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Evaluation of acetolactate synthase (ALS)-inhibiting herbicides for red sorrel (*Rumex acetosella* L.) management in lowbush blueberry (*Vaccinium angustifolium* Aiton)

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Abstract

Red sorrel is a common herbaceous perennial weed species in lowbush blueberry fields that may be managed with acetolactate synthase (ALS)-inhibiting herbicides. Greenhouse and field experiments were established to determine the crop tolerance and potential efficacy on red sorrel of tribenuron-methyl, nicosulfuron + rimsulfuron, foramsulfuron, flazasulfuron, pyroxsulam, and halosulfuron-methyl. Ramet density of greenhouse-grown red sorrel plants established from root fragments was reduced by tribenuron-methyl, flazasulfuron, and pyroxsulam, though tribenuron-methyl and flazasulfuron were the most consistently effective herbicides under field conditions. Spring non-bearing year tribenuron-methyl and flazasulfuron applications reduced both non-bearing and bearing year total red sorrel ramet density and reduced non-bearing year red sorrel flowering ramet and seedling density without injuring lowbush blueberry. Fall non-bearing year tribenuron-methyl and flazasulfuron applications reduced bearing year red sorrel total and flowering ramet density, and this application timing should be evaluated further to improve understanding of crop injury risks. Fall bearing year tribenuron-methyl and flazasulfuron applications reduced non-bearing year red sorrel total and flowering ramet density but did not reduce seedling density. Nicosulfuron + rimsulfuron, foramsulfuron, pyroxsulam, and halosulfuron-methyl efficacy on red sorrel were inconsistent or limited, and these herbicides are not recommended for red sorrel management in lowbush blueberry.

Key words: amino acid inhibiting herbicide, fall bearing year herbicide, fall non-bearing year herbicide, spring non-bearing year herbicide, sulfonylurea herbicide

Introduction

The lowbush blueberry (*Vaccinium angustifolium* Aiton) is a rhizomatous perennial berry species (Hall et al. 1979). Commercial fields are developed from native stands and managed primarily on a 2-year cycle in which fields are pruned to ground level by burning or flail mowing in the first year (non-bearing year) and fruit development and harvest occur in the second year (bearing year) (Jensen 1985; Eaton et al. 2004). Fields are managed to encourage the vegetative spread of blueberry plants, but this also encourages the growth and spread of perennial weeds (Yarborough and Bhowmik 1989; McCully et al. 1991).

Red sorrel (*Rumex acetosella* L.) is a common perennial weed species in commercially managed lowbush blueberry fields in Canada and Maine, USA (McCully et al. 1991; Ayers 2020) and occurs in >95% of the acreage of this crop in Nova Scotia (Lyu et al. 2021). The low pH soils and lack of tillage associated with commercial lowbush blueberry production contribute to the persistence of red sorrel, and the seed of this weed species is a common contaminant on harvesting equipment (Boyd and White 2009). Red sorrel spreads by seeds and a shallow creeping root system (Kennedy 2009; White 2014). Seedlings contribute to established red sorrel populations (White et al. 2014), but production of ramets from the creeping root system is the primary means of population maintenance (Kennedy 2009; White et al. 2014). Ramets emerge throughout the growing season in Nova Scotia, with ramet populations peaking in mid to late autumn of both the non-bearing and bearing years (White et al. 2015*a*). Emerged ramets remain as vegetative rosettes persisting below the blueberry canopy in the year of emergence, as flowering occurs primarily in overwintering ramets (White et al. 2014) and is induced by vernalization (White et al. 2015*b*). As such, opportunities for control of red sorrel exist in fall before ramet populations overwinter or in spring prior to bolting and flowering of overwintering ramets (White et al. 2015*c*).

Control of red sorrel with currently registered herbicides, such as hexazinone, is variable (Kennedy et al. 2010, 2011) due to occurrence of hexazinone-resistant populations in commercial blueberry fields in Nova Scotia (Li et al. 2014). Red sorrel can be suppressed with fall pronamide applications (Hughes et al. 2016; White et al. 2021), but this herbicide is expensive ($500.00 CAD ha^{-1}) and difficult to use due to the requirement for applications to cold soils in late autumn. Recent research determined that fall bearing year applications of the acetolactate synthase (ALS)-inhibiting herbicide tribenuron-methyl reduced red sorrel ramet density in the subsequent non-bearing year (White et al. 2021), indicating potential for the ALS-inhibiting class of herbicides to contribute to red sorrel management in lowbush blueberry. ALS-inhibiting herbicides inhibit the enzyme ALS which is required for catalyzing the first step in the biosynthetic pathway for the branch-chain amino acids isoleucine, valine, and leucine (Ray 1984; Rhodes et al. 1987; Kishore and Shah 1988; Zhou et al. 2007). Subsequent lack of these amino acids in susceptible plants results in protein deficiency and several other negative downstream effects that cause plant injury or death (Ray 1984; Rhodes et al. 1987; Bestman et al. 1990; Gaston et al. 2003). Although prone to resistance development (Tranel and Wright 2002), ALS-inhibiting herbicides generally exhibit good environmental profiles (Dinelli et al. 1998; Gigliotti and Allievi 2001; Russel et al. 2002), have low mammalian toxicity (Mazur and Falco 1989; Russel et al. 2002), are applied at low use rates (Brown 1990; Reddy and Whiting 2000; Russel et al. 2002), are generally of low cost per hectare (Donald and Prato 1991; Reddy and Whiting 2000), and likely degrade rapidly in acidic soils of lowbush blueberry fields (Sabadie 1996; Scrano et al. 1999; Sarmah and Sabadie 2002; Grey and McCullough 2012). These characteristics make these herbicides a desirable component of weed control programs in lowbush blueberry.

Red sorrel causes significant yield losses in lowbush blueberry (Kennedy et al. 2010; Hughes et al. 2016), may contribute to increased severity of Botrytis blossom blight (*Botrytis cinerea* Pers.) infections in blueberry flowers (Hughes 2012; Hughes et al. 2016) by serving as an alternative host for this disease (Giraud et al. 1999), interferes with harvesting (Jensen and Specht 2002), and becomes prolific if not controlled following fertilizer applications (Kennedy et al. 2010, 2011). Growers are therefore interested in effective and economically viable control options for this weed species. The objectives of this research were to (*i*) evaluate efficacy of several ALS-inhibiting herbicides for general efficacy on red sorrel under greenhouse conditions and (*ii*) evaluate these same herbicides for control of red sorrel when applied in spring and fall of the non-bearing year and fall of the bearing year in commercial lowbush blueberry fields. These objectives were based on the hypothesis that tribenuron-methyl would be the most effective ALS-inhibiting herbicide evaluated for red sorrel control. A spring bearing year application was not included as pre-harvest bearing year applications are not permitted for any currently registered ALS-inhibiting herbicides in lowbush blueberry.

