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Time of Application of *S*-Metolachlor Affects Growth, Marketable Yield and Quality of Carrot and Red Beet

Darren E. Robinson*, Kristen E. McNaughton

Department of Plant Agriculture, University of Guelph, Ridgetown Campus, Ridgetown, Canada.
Email: *drobinso@ridgetownc.uoguelph.ca

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ABSTRACT

Tolerance of carrot and red beet to *s*-metolachlor at three application timings—pre-emergence to crop (PRE), early postemergence (crop at two to four leaf stage-EPOST), and late postemergence (crop at five to seven leaf stage-LPOST)—was determined from 2008 to 2010. LPOST applications of *s*-metolachlor reduced carrot above ground plant dry weight, marketable yield and grower payment, but did not affect carrot length. PRE and LPOST applications of *s*-metolachlor reduced red beet above ground plant dry weight, total marketable yield, yield of No. 2 and No. 3 red beet, and grower payment. Our findings indicate that while carrot may be tolerant to PRE applications of *s*-metolachlor, applications made after the 5 leaf stage reduced plant dry weight enough to impact marketable yield and grower payment. In red beet, the potential reduction in growth, yield and grade would not justify the utility of a PRE or LPOST application timing.

Keywords: *S*-Metolachlor; Yield; Quality; Tolerance; Application Timing; Red Beet; Carrot

1. Introduction

In 2008, growers in Ontario planted approximately 3300 hectares of carrot and 400 hectares of red beet; in total, the farm gate value of these crops was approximately $20 million [1]. Effective weed management is essential to optimize yield of these relatively slow-growing, short statured crops. These crops are grown in similar soils in southwestern Ontario, and have similar environmental requirements for germination and growth [2]. These crops are also commonly grown in soils infested with yellow nutsedge (*Cyperus esculentus* L.), which is difficult to manage due to an extensive system of rhizomes and tubers that ensure its persistence and spread [3].

Weed control in carrot and red beet in Ontario is currently limited to a small number of registered herbicides. Linuron, the only herbicide registered for use in carrot in Ontario, only suppresses yellow nutsedge [4]. Prior to initiating this work, red beet growers' only herbicide option was pyrazon, which is ineffective on yellow nutsedge [4]. In both carrot and red beet, the level of control that could be obtained with registered products at the outset of this research was not acceptable and had to be augmented with cultivation and hand-weeding to avoid yield loss. A recent comparison of *s*-metolachlor and linuron in celery [5] illustrated that *s*-metolachlor is more efficacious on yellow nutsedge.

With the recent registrations of *s*-metolachlor in red beet and carrot, another area of interest to growers is whether carrot and red beet are tolerant to different application timings. *S*-metolachlor was registered EPOST (3 - 5 leaf stage) at a rate of 1200 g a.i. ha^{-1} in red beet, and EPOST (3 - 5 leaf stage) at a rate of 1600 g a.i. ha^{-1} in carrot [4]. Grichar *et al.* (1996) [6] observed similar levels of control of yellow nutsedge with preemergence (PRE) and early postemergence (EPOST) applications of *s*-metolachlor. This finding indicates that the option to apply *s*-metolachlor PRE in carrot could provide some flexibility with the use of this herbicide and still maintain efficacy, as long as crop tolerance is acceptable at both application timings. The option to apply *s*-metolachlor PRE to red beet and prior to emergence of yellow nutsedge would also be useful, since yellow nutsedge germination begins at a soil temperature of 12˚C [7], while the minimum temperatures at which carrot and red beet germinate are 4.0˚C and 4.5˚C, respectively [2]. *S*-metolachlor applied 20 days after emergence of peanut but prior to weed emergence and then irrigated provided 95% control of yellow nutsedge [6]. For those growers with access to irrigation, this would also be a useful management strategy, but only if red beet possessed tolerance to late postemergence (LPOST) applications of *s*-metolachlor. Based on their similarities in growth in the

*Corresponding author.

vegetable production area of southwestern Ontario, and the importance of *s*-metolachlor for weed control, we chose to examine the response of carrot and red beet to different application timings of this herbicide. The purpose of this research was therefore to compare the effects of PRE, EPOST and LPOST applications of *s*-metolachlor, at rates of 1200, 1600 and 3200 g a.i. ha^{-1} on carrot and red beet dry weight, marketable yield and grower payments based on current prices paid by processors.

