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Response of Eight Sweet Maize (*Zea mays* L.) Hybrids to Saflufenacil Alone or Pre-Mixed with Dimethenamid-P

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ABSTRACT

Saflufenacil is a new herbicide for use in field maize (*Zea mays* L.) and other crops that may have potential for weed management in sweet maize. Tolerance of eight sweet maize hybrids to saflufenacil and saflufenacil plus dimethenamid-p applied preemergence (PRE) were studied at two Ontario locations in 2008 and 2009. Saflufenacil applied PRE at 75 and 150 g·ha^{-1} and saflufenacil plus dimethenamid-p (pre-mixed) applied PRE at 735 and 1470 g·ha^{-1} caused minimal (less than 5%) injury in Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize hybrids at 1 and 2 weeks after emergence (WAE). Saflufenacil or saflufenacil plus dimethenamid-p applied PRE did not reduce plant height, cob size, or yield of any of the sweet maize hybrids tested in this study. Based on these results, saflufenacil and saflufenacil plus dimethenamid-p pre-mixed applied PRE at the doses evaluated can be safely used for weed management in Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize under Ontario environmental conditions.

Keywords: Cob Size; Height; Injury; Preemergence; Tolerance; Yield

1. Introduction

Sweet maize (*Zea mays* L.) is one of the most important field grown vegetables in Ontario [1]. In 2009, nearly 112,000 tonnes of sweet maize was produced on approximately 9000 hectares with a farm-gate value of $36 million, and ranked as the second largest field grown vegetable crop in Ontario in terms of farm-gate value [1]. Weed control is critical in sweet maize production to maintain quality and yield and be competitive in the global market place. More research is needed to identify herbicide options that can effectively control grass and broadleaved weeds in sweet maize production.

Saflufenacil (BAS 800H) is a new herbicide being developed by BASF for preemergence (PRE) broadleaved weed control in field maize (*Zea mays* L.), soybean (*Glycine max* L.) and other field and vegetable crops. Saflufenacil can control troublesome weeds such as velvetleaf (*Abutilon theophrasti*), common ragweed (*Ambrosia artemisiifolia*), giant ragweed (*Ambrosia trifida*), common cocklebur (*Xanthium strumarium*), ladysthumb (*Polygonum persicaria*), redroot pigweed (*Amaranthus retroflexus*), common waterhemp (*Amaranthus tuberculatus* var. *rudis*) and common lambsquarters (*Chenopodium album*) including triazine and acetolactate synthase resistant biotypes [2-6].

Saflufenacil is a pyrimidinedione that inhibits protoporphyrinogen-IX-oxidase (PPO). Susceptible weeds to saflufenacil show injury symptoms within a few hours and die in 1 to 3 days [6]. Saflufenacil has both contact and residual activity against susceptible weeds and is mainly translocated in the xylem [6]. Saflufenacil is applied at relatively low doses and has low environmental, toxicological and eco-toxicological impact with minimal residual carryover and persistence in the soil [6]. The proposed dosage for sweet maize in Ontario is 75 g a.i. ha^{-1}. Saflufenacil provides a novel mode of action (PPO inhibitor) for sweet maize that is different than currently used broadleaved herbicides reducing potential for the selection of herbicide resistant weed biotypes [6,7].

Saflufenacil is also compatible with residual herbicides that control grasses. BASF has developed saflufenacil plus dimethenamid-p premix (BAS781) for use in maize and other crops [6]. Dimethenamid-p is a chloroacetamide herbicide that in susceptible plants inhibits very long chain fatty acid synthesis [7]. Dimethenamid-p can provide season long control of a broad spectrum of grass and broadleaved weeds such as barnyardgrass (*Echinochloa crusgalli*), autumn panicum (*Panicum dichotomiflorum*), giant foxtail (*Setaria faberi*), green foxtail (*Setaria viridis*), yellow foxtail (*Setaria glauca*), large

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crabgrass (*Digitaria sanguinalis*), smooth crabgrass (*Digitaria ischaemum*), witchgrass (*Panicum capillare*), redroot pigweed (*Amaranthus retroflexus*), American black nightshade (*Solanum americanum*), and eastern black nightshade (*Solanum ptycanthum*) [2,7]. Dimethenamid-p at the registered application doses has been shown to cause little or no injury in field maize [8,9]. Saflufenacil plus dimethenamid-p can provide an effective broad spectrum herbicide option for the control of troublesome species in sweet maize.

