being in mixtures with other grasses on rights-of-way for site stabilization and erosion control.

There are reports of the presence of *Agrostis* spp. as a weed in some wildland meadows located in Maryland and New York. The U.S. National Park Service lists creeping bentgrass as present in many of its parks and monuments and is listed as being common or abundant in at least six parks (Cacek 2004). It is not clear that creeping bentgrass is being actively managed in the parks or other natural areas; however, glyphosate is the most common herbicide used in U.S. National Parks for weed management. One respondent felt that if glyphosate-resistant creeping bentgrass was introduced into U.S. parks, it would be a problem more in the developed areas where vegetation is being managed (i.e. around buildings, parking lots, fences, etc.) rather in the more undeveloped areas of the parks.

Several respondents concerned with vegetation management on public lands and rights-of – way were most concerned about situations where an area was to be renovated (removal of undesirable vegetation to re-establish native species). Glyphosate has commonly been used in these situations because it has no residual soil activity, thereby allowing immediate re-seeding. The presence of glyphosate-resistant creeping bentgrass or other grasses would require the use of a different herbicide or an additional herbicide(s). The presence of creeping bentgrass, *Polypogon* spp., or other *Agrostis* spp. were not identified as the reason such renovations are undertaken and it was not apparent that these species are often present or a significant problem during such renovations. However, as previously stated, red top and rough bentgrass are used in seed mixtures for roadside and slope stabilization in many states. Creeping bentgrass has been shown to hybridize with redtop and rough bentgrass (Table 1) and the use of these species could become a means for distributing a glyphosate- or glufosinate-resistant *Agrostis* spp. across large areas.

Wetland and riparian areas, which provide the best habitat for creeping bentgrass, could be most at risk from the spread of glyphosate-resistant creeping bentgrass. It was reported that many *Agrostis* species occur in non-crop areas of the Pacific Northwest (Table 4). In most cases the level of importance was listed as low to moderate. Imazapyr can be used in riparian areas and has good to excellent activity on *Agrostis* spp. (Table 5), but also has soil residual activity that can delay reseeding or replanting activities for many species. Spot treatments of imazapyr, which is labeled for use in riparian areas, or herbicides such as fluazifop, clethodim, or sethoxydim, could be used to manage glyphosate- or glufosinate-resistant *Agrostis* spp. The latter three herbicides are registered for use in non-crop areas but they cannot be applied to sites when standing water is present.. There was little concern pertaining to the introduction of glufosinate-resistant creeping bentgrass since glufosinate is very seldom used for vegetation management on public lands or on rights-of-way.

Some respondents expressed concern about the potential problem of managing glyphosate-resistant *Agrostis* spp. and its hybrids, in habitats where endangered plants are present. Glyphosate has been commonly used for managing unwanted grasses but, because of its non-selective nature, glyphosate may not be the best choice to use in the vicinity of endangered plant species. There are a number of more selective herbicide alternatives that could be used if glyphosate-resistant bentgrass or its hybrids need to be managed near endangered plant species. It is possible that users would need additional training to learn how to use these herbicides effectively and it may also be necessary to request section 18 Emergency Use Exemptions from EPA in specific situations.

## IMPLICATIONS OF THE ADOPTION OF GLYPHOSATE- OR GLUFOSINATE-RESISTANT CREEPING BENTGRASS

**Potential for the Development of Glyphosate or Glufosinate Resistance.** Herbicide resistance is defined by the Weed Science Society of America as “the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis” (Heap 2004).

By contrast, herbicide tolerance is defined as "the inherent ability of a plant species to survive and reproduce after herbicide treatment. This implies that there was no selection or genetic manipulation to make the plant tolerant; it is naturally tolerant" (Heap 2004). Worldwide there has only been one report of any *Agrostis* spp. evolving herbicide resistance in response to herbicide selection pressure. Creeping bentgrass has evolved resistance to amitrole, a triazole herbicide, however; the case is of little economic significance, as it occurred in a researcher's long term orchard study that was treated annually with amitrole, which is not a normal agricultural practice (Bulcke et al. 1988). The questionnaire sent to weed scientists and other experts in the U.S. resulted in no reports of *Agrostis* or *Polypogon* species that are resistant to glyphosate or glufosinate. *Agrostis* spp. are not considered a high risk for the development of herbicide resistance primarily because they are not commonly managed with herbicides.

The potential for weeds to evolve resistance to glyphosate and glufosinate is considered low. To date there have been no reports of glufosinate resistant weeds (Heap 2004). Worldwide, six weed species have developed resistance to glyphosate, with two of these in the U.S. However, it should be noted that far more hectares have been treated with glyphosate than glufosinate over a much greater time period. By comparison, some other modes of herbicide action such as ALS (acetolactate synthase) inhibitors, triazines (photosystem II inhibitors), and ACCase (acetyl CoA carboxylase) inhibitors have 83, 65, and 33 weed species, respectively, that have developed resistance to them worldwide. Figure 1 presents data for the U.S. indicating the relative risk of developing resistant weeds when using various herbicide modes-of-action.

To date only three grass species (goosegrass, Italian ryegrass, and rigid ryegrass) have developed resistance to glyphosate. It is clear that while glyphosate is a lower-risk herbicide for the evolution of resistance it is not a no-risk herbicide. This is especially true since the effect of increased glyphosate use in glyphosate-resistant crops may have impacts on the development of resistant weeds in the future. It is appropriate to consider the impact of increased glyphosate selection pressure on other weeds in response to the introduction of glyphosate-resistant creeping bentgrass.

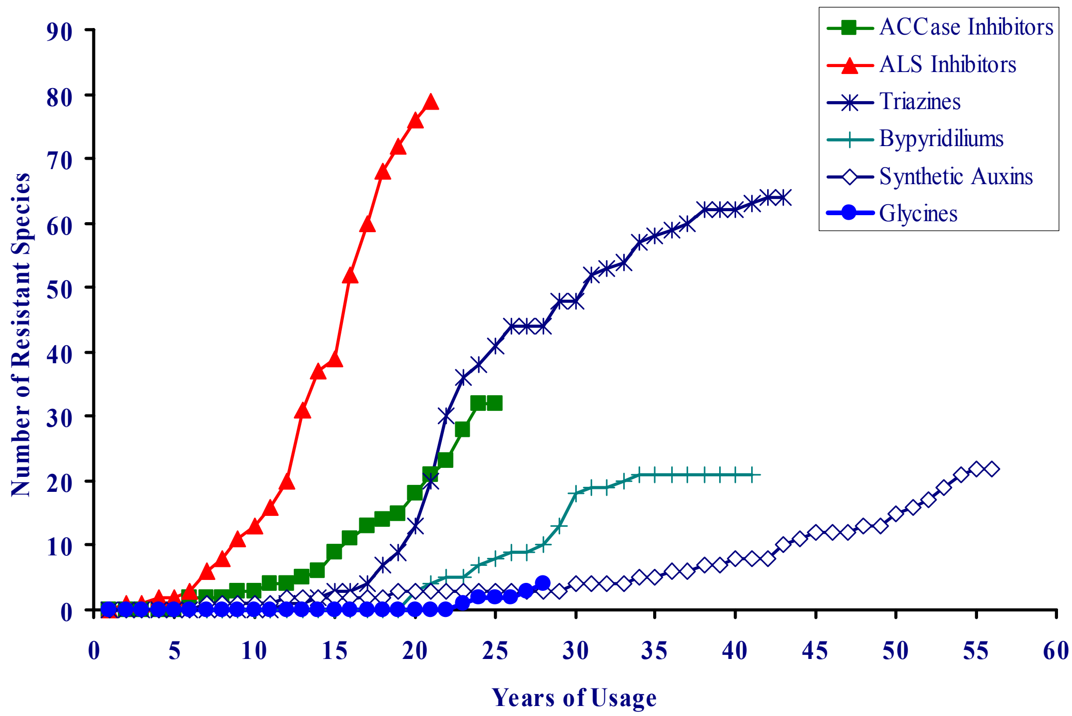


*Figure 1***.** The increase in the number of weed species with evolved resistance to six herbicide modes of action in the U.S. in relation to the number of years they have been used (Heap, 2004).

There are several weed species that are very adaptable and are likely candidates for the evolution of glyphosate or glufosinate resistance. Preliminary studies (Goss et al. 2001; Goss et al. 2002; Goss and Gaussoin 2003) suggest that applications of glyphosate to successive generations of annual bluegrass, large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and dandelion (*Taraxacum officinale* Weber in Wiggers) will select for more tolerant types of each species. Annual bluegrass has already evolved resistance to six different herbicide modes of action in various crops globally (Heap 2004) and it is the primary weed target on golf courses that will use glyphosate-resistant creeping bentgrass. Given sufficient time and selection pressure from repeated applications of glyphosate or glufosinate it is likely that glyphosate-or glufosinate-resistant annual bluegrass could develop. Given that current glyphosate-resistant grasses have developed in orchard and vine crops (Heap 2004; Perez-Jones et al. 2004) where glyphosate is commonly used two or more times per year, it is possible that glyphosate-resistant annual bluegrass will develop after 10 to 15 years. Alternative herbicides may be available (Park et al. 2002) should this occur, however, glyphosate- or glufosinate-resistant technology would then be worth considerably less. Annual bluegrass is not a serious weed in transgenic crops where glyphosate or glufosinate resistance technology is currently available.

