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Banana Pepper Response and Annual Weed Control with *S*-metolachlor and Clomazone

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Field experiments were conducted at the North Central Agricultural Research Station in Fremont, OH, in 2006 and 2007, to evaluate tolerance of banana pepper to *S*-metolachlor and clomazone, and the efficacy of these herbicides on green and giant foxtail, common lambsquarters, and common purslane. The crop was machine-transplanted in late spring of each year. Pretransplant (PRETP) herbicide treatments included two *S*-metolachlor rates (534 and 1,070 g ai ha^{-1}), two clomazone rates (560 and 1,120 g ai ha^{-1}), and four tank mixes of *S*-metolachlor plus clomazone (534 + 560 g ha^{-1}, 1,070 + 560 g ha^{-1}, 534 + 1,120 g ha^{-1}, and 1,070 + 1,120 g ha^{-1}). Crop injury and weed control data were collected at 2 and 4 wk after treatment (WAT). The crop was harvested two times from August to September. Minor crop injury was observed at 2 WAT only in 2006 and in plots treated with *S*-metolachlor, alone or in combination with clomazone. In 2007, slight crop injury at 6 WAT in most herbicide-treated plots was mostly related to weeds that grew regardless of herbicide treatment. In general, *S*-metolachlor provided less weed control than did clomazone or tank mixes of *S*-metolachlor plus clomazone. Clomazone did not reduce yield of banana pepper. Registration of clomazone would provide banana pepper growers an opportunity to control weeds caused by late emergence or poor initial control following a burndown herbicide application.

Nomenclature: Clomazone; *S*-metolachlor; common lambsquarters, *Chenopodium album* L; common purslane, *Portulaca oleracea* L.; giant foxtail, *Setaria faber* Herrm.; green foxtail, *Setaria viridis* (L.) Beauv.; banana pepper, *Capsicum annuum* L.
Key words: Crop tolerance, herbicide efficacy.

Experimentos de campo fueron realizados en la Estación de Investigación Agrícola del Centro Norte en Fremont, Ohio, en 2006 y 2007, para evaluar la tolerancia del pimiento banano a *S*-metolachlor y clomazone, y la eficacia de estos herbicidas para el control de *Setaria viridis*, *Setaria faberi*, *Chenopodium album*, y *Portulaca oleracea*. El cultivo fue trasplantado mecánicamente tarde en la primavera en ambos años. Los tratamientos de herbicidas pre-trasplante (PRETP) incluyeron dos dosis de *S*-metolachlor (534 y 1,070 g ai ha^{-1}), dos dosis de clomazone (560 y 1,120 g ai ha^{-1}), y cuatro mezclas en tanque de *S*-metolachlor más clomazone (534 + 560 g ha^{-1}, 1,070 + 560 g ha^{-1}, 534 + 1,120 g ha^{-1}, y 1,070 + 1,120 g ha^{-1}). Se colectaron datos de daño al cultivo y de control de malezas a 2 y 4 semanas después del tratamiento (WAT). El cultivo se cosechó dos veces entre Agosto y Septiembre. Se observó un poco de daño en el cultivo a 2 WAT solamente en 2006 y en parcelas tratadas con *S*-metolachlor, solo o en combinación con clomazone. En 2007, un ligero daño en el cultivo a 6 WAT en la mayoría de las parcelas tratadas con herbicidas estuvo mayoritariamente relacionado a malezas que crecieron sin importar el tratamiento de herbicidas. En general, *S*-metolachlor brindó menos control de malezas que clomazone o que las mezclas en tanque de *S*-metolachlor más clomazone. El clomazone no redujo el rendimiento del pimiento banano. El registro de clomazone proveería a los productores de pimiento banano de una oportunidad para el control de malezas producto de emergencia tardía o de un control inicial pobre antes del trasplante.

Pepper (*Capsicum* spp.) is one of the main vegetable crops grown worldwide. This crop is especially valued as a source of vitamins and of pungency, the latter a characteristic unique to this genus (Keyhaninejad et al. 2014). Different cultivars are grown worldwide with an estimated total production for both spice and vegetable uses of more than 25 million tons (Bosland et al. 2012).