Saflufenacil and saflufenacil plus dimethenamid-p are desirable compliments to the current weed management programs in sweet maize because of its low dosage; broad-spectrum weed control, environmental safety, and new mode of action that will help reduce selection for herbicide resistant biotypes. There is no published information on the sensitivity of sweet maize hybrids to the PRE application of saflufenacil or saflufenacil plus dimethenamid-p. If tolerance is adequate, registration of saflufenacil and saflufenacil plus dimethenamid-p will provide sweet maize growers with an additional option for annual weed control. Sensitivity of sweet maize to herbicides is dependent on the application dose, hybrid, and environmental conditions. Sweet maize hybrid sensitivity has been documented for foramsulfuron [10], bentazon [11], prosulfuron [12], mesotrione [13], nicosulfuron [14,15], primisulfuron [16], isoxaflutole [17], and thifensulfuron-methyl [18].

The objective of this study was to determine the sensitivity of Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize to saflufenacil and saflufenacil plus dimethenamid-p applied PRE under Ontario environmental conditions.

2. Materials and Methods

Field experiments were conducted at the University of Guelph, Ridgetown Campus, Ridgetown, Ontario and the Huron Research Station, Exeter, Ontario in 2008 and 2009. The soil at the Ridgetown location was a Watford/Brady loam composed of 51% sand, 32% silt, 16% clay, and 5.5% organic matter with a pH of 7.2 in 2008 and 49% sand, 34% silt, 17% clay, and 9.2% organic matter with a pH of 7.2 in 2009. The soil at the Exeter location was a Brookston clay loam composed of 34% sand, 36% silt, 30% clay, and 3.6% organic matter with a pH of 8.0 in 2008 and 39% sand, 37% silt, 24% clay, and 4.3% organic matter with a pH of 7.9 in 2009. Seedbed preparation consisted of moldboard plowing in the fall and cultivation in the spring. Fertilizer was broadcast and incorporated prior to seeding based on soil tests and local recommendations.

There were two experiments established side by side at each site (one evaluating saflufenacil and the other evaluating saflufenacil plus dimethenamid-p). The experiments were arranged in a split-plot design with four replications. The main plots were herbicide dose, and the subplots were sweet maize hybrids. Selection of herbicide doses was based on the manufacturer recommended use dose and twice the manufacturer recommended dosage.

Treatments consisted of a non-treated check and two doses of saflufenacil (0, 75 and 150 g a.i. ha^{-1}) or saflufenacil plus dimethenamid-p (0, 735 and 1470 g a.i. ha^{-1}) representing the untreated control and the 1X and 2X of the proposed label dose, respectively. Eight of the most commonly grown processing sweet maize hybrids in southwestern Ontario encompassing a range of endosperm genotypes were selected: Cahill (*su*), GH4927 (*su*), Harvest Gold (*su*), Rocker (*su*), BSS5362 (sh_2), GG236 (*su*), GG447 (*su*), and GG763 (*su*) sweet maize. Each of the main plots was 6 m wide by 8 m long at Ridgetown and 6 m wide by 10 m long at Exeter. The subplots each consisted of a single row of each sweet maize hybrid with rows spaced 75 cm apart. The sweet maize was thinned to 50,000 plants ha^{-1} shortly after emergence. The plots were then kept weed-free using inter-row cultivation and hand hoeing as required.

Herbicide treatments were applied PRE four to eight days after planting using a CO_2-pressurized backpack sprayer calibrated to deliver 200 L aqueous solution at 241 kPa. The boom was 1.5 m wide with four ULD120-02 nozzles (ULD120-02 nozzles tip; Spraying Systems Co., Wheaton, IL.) spaced 0.5 m apart.

Crop injury including stand reduction was evaluated visually comparing the non-treated hybrid to the respective treated hybrids on a scale of 0 to 100% at 1 and 2 weeks after emergence (WAE). A rating of 0% was defined as no visible effect of the herbicide and 100% was defined as plant death. Average maize height (based on ten random plants per subplot) was measured for each subplot 3 WAE. The height of the plant was defined as the maximum height from the soil surface with the leaves fully extended. At maturity, each subplot was harvested by hand and cob size, marketable yield (a cob greater than 5 cm in diameter) and total yield were recorded. Because the results of the statistical analyses for total and marketable yields were similar, only marketable yield is reported.