Populations of goosegrass [*Eleusine indica* (L.) Beauv.], commonly found on golf courses, have been reported to be resistant to glyphosate in Malaysia (Heap 2004). Goosegrass has also been found to be resistant to four different herbicide modes of action globally. Some of the populations of glyphosate-resistant goosegrass in Malaysia have also evolved resistance to ACCase inhibiting herbicides. The crabgrass species (*Digitaria spp.)* are also commonly found on golf courses and are quite adaptable, having evolved resistance to four different herbicide modes of action (Heap 2004). Goosegrass and crabgrass species commonly occur in a number of agronomic, vegetable, and fruit and nut crops (Webster 2000; Webster 2001; Webster 2002; Webster 2003). If these or other weeds evolve resistance to glyphosate due to expanded use on glyphosate-resistant creeping bentgrass, there is the potential for them to spread to other crops, particularly other glyphosate-resistant crops or where glyphosate is commonly used, resulting in weed management problems that would need to be addressed with other herbicides. There are a number of herbicides currently available in most crops that are effective on these species.

**Herbicide Resistant Crops in the U.S.** In 2003, total U.S. cropland devoted to the production of principal agronomic crops was approximately 133 million ha (Table 6; Anonymous 2004b). Corn, soybean, cotton, canola, and sugarbeet varieties having transgenic resistance to glyphosate or glufosinate are currently approved for grower use in the U.S., although no transgenic sugarbeets are currently being produced. In 2003, transgenic herbicide-resistant varieties represented 11, 32, 81 and >58% of the total hectareages of corn, cotton, soybean, and canola[3], respectively, (Anonymous 2004b).

[3] Canola hectareage consisted of 58% glyphosate-resistant varieties. Data were not available for percentage of total canola hectares planted with glufosinate-resistant varieties.

***Table 6.* Principal crop hectarage in the United States and use of transgenic glyphosate-resistant varieties, 2003 (Anonymous 2004a; Anonymous 2004b).**

| Crop | Area planted (ha x 1000) | Percentage of hectarage planted with glyphosate-resistant varieties. |
|---|---|---|
| Alfalfa | 9,527[a] | n/a[b] |
| Barley | 2,210 | n/a |
| **Canola** | **486** | **58** |
| **Corn (for grain)** | **31,998** | **9** |
| **Cotton** | **5,635** | **32** |
| Dry beans, peas, lentil | 998[c] | n/a |
| Flaxseed | 236 | n/a |
| Hay[d] | 16,527[a] | n/a |
| Mustard (for seed) | 39 | n/a |
| Oat | 1,892 | n/a |
| Peanut | 508 | n/a |
| Potatoes (all types) | 530[c] | n/a |
| Proso millet | 255 | n/a |
| Rapeseed | 0.65 | n/a |
| Rice (all types) | 1211 | n/a |
| Rye | 556 | n/a |
| Safflower | 86 | n/a |
| Sorghum (for grain) | 3835 | n/a |
| **Soybean** | **29,807** | **72** |
| **Sugarbeet** | **551** | **0** |
| Sugarcane | 403[a] | n/a |
| Sunflower | 941 | n/a |
| Sweet potatoes | 38 | n/a |
| Tobacco (all types) | 167[a] | n/a |
| Wheat (all types) | 24,662 | n/a |

[a] Harvested ha in 2003; information on planted ha not available.
[b] Glyphosate-resistant varieties not currently available.
[c] 2002 data; 2003 data currently unavailable.
[d] All hay crops excluding alfalfa and alfalfa mixtures.

The majority of transgenic herbicide-resistant crops grown in the U.S. contains the glyphosate-resistance gene. In 2003, glyphosate-resistant crops were grown on approximately 30.6 million hectares, or 23% of the total hectareage of principal crops listed in Table 6 (Anonymous 2004a). Total U.S. hectareage devoted to production of glyphosate-resistant crops has maintained an upward trend since the trait was first commercialized in soybean in 1996 (Figure 2). The most recent glyphosate-resistant crop registered and adopted by growers was canola (1999). Since 1999, the number of total hectares planted with glyphosate-resistant crops has increased at an average annual rate of 13% per year. If glyphosate-resistant wheat, alfalfa, and other transgenic crops currently under development are approved for commercialization, it is likely that total U.S. cropland devoted to production of transgenic herbicide-resistant crops will continue to increase at a significant rate.

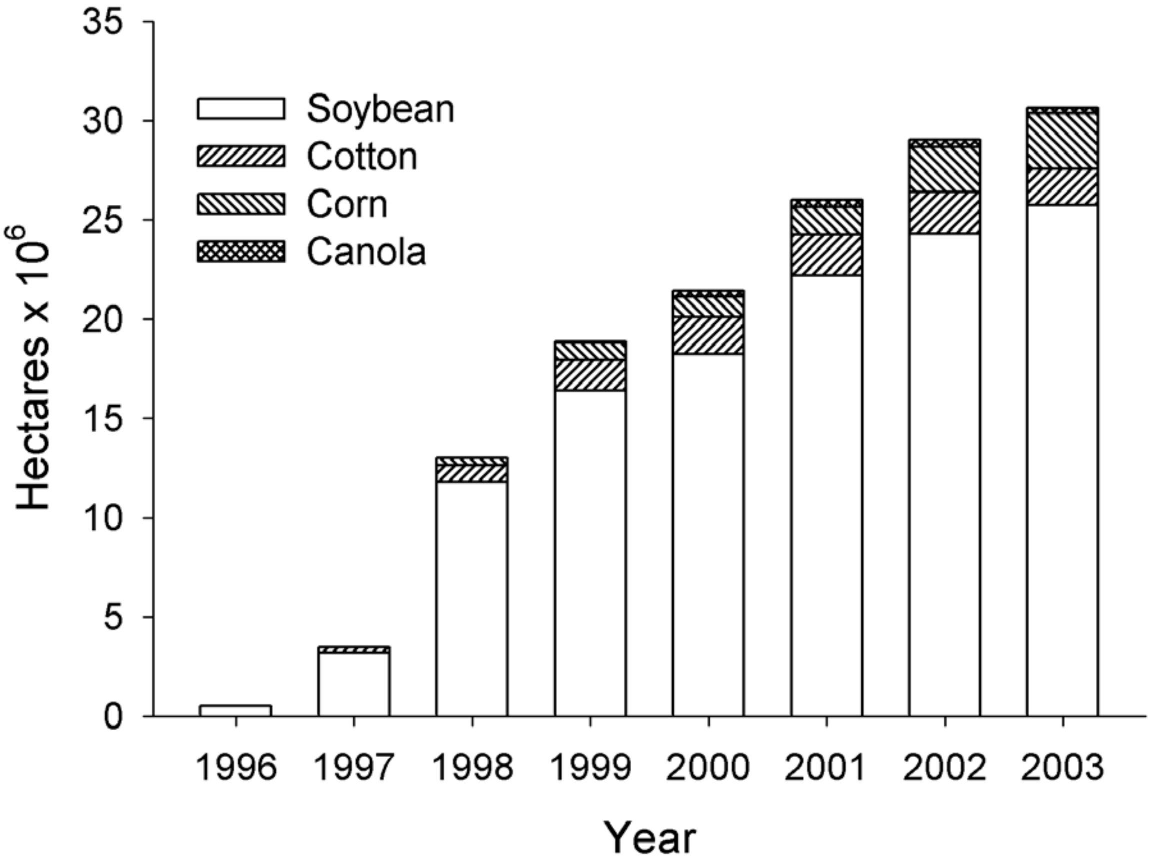


*Figure 2.* United States hectares planted with transgenic glyphosate-resistant crops, 1996-2003 (Anonymous 2004a).

**Herbicide Alternatives to Control Glyphosate- or Glufosinate-Resistant Creeping Bentgrass.** Herbicides and tillage are the principal weed control tools used by U. S. crop producers. The latest estimates published by the U. S. Department of Agriculture indicate that 89% of corn, 99% of soybean, and 86% of wheat hectareage in the U.S. were treated with herbicides (Anonymous 2004c) with 80% of the hectareage being tilled to some extent. A total of 37 herbicides with different active ingredients were used for weed control in corn, 38 in soybean, 16 in winter wheat, and 18 in spring wheat. Herbicides other than glyphosate or glufosinate that are currently registered for control of annual and/or perennial grasses (not all include *Agrostis* spp. on the label) on a variety of crops and situations are atrazine, bromacil, clethodim, dazomet (a fumigant), fluazifop, hexazinone, imazapic, imazapyr, imazaquin, isoxaflutole, mesotrione, nicosulfuron, norflurazon, oryzalin, paraquat, pendimethalin, pronamide, quizalofop, sethoxydim, sulfometuron, sulfosulfuron, terbacil, trifloxysulfuron, and trifluralin. Table 5 summarizes the known activity of some of these herbicides on various *Agrostis* and *Polypogon* species.

