Weed Technology. 1999. Volume 13:77–82

# Selective Control of Jointed Goatgrass (*Aegilops cylindrica*) with Imazamox in Herbicide-Resistant Wheat[1]

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**Abstract:** Jointed goatgrass (*Aegilops cylindrica*) is a serious problem for winter wheat producers throughout the western U.S. Interference from this weed can severely reduce grain yield and contaminate harvested grain, resulting in dockage losses. There are currently no selective herbicides registered for controlling jointed goatgrass in wheat. Imazamox, an imidazolinone herbicide, was applied to an imidazolinone herbicide-resistant (IMI) wheat mutant of the winter wheat cultivar 'Fidel.' Jointed goatgrass control from spring postemergence application of imazamox ranged from 61 to 97% when applied at 36 g/ha. Negligible crop injury from imazamox treatment was observed at 36 g/ha at several locations under dryland environments in the U.S. Pacific Northwest. Wheat yield was increased 19 to 41% by imazamox treatment in three of four experiments. Percent dockage resulting from jointed goatgrass spikelet contamination of harvested wheat grain was eliminated by imazamox treatment. Introduction of the IMI trait into commercial wheat cultivars could provide an effective method for selective control of jointed goatgrass in winter wheat.

**Nomenclature:** Imazamox, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid; jointed goatgrass, *Aegilops cylindrica* Host #[3] AEGCY; winter wheat, *Triticum aestivum* L. IMI-Fidel.

**Additional index words:** Herbicide-tolerant crop, IMI wheat, AEGCY, AVEFA, LOLMU, BROTE.

**Abbreviations:** AHAS, acetohydroxyacid synthase; IMI, imidazolinone herbicide-resistant; PNW, Pacific Northwest.

## INTRODUCTION

Jointed goatgrass is a serious weed problem for winter wheat producers throughout the western U.S. (Dewey 1996; Donald and Ogg 1991). Interference from this weed can reduce grain yield and contaminate harvested grain, thus increasing dockage losses. Current standards for certified seed wheat have a zero tolerance for jointed goatgrass contamination (Anonymous 1988), thereby eliminating seed wheat production potential in infested areas. Because jointed goatgrass seeds can remain viable for 3 to 5 yr (Donald and Zimdahl 1987) and no selective chemical control exists for jointed goatgrass in winter wheat–summer fallow rotations, jointed goatgrass can be controlled only by the use of extended fallow periods or long-term spring crop rotations (Donald 1991). In most regions of the dryland Pacific Northwest (PNW), these options are not profitable (Young and van Kooten 1989). One possible approach to managing jointed goatgrass in winter wheat is through the development of an herbicide-resistant winter wheat variety. An imidazolinone herbicide-resistant (IMI) hard red wheat mutant in the winter wheat cultivar Fidel was developed by American Cyanamid Company[4] for research purposes.

To develop the IMI wheat, seeds of the winter wheat cultivar Fidel was mutagenized by imbibing seeds and soaking with sodium azide (Newhouse et al. 1992). Treated seeds were planted in the field and grown to maturity, at which time seeds were harvested. This generation of seeds was germinated in the presence of imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}. Plants from surviving seedlings were further screened by spraying plants with imazethapyr. Four plants survived these treatments. The herbicide resistance trait from these selected plants can be inherited as a single dominant or semidominant gene (Shaner et al.

[1] Received for publication April 20, 1998, and in revised form November 17, 1998. Contribution from Columbia Basin Agricultural Research Center, Oregon State University, Pendleton, OR. Technical paper 11291.

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

[4] American Cyanamid Company, North America Agricultural Products Division, Parsippany, NJ 07054.

1984). Preliminary genetic analysis indicates that the herbicide resistance in the four initial selections are either allelic at a single locus or, if more than one gene, very tightly linked with no maternal effects on inheritance (Shaner et al. 1984).