2. Materials and Methods

We conducted six field experiments at the University of Guelph, Ridgetown Campus, Ridgetown, Ontario, from 2008 to 2010—three in carrot and three in red beet. The soil was a Watford/Brady clay loam with 36% sand, 33% silt, 32% clay, 2.9% organic matter and pH of 6.8 in 2008, a Watford/Brady fine sandy loam with 72% sand, 15% silt, 13% clay, 2.4% organic matter and pH of 6.5 in 2009, and a Normandale sandy loam with 58% sand, 24% silt, 18% clay, 3.2% organic matter and pH of 6.9 in 2010. Each experiment was arranged in a randomized complete block design with two factors: herbicide rate and herbicide timing. All treatments were replicated four times. Treatments included a non-treated weed-free control and *s*-metolachlor applied pre-emergence (PRE), early post-emergence (EPOST) and late post-emergence (LPOST) at 1200, 1600 and 3200 g a.i. ha^{-1} to either carrot or red beet.

Carrot plots were 3 m wide by 8 m long. Carrot (“Fontana”) was planted on 28, 29 and 23 April 2008, 2009 and 2010 at 260 000 seeds·ha^{-1} in three row beds, with two beds per plot. We spaced individual rows 38 cm apart, on 142-cm wide beds. Red beet plots had the same dimensions as the carrot plots, however we planted “Detroit Supreme” red beet on 29 May 2008, 4 June 2009 and 22 May 2010 at 265 684 seeds·ha^{-1}. Carrot and red beet plots were kept weed-free by hand hoeing, as required, to eliminate the potential for yield loss due to weed competition.

PRE herbicide applications were made one to two days after planting, but prior to crop emergence. EPOST applications were applied at the three to five leaf stage of carrot or red beet, while LPOST applications were made to carrot or red beet at the six to eight leaf stage. Spray applications were applied with a CO_2-pressurized backpack sprayer, calibrated to deliver 200 L·ha^{-1} with ULD120-02 air induction spray tips (Spraying Systems Co., PO Box 7900, Wheaton, IL 60189-7900) at 207 kPa pressure.

To determine the effect of each treatment combination on crop growth, aboveground portions of plants from three 1-m length of row per plot were harvested at 28 days after the LPOST application of *s*-metolachlor, and dried to a constant weight at 70˚C. Carrot and red beet were machine harvested from the center 6 m of each plot in September, the weight per plot was determined and converted to weight per hectare. For carrot, the length of a representative sample of 50 carrot roots was measured for each plot. Payments to growers were estimated based on a price of $89.44 per tonne of topped dicing carrot [8]. Red beet was sorted into grades: #1 (2.54 to 4.13 cm), #2 (4.13 to 6.35 cm) and #3 (6.35 to 7.62 cm), each grade was weighed on a per plot basis and converted to weight per hectare. Payments to growers were estimated based on grade prices of $159.20 (#1), $131.84 (#2) and $96.60 (#3) per tonne of red beet [8]. Ten beets from each plot were cored by hand and blended in a Waring CB-6 blender model 34BL22 (Waring Products, New Hartford, CT) for 40 seconds. Ten mL of blended red beet sample was filtered through Fisherbrand P8 coarse porosity filter paper (Cat. No. 09-795E, Fisher Scientific, Pittsburgh, PA). The first 2 mL of filtrate were discarded and the following 4mL were placed onto the prism of a Palette PR-101 digital refractometer (Atago USA, Inc., Bellevue, WA). Total soluble solids (Brix value) were determined on this subsample. Total soluble solids were determined on a second 4 mL subsample, and the two readings were averaged for each sample of 10 beets.

