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Effect of Imazamox Soil Persistence on Dryland Rotational Crops[1]

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Abstract: Imazamox is an imidazolinone herbicide being developed for weed control in imidazolinone-resistant wheat (IMI-wheat) cultivars and various legume crops. In a series of studies conducted under a range of dryland cropping environments in the Pacific Northwest United States, imazamox applied to IMI-wheat or pea injured barley and canola grown 1 yr after imazamox treatment in low-rainfall, low–soil pH locations of Oregon. Injury was not observed in higher rainfall locations near Pullman, WA. Non–herbicide-resistant wheat planted 1 yr after IMI-wheat treated with imazamox was not injured. Of particular concern for imazamox carryover are low-rainfall areas with low-pH soils. Reduced soil moisture appears to limit imazamox degradation. Imazamox sorption is reduced in low-pH soils, which increases its bioavailability, thereby increasing the potential for injury to rotational crops such as barley, canola, and spring wheat.

Nomenclature: Imazamox; barley, *Hordeum vulgare* L.; canola, *Brassica napa* L.; pea, *Pisum sativum* L.; wheat, *Triticum aestivum* L.

Additional index words: Barley, canola, carryover, Clearfield™, herbicide-resistant wheat, pea.

Abbreviations: IMI-wheat, imidazolinone-resistant wheat; PNW, Pacific Northwest.

INTRODUCTION

Imazamox is a imidazolinone herbicide being developed for weed control in several crops, including pea (Blackshaw 1998; Harvey et al. 1995) and herbicide-resistant wheat (Clearfield)[3] (Ball et al. 1999). Imazamox controls a broad spectrum of annual grass weeds, including jointed goatgrass (*Aegilops cylindrica* Host) (Ball et al. 1999), downy brome, (*Bromus tectorum* L.), (Ball and Walenta 1997; Gamroth et al. 1997; Neider and Thill 1997), wild oats (*Avena fatua* L.) (Belles and Thill 1998), Italian ryegrass (*Lolium multiflorum* Lam.) (Brewster et al. 1997), and others (Gamroth et al. 1997; Ogg et al. 2001). Because of soil persistence characteristics of imidazolinone herbicides (Mangels 1991), carryover to crops grown in rotation with either pea or imidazolinone-resistant wheat (IMI-wheat) needs to be considered. Imazethapyr and imazaquin persistence can restrict crop rotations (Loux et al. 1989). Imazamox produced injury to sugarbeet the year after application in Minnesota, where imazamox bioavailability and crop injury were increased by lowering the soil pH ($\text{pH} < 6$) (Bresnahan et al. 2002). Imazamox persisted only slightly on a sandy loam soil (pH 7.0) in Ontario, Canada (O'Sullivan et al. 1998), and had negligible effects on vegetable crops planted 1 yr after treatment. Crop rotation restrictions after imazamox application were identified for corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), rice (*Oryza sativa* L.), and pearl millet (*Pennisetum glaucum* L.) in the Brazilian Cerrado (Cobucci et al. 1998). In a Wyoming study with a soil pH of 7.3, no injury to corn or sunflowers was observed in a normal crop rotational sequence 14 to 18 mo after imazamox application to imidazolinone-resistant winter wheat (Miller and Alford 2001).

Bioavailability of imazamox is increased at low soil pH (Bresnahan et al. 2002) and at low levels of soil moisture (Cobucci et al. 1998). This research was conducted to determine the soil persistence effects of imazamox on dryland crops grown in rotation under dryland U.S. Pacific Northwest (PNW) conditions, where low soil pH and soil moisture conditions are common.

MATERIALS AND METHODS

Experiments were conducted under a range of dryland cropping environments to investigate the potential carryover effects of imazamox on rotational crops. The chosen locations represent PNW dryland cropping regions covering a range of annual rainfall totals (Table 1) where

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[3] Clearfield™ is a registered trademark of BASF Corp. Mention of specific products does not imply a product endorsement or recommendation for commercial use.

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

	Precipitation			
	Pullman, WA	Pendleton, OR		Moro, OR
Month	1998–1999	1995–1996	1998–1999	1995–1996
	mm			
September	31	24	31	26
October	26	34	10	16
November	102	75	120	81
December	134	60	75	56
January	51	71	30	47
February	105	62	55	62
March	21	38	31	17
April	9	59	25	40
May	20	51	42	37
June	32	10	15	9
July	4	0	1	4
August	37	1	30	1
Total	572	485	465	396
20-yr average	541	454		306

winter wheat–summer fallow cropping or winter wheat–pea cropping is practiced. Because imazamox has potential uses in IMI-wheat or in pea, five trials were conducted, three with IMI-wheat as the initially treated crop and two with pea as the initially treated crop.

