Weed Technology 2012 26:177–182

Saflufenacil Carryover Injury Varies among Rotational Crops

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Trials were established in 2007, 2008, and 2009 in Ontario, Canada, to determine the effect of soil residues of saflufenacil on growth, yield, and quality of eight rotational crops planted 1 yr after application. In the year of establishment, saflufenacil was applied PRE to field corn at rates of 75, 100, and 200 g ai ha^{-1}. Cabbage, carrot, cucumber, onion, pea, pepper, potato, and sugar beet were planted 1 yr later, maintained weed-free, and plant dry weight, yield, and quality measures of interest to processors for each crop were determined. Reductions in dry weight and yield of all grades of cucumber were determined at both the 100 and 200 g ha^{-1} rates of saflufenacil. Plant dry weight, bulb number, and size and yield of onion were also reduced by saflufenacil at 100 and 200 g ha^{-1}. Sugar beet plant dry weight and yield, but not sucrose content, were decreased by saflufenacil at 100 and 200 g ha^{-1}. Cabbage plant dry weight, head size, and yield; carrot root weight and yield; and pepper dry weight, fruit number and size, and yield were only reduced in those treatments in which twice the field corn rate had been applied to simulate the effect of spray overlap in the previous year. Pea and potato were not negatively impacted by applications of saflufenacil in the year prior to planting. It is recommended that cabbage, carrot, cucumber, onion, pepper, and sugar beet not be planted the year after saflufenacil application at rates up to 200 g ha^{-1}. Pea and potato can be safely planted the year following application of saflufenacil up to rates of 200 g ha^{-1}.

Nomenclature: saflufenacil; cabbage, *Brassica oleracea* var. *italica* Plenck.; carrot, *Daucus carota* L.; corn, *Zea mays* L.; cucumber, *Cucumis sativus* L.; onion, *Allium cepa* L.; pea, *Pisum sativum* L.; pepper, *Capsicum sativa* L.; potato, *Solanum tuberosum* L.; sugar beet, *Beta vulgaris* L.

Key words: Rotational crops, herbicide carryover.

En 2007, 2008 y 2009 se establecieron ensayos en Ontario, Canadá para determinar el efecto de residuos de saflufenacil en el suelo sobre el crecimiento, rendimiento y calidad de ocho cultivos en rotación sembrados un año después de la aplicación. En el año del establecimiento, el saflufenacil fue aplicado PRE en campos de maíz a dosis de 75, 100 y 200 g ia ha^{-1}. Los cultivos en rotación que se sembraron un año más tarde fueron: col, zanahoria, pepino, cebolla, arveja, pimiento, papa y remolacha azucarera; se mantuvieron libres de malezas y se determinaron para cada cultivo el peso seco, el rendimiento y los parámetros de calidad de interés para los procesadores. Reducciones en el peso seco y el rendimiento en todas las categorías de pepino fueron determinadas tanto para las dosis de 100 como de 200 g ha^{-1} de saflufenacil. El peso seco de la planta, el número de bulbos y el tamaño y rendimiento de la cebolla, también se redujeron con ambas dosis de saflufenacil. Con el uso de saflufenacil a 100 y 200 g ha^{-1}, el peso seco y el rendimiento de la remolacha disminuyeron, pero no así el contenido de sucrosa. El peso seco, el tamaño de la cabeza y el rendimiento de la col, el peso de la raíz y el rendimiento de la zanahoria, el peso seco, el número y tamaño de frutos y el rendimiento del pimiento, solamente se redujeron en aquellos tratamientos donde se aplicó el doble de la dosis normal para el maíz para simular el efecto del traslape de aspersión en el año anterior. La arveja y la papa no fueron negativamente impactadas por las aplicaciones de saflufenacil en el año anterior a la siembra. Se recomienda que la col, la zanahoria, el pepino, la cebolla, el pimiento y la remolacha no se siembren el año posterior a las aplicaciones de saflufenacil a dosis de hasta 200 g ha^{-1}. La arveja y la papa pueden sembrarse con seguridad el año siguiente a las aplicaciones de saflufenacil a dosis de hasta 200 g ha^{-1}.

