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# Dose-response of common lambsquarters, redroot pigweed, and foxtail species to pyroxasulfone plus encapsulated saflufenacil applied preemergence in corn

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**Short Title:** Poxasulfone+saflufenacil

**Abstract**

The premixture of pyroxasulfone and encapsulated saflufenacil is a new herbicide from BASF. There is limited research conducted on the biologically effective dose of pyroxasulfone and encapsulated saflufenacil premixture for the control of common lambsquarters, redroot pigweed, and green foxtail. A total of six field experiments were conducted over two years (2022 and 2023) at three locations in southwestern Ontario to determine the $ED_{50}$ of pyroxasulfone plus encapsulated saflufenacil for the control of common lambsquarters, redroot pigweed, and green foxtail. Assessment of visual weed control 8 WAE established the $ED_{50}$ for redroot pigweed, common lambsquarters, and green foxtail control were 170, 219, and 240 g ai $ha^{-1}$, respectively. The results of this study conclude that a higher dose of pyroxasulfone and encapsulated saflufenacil is necessary for agronomically acceptable control (>80%) of redroot pigweed, common lambsquarters, and green foxtail than the proposed label rate (146 to 245 g ai $ha^{-1}$).

**Nomenclature:** Pyroxasulfone; saflufenacil; common lambsquarters, *Chenopodium album* L.; redroot pigweed, *Amaranthus retroflexus* L.; Canada fleabane, *Conyza canadensis* (L.) Cronq.; velvetleaf, *Abutilon theophrasti* Medik.; waterhemp, *Amaranthus tuberculatus* (Moq.) J.D. Sauer; wild mustard (*Sinapis arvensis* L.); stinkweed, *Thlaspi arvense* L.; wild buckwheat, *Polygonum convolvulus* L.; green foxtail, *Setaria viridis* L.; barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv.; large crabgrass, *Digitaria sanguinalis* (L.) Scop.; corn, *Zea mays* L.

**Keywords:** Corn injury, corn yield, dose-response, encapsulation, herbicide formulation, preemergence herbicides, species-specific.

## Introduction

Corn (*Zea mays* L.) is a major crop in Canada; it is primarily grown in Ontario, where over 60% of Canada's 1.5 million hectares are produced (Statistics Canada 2023), equating to 2.35 billion CAD in total farm income in 2023 (MAFRA 2024). In the United States, corn was grown on 38.1 million hectares with a production value of 91.7 billion USD (USDA 2022; USDA 2023). Weed interference in field corn causes an average yield loss of 50% when no weed management tactics are used (Soltani et al. 2016). Herbicides are the most commonly used weed management tool, with 96% of corn hectares having at least one application (NASS 2022).

A new premixture herbicide containing pyroxasulfone (Group 15) plus encapsulated saflufenacil (Group 14) could combat challenging weed problems, inhibiting corn yields. This premixture herbicide combines two herbicide sites of action, a Group 15 very long-chain fatty acid elongases (VLCFAE) inhibitor and a Group 14 protoporphyrinogen oxidase (PPO) inhibitor (Shaner 2014). Pyroxasulfone has been available in Ontario, Canada since the 2016 growing season (Health Canada 2016). Pyroxasulfone provides 4 to 6 weeks (200 to 300 g ai ha$^{-1}$) residual weed control when applied before weed emergence; however, the herbicide can be applied early postemergence (POST) with a tank-mix partner to attain activity on already emerged weeds (Anonymous 2022a,b; OMAFRA 2021). Pyroxasulfone is predominately a rate-dependant grass herbicide with activity on a few broadleaf weeds and sedges (Anonymous 2022b; OMAFRA 2021; Shaner 2014). Grasses controlled by pyroxasulfone include barnyardgrass, foxtail species, and large crabgrass, while broadleaf weeds include redroot pigweed, velvetleaf, and waterhemp (Nurse et al. 2011; OMAFRA 2021; Yamaji et al. 2014). The suspension concentrate (SC) formulation of saflufenacil has been sold in Canada since the 2010 growing season, applied preplant (PP), preplant incorporated (PPI), or preemergence (PRE) for the control of a wide range of broadleaf weeds (Health Canada 2024; OMAFRA 2021). The SC formulation of saflufenacil applied before crop emergence controls common lambsquarters, redroot pigweed, common ragweed, Canada fleabane, velvetleaf, wild buckwheat, wild mustard, and stinkweed (Boydston et al. 2012; Geier et al. 2009; OMAFRA 2021).

