Weed Technology 2016 30:898–909

Evaluation of Season-Long Weed Management Programs in Red Beet

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Red beet growers have expressed interest in adopting the microrate herbicide approach originally implemented in sugarbeet to achieve season-long weed management. Several red beet herbicides were first labeled for use in sugarbeet and lack substantial residual weed control. In response, red beet herbicide programs were evaluated that included a PRE application followed by up to three POST applications of various herbicide combinations. This research, however, indicated that herbicide programs that included PRE herbicides followed by as few as one or two POST applications that involve multiple active ingredients can provide season-long weed control. This observation was consistent across a broad spectrum of weeds, between two study locations that varied in soil type, and during two growing seasons. Herbicide programs that included only a PRE and six-leaf red beet growth stage application were successful at two locations in maintaining weed control and crop yield relative to hand-weeded red beet. Furthermore, these herbicide programs reduced the number of applications by 50% compared with the full programs, reducing crop injury risk and grower cost.
Nomenclature: Red beet, *Beta vulgaris* L.; sugarbeet, *Beta vulgaris* L.
Key words: Minor crops, red beet, vegetables, weed management programs.

Los productores de remolacha roja han expresado interés en adoptar el uso de la estrategia de micro-dosis de herbicidas, originalmente implementada en la producción de remolacha azucarera para alcanzar un manejo de malezas a lo largo de toda la temporada de crecimiento. Varios herbicidas para remolacha roja fueron registrados primero para uso en remolacha azucarera, sin embargo carecen de control sustancial residual. En respuesta a estas necesidades, se evaluaron programas de herbicidas que incluyeron una aplicación PRE seguida por hasta tres aplicaciones POST de varias combinaciones de herbicidas. Esta investigación, sin embargo, indicó que los programas de herbicidas que incluyeron herbicidas PRE seguidos con tan sólo una o dos aplicaciones POST que incluyeron múltiples ingredientes activos pudieron brindar un control de malezas a lo largo de toda la temporada. Esta observación fue consistente para un amplio espectro de malezas, en dos localidades con diferente tipo de suelo, y durante dos temporadas de crecimiento. Los programas de herbicidas que incluyeron solamente una aplicación PRE en el estadio de seis hojas de la remolacha roja, fueron exitosas en dos localidades para mantener el control de malezas y el rendimiento del cultivo en relación a la remolacha roja con deshierba manual. Además, estos programas de herbicidas redujeron el número de aplicaciones en 50% al compararse con los programas completos, lo que redujo el riesgo de daño al cultivo y el costo al productor.

Red beet remains a small yet important rotational crop in the upper Midwest U.S. vegetable-processing industry. In Wisconsin alone, specialty crop production and processing account for more than $6 billion in economic activity and nearly 35,000 jobs (Arledge-Keene and Mitchell 2010). Among that, red beet was produced on 1,427 ha by 234 growers in 2012 (USDA-NASS 2014).

Red beet is a poor competitor with weeds, particularly in the early season. Kolota and Osinska (1997) reported that red beet marketable yield was reduced by 53% when the crop remained weedy throughout the season as compared with a weed-free crop. Red beet plants that remained weed-free for the first 3 wks of the growing season produced only 72% of the weed-free crop yield. The authors concluded that a 6-wk weed-free period was required to produce a red beet yield comparable to those that were weed free for the entire growing season.

Slow crop growth and attention to harvested root quality limit the use of herbicide alternatives to timely cultivation in commercial red beet production. Researchers in Poland recently explored the use of cover crops and no tillage in red beet. Although red beet plant emergence was unaffected, crop growth and yield were reduced in both study years when compared with conventional tillage without cover crops (Borowy et al. 2015).

DOI: 10.1614/WT-D-16-00015.1
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Table 1. Herbicide sources for studies in Arlington and Plover, WI, in 2013 and 2014.