One of the most costly practices required to produce pepper is weed management. The use of black polyethylene plastic mulch has been adopted as a weed-control system by many growers (Lament 1993). Although plasticulture production generally reduces weed emergence, weeds still emerge from the openings in the plastic used for transplants or direct seeding of crops (Norsworthy et al. 2008). Pepper seedlings usually grow slowly after transplanting (Isik et al. 2009); therefore, they do not

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compete well with weeds for limited resources (Adigun et al. 1991). Locations in which pepper cultivars are grown, most generally those with a warm climate and a long growing season, are favorable to increased weed pressure (Grey et al. 2001). Weeds can significantly reduce yields if proper weed-control measures are not taken. Although mechanical cultivation, cover crops, and mulches (Campiglia et al. 2012) have been shown to reduce weed incidence in organic vegetable production, herbicides remain the main strategy used in conventional pepper production.

S-metolachlor (Dual Magnum, Syngenta Crop Protection, 410 S. Swing Rd., Greensboro, NC 27409) has been used in many crops because of the broad spectrum of weeds controlled and the relative lack of crop sensitivity (Pekarek 2009). This chloroacetamide herbicide is applied PRE to preformed beds before laying polyethylene mulch, or it may be used PRE in bare-ground culture (Bangarwa et al. 2009). Clomazone (Command, 3ME herbicide label, FMC Corporation, Agricultural Products Group, 1735 Market St, Philadelphia, PA 19103), an herbicide from the isoxazolidinone family, provides residual control of several important annual grass and broadleaf weeds and is an important herbicide for weed management in peppers and other vegetable crops (Harrison and Farnham 2013).

Pepper is an important crop in the midwest and eastern regions of the United States. More than 1,200 ha of pepper are grown annually in Ohio for fresh market and processing with an estimated value of more than $20 million (NASS 2014). *S*-metolachlor application in plasticulture-grown bell pepper (*Capsicum frutescens* L.) was shown to have no effect on marketable yield while providing at least 88% control of several annual grasses (Pekarek 2009). The herbicide has been used for annual broadleaf, grass weeds, and nutsedge (*Cyperus* spp.) control in pepper in the United States for many years (Santos et al. 2013). *S*-metolachlor tank mixed with sulfentrazone and applied to the soil before transplanting pepper has also shown to provide acceptable levels of bell pepper tolerance and control of redroot pigweed (*Amaranthus retroflexus* L.), common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters, and eastern black nightshade (*Solanum ptychanthum* Dunal) (Robinson et al. 2008). Similarly, clomazone has been a staple of weed-control practice, for the pepper crop throughout the country. However, the label clearly prohibits the use of this herbicide on banana pepper. FMC corporation personnel indicated that concerns about banana pepper sensitivity to clomazone originated in the southwestern United States soon after initial registration on pepper (J Reed, H Guscar, personal communication). Identification of herbicides that are safe to banana pepper but effectively control a range of weeds is a key to sustainable banana pepper production in the midwestern United States. The objective of this study was to characterize banana pepper response to *S*-metolachlor and clomazone and to gather data needed to support registration of clomazone on this pepper type.

Materials and Methods

Field studies were conducted at the Ohio Agricultural Research and Development Center, North Central Agricultural Research Station, Fremont, Ohio (41.31°N, 83.17°W; elevation, 199 m), during the 2006 and 2007 growing seasons. 'Ethem' banana pepper (Seminis Inc., 2700 Camino Del Sol, Oxnard, CA 93030), with an 85 to 88 d maturity, was used for the experiments. Banana pepper was seeded into flats and grown in the greenhouse for 6 wk. Seedlings were machine transplanted on June 9, 2006, and May 31, 2007, in plots that were 3.1 m wide and 7.6 m long. Each plot consisted of six rows of peppers planted 0.6 m apart. Crop response data were collected only from the middle rows. The experimental design was a randomized complete block with four replications. Before transplanting, glyphosate (Roundup WeatherMax, Monsanto Co., 800 N. Lindburgh Blvd., St. Louis, Missouri, 63167) at 0.511 kg ae ha^{-1} was applied to kill weeds that had emerged on the beds.

