Imazethapyr Rate Responses for Wild Radish, Conventional Canola, and Imidazolinone-tolerant Canola

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Abstract
Greenhouse experiments were conducted to determine dose responses to imazethapyr for imidazolinone-tolerant canola (Brassica napus) Pioneer 45A71, conventional canola Oscar, and wild radish (Raphanus raphanistrum). Two weeks after treatment, foliar injury was rated and plants were harvested to determine plant dry weight. Plant responses to herbicide treatments were analyzed by non-linear regression procedures using a modified Mitscherlich plant growth model for visual injury and the negative exponential growth function for plant dry weight. Pioneer 45A71 was tolerant of all rates of imazethapyr (0.055 to 0.60 g ai/liter). In contrast, wild radish and Oscar were sensitive to imazethapyr with significant injury and approximately 50% reduction in dry plant weight at rates of 0.275 g ai/liter and greater. For the model, increased injury from herbicide treatment resulted in significantly different asymptotic maximum ($\beta_o$) injury for all plant types. The dry weight for the non-treated control was 1.3, 0.8, and 1.5 g/plant for wild radish, Pioneer 45A71, and Oscar, respectively. For the models, $\beta_1$ parameters indicated significant differences in response to imazethapyr treatment between the Pioneer 45A71, wild radish, and Oscar dry weights.

Introduction
In canola (Brassica napus L.) production, it is essential to control cruciferous weeds like wild radish (Raphanus raphanistrum L.). Wild radish is the most common and troublesome winter-annual weed in many small grain production regions of the world including Australia (1,10), Canada (16), and the southeastern (6,22) and northeastern United States (18). Cruciferous species compete vigorously with canola, and data indicate that significant yield losses can occur if these weeds are not controlled soon after crop emergence (1,11,12). Seed of cruciferous species are high in erucic acid and glucosinolates that can pose quality problems in harvested canola and may cause rejection or significant price dockage (5).

Research that screened a number of herbicides failed to demonstrate any naturally-occurring differential tolerance between conventional canola and wild radish for post-emergence dicot herbicides (2).

The introduction of herbicide tolerance has provided an alternative mechanism for achieving differential herbicidal selectivity between canola and monocot and dicot weed species. Enhanced tolerance to herbicides has been achieved with canola for atrazine (12), acetolactate synthase inhibitors (7,20), glyphosate (3,13,15), glufosinate (7,8,9), and bromoxynil (4).

Canola tolerant to imidazolinone herbicides was produced via selected cell culture. Imidazolinone-tolerant canola is tolerant to multiple imidazolinone herbicides including imazethapyr and imazamox (7). Prior to introduction of imidazolinone-tolerant canola cultivars, research indicated the cruciferous weed wild mustard (Brassica kaper L.) exhibited a linear rate response to imazamethabenz (17).
Imidazoline herbicides and related chemistries that share the same mechanism of action by inhibiting acetloactate synthase (ALS) are commonly used on crops such as corn (Zea mays L.), soybean (Glycine max (L.) Merr., peanut (Arachis hypogaea L.), and wheat (Triticum aestivum) L. (14). The use of cultivars with tolerance to imazethapyr offers the added advantage of a means of protection against re-crop injury from a host of ALS herbicides commonly used on crops in rotation with canola.

Reports of ALS-resistant wild radish have occurred in Australia (20) indicating that management practices utilizing different herbicide modes of action may prevent herbicide resistance of this weed in canola production regions. Herbicide-resistant canola has also been considered a weed in rotational crop production (16). The utilization of canola cultivars tolerant to imidazolinone herbicides would allow producers more rotational options in areas where these herbicides are used on conventional and herbicide-tolerant canola. A better understanding of crop tolerance and weed control efficacy in imidazolinone-tolerant systems is needed. The objective of this research was to determine the herbicide dose responses for imidazolinone-tolerant canola Pioneer 45A71, the conventional canola cultivar Oscar, and wild radish. From these, critical herbicide levels can be determined by graphical plant growth modeling procedures that will assist in establishment of tolerance and/or susceptibility.

