Tolerance of azuki bean to herbicides applied preplant for weed control in a strip-tillage cropping system

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Abstract
Five field experiments were conducted at Huron Research Station near Exeter, Ontario, Canada, during 2018 to 2020 to assess the tolerance of strip-till-grown azuki bean to various preplant (PP) herbicides. The herbicides selected have activity on glyphosate-resistant (GR) Canada fleabane, an emerging weed biotype in strip-till azuki bean production. Saflufenacil, metribuzin, 2,4-D ester, saflufenacil + metribuzin, saflufenacil + 2,4-D ester, metribuzin + 2,4-D ester, and saflufenacil + metribuzin + 2,4-D ester, applied PP 1 week before seeding, at the proposed label rate (1X) and twice that rate (2X) caused as much as 6%, 5%, 6%, 7%, 8%, 10%, and 13% visible azuki bean injury. The herbicide-induced azuki bean injury was transient and had no effect on plant density, aboveground dry biomass, height, maturity, and yield except for the dry biomass which was reduced by 28% with metribuzin + 2,4-D ester and 36% with saflufenacil + metribuzin + 2,4-D ester at the 2X rate and azuki bean height which was reduced 9% at the 2X rate with saflufenacil + metribuzin + 2,4-D ester. Based on these results, saflufenacil, metribuzin, 2,4-D ester, saflufenacil + metribuzin, saflufenacil + 2,4-D ester, and metribuzin + 2,4-D ester applied PP have potential for GR Canada fleabane control in strip-till azuki beans. However, there is not enough crop safety for using a three-way tankmix of saflufenacil + metribuzin + 2,4-D ester, applied PP, in azuki bean production.

KEYWORDS
2,4-D ester, Canada fleabane, Erigeron canadensis, metribuzin, saflufenacil, Vigna angularis

1 | INTRODUCTION

Azuki bean [Vigna angularis (Willd.) Ohwi & H. Ohashi] is an important niche market specialty legume crop grown in southwestern Ontario, Canada. Azuki bean plant grows up to 50 cm in height and produces yellow flowers followed by clusters of long green pods (Grant, 2020). There are different cultivars of azuki bean that produce red, white, black, and gray colored seeds, but the azuki bean plants grown in North America produce a small (approximately 5 mm) reddish-brown seed with a scar along its side which is enclosed by long green pods (Grant, 2020). The pod turns yellow in late summer as the seed matures indicating approximate harvest maturity (Grant, 2020). Azuki bean seed has a creamy, sweet, and nutty flavor and is used in confectionary products in Asia (Uwaegbute, 1996). The majority of the azuki bean produced in Ontario is for the export market to Japan and other countries in Asia.

Azuki beans grown in Ontario have been primarily grown using a conventional tillage cropping system. However, in recent years, bean growers are trying to adopt conservation tillage programs (no-, reduced-, and strip-tillage) to improve soil structure, enhance soil...
health, and provide protection against water and wind erosion (Deibert, 1995; Godsey et al., 2018). In a strip-till cropping system, only the in-row area is tilled which results in the positive attributes of a no-tillage cropping system while maintaining the favorable conditions of the conventional tillage including higher soil temperature, drier at soil at time of seeding, and fertilizer placement in the crop row at the time of planting (Bottenberg et al., 1999; Licht & Al-Kaisi, 2005).

In recent years, glyphosate-resistant (GR) weed, such as Canada fleabane (Erigeron canadensis L.), has become a troublesome weed in azuki bean as it is present in at least 30 counties across southern Ontario (Budd, 2016; Byker et al., 2013). GR Canada fleabane is a greater problem as tillage is reduced. Presently, there are no weed management programs to manage GR Canada fleabane in azuki bean in Ontario. Azuki bean producers need effective herbicide options to control GR Canada fleabane and other herbicide-resistant (HR) weeds to be able to adapt no-, reduced-, and strip-tillage cropping systems.