Materials and methods

Greenhouse evaluation of ALS-inhibiting herbicides on red sorrel

The experiment was conducted using plants established from planted root fragments. Root fragments were collected from a greenhouse stock population established by planting seeds collected from a lowbush blueberry field located in Collingwood, NS, Canada (45.5622, −63.8613). Seed dormancy was broken by soaking seeds in concentrated sulfuric acid for 1 min. Seeds were then rinsed with distilled water and planted in plastic greenhouse flats filled with Pro-Mix BX general-purpose growing medium (Premier Horticulture Inc., Quakertown, PA, USA). Flats were kept in a greenhouse maintained at 22 ± 1 °C under natural daylight extended to 16 h by metal halide lamps providing a photosynthetic photon flux density of 61 ± 3 μmol m^{-2} s^{-1} at plant level. After approximately 3 months of growth, a large mass of creeping roots was established in each flat that could be harvested for use in experiments. For this experiment, three 5 cm-long root fragments were planted in 715 cm^3 square plastic pots filled with a 1:2:2 (*v*:*v*:*v*) mixture of sand, potting soil (Pro-Gro Premium Organic Top Soil, Annapolis Valley Peat Moss Co., Ltd., Berwick, NS, Canada), and Pro-Mix BX general-purpose growing medium. Pots were then maintained in the same greenhouse under the conditions described above. Pots were fertilized 1 month after planting with 100 mL of 0.12% 20–20–20 (N–P–K) aqueous fertilizer per pot, and each pot constituted one experimental unit. The experiment consisted of seven herbicide treatments (Table 1) arranged in a completely randomized design with six replications. Herbicide application rates were based on currently labeled application rates for tribenuron-methyl, nicosulfuron + rimsulfuron, foramsulfuron, and flazasulfuron in lowbush blueberry and manufacturer recommendations for pyroxsulam and halosulfuron-methyl. The experiment was repeated once for a total of two experimental runs and run 2 was initiated 4 weeks after the start of run 1. Herbicides were applied 2 months after planting at the rates indicated in Table 1 using a single nozzle, CO_2-pressurized hand-held sprayer (model 601F4, R & D Sprayers, Opelousas, LA, USA) equipped with a single TeeJet 8002 DG nozzle (TeeJet Technologies, Spraying Systems Co., Springfield, PA, USA) and calibrated to deliver 200 L ha^{-1} at a pressure of 275 kPa for all herbicides. Mean red sorrel ramet density and leaf number at the time of herbicide applications were 6 ± 0.3 ramets pot^{-1} and 9 ± 1 leaves ramet^{-1}, respectively, in run 1 and 5 ± 1 ramets pot^{-1} and 11 ± 1 leaves ramet^{-1}, respectively, in run 2. Data collection included visual injury ratings on red sorrel at 14, 35, and 56 days after spraying (DAS) and final red sorrel ramet density in each pot at 56 DAS. Ramet biomass in each pot was to be collected but was not possible due to an unforeseen fire that damaged the building attached to the greenhouse in which the plants were maintained. Visual injury ratings were conducted using a 0–10 scale in which 0 = no injury and 10 = complete plant death.

Field evaluation of ALS-inhibiting herbicides on red sorrel

Field experiments were conducted to determine the crop tolerance and efficacy of red sorrel of spring non-bearing year, fall non-bearing year, and fall bearing year ALS-inhibiting herbicide applications in lowbush blueberry fields in Nova Scotia. Each application timing was conducted as a separate experiment due to the large number of treatments required for a single experiment, and treatments consisted of the herbicides and application rates outlined in Table 1. Each

Table 1. ALS-inhibiting herbicides evaluated for control of red sorrel under greenhouse conditions and in lowbush blueberry fields in Nova Scotia, Canada.

Common name	Trade name[a]	Application rate (g a.i. ha^{-1})	Manufacturer, city, state or province, country
Nontreated control	N/A	N/A	N/A
Tribenuron-methyl	Express	34	DuPont, Wilmington, DE, USA
Flazasulfuron	Chikara	50	ISK BioSciences, Concord, OH, USA
Pyroxsulam	Simplicity or	15	Dow AgroSciences, Calgary, AB, Canada
	Simplicity GoDri[b]		Dow AgroSciences, Calgary, AB, Canada
Nicosulfuron + rimsulfuron	Ultim	13 + 13	DuPont, Wilmington, DE, USA
Halosulfuron-methyl	Sandea	36	Canyon Group, Yuma, AZ, USA
Foramsulfuron	Option	35	Bayer CropScience, Regina, SK, Canada

[a] Express, Chikara, Simplicity or Simplicity GoDri, Ultim, and Sandea were applied in conjunction with 0.2% *v*/*v* Activate Plus non-ionic surfactant (NIS). Option was applied in conjunction with 28% liquid UAN fertilizer at 2.5 L ha^{-1}.

[b] Simplicity was used in the spring non-bearing year experiment, and Simplicity GoDri was used in the greenhouse, fall non-bearing year, and fall bearing year experiments.

experiment was conducted at two sites and was arranged in a randomized complete block design with five blocks and a 2 m × 4 m plot size. Locations, dates of trial establishment, dates of herbicide applications, and related weather conditions for each experiment are provided in Table 2. Herbicides were applied at each site using a CO_2-pressurized research plot sprayer (model 601 C, R & D Sprayers, Opelousas, LA, USA) equipped with four HYPRO ULD120-02 nozzles (Pentair, Delavan, WI, USA) and calibrated to deliver 200 L ha^{-1} at a pressure of 275 kPa. Spring non-bearing year, fall non-bearing year, and fall bearing year herbicide treatments were applied preemergence to wild blueberry, postemergence to wild blueberry after blueberry stems lost their leaves, and after field pruning that removed emerged blueberry stems, respectively. Red sorrel ramets were in the rosette (e.g., vegetative) stage and were green and lacking significant frost injury (leaf reddening and necrosis) at the time of all herbicide applications.