In corn-producing regions of North America, growers demand a high level of weed control efficacy with low acceptance of crop injury. Pyroxasulfone and encapsulated saflufenacil is a new herbicide formulation, but there is limited research on the necessary doses to control problematic weed species in southwestern Ontario. By conducting a biologically effective dose study, there is a better understanding of the rate required to control a particular weed species with this new encapsulated formulation. The objective of this study was to determine the biologically effective dose of pyroxasulfone plus encapsulated saflufenacil applied PRE for control of common lambsquarters, redroot pigweed, and foxtail species as well as assess corn injury.

**Materials and Methods**

This study consisted of six site-years conducted over two years (2022 and 2023) in southwestern Ontario; four in Ridgetown, Ontario, on the University of Guelph, Ridgetown Campus, and two located near Belmont, Ontario, on the BASF London Research Farm. Trials were set up as a randomized complete block design with 9 treatments and 4 replications; plot size of 2 x 8 m. Field preparation consisted of conventional tillage (chisel ploughed in the fall followed by cultivation in the spring) and fertilization as per Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) recommendation based on soil tests. Corn was then planted at approximately 80,000 seeds ha$^{-1}$ in rows spaced 75 cm apart to a depth of 5 cm. Refer to Table 1 for additional soil and crop information. Following planting, the herbicide treatments were applied PRE with a $CO_2$-pressurized backpack sprayer calibrated to deliver 200 L ha$^{-1}$. To establish the dose-response 9 doses of pyroxasulfone plus encapsulated saflufenacil (0, 18.25, 36.5, 73, 146, 195, 245, 490, and 980 g ai ha$^{-1}$) were applied prior to corn and weed emergence. Doses were established based on a proposed label rate of 146 to 245 g ai ha$^{-1}$. Refer to Table 2 for the treatment list and rate structure for individual active ingredients (pyroxasulfone and encapsulated saflufenacil) in this premixture.

Corn injury was rated 1, 2, and 3 weeks after emergence (WAE) on a 0 to 100% scale, where 0 indicates no visible symptoms and 100 is complete plant death. Weed control was assessed at 4 and 8 WAE on the same 0 to 100% scale. Weed density and biomass were collected at 8 WAE by placing a 0.25 m$^2$ quadrat at two random locations (between corn rows and at least 1 m$^{-1}$ from the plot edge) in each plot and counting, clipping at the soil surface, and collecting each weed species within the quadrats separately. The collected samples were then dried in a kiln until a consistent moisture was achieved. The dried plant material was then weighed to record above-ground biomass for each plot. The weed spectrum evaluated across all locations consisted of common lambsquarters, redroot pigweed, and foxtail species. Weed pressure was consistent across replications and sites to ensure accurate evaluations. Yield data was collected at crop maturity using a mechanical plot harvester to get weight and moisture content for each plot, which were used to adjust the yield to 15.5% moisture.

Data from all 6 site-years were combined for analysis and interpretation across multiple environments following the analysis of random effects. Two environments were removed for foxtail species and one for redroot pigweed before analysis due to low weed pressure. PROC NLIN, in SAS 9.4, was utilized to regress weed control, weed density, weed biomass, and corn yield evaluations over herbicide dose (SAS Institute Inc., Cary, NC). Regression curves that best fit the data from this study were chosen by assessing modeling efficiency and root mean squared error (Archontoulis and Miguez 2015). Weed control and yield data were regressed over an exponential to a maximum curve (Equation 1):

$$y = a - b\,(e^{(-c*dose)})$$

where y is the response parameter, a is the upper asymptote, b is the magnitude constant, and c is the slope. Weed density and biomass was regressed over an inverse exponential curve (Equation 2):

$$y = a + b\,(e^{(-c*dose)})$$

where y is the response parameter, a is the lower asymptote, b is the reduction in y from intercept to asymptote, and c is the slope from intercept to a. Effective dose (ED) for 50% control, density, and biomass was calculated using equations 1 and 2. Since density and biomass are not calculated on a 0 to 100 scale, 50% of the untreated control was calculated to establish the $ED_{50}$. $ED_{90}$ was not determined because it would be inappropriate when the dose required exceeded the range used in this study.

**Results and Discussion**

*Weed Control 4 and 8 WAE*

A lower rate of pyroxasulfone plus encapsulated saflufenacil was needed to control redroot pigweed compared to common lambsquarters and foxtail species at 4 WAE (Figure 1; Table 3). At 8 WAE redroot pigweed required the lowest rate for control, followed by common lambsquarters and foxtail species (Figure 2; Table 3). The required dose of pyroxasulfone plus encapsulated saflufenacil for 50% control of redroot pigweed, foxtail species, and common lambsquarters was 145, 204, and 214 g ai $ha^{-1}$, respectively at 4 WAE (Figure 1; Table 3). The required dose of pyroxasulfone plus encapsulated saflufenacil for 50% control of redroot pigweed, common lambsquarters, and foxtail species was 170, 219, and 240 g ai $ha^{-1}$, respectively at 8 WAE (Figure 1; Table 3). The $ED_{90}$ for visual weed control was not achieved for any weed species evaluated or evaluation timing (4 and 8 WAE) with the rates applied in this study.