Glyphosate could be used to manage glufosinate-creeping bentgrass in any situation where glyphosate is labeled for use. Glufosinate could also be used to manage glyphosate-resistant creeping bentgrass but would not be as efficacious as glyphosate since it has limited translocation (Butler et al. 2002; Vencill 2002). Both herbicides are considered non-selective (except when used in transgenic crops), foliar active with no soil residual activity. Either herbicide used to manage the other resistant type of creeping bentgrass would have to be used in a manner so as to not injure desirable species in the area.

Until recently, there was little information available on the deliberate control of bentgrasses with herbicides although the turfgrass literature has numerous articles describing the incidental injury to various bentgrasses from herbicides used to control weeds in bentgrass turf (Bingham and Schmidt 1983; Fagerness and Penner 1998; Johnson 1990; Johnson 1994; Johnson and Carrow 1989; Mueller-Warrant and Neidlinger 1994; Nus and Sandburg 1991; Park et al. 2002; Shim and Johnson 1992; West and Standell 1989). Few articles exist that describe the control of creeping bentgrass with herbicides, because until quite recently, there were no selective herbicides to manage bentgrasses in other types of turfgrasses and these species were of low concern in other crops. Bhowmik and Drohen (2001) reported that creeping bentgrass could be selective controlled in Kentucky bluegrass turf using isoxaflutole. Recently, the potential commercialization of glyphosate-resistant creeping bentgrass has sparked several studies on its and other *Agrostis* spp. response to various herbicide classes (Askew et al. 2003; Butler et al. 2002; Hart et al. 2002; Hart et al. 2004; Mueller-Warrant 2002; Reicher and Weisenberger 2002; Loux and Harrison 2002). A number of products provided good control of the species evaluated, but in most cases repeated applications were needed.

Of the agronomic crop weed scientists responding to the questionnaire, 82% were not aware of any herbicides or other practices used specifically to control *Agrostis* or *Polypogon* spp. and did not consider these species to be important weeds of agronomic crops. The remainder of respondents had some experience in evaluating herbicide efficacy on *Agrostis* species and reported that various ACCase inhibitors (e.g., fluazifop, clethodim, and quizalofop), atrazine, mesotrione, and isoxaflutole provided fair to excellent control (Table 5). Some indicated that glyphosate was used occasionally as a spot treatment to control *Agrostis* and/or *Polypogon* species in row crops (OR), in pastures/hayfields or turfgrass for renovation purposes (PA, OH, IA, MI, OR), or in non-crop situations for vegetation management (DE). The only publication found to contain management information for weedy *Agrostis spp*. was the Pacific Northwest Weed Management Handbook (William et al. 2003). None of the respondents indicated that naturally occurring glyphosate or glufosinate resistance in *Agrostis* spp. had been observed or reported.

Much of the information on the efficacy of herbicides on *Agrostis* species comes from the 2004 survey of weed scientists, and research conducted by Hart et al. 2004; Mueller-Warrant 2002; Butler et al. 2002 and Reicher and Weisenberger 2002; and Loux and Harrison 2002. Hart et al. (2004) conducted efficacy trials in North Brunswick, NJ and Merion County, OR to evaluate the response of glyphosate-resistant and glyphosate-susceptible creeping bentgrass hybrids, colonial bentgrass, red top bentgrass, and dryland bentgrass grown as individual plants to postemergence (POST) herbicides. Mueller-Warrant (2002) and Butler et al. (2002) conducted similar trials in Oregon. Loux and Harrison (2002) evaluated the control of creeping bentgrass in corn. This work and that of others is reviewed below and listed in Table 5.

**Glyphosate** is a non-selective, foliar active herbicide that has little or no soil activity (Vencill 2002). It can be used to remove unproductive or unwanted grasses that are grown for seed production, followed by tillage to improve control, including weedy bentgrass species. Glyphosate is also used as a spot treatment in many grass seed crops to control volunteer grasses, such as creeping bentgrass. Multiple applications are generally required to control creeping bentgrass (Mueller-Warrant 2002). Glyphosate is used prior to planting of many crops for broad spectrum annual weed control. Glyphosate is also frequently used in perennial crops, such as raspberry, blueberry, apple, and grape, where *Agrostis* spp. are occasionally reported as weeds, as well as in most other fruit and nut crops. In addition to grass seed and perennial crops that use glyphosate for *Agrostis* spp. control, it is the most commonly used “spot treatment" herbicide for creeping bentgrass even though it generally requires two or more applications combined with physical removal to provide effective control (Koski 2002).

The utility of glyphosate may be reduced in any of these systems should glyphosate-resistant creeping bentgrass become present. Glyphosate usually controls about 70 to 90% of creeping bentgrass in single treatments at typical dosages, however, it quickly recovers from such treatment. Most extension recommendations suggest that multiple glyphosate treatments should be used if complete creeping bentgrass control is desired. Even with sequential treatments, complete control is generally not achieved.

**Glufosinate** is a non-selective, foliar active herbicide with no soil activity. It is rarely used to control *Agrostis* spp. because it is less effective on perennial species, as previously stated, and more expensive than other products. In the Pacific Northwest, glufosinate products are applied at low rates in several perennial grasses in early spring to suppress relatively susceptible weeds like roughstalk bluegrass (*Poa trivialis* L.) and annual bluegrass. Glufosinate may suppress bentgrass seed production when applied in early maturing crops like tall fescue and perennial ryegrass by delaying maturity from burning back the most advanced bentgrass tillers. Initial control with glufosinate appears good but the lack of translocation in the plant allows for regrowth to occur (Mueller-Warrant 2002).

**ACCase inhibitors** (fluazifop, quizalofop, sethoxydim, clethodim) are foliar active, translocated herbicides with little soil activity (Vencill 2002). They have selective activity on grass species with little or no activity on broadleaf plants. They generally controlled creeping bentgrass equal to glyphosate, and noticeably better than glufosinate (Butler et al. 2002; Mueller-Warrant 2002; Reicher and Weisenberger 2002 ). In most cases, repeated applications were necessary to achieve higher levels of control. Although fine fescue growers can use sethoxydim or fluazifop to selectively manage *Agrostis* species, complete control is rarely achieved. In efficacy trials, Hart et al. (2004) found that fluazifop, clethodim, or sethoxydim may be viable alternatives to glyphosate for the control of glyphosate-resistant creeping bentgrass and related bentgrass species. Fluazifop at 0.4 kg/ha, clethodim at 0.3 kg/ha or sethoxydim at 0.4 kg/ha using two sequential applications provided the same level of creeping bentgrass control as two sequential applications of glyphosate at 1.7 kg/ha when evaluated eight weeks after treatment. Loux and Harrison (2002) found that clethodim applied postemergence provided 90% control of creeping bentgrass in soybean or non-crop situations. Mueller-Warrant (2002) reported some differences in the response of several *Agrostis* species to these herbicides, with dryland bentgrass and redtop being most difficult to control.

**Dazomet** is a non-selective soil fumigant that is registered for use in home lawns, professional turfgrass, potting soil, and various types of seedbeds nonselective vegetation control (Vencill 2002). Dazomet controls most types of weeds when the area is tarped with plastic following application with somewhat less control when the product is surface applied and watered in. The expense of this treatment is very high and would limit its use.

**Imazapyr** is an ALS inhibiting herbicide with foliar and soil activity that has excellent activity on many grasses (Vencill 2002), has been reported to give excellent control of creeping bentgrass (communication from BASF,) and can provide residual control depending on rate. Imazapyr can be used in riparian or terrestrial areas but there are limitations on reseeding due do its persistence in the soil.

**Mesotrione** and **Isoxaflutole** both have soil and foliar activity on a number of broadleaf and grass weeds and inhibit plastoquinone biosynthesis in plants causing bleaching symptoms on new growth (Vencill 2002). Both are currently registered for use in corn. While not registered for use in turfgrass, they have been shown to selectively control creeping bentgrass in cool-season turfgrasses such as tall fescue, Kentucky bluegrass, fine fescue, and perennial ryegrass (Askew et al. 2003; Bhowmik and Drohen 2001). Two treatments at 0.25 lb ai/A or three treatments at 0.15 lb ai/A at two-week intervals in the fall provided 95% control creeping bentgrass selectively in Kentucky bluegrass or tall fescue. These rates are similar to those used in corn. Mesotrione does not affect seedling establishment of desirable turfgrass and may have uses in other situations.

**Other herbicides: Atrazine** and **sulfosulfuron** provided (>80%) control 8 weeks after treatment (Hart et al. 2004). Atrazine, an inhibitor of photosynthesis, can be used in a number of crops, in established turf and roadside rights-of-ways in several states (Vencill 2002). Sulfosulfuron, and ALS inhibitor herbicide, can be used on roadsides, utility rights-of-way, fallow areas, ditch banks, railroads, and other non-crop areas (Vencill 2002). **Nicosulfuron**, also an ALS inhibitor, applied postemergence in corn gave 85% control of glyphosate-resistant creeping bentgrass (Loux and Harrison 2002). All three of these herbicides have soil residual activity (atrazine > sulfosulfuron > nicosulfuron) with some re-cropping restrictions listed on their labels. Additional herbicides listed in Table 5 are known to have activity on annual and perennial grasses and were reported to have activity on the species indicated by respondents to the questionnaire.

