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Sweet Corn Response and Weed Control to Saflufenacil plus Dimethenamid-P in Organic Soils

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There are limited PRE herbicide options available to provide residual weed control in sweet corn grown on organic soils in the Everglades Agricultural Area (EAA). Field studies were established to determine the efficacy of PRE applied saflufenacil + dimethenamid-P at six rates ranging from 10 + 88 to 319 + 2802 g ai ha^{-1} on weed control and sweet corn tolerance on organic soils in the EAA in 2011 and 2012. Saflufenacil + dimethenamid-P is a premix recently labeled for PRE weed control in field corn at 50 + 438 to 90 + 788 g ha^{-1} depending on soil texture. There was no phytotoxic effect of PRE applied saflufenacil + dimethenamid-P on sweet corn. At 42 d after treatment, common lambsquarters, common purslane, and spiny amaranth were controlled 90% with saflufenacil + dimethenamid-P at 58 + 508, 71 + 622, and 58 + 512 g ha^{-1}, respectively. Sweet corn yield at 95% of the weed-free yield was estimated to be obtained at 69 + 606 g ha^{-1} of saflufenacil + dimethenamid-P. Our results show that saflufenacil + dimethenamid-P at 69 + 606 to 71 + 622 g ha^{-1} controlled three common weeds and maintained acceptable sweet corn yield. Labeled rates of saflufenacil + dimethenamid-P for field corn on mineral soils were adequate for weed control in sweet corn on organic soils.

Nomenclature: Dimethenamid-P; saflufenacil; common lambsquarters, *Chenopodium album* L. CHEAL; common purslane, *Portulaca oleracea* L. POROL; spiny amaranth, *Amaranthus spinosus* L. AMASP; sweet corn, *Zea mays* L.

Keywords: Organic soils, residual weed control.

Existen pocas opciones de herbicidas PRE disponibles para el control residual de malezas en maíz dulce producido en suelos orgánicos en el Área Agrícola de los Everglades (EAA). Se establecieron experimentos de campo para determinar la eficacia de saflufenacil + dimethenamid-P aplicados PRE a seis dosis variando de 10 + 88 a 319 + 2802 g ai ha^{-1} para el control de malezas y la tolerancia del maíz dulce en suelos orgánicos en el EAA en 2011 y 2012. Saflufenacil + dimethenamid-P es una premezcla recientemente registrada para el control PRE de malezas en maíz para grano con dosis de 50 + 438 a 90 + 788 g ha^{-1} dependiendo de la textura del suelo. No hubo efecto fitotóxico de saflufenacil + dimethenamid-P aplicado PRE en maíz dulce. A 42 d después del tratamiento, *Chenopodium album*, *Portulaca oleracea*, y *Amaranthus spinosus* fueron controlados en 90% con saflufenacil + dimethenamid-P a 58 + 508, 71 + 622, y 58 + 512 g ha^{-1}, respectivamente. El rendimiento del maíz dulce a 95% del rendimiento del testigo libre de malezas se estimó que se pudo obtener con 69 + 606 g ha^{-1} de saflufenacil + dimethenamid-P. Nuestros resultados muestran que saflufenacil + dimethenamid-P de 69 + 606 a 71 + 622 g ha^{-1} controló tres de las malezas más comunes y mantuvo rendimientos aceptables en el maíz dulce. Las dosis en la etiqueta de saflufenacil + dimethenamid-P para maíz para grano en suelos minerales fueron adecuadas para el control de malezas en maíz dulce en suelos orgánicos.

Sweet corn is a high value crop grown on organic soils in the Everglades Agricultural Area (EAA) located on the southern edge of Lake Okeechobee in Florida. Weed control programs in sweet corn in the EAA are based primarily on PRE herbicides and between-row cultivation. Atrazine, *S*-metolachlor, and mesotrione are the main PRE herbicides used in sweet corn on organic and mineral soils for control of annual broadleaf and grass weeds (Anonymous 2013; Boydston et al. 2008; Malik et al. 2008; Mitchell et al. 2001; O'Connell et al. 1998; Williams et al. 2010). These herbicides have little residual activity on organic soils (up to 85% organic matter) in the EAA. Thus, there is need to evaluate alternative PRE herbicide options that can potentially provide sufficient residual weed control while maintaining acceptable sweet corn yield on organic soils in the EAA.