Applications of *S*-metolachlor and clomazone alone or in tank mixtures were made to evaluate the tolerance of banana pepper to these herbicides. Pretransplant (PRETP) applications were done 1 d before transplanting on June 8, 2006, and 2 d before transplanting on May 29, 2007. Treatments included two *S*-metolachlor rates (1× [1,070 g ai ha^{-1}], 1/2× [534 g ha^{-1}]); two clomazone rates (1× [1,120 g ai ha^{-1}], 1/2× [560 g ha^{-1}]); and four tank mixes of *S*-metolachlor plus clomazone (1/2× + 1/2× [534 + 560 g ha^{-1}], 1× + 1/2× [1,070 + 560 g ha^{-1}], 1/2× + 1× [534 + 1,120 g ha^{-1}], and 1× + 1× [1,070

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Table 1. Effect of metolachlor, clomazone, and *S*-metolachlor plus clomazone mix rates applied precrop transplant on banana pepper at Fremont, OH, in 2006 and 2007.[a]

Treatment	Herbicide rate	2006 Crop injury[b] 2 WAT	2006 Crop injury[b] 4 WAT	2006 Yield[b]	2007 Crop injury 2 WAT	2007 Crop injury 6 WAT	2007 Yield[b]
	g ai ha^{-1}	%	%	kg $plot^{-1}$	%	%	kg $plot^{-1}$
S-metolachlor	534	0	0	6.8 a	0	3	10.0 a
S-metolachlor	1,070	10	0	5.2 ab	0	5	8.5 a
Clomazone	560	0	0	4.9 b	0	1	9.5 a
Clomazone	1120	0	0	5.9 ab	0	0	8.7 a
S-metolachlor + clomazone	534 + 560	1	0	6.2 ab	0	3	8.9 a
S-metolachlor + clomazone	1,070 + 560	0	0	6.2 ab	0	3	8.7 a
S-metolachlor + clomazone	534 + 1,120	0	0	6.6 a	0	0	9.5 a
S-metolachlor + clomazone	1,070 + 1,120	5	0	5.5 ab	0	1	9.7 a
Weed-free control[c]		0	0	5.8 ab	0	1	5.7 b
Weedy control[c]		0	0	1.0 c	0	35	1.6 c
LSD (0.05)		NS	NS	1.7	NS	NS	2.3

[a] Abbreviations: WAT, weeks after treatment; NS, nonsignificant (P = 0.05).

[b] Means with the same letter are not significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

[c] Weed free and weedy control data were not included in the ANOVA for crop injury.

+ 1,120 g ha^{-1}]) as PRETP. Applications were made using a CO_2-pressurized sprayer, calibrated to deliver 234 L ha^{-1} at 276 kPa through 8002VS flat-fan spray nozzles (TeeJet Technologies, P.O. Box 7900, Wheaton, IL 60187). Nontreated weedy and weed-free controls were included for comparison. Air temperature at application time was 26 and 16 C in 2006 and 2007, and wind speed at the time of application for both years was below 5 km h^{-1}.

Crop injury symptoms, including necrosis, stunting, minor leaf malformation, and chlorosis, were assessed visually using the 0 to 100 scale, in which 0% indicated no crop injury, and 100% indicated death of the crop. Data were collected 2 and 4 WAT and 2 and 6 WAT for PRETP in 2006 and 2007, respectively. Peppers were harvested two times based on the visual maturity of the control plants, on August 14, 2006, and September 14, 2006, and August 13, 2007, and September 11, 2007, and reported as total yield per plot. Weed control, scored as the percentage of control of total grass and broadleaf weed species, was also assessed visually. Evaluations for PRETP treatments were done 2 and 4 WAT and 2 and 6 WAT in 2006 and 2007, respectively. The predominant weeds in plots included giant foxtail, green foxtail, common purslane, and common lambsquarters.