**Weediness Potential of Glyphosate- or Glufosinate-Resistant Creeping Bentgrass.** Gardner et al. (2003) found that several cultivars of glyphosate-resistant creeping bentgrass grew similarly or less aggressively than non-transformed creeping bentgrass when grown in competition with another grass. Loux and Harrison (2002) compared glyphosate-resistant creeping bentgrass with non-transformed creeping bentgrass in corn and soybean. They found no differences in the way the creeping bentgrass types responded to the herbicides applied, other than glyphosate, or in the amount of crop growth interference. Creeping bentgrass was not competitive with either crop. This is important since soybean and corn comprise approximately 93% of the 30 million U.S. hectares planted with glyphosate-resistant varieties in 2003 (Figure 2). Information pertaining to the comparison of glufosinate-resistant creeping bentgrass to non-transformed creeping bentgrass is not available; however, it is assumed that it would behave similarly.

In the survey responses to the question, "In what crop(s) would glyphosate- or glufosinate-resistant creeping bentgrass or other *Agrostis* species or hybrids be a potential problem and why?", 32% indicated that these species would not pose a problem as weeds of any crop. Two respondents indicated that glyphosate-resistant *Agrostis* spp. had some potential to become a weed of glyphosate-resistant soybean due to large-scale adoption of this crop, but both indicated that these weeds could be controlled with other herbicides that are currently available. Four respondents felt that glyphosate-resistant *Agrostis* spp. could become weedy in glyphosate-resistant corn, but suggested that the potential seriousness of the problem was low at present due to the fact that alternative control measures are available and *Agrostis* spp. would be at a strong competitive disadvantage in corn. Others indicated the possibility that *Agrostis* spp. or hybrids could become a problem in future glyphosate-resistant crops, including wheat (5 responses), alfalfa (4 responses), sugarbeet (2 responses), and potato (2 responses), and tree or vine fruit crops (1 response). Grain sorghum and pastures/hayfields were the other agronomic crops listed as potential problem areas. Weed scientists from the Pacific Northwest expressed concern that glyphosate-resistant *Agrostis* spp. would pose a serious weed problem in and around grass seed production fields, although this was not unanimous.

Almost 60% of the weed scientists surveyed did not anticipate any impact on current management practices from the release of glyphosate- or glufosinate-resistant creeping bentgrass. The possible need for alternative herbicide inputs was anticipated by 40% of respondents. One respondent was concerned that herbicide-resistant *Agrostis* spp. would increase the necessity for spring tillage or fall herbicide applications, and another indicated that exacerbation of herbicide resistance would likely occur only if cropland devoted to glyphosate-resistant crop production continued to increase.

One-half of the responding weed scientists felt there was low or no likelihood that transgenic herbicide-resistant creeping bentgrass would exacerbate known or possible herbicide resistance problems in their area. Thirty-six percent felt that development of glyphosate-resistant weed species could increase, and the remainder (14%) stated they were unsure about possible effects. Two respondents expressed strong concern over the development of glyphosate-resistant annual bluegrass populations in response to repeated glyphosate applications made to glyphosate-resistant creeping bentgrass.

For agronomic crops, 90% of the weed scientists ranked the potential as "low," 7% ranked the potential as "moderate", and 3% ranked it as high for the potential of glyphosate- or glufosinate-resistant creeping bentgrass to directly or indirectly increase weed problems. Most stated that no *Agrostis* spp. currently occur as weeds in their area, that alternative herbicides or cultivation are available for transgenic bentgrass control, and/or that crop rotation would likely prevent establishment. Other individuals commented that any potential weed problems would most likely occur in no-tillage systems or in irrigated land, or if adoption of new glyphosate-resistant crops continues to increase. Five respondents felt that glufosinate-resistant bentgrass is less likely to cause problems in crops than glyphosate-resistant bentgrass because glufosinate is used on fewer hectares and is less efficacious than glyphosate. Most weed scientists in the Pacific Northwest felt that the introduction of glyphosate-resistant creeping bentgrass, but not glufosinate-resistant creeping bentgrass, would increase weed problems in the seed production areas.

Reviews of issues pertaining to transgenic herbicide-resistant turfgrasses have concluded that there is low likelihood of transgenic herbicide-resistant creeping bentgrass becoming or creating weed problems in crop fields (Lee et al. 1996; Johnson and Riordan 1999). Reasons cited for this low likelihood are: creeping bentgrass is a prostrate, slow-growing species (when not being managed in a monoculture) and lacks the aggressive and competitive features of other weedy grasses of crops; its interspecific hybrids will be sterile or of low fertility; tillage, crop rotation, and/or use of multiple herbicides with different modes of action may prevent it from becoming established and competing in a field crop environment; and the herbicide resistance trait does not appear to confer a competitive advantage unless the herbicide is applied. In contrast, taxonomists and ecologists have described creeping bentgrass as a fast-growing perennial species, which is biologically and ecologically variable, adaptable and robust, with vegetative spread and wind-pollinated flowers producing tiny seed that can be spread by wind, water or animals (Bradshaw and Hardwick 1989; Eriksson 1989; Grime and Hunt 1975; Grime et al. 1988; Kik 1989; Kik et al. 1990a; Kik et al.1990b; Marrs and Proctor 1976; Misra and Tyler 2000a; Romero Garcia et al. 1988b; Sell and Murell 1996; Shipley et al. 1989; Smith and Bradshaw 1979; Teyssonneyre et al. 2002). However, *Agrostis* spp. have not been listed as important weeds in the U. S. (Holm et al. 1991; Holm et al. 1997), therefore, it appears that glyphosate- or glufosinate resistant creeping bentgrass do not have the potential to become important weeds except for some exceptions noted above.

**Gene Flow of Glyphosate- or Glufosinate-Resistance.** A recent report published by the National Academy of Sciences (2004) stated that transgenic turfgrasses, particularly *Agrostis* spp., can be considered potentially difficult to confine due to their open pollination, cross-compatibility with other species, potential for long distance pollen dispersal (>1000 m), and vegetative propagules that can be dispersed by machinery, animals, or other means. It has been demonstrated that gene flow via pollen dispersal from transgenic glufosinate-resistant creeping bentgrass to surrounding non-transgenic *Agrostis* species can occur under field conditions (Belanger et al. 2003a; Wipff and Fricker 2001), but some of the same participating authors (Meagher et al. 2003) also state that the trait is unlikely to persist in wild *Agrostis* populations in the absence of selection pressure from herbicide applications. However, Ellstrand (2003) summarizes that persistence of the trait is likely unless there is selection against the trait or chance loss of the gene.

Nonetheless, gene flow and introgression among *Agrostis* species remains a concern since there are over 34 known *Agrostis* species in the U.S. and there is high genetic diversity within species (Vergara and Bughrara 2003). In addition, creeping bentgrass survival, growth, and flowering may be influenced to a greater extent by environmental conditions than genetics of the population (Kik et al. 1990a). Weedy species that are genetically diverse and cross-pollinated may be capable of rapid evolution of herbicide-resistant biotypes when placed under high selection pressure (Tranel and Wright 2002). Consequently, it is possible that aggressive management of transgenic glyphosate- or glufosinate-resistant *Agrostis* spp. in crops using alternative herbicides could lead to development of populations with additional herbicide resistance traits.

**Longevity of *Agrostis* Seed in Soil**. If herbicide-resistant creeping bentgrass escapes from golf courses or seed production fields, the viability and dormancy of the seed produced in the wild will affect the probability of the trait survival. The germination rate of commercial bentgrass seed is very high, with little viable seed remaining one year after planting. Hancock and Mallory-Smith (2004) demonstrated that the germination and dormancy characteristics of glyphosate-resistant creeping bentgrass and non-transformed creeping bentgrass were the same. However, feral bentgrasses could be expected to have a significant dormancy mechanism. If herbicide-resistant creeping bentgrass crossed with feral bentgrasses there may be potential to produce seed with a considerable dormancy period.

Hill and Stevens (1981) examined the seed bank of several forests that had dense canopies where no vegetation grew under the canopy. The authors found colonial and velvet bentgrass had survived relatively long periods in the soil. Little viable *Agrostis* seed was found from the oldest site (45 years) tested; but both species showed good viability from a site that had been forested for 25 years. Thompson and Grime (1979) classified colonial bentgrass and velvet bentgrass as having a Type IV seed bank – large and persistent; and Hill and Stevens (1981) data corroborate that classification. Rampton and Ching (1970) found that up to 1.8 % of buried colonial bentgrass seed germinated after 7 years, with 11.7 % still viable but dormant. However, if given ideal conditions, 94 % of the seed will germinate in the first year.

Jutila (1998) recently studied the seed bank of grazed and non-grazed seashores in Finland and found creeping bentgrass in abundance. It was the fourth most commonly found species in the study and was classified with the other *Agrostis* species as having a large and persistent seed bank. Colonial bentgrass was also found frequently in Jutila's study.