*Weed Density and Biomass*

The required dose of pyroxasulfone plus encapsulated saflufenacil for a 50% reduction in common lambsquarters, redroot pigweed, and foxtail species density was 34, 86, and 108 g ai $ha^{-1}$, respectively (Figure 3; Table 4). Higher doses of pyroxasulfone plus encapsulated saflufenacil were required for a 50% reduction in biomass. The required dose of pyroxasulfone plus encapsulated saflufenacil for a 50% reduction in redroot pigweed, common lambsquarters, and foxtail species biomass was 125, 183, and 528 g ai $ha^{-1}$, respectively (Figure 4; Table 4). Biomass data were variable, but Figure 4 shows a dramatic decrease in foxtail species biomass as the dose increased, while common lambsquarters and redroot pigweed have a less dramatic decrease in biomass. The $ED_{90}$ for weed density and biomass was not achieved for any weed species evaluated with the rates applied in this study.

A previous field study conducted by Knezevic et al. (2009) established the $ED_{90}$ of pyroxasulfone was 200 to 300 g ai $ha^{-1}$ across multiple grass and broadleaf weed species. Previous greenhouse research on dose-response of saflufenacil applied PRE for control of multiple broadleaf weeds had 90% biomass reduction at 9 g ai $ha^{-1}$ (Geier et al. 2009). This

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contrasts with the results of this study, where the dose required for a 50% reduction in biomass of redroot pigweed, common lambsquarters, and foxtail species was much higher. Higher rates for control in field trials, as opposed to greenhouse studies, is to be expected due to increased environmental variance. Mahoney et al. (2014) established the $ED_{50}$ of pyroxasulfone/flumioxazin for common lambsquarters, pigweed species, and green foxtail at 8 weeks after application was 46, 3, and 57 g ai $ha^{-1}$, respectively, by conducting 11 field experiments. While comparison of field trials from different studies can be impacted by soil characteristics and environment the results of this study suggest that weed control efficacy may be reduced with the encapsulated formulation.

*Corn Injury and Yield*

Pyroxasulfone plus encapsulated saflufenacil applied PRE caused no corn injury in this study, even at extreme rates of 490 and 980 g ai $ha^{-1}$ (data not shown). This is not surprising given that the SC formulation of saflufenacil and pyroxasulfone is both registered for PRE application in corn (Anonymous 2022a; Anonymous 2022b; OMAFRA 2021). Reduced weed interference with increasing doses of pyroxasulfone plus encapsulated saflufenacil increased corn yield (Figure 5). Corn yield plateaued at 245 g ai $ha^{-1}$ with no further increase in corn yield when pyroxasulfone plus encapsulated saflufenacil was applied at doses above 245 g ai $ha^{-1}$.

Based on this study, the doses of pyroxasulfone and encapsulated saflufenacil required for 50% control are weed species-specific. The required dose of pyroxasulfone and encapsulated saflufenacil was lower for redroot pigweed than common lambsquarters and foxtail species. Reduced weed interference with increasing doses of pyroxasulfone and encapsulated saflufenacil resulted in an increase in corn yield up to 245 g ai $ha^{-1}$. In this study the $ED_{90}$ was not achieved with rates up to 980 g ai $ha^{-1}$ of pyroxasulfone plus encapsulated saflufenacil for all weed species evaluated when the proposed label rate is 146 to 245 g ai $ha^{-1}$. Since the $ED_{90}$ of pyroxasulfone and encapsulated saflufenacil for the control of redroot pigweed, common lambsquarters, and foxtail species was greater than the doses evaluated in this study, future research should evaluate a complementary pyroxasulfone plus encapsulated saflufenacil dose with appropriate tank-mix partners.