Rotational crops were evaluated for crop stand count, percent visible injury (0 to 100 scale), aboveground dry weight, and yield. For cereal crops, spike counts and standing plant height also were obtained at crop maturity. Percent visible injury data were arcsine transformed before performing analysis of variance. Crop stand counts were obtained by counting all emerged crop plants in two to five, 1-m sections of row per plot. Rotational crops were harvested with a plot combine at appropriate maturity. Yields were converted to kilograms per hectare harvested grain. Spike counts of barley and wheat were obtained by counting spikes in two, 1-m sections of row per plot. Late-season, aboveground dry weights of all rotational crops were obtained at maturity by harvesting two, 1-m sections of row per plot, oven drying for 48 h at 60 C, and weighing.

Experiments in which IMI-wheat was the initially treated crop were conducted at the Columbia Basin Agricultural Research Center near Pendleton, OR, during 1995 to 1997, and near Pullman, WA, at the Washington State University, Cunningham Farm during 1998 to 2000; these sites are considered to be intermediate- and high-rainfall zones, respectively, in the PNW dryland cropping region (Douglas et al. 1992). A related trial with imazamox-treated IMI-wheat was conducted at the Columbia Basin Agricultural Research Center near Moro, OR, a low-rainfall zone, during 1995 to 1997. An

Table 2. Planting information, soil characteristics, and tillage before rotation of crops.

Location number	Location	Seeding date	Seeding rate	Drill type	Soil type	Organic matter	Soil pH	Preplant tillage	Rotation crops
			kg/ha			%			
1	Pendleton, OR	October 5, 1995 (wheat)	65	Double disk	Walla Walla silt loam	1.7	5.8	Chisel–cultivate	Barley–canola–SW[a]
2	Pullman, WA	October 15, 1998 (wheat)	95	Double disk	Palouse silt loam	3.4	5.6	Chisel–cultivate	Barley–canola–WW
3	Moro, OR	October 4, 1995 (wheat)	78	Deep furrow	Walla Walla silt loam	1.3	6.2	Chisel–cultivate	Barley
4	Pendleton, OR	April 10, 1998 (pea)	200	Double disk	Walla Walla silt loam	1.8	6.0	Chisel–cultivate	Barley–canola–SW–WW
5	Pullman, WA	April 28, 1998 (pea)	260	Cross-slot	Naff silt loam	3.5	5.8	No till	SW–WW

[a] Abbreviations: SW, spring wheat; WW, winter wheat.

Table 3. Plot sizes, imazamox application rates, spray timing, spray pressure, and spray volume for field studies.

Location number	Location	Plot size	Imazamox rate	Spray timing	Spray pressure	Spray volume
		m	g/ha		kPa	L/ha
1	Pendleton, OR	4.5 by 3	45/90	Fall–spring	207	150
2	Pullman, WA	3 by 12	45/90	Fall–spring	235	94
3	Moro, OR	2.5 by 9	27/36/45/54/72	Fall–spring	235	94
4	Pendleton, OR	3.6 by 3	45/90	Spring	207	150
5	Pullman, WA	3 by 12	36/54/72	Spring	235	94

IMI-wheat from a single seed source (var. ‘CV9804′) was planted in all experiments.

Experiments in which pea was the initially treated crop were conducted during 1998 to 1999, both at the Columbia Basin Agricultural Research Center near Pendleton, OR, and at the USDA-ARS Palouse Conservation Field Station near Pullman, WA. Analysis of data revealed heterogeneity of variance between locations, which prevented pooling between locations. Therefore, results for individual locations are reported separately.

Initial crop-seeding practices, soil characteristics, tillage performed before rotational crop planting, and the rotation crops planted in each experiment are summarized in Table 2. All treatments were applied with a 3-m handheld spray boom, with treatments replicated four times. All imazamox treatments included 32% liquid nitrogen solution at 2.3 L/ha and a nonionic surfactant at 0.25% v/v. Individual plot size for rotational crops, imazamox application rate, spray timing, spray volume, and spray pressure are summarized in Table 3.

IMI-Wheat Trials. For the Pendleton experiment, fall imazamox treatments were applied on November 2, 1995, to 2.5-leaf IMI-wheat. Spring treatments were applied on March 19, 1996, to eight-leaf IMI-wheat. After IMI-wheat harvest, main plots were split the following spring into 4.5- by 3-m subplots and seeded with a double-disk drill on March 31, 1997, to spring barley var. ‘Baronesse’ at 80 kg/ha, spring canola var. ‘Legend’ at 11 kg/ha, or spring wheat var. ‘936R’ at 100 kg/ha.