Thus, it is clear that creeping bentgrass and related species, colonial bentgrass and velvet bentgrass can persist for long periods in soil. Herbicide-resistant creeping bentgrass is most likely to spread outside of golf courses by vegetative means; however, seed produced by pollen flow from these plants could also persist in the soil for many years.

## SUMMARY

The authors of this report have reviewed the existing literature and surveyed knowledgeable scientists across the U.S. regarding the probable weed management impact resulting from the release of glyphosate- or glufosinate-resistant creeping bentgrass on golf courses.

Creeping bentgrass, other *Agrostis* spp., and *Polypogon* spp. are relatively non-aggressive weeds where they occur. Absent the selection pressure (removal of the susceptible types plus other susceptible species through use of glyphosate or glufosinate), glyphosate- or glufosinate-resistant types of these species do not pose any more of a problem in most cropped or natural systems than susceptible biotypes. Due to the current minimal use of glufosinate in the U.S., there is no evidence that the introduction of glufosinate-resistant creeping bentgrass would pose any additional weed management problems compared to non-transformed creeping bentgrass. The primary situations where glyphosate-resistant creeping bentgrass could be a greater problem than non-transformed creeping bentgrass are:

1. Stand removal of conventional bentgrass crops (sod or seed) where glyphosate and tillage are currently utilized. With glyphosate-resistant creeping bentgrass, the grower no longer would have the option of using glyphosate. Herbicides such as the ACCase inhibitors could be used, if given label approval, along with tillage.

2. Control of glyphosate-resistant creeping bentgrass with spot spraying of glyphosate in grass seed crops. Alternative herbicides exist that are effective but none are currently registered for this use and those with soil activity could complicate reseeding.

3. Glyphosate-resistant creeping bentgrass or its hybrids could become a problem weed in the Pacific Northwest where glyphosate is commonly used for weed management in perennial tree or vine fruit crops. If glyphosate-resistant bentgrasses become a problem in these situations, grower education programs would be needed. Alternative herbicides exist that have activity on these species and are registered for use.

4. As additional glyphosate-resistant crops, such as alfalfa, sugarbeet, potato, and wheat are introduced in the northwestern U.S. and some western, high altitude areas of the U.S., there is potential for glyphosate-resistant creeping bentgrass or its hybrids to become weedy given a continuous glyphosate selection pressure and an environment for which these species are best adapted. Alternative products, such as ACCase inhibitors and soil applied herbicides that are effective on annual and perennial grasses could be used to manage these species.

5. The hybridization between glyphosate- or glufosinate-resistant creeping bentgrass and the weedier rabbitfoot polypogon may create a more serious weed than glyphosate- or glufosinate-resistant creeping bentgrass, although, the vigor of this hybrid is not known. Hybridization with other more drought tolerant bentgrass species (such as redtop, dryland bentgrass, spike bentgrass, or rough bentgrass), could be more of a problem than glyphosate-resistant creeping bentgrass. It is unknown how long it would take for the development of these hybrids in the field. Further, for the trait to be important, the hybrids would need to be treated with glyphosate or glufosinate. It is not known if these hybrids will persist in the absence of glyphosate- or glufosinate-selection pressure, although it is assumed they will. In most cropping situations and natural areas, alternative herbicides to glyphosate and glufosinate exist that can effectively manage these hybrids, although in some specific situations additional registrations or emergency use permits may be necessary.

6. It is probable that the repeated use of glyphosate on glyphosate-resistant creeping bentgrass will eventually select for resistance in the target weeds. The current cases of glyphosate-resistant grasses have all developed in orchard or vine crops where glyphosate was used repeatedly for many years. The use on golf courses would likely follow a similar pattern.

The probability that deregulation and release of transgenic glyphosate- or glufosinate-resistant creeping bentgrass varieties will cause significant new weed problems in the principal U.S. crops or non-crop areas appears to be low. The strongest evidence supporting this conclusion are as follows:

1. *Agrostis* spp. or *Agrostis*-compatible *Polypogon* spp. have no history as important weeds of the principal U.S. crops, excluding turf and grass seed crops, indicating an inherent lack of weedy traits necessary for their adaptation and survival in crop culture.
2. There is little evidence of active management of these species as weeds in non-crop situations.
3. Alternative control methods to glyphosate or glufosinate (e.g., alternative herbicides, tillage, and crop rotation) are available for control of transgenic herbicide-resistant creeping bentgrass in transgenic and non-transgenic crops that are currently grown and in non-crop areas. However, it may be necessary to obtain emergency use permits for some products.

The off-site movement of glyphosate- or glufosinate-resistant creeping bentgrass or hybrids is anticipated to occur at some time if deregulated. The areas at greatest risk for infestation by transgenic creeping bentgrass, or its hybrids, are where the *Agrostis* species are currently well-adapted and areas of the Pacific Northwest that are close to grass seed production fields. This assessment could change, if the herbicide resistant trait is incorporated into future selections of creeping bentgrass that are adapted to environmental conditions dramatically different than those for the current types.


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# APPENDICES

## *Appendix 1*. Common and Scientific Names of Crops

| **Common Name** | **Scientific Name** |
|---|---|
| Alfalfa | *Medicago sativa* L. |
| Apple | *Malus pumila* Mill. |
| Asparagus | *Asparagus officinalis* L. |
| Blueberry | *Vaccinium spp*. |
| Canola | *Brassica napus* L. |
| Corn | *Zea mays* L. |
| Cotton | *Gossypium hirsutum* L. |
| Fir | *Abies spp*. |
| Grain sorghum | *Sorghum bicolor* (L.) Moench |
| Grape | *Vitis spp*. |
| Kentucky bluegrass | *Poa pratensis* L. |
| Kiwi fruit | *Actinidia deliciosa* (A. Chev.) C.F. Liang & A.R. Ferg. |
| **Oat** | *Avena sativa* L. |
| Olive | *Olea spp*. |
| Orchardgrass | *Dactylis glomerata* L. |
| Pear | *Pyrus communis* L. |
| Peppers | *Capsicum spp*. |
| Perennial ryegrass | *Lolium perenne* L. |
| Pine | *Pinus spp*. |
| Potato | *Solanum tuberosum* L. |
| Raspberry | *Rubus spp*. |
| Soybean | *Glycine max* (L.) Merrill |
| Sugarbeet | *Beta vulgaris* L. |
| Tall fescue | *Festuca arundinacea* Schreb. |
| Walnut | *Juglans spp*. |
| Wheat | *Triticum aestivum* L. |

*Appendix 2*. **Common and chemical names for herbicides mentioned in the manuscript.**

| Common Name | Chemical Name |
|---|---|
| Atrazine | 6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine |
| Bromacil | 5-bromo-6-methyl-3-(1-methylpropyl)-2,4(1*H*,3*H*) pyrimidinedione |
| Clethodim | (*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one |
| Dazomet | Tetrahydro-3,5-dimethyl-2*H*-1,3,5-thiadiazine-2-thione |
| Dimethenamid | 2-chloro-N-[(1-methyl-2methoxy)ethyl]-N-(2,4-dimethyl-thien-3-yl)-acetamide |
| Diuron | *N*'-(3,4-dichlorophenyl)-*N*,*N*-dimethylurea |
| EPTC | *S*-ethyl dipropyl carbamothioate |
| Ethofumesate | (±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate |
| Fluazifop | (±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy] propanioc acid |
| Flufenacet | N-(4-fluorophenyl)-N-(1-methylethyl)-2-[[5-(trifluoromethyl)-1,3,4-thiadiazol-2-yl]oxy]acetamide |
| Foramsulfuron | 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]-4-(formylamino)-*N*,*N*-dimethylbenzamide |
| Glufosinate | 2-amino-4-(hydroxymethylphosphinyl)butanoic acid |
| Glyphosate | *N*-(phosphonomethyl)glycine |
| Hexazinone | 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione |
| Imazapic | (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid |
| Imazapyr | (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid |
| Imazaquin | 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid |
| Isoxaflutole | (5-cyclopropyl-4-isoxazolyl)[2-(methylsulfonyl)-4-(trifluoromethyl)-phenyl]methanone |
| Mesotrione | 2-(4-mesyl-2-nitrobenzoyl)-3-hydroxycylohex-2-enone |
| Metolachlor | 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide |
| Metribuzin | 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one |
| Napropamide | *N*,*N*-diethyl-2-(1-naphthalenyloxy)propanamide |
| Nicosulfuron | 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]-*N*,*N*-dimethyl-3-pyridinecarboxamide |