Many producers in southern Ontario grow vegetables in rotation with field corn because they offer a higher value than traditional agronomic crops. This also provides producers an opportunity to utilize the wider array of field corn herbicides to manage populations of species that are difficult to control in vegetables. Vegetable crops differ in their response to residues from herbicides applied in previous years (Felix and Doohan 2005; Felix et al. 2007; Robinson 2008; Soltani et al. 2005). The potential for herbicide carryover to reduce vegetable crop yield is a significant concern for producers of these high value crops.

Saflufenacil was registered for use in Canada in 2010 by BASF for residual control of broadleaved weeds in corn and soybean [*Glycine max* (L.) Merr.]. Preemergence applications of saflufenacil can control troublesome weeds found in Ontario field cropping systems, including velvetleaf (*Abutilon theophrasti* Medik.), common ragweed (*Ambrosia artemisiifolia* L.), giant ragweed (*Ambrosia trifida* L.), redroot pigweed (*Amaranthus retroflexus* L.), and common lambsquarters (*Chenopodium album* L.) (Liebl et al. 2008). This herbicide therefore has potential to be used throughout much of the growing region in the province.

The labeled saflufenacil rate for field corn in Ontario is 100 g ha^{-1} (BASF Canada Inc. 2010). Saflufenacil is a pyrimidinedione that inhibits protoporphyrinogen-IX-oxidase (PPO) and is absorbed by both roots and foliage in plants and translocated primarily in the xylem because it has limited phloem mobility (Liebl et al. 2008). Susceptible weeds show injury symptoms within a few hours and die in 1 to 3 d. Saflufenacil is applied at relatively low doses and has low environmental, toxicological, and ecotoxicological impact (Anonymous 2008). This herbicide is expected to have

DOI: 10.1614/WT-D-11-00080.1

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minimal residual carryover due to its low persistence. However, data on the tolerance of vegetable crops to saflufenacil applications made in previous years do not currently exist in the literature.

Soil chemical and physical properties regulate the adsorption and persistence of saflufenacil. Hixon (2008) observed that soil sorption of saflufenacil was strongly correlated with organic matter and clay content. Ferrell and Vencill (2003) found that high clay content increased soil sorption of another PPO-inhibiting herbicide, flumioxazin, which reduced the availability of the herbicide to soil microbes, thereby increasing potential for carryover. Saflufenacil sorption and persistence are greater in acidic soils and decrease with increasing pH (Pest Management Regulatory Agency [PMRA] 2009), which also has been observed for sulfentrazone, another PPO-inhibiting herbicide (Grey et al. 1997). Though no data are currently reported to explain the relationship between temperature or moisture availability and persistence of saflufenacil, the impact of soil moisture and temperature on flumioxazin (Ferrell and Vencill 2003) and sulfentrazone (Martinez et al. 2008) persistence is considered minor relative to the effects of organic matter, clay content, and soil pH.

Residues of other PPO-inhibiting herbicides have caused variable levels of injury to crops grown the year following application. Sulfentrazone, another PPO-inhibiting herbicide, reduced yield in cotton (*Gossypium hirsutum* L.), but did not reduce yield of bell pepper, cabbage, cucumber, onion, snap bean (*Phaseolus vulgaris* L.), and tomato (*Solanum lycopersicum* L.) in the year after application (Pekarek et al. 2010). Similarly, another PPO inhibitor, fomesafen, caused less than 10% injury to snap bean, cucumber, and cantaloupe (*Cucumis melo* L.), but up to 38% injury in watermelon (*Citrullus lanatus* Thunb.), sunflower (*Helianthus annuus* L.), and tomato, when these crops were planted 10 to 11 mo after application (Johnson and Talbert 1993). Cobucci et al. (1997) also observed that residues of fomesafen caused variable levels of injury to corn depending on herbicide rate and the time elapsed between herbicide application and planting.

The lack of data on the effect of saflufenacil residues on vegetable crops grown the year after application and the potential for carryover observed with other PPO-inhibiting herbicides are of concern for vegetable producers. In Ontario, Canada, vegetable crops that are often grown following field, seed, and sweet corn are cabbage, carrot, cucumber, onion, pea, pepper, potato, and sugar beet. The objective of this research was to determine the level of carryover injury caused by saflufenacil on these eight crops, grown 1 yr after application.