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## Practical Implications

The results of this study provide important information for growers and agronomists using pyroxasulfone plus encapsulated saflufenacil as a preemergence herbicide in corn production. No corn injury was observed with pyroxasulfone plus encapsulated saflufenacil, supporting the crop safety of this herbicide mixture in corn production systems. The pyroxasulfone plus encapsulated saflufenacil herbicide mixture demonstrated species-specific efficacy, requiring lower doses for effective control of redroot pigweed and higher doses for common lambsquarters and foxtail species, particularly extended periods after application (8 weeks after emergence). Importantly, higher herbicide rates consistently resulted in reduced weed density, biomass, and weed interference, leading to significant improvements in corn yield which plateaued at approximately 245 g ai $ha^{-1}$. Despite these yield benefits, the study found that the doses required for 90% weed control ($ED_{90}$) were not achieved within the range of doses tested, especially for more difficult-to-control species like foxtail. Overall, for improved weed management and optimal crop yield, this study supports a more tailored approach that accounts for weed species present and potentially integrating higher doses or additional herbicide sites of action. Future product recommendations and weed management programs should incorporate these findings to enhance control efficacy and crop yield while minimizing the risk of herbicide resistance through diversified weed control strategies.

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**Competing Interests.** A co-author of this manuscript, Chris Budd is the Senior Biologist with BASF Canada Inc. Other authors declare no conflicts of interest.

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**Table 1.** Year, location, soil characteristics, corn hybrid, planting, emergence, and harvest dates, and herbicide application date for six field trials conducted in southwestern Ontario, Canada in 2022 and 2023.

| | | Soil characteristics | | | | Crop information | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Location | Texture | OM | pH | CEC | Hybrid | Planting date | Emergence date | Harvest date | Herbicide application date |
| | | | % | | | | | | | |
| 2022 | Ridgetown Campus (A) | Sandy loam | 2.9 | 7.4 | 8.4 | DKC39-97RIB | May 11 | May 17 | Nov 4 | May 12 |
| | Ridgetown Campus (B) | Clay loam | 4.1 | 7.2 | 18.0 | DKC39-97RIB | May 13 | May 23 | Nov 2 | May 16 |
| | BASF Research Farm | Loam | 2.9 | 6.6 | 13.5 | DKC48-56RIB | Jun 14 | Jun 21 | Nov 10 | Jun 16 |
| 2023 | Ridgetown Campus (A) | Sandy clay loam | 4.3 | 6.6 | 10.8 | DKC39-97RIB | May 11 | May 19 | Oct 24 | May 12 |
| | Ridgetown Campus (B) | Clay loam | 4.9 | 6.7 | 15.2 | DKC39-97RIB | May 16 | May 25 | Oct 25 | Jun 2 |
| | BASF Research Farm | Loam | 2.8 | 7.2 | 9.6 | DKC48-56RIB | May 25 | Jun 2 | Nov 15 | Jun 9 |

Abbreviations: OM, organic matter; CEC, cation exchange capacity.

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**Table 2.** Treatment list, product rate, and active ingredient rate structure for the premixture herbicide applied for six field trials conducted in southwestern Ontario, Canada in 2022 and 2023.

| Herbicide treatment | Rate | | |
|---|---|---|---|
| | Premixture[a] | Pyroxasulfone | Encapsulated Saflufenacil |
| | g ai $ha^{-1}$ | | |
| Nontreated control | 0 | 0 | 0 |
| Pyroxasulfone plus encapsulated saflufenacil | 18 | 11 | 7 |
| Pyroxasulfone plus encapsulated saflufenacil | 25 | 15 | 10 |
| Pyroxasulfone plus encapsulated saflufenacil | 36.5 | 22.5 | 14 |
| Pyroxasulfone plus encapsulated saflufenacil | 73 | 45 | 28 |
| Pyroxasulfone plus encapsulated saflufenacil | 146 | 90 | 56 |
| Pyroxasulfone plus encapsulated saflufenacil | 195 | 120 | 75 |
| Pyroxasulfone plus encapsulated saflufenacil | 245 | 151 | 94 |
| Pyroxasulfone plus encapsulated saflufenacil | 490 | 301.5 | 188.5 |
| Pyroxasulfone plus encapsulated saflufenacil | 980 | 603 | 377 |

[a]Premixture herbicide containing pyroxasulfone plus encapsulated saflufenacil

**Table 3.** Non-linear regression parameters and predicted pyroxasulfone plus encapsulated saflufenacil dose required for 50% visual control of common lambsquarters, redroot pigweed, and foxtail species 4 and 8 weeks after emergence from six field trials conducted in southwestern Ontario, Canada in 2022 and 2023.

| | Weed species | Regression parameters (± SE)[a] | | | Predicted dose |
|---|---|---|---|---|---|
| | | a | b | c | $ED_{50}$[b] |
| | | | | | g ai $ha^{-1}$ |
| 4 WAE | Common lambsquarters | 82.85 (5.05) | 81.69 (5.36) | 0.0043 (0.0007) | 214 |
| | Redroot Pigweed | 84.77 (5.15) | 83.81 (6.06) | 0.0061 (0.0011) | 145 |
| | Foxtail species | 81.87 (5.89) | 80.33 (6.36) | 0.0045 (0.0009) | 204 |
| 8 WAE | Common lambsquarters | 86.18 (4.28) | 89.24 (5.08) | 0.0041 (0.0006) | 219 |
| | Redroot Pigweed | 90.62 (5.45) | 93.02 (6.02) | 0.0049 (0.0008) | 170 |
| | Foxtail species | 82.92 (6.77) | 86.04 (7.06) | 0.0040 (0.0008) | 240 |

Abbreviations: WAE, weeks after emergence.

