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Title: Response of Dry Bulb Onion (Allium cepa), Sugar Beet (Beta vulgaris), and Pinto Beans (Phaseolus vulgaris) to Imazosulfuron Soil Residues

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Abstract: Field studies were conducted in 2010 in Ontario, OR to evaluate the response of direct-seeded dry bulb onion, sugar beet, and pinto bean to imazosulfuron soil residues 12 months after application to control weeds in potato. The studies followed randomized complete block design with three replications each. Imazosulfuron was applied alone PRE at 224- and 450 g ai ha-1, sequentially at 224 g ha-1 PRE and POST, or in tank mixture with s-metolachlor 1,060 g ha-1. Very few onion plants emerged in plots previously treated with imazosulfuron at 224 g ha-1, regardless of timing. Emerged onion plants were severely injured and never matured. No onions emerged from residues of imazosulfuron applied at 450 g ha-1. Few sugar beet plants emerged from 224 g ha-1 but were severely stunted and never grew beyond the first set of leaves. There was no sugar beet emergence from imazosulfuron sequential applications, regardless of the rate and application timing. However, imazosulfuron residues did not affect pinto beans, which emerged and produced marketable yield similar to grower standard and nontreated treatments. The results suggest sensitivity of direct-seeded dry bulb onion and sugar beet to imazosulfuron residues 12 months after application, but not pinto beans.

Felix: Crops and imazosulfuron residues

# Response of Dry Bulb Onion (*Allium cepa*), Sugar Beet (*Beta vulgaris*), and Pinto Beans (*Phaseolus vulgaris*) to Imazosulfuron Soil Residues

Joel Felix*

Field studies were conducted in 2010 in Ontario, OR to evaluate the response of direct-seeded dry bulb onion, sugar beet, and pinto bean to imazosulfuron soil residues 12 months after application to control weeds in potato. The studies followed randomized complete block design with three replications each. Imazosulfuron was applied alone PRE at 224- and 450 g ai ha$^{-1}$, sequentially at 224 g ha$^{-1}$ PRE and POST, or in tank mixture with *S*-metolachlor 1,060 g ha$^{-1}$. Very few onion plants emerged in plots previously treated with imazosulfuron at 224 g ha$^{-1}$, regardless of timing. Emerged onion plants were severely injured and never matured. No onions emerged from residues of imazosulfuron applied at 450 g ha$^{-1}$. Few sugar beet plants emerged from 224 g ha$^{-1}$ but were severely stunted and never grew beyond the first set of leaves. There was no sugar beet emergence from imazosulfuron sequential applications, regardless of the rate and application timing. However, imazosulfuron residues did not affect pinto beans, which emerged and produced marketable yield similar to grower standard and nontreated treatments. The results suggest sensitivity of direct-seeded dry bulb onion and sugar beet to imazosulfuron residues 12 months after application, but not pinto beans.

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**Nomenclature:** Imazosulfuron; potato, *Solanum tuberosum* L., 'Ranger Russet', SOLTU; sugar beet, *Beta vulgaris* L., 'HM91122RR' BEAVA; pinto beans, *Phaseolus vulgaris* 'GTS-900', PHSVN.

**Key words:** Potato, soil carryover, crop rotation, vegetables.

Vegetable growers often take advantage of more effective herbicides available to control weeds in crops grown in rotation in preceding years. The practice helps to control problematic weeds that may otherwise not be controlled by herbicides used in vegetable crops (Felix and Doohan 2005). The herbicide imazosulfuron is being evaluated for possible registration and use to control yellow nutsedge (*Cyperus esculentus* L.) on several solanaceous crops including potato. Imazosulfuron belongs to sulfonylurea herbicides; a family that controls weeds at low application rates and has high selectivity and low mammalian toxicity (Hay 1990; Morrica et al. 2001). Imazosulfuron properties include a molecular weight of 412.8, a pKa of 4, octanol-water partition coefficient (Kow) of 1.12 (pH 7, 25 C), and its solubility in water is 308 mg $L^{-1}$ (pH 7 and 25 C). Injury in susceptible plants is characterized by chlorosis followed by necrosis of meristematic tissue.