*Appendix 2*. **Common and chemical names for herbicides mentioned in the manuscript (Continued).**

| **Common Name** | **Chemical Name** |
|---|---|
| Norflurazon | 4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(2*H*)-pyridazinone |
| Oryzalin | 4-(dipropylamino)-3,5-dinitrobenzenesulfonamide |
| Oxyfluorfen | 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene |
| Paraquat | 1,1'-dimethyl-4,4'-bipyridinium ion |
| Pendimethalin | *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine |
| Pronamide | 3,5-dichloro (*N*-1,1-dimethyl-2-propynyl)benzamide |
| Quizalofop | (±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid |
| Sethoxydim | 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one |
| Sulfometuron | 2-[[[[4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]benzoic acid |
| Sulfosulfuron | *N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-2-(ethylsulfonyl)imidazo[1,3-*a*]pyridine-3-sulfonamide |
| Terbacil | 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4-(1*H*,3*H*)-pyrimidinedione |
| Triclopyr | [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid |
| Trifloxysulfuron | *N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-3-(2,2,2-trifluoroethoxy)-2-pyridinesulfonamide |
| Trifluralin | 2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine |

*Appendix 3*. **Details on Some *Agrostis* and *Polypogon* in Temperate North America.**

| ***Agrostis* Species** (some synonyms), [and subg. *Agrostis* section, or other subgenus]; **also Bigeneric Hybrids** | **USA; & Nativity (Native Range)** | **Species, Bigeneric Hybrids: Ploidy and Genomic Details** (bolded main cytotype) | **Natural Hybrids: Parents of Crosses** | **Natural or Spontaneous Hybrids: Country of Occurrence Reported** ("spontaneous" hybrids are from naturalized parents) | **Experimental Hybrids: Cross in Greenhouse, or by Spontaneous Pollen Flow in Field Test** (analysis **K**aryological, **T**ransgenic, or **O**ther) | **Hybrids: Ploidy and Genome, Information About Sexual Reproduction; Comments** (not indicating direction of cross, *i.e.* which species was female parent, which male) |
|---|---|---|---|---|---|---|
| 30. ***A. stolonifera*** (*A. alba* of some authors, but not Linnaeus; *A. alba* var. *palustris*, *A. stolonifera* var. *palustris*, *A. palustris*; *A. stolonifera* var. *compacta*; *A. stolonifera* var. *maritima*) [Sect. *Vilfa*]; **Creeping Bentgrass** | Naturalized only, or perhaps native at some northern salt marshes and lakesides (but not native in New England). Native Iceland, Eurasia and North Africa. | **2n = 4x = 28**, $A_2A_2A_3A_3$ (strict allotetraploid – Jones 1956b, 1956c; Warnke *et al.* 1998); also, at least in Europe (Harvey 1999), 2n = 5x = 35, $A_2A_2A_3A_3A_3$ or $A_2A_2A_2A_3A_3$ and 2n = 6x = 42, $A_2A_2A_2A_3A_3A_3$ Also aneuploidy (frequent), *B-chromosomes, aneusomaty (Björkman 1954, Kik* et al. *1993, Frey 1997).* | *30 × 5;* *30 × 6 (***A. × murbeckii***);* 30 × 7; 30 × 12 (apparently); 30 × 13; 30 × 21; 30 × 32; 30 × 34; 30 × 1P (intergeneric); 30 × 2P (intergeneric); 30 × 3P (intergeneric). | See under the other parental species. Some hybrids are sterile but vegetatively vigorous by stolons or rhizomes (or both). | 30 × 5 (T + O); 30 × 6 (T + K); 30 × 7 (T); 30 × 13 (T + K); 30 × 20 (T); 30 × 23 failed (T); 30 × 25 (T); 30 × 29 (T); 30 × *A.* sp. (T); 30 × 32 (T + O); 30 × 34 (K); 30 × 1P (T + O); 30 × 2P (T + O); 30 × 3P (T + O). | See *Agrostis stolonifera* hybrids under the other parental species (listed alphabetically).<br><br>Reproduction of *Agrostis stolonifera* often mainly vegetative, by stolons (*e.g.* Kik *et al*. 1990b, 1992). Sexual reproduction predominately outcrossing (Davies 1953; Belanger *et al.* 2003b), with some cultivars perhaps obligately so (Warnke *et al.* 1998; *cf.* Belanger *et al*. 2003b). Also highly self-fertile clone, and selfing has been utilized (Warnke *et al*. 1998; Tomić *et al.* 1999). |
| 5. ***A. canina*** (*A. canina* var. *fascicularis*; *A. pallida* With., but not DC.) [Sect. *Agrostis*]; **Velvet Bentgrass** | Naturalized. Native Europe into E Asia. | **2n = 2x = 14**, $A_1A_1$ Also aneuploidy, possibly polyploidy (4x, 5x, 6x, 8x); and B-chromosomes (Romero García & Blanca 1988, Frey 1997). | 30 × 5; 5 × 6 & 5 × 13 (both unconfirmed, or error – Widén 1971). | **30 × 5:** Fennoscandia, rare (Widén 1971). | 30 × 5: Greenhouse (Belanger *et al.* 2003b; had failed: Davies 1953, Björkman 1954); and transgenic field tests; 5 × 21 (Björkman 1954); 5 × 34 (Davies 1953, Björkman 1954). | **30 × 5** (would be 2n = 21 *per* Widén 1971)**:** Confirmation needed – Bradshaw 1975a; transgenic tests: field – Wipff & Fricker 2001, Christoffer 2003, greenhouse – Belanger *et al.* 2003b.<br>**5 × 21:** Certainly sterile (Widén 1971).<br>**5 × 34** (2n = 21)**:** Quite sterile (Widén 1971). |

*Appendix 3.* (cont.) **Details on Some *Agrostis* and *Polypogon* in Temperate North America.**