For the Pullman experiment, fall imazamox treatments were applied on November 18, 1998, to one-leaf IMI-wheat. Spring treatments were applied on April 27, 1999, to seven-leaf IMI-wheat. After IMI-wheat harvest, main plots were split into 3- by 12-m subplots and seeded with a double-disk drill to winter wheat var. ‘Madsen’ at 95 kg/ha on October 21, 1999, or spring barley var. Baronesse at 90 kg/ha or spring canola var. ‘Sunrise’ at 13 kg/ha on April 27, 2000.

For the Moro experiment, fall imazamox treatments were applied on November 16, 1995, to 2.5-leaf IMI-wheat. Spring treatments were applied on March 13, 1996, to six-leaf IMI-wheat. After IMI-wheat harvest, the plot area was seeded the following spring to barley var. Baronesse on March 23, 1997, with a double-disk drill at 90 kg/ha.

Pea Trials. A trial at Pendleton was initially seeded to green peas var. ‘Nomad’ on April 10, 1998. Imazamox treatments were applied on June 2, 1998, to 9 to 11 node green peas. After pea harvest, main plots were split into 3.6- by 3-m subplots. Winter wheat var. ‘Stephens’ was seeded at a 100-kg/ha rate on October 6, 1998. Spring wheat var. ‘Alpowa’ and spring barley var. Baronesse were seeded on March 24, 1999, at 100 kg/ha. Spring canola var. ‘Springfield’ was seeded on May 4, 1999, at 10 kg/ha.

For the Pullman experiment, green peas var. ‘Columbia’ were direct seeded into winter wheat stubble at 260 g/ha on April 28, 1998. Imazamox treatments were applied on May 28, 1998, to pea with six nodes. After pea harvest, each plot was split into 3- by 12-m subplots and seeded at 130 kg/ha with either winter wheat var. Madsen on October 12, 1998, or spring wheat var. Alpowa on April 24, 1999.

RESULTS AND DISCUSSION

IMI-Wheat Trials. At Pendleton, precipitation was 6% above normal in the first year after imazamox treatment (Table 1). At an imazamox application of 90 g/ha, twice the proposed use rate, early-season stand count, head count, and late-season biomass of barley were not affected adversely by previous imazamox application. However, barley plant height and grain yield were reduced when compared with the untreated check (Table 4). All imazamox rates and timings injured canola when compared with the untreated check (Table 4). Injury was expressed as reduced plant height, a slight chlorosis of new growth, and a tendency toward increased lateral branching (data not shown). Seedling canola stand density and late-season, aboveground biomass were not affected by herbicide treatments made to the previous wheat crop. Canola seed yield was reduced by all ima-

Table 4. Spring barley and canola response to imazamox previously applied to imidazolinone-resistant wheat, Pendleton, OR, 1997.

Imazamox rate	Timing	Stand count	Visible inury	Plant height	Head count	Late-season dry weight	Crop yield
g/ha		plants/m²	%	cm	spikes/m²	gm/m²	kg/ha
Spring barley							
0	—	135	0	67	673	728	4,530
45	November 2, 1995	138	0	66	594	819	4,630
90	November 2, 1995	136	4	62	618	681	4,030
45	March 19, 1996	148	2	66	630	850	4,540
90	March 19, 1996	129	2	64	598	665	4,250
LSD (0.05)		NS[a]	NS	3	NS	NS	230
Canola							
0	—	75	0	—	—	469	987
45	November 2, 1995	110	14	—	—	402	775
90	November 2, 1995	87	50	—	—	520	319
45	March 19, 1996	90	30	—	—	665	536
90	March 19, 1996	94	53	—	—	421	290
LSD (0.05)		NS	14	—	—	NS	168

[a] Abbreviation: NS, not significant.

zamox applications (Table 4). Spring wheat generally was unaffected by imazamox soil persistnce in this study (data not shown).

At Pullman, precipitation was 5% above normal in the first year after imazamox treatment (Table 1). The crops grown in rotation after IMI-winter wheat included winter wheat, spring barley, or canola. There were no differences due to previous imazamox treatments on seedling stand counts or plant heights for any of the rotational crops (data not shown). Similarly, no significant trends in late-season dry matter accumulation or seed yield were observed. This trial was conducted in a year with above-normal precipitation. The lack of crop injury in this trial in comparison with the that at Pendleton sites may be attributable to the higher level of seasonal precipitation (Cobucci et al. 1998; Mangels 1991) because the soil pH at both sites were similar (Table 2). The higher level of organic matter at the Pullman site also may have contributed to the lack of crop injury (Oliveira et al. 1999).