Herbicide	Trade name	Manufacturer	Location
Bicyclopyrone	—	Syngenta Crop Protection, Inc.	Greensboro, NC
Clopyralid	Stinger	Dow AgroSciences	Indianapolis, IN
Cycloate	Ro-Neet	Helm Agro US, Inc.	Memphis, TN
Desmedipham	Alphanex	United Phosphorus Inc. (UPI)	King of Prussia, PA
Ethalfluralin	Curbit	Loveland Products	Loveland, CO
Ethofumesate	Ethotron	UPI	King of Prussia, PA
Phenmedipham	Spin-Aid	Engage Agro USA	Prescott, AZ
S-metolachlor	Dual Magnum	Syngenta Crop Protection, Inc.	Greensboro, NC
Triflusulfuron	UpBeet	DuPont Crop Protection	Wilmington, DE

Several of the herbicides used in red beet were initially developed for use in sugarbeet. Weed-control options in red beet are rather limited and have become more so since the introduction of glyphosate-resistant sugarbeet around 2008. This technology enhanced weed-control timing flexibility, often improving overall weed control and resulting sugarbeet yields compared with conventional weed-control programs (Spangler et al. 2014). By 2011, glyphosate-resistant sugarbeet was planted on 95% of the North American hectarage (Bartlett 2011), thus reducing the economic impetus to develop and register new herbicides for the crop. Additionally, herbicide mainstays previously registered for use in red beet are no longer available, such as pyrazon and tank-mix products that contained phenmedipham plus desmedipham.

The narrowing of available herbicide options in red beet has focused attention on a few active ingredients used in multiple PRE and POST applications to achieve season-long weed control. In Wisconsin, *S*-metolachlor is available for use in red beet through a Special Local Needs (24c) label. Other active ingredients commonly used in PRE applications include cycloate and ethofumesate (Colquhoun et al. 2016). Multiple early season POST applications are often needed given the lack of crop competitive ability with weeds during the first 6 wk after seeding. However, the optimal timing, rates, tank-mixes, and order of application for these herbicides in terms of weed control, crop safety, and yield are largely unknown. With that in mind, the objective of these studies was to evaluate a programmatic approach to red beet weed management with existing and potential herbicides that would achieve the greatest weed control and crop yield. The studies were conducted in 2 yr and at two locations to evaluate the resilience of these programs in diversified conditions.

Materials and Methods

Studies were conducted in 2013 and 2014 in Arlington, WI, at the University of Wisconsin Arlington Agricultural Research Station and in a grower's field in Plover, WI. The Arlington studies were conducted on a Joy silt loam soil (fine-silty, mixed, superactive, mesic Aquic Hapludolls) with a pH of 7.0 and 2.8 and 3.6% organic matter in 2013 and 2014, respectively. The Plover studies were conducted on a Meehan loamy sand (mixed, frigid Aquic Udipsamments) with 1.5 to 2.5% organic matter. Soil moisture was monitored and supplemental irrigation was delivered through a pivot system at the Plover site, which is standard commercial practice in that region.

Individual plots measured 1.8 m wide by 6.1 m long and included one row of each red beet variety: 'Ruby Queen', 'Detroit Supreme', 'Red Ace', and 'Red Titan'. The studies were arranged in a randomized complete-block design with four replications of each herbicide program. The Arlington studies were planted on May 21, 2013, and May 19, 2014, whereas the Plover studies were planted on May 20, 2013, and May 16, 2014. Target plant population was 66 m^{-1} of row. The evaluated herbicide programs for the Plover location are listed in Tables 1 and 2. Two additional reduced-input programs were included in 2014 at both locations based on 2013 results. The two-, four- and six-leaf herbicide applications were based on red beet growth stage and ranged across locations and years from 13 to 21, 26 to 35, and 32 to 42 d after seeding (DAS), respectively. The herbicide programs were similar in Arlington, with the following

https://doi.org/10.1614/WT-D-16-00015.1 Published online by Cambridge University Press

Table 2. Red beet weed management programs in Plover, WI, in 2013 and 2014. Programs 11 and 12 were included in 2014 only.