Imazosulfuron is currently registered for control of many annual and perennial broadleaf weeds and sedges in paddy rice (75 to 95 g ai $ha^{-1}$) and turf (500 to 1,000 g ai $ha^{-1}$) (Tomlin 1997). Morrica et al. (2001) reported that once applied to the soil, imazosulfuron degrades aerobically to 2-chloroimidazo[1,2-a]pyridine-3-sulfonamide and 1-(2-chloroimidazol chloroimidazol[1,2-]pyridine-3-ylsulfonyl)-3-(4-hydroxy-6-methoxypyrimidin-2-yl)urea; whereas, anaerobic conditions produce 2-amino-4,6-dimethoxypyrimidine, suggesting that degradation was due to microorganisms, which have the ability to demethylate imazosulfuron. In aerobic and anaerobic conditions, imazosulfuron dissipated from the soil with a half-life of approximately 70 and 4 d, respectively.

Several studies have been conducted to evaluate the suitability of imazosulfuron for weed control in various crops. Boydston and Felix (2008) reported yellow nutsedge control with imazosulfuron in potato. There was no effect on fresh-market tomato fruit shape and time to maturity when imazosulfuron was applied POST-directed at rates ranging from 40 to 330 g $ha^{-1}$ in North Carolina (Jennings 2010). Similarly, other field studies in North Carolina indicated 10% injury to bell pepper (*Capsicum anuum* L.) with no reduction in yield when imazosulfuron was applied POST-directed at rates ranging from 56 to 448 g $ha^{-1}$ (Pekarek 2008). However, Dittmar et al. (2010) reported 30% injury to watermelon (*Citrullus lanatus* Thunb) when imazosulfuron was applied at 400 g $ha^{-1}$. Recently, field studies conducted in Oregon and Washington indicated imazosulfuron efficacy on yellow nutsedge and potato tolerance when applied at rates ranging from 336 to 560 g $ha^{-1}$ alone or sequentially (Felix and Boydston 2010). However, inspection of the field in the subsequent year indicated severe injury to rotational sugar beet (*Beta vulgaris* L.) (J. Felix, personal observation).

Crop rotations in eastern Oregon and southwestern Idaho include onion, sugar beet, wheat (*Triticum aestivum* L.), potato, pinto bean, and corn (*Zea mays* L.) grown in different sequences. Felix and Boydston (2010) suggested follow up studies to elucidate rotational crop responses in subsequent years after imazosulfuron application to potato. Therefore, the objective of these studies was to evaluate the response of direct-seeded dry bulb onion, sugar beet, and pinto bean to imazosulfuron soil residues 12 months after application to control weeds in potato.

