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Weed control and sweet maize (*Zea mays* L.) yield as affected by pyroxasulfone dose

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A B S T R A C T

Pyroxasulfone is a new herbicide being considered for registration in sweet maize in Canada; however, there is still little information on the doses required to provide 90% control of annual grass and broadleaved weeds found in southwestern Ontario. The objective of this study was to determine pyroxasulfone doses that would provide at least 90% control of several economically important weeds, without impacting final sweet maize yield by more than 5% in comparison to a weed-free control. Six field trials were conducted over a two-year period (2007 and 2008) at three Ontario locations to evaluate the effectiveness of pyroxasulfone at doses ranging from 31.25 to 1000 g a.i. ha^{-1}. The doses required to reduce weed biomass by at least 90% (I_{90}) varied by weed species. Doses of 93, 499, and 111 g a.i. ha^{-1} were required to reduce the biomass by 90% of redroot pigweed, common lambsquarters and green foxtail, respectively. There was greater than 95% control of velvetleaf, large crabgrass and barnyardgrass with 31.25 g a.i. ha^{-1}, the lowest dose tested. Sweet maize yield could not be consistently maintained within 5% of the weed-free control. There are several factors that may have contributed to the reduced yield, including soil texture effects, competition as a result of poor common lambsquarters control, and hybrid sensitivity. These results show that biologically effective weed control with pyroxasulfone may be achieved at lower than proposed doses for several weed species; it remains unclear if this is economically sustainable due to the potential impacts on yield.

1. Introduction

Pyroxasulfone is a new herbicide that provides residual control of a broad spectrum of weed species in grain maize and soybean. Sweet maize hybrids have also shown good tolerance to pyroxasulfone (Sikkema et al., 2008). Registration of this active ingredient in sweet maize will be beneficial to Ontario growers by providing an additional pre-emergence control option for annual grasses; for which there are currently few (OMAFRA, 2008). Furthermore, for broadleaved weed control, pyroxasulfone will provide an alternative to atrazine, a mode of action that is heavily relied upon in both grain and sweet maize (Williams et al., 2010). Atrazine no longer controls some weeds due to resistance (Heap, 2009) and has an uncertain future in North America due to potential surface water contamination (Nice et al., 2008; Swanton et al., 2007).

The mode of action for pyroxasulfone is still unclear; however, it is thought to be a seedling growth inhibitor. This is supported by Tanetani et al. (2009) who documented that pyroxasulfone was a potent inhibitor of very-long-chain fatty acids in germinating rice seedlings. The dose of pyroxasulfone will be dependent on soil texture and therefore there are three proposed doses: 166, 209, and 250 g a.i. ha^{-1} for use on sandy, loam, and clay soils, respectively (Anonymous, 2006). Pyroxasulfone has also been reported to be sensitive to soil organic matter content. Knezevic et al. (2009) reported that the dose of pyroxasulfone required to control several weed species increased with increasing soil organic matter. At these proposed doses, the spectrum of weed control is reported to include velvetleaf (*Abutilon theophrasti* Medic.), redroot pigweed (*Amaranthus retroflexus* L.), common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.), crabgrass species (*Digitaria* spp.), foxtail species (*Setaria* spp.), and barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) (Anonymous, 2006).

In Canada, a dose must be identified that consistently controls at least 80% of proposed labeled weeds in order for successful registration. However, to prevent yield losses due to competition, growers demand efficacy above 90%. Therefore, the concept of a biologically effective dose has been developed and is defined as the dose of the herbicide required to obtain at least 90% control of

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a weed species without sacrificing crop safety (Nurse et al., 2007). This concept has also been identified as an important component in the development of an integrated weed management program (Dieleman et al., 1996; Streibig and Kudsk, 1993).

Currently, there are relatively few data describing the weed control provided by pyroxasulfone across a diverse spectrum of environments (Geier et al., 2006; Knezevic et al., 2009, and Steele et al., 2005). As such, more information is required to better describe the biologically effective dose (I_{90}) of pyroxasulfone required to provide acceptable control for several weed species in sweet maize. Therefore, the specific objectives of this study were 1) to develop dose-response curves for the control of redroot pigweed, common lambsquarters, velvetleaf, green foxtail, large crabgrass and barnyardgrass in sweet maize for a range of pyroxasulfone doses and determine the I_{90}; and 2) to determine from the dose of pyroxasulfone required to provide acceptable crop safety ($<5\%$ yield reduction).

2. Materials and methods

2.1. Experimental sites

Six field experiments were conducted over a two-year period (2007 and 2008) at the Agriculture and Agri-Food Canada, Greenhouse and Processing Crops Research Station, Harrow, ON (42.034245,-82.900429); the Huron Research Station, University of Guelph, Exeter, ON (43.316747,-81.501002); and the Ridgetown Campus, University of Guelph, Ridgetown, ON (42.444978,-81.878014). The soil at Harrow was a Fox sandy loam (Brunisolic Gray Brown Luvisol) with 2.6% organic matter and pH of 6 in both years. The soil at Exeter was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained) with 3.7 and 3.6% organic matter and pH of 7.8 and 8.0 in 2007 and 2008, respectively. The soil at Ridgetown was a Watford/Brady loam (Gleyed Brunisolic Gray Brown Luvisol) with 9.2 and 5.5% organic matter and pH of 7.2 in 2007 and 2008, respectively.