Data collection was similar across experiments but varied in frequency and timing based on extent of the lowbush blueberry production cycle remaining following herbicide applications. Data collection for red sorrel consisted of total ramet density, seedling density, and flowering ramet density. Total red sorrel ramet density was determined at the time of herbicide applications in each experiment and again in June, August, and October of the non-bearing year and May and June of the bearing year in the spring non-bearing year experiment, May and June of the bearing year in the fall non-bearing year experiment, and May, June, August, and October of the non-bearing year and May and June of the subsequent bearing year in the fall bearing year experiment. Red sorrel seedling density was determined in May or June of the non-bearing and bearing year in the spring non-bearing year and fall bearing year experiments and in May of the bearing year in the fall non-bearing year experiment. Red sorrel flowering ramet density was determined in June of the non-bearing and bearing year in the spring non-bearing year and fall bearing year experiments and in June of the bearing year in the fall non-bearing year experiment.

Data collection for lowbush blueberry consisted of lowbush blueberry stem density, stem height, and flower bud number per stem in the spring non-bearing year and fall bearing year experiments, and yield in all experiments. Lowbush blueberry stem density, stem height, and flower bud number per stem were determined in October of the non-bearing year, and lowbush blueberry yield was determined in August of the bearing year.

Red sorrel ramet and seedling density and lowbush blueberry stem density were determined in three 0.3 m × 0.3 m quadrats in each plot on each counting date. Lowbush blueberry stem height and flower bud number $stem^{-1}$ were determined directly in the field on 20 stems per plot selected using a line transect method previously described (White and Kumar 2017). Lowbush blueberry yield was determined by hand raking all berries in two 1 m × 1 m quadrats per plot. Debris was removed from the berries via wind, and berries were weighed at the time of harvest in the field.

Statistical analysis

The effect of herbicide treatment, experimental run, and the herbicide treatment by experimental run interaction on final red sorrel ramet density in the greenhouse experiment was determined using analysis of variance (ANOVA) in PROC MIXED in SAS (SAS Version 9.4, Cary, NC, USA). Herbicide treatment and experimental run were modeled as fixed effects in the analysis. The effect of herbicide treatment on total red sorrel ramet density throughout the duration of each field experiment was determined using a repeated measures ANOVA in PROC MIXED in SAS. Herbicide treatment was modeled as a fixed effect in the analysis, and data collection date (expressed as Julian day) was modeled as the repeated effect in the analysis using a spatial power covariance structure that assumed homogeneous variance over time due to the unequal temporal spacing that occurred between counting dates. Sites were analyzed separately for this analysis due to differing dates of data collection at each site. The effect of site and herbicide treatment on red sorrel flowering ramet density, red sorrel seedling density, lowbush blueberry stem density, stem height, flower bud number per stem, and yield was determined using ANOVA in PROC MIXED in SAS.

Table 2. Locations, dates of trial establishment, dates of herbicide applications, and related weather conditions for field experiments used to evaluate ALS-inhibiting herbicides for red sorrel control in lowbush blueberry fields in Nova Scotia, Canada.

Experiment	Site	GPS ccoordinates	Date of establishment	Date of herbicide applications	Weather conditions at the time of herbicide applications			Days until first rainfall
					Wind velocity (km h^{-1})	Air temperature (°C)	Relative humidity (%)	
Spring non-bearing year	Collingwood	45.581941, −63.725822	27 April 2017	4 May 2017	1.6	18	36	2
	Murray Siding	45.364100, −63.214517	5 May 2017	5 May 2017	1.6	21	30	1
Fall non-bearing year	Collingwood	45.581941, −63.725822	27 April 2017	24 November 2017	3.5	12	40	2
	Mount Pleasant	45.769847, −63.841700	16 October 2018	9 November 2018	3	11	43	1
Fall bearing year	Mount Pleasant	45.769847, −63.841700	3 November 2017	5 November 2017	4	11	48	1
	Sherbrooke	45.402201, −62.288557	23 October 2017	1 November 2017	11	12	42	2

Data transformations [SQRT(Y + 1) or LOG(Y + 1)] were used where necessary to meet the assumptions of normality and constant variance in all analyses. Data transformations used are indicated in the results tables. Significance of all main and interactive effects in all analyses was assessed at $\alpha = 0.05$, and means separations, where necessary, were conducted using a Tukey's test at $\alpha = 0.05$.

Results

Greenhouse ALS-inhibiting herbicide evaluation

Visual injury data were similar in both experimental runs and were averaged across runs for presentation. There was a significant herbicide treatment by experimental run interaction effect on final ramet density ($P = 0.004$), so these data were analyzed separately across experimental runs. Visual injury occurred slowly in all treatments but was generally highest in the tribenuron-methyl and flazasulfuron treatments (Table 3). There was a significant herbicide treatment effect on final ramet density in each experimental run ($P < 0.0001$). Final ramet density was generally lowest in the tribenuron-methyl, flazasulfuron, and pyroxsulam treatments in each experimental run, though density was also reduced by nicosulfuron + rimsulfuron and halosulfuron-methyl (Table 3). Foramsulfuron caused low visual injury and did not reduce final ramet density (Table 3).

Effect of ALS-inhibiting herbicide applications on total red sorrel ramet density in the field

There was a significant herbicide treatment and data collection date effect on total red sorrel ramet density at each site in all experiments ($P < 0.0001$). There was, however, no significant herbicide treatment by data collection date interaction effect on total red sorrel ramet density at each site in the spring non-bearing year experiment ($P \geq 0.1790$), the Mount Pleasant site in the fall bearing year experiment ($P = 0.098$), or the Sherbrooke site in the fall bearing year experiment ($P = 0.118$), suggesting differences between treatments remained consistent throughout the experiments at these sites. Data were, however, still analyzed using the full repeated measures analysis to ascertain differences within and between treatments over time in each experiment.

Spring non-bearing year tribenuron-methyl and flazasulfuron applications reduced ramet density by June of the non-bearing year, and density in these treatments was lower than most other treatments at each site in both June and August of the non-bearing year (Table 4). Density increased in these treatments by October of the non-bearing year but still remained lower than the non-treated control and most other herbicides evaluated (Table 4). Although ineffective at Collingwood, pyroxsulam reduced ramet density early in the non-bearing year at Murray Siding (Table 4). Nicosulfuron + rimsulfuron, halosulfuron-methyl, and foramsulfuron did not reduce non-bearing year density at either site (Table 4). Ramet density in May of the bearing year was similar to May of the non-bearing year in the tribenuron-methyl treatment at each site and in the flazasulfuron treatment at Murray Siding, though density had increased by May of the bearing year relative to May of the non-bearing year in all other treatments (Table 4). Ramet density in June of the bearing year was also generally lowest in the tribenuron-methyl and flazasulfuron treatments at each site (Table 4).