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The premix of PRE applied saflufenacil (68 g ai L^{-1}) + dimethenamid-P (599 g ai L^{-1}) labeled for residual control of many annual grasses, broadleaf weeds, and sedges in field corn, popcorn, grain sorghum (*Sorghum bicolor* (L.) Moench ssp. bicolor), and soybean [*Glycine max* (L.) Merr.] was recently developed by BASF (Anonymous 2010, 2012). Saflufenacil is a pyrimidinedione herbicide that inhibits protoporphyrinogen-IX-oxidase (PPO), an enzyme for chlorophyll and heme biosynthesis (Grossmann et al. 2010; Liebl et al. 2008; Senseman 2007). This low-use rate herbicide was recently registered for preplant burndown and PRE control of broadleaf weeds in several crops and noncropland areas (Anonymous 2012; Davis et al. 2010; Geier et al. 2009; Grossmann et al. 2010; Morichetti et al. 2012; Odero 2012; Owen et al. 2011; Waggoner et al. 2011). Saflufenacil applied PRE at rates up to 200 g ha^{-1} did not negatively affect field corn yield (Moran et al. 2011a; Soltani et al. 2009). Saflufenacil has a soil organic carbon coefficient (K_{oc}) of 9 to 56 L kg^{-1} (Anonymous 2009). Dimethenamid-P, the *S* isomer of the chloroacetamide herbicide dimethenamid is thought to inhibit very long chain fatty acid synthesis (Böger et al. 2000; Courdechet et al.1997; Senseman 2007). Dimethenamid-P is primarily absorbed by emerging shoots of susceptible grass and broadleaf weeds (Senseman 2007). The K_{oc} of dimethenamid-P is 55 to 149 L kg^{-1} (Senseman 2007; Westra 2012). Saflufenacil + dimethenamid-P is a potential PRE herbicide option that may provide effective residual broad-spectrum weed control in sweet corn on organic soils in the EAA. In mineral soils with 3.0 to 9.2% organic matter, Robinson et al. (2012) reported sweet corn tolerance to saflufenacil + dimethenamid-P at rates up to 150 + 1320 g ha^{-1} and Moran et al. (2011b) estimated the rate of saflufenacil + dimethenamid-P that would result in 95% total weed biomass reduction in field corn ranged from 13 + 113 to 69 + 606 g ha^{-1} and was mainly influenced by weed species. Currently, there are no studies that have examined sweet corn tolerance and weed control with PRE saflufenacil + dimethenamid-P on organic soils. Our study was conducted to determine the efficacy of PRE applied saflufenacil + dimethenamid-P on weed control and sweet corn tolerance on organic soils of the EAA.

Materials and Methods

Field studies were established at the University of Florida Everglades Research and Education Center in Belle Glade, FL in 2011 and 2012 on Dania Muck (Euic, hyperthermic, shallow Lithic Haplosaprists) soil with pH of 7.3 and 80% organic matter. Sweet corn 'Garrison' was planted on October 13, 2011 and February 1, 2012 at a seeding rate of 79,000 seeds ha^{-1} in 76-cm rows. Plots were 3 m wide (four rows) by 7.6 m long. The experimental design was a randomized complete block with four replications both years.

Saflufenacil + dimethenamid-P (Verdict™, BASF Corporation, Research Triangle Park, NC 27709) was applied PRE immediately after sweet corn planting at 10 + 88, 20 + 175, 40 + 350, 80 + 701, 160 + 1401, and 320 + 2802 g ha^{-1}. In addition, full season weed-free and weedy control plots were included. Herbicide treatments were applied with a CO_2 pressurized sprayer at 276 kPa delivering 180 L ha^{-1} using Teejet® XR8002VS nozzle tips (Spraying Systems Co., Wheaton, IL 60187). Over-head irrigation (1.3 cm) was used to activate the herbicides immediately following application. The fields were subsequently subsurface irrigated from field ditches by raising the water table.