## Materials and Methods

Three field studies were conducted in 2009 at the Malheur Experiment Station, Ontario, OR to evaluate imazosulfuron herbicide for weed control in potato. The fields were adjacent to each other and the descriptions for soil type and properties are presented in Table 1. Each experiment was established in a randomized complete block design with three replications. Plots were 6.6 m wide by 9.1 m long. Plots were wide enough to accommodate three rotational crops each. Primary tillage in 2009 was completed according to local potato production practices. Similarly, fertilization, other pest control, and irrigation followed standard potato practices in western states (Strand 2006). Potato variety ‘Ranger Russet’ was planted on April 24, 2009 at seed piece spacing of 22.5 cm in rows spaced at 91 cm. Potato hills were harrowed and rebuilt (standard grower practice in Pacific Northwest) just prior to potato emergence. Imazosulfuron rates evaluated were 224- and 450, g $ha^{-1}$ applied pre-emergence (PRE); while the sequential treatment was applied at 224 g $ha^{-1}$ PRE and post emergence (POST). Other treatments were tank mixture of imazosulfuron 450 g $ha^{-1}$ plus *S*-metolachlor 1,060 g $ha^{-1}$ PRE followed by imazosulfuron at 224 g $ha^{-1}$ POST; a grower standard, which was a tank mixture of EPTC 4,400 g $ha^{-1}$ plus pendimethalin 840 g $ha^{-1}$ plus *S*-metolachlor 1,060 g $ha^{-1}$, followed by rimsulfuron at 70 g $ha^{-1}$ POST. The studies also included a hand weeded only treatment, which also served as a weed-free control. All imazosulfuron POST application timings included methylated seed oil (MSO) at 1% (V/V) while rimsulfuron included a nonionic surfactant at 0.25% V/V spray solution. The herbicides were applied in a total spray volume of 187 L $ha^{-1}$ on May 18 and June 9, 2009 PRE and POST, respectively. Herbicides were applied with a compressed $CO_2$ backpack sprayer[1] and a boom equipped with six TeeJet 8002 EVS[2] flat fan nozzles operated at 241 kPa. All POST herbicide treatments were applied when potato sprouts averaged 15 cm tall. Potato yield was determined on October 16, 2009 by weighing tubers harvested with the use of a mechanical harvester from 6 m of the center row. Tubers from each plot were subsequently graded by size and quality according to U.S. Department of Agriculture grading standards (Anonymous 1991).

The study area in each field was marked to maintain the integrity of the plots. Immediately after potato harvest, the study area was disked twice along the beds to minimize herbicide residue dilution and degradation enhancement, which has been reported to occur when fields are moldboard plowed (Felix and Doohan 2005). Each study was disked approximately 15 cm deep during fall 2009 and beds formed on 55 cm spacing to facilitate furrow irrigation of rotational crops in 2010. Rotational crops in each study included direct-seeded dry bulb onion variety 'Vaquero', transgenic sugar beet variety 'HM91122RR', and pinto beans variety 'GTS-900'. The plot size for each rotational crop was 2.2 m wide (4 beds) by 9.1 m long. On March 23, 2010, the beds intended for onion were harrowed and a precision planter used to plant double rows spaced 10 cm apart and 9 cm within row. Beds for sugar beet were harrowed on April 13 and planted on April 14, 2010 on 55 cm beds using tractor-mounted flexi-planter units with double-disc furrow openers and cone seeders fed from a spinner divider that uniformly distributed the seeds within the row. Sugar beet seeds were planted at the spacing of 11.43 cm within the row (153,980 seeds $ha^{-1}$). The area intended for pinto beans was harrowed on June 8 and the beans were planted at a rate of 90 kg $ha^{-1}$. No herbicides were used to control weeds in 2010, instead plots were periodically hand weeded to keep rotational crops weed free. Fertilization and other crop protection activities followed standard local practices. Field irrigation in both years was scheduled based on Watermark sensor readings (Model 200SS[3]) to prevent the soil at the 20 cm depth from drying beyond 60 kPa soil water tension.

Rotational crops were evaluated for visible injury at 7, 14, and 42 d after emergence (DAE) based on a scale of 0% (no apparent observable injury) to 100% (total plant death). All crops were raised to maturity, and plants within 8 m length of the two center rows were hand-harvested to determine yield. Onions were graded to determine the marketable yield following USDA standards (Anonymous 1995). Sugar beet roots were dug using a mechanical harvester, weighed and samples transported to the sugar factory for percent sucrose analysis. Pinto beans were hand harvested, cleaned and weighed to determine the final marketable yield (Anonymous 2008).

Nontransformed data were subjected to ANOVA with the use of PROC GLM procedure in SAS[4]. Type III statistics were used to test for significant differences ($P \leq 0.05$) among herbicide treatments, studies, and their interactions for visual plant injury and potato yield variables in 2009 and rotational dry bulb onion, sugar beet and pinto beans in 2010. The data for plant injury, potato yield, and rotational crop yield were subjected to a normality test. Because analysis of square-root-transformed data did not change the results of ANOVA, the nontransformed data were used in the final analysis. Data were pooled across studies when no significant study or study-by-treatment interactions were detected. Mean separations were performed with the use of Fisher's protected LSD test at a $P \leq 0.05$.