Program No.	Descriptor	Crop growth stage	Herbicide[a]	Rate
				kg ai or ae ha^{-1}
1	Hand-weeded check	—	—	—
2	Nontreated check	—	—	—
3	*S*-metolachlor	PRE	*S*-metolachlor + ethofumesate	0.80 + 0.56
		Two-leaf	Ethofumesate + triflusulfuron + COC	0.18 + 0.07 + 0.25%
		Four-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.11 + 0.07 + 0.12 + 0.11
		Six-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.14 + 0.14 + 0.18 + 0.11
4	Cycloate	PPI/PRE	Cycloate (PPI) + ethofumesate (PRE)	3.36 + 0.56
		Two-leaf	Ethofumesate + triflusulfuron + COC	0.18 + 0.07 + 0.25%
		Four-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.11 + 0.07 + 0.12 + 0.11
		Six-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.14 + 0.14 + 0.18 + 0.11
5	Ethofumesate high PRE rate	PRE	*S* -metolachlor + ethofumesate	0.80 + 1.4
		Two-leaf	Ethofumesate + triflusulfuron + COC	0.18 + 0.07 + 0.25%
		Four-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.11 + 0.07 + 0.12 + 0.11
		Six-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.14 + 0.14 + 0.18 + 0.11
6	Desmedipham, no Six-leaf application	PRE	*S* -metolachlor + ethofumesate	0.80 + 0.56
		Two-leaf	Ethofumesate + desmedipham + clopyralid + MSO	0.18 + 0.27 + 0.05 + 0.63%
		Four-leaf	Ethofumesate + desmedipham + clopyralid + MSO	0.18 + 0.27 + 0.05 + 0.63%
7	Phenmedipham two-leaf	PRE	*S*-metolachlor + ethofumesate	0.80 + 0.56
		Two-leaf	Ethofumesate + triflusulfuron + phenmedipham	0.11 + 0.07 + 0.12
		Four-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.11 + 0.07 + 0.12 + 0.11
		Six-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.14 + 0.14 + 0.18 + 0.11
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	PRE	*S*-metolachlor	0.80
		Two-leaf	Ethofumesate + phenmedipham	0.18 + 0.18
		Four-leaf	Ethofumesate + phenmedipham	0.18 + 0.27
		Six-leaf	Ethofumesate + triflusulfuron + clopyralid + COC	0.37 + 0.28 + 0.16 + 0.25%
9	Ethalfluralin PRE	PRE	Ethalfluralin	1.26
		Two-leaf	Ethofumesate + clopyralid + MSO	0.18 + 0.11 + 0.63%
		Four-leaf	Ethofumesate + clopyralid + MSO	0.18 + 0.11 + 0.63%
10	Bicyclopyrone PRE	PRE	Bicyclopyrone	0.48
		Two-leaf	Ethofumesate + clopyralid + MSO	0.18 + 0.11 + 0.63%
		Four-leaf	Ethofumesate + clopyralid + MSO	0.18 + 0.11 + 0.63%

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Table 2. Continued.

Program No.	Descriptor	Crop growth stage	Herbicide[a]	Rate
11	*S*-metolachlor PRE, no two- or four-leaf application	PRE	*S*-metolachlor + ethofumesate	0.80 + 1.4
		Six-leaf	Ethofumesate + triflusulfuron + clopyralid + COC	0.37 + 0.28 + 0.16 + 0.25%
12	Cycloate PPI, no two- or four-leaf application	PPI/PRE	Cycloate (PPI) + ethofumesate (PRE)	3.36 + 1.4
		Six-leaf	Ethofumesate + triflusulfuron + phenmedipham + clopyralid	0.14 + 0.14 + 0.18 + 0.11

[a] Abbreviations: COC, crop oil concentrate, MSO, methylated seed oil.

exceptions adjusted for the heavier soil type: the *S*-metolachlor rate was 1.07 kg ai ha^{-1}, the triflusulfuron rates were 0.14 kg ai ha^{-1} for the two-leaf application and 0.28 kg ha^{-1} for the four- and six-leaf applications, the ethofumesate rate in treatments 5, 11, and 12 was 2.1 kg ai ha^{-1}, and the cycloate rate in treatment 12 was 4.45 kg ai ha^{-1}.

Herbicides were applied with a tractor-mounted air pressure sprayer calibrated to deliver 187 L ha^{-1} at 186 kPa with TeeJet XR8003VS nozzle tips. The PPI herbicide applications were incorporated by hand with a garden rake. All other production practices, including fertilizer and maintenance insecticide applications, followed typical commercial practices (Colquhoun et al. 2016). Red beet injury was visually estimated on a scale of 0 (no injury) to 100% (plant death). Red beets were harvested by variety at maturity and graded by diameter. The studies were analyzed independently given rate and treatment differences between locations and years. Weed control and red beet injury and yield were analyzed independently by variety. Data were subjected to ANOVA to determine whether there was a treatment effect. Means were separated using Fisher's protected LSD test at $P = 0.05$.

Results and Discussion

Weed Management. In 2013 at the Plover study site, early season weed control was outstanding after PRE and two-leaf herbicide applications in all of the control programs (Table 3). Weed control across the spectrum of weeds at 35 DAS was 95% or greater, except for wild-proso millet (*Panicum milliaceum* L.) control where bicyclopyrone was included (92% control). Common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and common ragweed (*Ambrosia artemisiifolia* L.) control was 100% in all herbicide programs at 86 DAS. Wild buckwheat (*Polygonum convolvulus* L.) control 86 DAS was 94% where cycloate was included in the herbicide program and 48 and 60% where ethalfluralin and bicyclopyrone were applied, respectively. Wild-proso millet control 86 DAS was 81% where ethalfluralin was applied. In contrast to the 35 DAS evaluation timing, by 86 DAS wild-proso millet control was 100% in the herbicide program that included bicyclopyrone, indicating the effectiveness of the POST applications.