Fall non-bearing year tribenuron-methyl, flazasulfuron, and nicosulfuron + rimsulfuron applications reduced ramet density by May of the bearing year at Collingwood, and density was lowest in these treatments at this time relative to the other treatments (Table 5). Density in the tribenuron-methyl treatment remained lower than all other treatments at Collingwood by June 2018, though density in the flazasulfuron treatment was also lower than the nontreated control at this site (Table 5). Ramet density declined significantly in all treatments between October of the non-bearing year and May of the bearing year at Mount Pleasant but remained low-

Table 3. Effect of ALS-inhibiting herbicides on visual injury and final ramet density of greenhouse-grown red sorrel plants.

	Visual injury ratings[a]			Final ramet density (ramets m^{-2})	
Treatment	14 DAS[b]	35 DAS	56 DAS	Run 1	Run 2[c]
Nontreated control	1 ± 0.2	1 ± 0.3	1 ± 0.3	12 ± 1a	13a
Tribenuron-methyl	3 ± 0.3	6 ± 0.5	8 ± 0.4	3 ± 1c	1c
Flazasulfuron	3 ± 0.4	4 ± 0.5	7 ± 0.5	4 ± 1c	3bc
Pyroxsulam	1 ± 0.3	2 ± 0.4	3 ± 0.4	4 ± 1c	4bc
Nicosulfuron + rimsulfuron	1 ± 0.2	1 ± 0.3	2 ± 0.3	6 ± 1bc	5b
Halosulfuron-methyl	1 ± 0.2	1 ± 0.3	2 ± 0.3	6 ± 1bc	6b
Foramsulfuron	1 ± 0.2	1 ± 0.4	1 ± 0.4	9 ± 1ab	17a

Note: Means within columns with the same lowercase letter are not significantly different according to a Tukey's test at $\alpha = 0.05$. Values represent the mean ± 1 SE.

[a]Visual injury ratings were conducted on a scale of 0–10 in which 0 = no plant injury and 10 = complete plant death.

[b]DAS, days after spraying.

[c]Final ramet density data in run 2 were LOG(Y + 1) transformed prior to analysis to meet the assumptions of the variance analysis. Geometric means determined using PROC MEANS in SAS are presented.

Table 4. Effect of spring non-bearing year ALS-inhibiting herbicide applications on non-bearing year and bearing year total red sorrel ramet density at Collingwood and Murray Siding, Nova Scotia, Canada.

		Red sorrel ramet density (ramets m^{-2})[a]					
		Non-bearing year (2017)				Bearing year (2018)	
Site[b]	Treatment	May	June	August	October	May	June
Collingwood	Nontreated control	462a(B)	509a(B)	469a(B)	914a(A)	1088a(A)	1154a(A)
	Tribenuron-methyl	381a(A)	82b(B)	93b(B)	387bc(A)	384c(A)	396c(A)
	Flazasulfuron	360a(BC)	222b(C)	131b(C)	499b(B)	854b(A)	710b(AB)
	Pyroxsulam	536a(B)	436a(B)	444a(B)	943a(A)	1094ab(A)	1023ab(A)
	Nicosulfuron + rimsulfuron	569a(B)	433a(B)	404a(B)	760ab(AB)	890b(AB)	959ab(A)
	Halosulfuron-methyl	585a(B)	444a(B)	387a(B)	744ab(B)	1344a(A)	809ab(B)
	Foramsulfuron	453a(B)	453a(B)	390a(B)	852a(B)	1279ab(A)	1019ab(AB)
Murray Siding	Nontreated control	195a(C)	513a(B)	316a(BC)	531a(B)	1112a(A)	867a(AB)
	Tribenuron-methyl	207a(AB)	29c(BC)	76bc(B)	224b(AB)	370b(A)	384b(A)
	Flazasulfuron	198a(AB)	100bc(B)	101b(B)	174b(AB)	328b(A)	373b(A)
	Pyroxsulam	207a(B)	253b(B)	279a(B)	443ab(B)	918a(A)	791a(A)
	Nicosulfuron + rimsulfuron	179a(C)	267ab(BC)	254ab(BC)	422ab(B)	1057a(A)	681ab(AB)
	Halosulfuron-methyl	196a(B)	347ab(B)	219abc(B)	324ab(B)	890a(A)	593ab(A)
	Foramsulfuron	234a(C)	513a(B)	269ab(BC)	466ab(BC)	1048a(A)	685ab(AB)

Note: Means within columns for each site with the same lowercase letter are not significantly different according to a Tukey's test at $\alpha = 0.05$. Means within rows for each site with the same uppercase letter are not significantly different according to a Tukey's test at $\alpha = 0.05$.

[a]Total ramet density data for each site were SQRT(Y + 1) transformed prior to analysis to meet the assumptions of the variance analysis. Geometric means determined using PROC MEANS in SAS are presented.

[b]Herbicides were applied on 4 May 2017 and 5 May 2017 at Collingwood and Murray Siding, respectively. Non-bearing year ramet density was determined on 4 May, 22 June, 24 August, and 19 October 2017 at Collingwood and on 5 May, 22 June, 17 August, and 19 October 2017 at Murray Siding. Bearing year ramet density was determined on 1 May and 21 June 2018 at Collingwood and on 2 May and 19 June 2018 at Murray Siding.

est in the tribenuron-methyl and flazasulfuron treatments by June of the bearing year at this site (Table 5).

Fall bearing year tribenuron-methyl, flazasulfuron, and pyroxsulam applications reduced ramet density by May of the non-bearing year at each site, and density was lowest in these treatments on this data collection date (Table 6). Density in these treatments also remained lower than the nontreated control throughout the non-bearing year at each site (Table 6), though density in the pyroxsulam treatment had increased in October relative to May at Mount Pleasant and was similar to the nontreated control (Table 6). Fall bearing year nicosulfuron + rimsulfuron and foramsulfuron applications also reduced density relative to the nontreated control in May and June of the non-bearing year at Mount Pleasant (Table 6), though density in these treatments increased in August and October relative to May and density did not differ from the nontreated control. Ramet density in the halosulfuron-methyl treatment was lower than the nontreated control in June of the non-bearing year at each site (Table 6), though density was once again similar to the nontreated control by August. Ramet density declined in most treatments between October of the non-bearing year and May of the bearing year at Mount Pleasant, and density was similar across all treatments throughout the bearing year at this site (Table 6). A similar decline in density did not occur at Sherbrooke where density in both May and June of the bearing

Table 5. Effect of fall non-bearing year ALS-inhibiting herbicide applications on total red sorrel ramet density at Collingwood and Mount Pleasant, Nova Scotia, Canada.