Materials and Methods

Field studies were established in 2007, 2008 and 2009 at University of Guelph, Ridgetown Campus, Ridgetown, Ontario. Glyphosate-tolerant field corn was planted in a Normandale loamy fine sand (pH 6.7, organic matter [OM] 5.7%, sand 79%, silt 13%, clay 8%) in 2007, a Tavistock loam (pH 7.3, OM 4.5%, sand 45%, silt 29%, clay 26%) in 2008, and a Watford/Brady sandy loam (pH 7.5, OM 5.7%, sand 55%, silt 28%, clay 17%) in 2009. All soil types possessed 2 : 1 montmorillic clay minerals. Seedbed preparation at all locations consisted of fall moldboard plowing followed by two passes with a field cultivator in the spring. Two-meter untreated buffers were kept between plots to prevent movement of herbicide treatments among treated areas in adjacent plots.

In the year of herbicide application (i.e., 2007, 2008, and 2009), the experimental design was a randomized complete block with four replications. Each plot was 9 m wide and 28 m long. Saflufenacil was applied PRE at 75, 100, and 200 g ha^{-1}, 1 d after planting. A nontreated control was also included. Field corn was maintained weed-free with two applications of glyphosate (450 g ha^{-1}), grown to maturity, and harvested according to standard agronomic practices. Herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} of spray solution at a pressure of 200 kPa using flat-fan nozzles. The boom was 3 m wide with six nozzles spaced 0.5 m apart.

One year following herbicide application (i.e., 2008, 2009, and 2010), the trial areas were shallow disked (10-cm depth). Two-meter untreated buffers were kept between subplots to prevent movement of herbicide treatments among adjacent subplots. The experimental design was a randomized complete block with a split-plot arrangement and four replications with herbicide treatment (0, 75, 100, and 200 g ha^{-1} saflufenacil) as main plots and vegetable crop (cabbage, carrot, cucumber, onion, pea, pepper, potato, and sugar beet) as subplots. 'Blue Dynasty' cabbage was transplanted at a rate of 14,583 plants ha^{-1} in 75-cm rows to 10-cm depth on May 16, 2008, May 8, 2009, and May 26, 2010. 'Fontana' carrot was direct seeded at a rate of 2 kg ha^{-1} in 38-cm rows to a depth of 2 cm on April 28, 2008, May 5, 2009, and April 23, 2010. 'Fancipak' cucumber was direct seeded at a rate of 32,808 plants ha^{-1} in 1.2-m rows to a depth of 2 cm on May 29, 2008, May 22, 2009, and May 30, 2010. 'Montero' dry bulb onion was transplanted at a rate of 58,334 plants ha^{-1} in 38-cm rows to a depth of 10 cm on April 30, 2008, April 30, 2009, and April 28, 2010. 'Spring' pea was direct seeded at a rate of 325 kg ha^{-1} in 75-cm rows at a depth of 2 cm on April 28, 2008, May 4, 2009, and April 19, 2010. 'Superior' potato pieces were hand-planted at a rate of 33,750 pieces ha^{-1} in 1-m rows to a depth of 8 cm on April 22, 2008, April 30, 2009, and April 20, 2010. 'RR Crystal 827' sugarbeet was direct seeded at a rate of 146,666 plants ha^{-1} in 75-cm rows to a depth of 2 cm on April 24, 2008, May 5, 2009, and April 22, 2010. All subplots were planted perpendicular to the herbicide treatments, in 9-m-long rows, spaced 2 m apart from one another, and fertilized according to Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA 2006) recommendations. Trials were maintained weed-free by hand-weeding as required in the recropping years to prevent confounding the effect of herbicide injury with weed competition.

At 28 d after emergence, aboveground biomass of each crop was removed from 1 m of row in each herbicide treatment and in the nontreated control. The plant samples were dried to constant moisture at 60 C, and dry weight was recorded. At maturity, the center 6 m of the middle row of each crop was

Table 1. Monthly precipitation and mean monthly temperatures (and SE) in each study year from the time of herbicide application to the time that crops were planted the following year.