Greenhouse Experiments with Imazethapyr

Experiments were conducted in 1999 in a greenhouse under natural light with average day/night temperatures of 30/25°C. Daily high temperatures varied by 5°C, and night temperatures varied by 3°C. The imidazolinone-tolerant cultivar Pioneer 45A71 was compared with wild radish and the conventional cultivar Oscar. All plants were grown in standard insert six-cell packs (TFI Plastics, Progress Growers Supply Inc., Canton, GA). Each cell measured 38 mm² with a volume of 45 ml and was filled with a commercial potting mix (Fafard potting soil mix no. 3-B, Progress Growers Supply Inc., Canton, GA). Each cell was hand-seeded with five seeds of the appropriate plant material, thinned to two plants per cell after emergence, watered as needed throughout the experiment (visually determined), and fertilized weekly with soluble plant food (Peters Professional All-Purpose Plant Food, Scotts-Sierra Horticultural Products Company, Marysville, OH) at 1.6 g/liter. Two-week-old seedlings were uniformly exposed to imazethapyr by submerging the entire six-cell pack and the seedlings in an herbicide solution for 5 s. This procedure uniformly exposed shoot and roots to herbicide treatment and has been previously utilized with herbicide testing (19). At the time of imazethapyr application, canola had one to two leaves at three to five cm in height. Wild radish had one to three leaves at two to five cm in height. Imazethapyr (Pursuit herbicide, BASF Corp. Research Triangle Park, NC) was applied using solution concentrations of 0.055, 0.11, 0.165, 0.22, 0.275, 0.33, 0.385, 0.43, 0.53, and 0.60 g ai/liter, respectively. Normal field rates of imazethapyr are applied at 52 g ai/ha (Pursuit herbicide, BASF Corp. Mississauga, ON Canada). When this rate is applied in water at a volume of 187 liter/ha (20 gal/acre) the solution concentration is 0.27 g ai/liter. Non-ionic surfactant (Chem Nut 80-20 Non Ionic Surfactant-Adjuvant, Chem Nut Inc., Albany, GA) at 0.5% (v/v) was included with this treatment.

The experimental design was a factorial arrangement of herbicide rate by species/cultivar in a completely random design with three replicates. The experiment was conducted twice.

Visual estimates of percent crop injury and wild radish control (stunting and chlorosis) were recorded 2 weeks after treatment on a scale of 0 (no control) to 100% (complete injury or death) relative to the non-treated control. The number of surviving plants per six-cell pack was recorded and then harvested by clipping at the soil surface. Plant material was oven dried at 85°C for 48 hours and weighed. Average dry weight per plant was calculated by dividing the total dry weight of all plants within a six-cell pack by the number of surviving plants. Dry weight data were also expressed as a percentage of the non-treated control. Dead plants were not used for dry weight determination (0% dry weight).
**Statistical Analysis**

Data were subjected to analysis of variance (ANOVA $P \leq 0.05$). Data were combined over experimental runs after analysis indicated no significant differences between experiments. General linear models procedures were then used with mean separation using 95% asymptotic confidence intervals.

Visual injury data were regressed against herbicide concentration using the modified Mitscherlich equation (21):

$$g = \beta_o \left[ (1-P)e^{-\beta_1(x-\beta_2)} \right]$$

where $g = 90\%$ of maximum response, $\beta_o$ is the asymptote, $\beta_1$, the slope, and $\beta_2$ the value of $x$ when $P = 0.10$. $P$ was set at 0.10 for the modified Mitscherlich equation in order to determine the 90% $g$ response. Plant dry weights and percent dry weight relative to the non-treated control were regressed against herbicide concentration using the negative exponential growth function:

$$Y = \beta_o e^{(-\beta_1 x)}$$

where $Y$ is plant dry weight or percent dry weight, $\beta_o$ is the intercept, $\beta_1$ the slope, and $x$ is the herbicide rate (g ai/ha) based on exposure at 187 liter/ha.

**Effect of Imazethapyr on Pioneer 45A71, Oscar, and Wild Radish**

Herbicide treatment resulted in significantly different asymptotic maximum ($\beta_o$) for all plant types (Table 1), indicating that the models were useful in predicting herbicide dose responses for the susceptible species wild radish and Oscar canola. Additionally, $\beta_1$ parameter for plant dry weight indicated significant differences between Pioneer 45A71, wild radish, and Oscar dry weights. These data indicate that utilizing proper herbicide dose to control wild radish and volunteer canola could reduce the potential development of ALS resistance in these weeds. Past incidences of herbicide resistance have occurred as a result of reduced herbicide rates over time (14,15).