		Red sorrel ramet density (ramets m^{-2})		
		Non-bearing year	Bearing year	
Site[a]	Treatment	October 2017	May 2018	June 2018
Collingwood	Nontreated control	1019 ± 118a(A)	1168 ± 118ab(A)	964 ± 118a(A)
	Tribenuron-methyl	963 ± 118a(A)	490 ± 118c(B)	193 ± 118c(B)
	Flazasulfuron	1095 ± 118a(A)	493 ± 118c(B)	627 ± 118b(B)
	Pyroxsulam	1244 ± 118a(A)	950 ± 118b(AB)	842 ± 118ab(B)
	Nicosulfuron + rimsulfuron	1102 ± 118a(A)	628 ± 118c(B)	714 ± 118ab(B)
	Halosulfuron-methyl	1090 ± 118a(A)	1186 ± 118ab(A)	691 ± 118ab(B)
	Foramsulfuron	1109 ± 118a(A)	1376 ± 118a(A)	906 ± 118ab(B)
		October 2018	May 2019	June 2019
Mount Pleasant	Nontreated control	872 ± 60a(A)	341 ± 60ab(B)	363 ± 60a(B)
	Tribenuron-methyl	737 ± 60a(A)	93 ± 60b(B)	21 ± 60b(B)
	Flazasulfuron	769 ± 60a(A)	159 ± 60b(B)	150 ± 60b(B)
	Pyroxsulam	684 ± 60a(A)	242 ± 60b(B)	273 ± 60ab(B)
	Nicosulfuron + rimsulfuron	760 ± 60a(A)	349 ± 60ab(B)	371 ± 60a(B)
	Halosulfuron-methyl	829 ± 60a(A)	390 ± 60ab(B)	408 ± 60a(B)
	Foramsulfuron	767 ± 60a(A)	410 ± 60a(B)	313 ± 60a(B)

Note: Means within columns with the same lowercase letter for each site are not significantly different according to a Tukey's test at $\alpha = 0.05$. Means within rows with the same uppercase letter for each site are not significantly different according to a Tukey's test at $\alpha = 0.05$. Values represent the mean ± 1 SE.

[a] Herbicides were applied on 24 November 2017 and 9 November 2018 at Collingwood and Mount Pleasant, respectively. Non-bearing year ramet density was determined on 19 October 2017 and 16 October 2018 at Collingwood and Mount Pleasant, respectively. Bearing year ramet density was determined on 1 May 2018 and 21 June 2018 at Collingwood and on 1 May 2019 and 20 June 2019 at Mount Pleasant.

Table 6. Effect of fall bearing year ALS-inhibiting herbicide applications on total red sorrel ramet density at Mount Pleasant and Sherbrooke, Nova Scotia, Canada.

		Red sorrel ramet density (ramets m^{-2})[a]						
		Bearing year (2017)	Non-bearing year (2018)				Bearing year (2019)	
Site[b]	Treatment	October—November	May	June	August	October	May	June
Mount Pleasant	Nontreated control	450a(B)	581a(AB)	707a(A)	653a(AB)	748a(A)	366a(B)	600a(AB)
	Tribenuron-methyl	433a(A)	36c(C)	112c(BC)	213c(B)	430b(A)	344a(AB)	457a(A)
	Flazasulfuron	486a(A)	44c(BC)	12 d(C)	87 d(B)	370b(A)	340a(A)	516a(A)
	Pyroxsulam	444a(AB)	73c(C)	246b(B)	447b(AB)	628ab(A)	407a(B)	544a(AB)
	Nicosulfuron + rimsulfuron	437a(AB)	243b(B)	402b(B)	599ab(AB)	658a(A)	344a(B)	547a(AB)
	Halosulfuron-methyl	438a(AB)	399ab(B)	389b(B)	603ab(A)	592ab(A)	361a(B)	495a(AB)
	Foramsulfuron	427a(B)	288b(B)	418b(B)	581ab(AB)	754a(A)	376a(B)	592a(AB)
Sherbrooke	Nontreated control	511a(AB)	351a(B)	534a(AB)	519a(AB)	650a(A)	361a(B)	361a(B)
	Tribenuron-methyl	485a(A)	58b(B)	100c(B)	98bc(B)	156c(B)	150b(B)	159b(B)
	Flazasulfuron	341a(A)	5b(C)	4 d(C)	33c(BC)	24 d(BC)	89b(BC)	110b(B)
	Pyroxsulam	466a(A)	20b(C)	252b(AB)	162b(B)	259bc(AB)	191ab(B)	235ab(AB)
	Nicosulfuron + rimsulfuron	588a(A)	167a(B)	373ab(B)	393ab(AB)	362b(B)	241ab(B)	347ab(B)
	Halosulfuron-methyl	418a(A)	272a(A)	279b(A)	339ab(A)	415ab(A)	266ab(A)	287ab(A)
	Foramsulfuron	541a(A)	309a(AB)	424a(AB)	366ab(AB)	410ab(AB)	333ab(AB)	281ab(B)

Note: Means within columns for each site with the same lowercase letter are not significantly different according to a Tukey's test at $\alpha = 0.05$. Means within rows for each site with the same uppercase letter are not significantly different according to a Tukey's test at $\alpha = 0.05$.

[a] Ramet density data at each site were SQRT(Y + 1) transformed prior to analysis to meet the assumptions of the variance analysis. Geometric means determined using PROC MEANS in SAS are presented.

[b] Herbicides were applied on 5 November 2017 and 1 November 2017 at Mount Pleasant and Sherbrooke, respectively. Ramet density at Mount Pleasant was determined on 3 November 2017, 1 May 2018, 21 June 2018, 22 August 2018, 16 October 2018, 1 May 2019, and 20 June 2019. Ramet density at Sherbrooke was determined on 23 October 2017, 2 May 2018, 20 June 2018, 22 August 2018, 22 October 2018, 2 May 2019, and 26 June 2019.

year was lowest in the tribenuron-methyl and flazasulfuron treatments (Table 6).