	2007–2008		2008–2009		2009–2010	
Month	Precipitation	Temperature (± SE)	Precipitation	Temperature (± SE)	Precipitation	Temperature (± SE)
	mm	C	mm	C	mm	C
April	70.3	6.3 (1.9)	50.1	8.7 (2.0)	152.0	7.8 (2.1)
May	63.2	14.4 (2.1)	93.8	11.3 (2.0)	48.5	13.0 (2.1)
June	39.2	19.2 (2.2)	113.4	19.7 (1.9)	65.4	17.3 (2.0)
July	68.3	19.6 (2.1)	108.1	20.8 (2.1)	30.5	18.5 (2.1)
August	93.9	20.4 (2.0)	73.0	18.8 (2.1)	92.4	19.6 (2.0)
September	49.3	17.2 (2.1)	131.7	16.7 (2.1)	36.0	16.1 (2.1)
October	39.6	14.3 (1.9)	52.0	8.6 (2.1)	70.2	8.6 (1.9)
November	49.0	3.1 (1.8)	138.4	2.9 (1.6)	30.3	6.2 (1.7)
December	120.4	−2.1 (1.5)	182.8	−3.2 (1.7)	137.5	−2.5 (1.6)
January	153.1	−2.5 (1.6)	147.1	−10.1 (2.0)	227.3	−5.5 (1.5)
February	142.9	−5.1 (1.6)	105.5	−3.8 (1.8)	97.8	−4.8 (1.6)
March	147.3	−1.6 (1.7)	106.4	1.1 (1.9)	67.0	3.4 (2.0)
April	50.1	8.7 (2.0)	152.0	7.8 (2.1)	63.3	9.8 (2.1)
May	93.8	11.3 (2.0)	48.5	13.0 (2.1)	122.2	14.4 (1.9)

harvested to determine yield. The number of marketable cabbage heads (i.e., Ontario No. 1 Grade; Ontario Processing Vegetable Growers [OPVG] 2009) per plot was counted, and the weight of each marketable head determined. Average head size and marketable yield were determined. Carrot was topped at maturity, and mean carrot root length and weight of a subsample of 20 carrot roots per plot was determined. Yield was determined from the remaining plants in the center row of each plot. Cucumber was harvested five times as is done in commercial production, from the middle row in each plot. Fruit that were crooked or malformed were weighed separately and graded as Ontario No. 5. The remaining fruit was graded according to size (No. 1, 1.5 to 2.7 cm; No. 2, 2.7 to 3.8 cm; No. 3, 3.8 to 5.0 cm; and No. 4, > 5.0 cm [OPVG 2009]); yield of each grade was determined, and total marketable yield was determined as the sum of all grades. The number, weight, and yield of onion bulbs per plot were determined. Pea pods were harvested, shelled in a pea bine, and yield determined. Three 20-g subsamples of shelled pea from each plot were analyzed for tenderness in an FMC Tenderometer (Food Machinery and Chemical Corporation, Philadelphia, PA); the three readings were averaged to calculate tenderness. Pepper was harvested by hand at maturity; all unmarketable fruit were discarded (i.e., < 7 cm diameter; OPVG 2009), and marketable fruit number, weight, and yield were determined. Potato was harvested from the middle 6 m of the plot; all potatoes < 44 mm in diameter or with > 5% scab, cracking, or bruising were removed, and total marketable potato yield (i.e. Canada No. 1 and No. 2 combined; Canadian Food Inspection Agency [CFIA] 2006) was determined. Twenty sugar beet roots from each subplot were analyzed for recoverable white sucrose by the Michigan Sugar Company (Bay City, MI). Yields were measured at crop maturity by hand-harvesting the center row of the middle 6 m each plot.

All data were subjected to analysis of variance. Variance analyses for response variables were performed using the PROC MIXED procedure (SAS 2004) of SAS Version 9.1 (SAS Institute, Cary, NC). For each crop, variances were partitioned into the fixed effects of herbicide treatment and into random effects of years, blocks within years, and their interactions with fixed effects. 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 assumptions of the variance analysis, percent sugar of sugar beet was subjected to an arcsine square root transformation (Bartlett 1947). Means of all crop quality parameters and yield at each saflufenacil rate were compared to the untreated control using Dunnett's Test ($\alpha = 0.05$).