Studies conducted in Ontario with soybean have shown that various combinations of herbicides that include saflufenacil, metribuzin, and 2,4-D ester applied preplant (PP) can be effective for the control of GR Canada fleabane (Budd et al., 2016; Byker et al., 2013; Soltani et al., 2017). However, these herbicides are not currently registered for utilization in azuki bean. Earlier research on Phaseolus vulgaris dry bean market classes has shown that saflufenacil, metribuzin, and saflufenacil + metribuzin applied 1 week PP can cause significant injury in dry beans (Soltani et al., 2014, 2019a). Dry beans come from different geographic origins and thus differ in genetic pools which can affect their sensitivity to herbicides (Renner & Powell, 2002; Singh, Gepts, & Debouck, 1991; Singh, Gutierrez, et al., 1991; Singh, Nodari, & Gepts, 1991). More studies are needed to evaluate the crop safety of these herbicides and their tankmixes for utilization in azuki bean production. If the crop safety is acceptable, these herbicides applied alone or in tankmixtures may provide a viable PP option for the management of GR Canada fleabane and other HR weeds in azuki bean production.

The purpose of this study was to ascertain the tolerance of strip-till-grown azuki bean to saflufenacil, metribuzin, 2,4-D ester, saflufenacil + metribuzin, saflufenacil + 2,4-D ester, metribuzin + 2,4-D ester, and saflufenacil + metribuzin + 2,4-D ester, applied PP, at the proposed label rate (1X) and twice that rate (2X).

2 | MATERIALS AND METHODS

Five field trials (one in 2018 and two in each year in 2019 and 2020) were conducted at the Huron Research Station, University of Guelph, Exeter, Ontario, Canada. The soil was a Brookston clay loam with 18%–41% sand, 40%–46% silt, 19%–36% clay, 3.3%–4.7% organic matter, and pH of 7.5–7.7. Till strips (20 cm wide) were made in the autumn with a four-row Orthman 1TRIP (Orthman Mfg., 75765 Road 435, Lexington, NE, USA) strip-tillage implement. The azuki bean was planted within the strip-tilled area the following spring.

Treatments (replicated four times in a randomized complete block design) included an untreated control, saflufenacil (25 g ai ha⁻¹), metribuzin (400 g ai ha⁻¹), 2,4-D ester (532 g ai ha⁻¹), saflufenacil + metribuzin (25 + 400 g ai ha⁻¹), saflufenacil + 2,4-D ester (25 + 532 g ai ha⁻¹), metribuzin + 2,4-D ester (400 + 532 g ai ha⁻¹), saflufenacil + metribuzin + 2,4-D ester (25 + 400 + 532 g ai ha⁻¹), saflufenacil (50 g ai ha⁻¹), metribuzin (800 g ai ha⁻¹), 2,4-D ester (1064 g ai ha⁻¹), saflufenacil + metribuzin (50 + 800 g ai ha⁻¹), saflufenacil + 2,4-D ester (50 + 1064 g ai ha⁻¹), metribuzin + 2,4-D ester (800 + 1064 g ai ha⁻¹), and saflufenacil + metribuzin + 2,4-D ester (50 + 800 + 1064 g ai ha⁻¹). Doses of herbicides assessed are once (1X) and twice (2X) the dose needed to control GR Canada fleabane in soybean. Each plot consisted of four rows of azuki bean (232,000 seeds ha⁻¹; seeded late May to early June) spaced 75 cm apart in rows that were 10 m long.

A CO₂–pressurized backpack sprayer calibrated to deliver 200 L ha⁻¹ at 240 kPa was used to apply the herbicides 7 days before azuki bean was seeded. The spray boom was 1.5 m long with four ultralow drift ULD120-02 nozzles (VeeJet® Ultra low-drift 12002 nozzles, Spraying Systems Company, P.O. Box 7900 Wheaton, IL 60189-7900) spaced 0.5 m apart producing a 2.0 spray width. All plots were kept free of weeds throughout the study.

Crop injury was assessed (0–100 = no injury-complete necrosis) 1, 2, 4, and 8 weeks after crop emergence (WAE). At 3 WAE, azuki density (number per m of row) and dry biomass (g m⁻¹ row⁻¹ and plant⁻¹) were measured. At 3 WAE, the height of 10 randomly selected azuki bean plants was measured in each plot. Azuki bean was harvested at maturity; seed yield was corrected to 13% moisture.