Effect of ALS-inhibiting herbicide applications on red sorrel flowering ramet and seedling density in the field

There was a significant site by treatment effect on non-bearing year flower ramet density and seedling density ($P \leq 0.0189$) in the spring non-bearing year experiment, and these data were therefore analyzed separately across sites. Bearing year flower ramet density and seedling density, however, were not affected by the site by treatment interaction in this experiment ($P \geq 0.5381$) and, these data were pooled across sites for analysis. There was a significant herbicide treatment effect on non-bearing year red sorrel seedling and flowering ramet density ($P \leq 0.001$) at each site in the spring non-bearing year experiment. Spring non-bearing year tribenuron-methyl and flazasulfuron applications reduced non-bearing year red sorrel seedling and flowering ramet density at each site (Table 7). Pyroxsulam was once again ineffective at Collingwood but did reduce non-bearing year seedling and flowering ramet density at Murray Siding (Table 7). Nicosulfuron + rimsulfuron reduced non-bearing year flowering ramet density at Murray Siding and foramsulfuron did not reduce non-bearing year seedling or flowering ramet density at either site (Table 7). Spring non-bearing year herbicide applications did not affect bearing year seedling or flowering ramet density in the pooled data set ($P \geq 0.0814$) with mean bearing year seedling and flowering ramet density of 101 ± 13 seedlings m^{-2} and 265 ± 20 flowering ramets m^{-2}, respectively, across sites.

There was no significant site by treatment effect on bearing year flower ramet density and seedling density ($P \geq 0.3552$) in the fall non-bearing year experiment, and these data were therefore pooled across sites for analysis. There was a significant herbicide treatment effect on bearing year flower ramet density ($P < 0.0001$). Fall non-bearing year tribenuron-methyl applications gave the greatest reductions in bearing year flowering ramet density (Table 8), though flazasulfuron and pyroxsulam also reduced flowering ramet density relative to the nontreated control (Table 8). There was no effect of fall non-bearing year herbicide applications on bearing year red sorrel seedling density ($P = 0.1382$) with a mean seedling density of 114 ± 13 seedlings m^{-2}.

There was no significant site by herbicide treatment effect on non-bearing or bearing year red sorrel flowering ramet and seedling density ($P \geq 0.1374$) in the fall bearing year experiment. All data were therefore pooled across sites for analysis. There was a significant fall bearing year herbicide treatment effect on non-bearing year flowering ramet density ($P < 0.0001$) with fall bearing year tribenuron-methyl, flazasulfuron, and pyroxsulam applications giving the greatest reductions in flowering ramet density (Table 8). Fall bearing year nicosulfuron + rimsulfuron, halosulfuron-methyl, and foramsulfuron applications, however, also reduced non-bearing year flowering ramet density relative to the nontreated control (Table 8). There was no significant fall bearing year herbicide treatment effect on non-bearing year seedling density ($P = 0.9818$), bearing year flower ramet density ($P = 0.7294$), or bearing year seedling density ($P = 0.2560$). Mean non-bearing year seedling density, bearing year flower ramet density, and bearing year seedling density were 234 ± 31 seedlings m^{-2}, 180 ± 16 ramets m^{-2}, and 72 ± 10 seedlings m^{-2}, respectively.

Effect of ALS-inhibiting herbicide applications on lowbush blueberry

There was no significant site by herbicide treatment effect on lowbush blueberry stem density ($P = 0.8877$), stem height ($P = 0.9564$), flower buds per stem ($P = 0.6379$), or yield ($P = 0.3133$) in the spring non-bearing year experiment. All data were therefore pooled across sites for analysis. There was a significant herbicide treatment effect on lowbush blueberry stem density ($P = 0.0111$), though this was due mainly to fewer stems in the halosulfuron treatment (343 ± 36) relative to the other treatments (405 ± 36 to 456 ± 36). There was no herbicide treatment effect on lowbush blueberry stem height ($P = 0.7200$), flower buds per stem ($P = 0.0612$), or yield ($P = 0.6955$), with mean lowbush blueberry stem height, flower buds per stem, and yield of 19 ± 1 cm, 3 ± 0.3 buds $stem^{-1}$, and 2062 ± 180 kg ha^{-1}, respectively.

There was no significant site by herbicide treatment effect on lowbush blueberry yield in the fall non-bearing year experiment ($P = 0.1084$). Yield data were therefore pooled across sites for analysis. There was no herbicide treatment effect on yield ($P = 0.2259$) with mean yield across sites of 2515 ± 223 kg ha^{-1}.

There was no significant site by herbicide treatment effect on lowbush blueberry stem density ($P = 0.8893$), stem height ($P = 0.9241$), flower buds per stem ($P = 0.5608$), or yield ($P = 0.6236$) in the fall bearing year experiment. All data were therefore pooled across sites for analysis. There was no significant herbicide treatment effect on lowbush blueberry stem density ($P = 0.1165$) or stem height ($P = 0.8349$) with mean stem density and height of 694 ± 29 stems m^{-2} and 16 ± 0.3 cm, respectively. There was, however, a significant herbicide treatment effect on flower bud number per stem ($P < 0.0001$) and yield ($P < 0.0001$), with fall bearing year flazasulfuron applications providing the greatest increase in flower bud number per stem and yield (Table 9). Fall bearing year tribenuron-methyl applications increased flower bud number per stem but not yield, and all other herbicide treatments had flower bud numbers and yield similar to the nontreated control (Table 9).

Discussion

Results of the greenhouse and field experiments demonstrate fairly consistently that tribenuron-methyl, flazasulfuron, and pyroxsulam were the most effective ALS-inhibiting herbicides evaluated for red sorrel control. Tribenuron-methyl currently has both spring and fall applications approved for use in lowbush blueberry (Anonymous 2015), and results of this study provide an additional use for this important herbicide. In terms of application timing, spring non-bearing year tribenuron-methyl applications seem most ef-

Table 7. Effect of spring non-bearing year ALS-inhibiting herbicide applications on non-bearing year red sorrel seedling and flowering ramet density at Collingwood[a] and Murray Siding, Nova Scotia, Canada.

	Red sorrel seedling density (seedlings m^{-2})[b]		Red sorrel flowering ramet density (ramets m^{-2})[c]	
Treatment	Collingwood	Murray Siding	Collingwood	Murray Siding
Nontreated control	1262a	117a	238a	243a
Tribenuron-methyl	91b	8bc	4c	1c
Flazasulfuron	66b	3c	61bc	11c
Pyroxsulam	1296a	8bc	148ab	1c
Nicosulfuron + rimsulfuron	957a	11abc	222ab	66bc
Halosulfuron-methyl	933a	13abc	244a	156ab
Foramsulfuron	1339a	74ab	165ab	220ab

Note: Means within columns with the same letter are not significantly different according to a Tukey's test at $\alpha = 0.05$.