Results and Discussion

Total precipitation between time of herbicide application in the establishment year and time of planting in the recropping year varied from 1,180.4 mm in 2007–2008 to 1,502.8 mm in 2008–2009 and 1,240.4 mm in 2009–2010 (Table 1). Mean monthly temperatures varied little from year to year. Despite the variability in rainfall among the 3 yr, the random effect of year and its interaction with saflufenacil rate applied in the previous year and vegetable crop was not significant for any of the response variables analyzed. This finding agrees with Ferrell and Vencill (2003) and Martinez et al. (2008), who have shown that the effect of soil moisture and temperature on the persistence of other PPO-inhibiting herbicides, such as flumioxazin and sulfentrazone, is considered minor relative to the effects of organic matter, clay content, and soil pH. There was a significant interaction between crop species and saflufenacil rate; therefore, the means of the dependant variables as a function of rate were analyzed separately for each vegetable crop.

Cabbage. At the rates of 75 and 100 g ha^{-1}, saflufenacil did not reduce shoot dry weight or marketable head number, head weight, and yield when applied 1 yr prior to transplanted cabbage (Table 2). However, there was a 7% reduction in shoot dry weight, an 11% reduction in marketable head weight, and a 10% reduction in yield when saflufenacil was applied at 200 g ha^{-1} in the previous year. These reductions

https://doi.org/10.1614/WT-D-11-00080.1 Published online by Cambridge University Press

Table 2. Effect of saflufenacil rate on cabbage shoot dry weight, marketable head number per plot, and marketable head weight and yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	Head number	Head weight	Yield
g ai ha^{-1}	g m^{-2}	*n* plot^{-1}	g head^{-1}	Mg ha^{-1}
0	18.6	26	2,585	32.8
75	18.7	26	2,597	32.8
100	17.9	26	2,452	30.7
200	17.3*	26	2,300*	29.6*

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α = 0.05).

in growth and yield are comparable to those caused by soil residues of sulfentrazone (Pekarek et al. 2010), which, like saflufenacil, is a PPO inhibitor. Other studies have demonstrated that cabbage has excellent tolerance to lower rates of PPO inhibitors like sulfentrazone and oxyfluorfen, even in the year of application (Sikkema et al. 2007).

Carrot. Saflufenacil did not reduce shoot dry weight or carrot root length, root weight, and yield when applied 1 yr prior to direct-seeded carrot (Table 3). A 15% reduction in shoot dry weight, a 10% reduction in carrot root weight, and a 5% yield reduction were observed at the 200 g ha^{-1} rate of saflufenacil. Carrot has shown variable tolerance to other PPO-inhibiting herbicides (Ogbuchiekwe et al. 2004; Pesticides Safety Directorate 2004) applied in the year of planting; however, there are no data available in the literature on the effect of PPO-inhibiting herbicide soil residues on carrot. It should be noted that the saflufenacil label has an 11-mo recropping interval for carrot grown on muck soils, but not for mineral soils (BASF Canada Inc. 2010). Our trials were conducted on mineral soils that have much lower OM levels than muck soils, which typically are greater than 30%. Since saflufenacil sorption is positively correlated with OM (Hixon 2008), we hypothesize that growth and yield reductions may have occurred in our study because the herbicide was not as tightly bound to the soil.

Cucumber. Saflufenacil applied at 100 and 200 g ha^{-1} reduced cucumber shoot dry weight and yield of direct-seeded cucumber planted the following year (Table 4). Shoot dry weight was 34 and 43% less in the 100 and 200 g ha^{-1} treatments, respectively. Yield of all cucumber grades also decreased at the two highest rates of saflufenacil. For example, the yield of No. 1 fruit in the 100 and 200 g ha^{-1} treatments decreased by 19 and 22%, respectively. Though residues of flumioxazin and sulfentrazone applied at typical use rates in

Table 3. Effect of saflufenacil rate on carrot shoot dry weight, carrot root length and weight, and marketable yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	Root length	Root weight	Yield
g ai ha^{-1}	g m^{-2}	cm	g	Mg ha^{-1}
0	3.2	24	187	77.4
75	2.9	23	182	77.9
100	2.6	22	178	77.9
200	2.4*	22	168*	73.1*

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α = 0.05).