[a]Regression parameters calculated using $y = a - b\,(e^{(-c*dose)})$ where y is the response parameter, a is the upper asymptote, b is the magnitude constant, and c is the slope.

[b]$ED_{50}$ is effective dose require to achieve 50% visible control.

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**Table 4.** Non-linear regression parameters and predicted pyroxasulfone plus encapsulated saflufenacil dose required for 50% reduction of common lambsquarters, redroot pigweed, and foxtail species density and biomass at 8 weeks after emergence for six field trials conducted in southwestern Ontario, Canada in 2022 and 2023.

| | Weed species | Regression parameters (± SE) a | b | c | Predicted dose $ED_{50}$ (± SE) |
|---|---|---|---|---|---|
| | | | | | g ai $ha^{-1}$ |
| Density | Common lambsquarters | 7.86 (3.26) | 49.04 (6.85) | 0.024 (0.0081) | 34 |
| | Redroot pigweed | 1.25 (2.00) | 25.18 (2.84) | 0.011 (0.0033) | 86 |
| | Foxtail species | 11.66 (2.92) | 16.30 (5.32) | 0.018 (0.0150) | 108 |
| Biomass | Common lambsquarters | 11.27 (6.47) | 45.01 (7.42) | 0.006 (0.0023) | 183 |
| | Redroot pigweed | 7.24 (13.25) | 114.80 (17.10) | 0.008 (0.0033) | 125 |
| | Foxtail species | 3.08 (9.14) | 17.11 (8.56) | 0.002 (0.0029) | 528 |

Abbreviations: WAE, weeks after emergence.

[a]Regression parameters calculated using y = a + b ($e^{(-c*dose)}$) where y is the response parameter, a is the lower asymptote, b is the reduction in y from intercept to asymptote, and c is the slope from intercept to a.

[b]$ED_{50}$ is effective dose require to achieve 50% visible control.

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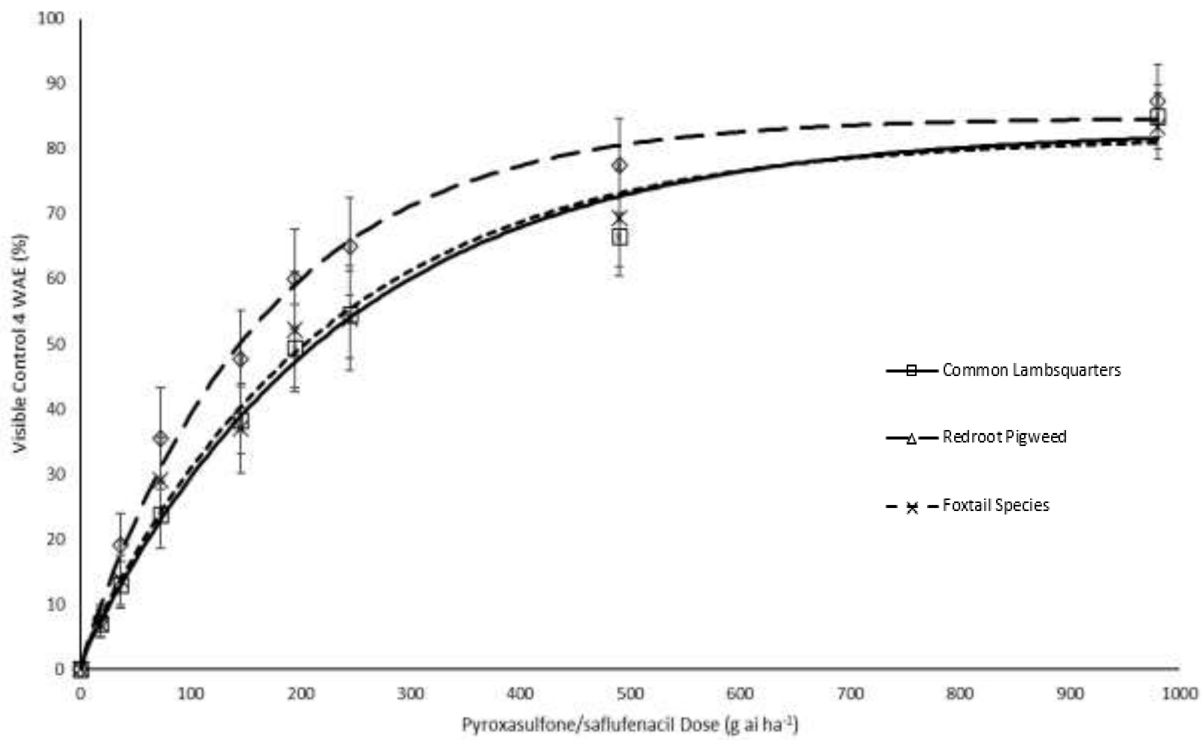