In 2014, barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] control with the ethalfluralin and bicyclopyrone herbicide programs were poor through 60 DAS (Table 4). Additionally, POST treatments that followed ethalfluralin and bicyclopyrone did not adequately control wild-proso millet. The contrast in wild-proso millet control between 2013 and 2014 can be attributed to emergence timing and growth stage, where wild-proso millet emerged earlier in 2014 and was already about 5 cm tall at the same timing in 2014. With the exception of common ragweed control at 32 DAS, treatments that included just PRE and six-leaf red beet growth stage herbicide applications resulted in 98% or greater weed control, indicating an ability to reduce herbicide inputs and applications without compromising weed control.

Velvetleaf (*Abutilon theophrasti* Medik.) and yellow foxtail [*Setaria pumila* (Poir.) Roemer & J.A. Schultes] were dominant weeds at the Arlington, WI, study location in 2013 (data not shown). Velvetleaf control at 33 DAS was greater than 90% in all herbicide programs, except where ethalfluralin was applied. Yellow foxtail control at 33 DAS was complete in all herbicide programs, except where ethalfluralin (88% control) or bicyclopyrone (95%) were included. By 85 DAS, grass control was

https://doi.org/10.1614/WT-D-16-00015.1 Published online by Cambridge University Press

Table 3. Visual evaluation of weed control in red beet in Plover, WI, in 2013, where 0% represents no control and 100% represents complete weed control.

		Weed control visual evaluation[a,b]											
		35 DAS						86 DAS					
Program No.	Descriptor	CHEAL	POROL	AMARE	AMBEL	POLCO	PANMI	CHEAL	POROL	AMARE	AMBEL	POLCO	PANMI
		%											
1	Hand-weeded check	100	100	100	100	100	100	100 a	100	100	100	100 a	100 a
3	*S*-metolachlor	99	100	100	100	100	99	97 b	100	100	100	97 a	96 b
4	Cycloate	100	100	100	100	100	99	99 ab	100	100	100	94 a	100 a
5	Ethofumesate high PRE rate	100	100	100	100	100	100	100 a	100	100	100	100 a	100 a
6	Desmedipham, no six-leaf application	100	100	100	100	100	100	100 a	100	100	100	100 a	100 a
7	Phenmedipham two-leaf	100	100	100	100	100	100	100 a	100	100	99	100 a	100 a
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	100	100	100	100	100	99	100 a	100	100	100	100 a	100 a
9	Ethalfluralin PRE	100	100	100	100	100	96	97 b	100	100	100	48 b	81 b
10	Bicyclopyrone PRE	100	100	100	100	100	92	97 b	100	100	100	60 b	100 a

[a] Abbreviations: DAS, days after seeding; CHEAL, common lambsquarters; POROL, common purslane; AMARE, redroot pigweed; AMBEL, common ragweed; POLCO, wild buckwheat; PANMI, wild-proso millet.

[b] Means followed by the same letter are not different according to Fisher's protected LSD test at $P = 0.05$. If no letters are included for a column then there were no statistical differences noted.

https://doi.org/10.1614/WT-D-16-00015.1 Published online by Cambridge University Press

Table 4. Visual evaluation of weed control in red beet in Plover, WI, in 2014, where 0% represents no control and 100% represents complete weed control.

		Weed control visual evaluation[a,b]											
		32 DAS						60 DAS					
Program No.	Descriptor	CHEAL	AMARE	POROL	AMBEL	ECHCG	PANMI	CHEAL	AMARE	POROL	AMBEL	ECHCG	PANMI
		%											
1	Hand-weeded check	100	100	100	100 a	100	100	100	100	100	100	100 a	100 a
3	*S*-metolachlor	100	100	100	96 c	100	100	100	100	100	100	100 a	95 a
4	Cycloate	100	100	100	100 a	100	100	100	100	100	100	100 a	100 a
5	Ethofumesate high PRE rate	100	100	100	99 abc	100	100	100	100	100	100	100 a	99 a
6	Desmedipham, no six-leaf application	100	100	100	100 a	100	100	100	100	100	100	100 a	98 a
7	Phenmedipham two-leaf	100	100	100	98 abc	100	100	100	100	100	100	100 a	99 a
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	99	100	100	98 bc	100	100	100	100	99	100	100 a	97 a
9	Ethalfluralin PRE	98	100	96	97 bc	91	100	100	98	99	100	49 c	43 c
10	Bicyclopyrone PRE	100	100	100	100 a	86	100	100	100	100	100	75 b	63 b
11	*S*-metolachlor PRE, no two- or four-leaf application	98	100	100	76 d	98	100	99	99	98	98	100 a	91 a
12	Cycloate PPI, no two- or four-leaf application	100	100	100	99 abc	100	100	100	100	100	100	100 a	98 a