[a] Herbicides were applied on 4 May 2017 and on 5 May 2017 at Collingwood and Murray Siding, respectively. Red sorrel seedling and flowering ramet density were determined on 22 June 2017 at each site.

[b] Red sorrel seedling density data at Collingwood and Murray Siding were SQRT(Y + 1) and LOG(Y + 1) transformed, respectively, prior to analysis to meet the assumptions of the variance analysis. Geometric means determined using PROC MEANS in SAS are presented.

[c] Red sorrel flowering ramet density data at Collingwood and Murray Siding were SQRT(Y + 1) and LOG(Y + 1) transformed, respectively, prior to analysis to meet the assumptions of the variance analysis. Geometric means determined using PROC MEANS in SAS are presented.

Table 8. Effect of ALS-inhibiting herbicide applications on bearing year red sorrel flowering ramet density at Collingwood[a] and Mount Pleasant (fall non-bearing year experiment) and on non-bearing year flowering ramet density at Mount Pleasant and Sherbrooke (fall bearing year experiment), Nova Scotia, Canada.

	Red sorrel flowering ramet density (ramets m^{-2})[b]	
Treatment	Fall non-bearing year experiment	Fall bearing year experiment
Nontreated control	214a	349a
Tribenuron-methyl	6d	26c
Flazasulfuron	96bc	3c
Pyroxsulam	74c	9c
Nicosulfuron + rimsulfuron	159abc	125b
Halosulfuron-methyl	194ab	124b
Foramsulfuron	175ab	100b

Note: Means within columns with the same letter are not significantly different according to a Tukey's test at $\alpha = 0.05$.

[a] Herbicides were applied on 24 November 2017 and 9 November 2018 at Collingwood and Mount Pleasant, respectively, and on 5 November 2017 and 1 November 2017 at Mount Pleasant and Sherbrooke, respectively. Red sorrel flowering ramet density was determined on 21 June 2018 and 20 June 2019 at Collingwood and Mount Pleasant, respectively, and on 21 June 2018 and 20 June 2018, respectively, at Mount Pleasant and Sherbrooke.

[b] Red sorrel flowering ramet density data in each experiment were SQRT(Y) transformed prior to analysis to meet the assumptions of the variance analysis. Back-transformed means are presented.

fective as they reduced ramet density throughout the entire 2-year production cycle (Table 4) and reduced both seedling and flowering ramet density in the non-bearing year (Table 7). Fall bearing year tribenuron-methyl applications reduced ramet density in the non-bearing year at both Mount Pleasant and Sherbrooke, but only at Sherbrooke in the bearing year (Table 6). Fall bearing year tribenuron-methyl applications also failed to control red sorrel seedlings in the non-bearing year, thus allowing red sorrel to recover from seed following fall bearing year applications. Tribenuron-methyl residues in soil damage weeds and sensitive crop plants (Kotoula-Syka et al. 1993a; Mehdizadeh et al. 2016), suggesting that soil residual activity from spring applications may have contributed to red sorrel seedling control. Soil residual activity of tribenuron-methyl, however, is reduced at low soil pH (Kotoula-Syka et al. 1993b), presumably due to rapid degradation (Sarmah and Sabadie 2002). This may explain lack of seedling control by fall tribenuron-methyl applications. Although spring tribenuron-methyl applications pose a greater crop injury risk than fall bearing year applications (Yarborough and Hess 1996; Jensen and Specht 2004; Anonymous 2015), vegetative red sorrel ramets overwinter (White et al. 2014) and can therefore be treated with tribenuron-methyl prior to blueberry emergence (White et al. 2015*c*). New red sorrel ramets and seedlings also begin emerging earlier than lowbush blueberries (White et al. 2012, 2015*a*), again providing opportunity to control or suppress this weed prior to blueberry emergence and therefore reduce risk of crop injury. Fall non-bearing year tribenuron-methyl applications reduced total and flowering red sorrel ramet density in the bearing year (Tables 5 and 8). Although not currently registered for use, additional work should be

Table 9. Effect of fall bearing year ALS-inhibiting herbicide applications on lowbush blueberry flower bud number and yield at Mount Pleasant[a] and Sherbrooke, Nova Scotia, Canada.

Treatment	Flower bud number (buds stem^{-1})	Yield (kg ha^{-1})
Nontreated control	2.5 ± 0.17c	1870 ± 331b
Tribenuron-methyl	3.4 ± 0.17b	1665 ± 331b
Flazasulfuron	4.2 ± 0.17a	4080 ± 331a
Pyroxsulam	2.9 ± 0.17bc	1785 ± 331b
Nicosulfuron + rimsulfuron	2.6 ± 0.17bc	1590 ± 331b
Halosulfuron-methyl	3 ± 0.17bc	2080 ± 331b
Foramsulfuron	2.6 ± 0.17c	1789 ± 331b

Note: Means within columns with the same letter are not significantly different according to a Tukey's test at $\alpha = 0.05$. Values represent the mean ± SE.

[a] Herbicides were applied on 5 November 2017 and 1 November 2017 at Mount Pleasant and Sherbrooke, respectively. Lowbush blueberry flower bud number stem^{-1} was determined on 16 October 2018 and 22 October 2018 at Mount Pleasant and Sherbrooke, respectively. Lowbush blueberry yield was determined on 15 August 2019 and 16 August 2019 at Mount Pleasant and Sherbrooke, respectively.

conducted to improve our understanding of crop injury risks and weed control associated with this application timing as this use would be beneficial to growers for reducing potential interference from red sorrel or other weeds in the bearing year.

Flazasulfuron efficacy on red sorrel was similar to tribenuron-methyl across all application timings, suggesting similar postemergence and preemergence activity of these herbicides on red sorrel. Fall bearing year flazasulfuron applications, however, caused greater reductions in non-bearing year red sorrel ramet density than tribenuron-methyl during June and August at Mount Pleasant and June, August, and October at Sherbrooke (Table 6). Flazasulfuron was recently registered for suppression of *Festuca* spp. in lowbush blueberries (Zhang et al. 2018), with both fall bearing year and spring non-bearing year applications approved for use. Results of this study indicate that growers could expect good control of red sorrel when using these flazasulfuron application timings as well. The potential for use of both tribenuron-methyl and flazasulfuron for management of red sorrel, however, necessitates timely development of resistance management strategies due to the high risk of resistance development to ALS-inhibiting herbicides (Tranel and Wright 2002). Fall bearing year dicamba, dichlobenil, and pronamide applications also suppress or control red sorrel in lowbush blueberry (White et al. 2021) and use of these herbicides in conjunction with tribenuron-methyl and flazasulfuron will be important for mitigating resistance to the ALS-inhibitor site of action. Given the high seedling densities and lack of seedling control from some application timings and herbicides, identification of tank mixtures, or alternative herbicides that improve residual control of red sorrel seedlings will also be important for improving weed control and ensuring sustainability of tribenuron-methyl and flazasulfuron for red sorrel management.