All data were subjected to analysis of variance (ANOVA). Tests were combined over locations and years and analyzed using the PROC MIXED procedure of SAS (Statistical Analysis Systems Institute, Cary, NC, USA). Variances of percent crop injury at 1 and 2 WAE, plant height, cob size, and yield were partitioned into the fixed effects of herbicide treatment, hybrid, and herbicide-hybrid interaction and into the random effects of site-year, block (site-yr), site year-treatment, site year-hybrid and site year-hybrid-treatment. Significance of random effects was tested using a Z-test of the variance estimate and fixed effects were tested using F-tests. Error assumptions of the variance analyses (random, homogeneous, normal distribution of error) were confirmed using residual plots and the Shapiro-Wilk normality test. To meet the assumptions of the variance analysis, visual injury at 1 and 2 WAE were subjected to an arcsine square root transformation and cob size data were log transformed. No transformation was required for plant height or yield. Treatment means were separated using Fisher's protected LSD test. Means of percent injury and cob size were compared on the transformed scale and were converted back to the original scale for presentation of results. Type I error was set at $P \leq 0.05$ for all statistical comparisons.

3. Results and Discussion

Statistical analysis of the data on visible injury, plant height, cob size and yield showed that the random effects of location, year, year by location and interactions with treatments were not significant. Therefore, data were pooled and averaged over years and locations (**Tables 1-4**).

Table 1. Injury at 1 and 2 weeks after emergence (WAE) of eight sweet maize hybrids treated prior to emergence with saflufenacil at 0, 75, and 150 g·ha^{-1} or saflufenacil plus dimethenamid-p at 0, 735, and 1470 g·ha^{-1} at Exeter, ON, and Ridgetown, ON, in 2008 and 2009.

Treatment/Hybrid[a]	Injury 1 WAE		Injury 2 WAE	
	75/735[b]	150/1470[b]	75/735[b]	150/1470[b]
	%			
Saflufenacil				
Cahill (*su*)	1a	2a	0a	1a
GH 4927 (*su*)	1a	3a	0a	1a
Harvest Gold (*su*)	2a	4a	1a	1a
Rocker (*su*)	1a	2a	0a	0a
BSS 5362 (*sh*$_2$)	1a	4a	0a	1a
GG 236 (*su*)	1a	3a	0a	1a
GG 447 (*su*)	2a	3a	0a	0a
GG 763 (*su*)	2a	4a	1a	1a
Saflufenacil plus dimethenamid-p				
Cahill (*su*)	1a	2a	1a	1a
GH 4927 (*su*)	1a	2a	1a	1a
Harvest Gold (*su*)	2a	3a	1a	2a
Rocker (*su*)	2a	2a	1a	2a
BSS 5362 (*sh*$_2$)	2a	3a	2a	2a
GG 236 (*su*)	2a	2a	1a	2a
GG 447 (*su*)	2a	2a	1a	2a
GG 763 (*su*)	3a	3a	2a	3a

[a]Abbreviations: *su* = sugary; *sh*$_2$ = shrunken endosperm mutant genotype; [b]Results are averaged for both locations and years; means followed by the same letter within a row for each treatment are not significantly different according to Fisher's Protected LSD test ($P \leq 0.05$).

Table 2. Plant height at 3 weeks after emergence (WAE) of eight sweet maize hybrids treated prior to emergence with saflufenacil at 0, 75, and 150 g·ha^{-1} or saflufenacil plus dimethenamid-p at 0, 735, and 1470 g·ha^{-1} at Exeter, ON, and Ridgetown, ON, in 2008 and 2009.

Treatment/Hybrid[a]	Plant height		
	Herbicide dose (g·ha^{-1})		
	0[b]	75/735[b]	150/1470[b]
	cm		
Saflufenacil			
Cahill (*su*)	32a	29a	28a
GH 4927 (*su*)	37a	36a	34a
Harvest Gold (*su*)	32a	31a	30a
Rocker (*su*)	37a	35a	35a
BSS 5362 (*sh*$_2$)	28a	29a	26a
GG 236 (*su*)	32a	32a	30a
GG 447 (*su*)	33a	34a	32a
GG 763 (*su*)	25a	24a	23a
Saflufenacil plus dimethenamid-p			
Cahill (*su*)	30a	32a	31a
GH 4927 (*su*)	36a	37a	35a
Harvest Gold (*su*)	34a	34a	31a
Rocker (*su*)	36a	37a	34a
BSS 5362 (*sh*$_2$)	27a	29a	28a
GG 236 (*su*)	33a	33a	32a
GG 447 (*su*)	34a	35a	33a
GG 763 (*su*)	24a	23a	22a

[a]Abbreviations: *su* = sugary; *sh*$_2$ = shrunken endosperm mutant genotype; [b]Results are averaged for both locations and years; means followed by the same letter within a row for each treatment are not significantly different according to Fisher's Protected LSD test ($P \leq 0.05$).