## Results and Discussion

There were no differences among studies or interactions with herbicide treatments for any of the crop variables; so the data for each crop were combined across studies and analyzed for herbicide treatment effects. Total precipitation during May to December 2009 when the potato crop was growing was 22.7 cm, which was 51% greater than the 10-yr historical average (Table 1). Cumulative precipitation during January to October 2010 was 26.8 cm, which was 53% greater than the 10-yr average. However, no moisture deficits were experienced as plants were irrigated in both years to prevent the soil at the 20 cm from drying beyond 60 kPa soil water tension. Weed control for the potato crop during 2009 was provided by the herbicide treatments tested and hand weeding for the untreated control. None of the herbicide rates tested injured potato (data not shown). No potato phytotoxicity from imazosulfuron applied at the tested rates had been observed in previous studies (Felix and Boydston 2010; Boydston and Felix 2008). Potato tuber yield in 2009 was combined for the three studies and there was no significant difference among treatments for <113 g and U.S. No.1 potato sizes (Data not shown). Total potato tuber yield ranged from 74 to 80 T $ha^{-1}$ for treatments that included imazosulfuron, which were not significantly different from the yield obtained when the grower standard was used (81 T $ha^{-1}$). The results further confirm the suitability of imazosulfuron for weed control in potato.

**Direct-seeded dry bulb onion response.** Dry bulb onions were severely injured by imazosulfuron soil residues and no yield was recorded from any of the treatments (Table 2). A few onion seedlings that emerged in plots previously treated with PRE imazosulfuron at 224 g ai $ha^{-1}$ and sequentially at 224 g $ha^{-1}$ PRE and POST remained severely stunted throughout the growing season and did not reach maturity at the time of harvest (data not shown). Soil residues from imazosulfuron applied at 450 g $ha^{-1}$ completely inhibited onion emergence. Marketable dry bulb onion yield was 83 and 71 T $ha^{-1}$ for the grower standard (tank mixture of EPTC 4,400 g $ha^{-1}$ plus pendimethalin 840 g $ha^{-1}$ plus *S*-metolachlor 1,060 g $ha^{-1}$, followed by rimsulfuron at 70 g $ha^{-1}$ POST) and hand weeded control treatments, respectively. The corresponding total onion yield was 86 and 74 T $ha^{-1}$, respectively. Imperfect weed control in the untreated plots in 2009 resulted in greater onion/weed competition in 2010, albeit season long efforts were made to remove weeds by hand. Sensitivity of onion to sulfonylurea herbicides has been reported. Greenland (2003) reported 43% and 51% reduction in onion yield from nicosulfuron soil residues 12 months after application to corn at 70 and 140 g $ha^{-1}$, respectively.

**Sugar beet response to imazosulfuron residues.** It is a common practice for growers in eastern Oregon to plant sugar beets in rotation with potato (J. Felix, personal observation). Sugar beet emergence was affected by soil residues from imazosulfuron 224 g $ha^{-1}$ or greater, regardless of the application timing (Table 2). The few plants that emerged in plots previously treated with imazosulfuron at 224 g $ha^{-1}$ PRE were severely stunted, chlorotic, and never grew beyond the first pair of leaves. Sugar beet root yield for the grower standard and hand weeded treatments was 116 and 115 T $ha^{-1}$, respectively. The corresponding sucrose content was 17 and 16%; while estimated recoverable sugar was 15 and 16 T $ha^{-1}$, respectively. Sugar beet sensitivity to sulfonylurea herbicides has been reported by other researchers. Moyer and Esau (1996) reported sugar beet yield reductions up to 3 yr after imazethapyr application to dry bean. Sugar beet was injured by chlorsulfuron residues following application to wheat in the previous year (Brewster and Appleby 1983). In studies by Moyer (1995), irrigated sugar beets were greatly injured by residues of the sulfonylurea herbicides tribenuron and thifensulfuron. Novosel et al. (1995) reported increased levels of sugar beet injury and corresponding yield loss from soil residues of primisulfuron herbicide applied at 40 and 80 g $ha^{-1}$. They reported a correlation between organic matter and the adsorption of primisulfuron across soil types. Soil organic matter in our studies ranged from 1.24 to 1.91% (Table 1) and sugar beet injury was similar across fields.