Data from all experiments were subjected to ANOVA using PROC GLM ($\alpha = 0.05$) in SAS 9.2 (SAS Institute Inc., SAS Campus Dr., Cary, NC 27513). Years and replications, and all interactions containing either of these effects were considered random (Carmer et al. 1989). All other variables (application timing and herbicide rate) were considered fixed effects. Data from field experiments were analyzed separately for each year because there was a significant treatment-by-year interaction. Means for those variables were separated with the use of Fisher's protected LSD test. Weed-free and weedy control data were included in the ANOVA for yield but not for crop injury.

Results and Discussion

Crop Injury. Slight injury, from 1 to 10%, was observed at 2 WAT in 2006 (Table 1). Injury occurred only in plots treated with *S*-metolachlor, alone or in combination with clomazone, and did not differ statistically among the treatments. Injury symptoms were not detected 4 WAT. In contrast to 2006, pepper plants in 2007 were completely free of symptoms at 2 WAT. Weed pressure was more intense during 2007 than it was in 2006, as reflected by reduced control of common lambsquarters and common purslane at 2 WAT (Table 2). For this reason, at 5 WAT, all plots were cultivated and weeded by hand. However, this was not in time to prevent a detrimental effect on the crop vigor,

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Table 2. Effect of *S*-metolachlor, clomazone, and *S*-metolachlor plus clomazone mix rates applied precrop transplant on annual grass and broadleaf weed control in banana pepper at Fremont, Ohio in 2006.[a]

Treatment	Herbicide rate	Weed control[b]								
		2006						2007		
		2 WAT			4 WAT			2 WAT		
		AG	CA	PO	AG	CA	PO	AG	CA	PO
	g ai ha^{-1}	%								
S-metolachlor	534	87 ab	99	67	24 c	85 d	0 b	73	13 d	25
S-metolachlor	1,070	79 b	96	61	55 b	90 c	25 b	74	28 cd	0
Clomazone	560	99 a	99	96	96 a	94 b	98 a	99	73 ab	36
Clomazone	1,120	99 a	99	99	95 a	95 b	99 a	74	53 bc	24
S-metolachlor + clomazone	534 + 560	98 a	99	98	91 a	99 a	99 a	95	80 a	60
S-metolachlor + clomazone	1,070 + 560	92 a	99	79	95 a	97 ab	99 a	99	80 a	34
S-metolachlor + clomazone	534 + 1,120	99 a	99	99	96 a	99 a	99 a	98	86 a	60
S-metolachlor + clomazone	1,070 + 1,120	99 a	99	99	97 a	99 a	99 a	99	90 a	50
Weed free control[c]		99	99	99	99	99	99	99	99	99
Weedy control[c]		0	0	0	0	0	0	0	0	0
LSD (0.05)		12	NS	NS	23	3	23	NS	25	NS

[a] Abbreviations: WAT, weeks after treatment; AG, annual grasses (green foxtail and giant foxtail); CA, common lambsquarters; PO, common purslane; NS, nonsignificant ($P = 0.05$).

[b] Means with the same letter are not significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

[c] Weed free and weedy control data were not included in the ANOVA.

reflected in the injury ratings at 6 WAT (Table 1). In particular, pepper plants in the weedy control plots displayed 35% stunting relative to plants in the weed-free control plots. Slight stunting observed in most herbicide-treated plots was almost certainly related to common lambsquarters and common purslane plants that grew despite herbicide treatment.

Evidence of residual effects of herbicide treatment on pepper yield was not observed in 2006 (Table 1). Yields did not differ among the herbicide-treated and weed-free control plots. In contrast, yield in the weedy control was reduced approximately 80% compared with that of the weed-free plots, confirming the observations of Adigun et al. (1991) regarding sensitivity of pepper to weed competition. Slightly reduced yield was also observed in plots treated with clomazone at 560 g ha^{-1}. The reason for reduced yield with this treatment is not clear because weed control was similar with all herbicides at the rating intervals used (Table 2); however, it was clearly not a clomazone rate effect on the crop. In 2007, PRETP herbicides resulted in higher yields than the control plots, although not different among treatments. Yields were from 1.5- to 1.8-fold greater than yields from the weed-free control and 5.3- to 6.3-fold greater than yields from the weedy control (Table 1). Yield suppression in the weed-free control may have been due to imperfect weed control done by hand weeding, although this cannot be confirmed by data. It has been reported that other pepper varieties, such as bell pepper, have yield loss up to 44% from weed infestation (Morales-Payan et al. 1997).