3.1. Crop Injury

Visible injury symptom observed was leaf speckling. Saflufenacil applied PRE at 75 and 150 g a.i. ha^{-1} caused minimal injury (4% or less) in Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize at 1 and 2 WAE (**Table 1**). Similarly, saflufenacil plus dimethenamid-p applied PRE at 735 and 1470 g a.i. ha^{-1} caused minimal injury (3% or less) in Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize 1 and 2 WAE (**Table 1**).

Results are similar to those reported in field maize. Soltani *et al.* (2009) [19] found 1% or less injury in maize with saflufenacil applied PRE at 50, 100 and 200 g a.i. ha^{-1}. Moran (2010) [20] also found no injury in field maize with saflufenacil applied PRE at 75 and 150 g a.i. ha^{-1} or saflufenacil plus dimethenamid-p applied PRE at 735 and 1470 g a.i. ha^{-1}. Little visible injury seen in different sweet maize varieties evaluated in this study is similar with previous studies on clopyralid [21] and to

Table 3. Mean weight of marketable cobs at harvest of eight sweet maize hybrids treated prior to emergence with saflufenacil at 0, 75, and 150 g·ha^{-1} or saflufenacil plus dimethenamid-p at 0, 735, and 1470 g·ha^{-1} at Exeter, ON, and Ridgetown, ON, in 2008 and 2009.

Treatment/Hybrid[a]	Mean weight of marketable cobs		
	Herbicide dose (g·ha^{-1})		
	0[b]	75/735[b]	150/1470[b]
	g/cob		
Saflufenacil			
Cahill (*su*)	302a	307a	310a
GH 4927 (*su*)	307a	312a	307a
Harvest Gold (*su*)	332a	343a	336a
Rocker (*su*)	346a	350a	345a
BSS 5362 (sh_2)	302a	315a	310a
GG 236 (*su*)	325a	324a	325a
GG 447 (*su*)	398a	406a	393a
GG 763 (*su*)	341a	340a	342a
Saflufenacil plus dimethenamid-p			
Cahill (*su*)	312b	303b	339a
GH 4927 (*su*)	307a	300a	303a
Harvest Gold (*su*)	350a	334a	349a
Rocker (*su*)	347a	348a	341a
BSS 5362 (sh_2)	287a	300a	304a
GG 236 (*su*)	309a	319a	308a
GG 447 (*su*)	395a	398a	387a
GG 763 (*su*)	343a	337a	344a

[a]Abbreviations: *su* = sugary; sh_2 = shrunken endosperm mutant genotype; [b]Results are averaged for both locations and years; means followed by the same letter within a row for each treatment are not significantly different according to Fisher's Protected LSD test (P ≤ 0.05).

Table 4. Marketable yield of eight sweet maize hybrids treated prior to emergence with saflufenacil at 0, 75, and 150 g·ha^{-1} or saflufenacil plus dimethenamid-p at 0, 735, and 1470 g·ha^{-1} at Exeter, ON, and Ridgetown, ON, in 2008 and 2009.

Treatment/Hybrid[a]	Marketable yield		
	Herbicide dose (g·ha^{-1})		
	0[b]	75/735[b]	150/1470[b]
	t·ha^{-1}		
Saflufenacil			
Cahill (*su*)	14.3a	12.4a	13.0a
GH 4927 (*su*)	15.2a	16.4a	15.5a
Harvest Gold (*su*)	14.5a	13.7a	13.4a
Rocker (*su*)	15.9a	17.5a	17.3a
BSS 5362 (sh_2)	14.2a	13.2a	12.1a
GG 236 (*su*)	12.8a	12.9a	12.4a
GG 447 (*su*)	18.8a	20.0a	19.0a
GG 763 (*su*)	11.9a	12.8a	11.5a
Saflufenacil plus dimethenamid-p			
Cahill (*su*)	13.2a	13.1a	13.7a
GH 4927 (*su*)	15.3a	16.0a	15.4a
Harvest Gold (*su*)	15.9a	15.3a	14.6a
Rocker (*su*)	17.2a	18.0a	16.7a
BSS 5362 (sh_2)	13.2a	14.2a	13.8a
GG 236 (*su*)	13.3a	13.8a	12.2a
GG 447 (*su*)	19.3a	21.0a	19.4a
GG 763 (*su*)	12.6a	12.8a	11.5a

[a]Abbreviations: *su* = sugary; sh_2 = shrunken endosperm mutant genotype; [b]Results are averaged for both locations and years; means followed by the same letter within a row for each treatment are not significantly different according to Fisher's Protected LSD test (P ≤ 0.05).

pramezone [22]. However, other herbicides such as bentazon [11], isoxaflutole [17], mesotrione [13], nicosulfuron [14,23], nicosulfuron plus rimsulfuron [24,25], primisulfuron [16], prosulfuron [12] or thifensulfuron-methyl [18] have been shown to cause significant injury in some sweet maize hybrids.