**Pinto bean response to imazosulfuron residues.** Pinto beans were not affected by imazosulfuron soil residues at any of the rates and application timing used in these studies (Table 2). The yield for pinto beans ranged from 4.6- to 5.1 T $ha^{-1}$ for plants growing in plots previously treated with PRE imazosulfuron at 224- and 450 g $ha^{-1}$ alone or applied POST in tank mixture with *S*-metolachlor. Pinto bean yield was lowest in hand weeded plots possibly due to increased weed competition resulting from incomplete control the previous year.

The results of these studies suggest that soil pH may have contributed to imazosulfuron carryover. The soil pH in the three study sites at Ontario was 6.9, 7.8, and 7.9 (Table 1). Morrica et al. (2001) reported that the hydrolysis rate of imazosulfuron was characterized by a first-order kinetics, pH and temperature dependent, and accelerated by acidic conditions and higher temperatures. Imazosulfuron half-lives at pH 4.5 and 5.9 were reported to be 36.5 and 578 d, respectively (Morrica et al. 2001). Previous studies have also indicated no significant change in imazosulfuron concentration after 150 d at soil pH 6.6, 7.4, 9.2, and 12.3 (Morrica et al. 2001; WSSA 2007). Sulfonylurea herbicides are primarily degraded by hydrolysis and microbes. Consequently, the possibility for carryover is greater in higher pH soils (pH >6.8) because acid hydrolysis ceases at high pH levels. Onion, sugar beet, and pinto beans were planted 309, 331, and 366 d after imazosulfuron application. It is possible that imazosulfuron residues had further subsided by the time pinto beans were planted. Because studies were irrigated, soil moisture can be discounted as a factor in imazosulfuron carryover in these studies. These results suggest greater sensitivity of direct-seeded onion and sugar beet to imazosulfuron soil residues. However, pinto beans may safely be planted 12 months after imazosulfuron application. Further studies are needed to determine the period needed before rotational onion and sugar beet can be safely planted in fields previously treated with imazosulfuron.

## Source of Material

[1] $CO_2$ Sprayers Systems, Bellspray Inc., R&D Sprayers, P. O. Box 267, Opelousas, LA 70571.

[2] TeeJet 8002 EVS and 8002 XR flat-fan nozzle tips, Spraying Systems Co., P. O. Box 7900, Wheaton, IL 60188.

[3] Irrometer moisture sensors, Irrometer Company, Inc., P.O. Box 2424, Riverside, CA 92516-2424.

4 SAS user’s guide. Version 9.2. Statistical Analysis Systems Institute, Inc., P. O. Box 8000, Cary, NC 25712-8000.


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Table 1. Soil properties, precipitation, and irrigation for imazosulfuron studies at Ontario, OR in 2009 and 2010.

| Soil type | Owyhee silt loam [a] | | |
|---|---|---|---|
| pH | 6.9 | 7.8 | 7.9 |
| Organic matter (%) | 1.87 | 1.91 | 1.24 |
| Soil texture | | | |
| Sand (%) | 15 | 17 | 14 |
| Silt (%) | 68 | 67 | 68 |
| Clay (%) | 17 | 15 | 18 |