Weed Control. In 2006, clomazone and *S*-metolachlor plus clomazone treatments provided better control of foxtail species than did *S*-metolachlor at 1,070 g ha^{-1} (Table 2). Inferior grass control with *S*-metolachlor was more apparent at 4 WAT, and the rate effect was significant. Precipitation during this time in 2006 was about 50% higher than normal, which may have contributed to *S*-metolachlor leaching out of the treated zone where grass seeds germinate.

Clomazone alone and treatments containing clomazone provided 91% or greater control of foxtail species, compared with 24 and 55% control with *S*-metolachlor at 534 and 1,070 g ha^{-1}, respectively. Clomazone and clomazone mixes with *S*-metolachlor also provided better control of common lambsquarters and common purslane (94% or greater for the two species) than did solo treatments of *S*-metolachlor. *S*-metolachlor provid-

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ed 85 to 90% control of common lambsquarters, but control of common purslane was 0 and 25% at 534 and 1,070 g ha^{-1}, respectively. These results with *S*-metolachlor clearly illustrate the need for one or more additional herbicides to augment control of prevalent weeds in banana pepper, a role that could be well filled by clomazone.

In 2007, annual grass control 2 WAT was similar among herbicide treatments. However, common lambsquarters control in plots treated with *S*-metolachlor at 534 and 1,070 g ha^{-1} and clomazone at 1,120 g ha^{-1} was only 13, 28, and 53%, respectively. In contrast to 2006, and reflective of the greater weed pressure in 2007, no herbicide treatment provided acceptable control of common purslane. Considering both years and all three weed species, clomazone and combinations *S*-metolachlor with clomazone improved control over that obtained with *S*-metolachlor alone confirming the need for a registration of clomazone on banana pepper. Before the last rating (6 WAT) in 2007 plots were hand weeded (5 WAT) because of growth of annual weeds and the need to prevent confounding effects of the herbicide and effects of weed competition.

Previous studies have indicated that pepper varieties such as bell pepper, 'red chili', and 'jalapeno' were not injured by clomazone (Ackley et al. 1998; Grey et al. 2001). Our results are in agreement with previous published articles. Minimal banana pepper injury observed in clomazone treated plots in 2007 was almost certainly due to weed competition, rather than herbicide effects (Table 1). The slight crop injury observed in 2006 was most likely caused by the tank-mixed *S*-metolachlor and is consistent with reports from growers (J Cunningham, personal communication). Yield of banana pepper was also not affected by any of the proposed use rates of clomazone. Higher yields in plots treated with herbicide indicate a positive crop response to weed control.

These results indicate that the PRETP rates of clomazone and clomazone plus *S*-metolachlor can provide commercially acceptable and persistent control of giant and green foxtail and common lambsquarters. Control of common purslane was inconsistent in these experiments. *S*-metolachlor, in particular, is known to provide poor control of this species. PRETP rates of *S*-metolachlor did not provide adequate control of giant and green foxtail, common lambsquarters, and common purslane, and the need for supplemental weed control measures should be considered, especially early in the season when there is high infestation of these weeds. POSTTP *S*-metolachlor at the rates of 534 and 1,070 g ha^{-1} can provide commercially acceptable control of the above weeds later in the season (Table 2).

Further research is needed to evaluate the combination of *S*-metolachlor and other herbicides to provide a broader spectrum of weed control. Overall, our results indicate that banana pepper tolerance to clomazone is sufficient to allow safe use of the herbicide at the tested rates. State registration (section 24C) has already been granted for use of clomazone in banana pepper in Michigan and in Ohio. Registration of clomazone herbicide at the tested rates would provide banana pepper growers with a more-effective means of controlling emerged weeds than currently available options.

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