| ***Agrostis* Species]; also** Bigeneric Hybrids | USA; & Nativity (Native Range) | **Species, Bigeneric Hybrids: Ploidy and Genomic Details** | **Natural Hybrids: Parents of Crosses** | **Natural or Spontaneous Hybrids: Country of Occurrence Reported** (“spontaneous” hybrids are from naturalized parents) | **Experimental Hybrids: Cross in Greenhouse, or by Spontaneous Pollen Flow in Field Test** | Hybrids: Ploidy and Genome, Information About Sexual Reproduction; Comments **(not indicating direction of cross, *i.e.* which species was female parent, which male)** |
|---|---|---|---|---|---|---|
| 6. ***A. capillaris*** (*A. tenuis*; *A. vulgaris*) [Sect. *Vilfa*]; **Colonial Bentgrass (Rhode Island Bentgrass, Browntop)** | Naturalized. Native Eurosiberia. | **2n = 4x = 28**, $A_1A_1A_2A_2$ (segmental allotetraploid, partly from a 2x *A. canina*-like ancestor – Jones 1956b, 1956c, *cf.* Romero García *et al.* 1988b).<br><br>Occasional aneuploidy, *B-chromosomes*<br><br>*(Frey 1997).* | 30 × 6 (***A.* × *murbeckii***); 30 or 13 × 6 (*A.s. s.l.*); 5 × 6 (unconfirmed, or error – Widén 1971); 6 × 7 (***A.* × *fouilladei***); 6 × 13 (***A.* × *bjoerkmanii***); 6 × 14 (probable); 6 × 34 (***A.* × *sanionis***). | **30 × 6:** *e.g.* Fennoscandia (Widén 1971); Germany (Weber 1920); U.K. (Bradshaw 1958, 1975a, *cf.* Smith 1972, Sell & Murrell 1996); Belgium (Meerts & Lefèbvre 1989); France (Fouillade 1932); Spain (Romero García *et al.* 1988b); **Canada** (Malte 1928, Hinds 1986); **USA: NW?, UT?** (Carlbom 1967, Welsh *et al.* 1993); New Zealand (Edgar & Forde 1991, Edgar & Connor 2000).<br>**6 × 7:** U.K. (Sell & Murrell 1996); France (Fouillade 1932); Spain (Romero García *et al.* 1988b); Australia (Batson 1998a); New Zealand (Edgar & Forde 1991, Edgar & Connor 2000).<br>**6 × 13:** U.K. (Sell & Murrell 1996); **USA: NE** likely (Stuckey & Banfield 1946, *per* Björkman 1954, Widén 1971, Bradshaw 1975a, Edgar & Forde 1991), **UT?** (Welsh *et al.* 1993).<br>**6 × 14: NW USA?** (Pendergrass 2001).<br>**6 × 34:** U.K., Europe, Russia (Widén 1971, Bradshaw 1975a, Sell & Murrell 1996). | 30 × 6; 6 × 7 (Edgar & Forde 1991, Rumball & Forde 1977 *per* Batson 1998a); 6 × 13; 6 × 34 (Davies 1953, but probably most were not hybrids *per* Widén 1971). | **30 × 6** (2n = 28, $A_1A_2A_2A_3$)**:** Parents readily crossing, with $F_1$ vegetatively vigorous and widespread, but with high sterility (Bradshaw 1975a, Sell & Murrell 1996); almost wholly abortive pollen, exceptionally a few seeds observed (Widén 1971); semi-fertile in New Zealand, with pollen fertility 41% (Edgar & Forde 1991); suspected U.S. hybrids in OR (Carlbom 1967, p. 39), perhaps UT (Welsh *et al.* 1993 treat *A.s. sensu lato*). Transgenic tests: field – Wipff & Fricker 2001, field and greenhouse – Belanger *et al.* 2003a, 2003b.<br>**6 × 7** (some 2n = 35)**:** Partially fertile (Sell & Murrell 1996). Backcrossing into #6 in New Zealand (Edgar & Forde 1991, Edgar & Connor 2000).<br>**6 × 13** (2n = 35, $A_1A_1A_2A_2A_3$)**:** Crossing rather readily, including backcrosses and $F_2$. $F_1$ vegetatively vigorous, but “infertile” (pollen fertility 45%, seeds 50%). $F_2$ and backcrosses aneuploid, low vigor (Bradshaw 1975a). Highly sterile (Sell & Murrell 1996). Perhaps UT (Welsh *et al.* 1993 treat *A.s. sensu lato*).<br>**6 × 14:** Probable in OR (K.L. Pendergrass [U.S. FWS], *via* M. Jordan [TNC] 2001 letter to J.L. White [APHIS]).<br>**6 × 34** (2n = 28)**:** Unclear facility of crossing in nature and experimentally (readily crossing *per* Harvey 1999); most experimental “hybrids” (Davies 1953, Jones 1956b) likely instead selfs of #34 or #6 (Widén 1971, Bradshaw 1975a). Probably natural hybrids sterile (Widén 1971, Sell & Murrell 1996). |
| 7. ***A. castellana*** [Sect. *Vilfa*]; **Dryland Bentgrass (including Highland Bentgrass)** | Introduced. Native Western Mediterranean. | **2n = 4x = 28**, $A_1A_1A_2A_2$ and 2n = 6x = 42, $A_1A_1A_1A_2A_2A_2$<br><br>In Portugal also aneuploidy, B-chromosomes (Frey 1997). | 30 × 7; 6 × 7 (***A.* × *fouilladei***). | **Both:** France (Fouillade 1932); **6 × 7:** U.K. (Sell & Murrell 1996); France (Fouillade 1932); Spain (Romero García *et al.* 1988b); Australia (Batson 1998a); New Zealand (Edgar & Forde 1991, Edgar & Connor 2000). | 30 × 7 (varied results in transgenic field tests); 6 × 7 (Edgar & Forde 1991, Rumball & Forde 1977 *per* Batson 1998a). | **30 × 7:** Pollen very irregular (Romero García *et al.* 1988b). Transgenic tests: greenhouse and field – Belanger *et al.* 2003a, 2003b, field – Wipff & Fricker 2001, but not Christoffer 2003.<br>**6 × 7** (some 2n = 35)**:** Partially fertile (Sell & Murrell 1996). Backcrossing into #6 in New Zealand (Edgar & Forde 1991, Edgar & Connor 2000). |
| 10. ***A. densiflora***; **Dense-flowered Bentgrass** | **Native** California to Oregon. | **2n = 6x = 42** (Harvey 1993). | 10 × 12 (perhaps). | | 10 × 12 (perhaps, as $F_1$ seeds not grown out). | Good seed set in experimental cross, but the seeds not grown out to confirm, and #10 can self-pollinate (Carlbom 1967, p. 88). |
| 12. ***A. exarata***; **Spike Redtop, Spike Bentgrass** | **Native** Far E Siberia and W North America: Alaska–Mexico. | **2n** = 4x = 28, **6x = 42**, and 8x = 56 (Harvey 1999, Frey 1997, Taylor & Mulligan 1968). | 30 × 12 (apparently); 30 or 13 × 12; 10 × 12 (perhaps); 12 × 29 | **30 × 12: NW USA?** (Carlbom 1967).<br>**30 or 13 × 12: USA: UT?** (Welsh *et al.* 1993).<br>**12 × 29: USA: UT?** (Welsh *et al.* 1993). | 10 × 12 (perhaps, as $F_1$ seeds not grown out). | **30 × 12:** Suspected in WA and OR, sterile (Carlbom 1967, pp. 109-110, 112).<br>**30 or 13 × 12:** Apparently; Welsh *et al.* 1993 treat *A. stolonifera sensu lato* (as #13 + #30).<br>**10 × 12:** Good seed set in experimental cross, but the seeds not grown out to confirm, and #10 can self-pollinate (Carlbom 1967, p. 88).<br>**12 × 29:** Apparently; Welsh *et al.* 1993. |

*Appendix 3*. (cont.) **Details on Some *Agrostis* and *Polypogon* in Temperate North America.**

| ***Agrostis* Species]; also** Bigeneric Hybrids | USA; & Nativity (Native Range) | **Species, Bigeneric Hybrids: Ploidy and Genomic Details** | **Natural Hybrids: Parents of Crosses** | **Natural or Spontaneous Hybrids: Country of Occurrence Reported** ("spontaneous" hybrids are from naturalized parents) | **Experimental Hybrids: Cross in Greenhouse, or by Spontaneous Pollen Flow in Field Test** | Hybrids: Ploidy and Genome, Information About Sexual Reproduction; Comments **(not indicating direction of cross, *i.e.* which species was female parent, which male)** |
|---|---|---|---|---|---|---|
| 13. ***A. gigantea*** (*A. stolonifera* var. *major*; *A. stolonifera* var. *gigantea*, *A. alba* var. *gigantea*; just *A. stolonifera* or *A. alba* for some authors; *A. nigra*) [Sect. *Vilfa*]; **Redtop (Black Bentgrass)** | Naturalized. Native Eurasia (especially Central Asia). | **2n = 6x = 42**, $A_1A_1A_2A_2A_3A_3$ (Jones 1956c; ancestry perhaps by fusion of $A_1A_2A_3$ gametes of an *A.* × *murbeckii* – Widén 1971). Also B-chromosomes (Frey 1997). | 30 × 13; 5 × 13 (unconfirmed, or error – Widén 1971); 6 × 13 (***A.* × *bjoerkmanii***); 6 × 13 or 30 (*A.s. s.l.*); 12 × 13 or 30 (*A.s. s.l.*); 13 × 21 | **30 × 13, 6 × 13, & 13 × 21:** Fennoscandia (Widén 1971). **30 × 13:** Sweden (Blom 1961 *per* Widén 1971); U.K. (Davies 1953, Bradshaw 1975a, Sell & Murrell 1996). **6 × 13:** U.K. (Sell & Murrell 1996); **USA: NE** likely (Stuckey & Banfield 1946, *per* Björkman 1954, Widén 1971, Bradshaw 1975a, Edgar & Forde 1991), **UT?** (Welsh *et al*. 1993). **12 × 13 or 30: USA: UT?** (Welsh *et al*. 1993). | 30 × 13; 6 × 13 | **30 × 13** (2n = 35, $A_1A_2A_2A_3A_3$)**:** Experimental $F_1$ cross easy; vegetatively vigorous, but only 25% pollen and seed fertilities (Bradshaw 1975a), or highly or usually sterile (Sell & Murrell 1996, Dore & McNeill 1980, Widén 1971); transgenic tests: field – Wipff & Fricker 2001, greenhouse – Belanger *et al*. 2003b. **6 × 13** (2n = 35, $A_1A_1A_2A_2A_3$)**:** Crossing rather readily, including backcrosses and $F_2$. $F_1$ vigorous vegetatively, but "infertile" (pollen fertility 45%, seeds 50%). $F_2$ and backcrosses aneuploid, low vigor (Bradshaw 1975a). Highly sterile (Sell & Murrell 1996). Perhaps UT (Welsh *et al*. 1993 treat *A.s. sensu lato*). **12 × 13 or 30:** Apparently; Welsh *et al*. 1993 treat *A. stolonifera sensu lato* (as #13 + #30). **13 × 21** (2n = 49)**:** Probably not easily formed in nature; rare, no pollen or seeds (Widén 1971). |
| 14. ***A. hallii***; **A. Hall's Bentgrass** | **Native** California and Oregon, and also Washington? | **2n = 6x = 42** (Harvey 1993). | 6 × 14 (probable); 14 × 25 (apparently). | **6 × 14: NW USA?** (Pendergrass 2001). **14 × 25: NW USA?** (Carlbom 1967). | | **6 × 14:** Probable in OR (K.L. Pendergrass [U.S. FWS], *via* M. Jordan [TNC] 2001 letter to J.L. White [APHIS]). **14 × 25:** Probable (and fertile) in OR (Carlbom 1967, pp. 98, 126). |
| 20. ***A. idahoensis***; **Idaho Bentgrass, Idaho Redtop** | **Native** Western North America — Alaska to California and New Mexico. | **2n = 4x = 28** | | | 30 × 20 (transgenic test – Christoffer 2003). | **30 × 20:** Transgenic test: field – Christoffer 2003. (Perhaps "*A. idahoensis*" is not a sp. but varied hybrids, from #12 crossing with #29 and/or each crossing with #33, *per* Welsh *et al*. 1993, but *cf*. Harvey 1993, 1999, 2001.) |
| 21. ***A. mertensii*** (*A. borealis*) [Sect. *Agrostis*]; **Northern or Arctic Bentgrass** | **Native**, somewhat circumpolar, plus mountains. | **2n** = 2x = 14, 3x = 21, 6x = 42 (but 6x is *A. scabra per* Harvey 1999), 7x = 49, and **8x = 56**; also aneuploidy (Frey 1997). | 30 × 21; 13 × 21; 21 × 34 | **All three:** Fennoscandia (Widén 1971). | 5 × 21 (Björkman 1954); 21 × 34 (Björkman 1954). | **30 × 21** (2n = 42) (Björkman 1954, Widén 1971). **5 × 21:** Certainly sterile (Widén 1971). **13 × 21** (2n = 49)**:** Probably not easily formed in nature; rare, no pollen or seeds (Widén 1971). **21 × 34** (2n = 42) (Widén 1971). |
| 23. ***A. nebulosa*** [Subg. *Zingrostis*]; **Cloudgrass** | Cultivated; occasional escape, in Ohio established (Harvey 1999). Native Iberian Peninsula. | **2n = 2x = 14** (Tinney 1936, Romero García & Blanca 1988, Frey 1997). | | | 30 × 23 (no transgenic flow found in field test – Christoffer 2003). | No transgenic flow found (Christoffer 2003). |