[a] Abbreviations: DAS, days after seeding; CHEAL, common lambsquarters; AMARE, redroot pigweed; POROL, common purslane; AMBEL, common ragweed; ECHCG, barnyardgrass; PANMI, wild-proso millet.

[b] Means followed by the same letter are not different according to Fisher's protected LSD test at $P = 0.05$. If no letters are included for a column then there were no statistical differences noted.

https://doi.org/10.1614/WT-D-16-00015.1 Published online by Cambridge University Press

generally poor in the herbicide program that included ethalfluralin, ranging from 44% for barnyardgrass to 53% for yellow foxtail. In 2014, no velvetleaf or yellow foxtail were present in the research area and common lambsquarters, redroot pigweed, common purslane (*Portulaca oleracea* L.), common ragweed, and barnyardgrass control at 31 DAS was 90% or greater (data not shown). This level of weed control was maintained through 56 DAS, except for redroot pigweed (78% control) and common ragweed 84% control) where ethalfluralin was applied.

Red Beet Injury. In 2013, at the Plover study site, Ruby Queen, Red Ace, and Red Titan injury from ethalfluralin ranged from 29 to 35% when evaluated at 29 and 35 DAS (Table 5). Detroit Supreme was very sensitive to ethalfluralin, with 93% injury persisting at 86 DAS. Red beet injury was initially observed 29 and 35 DAS where cycloate or desmedipham were applied; however, this injury was outgrown by 86 DAS. Ruby Queen, Red Ace, and Red Titan injury was 5% or less by 86 DAS, whereas Detroit Supreme injury was more persistent for most herbicide programs.

In contrast to 2013, red beet injury at the Plover location in 2014 was generally minor, with the exception of where ethalfluralin or bicyclopyrone were applied (Table 6). Detroit Supreme was again sensitive, with injury observed 60 DAS in all herbicide programs. Red beet injury was 4% or less at all evaluation timings for the herbicide programs that included only PRE and six-leaf red beet growth stage applications.

In 2013, at the Arlington research site, transient injury was observed at 35 DAS in herbicide programs that included clopyralid in the two-leaf red beet growth stage application (data not shown). Red beet symptoms included cupped leaves and twisted petioles. Ethalfluralin injury was persistent throughout the season and among red beet varieties, particularly Detroit Supreme, where injury was up to 98% by 86 DAS. Similar ethalfluralin injury was observed in 2014, but no clopyralid injury was observed (data not shown). By 60 DAS, injury was less than 5% in all varieties and herbicide programs. with the exception of ethalfluralin and Detroit Supreme where injury was again 98%.

Red Beet Yield. In 2013, at the Plover location, Detroit Supreme red beet yield at both grade sizes and in total was reduced by the ethalfluralin injury compared with the hand-weeded red beet crop (Table 7). The recovery from ethalfluralin injury observed with the other varieties led to total red beet yields similar to the hand-weeded red beet crop. Detroit Supreme total yield and yield of beets greater than 4.8 cm diameter were greater than the hand-weeded beet plants where desmedipham was included in the two- and four-leaf growth-stage applications but without a six-leaf growth-stage herbicide program, despite early season injury. This suggests that herbicide programs could be adopted with a reduced number of applications without compromising red beet yield, hence, the inclusion of such herbicide programs in the 2014 study year.

In 2014, despite minor injury and excellent weed control, Ruby Queen red beet yield in total and in the greater than 4.8-cm diameter grade size were reduced compared with the hand-weeded red beet plants in 6 of the 10 herbicide programs (Table 8). Ethalfluralin and bicyclopyrone herbicide programs reduced large beet and total yield of all varieties compared with the hand-weeded red beet, with the exception of Red Titan total yield. Red beet yield in both grade sizes and in total was similar to the hand-weeded red beet crop in the herbicide programs that did not include two- or four-leaf growth-stage applications, with the exception of where cycloate was applied to Ruby Queen. This suggests that the number of herbicide applications can be reduced by 50% without yield loss.