| | Rainfall (cm)[b] | | Irrigation and Evapotranspiration (cm)[c] | |
|---|---|---|---|---|
| | 2009 | 2010 | 2009 | 2010 |
| January – April | 5.3 (8.3) | 13.0 (8.3) | -- | 10 (0.4) |
| May | 3.7 (2.6) | 3.0 (2.8) | 2.1 (2.5) | 0 (5.6) |
| June | 5.8 (1.7) | 5.0 (2.2) | 5.4 (14.8) | 20 (15.2) |
| July | 0.2 (0.4) | 0.1 (0.4) | 16.2 (25.3) | 50 (28.7) |
| August | 3.5 (0.7) | 2.2 (0.9) | 6.6 (19.0) | 50 (22.0) |
| September | 0.1 (1.0) | 0.5 (1.1) | 3.3 (7.7) | 0 (11.6) |
| October | 3.2 (2.1) | 3.0 (1.9) | -- | |
| November | 1.6 (2.3) | | -- | |
| December | 4.6 (4.2) | | -- | |

| | | | |
|---|---|---|---|
| Total | 28.0 (23.3) | 26.8 (17.6) | -- |

[a] Monthly rainfall with 10 yr average in brackets, with November and December including snow.

[b] Owyhee silt loam (coarse-silty, mixed, mesic, xerollic camborthid).

[c] Monthly irrigation amount with evapotranspiration in brackets. Potato was sprinkler irrigated in 2009 with schedule based on six Watermark soil moisture sensors (Irrometer Co., Riverside, CA) connected to an AM400 data logger (M.K. Hansen Co., Wenatchee, WA), that recorded soil water tension at seed-piece depth. Irrigations were managed to prevent the soil at the seed-piece depth from drying beyond 60 kPa soil water tension. In 2010, rotational crops were furrow irrigated for 24 h per occurrence (water inflow was estimated to be 10 cm). Furrow irrigation was schedule to maintain moisture in the top 20 cm of the soil profile.

Table 2. Pooled yield for direct-seeded dry bulb onion, sugar beet, and pinto bean in response to imazosulfuron soil residues 12 months after application to potato at the Malheur Experiment station, Ontario, OR in 2010.

| | | | Onion yield[a] | | | Sugar beet | | | Pinto bean | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Dose | Timing | Small | Marketable | Total | Yield | Sucrose | ERS[b] | Stand | Yield |
| | g ai/ha | | ------------------------ $T\ ha^{-1}$ -------------------------- | | | | % | T/ha | no. (x000) $ha^{-1}$ | $T\ ha^{-1}$ |
| Imazosulfuron | 224 | PRE | 0 c | 0 c | 0 c | 0 b | 0 b | 0 b | 433 a | 5.1 a |
| Imazosulfuron | 450 | PRE | 0 c | 0 c | 0 c | 0 b | 0 b | 0 b | 456 a | 4.6 ab |
| Imazosulfuron | 224; 224 | PRE; POST[c] | 0 c | 0 c | 0 c | 0 b | 0 b | 0 b | 436 a | 5.0 ab |
| *S*-metolachlor + | 1,060 | PRE | 0 c | 0 c | 0 c | 0 b | 0 b | 0 b | 432 a | 4.8 ab |
| Imazosulfuron | 450; 224 | PRE; POST | | | | | | | | |
| Grower standard[d] | | | 3 a | 83 a | 86 a | 116 a | 17 a | 15 a | 436 a | 4.1 b |
| Hand weeded | | | 3 a | 71 b | 74 b | 115 a | 16 a | 16 a | 437 a | 4.1 b |

[a] Means within a column for each crop followed by the same letter are not significantly different according to LSD *P*=0.05. Small onions have diameter ≤ 3.81 cm while marketable are > 3.81 cm.

[b] Estimated recoverable sugar.

[c] POST treatment included methylated seed oil (MSO) at 1% V/V.

[d] Grower standard treatments was tank mixes of EPTC plus pendimethalin plus *S*-metolachlor at 4,400 plus 840 plus 1,060 g ai $ha^{-1}$ PRE followed by rimsulfuron 70 g ai/ha plus 0.25% V/V POST.

***Response to Reviewers**

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