All data were subjected to analysis of variance using the PROC MIXED procedure of SAS/STAT® software, version 9.1 [9]. Variances of plant dry weight, carrot length, red beet total soluble solids, yield (as well as individual grade yields in the case of red beet), and grower payment were partitioned into the fixed effects of herbicide application timing, herbicide rate, the interaction between timing and rate, and the random effects of year and the various year-by-treatment interactions. Significance of random effects was tested using a Z-test of the variance estimate and fixed effects were tested with F-tests. Error assumptions of the variance analyses (random, homogeneous distribution of error terms and normality) were confirmed using residual plots and the Shapiro-Wilk normality test. Assumptions of homogeneity of error terms and normality were met, so data were not transformed. As there were no significant effects of year or the year-by-herbicide timing or year-by-herbicide rate interactions, data for each crop were combined over the three years of the study for the analysis. Since there were no differences among rates at each herbicide timing, orthogonal contrasts ($\propto = 0.05$) were constructed to determine if each treatment differed from the untreated check.

3. Results and Discussion

S-metolachlor reduced above ground dry weight, marketable yield and grower payment when applied late post-emergence (LPOST) to carrot, while pre-emergence (PRE) and early-postemergence (EPOST) application timings of *s*-metolachlor did not reduce growth of carrot relative to the untreated check (**Table 1**). Dry weight was between 21% and 29% less in the LPOST treatment than in the untreated check. This reduction in plant dry weight corresponded to marketable yields and grower payments that were 29% to 36% less than the untreated check (**Table 1**). *S*-metolachlor is taken up through various tissues, including root, emerging shoot, hypocotyl and foliage of different species [10,11]. However, since we observed less growth reduction in carrot when *s*-metolachlor was applied PRE and EPOST than LPOST, uptake may increase with plant age, or ability to metabolize the herbicide may decrease with age. Studies have shown that LPOST applications of *s*-metolachlor can injure other species, including peanut [12] and tomato [13].

S-metolachlor reduced above ground dry weight, marketable yield and grower payment when applied PRE and LPOST, but not EPOST, to red beet (**Table 2**). Dry weight was 14% to 16% less in the PRE treatments than in untreated check, and 9% to 15% less in the EPOST treatment than in the untreated check. Total marketable yield was 17% to 21% and 19% to 25% lower in the PRE and LPOST treatments, respectively, than in the untreated check. This corresponded to grower payments that were between 15% and 19% and 17% and 23% less in the PRE and LPOST treatments than in the untreated check, respectively. Though No. 1 yield was not reduced by any treatment timings, PRE and LPOST applications of *s*-metolachlor reduced red beet size at harvest, therefore resulting in lower No. 2 and No. 3 yield (**Table 3**). The PRE timings reduced No. 2 beet yield from 16% to 35%, while the LPOST application timing reduced yield of No. 2 beet between 13% and 22% compared to the untreated check. No. 3 red beet yield was 30% to 31% and 33% to 39% less in the PRE and LPOST timings, respectively, than in the untreated check (**Table 3**). Studies have shown that *s*-metolachlor injury in sugar beet is greater when applied PRE than EPOST as a result of greater uptake through root than hypocotyl or foliar tissues [14]. Similarly, early planted cabbage was injured more by applications made prior to transplanting than after transplanting [15]. The greater levels of growth reduction we observed in PRE than EPOST applications of *s*-metolachlor in red beet conform to those of other studies [14] and [15]. Similarly to what we observed in carrot, red beet was injured enough to reduce plant dry weight and yield by LPOST applications of *s*-metolachlor. These observations suggest that there may be foliar uptake of *s*-metolachlor in carrot and red beet, particularly at later leaf stages.

4. Conclusion

Submissions to register *s*-metolachlor in carrot and red beet were recently approved by the Pest Management Regulatory Agency in Canada. Growers have expressed interest in expanding those registrations to include other application timings. Our findings indicate that while carrot may be tolerant to PRE applications of *s*-metolachlor, applications made after the 5 leaf stage would reduce plant dry weight enough to impact marketable yield and

Table 1. Effect of *s*-metolachlor timing and rate on above ground dry weight 4 weeks after emergence, and carrot root length, marketable yield and grower payment at harvest at Ridgetown, Ontario from 2008 to 2010.