Table 4. Effect of saflufenacil rate on cucumber shoot dry weight, and yield of Ontario No. 1, No. 2, No. 3, No. 4, and No. 5 (nubs and crooks) cucumber, 1 yr after saflufenacil application.[a]

		Cucumber yield				
Saflufenacil rate	Dry weight	No. 1	No. 2	No. 3	No. 4	No. 5
g ai ha^{-1}	g m^{-2}	Mg ha^{-1}				
0	105	3.2	3.6	12.3	5.6	2.9
75	87	2.9	3.1	10.6	4.7	2.0
100	69*	2.6*	2.5*	9.9*	3.9*	1.2*
200	60*	2.5*	2.1*	8.8*	3.5*	0.6*

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α = 0.05).

the previous year did not reduce growth or yield of cucumber (Particka and Zandstra 2004), Pekarek et al. (2010) observed a negative growth response in cucumber as sulfentrazone rates increased beyond normal field rates. Our data suggest that cucumber is more sensitive to residues of saflufenacil than other PPO-inhibiting herbicides, and that higher residue levels, such as those that may result from spray overlap, could injure cucumber grown 1 yr after saflufenacil application.

Onion. Onion shoot dry weight, bulb number per plot, bulb weight, and yield were reduced when saflufenacil was applied at 100 and 200 g ha^{-1} in the previous year (Table 5). The 100 g ha^{-1} rate reduced shoot dry weight, bulb number per plot, and marketable yield 18, 16, 17, and 25%, respectively. Onion shoot dry weight, bulb number per plot, bulb weight, and marketable yield were 27, 20, 28, and 40% less in the 200 g ha^{-1} treatment compared to the untreated, weed-free check. Though some PPO-inhibiting herbicides, including oxyfluorfen and flumioxazin, are registered for use in onion, sulfentrazone carryover reduced bulb number and yield (Grey and Culpepper 2005). The results of this study suggest saflufenacil residues could cause similar levels of growth and yield reduction to onion as sulfentrazone, 1 yr after application.

Pea. Pea shoot weight, tenderness and marketable yield were not reduced by saflufenacil residues at any of the three rates tested (Table 6). Shoot dry weight and yield were reduced less than 5% when saflufenacil was applied immediately prior to planting processing pea (Soltani et al. 2010). Pea tolerance to saflufenacil is high enough that the Canadian Pest Management Regulatory Agency (PMRA 2010) has prepared a submission for registration of saflufenacil in pea. It is therefore not surprising that saflufenacil did not cause injury to pea grown 1 yr after application in our study.

Table 5. Effect of saflufenacil rate on onion shoot dry weight, bulb number per plot and bulb weight, and marketable yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	No. of bulbs	Bulb weight	Yield
g ai ha^{-1}	g m^{-2}	*n* plot^{-1}	g bulb^{-1}	Mg ha^{-1}
0	3.3	50	380	47.6
75	2.9	46	344	39.8
100	2.7*	42*	314*	35.9*
200	2.4*	40*	274*	28.7*

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α=0.05).

Table 6. Effect of saflufenacil rate on pea shoot dry weight, tenderometer readings, and marketable yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	Tenderometer	Yield
g ai ha^{-1}	g m^{-2}	kPa	Mg ha^{-1}
0	22.3	642	4.3
75	22.9	642	4.4
100	22.2	649	3.8
200	22.9	649	4.0

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α=0.05).

Table 8. Effect of saflufenacil rate on potato shoot dry weight and marketable yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	Yield
g ai ha^{-1}	g m^{-2}	Mg ha^{-1}
0	53.5	32.7
75	47.1	31.6
100	50.7	33.1
200	53.3	30.4

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α = 0.05).