*Appendix 3.* (cont.) **Details on Some *Agrostis* and *Polypogon* in Temperate North America.**

| ***Agrostis* Species**]; **also** Bigeneric Hybrids | USA; & Nativity (Native Range) | **Species, Bigeneric Hybrids: Ploidy and Genomic Details** | **Natural Hybrids: Parents of Crosses** | **Natural or Spontaneous Hybrids: Country of Occurrence Reported** (“spontaneous” hybrids are from naturalized parents) | **Experimental Hybrids: Cross in Greenhouse, or by Spontaneous Pollen Flow in Field Test** | Hybrids: Ploidy and Genome, Information About Sexual Reproduction; Comments **(not indicating direction of cross, *i.e.* which species was female parent, which male)** |
|---|---|---|---|---|---|---|
| 25. ***A. pallens*** (*A. diegoensis*); **Leafy or Dune Bentgrass** | **Native** Western North America: W BC — Calif., & NV, ID, MT. | **2n = 6x = 42**, 8x = 56 (Harvey 1993, 1999, Frey 1997). | 14 × 25 | **NW USA?** (Carlbom 1967). | 30 × 25 (transgenic test – Wipff & Fricker 2001, Christoffer 2003). | **30 × 25:** Transgenic test: field – Wipff & Fricker 2001, Christoffer 2003.<br>**14 × 25:** Probable (and fertile) in OR (Carlbom 1967, pp. 98, 126). |
| 29. ***A. scabra*** (*A. hyemalis* or *hiemalis* var. *scabra*); **Rough Bentgrass, Ticklegrass** | **Native** Greenland, North America to Mexico and NE Asia. | **2n = 6x = 42** (Frey 1997). | 30 or 13 × 29; 12 × 29 | **USA: UT?** (Welsh *et al*. 1993). | 30 × 29 (transgenic test – Christoffer 2003). | **30 × 29:** Transgenic test: field – Christoffer 2003. |
| ***A.* sp.** | Unknown: from eastern Oregon | | 30 × *A*. sp. | | 30 × *A*. sp. (transgenic test – Wipff & Fricker 2001). | Species unidentified (Wipff & Fricker 2001); native or introduced and perhaps naturalized. |
| 32. ***A. trinii*** (*A. vinealis* subsp. *trinii*, *A. coarctata* subsp. *trinii*; *A. flaccida* subsp. *trinii*); **Trinius' Bentgrass** | **Native** E Asia to W Alaska. | **2n** = 2x = 14, **4x = 28** (Frey 1997).<br><br>Also B-chromosomes (Frey 1997). | 30 × 32 (***A.* × *ussuriensis***). | Far E Russia (Probatova 1984). | 30 × 32 (transgenic test – Christoffer 2003). | **30 × 32:** Transgenic test: field – Christoffer 2003. Note: *A. trinii* taxonomy unsettled; a synonym of *A. vinealis* in Kartesz 2003 ms, but variously accepted by Koyama 1987 for Japan and several authors for Russia (*e.g.* Kurchenko & Ianova 1976, Kurchenko 1979c, Tsvelev 1984, Malyschev & Peschkova 1990, and Probatova 1984 *etc*.). |
| 34. ***A. vinealis*** (*A. stricta*; *A. canina* subsp. *montana*; *A. canina* var. *arida*; *A. coarctata*) [Sect. *Agrostis*]; **B. Brown Bentg rass** | Introduced. **Native** Alaska and Eurasia. | **2n = 4x = 28**, $A_1A_1A_2A_2$ or $A_1A_1A_1A_1$ (somewhat as autotetraploid with 2x *A. canina*-like ancestry, or perhaps from cross of 4x *A. canina* [if such] and *A. capillaris* – Jones 1956b, *cf.* Romero García *et al*. 1988b, but the “*A. canina*” ploidy over 2x may not be *A. canina* – Romero García & Blanca 1988; *cf.* Vergara & Bughrara 2003). | 30 × 34; 6 × 34 (***A.* × *sanionis***); 21 × 34 | **All three:** Fennoscandia, with 30 × 34 rare (Widén 1971); both **30 × 34 & 6 × 34:** U.K. (Hubbard 1984, Sell & Murrell 1996). | 30 × 34; 5 × 34 (Davies 1953, Björkman 1954); 6 × 34 (Davies 1953, but probably most were not hybrids *per* Widén 1971); 21 × 34 (Björkman 1954). | **30 × 34** (2n = 28)**:** Experimental hybrids completely sterile (Bradshaw 1975a); a few viable seeds (Davies 1953). Björkman 1954 also made a cross of 5x #30 and #34.<br>**5 × 34** (2n = 21)**:** Quite sterile (Widén 1971).<br>**6 × 34** (2n = 28)**:** Unclear facility of crossing in nature and experimentally (readily crossing *per* Harvey 1999); most experimental “hybrids” (Davies 1953, Jones 1956b) likely instead selfs of #34 or #6 (Widén 1971, Bradshaw 1975a). Probably natural hybrids sterile (Widén 1971, Sell & Murrell 1996).<br>**21 × 34** (2n = 42) (Widén 1971). |

*Appendix 3.* (cont.) **Details on Some *Agrostis* and *Polypogon* in Temperate North America.**

**Table 2 Subpart: Intergeneric Hybrids, *Agrostis stolonifera* × *Polypogon* species, × *Agropogon***

| Bigeneric Hybrids | Hybrid Range | Hybrid Ploidy | Natural Hybrids & Spp. | Hybrids' Country of Occurrence | Experimental Hybrids | Hybrids' Sexual Reproduction; Comments |
|---|---|---|---|---|---|---|
| **1P.** (× ***Agropogon***, but since without name use crossing parental species) | Not native if in USA (HI) now, but likely not (*cf.* Herbst & Clayton 1998, also Wipff & Fricker 2001). | | **30 × *Polypogon fugax*** [sp. (2n = 42, Björkman 1954) native in Asia Minor, not found in Hawaii since 1916 – Herbst & Clayton 1998]. Unknown if Hybrid is Native, Spontaneous (*i.e.* from introduced parents), or Experimental (Björkman 1960 *per* Wipff & Fricker 2001). Transgenic test – Christoffer 2003. | | | **30 × 1P:** Transgenic test: field – Christoffer 2003. |
| 2P. × ***Agropogon littoralis***; **Coast Agropogon** | Spontaneous, naturalized parent(s). Native Western Eurasia, North Africa. | **2n = 4x = 28** (Tutin 1980, Sell & Murrell 1996). | 30 × *Polypogon monspeliensis* [sp. (2n = 28 & 35, Harvey 1993) Europe to SW Asia - Annual Rabbit's-foot Grass] | U.K., France (Sell & Murrell 1996, Hubbard 1984); Canada (BC), **W & SE USA** (Kartesz 2003 ms); Chile (Rúgolo de Agrasar & Molina 1997b); New Zealand (Edgar & Connor 2000); Australia (Weiller *et al.* 1995- ms); China (Qian & Sun 1998). | 30 × 2P (transgenic test – Christoffer 2003). | **30 × 2P:** Almost complete pollen and seed sterilities. Vigor varies, perhaps because of hybridization with different ecotypes of #30, which is more vigorous (Bradshaw 1975b; *cf.* Welsh *et al.* 1993). Transgenic test: field – Christoffer 2003. |
| 3P. × ***Agropogon robinsonii*** | Spontaneous, naturalized parent(s). Native Western Eurasia? | **2n = 4x = 28** | 30 × *Polypogon viridis* (*Agrostis viridis*; *A. semiverticillata*, *P. semiverticillatus*) [sp. (2n = 28, Harvey 1993) Europe to SW Asia - Beardless Rabbit's-foot Grass] | U.K., rare (Hubbard 1984, Sell & Murrell 1996); **USA: UT?** (Welsh *et al.* 1993). | 30 × 3P (transgenic test – Christoffer 2003). | **30 × 3P:** Experimental crossing facility uncertain. Parents highly self-incompatible; hybrid has complete pollen sterility (Bradshaw 1975b, Hubbard 1984). Short-lived perennial (Sell & Murrell 1996). UT possibly, although Welsh *et al.* 1993 treat *A. stolonifera sensu lato* (as #30 + #13). Transgenic test: field – Christoffer 2003. |