The phytotoxic effect of saflufenacil + dimethenamid-P on sweet corn was evaluated on a scale of 0 to 100% with 0 being no injury and 100 being complete plant death, 21 and 42 d after treatment (DAT). Weed species were counted in a randomly selected area (2.3 m^2) within and between the middle two rows of each plot, 21 and 42 DAT to determine the level of weed control. Common lambsquarters, common purslane, and spiny amaranth were the predominant weed species both years at an average of 85, 62, and 10 plants m^{-2}, respectively. Control of individual weed species was expressed as a percentage of the number of weeds in each plot divided by the average number of each weed in weedy control plots. Sweet corn yield was determined by hand-harvesting the middle two rows in each plot at corn maturity on January 4, 2012 and May 1, 2012 to determine yield.

Sweet corn phytotoxicity and weed control data were subjected to ANOVA using the lme function in R (Pinheiro and Bates 2000; R Development Core Team 2012). Year was considered a random variable, and the herbicide treatment main effects were tested for error associated with the appropriate

Table 1 Model parameters (with standard errors) and ED_{90} values of PRE applied saflufenacil + dimethenamid-P at 42 d after treatment for sweet corn on organic soil in Belle Glade, FL combined over 2011 and 2012 and fitted using Equation 1.

Weed species	Parameter estimates (± SE)			ED_{90}[a]	
	b	*d*	*e*	Saflufenacil	Dimethenamid-P
				g ha^{-1}	
Common lambsquarters	−1.60 (0.27)	102.32 (3.50)	143.38 (13.15)	57.73	508.27
Common purslane	−1.51 (0.23)	104.21 (3.60)	162.43 (15.72)	70.69	622.31
Spiny amaranth	−1.49 (0.28)	102.23 (3.69)	130.82 (12.92)	58.14	511.86

[a] ED_{90}: rate required to provide 90% weed control.

year by treatment interaction. Data were pooled across years when no significant year-by-treatment interaction occurred. A three parameter log-logistic model (Equation 1) was then fit to weed control data for each weed species to describe the relationship between saflufenacil + dimethenamid-P rate and the level of weed control:

$$Y = d/1 + \exp[b(\log x - \log e)] \qquad [1]$$

where Y is percentage weed control for each species, x is the saflufenacil + dimethenamid-P rate in g ha^{-1}, b is the slope of the inflection point of the fitted line, d is the upper limit of the fitted line, and e is the inflection point of the fitted line or ED_{50} (equivalent to the rate required to cause 50% weed control).

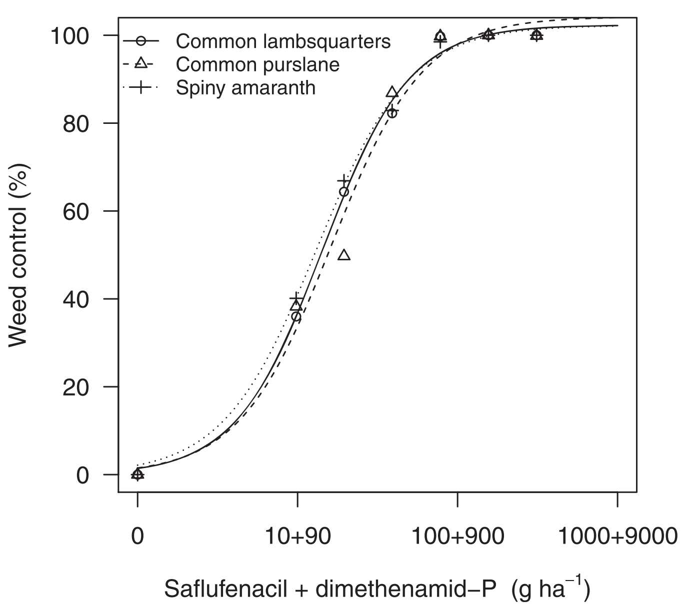

Figure 1. The relationship between PRE applied saflufenacil + dimethenamid-P and weed control at 42 d after treatment (DAT) in Belle Glade, FL combined over 2011 and 2012.