Herbicide timing	Herbicide rate (g a.i. ha^{-1})	Dry weight[z] ($g \cdot m^{-2}$)	Carrot length[z] (cm)	Marketable yield[z] ($t \cdot ha^{-1}$)	Grower payment[z] ($\$ \cdot ha^{-1}$)
Untreated check		84	16	63	7042
PRE	1200	80	17	63	6901
	1600	82	16	61	6702
	3200	84	15	62	6758
EPOST	1200	86	16	64	7062
	1600	86	16	65	7140
	3200	83	15	64	7024
LPOST	1200	**66**	15	**45**	**5013**
	1600	**61**	15	**42**	**4662**
	3200	**60**	14	**40**	**4460**
Standard error		4	3	2	258

[z]Values within a column in bold typeface indicate a significant difference between that treatment and the untreated check using single degree-of-freedom contrasts ($P \leq 0.05$).

Table 2. Effect of *s*-metolachlor timing and rate on red beet above ground dry weight 4 weeks after emergence, total soluble solids, marketable yield and grower payment at harvest at Ridgetown, Ontario from 2008 to 2010.

Herbicide timing	Herbicide rate (g a.i. ha^{-1})	Dry weight[z] ($g \cdot m^{-2}$)	Total soluble solids[z] (Brix)	Marketable yield[z] ($t \cdot ha^{-1}$)	Grower payment[z] ($\$ \cdot ha^{-1}$)
Untreated check		136	11	24.0	2981
	1200	128	11	**19.9**	**2548**
PRE	1600	**117**	11	**19.1**	**2441**
	3200	**114**	11	**18.9**	**2415**
	1200	145	11	24.2	3008
EPOST	1600	140	11	23.6	2934
	3200	136	10	23.8	2976
	1200	**124**	11	**19.4**	**2488**
LPOST	1600	**118**	10	**18.5**	**2376**
	3200	**114**	11	**17.9**	**2300**
Standard error		10	2	3.0	305

[z]Values within a column in bold typeface indicate a significant difference between that treatment and the untreated check using single degree-of-freedom contrasts ($P \leq 0.05$).

Table 3. Effect of *s*-metolachlor timing and rate on red beet yield, sorted by grade at Ridgetown, Ontario from 2008 to 2010.

Herbicide timing	Herbicide rate (g a.i. ha^{-1})	Grade 1[zy]	Grade 2[zy] ($t \cdot ha^{-1}$)	Grade 3[zy]
Untreated check		6.3	7.6	**10.1**
	1200	6.4	**6.4**	**7.1**
PRE	1600	6.2	**5.9**	**7.0**
	3200	6.2	**5.7**	**7.0**
	1200	6.2	8.0	10.0
EPOST	1600	6.0	7.9	9.7
	3200	6.1	8.4	9.3
	1200	6.1	**6.6**	**6.7**
LPOST	1600	5.8	**6.4**	**6.3**
	3200	5.8	**5.9**	**6.2**
Standard error		1.1	0.9	2.1

[z]Values within a column in bold typeface indicate a significant difference between that treatment and the untreated check using single degree-of-freedom contrasts ($P \leq 0.05$); [y]Red beet was sorted into grades based on industry-accepted size standards (OPVG 2009): No. 1 (2.54 to 4.13 cm), No. 2 (4.13 to 6.35 cm) and No. 3 (6.35 to 7.62 cm).

grower payment. In red beet, the potential reduction in yield would not justify the utility of a LPOST application timing, due to reductions in plant dry weight, marketable yield and grower payment. Our analysis of yield-by-grade also indicated that fewer larger beets were produced when *s*-metolachlor was applied after the five leaf stage. We conclude that carrot and red beet are not tolerant to this herbicide after the five leaf stage of development, and that expanding the current labels to include later application timings is not possible.

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