**Figure 1.** Visible weed control (%) of common lambsquarters, redroot pigweed, and foxtail species with pyroxasulfone and encapsulated saflufenacil 4 weeks after emergence (WAE). Vertical bars represent ± SE of means. Dose-response curves were fit to an exponential to a maximum model using nonlinear regression (Equation 1).

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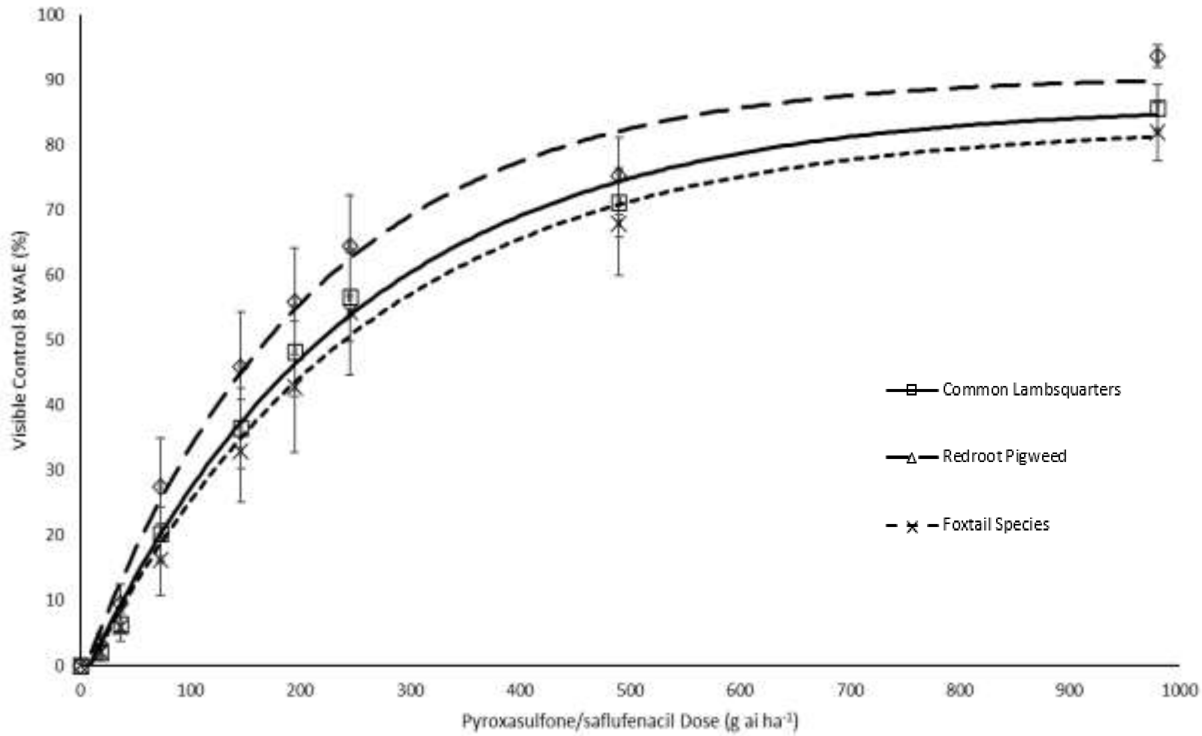


**Figure 2.** Visible weed control (%) of common lambsquarters, redroot pigweed, and foxtail species with pyroxasulfone and encapsulated saflufenacil 8 weeks after emergence (WAE). Vertical bars represent ± SE of means. Dose-response curves were fit to an exponential to a maximum model using nonlinear regression (Equation 1).