Herbicides in the imidazolinone class control many weeds, including several winter annual grass species. These herbicides inhibit the enzymatic activity of acetohydroxyacid synthase (AHAS), the first enzyme in the pathway for the synthesis of the branched-chain amino acids (valine, leucine, and isoleucine) (Shaner et al. 1984). Imazamox was used in these IMI wheat studies. This compound is an imidazolinone herbicide being developed by American Cyanamid Company. Imazamox controls a broad spectrum of annual grass weeds, including jointed goatgrass (Ball and Walenta 1997), downy brome (*Bromus tectorum* L. # BROTE, Ball and Walenta 1997; Gamroth et al. 1997; Neider and Thill 1997), wild oat (*Avena fatua* L. # AVEFA, Belles and Thill 1998), Italian ryegrass (*Lolium multiflorum* Lam. # LOLMU, Brewster et al. 1997), and others (Gamroth et al. 1997). However, imazamox has soil persistence properties that may limit rotational crop options due to carryover phytotoxicity to certain crops in the PNW (Ball and Walenta 1998) and elsewhere (Cobucci et al. 1998). The objective of this field study was to determine the rate response of jointed goatgrass and winter wheat to imazamox and to determine if treating IMI wheat with imazamox might be a successful practice for controlling jointed goatgrass in wheat lands.

## MATERIALS AND METHODS

Experiments were conducted at the Columbia Basin Agricultural Research Center near Moro, OR, in 1996; near Helix, OR, in 1997; and at the Palouse Conservation Field Station near Pullman, WA, in 1996 and 1997. The chosen locations represent the PNW dryland cropping region covering a range of soils and annual rainfall totals (Table 1). IMI-Fidel wheat from a single seed source was planted in each experiment using seeding practices and rates typical for each site. At Moro and Pullman in 1996, jointed goatgrass spikelets were broadcast over the plot area before seeding wheat. The other experiments were located in areas naturally infested with jointed goatgrass. Treatments consisted of imazamox rates from 27 to 71 g ai/ha, applied as fall and spring application timings, and an untreated control in the 1996 Moro experiment and as early and late spring treatments in the 1997 Helix experiment. For both Washington experiments, the same rates were applied but at only one spring application timing. At Pullman, jointed goatgrass emerged too late in the fall for treatments to be applied without freezing nighttime temperatures.

*Table 1.* Monthly growing season precipitation totals at four study sites.

| Month | Moro, OR 1995–1996 | Helix, OR 1996–1997 | Pullman, WA 1995–1996 | Pullman, WA 1996–1997 |
|---|---|---|---|---|
| | mm | | | |
| September | 26 | 4 | 21 | 27 |
| October | 16 | 38 | 58 | 72 |
| November | 81 | 31 | 91 | 90 |
| December | 56 | 78 | 75 | 140 |
| January | 47 | 58 | 95 | 68 |
| February | 62 | 8 | 117 | 45 |
| March | 17 | 37 | 16 | 47 |
| April | 40 | 29 | 116 | 66 |
| May | 37 | 9 | 51 | 27 |
| June | 9 | 14 | 15 | 21 |
| July | 4 | 18 | 5 | 41 |
| August | 1 | 1 | 1 | 4 |
| Total | 396 | 324 | 661 | 648 |

**Oregon Locations.** For the Moro experiment, IMI-Fidel wheat was seeded 5 cm deep at 78 kg/ha on October 4, 1995, into moist soil with a John Deere HZ[5] deep-furrow drill with 40-cm row spacing. Postemergence imazamox treatments were applied with a 3-m wide hand-held boom calibrated to apply 150 L/ha at 207 kPa. Fall treatments were applied November 16, 1995, to two-and-one-half-leaf wheat and two-leaf jointed goatgrass. Spring treatments were applied on March 13, 1996, to six-leaf wheat and four-leaf jointed goatgrass. Imazamox was applied at 27, 36, 45, 54, and 71 g/ha. All postemergence treatments included 32% liquid nitrogen (N) solution at 2.3 L/ha and a nonionic surfactant at 0.25% (v/v). Plots were 2.5 by 9 m with four replicates arranged in a randomized complete block factorial arrangement with timing and rate as factors. Soil at the site was a Walla Walla silt loam (mixed mesic Typic Haploxeroll, 25.2% sand, 58.0% silt, 16.6% clay, 1.3% organic matter, 6.2 soil pH, and cec of 13.9 cmol/kg). Jointed goatgrass was broadcast over the plot area immediately prior to wheat planting and resulted in a light and uniform jointed goatgrass infestation throughout the plot area (< 5 plants/m$^2$). Plots were evaluated visually for jointed goatgrass control and crop injury from 0 (no control) to 100% (complete control) on May 29, 1996. Winter wheat was harvested on August 1, 1996.