2.2. Experimental procedures

Seedbed preparation at all sites consisted of autumn moldboard plowing followed by two passes with a field cultivator in the spring. Sweet maize variety GH2547 was seeded at all locations in rows spaced 75 cm apart. Each plot was 8 m long by 2 m wide at Harrow, 10 m by 2 m at Exeter and 8 m by 2 m at Ridgetown.

The experiment was organized as a randomized complete block design with ten treatments and four replications. Eight application doses of pyroxasulfone (31.25, 62.5, 125, 166, 209, 250, 500, and 1000 g a.i. ha^{-1}) were applied pre-emergence. A weed-free control was established by applying s-metolachlor/atrazine/benoxacor at 2880 g a.i. ha^{-1} pre-emergence followed by hand weeding as needed. The final treatment was maintained as an untreated weedy control.

Weed dry matter, crop injury, and crop yield were measured at all sites. Weed dry matter harvests were made approximately 56 d after maize emergence from a 1-m^2 area within each plot. Plants were removed at the soil surface, separated by species, and dried to a constant weight at 80 C. Injury of maize was recorded on a scale ranging from 0 (no visible injury) to 100 (total plant death) 7, 14, and 28 d after sweet maize emergence. Sweet maize was hand harvested at maturity and the total and marketable yield was recorded. Maize cobs were considered marketable if they were at least 5 cm in diameter and there was at least 75% kernel fill. Only the marketable yields are reported in this manuscript, because the marketable yields were statistically similar to the total yields. The maize yields from the weed-free control were used as a base for calculating percentage of maximum crop yield in all plots treated with pyroxasulfone.

2.3. Statistical analysis

All data (weed dry matter, and crop injury) were subjected to analysis of variance (ANOVA) using the MIXED model of SAS statistical software (Ver. 8, SAS Inst., Cary, NC). The variances were partitioned into the fixed effect of pyroxasulfone dose and into the random effects of environment (year and location), the interaction between environment and the fixed effect, and blocks nested within environment. The assumptions of the variance analysis were tested by ensuring that the residuals were random, homogeneous, with a normal distribution about a mean of zero using residual plots and the Shapiro–Wilk normality test. When the environment and pyroxasulfone dose interaction was not significant after analysis, data were pooled by environment.

To assess weed control and estimate the dose of foramsulfuron required to provide 90% (I_{90}) weed control, regression of weed dry matter over herbicide dose was performed using the log-logistic model described by Seefeldt et al. (1995) and modified by Schabenberger et al. (1999).

$$Y = A + ((D - A)/(1 + (K/100 - K) \times \exp(B(X/I_K)))) \qquad (1)$$

Where Y is the response (e.g. weed dry matter), A is the lower limit, D is the upper limit, K is percentage reduction in weed dry matter, B is the slope of the line, I_k is the dose giving K response, and X is the herbicide dose. The doses of pyroxasulfone required to obtain a 90% reduction of weed dry matter and the regression parameters were estimated using the NLIN procedure in SAS and were performed separately for each weed species. The dose-response curves that were generated describe the relationship of the herbicide dose (on a logarithmic scale) against the percent reduction (linear scale) of weed dry matter as a percentage of weed dry matter in an untreated check.

Sweet maize yield data were subjected to an ANOVA using the MIXED procedure in SAS. The interaction of environment and pyroxasulfone dose was not significant ($P > 0.05$), therefore, data were pooled by environment. Maize yields for each location were converted to a percentage of the yield obtained in the weed-free control. An ANOVA was performed on these data and confirmed that the environment interaction still did not exist. A regression of the transformed maize yield data against herbicide dose was then performed using a hyperbolic model described by Cousens (1985).

$$Y = I \times d/(1 + I \times d/A) \qquad (2)$$

Where Y is maize yield as a percentage of yield obtained in the weed-free control, d is herbicide dose, I is the slope, and A is the asymptote of the hyperbolic line. The regression parameters were obtained using the NLIN procedure in SAS and the graphical representation was generated using Sigma Plot. The curve was used to determine the dose of pyroxasulfone required to obtain at least 95% of the maize yield in comparison to the weed-free control. This percentage was based on the optimal grain maize yields used in previous research (Knezevic et al., 2009; Nurse et al., 2007; Nurse et al., 2010; Sikkema et al., 1999), and is deemed commercially acceptable.

3. Results and discussion

The interaction between environment (location and year) and treatment was not significant for any weed species ($P > 0.05$). Therefore, data for each weed species were pooled across all environments.

3.1. Redroot pigweed

The control of redroot pigweed, measured as a reduction in biomass, was influenced by pyroxasulfone dose (Fig. 1). As pyroxasulfone dose increased the control of redroot pigweed also