In 2013, at the Arlington location, total yield was similar to the hand-weeded red beet crop with most herbicide program and variety combinations (data not shown). The early season clopyralid injury did not affect red beet yield compared with other herbicide programs. The high level of Detroit Supreme injury (up to 98%) from ethalfluralin reduced total yield by about 90% compared with the hand-weeded red beet plants. Interestingly, Detroit Supreme yield in total and in the larger-size grade was greater than the hand-weeded check in the herbicide program that did not include a six-leaf growth-stage application. In 2014, the only yield reduction from the herbicide programs when compared with the hand-weeded beet plants was where ethalfluralin was applied to

Table 5. Visual evaluation of red beet herbicide injury in Plover, WI, in 2013, where 0% represents no crop injury and 100% represents total crop death.

Program No.	Descriptor	Red beet injury[a,b] 'Ruby Queen 29 DAS	'Ruby Queen 35 DAS	'Ruby Queen 86 DAS	Detroit Supreme 29 DAS	Detroit Supreme 35 DAS	Detroit Supreme 86 DAS	Red Ace 29 DAS	Red Ace 35 DAS	Red Ace 86 DAS	Red Titan 29 DAS	Red Titan 35 DAS	Red Titan 86 DAS
		%											
1	Hand-weeded check	0 c	0 d	0	0 d	0 d	0 d	0 c	0 c	0 c	0 c	0 d	0 b
2	Nontreated check	0 c	0 d	0	0 d	0 d	0 d	0 c	0 c	0 c	0 c	0 d	0 b
3	*S*-metolachlor	7 bc	6 bcd	0	11 b	9 bcd	8 b	8 bc	4 bc	5 a	9 bc	5 bcd	0 b
4	Cycloate	12 ab	24 ab	0	11 b	16 b	4 c	10 b	8 bc	0 c	11 b	9 bc	0 b
5	Ethofumesate high PRE rate	12 ab	5 cd	1	5 bc	8 bcd	5 bc	8 bc	6 bc	3 b	10 bc	6 bcd	3 a
6	Desmedipham, no six-leaf application	18 ab	11 bc	0	12 b	11 bc	0 d	11 b	10 b	0 c	11 b	11 b	0 b
7	Phenmedipham two-leaf	4 bc	4 cd	1	1 cd	6 cd	6 bc	3 bc	5 bc	4 ab	8 bc	8 bcd	0 b
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	0 c	4 cd	0	0 d	5 cd	8 b	0 c	3 bc	4 ab	0 c	0 c	0 b
9	Ethalfluralin PRE	31 a	35 a	0	40 a	86 a	93 a	29 a	30 a	0 c	30 a	30 a	0 b
10	Bicyclopyrone PRE	3 bc	6 cd	0	3 bcd	8 bcd	0 d	6 bc	8 bc	0 c	11 b	11 b	0 b

[a] Abbreviation: DAS, days after seeding

[b] Means followed by the same letter are not different according to Fisher's protected LSD test at $P = 0.05$. If no letters are included for a column then there were no statistical differences noted.

https://doi.org/10.1614/WT-D-16-00015.1 Published online by Cambridge University Press

Table 6. Visual evaluation of red beet herbicide injury in Plover, WI, in 2014, where 0% represents no crop injury and 100% represents total crop death.