For the Helix experiment, IMI-Fidel wheat was seeded 3 cm deep at 70 kg/ha on October 23, 1996, into moist soil with a John Deere HZ[5] deep-furrow drill with 35-cm row spacing. The area was naturally infested with a

[5] Deere & Company, Moline, IL 61265.

dense, uniform population of jointed goatgrass (> 25 plants/m$^2$). Imazamox was applied postemergence with a 3-m wide hand-held boom calibrated to apply 150 L/ha at 207 kPa. Early spring treatments were applied February 21, 1997, to two-and-one-half-leaf wheat and two to two-and-one-half-leaf jointed goatgrass. Late spring treatments were applied on March 21, 1997, to four-leaf wheat and five-leaf jointed goatgrass. Imazamox was applied at 27, 36, 45, 54, and 71 g/ha. All postemergence treatments included 32% liquid N solution at 2.3 L/ha and a nonionic surfactant at 0.25% (v/v). Plots were 2.5 m by 9 m with four replicates arranged in a randomized complete block factorial arrangement with timing and rate as factors. Soil at the site was a Walla Walla silt loam (38% sand, 59% silt, 2.4% clay, 1.4% organic matter, 6.2 soil pH, and cec of 10.1 cmol/kg). Plots were evaluated for visible crop injury on April 21, 1997, and jointed goatgrass control on May 21, 1997. Wheat and jointed goatgrass biomass samples were taken on June 23, 1997, by clipping above-ground plant portions from a 0.25-m$^2$ area, separating grass species, and drying at 60 C until dry-weight equilibrated. Winter wheat was harvested on July 22, 1997. Percent dockage was estimated by separating jointed goatgrass spikelets from a 100-g subsample of the harvested wheat grain and expressing jointed goatgrass weight as a percentage of the total subsample weight.

**Washington Locations.** For the first Pullman experiment, IMI-Fidel wheat was seeded 4 cm deep at 84 kg/ha on October 10, 1995, into dry soil with a double-disk drill with 19-cm row spacing. Imazamox was applied postemergence with a hand-held boom calibrated to apply 93 L/ha at 165 kPa. Postemergence treatments were applied April 7, 1996, to five- to six-leaf wheat and five- to six-leaf jointed goatgrass. Imazamox was applied at 27, 36, 45, 54, and 71 g/ha, and postemergence treatments included a 28% liquid N and nonionic surfactant blend at 2.3 L/ha. Plots were 3 by 15 m with four replicates arranged in a randomized complete block. Soil at the site was a Latah silt loam (19% sand, 64% silt, 17% clay, 3.6% organic matter, 5.8 soil pH). The jointed goatgrass populations were dense and uniform throughout the plot area (population counts not obtained in Washington experiments). Plots were evaluated for visible crop injury on April 21, 1996, and for jointed goatgrass control on June 22, 1996. Jointed goatgrass biomass was collected in late July 1996 in a 3-m$^2$ area in each plot and dried at 50 C for 3 d. Wheat was harvested on August 8, 1996. Percent dockage was estimated by separating jointed goatgrass spikelets from a 100-g subsample of the harvested wheat grain and expressing jointed goatgrass weight as a percentage of the total subsample weight.