Table 5. Spring barley response to imazamox previously applied to imidazolinone-resistant winter wheat, Moro, OR, 1996.

Imazamox rate	Timing	Visible injury	Plant height	Head count	Late-season dry weight	Crop yield
g/a		%	cm	spikes/m²	kg/ha	kg/ha
0	—	0	54	122	6,480	3,760
27	Fall	1	52	117	7,090	3,320
36	Fall	6	52	112	5,880	3,000
45	Fall	10	51	114	5,890	2,780
54	Fall	16	46	92	4,630	2,430
71	Fall	29	44	87	4,870	2,010
27	Spring	1	53	120	5,950	3,670
36	Spring	0	53	123	5,730	3,670
45	Spring	0	54	120	5,940	3,620
54	Spring	3	54	122	5,680	3,470
71	Spring	6	51	117	5,990	3,240
LSD (0.05)		6	3	17	NS[a]	720

[a] Abbreviation: NS, not significant.

At the Moro, OR, site barley was injured by increasing rates of imazamox applied in the fall. As was the case in the Pendleton studies, visible injury was evident as chlorosis, slightly reduced plant height, and reductions in spike number and grain yield (Table 5). Even though the time was shorter between spring imazamox application to IMI-wheat and replanting of barley, injury was limited to fall applications. This can be explained by the fact that there was less wheat foliage present at the time of fall application, thereby resulting in greater concentrations of imazamox reaching the soil. This is similar to an effect observed with sulfosulfuron residual effects on dryland rotational crops (Shinn et al. 1998), where fall application of a residual herbicide to winter wheat resulted in greater carryover problems than did a later spring application. Wheat plants had considerably more leaf area available in spring to intercept the broadcast-applied sulfosulfuron and subsequently metabolized the herbicide.

Pea Trials. During the first year of this Pendleton experiment, precipitation was 3% above normal. Spring wheat grown after pea treated with imazamox exhibited slight visible injury and reduction in late-season dry weight (Table 6). Yield of spring wheat grown after pea treated with imazamox was reduced only by the 90-g/ha rate. Spring barley and canola also were injured by previous imazamox application rates. Injury was expressed as reduced plant height and late-season dry weight of barley and seed yields of both crops (Table 6). Canola

Table 6. Spring wheat, barley, and canola response to imazamox previously applied to pea, Pendleton, OR, 1999.

Imazamox rate	Stand count	Visible injury	Plant height	Late-season dry weight	Crop yield
g/ha	plants/m^2	%	cm	gm/m^2	kg/ha
Spring wheat					
0	106	0	62	753	3,240
45	106	5	64	913	3,590
90	106	13	60	525	2,380
LSD (0.05)	NS[a]	4	NS	256	630
Spring barley					
0	118	0	70	964	4,220
45	114	10	60	763	2,930
90	110	25	45	248	880
LSD (0.05)	NS	4	3	269	690
Canola					
0	40	0	—	128	126
45	32	65	—	107	14
90	32	64	—	177	21
LSD (0.05)	NS	18	—	NS	89

[a] Abbreviation: NS, not significant.

dry weight was not significantly different from the untreated check because of late-spring seeding, variable stand establishment, and insect injury. However, severe visible injury from residual soil concentrations of imazamox was apparent on canola throughout the growing season. Winter wheat grown after pea treated with imazamox was not affected measurably by imazamox residues in the soil (data not shown).

Higher precipitation amounts in the Pullman, WA, trial than in Pendleton (Table 1) may have contributed to a higher rate of imazamox soil dissipation. Yield of spring or winter wheat seeded in a normal rotation after an application of imazamox to herbicide-resistant wheat was not affected by imazamox carryover (data not shown).

These results demonstrate that dryland rotational crops can be affected adversely by imazamox application to pea or IMI-wheat under certain PNW dryland conditions, thereby limiting crop rotation options in some PNW locations. Of particular concern are areas where low precipitation and low-pH soils occur. Insufficient soil moisture for microbial degradation may limit decomposition of imazamox (Cobucci et al. 1998; Mangels 1991), thereby increasing the potential for injury to rotational crops such as barley, canola, and spring wheat. In addition, the sites reported in this study were in areas with relatively low soil pH (range 5.6 to 6.2), typical of many PNW dryland soils. Imidazolinone herbicides typically have greater persistence as soil pH decreases (Loux and Reese 1993; Renner et al. 1988). The reduced sorption of imazamox at low soil pH increases its bioavailabily and potential for carryover injury (Bresnahan et al. 2002). The low levels of soil moisture and low soil pH likely contributed at the Moro and Pendleton sites to the crop injury observed at these locations from imazamox carryover. It will be necessary to limit planting of rotational crops after imazamox application in areas with soil and moisture characteristics similar to the PNW sites described in this study.