Sweet corn yield for each plot were expressed as a percentage of weed-free yields. The transformed sweet corn yield data (expressed as a percentage of weed-free yields) was subjected to ANOVA as previously described and data pooled across years when no significant year-by-treatment interaction occurred. A four-parameter log-logistic model was used to describe the relationship between sweet corn yield and saflufenacil + dimethenamid-P rate:

$$Y = c + (d - c)/1 + \exp[b(\log x - \log e)] \qquad [2]$$

where Y is sweet corn yield (expressed as a percentage of full season weed-free yield), c is the lower limit of the fitted line, and x, b, d, and e are the same as in Equation 1. Nonlinear regression models (Equations 1 and 2) were fitted using the drc package of R (R Development Core Team 2012; Ritz and Streibig 2005).

Results and Discussion

Treatment-by-year interaction for percentage weed control at 21 (data not shown) and 42 DAT was not significant, so data were pooled across years for analysis. The three-parameter log-logistic model (Equation 1) was appropriate for describing the relationship between saflufenacil + dimethenamid-P rate and control of all weed species based on nonsignificant lack-of-fit test at the 95% level for the fitted curves (Ritz and Streibig 2005). Model parameters for the fitted curves are listed in Table 1. Overall, weed control increased as saflufenacil + dimethenamid-P rate increased at 42 DAT (Figure 1). The predicted rates of saflufenacil + dimethenamid-P required to provide 90% control (ED_{90}) of common lambsquarters, common purslane, and spiny amaranth were 58 + 508, 71 + 622, and 58 + 512 g ha^{-1}, respectively. However, the relative

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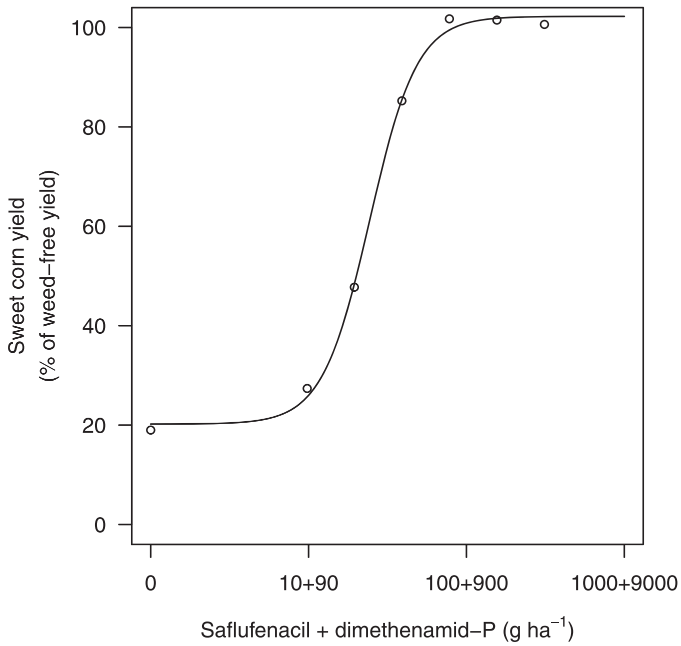

Figure 2. The relationship between sweet corn yield and PRE applied saflufenacil + dimethenamid-P on organic soil in Belle Glade, FL combined over 2011 and 2012. Model parameters (with standard errors) of the fitted curve (Equation 2) are $b =$ –2.89 (0.67), $c =$ 20.20 (4.44), $d =$ 102.24 (3.23), and $e =$ 243.91 (23.67).