Data were examined utilizing the GLIMMIX procedure in SAS (2016). The fixed effect was treatment, and random effects were year–location combinations (environment), replicate within the environment, and the environment by treatment interaction. The Shapiro–Wilk statistic, fit statistics, residual plots, and the potential distributions were used to identify the best distribution and associated link function for each parameter. Least square means (LSMEANS) were calculated on the data scale by utilizing the inverse link function, and pairwise comparisons were subjected to Tukey’s adjustment before determining treatment differences at P < 0.05. The arcsine square root transformation with a normal distribution and identity-link was utilized for % azuki bean injury at 1, 2, 4, and 8 WAE. Azuki density, dry biomass, height, and yield were examined using the normal distribution. Azuki bean seed moisture was examined using a log-normal distribution. The untreated control was given a value of 0 for all injury assessments and therefore was not included in the analysis because there was no variance. However, differentiation between the 0 value and other treatments was still doable by utilizing the LSMEANS and identifying variations.

3 | RESULTS AND DISCUSSION

At 1, 2, 4, and 8 WAE, saflufenacil applied PP caused 2%, 3%, 1%, and 0% at the 1X rate and 4%, 6%, 6%, and 2% azuki bean injury at the 2X
TABLE 1  Five trials conducted near Exeter, Ontario, Canada, between 2018 and 2020 to assess azuki bean injury with three different preplant herbicides applied alone and in combination at 1X and 2X rates

| Treatment                        | Rate (g ai ha⁻¹) | Visible injury (%) |
|----------------------------------|------------------|--------------------|
|                                  |                  | 1 WAE  | 2 WAE  | 4 WAE  | 8 WAE  |
| Untreated control                |                  | 0.0f   | 0.0e   | 0.0g   | 0.0e   |
| Saflufenacil                     | 25               | 2.0e   | 2.5d   | 0.6f   | 0.2ed  |
| Metribuzin                       | 400              | 2.2de  | 2.3d   | 1.9def | 0.4cde |
| 2,4-D ester                      | 532              | 3.3cde | 2.8cd  | 1.3ef  | 0.4cde |
| Saflufenacil + metribuzin        | 25 + 400         | 2.8cde | 2.6d   | 1.8def | 0.3de  |
| Saflufenacil + 2,4-D ester       | 25 + 532         | 2.9cde | 3.0c   | 2.7cde | 0.9bcd |
| Metribuzin + 2,4-D ester         | 400 + 532        | 4.0cde | 3.2cd  | 2.3cde | 0.9bcd |
| Saflufenacil + metribuzin + 2,4-D ester | 25 + 400 + 532 | 4.0cde | 4.9bcd | 4.5bcde | 1.3bcd |
| Saflufenacil                     | 50               | 4.2cde | 5.6bcd | 5.8bcde| 1.5bcd |
| 2,4-D ester                      | 1064             | 6.3abcd| 5.4bcd | 5.2bcde| 1.4bcd |
| Saflufenacil + metribuzin        | 50 + 800         | 4.2bcd | 5.9bcde| 7.1abc | 1.3bcd |
| Saflufenacil + 2,4-D ester       | 50 + 1064        | 7.2abc | 7.6abc | 7.3abc | 2.0abc |
| Metribuzin + 2,4-D ester         | 800 + 1064       | 9.8ea  | 9.9ab  | 10.3ab | 2.4ab  |
| Saflufenacil + metribuzin + 2,4-D ester | 50 + 800 + 1064 | 11.8a  | 12.7a  | 13.4a  | 4.6a   |

Note: Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$. Abbreviation: WAE, weeks after crop emergence.

TABLE 2  Five trials conducted near Exeter, Ontario, Canada, between 2018 and 2020 to determine azuki bean density, dry biomass, moisture, and yield with three different preplant herbicides applied alone and in combination at 1X and 2X rates