For the second Pullman experiment, IMI-Fidel wheat was seeded 4 cm deep into moist soil at 100 kg/ha on October 2, 1996, with a double-disk opener drill with 19-cm row spacing. Herbicides were applied postemergence with a hand-held boom calibrated to apply 93 L/ha at 165 kPa. Experimental treatments were applied April 4, 1997, to three- to four-leaf, one-tiller wheat and five- to seven-leaf, two- to three-tiller jointed goatgrass. Imazamox and spray additive rates were the same as the previous year in Washington. Plots were 3 by 10 m with three replicates arranged in a randomized complete block. Soil at the site was similar to that described for the 1995–1996 Pullman experiment. Jointed goatgrass infestations were dense throughout the plot area. Jointed goatgrass and wheat lodged in the nontreated plots. Jointed goatgrass control was estimated visually in late July. Wheat and jointed goatgrass plant biomass was obtained from a 1-m$^2$ area per plot in late July 1997. Winter wheat was harvested on August 11, 1997. Dockage estimates were made as described previously.

**Statistical Analysis.** Visual estimates of jointed goatgrass control, wheat injury, and wheat yield were subjected to a chi-square test for heterogeneity of variance among the four experiments (Gomez and Gomez 1984). Because heterogeneity of variance occurred for the variables measured, data were not pooled across experiments. Visual estimates of jointed goatgrass control and wheat injury from individual experiments were arcsine transformed prior to statistical analysis and subjected to ANOVA procedures. The data presented are nontransformed means. Means were separated using Fisher's protected LSD at the $P = 0.05$ level of probability.

## RESULTS AND DISCUSSION

The optimum rate of imazamox for jointed goatgrass control varied with experiment and application timing. There was a significant timing by rate interaction for spring and fall applications at Moro in 1996. Spring application of imazamox controlled jointed goatgrass better at lower rates than did fall applications. This was true for all but the highest rate, at which jointed goatgrass control averaged 89% (Table 2). At Helix in 1997, the early spring timing averaged across application rates gave better jointed goatgrass control than the late spring timing. There was no timing by rate interaction. (Table 3). For spring applications at Pullman in both years, all

*Table 2.* Visible wheat injury, jointed goatgrass control, and grain yield in imidazolinone-resistant wheat treated with imazamox. Moro, OR 1996.

| Rate[a] | Timing | Crop injury (May 29) | Jointed goatgrass control (May 29) | Grain yield |
|---|---|---|---|---|
| g/ha | | % | % | kg/ha |
| 0 | — | 0 | 0 | 4,330 |
| 27 | November 16 | 0 | 25 | 4,700 |
| 36 | November 16 | 0 | 48 | 4,600 |
| 45 | November 16 | 0 | 49 | 4,520 |
| 54 | November 16 | 0 | 53 | 4,760 |
| 71 | November 16 | 0 | 88 | 4,660 |
| 27 | March 13 | 0 | 69 | 4,160 |
| 36 | March 13 | 0 | 83 | 4,320 |
| 45 | March 13 | 0 | 85 | 4,420 |
| 54 | March 13 | 0 | 86 | 4,190 |
| 71 | March 13 | 0 | 90 | 4,320 |
| LSD (0.05) | | ns | 22 | ns |

[a] Imazamox treatments were applied with a 32% N solution at 2.3 L/ha and nonionic surfactant at 0.25% v/v.

*Table 4.* Visible wheat injury, jointed goatgrass control, grain yield, and dockage in imidazolinone-resistant wheat treated with imazamox. Pullman, WA 1996.

| Rate[a] | Crop injury (April 21) | Jointed goatgrass control (June 22) | Grain yield | Dockage |
|---|---|---|---|---|
| g/ha | % | % | kg/ha | % |
| 0 | 0 | 0 | 5,280 | 7.2 |
| 27 | 3 | 89 | 6,009 | 0.3 |
| 36 | 5 | 91 | 5,907 | 0.1 |
| 45 | 8 | 95 | 5,807 | 0.1 |
| 54 | 5 | 96 | 6,502 | 0 |
| 71 | 20 | 99 | 5,880 | 0 |
| LSD (0.05) | 7 | 7 | 763 | 2.1 |

[a] Imazamox treatments received a 28% liquid N solution and nonionic surfactant blend at 2.3 L/ha. Treatments applied April 7, 1996.

imazamox treatments gave a high level of jointed goatgrass control (Tables 4 and 5). At Helix in 1997, jointed goatgrass control was less from the 27 g/ha imazamox rate than from the higher application rates (Table 3). This site had the lowest growing season precipitation of the four study sites (Table 1).