		Red beet injury[a,b]											
		Ruby Queen			Detroit Supreme			Red Ace			Red Titan		
Program No.	Descriptor	26 DAS	32 DAS	60 DAS	26 DAS	32 DAS	60 DAS	26 DAS	32 DAS	60 DAS	26 DAS	32 DAS	60 DAS
		%											
1	Hand-weeded check	0	0 c	0	0 b	0 c	0 e	0 c	0 c	0 c	0 b	0	0
2	Nontreated check	0	0 c	0	0 b	0 c	0 e	0 c	0 c	0 c	0 b	0	0
3	*S*-metolachlor	0	1 c	0	0 b	0 c	4 b	0 c	0 c	3 a	0 b	0	2
4	Cycloate	3	0 c	0	1 b	0 c	4 b	1 c	0 c	4 a	0 b	0	1
5	Ethofumesate high PRE rate	0	0 c	0	0 b	1 c	3 bc	0 c	0 c	4 a	0 b	0	1
6	Desmedipham, no six-leaf application	1	4 bc	0	5 b	4 c	1 de	5 bc	4 c	0 c	1 b	3	0
7	Phenmedipham two-leaf	3	1 c	0	4 b	1 c	3 bcd	4 bc	1 c	3 ab	3 b	1	1
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	3	1 c	0	1 b	0 c	4 bc	3 c	0 c	0 c	0 b	0	0
9	Ethalfluralin PRE	6	14 a	0	14 a	55 a	98 a	9 ab	31 a	0 c	4 ab	10	0
10	Bicyclopyrone PRE	8	8 b	0	13 a	14 b	2 cde	13 a	11 b	1 c	8 a	8	1
11	*S*-metolachlor PRE, no two- or four-leaf application	0	0 c	0	1 b	0 c	4 b	1 c	0 c	1 bc	0 b	0	0
12	Cycloate PPI, no two- or four-leaf application	1	0 c	0	1 b	0 c	1 de	3 c	0 c	0 c	1 b	0	0

[a] Abbreviation: dAS, days after seeding.

[b] Means followed by the same letter are not different according to Fisher's protected LSD test at $P = 0.05$. If no letters are included for a column then there were no statistical differences noted.

https://doi.org/10.1614/WT-D-16-00015.1 Published online by Cambridge University Press

Table 7. Red beet yield by beet size and in total in Plover, WI, in 2013.

Program No.	Descriptor	Red beet yield[a]											
		Ruby Queen			Detroit Supreme			Red Ace			Red Titan		
		2.2–4.8 cm	> 4.8 cm	Total	2.2–4.8 cm	> 4.8 cm	Total	2.2–4.8 cm	>4.8 cm	Total	2.2–4.8 cm	>4.8 cm	Total
		$kg\ ha^{-1}$											
1	Hand-weeded check	18,231 abc	17,922	36,153 ab	18,386 ab	9,829 bc	28,367 bc	18,231 abc	10,715 bc	28,946	17,229	13,952 bc	31,181 bcd
2	Nontreated check	14,337 cd	9,327	23,665 c	13,071 b	5,165 cd	18,964 c	14,030 c	6,359 c	20,390	14,877	15,032 bc	29,910 bcd
3	*S*-metolachlor	21,275 ab	14,685	35,962 ab	19,607 ab	6,745 bcd	26,480 bc	20,506 a	10,215 bc	30,719	13,992	7,014 c	21,006 d
4	Cycloate	16,960 abc	11,717	28,677 bc	16,086 ab	10,215 bc	26,556 bc	18,269 abc	10,639 bc	28,908	13,721	18,693 ab	32,416 abc
5	Ethofumesate high PRE rate	20,697 ab	11,062	31,759 bc	22,042 a	10,175 bc	32,223 ab	20,466 a	15,108 b	35,576	16,960	23,010 ab	39,970 ab
6	Desmedipham, no six-leaf application	18,540 abc	23,203	41,743 a	21,407 a	17,191 a	38,659 a	18,964 ab	16,651 b	35,615	15,418	22,741 ab	38,159 abc
7	Phenmedipham two-leaf	21,082 ab	14,763	35,845 ab	20,954 a	8,787 bc	30,064 ab	21,584 a	12,064 bc	33,649	16,651	22,779 ab	39,430 abc
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	21,970 a	16,110	38,080 ab	21,882 a	11,369 b	33,456 ab	21,468 a	13,914 bc	35,384	16,341	26,325 a	42,667 a
9	Ethalfluralin PRE	11,331 d	19,078	30,412 bc	134 c	2,428 d	2,699 d	9,327 d	25,207 a	34,534	12,295	16,805 b	29,100 cd
10	Bicyclopyrone PRE	16,727 bc	13,490	30,219 bc	17,480 ab	11,486 b	29,177 ab	15,765 bc	14,106 bc	29,872	15,070	16,496 b	31,566 bc

[a] Means followed by the same letter are not different according to Fisher's protected LSD test at $P = 0.05$. If no letters are included for a column then there were no statistical differences noted.

Table 8. Red beet yield by beet size and in total in Plover, WI, in 2014.