Pioneer 45A71 was tolerant to all rates of imazethapyr (Figs. 1A, B, and C). Data indicated that Pioneer 45A71 had no significant reduction in plant dry weight (Fig. 1A). Visual injury ratings of less than 3% were observed (Fig. 1A) for imazethapyr. No injury has been previously reported for 45A71 up to 30 g ai/ha in field trials (8) corresponding to 0.165 g ai/liter in this study assuming 187 liter/ha. In contrast, wild radish and Oscar were sensitive to imazethapyr with reduction in dry plant weight following a concentration response. For imazethapyr-sensitive plants, both the modified Mitscherlich equation and the negative exponential growth function provided a good fit for the injury data and the plant dry weight data sets, respectively, as indicated by high $R^2$ values for Oscar and wild radish (Table 1). In contrast, neither equation adequately described Pioneer 45A71 data, which were practically linear for all evaluations (Fig. 1A, B, and C).
Table 1. Estimated parameters for the modified Mitscherlich and negative exponential models used to characterize the relationship between imazethapyr concentration, injury, and plant dry weight for Figure 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Equation</th>
<th>Species</th>
<th>β₀</th>
<th>β₁</th>
<th>β₂</th>
<th>R²</th>
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<tr>
<td>Visual injury (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Figure 1A</td>
<td>Mitscherlich</td>
<td>Wild radish</td>
<td>169</td>
<td>2.2 a</td>
<td>1.1 a</td>
<td>0.89</td>
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<td>Figure 1A</td>
<td>Mitscherlich</td>
<td>Pioneer 45A71</td>
<td>6</td>
<td>9.3 c (ns)</td>
<td>0.3 a (ns)</td>
<td>NF</td>
</tr>
<tr>
<td>Figure 1A</td>
<td>Mitscherlich</td>
<td>Oscar</td>
<td>108</td>
<td>4.5 b</td>
<td>0.5 a</td>
<td>0.92</td>
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<tr>
<td>Dry weight (g/plant)</td>
<td>Negative exponential</td>
<td>Wild radish</td>
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<td>6.6 a</td>
<td></td>
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</tr>
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<td>Pioneer 45A71</td>
<td>0.8 b</td>
<td>-0.1 b (ns)</td>
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<td>NF</td>
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<td>Oscar</td>
<td>1.5</td>
<td>5.3 a</td>
<td></td>
<td>0.71</td>
</tr>
<tr>
<td>Dry weight (% nontreated)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Figure 1C</td>
<td>Negative exponential</td>
<td>Wild radish</td>
<td>90 b</td>
<td>6.6 a</td>
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<td>Negative exponential</td>
<td>Pioneer 45A71</td>
<td>118 a</td>
<td>-0.1 b (ns)</td>
<td></td>
<td>NF</td>
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<tr>
<td>Figure 1C</td>
<td>Negative exponential</td>
<td>Oscar</td>
<td>92 b</td>
<td>5.3 a</td>
<td></td>
<td>0.71</td>
</tr>
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x Modified Mitscherlich equation, \( g = \beta_0[(1-P)e^{\beta_1(x-\beta_2)}] \), \( P = 0.10 \) in order to determine 90% \( g \) response; negative exponential growth function, \( Y = \beta_0 e^{(\beta_1 x)} \).

Y For their respective variable, values in each column followed by the same letter are not significantly different from each other according to Fisher’s protected LSD test at \( P \leq 0.05 \) level. (ns) indicates that this parameter did not significantly contribute to the respective equation; NF indicates the model did not accurately depict the data. To obtain the equation for the respective regression line in Figure 1, fill in the parameters from Table 1.

z \( R^2 \) is defined as 1.0 minus the ratio of residual sum of squares to the total corrected sum of squares.
Fig. 1. Percent visual injury (A), shoot dry weight (B), and dry weight as a percentage of the nontreated (C) for the imidazolinone canola cultivar Pioneer 45A71, susceptible canola cultivar Oscar, and wild radish.
Asymptotic maximum values for $\beta_o$ for the visual injury rate-response curves of Oscar and wild radish were similar to each other, but significantly different from the asymptotic values of the corresponding Pioneer 45A71 rate-response curves. Intercept values $\beta_o$ for the dry weight and dry weight as a percent of the untreated control rate-response curves of Oscar and wild radish were similar to each other, but significantly different from the intercept values of the corresponding Pioneer 45A71 rate-response curves. The tolerance of 45A71 to imazethapyr was further extenuated in that $\beta_1$ and $\beta_2$ did not significantly contribute to the respective equations.

These results indicate that the increase in injury from imazethapyr treatment resulted in significantly different $\beta_o$ asymptotic maximum injury for all plant types (Table 1). The dry weight ($\beta_o$ parameter) of each plant type for non-treated control was 0.8 g per plant for Pioneer 45A71, 1.5 g per plant for canola cultivar Oscar, and 1.3 g per plant for wild radish (Table 1). Injury to imazethapyr-sensitive plants increased with herbicide rate and ranged from 0 to 100% (Fig. 1C). Oscar and wild radish were sensitive to imazethapyr exhibiting injury at rates as low as 28 g ai/ha. Pioneer 45A71 was very tolerant to imazethapyr at all concentrations. The $\beta_1$ parameters indicated significant differences between the imidazolinone-tolerant canola, conventional canola, and wild radish.

In future breeding of imidazolinone-tolerant lines of canola, these data will assist in establishing the level of tolerance, either in crop or when as a weed in rotational crops, and weed susceptibility.

**Acknowledgment**

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**Literature Cited**