| Treatment                        | Rate (g ai ha⁻¹) | Density m⁻¹ (no.) | Dry biomass m⁻¹ (g) | Dry biomass plant⁻¹ (g) | Height (cm) | Moisture (%) | Yield (t ha⁻¹) |
|----------------------------------|------------------|------------------|--------------------|-------------------------|-------------|--------------|----------------|
|                                  |                  | 1 WAE            | 2 WAE             | 4 WAE                   | 8 WAE       |
| Untreated control                |                  | 16.1             | 10.3cd            | 0.64 ab                  | 32.5 a      | 14.22abc     | 1.52ab         |
| Saflufenacil                     | 25               | 16.1             | 11.1d             | 0.68a                   | 32.9a       | 14.17ab      | 1.57ab         |
| Metribuzin                       | 400              | 15.1             | 10.5cd            | 0.70a                   | 32.9a       | 14.19ab      | 1.58ab         |
| 2,4-D ester                      | 532              | 14.9             | 9.8bcd            | 0.67a                   | 32.5a       | 14.12a       | 1.55ab         |
| Saflufenacil + metribuzin        | 25 + 400         | 14.8             | 9.4bcd            | 0.64ab                  | 32.8a       | 14.20ab      | 1.62a          |
| Saflufenacil + 2,4-D ester       | 25 + 532         | 14.9             | 9.9bcd            | 0.66ab                  | 32.5a       | 14.21abc     | 1.55ab         |
| Metribuzin + 2,4-D ester         | 400 + 532        | 15.2             | 10.7cd            | 0.68a                   | 32.3a       | 14.17ab      | 1.59ab         |
| Saflufenacil + metribuzin + 2,4-D ester | 25 + 400 + 532 | 14.2             | 9.6bcd            | 0.66ab                  | 31.5ab      | 14.28abc     | 1.48ab         |
| Saflufenacil                     | 50               | 15.3             | 8.8abcd           | 0.59abc                 | 31.3ab      | 14.39bc      | 1.54ab         |
| Metribuzin                       | 800              | 15.0             | 9.4bcd            | 0.61abc                 | 31.9ab      | 14.31abc     | 1.48ab         |
| 2,4-D ester                      | 1064             | 14.9             | 8.8abcd           | 0.59abc                 | 31.6ab      | 14.25abc     | 1.43b          |
| Saflufenacil + metribuzin        | 50 + 800         | 15.3             | 9.2abcd           | 0.61abc                 | 31.2ab      | 14.34abc     | 1.46ab         |
| Saflufenacil + 2,4-D ester       | 50 + 1064        | 14.3             | 8.2abc            | 0.57abc                 | 30.9ab      | 14.30abc     | 1.41b          |
| Metribuzin + 2,4-D ester         | 800 + 1064       | 14.1             | 7.4ab             | 0.52bc                  | 31.0ab      | 14.38bc      | 1.48ab         |
| Saflufenacil + metribuzin + 2,4-D ester | 50 + 800 + 1064 | 13.1             | 6.6a              | 0.48c                   | 29.6b       | 14.44c       | 1.40b          |

Note: Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

rate, respectively (Table 1). Saflufenacil applied PP at either rate had no negative effect on azuki bean density (3 WAE), dry biomass $m⁻¹ row⁻¹$ (3 WAE), dry biomass plant⁻¹ (3 WAE), height (6 WAE), maturity (seed moisture), and yield (Table 2).

At 1, 2, 4, and 8 WAE, metribuzin applied PP, injured azuki bean caused 2%, 2%, 2%, and 0% at the 1X rate and 5%, 5%, 5%, and 1% at the 2X rate, respectively (Table 1). Metribuzin applied PP at either rate had no negative effect on azuki bean plant density,
dry biomass m−1 row−1, dry biomass plant−1, height, maturity, and yield (Table 2).

At 1, 2, 4, and 8 WAE, 2,4-D ester applied PP, injured azuki bean caused 3%, 3%, 1%, and 0% at the 1X rate and 6%, 5%, 5%, and 1% at the 2X rate, respectively (Table 1). 2,4-D ester applied PP at either rate had no negative effect on azuki bean plant density, dry biomass m−1 row−1, dry biomass plant−1, height, maturity, and yield (Table 2).

At 1, 2, 4, and 8 WAE, saflufenacil + metribuzin applied PP, injured azuki bean caused 3%, 3%, 2%, and 0% at the 1X rate and 4%, 6%, 7%, and 1% at the 2X rate, respectively (Table 1). Saflufenacil + metribuzin applied PP at either rate had no negative effect on azuki bean plant density, dry biomass m−1 row−1, dry biomass plant−1, height, maturity, and yield (Table 2).

At 1, 2, 4, and 8 WAE, saflufenacil + 2,4-D ester applied PP, injured azuki bean caused 3%, 3%, 3%, and 1% at the 1X rate and 7%, 8%, 7%, 2% at the 2X rate, respectively (Table 1). Saflufenacil + 2,4-D ester applied PP at either rate had no negative effect on azuki bean plant density, dry biomass m−1 row−1, dry biomass plant−1, height, maturity, and yield except for dry biomass m−1 of row which was reduced 28% at the 2X rate compared with the control (Table 2).