3.2. Plant Height

No reduction in plant height was observed for any of the eight sweet maize hybrids treated with saflufenacil or saflufenacil plus dimethenamid-p applied PRE at doses evaluated (**Table 2**). Plant height was similarly unaffected by increasing herbicide doses.

In other studies, Soltani *et al.* (2009) [19] reported no adverse effect in field maize height with saflufenacil applied PRE in field maize at dose up to 200 g a.i. ha^{-1}. Lack of any height reduction between sweet maize hybrids evaluated in this study with saflufenacil and saflufenacil plus dimethenamid-p is similar to those found with other herbicides such as clopyralid, halosulfuron and topramezone [21,26].

3.3. Cob Size

Saflufenacil and saflufenacil plus dimethenamid-p applied PRE at doses evaluated caused no decrease in cob size of Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize (**Table 3**). Results in these trials are similar to findings with other herbicides such as halosulfuron which did not caused any negative impact on cob size at 1X or 2X of the proposed label dose for any of the sweet maize hybrids studied [26]. However, other studies have shown that cob size of susceptible hybrids can be reduced up to 67% with clopyralid or thifensulfuron-methyl [18,21].

3.4. Yield

Saflufenacil applied and saflufenacil plus dimethenamid-p applied PRE at doses evaluated caused no adverse effect on yield of Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 sweet maize (**Ta-**

ble 4). Yield was similarly unaffected by increasing herbicide doses in all sweet maize hybrids evaluated.

In other studies, Soltani et al. (2009) [19] reported no adverse effect in yield with saflufenacil applied PRE in field maize at dose up to 200 g a.i. ha^{-1}. Moran (2010) [20] also found no yield reduction in field maize with saflufenacil applied PRE at 75 and 150 g a.i. ha^{-1} or saflufenacil plus dimethenamid applied PRE at 735 and 1470 g a.i. ha^{-1}. Yield response with saflufenacil and saflufenacil plus dimethenamid-p are similar to yield response in other herbicides, such as clopyralid [21], topramezone [22] and halosulfuron [26] which were not adversely affected when the herbicide was applied at the label dose. However, other studies have reported significant injury in some sweet maize hybrids with certain herbicides. Diebold *et al.* (2003, 2004) [10] reported up to 94% reduction in yield with formsulfuron in sweet maize. Similar yield reduction were reported with mesotrione [13], nicosulfuron [14], foramsulfuron [10] and nicosulfuron plus rimsulfuron [24,25] in some sensitive sweet maize hybrids. The potential for and level of crop injury from use of nicosulfuron, mesotrione, and foramsulfuron on any specific sweet maize hybrid is conditioned largely by CYP alleles at the *nsf*1/*ben*1 locus on the short arm of chromosome 5 [27]. However, the sensitivity of sweet maize to other herbicides is controlled by other gene loci. Bentazon metabolism, for example, is controlled by *ben1*, as well as two independent genes, Cr1 and Cr2 [28]. It is hypothesized that sweet maize tolerance to saflufenacil is also conditioned by alternate alleles of the above genes and/or different gene loci, which have, as yet, not been determined.

4. Conclusion

Based on this study, the sweet maize hybrids Cahill, GH4927, Harvest Gold, Rocker, BSS5362, GG236, GG447, and GG763 are tolerant to saflufenacil and saflufenacil plus dimethenamid-p applied PRE at doses evaluated. Saflufenacil and saflufenacil plus dimethenamid-p applied PRE to eight sweet maize hybrids had no negative effect on sweet maize injury, height, cob size, or yield. As the dose of saflufenacil or saflufenacil plus dimethenamid-p was increased from 1X to 2X of the proposed label dose, there was no negative effect on any sweet maize hybrid. This study shows that saflufenacil and saflufenacil plus dimethenamid-p can be safely applied to these eight sweet maize hybrids at the proposed label dose. The registration of saflufenacil alone or premixed with dimethenamid-p would provide Ontario sweet maize producers with a new, broad-spectrum herbicide that controls selected annual grass and broadleaved weed species. Furthermore, if used in a diversified, integrated weed management program it would reduce the selection intensity for herbicide resistant weeds.

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