Pepper. Saflufenacil soil residues caused reductions in pepper shoot dry weight, fruit number per plot, fruit weight, and marketable yield (Table 7). Shoot dry weight in the 200 g ha^{-1} rate of saflufenacil treatment was 27% less compared to the untreated check. Fruit number per plot and fruit weight decreased by 12 and 5% in the 200 g ha^{-1} saflufenacil treatment. The 200 g ha^{-1} rate of saflufenacil reduced pepper yield by 16%. There is limited evidence in the literature that carryover of PPO-inhibiting herbicides reduces growth and yield of pepper. Though residues of sulfentrazone did not reduce pepper yield 1 yr after application (Pekarek et al. 2010), rates of 420 g ha^{-1} of sulfentrazone applied immediately prior to transplanting reduced yield (Grey et al. 2002). These studies, and the results of our research, indicate that pepper may be more sensitive to saflufenacil than to other PPO-inhibiting herbicides.

Potato. Saflufenacil residues did not reduce shoot dry weight or yield of potato (Table 8). Potato tolerance to other PPO-inhibiting herbicides in the year of production has been established (Wilson et al. 2002). Our data indicate that potato growth and yield would not be reduced by residues of saflufenacil applied in the previous year.

Sugar beet. Though sucrose content was not affected, sugar beet shoot dry weight and root yield were reduced by residues of saflufenacil (Table 9). Shoot dry weight decreased by 11 and 20% and yield decreased by 6 and 9%, where saflufenacil had been applied at 100 and 200 g ha^{-1} the previous year, respectively. Sulfentrazone residues applied in the previous year reduced growth and yield of sugar beet (Particka and Zandstra 2004).

The effect of saflufenacil residues applied 1 yr before different vegetable crops varied as a function of rate and crop species. Plant dry weight, yield, and quality of cucumber, onion, and sugar beet were reduced 1 yr after application of saflufenacil at the field corn rate. Cabbage, carrot, and pepper growth and yield were only reduced in those treatments where twice the field corn rate had been applied to simulate the effect of spray overlap in the previous year. Pea and potato were not negatively impacted by applications of saflufenacil in the year prior to planting. Pekarek et al. (2010) found that while residues of sulfentrazone, another PPO inhibitor, caused up to 32% yield loss in cotton, that yield of pepper, cabbage, cucumber, onion, snap bean, and tomato were not reduced in the year after application. Johnson and Talbert (1993) observed that fomesafen caused less than 10% injury to snap bean, cucumber and cantaloupe, but as much as 10, 16, and 38% injury in watermelon, sunflower, and tomato, respectively, when these crops were planted 10 to 11 mo after application. Fomesafen also injured corn planted 10 d after application at 0.125 to 0.5 kg ai ha^{-1}, but when planting was delayed to 212 d after application, injury did not occur (Cobucci et al. 1997). Based on this study, cabbage, carrot, cucumber, onion, pepper and sugar beet should not be grown in the year following PRE application of saflufenacil. PRE applications of saflufenacil did not reduce growth and yield of pea and potato planted 1 yr after application.

Acknowledgments

The authors would like to acknowledge Dave Bilyea for his expertise and technical assistance in these studies and Dr. Peter Sikkema for reviewing the manuscript prior to submission. Funding for this project was provided by BASF Canada.

Table 7. Effect of saflufenacil rate on pepper shoot dry weight, marketable fruit number per plot, and marketable fruit weight and yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	No. of fruits	Fruit weight	Yield
g ai ha^{-1}	g m^{-2}	*n* plot^{-1}	g fruit^{-1}	Mg ha^{-1}
0	21.4	68	184	17.1
75	20.5	69	189	17.4
100	18.6*	65	186	16.8
200	15.6*	60*	174*	14.4*

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α = 0.05).

Table 9. Effect of saflufenacil rate on sugar beet shoot dry weight, sucrose content, and root yield, 1 yr after saflufenacil application.[a]

Saflufenacil rate	Dry weight	Sucrose content	Yield
g ai ha^{-1}	g m^{-2}	%	Mg ha^{-1}
0	16.6	18.7	100.0
75	15.8	18.1	97.0
100	14.7*	18.5	93.8*
200	13.2*	18.3	91.1*

[a] Means within a column with an asterisk (*) beside them are different from the untreated check using Dunnett's procedure (α = 0.05).

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Received June 13, 2011, and approved November 24, 2011.