LITERATURE CITED

Ball, D. A., F. L. Young, and A. G. Ogg, Jr. 1999. Selective control of jointed goatgrass with imazamox in herbicide-resistant wheat. Weed Technol. 13(1):77–82.

Ball, D. A. and D. L. Walenta. 1997. Jointed Goatgrass and Downy Brome Control in Imidazolinone Resistant Winter Wheat. Western Society of Weed Science (WSWS) Research Progress Report. p. 89.

Belles, W. S. and D. C. Thill. 1998. Weed Control in Imidazolinone Resistant Winter Wheat. WSWS Research Progress Report. 146 p.

Blackshaw, R. E. 1998. Postemergence weed control in pea (*Pisum sativum*) with imazamox. Weed Technol. 12:64–68.

Bresnahan, G., A. Dexter, W. Koskinen, and W. Lueschen. 2002. Influence of soil pH-sorption interactions on the carry-over of fresh and aged soil residues of imazamox. Weed Res. 42:45–51.

Brewster, B. D., D. M. Gamroth, and C. Mallory-Smith. 1997. Control of Annual Grasses in Imidazolinone-Resistant Winter Wheat with Imazamox. WSWS Research Progress Report. p. 92.

Cobucci, T., H. T. Prates, C.L.M. Falcao, M.M.V. Rezende. 1998. Effect of imazamox, fomesafen, and acifluorfen soil residue on rotational crops. Weed Sci. 46:258–263.

Douglas, Jr., C. L., R. W. Rickman, B. L. Klepper, J. F. Zuzel, and D. J. Wysocki. 1992. Agroclimatic zones for dryland winter wheat producing areas of Idaho, Washington, and Oregon. Northwest Sci. 66(1):27–34.

Gamroth, D. M., B. D. Brewster, and C. A. Mallory-Smith. 1997. Screen of Thirteen Herbicides Across Sixteen Grass Species. WSWS Research Progress Report. pp. 39–40.

Harvey, R. G., J. W. Albright, T. M. Anthon, and J. L. Kutil. 1995. Annual weed control in canning peas study. Proc. N. Cent. Weed Sci. Soc. 52: 16–17.

Loux, M. M., R. A. Liebl, and F. W. Slife. 1989. Availability and persistence of imazaquin, imazethapyr, and clomazone in soil. Weed Sci. 37:259–267.

Loux, M. M. and K. D. Reese. 1993. Effect of soil type and pH on persistence and carryover of imidazolinone herbicides. Weed Technol. 7:452–458.

Mangels, G. 1991. Behavior of the imidazolinone herbicides in soil, a review of the literature. *In* D. L. Shaner and S. L. O'Connor, eds. The Imidazolinone Herbicides. Boca Raton, FL: CRC Press. pp. 191–210.

Miller, S. D. and C. M. Alford. 2001. Weed control and rotational response to imazamox applications in winter wheat. Proc. West. Soc. Weed Sci. 54:73.

Neider, T. L. and D. C. Thill. 1997. Weed control in imidazolinone resistant winter wheat with AC 299,263. WSWS Research Progress Report. p. 101.

Ogg, P. J., G. Foster, D. J. Lyon, S. D. Miller, and P. Westra. 2001. Imazamox efficacy on different grass species in Clearfield winter wheat in the central great plains. Proc. West. Soc. Weed Sci. 54:73.

Oliveira, Jr., R. S., W. C. Koskinen, F. A. Ferreira, B. R. Khakural, D. J. Mulla, and P. C. Robert. 1999. Spatial variability of sorption/desorption of imazethapyr. Weed Sci. 47:243–248.

O'Sullivan, J., R. J. Thomas, and W. J. Bouw. 1998. Effect of imazethapyr and imazamox soil residues on several vegetable crops grown in Ontario. Can. J. Plant. Sci. 78:647–651.

Renner, K. A., W. F. Meggitt, and D. Penner. 1988. Effect of soil pH on imazaquin and imazethapyr adsorption to soil and phytotoxicity to corn. Weed Sci. 36:78–83.

Shinn, S. L, D. C. Thill, W. J. Price, and D. A. Ball. 1998. Response of downy brome (*Bromus tectorum*) and rotational crops to MON 37500. Weed Technol. 12:690–698.