Program No.	Descriptor	Red beet yield[a]											
		Ruby Queen			Detroit Supreme'			'Red Ace'			'Red Titan'		
		2.2 −4.8 cm	> 4.8 cm	Total	2.2 −4.8 cm	> 4.8 cm	Total	2.2 −4.8 cm	>4.8 cm	Total	2.2 −4.8 cm	>4.8 cm	Total
		kg ha^{-1}											
1	Hand-weeded check	7,361 bc	33,873 a	41,936 a	10,137 ab	34,151 a	44,480 a	11,255 bcd	30,026 a	41,279 a	9,020 b	29,486 a	38,504 abc
2	Nontreated check	2,659 d	1,381 d	4,046 d	4,279 cd	2,138 c	6,669 c	4,624 f	2,082 c	6,707 d	4,779 c	3,932 e	8,711 e
3	*S*-metolachlor	9,135 abc	21,060 ab	32,183 ab	11,755 a	27,556 a	40,239 a	13,376 abc	29,177 a	42,552 a	10,560 ab	29,641 a	40,201 ab
4	Cycloate	9,906 ab	16,812 b	27,365 b	13,183 a	25,207 ab	39,506 a	12,950 abc	26,980 ab	39,932 a	11,833 ab	28,137 ab	39,970 ab
5	Ethofumesate high PRE rate	9,058 abc	23,519 ab	33,687 ab	13,183 a	23,703 ab	37,078 a	14,378 ab	24,783 ab	39,161 a	10,831 ab	27,789 abc	38,621 abc
6	Desmedipham, no six-leaf application	9,944 ab	18,179 b	28,484 b	13,721 a	29,643 a	43,978 a	15,380 a	23,127 ab	38,504 a	13,028 a	25,940 abc	38,968 ab
7	Phenmedipham two-leaf	9,020 abc	24,530 ab	34,189 ab	10,715 ab	31,790 a	43,592 a	11,177 bcd	31,528 a	42,707 a	12,179 ab	30,950a	43,131 a
8	No ethofumesate PRE, no two- or four-leaf triflusulfuron	10,831 a	17,711 b	28,791 b	12,219 a	28,352 a	40,701 a	14,492 ab	24,436 ab	38,930 a	12,295 ab	17,112 cd	29,408 bcd
9	Ethalfluralin PRE	6,090 c	6,682 cd	13,645 cd	231 d	962 c	1,657 c	6,090 ef	8,980 c	15,070 c	9,637 ab	10,677 de	20,313 de
10	Bicyclopyrone PRE	8,980 abc	13,669 bc	24,821 bc	6,900 bc	15,969 b	24,476 b	8,594 def	18,733 b	27,327 b	9,058 b	17,769 bcd	26,825 cd
11	*S* -metolachlor PRE, no two- or four-leaf application	8,480 abc	25,391 ab	34,034 ab	11,369 a	30,777 a	42,205 a	10,791 bcd	29,139 a	39,932 a	8,827 b	25,361 abc	34,189 abc
12	Cycloate PPI, no two- or four-leaf application	10,446 ab	16,890 b	28,329 b	11,872 a	32,021 a	44,325 a	9,906 cde	32,145 a	42,050 a	9,173 b	32,994 a	42,167 a

[a] Means followed by the same letter are not different according to fisher's protected LSD test at $P = 0.05$. If no letters are included for a column then there were no statistical differences noted.

Detroit Supreme and Red Ace red beet varieties (data not shown).

Before the introduction of glyphosate-resistant sugarbeet, weed control programs focused on a "microrate" approach in which multiple applications were used at lower rates to reduce crop injury risk and extend weed control (Dexter et al. 1996, 1997). Odero et al. (2008) reported that common lambsquarters control was greater with four microrate herbicide applications compared with programs that included three applications, and that green foxtail [*Setaria viridis* (L.) Beauv.] control increased up to 7% when the number of herbicide applications was increased. Red beet growers have expressed interest in expanding such an approach to red beet, given that the common herbicides were often originally labeled for use in sugarbeet and similarly suffer from the lack of season-long residual weed control. This research, however, indicates that herbicide programs that include PRE herbicides followed by one or two POST applications that involve multiple active ingredients can provide season-long weed control. This observation was consistent across a broad spectrum of weeds and between two study locations that varied in soil type. Although the herbicide programs that included only a PRE and six-leaf red beet growth-stage application were only included in 1 study yr, these programs were successful at two locations in maintaining weed control and crop yield relative to the hand-weeded red beet crop. Furthermore, these herbicide programs reduced the number of applications by 50% compared with the full programs, reducing crop injury risk and grower cost. Future research should refine this reduced-application approach and evaluate it in additional production environments.

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Received January 29, 2016, and approved May 10, 2016.

Associate editor for this paper: Robert Nurse, Agriculture and Agri-Food Canada.