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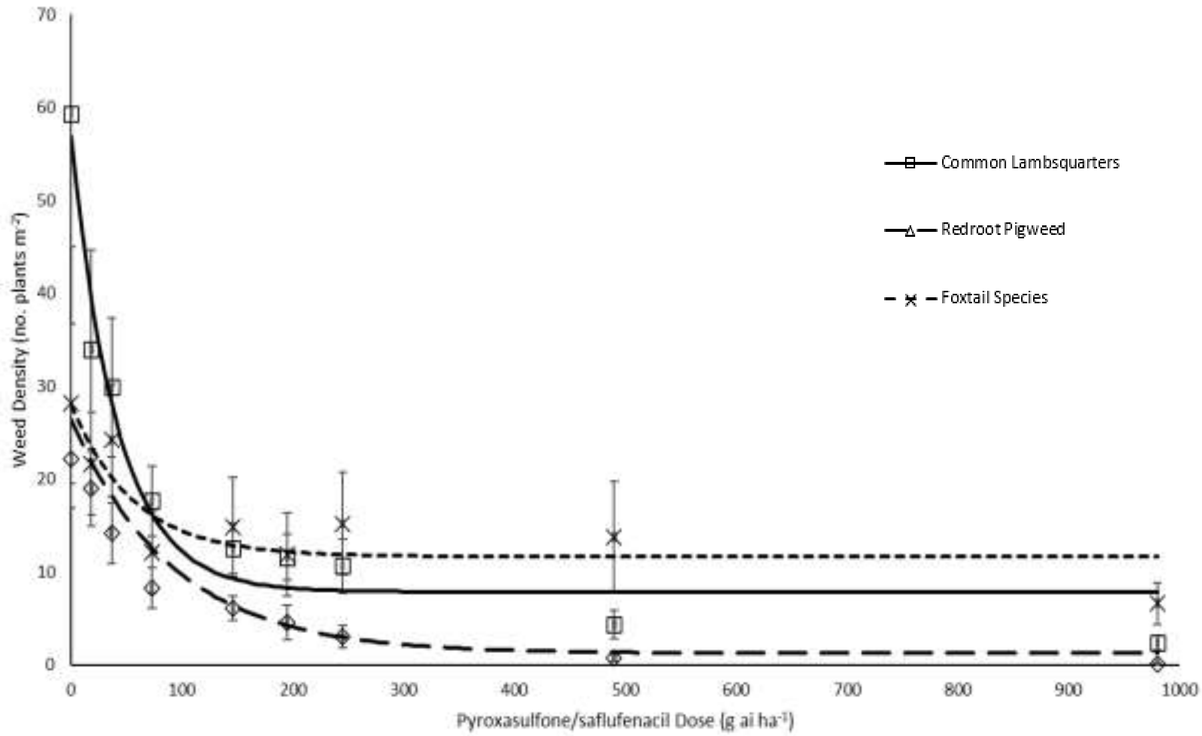


**Figure 3.** Weed density (no. plants m $^{-2}$) of common lambsquarters, redroot pigweed, and foxtail species with pyroxasulfone and encapsulated saflufenacil 8 weeks after emergence (WAE). Vertical bars represent ± SE of means. Dose-response curves were fit to an inverse exponential model using nonlinear regression (Equation 2).

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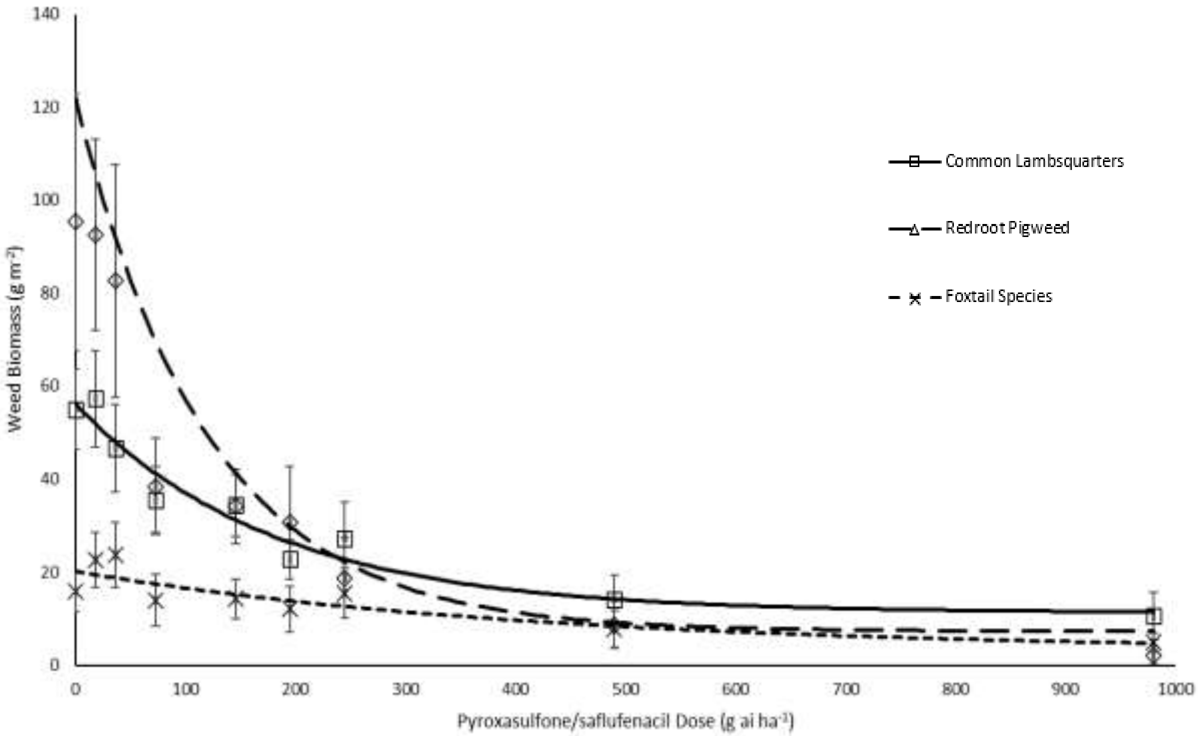