All imazamox treatments enhanced grain yield from spring applications at Pullman in both years (Tables 4 and 5). Grain yield was not enhanced by imazamox treatment at Moro (Table 2) because the light jointed goatgrass population density (< 5 plants/m$^2$) was noncompetitive. Jointed goatgrass control and grain yield tended to increase as treatment rates increased at Helix in 1997 (Table 3). For the three experiments where jointed goatgrass dockage was evaluated, all treatment rates and timings reduced percent dockage (Tables 3–5). Current dockage standards discount wheat approximately 1% for each 0.1% jointed goatgrass dockage over the 0.5% level of jointed goatgrass, so observed reductions in jointed goatgrass dockage would directly benefit wheat producers.

Imazamox did not injure IMI-Fidel at Moro in 1996 (Table 2). Slight, visible crop injury was evident from the 45 and 54 g/ha late treatments at Helix in 1997 (Table 3). Visible wheat injury was estimated at 20% from the 71 g/ha treatment at Pullman in 1996 (Table 4). Injury appeared as reduced plant height and abnormal proliferation and deformation of tillers. Imazamox treatments to IMI-Fidel wheat have caused significant crop injury at other test locations in the western U.S. (Brewster et al. 1997; S. D. Miller, personal communication). Grain yield was not reduced by imazamox injury at any experiment evaluated in this study. Visible injury was not evaluated at Pullman in 1997 because of variable crop stand from excessive moisture conditions.

Based on observation of visible jointed goatgrass control and wheat injury, it appears that application rates between 36 and 54 g/ha controlled jointed goatgrass with minimal crop injury across all test sites. Imazamox rates

*Table 3.* Visible wheat injury, jointed goatgrass control, grain yield, and dockage in imidazolinone-resistant wheat treated with imazamox. Helix, OR 1997.

| Rate[a] | Timing | Crop injury (April 21) | Jointed goatgrass control (May21) | Grain yield | Dockage |
|---|---|---|---|---|---|
| g/ha | | % | % | kg/ha | % |
| 0 | — | 0 | 0 | 1,320 | 62.5 |
| 27 | February 21 | 1.3 | 39 | 2,000 | 9.0 |
| 36 | February 21 | 3.8 | 66 | 1,590 | 2.6 |
| 45 | February 21 | 0 | 76 | 2,020 | 2.4 |
| 54 | February 21 | 2.5 | 91 | 1,630 | 1.1 |
| 71 | February 21 | 3.8 | 89 | 1,950 | 0.9 |
| 27 | March 21 | 3.8 | 46 | 1,180 | 11.9 |
| 36 | March 21 | 3.8 | 61 | 1,500 | 7.2 |
| 45 | March 21 | 5.0 | 62 | 1,530 | 3.4 |
| 54 | March 21 | 5.0 | 75 | 1,550 | 1.9 |
| 71 | March 21 | 3.8 | 84 | 1,760 | 0.6 |
| LSD (0.05) | | 3.8 | 14 | 400 | 11.9 |

[a] Imazamox treatments were applied with a 32% N solution at 2.3 L/ha and nonionic surfactant at 0.25% v/v.