difference of the ED_{90} values among the curves was not significant even though a higher rate of saflufenacil + dimethenamid-P was required to provide 90% control of common purslane. In contrast, on mineral soils with 3.0 to 6.7% organic matter Moran et al. (2011b) estimated that saflufenacil + dimethenamid-P need to be applied at 33 + 392 and 19 + 167 g ha^{-1} to provide 95% common lambsquarters and *Amaranthus* species control, respectively. Previous studies have shown that saflufenacil is extremely effective at controlling *Amaranthus* species. Saflufenacil applied PRE at 9 g ha^{-1} provided more than 90% reduction of Palmer amaranth (*A. palmeri* S. Wats.), redroot pigweed (*A. retroflexus* L.), and tumble pigweed (*A. albus* L.) biomass in a mineral soil with 2.1% organic matter (Geier et al. 2009). The rates of saflufenacil + dimethenamid-P in our study were higher than rates previously reported for efficacious weed control in mineral soils. This may be attributed to the herbicides binding more tightly to the organic component on these organic soils. This implies that higher rates of saflufenacil + dimethenamid-P are required for the organic soils of the EAA. The label use rate of PRE applied saflufenacil + dimethenamid-P in field corn is 50 + 438 to 90 + 788 g ha^{-1} depending on the soil texture (Anonymous 2012). Our results show that saflufenacil + dimethenamid-P can be used to provide effective residual weed control on organic soils of the EAA within the label use rate for field corn.

There was no phytotoxic effect of saflufenacil + dimethenamid-P on sweet corn at any of the rates used in this study (data not shown). Similarly, Robinson et al. (2012) reported no phytotoxicity on eight sweet corn hybrids from PRE applications of saflufenacil + dimethenamid-P at rates up to 150 + 1320 g ha^{-1} on mineral soils. Soltani et al. (2009) observed no phytotoxicity on field corn 28 DAT following PRE application of saflufenacil at 200 g ha^{-1}. However, field corn height was reduced by as much as 12% even though yield was not affected (Soltani et al. 2009).

Sweet corn yield in the full season weed-free control plots averaged 14,184 kg ha^{-1} combined across years. Treatment-by-year interaction for sweet corn yield was not significant, so data were pooled across years for analysis. The four-parameter log-logistic model (Equation 2) was appropriate for describing the relationship between sweet corn yield and saflufenacil + dimethenamid-P rate based on a nonsignificant lack-of-fit test at the 95% level for the fitted curve (Ritz and Streibig 2005). Sweet corn yield increased as herbicide rate increased (Figure 2). Sweet corn yield at 95% of the weed-free yield was obtained at 69 + 606 g ha^{-1}. This rate was higher than the estimated rate required to provide 90% control of all the weed species, 42 DAT, with the exception of common purslane control. The rate required to maintain the yield at 95% of the weed-free control was higher than estimated rates for control of individual weed species because it was determined based on the combined effect of the three weed species on yield. This implies that the rate would be probably lower if it was calculated based on a monoculture of a single weed species. Moran et al. (2011b) reported that decreasing the rate saflufenacil + dimethenamid-P from 75 + 660 to 56 + 495 g ha^{-1} or lower resulted in reduction in sweet corn yield on mineral soils.

Our study shows that PRE application of saflufenacil + dimethenamid-P provided acceptable residual control of common lambsquarters, common purslane, and spiny amaranth in sweet corn on

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organic soils in the EAA. All the weed species were controlled > 90% at 71 + 622 g ha^{-1} of saflufenacil + dimethenamid-P, 42 DAT. The rate required to maintain the yield at 95% of the weed-free control was 69 + 606 g ha^{-1} of saflufenacil + dimethenamid-P. The label use rate of PRE saflufenacil + dimethenamid-P in field corn is 50 + 438 to 90 + 788 g ha^{-1}, showing that much higher rates of the herbicide premix are not necessary for acceptable residual weed control in sweet corn on the organic soils of the EAA. Therefore, the rate of saflufenacil + dimethenamid-P on organic soils can be varied depending on the prevalent weed species to achieve acceptable weed control. These results indicate that saflufenacil + dimethenamid-P has the potential to provide efficacious weed control while maintaining acceptable sweet corn yield on organic soils of the EAA.

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