Pyroxsulam was effective in the greenhouse experiment (Table 3) but exhibited inconsistent efficacy under field conditions. Spring non-bearing year applications did not reduce total red sorrel ramet density (Table 4) and gave inconsistent reductions in red sorrel seedling and flowering ramet density (Table 7), indicating limited efficacy of spring applications of this herbicide on red sorrel. Fall non-bearing year and fall bearing year applications gave more consistent reductions in red sorrel ramet density (Tables 5 and 6), though red sorrel recovered in the pyroxsulam treatments more quickly than in the tribenuron-methyl or flazasulfuron treatments. Yellow nutsedge (*Cyperus esculentus* L.) response to ALS-inhibiting herbicides also varied between field and greenhouse trials (Ackley et al. 1996; Nelson and Renner 2002), suggesting that greenhouse research on perennial weeds with ALS-inhibiting herbicides should be accompanied by field experiments before drawing conclusions on herbicide efficacy. Clopyralid, sulfentrazone, and flumioxazin also controlled red sorrel in greenhouse pot experiments but failed to control this weed in the field (White et al. 2021), suggesting that greenhouse red sorrel plants are more susceptible to some herbicides than plants in the field. Given that more effective herbicides than pyroxsulam are available, pursuit of a pyroxsulam registration in lowbush blueberry should be based on efficacy on weeds other than red sorrel and may be worth pursuing given the crop tolerance associated with this herbicide.

Efficacy of the remaining herbicides was limited relative to that of tribenuron-methyl, flazasulfuron, and pyroxsulam. Spring non-bearing year nicosulfuron + rimsulfuron applications did not reduce total ramet or seedling density (Tables 4 and 7), though a reduction in flowering ramet density at Murray Siding (Table 7) likely explains the suppressive effects of this herbicide perceived by growers as non-flowering red sorrel ramets remain below the blueberry canopy and are not readily visible when scouting fields. Nicosulfuron + rimsulfuron applications in fall of the non-bearing year at Collingwood (Table 5) and fall of the bearing year at Mount Pleasant (Table 6) provided temporary reductions in ramet density, indicating that this herbicide may be more effective for red sorrel management when used as part of a fall weed control program. Superior efficacy of tribenuron-methyl and flazasulfuron, however, likely precludes fall nicosulfuron + rimsulfuron use for red sorrel management. Halosulfuron-methyl appeared promising for red sorrel management under greenhouse conditions (Table 3) but was generally ineffective in the field. Although effective on some annual broadleaf weeds (Brandenberger et al. 2005; Macrae et al. 2008), halosulfuron-methyl is most commonly used to control sedges such as yellow nutsedge and purple nutsedge (*Cyperus rotundus* L.) (Blum et al. 2000; Grichar et al. 2003) and should be evaluated further for sedge control in lowbush blueberry given the opportunities for crop tolerance identified in this study. Foramsulfuron provides control or suppression of some grass and broadleaf weed species in lowbush blueberry (White and Webb 2018; Zhang et al. 2018; White and Zhang 2019) but appears to be ineffective on red sorrel.

Lowbush blueberry appeared to exhibit good crop tolerance to most of the herbicides evaluated across all application timings. None of the spring non-bearing year applications reduced lowbush blueberry stem density, flower bud number, or yield, nor did the fall non-bearing year herbicide applications reduce yield. These data do, however, highlight the fact that control of red sorrel at these sites did not increase yield. Reasons for this are unclear, though exact mechanisms of weed interference between red sorrel and lowbush blueberry have yet to be elucidated, and it is not clear what red sorrel density is required to cause detectable yield loss. Several grass species, particularly rough bent grass (*Agrostis hyemalis* (Walt.)), gradually infiltrated the plot sites as well, which may have affected yields (Boyd et al. 2014). Red sorrel may therefore require a larger systems-based approach that integrates factors associated with pollination, fertility inputs, control of other weeds, and disease management into experimental design to detect true impacts of this weed species on lowbush blueberry. In the meantime, growers are cautioned that control of red sorrel with tribenuron-methyl may not lead to yield increases and they will need to justify the herbicide application based on anticipated weed interference with other aspects of crop management.

Fall bearing year control of red sorrel with flazasulfuron, and to some extent tribenuron-methyl increased flower bud number per stem at Mount Pleasant and Sherbrooke and increased yield in the flazasulfuron treatment (Table 9). Flazasulfuron was a more effective fall bearing year herbicide than tribenuron-methyl and maintained lower red sorrel ramet density throughout the non-bearing year (Table 6), potentially contributing to the yield increase in this treatment. Sporadic patches of poverty oat grass (*Danthonia spicata* (L.) P. Beauv. Ex Roem. & Schult.) and rough bent grass also developed during the course of the fall bearing year trial at each site, particularly at Sherbrooke, which, as indicated above, may have also affected yield of some plots. Ongoing ALS-inhibiting herbicide evaluations for red sorrel should therefore likely be combined with additional non-bearing or bearing year herbicide applications to suppress other weeds such as grasses that become established in plots.

Conclusion

In conclusion, tribenuron-methyl and flazasulfuron were identified as ALS-inhibiting herbicides that may contribute to management of red sorrel in lowbush blueberry fields. Pyroxsulam was most effective as a fall non-bearing year or fall bearing year application, but superior efficacy of tribenuron-methyl and flazasulfuron likely negates further consideration of this herbicide for red sorrel control in lowbush blueberry fields. Nicosulfuron + rimsulfuron, halosulfuron-methyl, and foramsulfuron provided inconsistent or limited control of red sorrel and are not recommended for red sorrel management in lowbush blueberry fields. Given that tribenuron-methyl and flazasulfuron are currently registered for weed control in lowbush blueberries, growers can readily utilize this information in their weed management programs. Growers are, however, cautioned that control of red sorrel with tribenuron-methyl in this research was incomplete and did not lead to yield increases. Further research is needed to understand the mechanisms of red sorrel interference with lowbush blueberry.

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Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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