*Table 5.* Visible jointed goatgrass control, grain yield, and dockage in imidazolinone-resistant wheat treated with imazamox. Pullman, WA 1997.

| Rate[a] | Jointed goatgrass control | Grain yield | Dockage |
|---|---|---|---|
| g/ha | % | kg/ha | % |
| 0 | 0 | 3,660 | 26.1 |
| 27 | 91 | 5,330 | 0.3 |
| 36 | 97 | 6,050 | 0 |
| 45 | 97 | 5,970 | 0 |
| 54 | 99 | 6,160 | 0 |
| 71 | 100 | 6,170 | 0 |
| LSD (0.05) | 5 | 760 | 3.8 |

[a] Imazamox treatments received a 28% liquid N solution and nonionic surfactant blend at 2.3 L/ha. Treatments applied April 4, 1997.

of 27 and 36 g/ha were more effective at controlling jointed goatgrass at Pullman than at the Oregon sites that had less growing season precipitation (Table 1). Spring application of imazamox gave better jointed goatgrass control than fall application in one experiment averaged over all rates (Table 2).

A more quantitative assessment of optimum application timing and rate was obtained from evaluation of jointed goatgrass and wheat dry matter measured near the end of the growing season (Table 6). At Helix in 1997, jointed goatgrass dry weights were reduced more when imazamox was applied at the two- to three-leaf stage than at the five-leaf stage, except at the 27 g/ha rate. For the early application timing at Helix and for the single application timing at Pullman in 1997, no additional increase in wheat dry weight and little to no additional decrease of jointed goatgrass dry weight resulted at rates above 45 g/ha. These observations indicate that the 45 g/ha application rate may offer optimum jointed goatgrass control.

Further development of weed management techniques utilizing imazamox and an IMI winter wheat may offer an option for selective control of jointed goatgrass in locations where dryland crops other than winter wheat are not profitable. This may apply especially to the driest areas of the PNW where cropping is limited to winter wheat in rotation with fallow. Crop rotation can also facilitate management of jointed goatgrass (Lyon and Baltensperger 1995), but the profitability of changing cropping systems is unknown. However, before the suitability of imazamox and IMI wheat for jointed goatgrass control can be determined, transferring the herbicide-tolerant trait into regionally adapted wheat varieties is needed. Also, the potential for transference of the herbicide resistance trait to jointed goatgrass and other weedy grass species needs to be fully investigated, as the potential for such an occurrence cannot be completely ruled out at this time (Zemetra et al. 1998).

*Table 6.* Jointed goatgrass and wheat dry weight response to imazamox treatments. Helix, OR and Pullman, WA 1997.

| | | Helix | | Pullman | |
|---|---|---|---|---|---|
| Rate[a] | Jointed goatgrass growth stage | Jointed goatgrass dry weight | Wheat dry weight | Jointed goatgrass dry weight | Wheat dry weight |
| g/ha | Haun leaf stage[b] | g/m² | | | |
| 0 | — | 340 | 140 | 340 | 840 |
| 27 | 2.5 | 130 | 460 | — | — |
| 36 | 2.5 | 30 | 540 | — | — |
| 45 | 2.5 | 20 | 540 | — | — |
| 54 | 2.5 | 20 | 460 | — | — |
| 71 | 2.5 | 10 | 550 | — | — |
| 27 | 5.0 | 130 | 320 | 5.0 | 1,100 |
| 36 | 5.0 | 90 | 430 | 0.2 | 1,090 |
| 45 | 5.0 | 50 | 390 | 0.3 | 1,260 |
| 54 | 5.0 | 50 | 400 | 0.4 | 1,280 |
| 71 | 5.0 | 20 | 530 | 0.0 | 1,310 |
| LSD (0.05) | — | 10 | 40 | 80 | 150 |

[a] Imazamox treatments were applied with a 32% N solution at 2.3 L/ha and nonionic surfactant at 0.25% v/v at Helix, and a 28% liquid N and nonionic surfactant blend at 2.3 L/ha at Pullman. Treatments applied February 21 and March 21 at Helix, and April 4 at Pullman.

[b] Haun leaf stage (Haun 1973).

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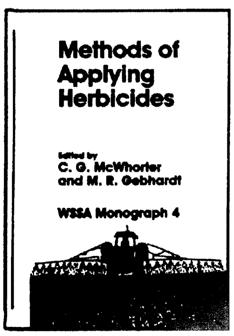
## *Methods of Applying Herbicides*

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