**Figure 4.** Weed biomass (g m $^{-2}$) of common lambsquarters, redroot pigweed, and foxtail species with pyroxasulfone and encapsulated saflufenacil 8 weeks after emergence (WAE). Vertical bars represent ± SE of means. Dose-response curves were fit to an inverse exponential model using nonlinear regression (Equation 2).

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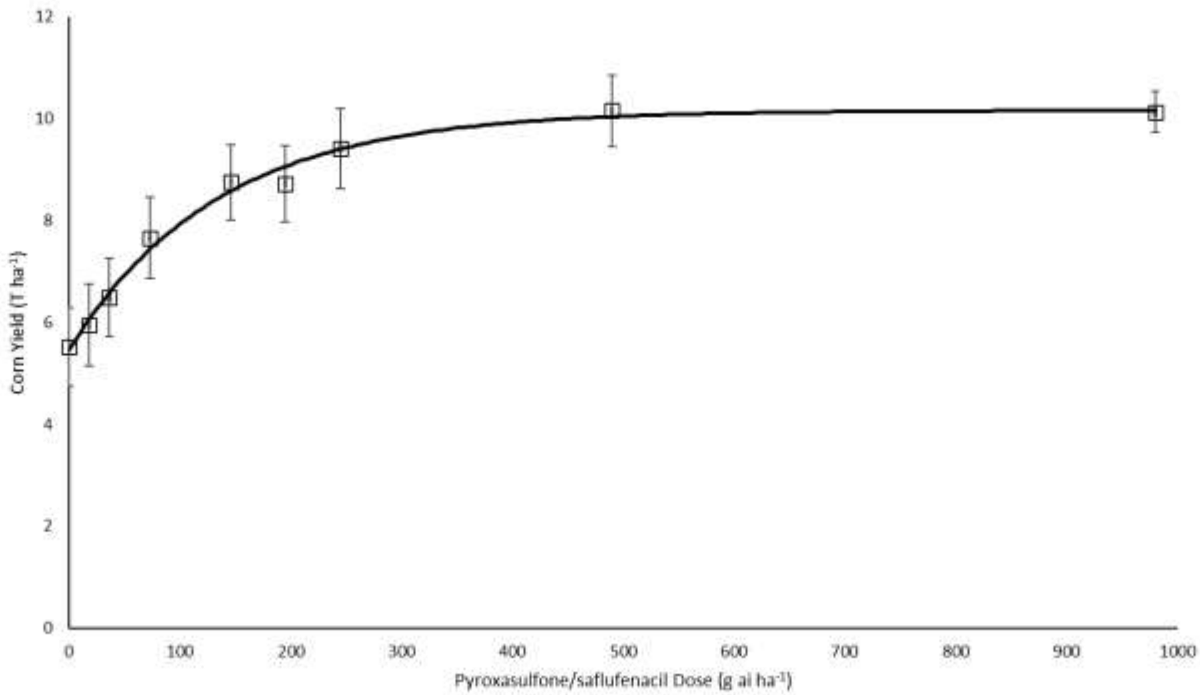


**Figure 5.** Corn yield (T ha$^{-1}$) with pyroxasulfone and encapsulated saflufenacil. Vertical bars represent ± SE of means. Dose-response curves were fit to an exponential to a maximum model using nonlinear regression (Equation 1).