At 1, 2, 4, and 8 WAE, metribuzin + 2,4-D ester applied PP, injured azuki bean caused 4%, 3%, 2%, and 1% at the 1X rate and 10%, 10%, 10%, and 2% at the 2X rate, respectively (Table 1). Metribuzin + 2,4-D ester applied PP at either rate had no negative effect on azuki bean plant density, dry biomass m−1 row−1, dry biomass plant−1, height, maturity, and yield except for dry biomass m−1 of row which was reduced 28% at the 2X rate compared with the control (Table 2).

At 1, 2, 4, and 8 WAE, saflufenacil + metribuzin + 2,4-D ester applied PP, injured azuki bean caused 4%, 5%, 5%, and 1% at the 1X rate and 12%, 13%, 13%, and 5% at the 2X rate, respectively (Table 1). Saflufenacil + metribuzin + 2,4-D ester applied PP at either rate had no negative effect on azuki bean plant density, dry biomass m−1 row−1, dry biomass plant−1, height, maturity, and yield except for azuki bean dry weight/meter of row which was reduced 36%, dry weight/plant which was reduced 25%, and height which was reduced 9% at the 2X rate (Table 2).

These results are in contrast with research in P. vulgaris market classes which exhibited as much as 18%, 5%, 12%, and 22% visible injury with saflufenacil, metribuzin, 2,4-D ester, and saflufenacil + metribuzin, respectively (Soltani et al., 2019a). In the same study, dry biomass of P. vulgaris market classes was not adversely affected with 2,4-D ester but was decreased up to 42%, 58%, and 58% with saflufenacil, metribuzin, and saflufenacil + metribuzin, respectively (Soltani et al., 2019a). In addition, 2,4-D ester caused no adverse effect on height, but saflufenacil and saflufenacil + metribuzin reduced height 32% and 34% in white beans, respectively (Soltani et al., 2019a). The same study found as much as 76% reduction in yield of kidney bean, small red bean, and white bean with saflufenacil, metribuzin, and saflufenacil + metribuzin, but the yield of kidney bean, small red bean, and white bean was not adversely affected with 2,4-D ester applied PP 1 week before seeding (Soltani et al., 2019a). In another study, saflufenacil applied PRE at 25 and 50 g ai ha−1 decreased yield of azuki bean 31% and 64%, respectively (Soltani et al., 2014). Stewart et al. (2010) reported 6%–12% azuki bean injury without any reduction in dry biomass, height, and yield with metribuzin applied PPI or PRE at 560 g ai ha−1. 2,4-D ester applied 14-, 7- and 1-day PP caused up to 1%, 5%, and 7% azuki bean injury at 528 g ai ha−1 and 6%, 7%, and 10% azuki bean injury at 1056 g ai ha−1, respectively, in another study (Soltani et al., 2019b). Similar to the current study, these initial injuries caused no negative responses on azuki bean density, dry biomass, height, maturity, or yield (Soltani et al., 2019b).

4 | CONCLUSION

Based on these results, saflufenacil, metribuzin, 2,4-D ester, saflufenacil + metribuzin, saflufenacil + 2,4-D, metribuzin + 2,4-D ester, and saflufenacil + metribuzin + 2,4-D ester applied PP at the 1X rate caused up to 5% injury in azuki bean with no significant effect on azuki bean density, dry biomass, height, maturity, and yield. Saflufenacil, metribuzin, 2,4-D ester, saflufenacil + metribuzin, saflufenacil + 2,4-D ester, metribuzin + 2,4-D ester, and saflufenacil + metribuzin + 2,4-D ester applied PP at the 2X rate caused up to 13% injury in azuki bean. The injury was minimal for most treatments and had no significant effect on the maturity and final seed yield of the azuki bean. This study concludes that saflufenacil, metribuzin, 2,4-D ester, saflufenacil + metribuzin, saflufenacil + 2,4-D ester, and metribuzin + 2,4-D ester applied PP 1 week before seeding at the proposed rates have the potential for GR Canada fleaebane in azuki bean production. However, there is not enough crop safety for using a three-way tankmix of saflufenacil + metribuzin + 2,4-D ester, applied PP, 1 week before seeding in azuki bean production.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The source data are available upon request.

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