Occurrence of hexazinone-resistant red sorrel (*Rumex acetosella* L.) and evaluation of spring non-bearing year and autumn bearing year herbicides for red sorrel management in lowbush blueberry (*Vaccinium angustifolium* Ait.) fields in Nova Scotia

by

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ABSTRACT

Weeds are a major limiting factor in wild blueberry production and compete with wild blueberries for space, light, moisture, and nutrients. Red sorrel is a common creeping herbaceous perennial weed in commercially managed wild blueberry fields in Nova Scotia, Canada. Herbicides are the primary source of weed control in wild blueberry fields and current management practices do not provide adequate control of red sorrel. Multiple experiments were conducted over two years to evaluate 1) ocurrence of hexazinone-resistant red sorrel 2) spring herbicide applications 3) autumn herbicide applications and 4) autumn mowing and application timing on herbicide efficacy on red sorrel in wild blueberry fields. The majority of red sorrel populations sampled from blueberry fields in Nova Scotia were susceptible to hexazinone despite the occurrence of resistant biotypes of this weed species. Autumn applications of dicamba, dichlobenil, and tribenuron-methyl gave most consistent reductions in over-wintered ramet density across sites and are tentatively recommended for red sorrel management in wild blueberry fields. Spring applications were less effective than autumn applications, though pyroxsulam, hexazinone + pyroxsulam, sulfentrazone and hexazinone + sulfentrazone significantly reduced total non-bearing year ramet density relative to the nontreated control. Efficacy of autumn herbicide applications on red sorrel was not affected by mowing or application timing. Results indicate that red sorrel will be most effectively managed by autumn herbicide applications in wild blueberry. Additional research is required to determine acceptable spring herbicide treatments for this weed species and also alternative treatments to control red sorrel in wild blueberry fields.

LIST OF SYMBOLS AND ABBREVIATIONS USED

% - Percent

< - Less than

> - greater than

°C - Degrees Celsius

v/v - Volume by volume

± - standard error of a quantity

≤ - Less Than or Equal

≥ - Greater or equal

® - Registered trademark

AAFC - Agriculture and Agri-Food Canada

ANOVA - Analysis of Variance

cm - Centimeter

CO_2 - Carbon dioxide

DAS - Days after spraying

g - Grams

g a.e. ha^{-1} - Grams acid equivalent per hectare

g a.i. ha^{-1} - Grams active ingredient per hectare

km h^{-1} - Kilometer per hour

kPa – Kilopascal

kg – Kilogram

L- Liter

L ha^{-1} - Liters per hectare

LS Means - Least Squared Means

m - Meter

m^{-2} - Per square meter

N – North

PS II - photosystem

SAS® - Statistical Analysis System

SE - Standard error

W - West

XR - Extended range nozzles

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Chapter 1.0 Introduction

1.1 Introduction to the problem

Lowbush blueberry (*Vaccinium augustifolium* Ait.), also referred to as wild blueberry, is an important fruit crop that is grown commercially in the state of Maine in the United States, in Quebec, and in the four Atlantic Provinces of Canada (Yarborough 2004). Wild blueberry is a significant part of Nova Scotia's provincial heritage and natural vegetation and has been the key to a remarkable story of provincial economic growth and development. In 2016, Canada produced 145,765 t of lowbush blueberry, with approximately 30,826 t produced in Nova Scotia with an estimated farm gate value of $19 million (Stats Canada 2016). Unlike other crops, wild blueberries are not planted but are developed from native stands (McIsaac 1997). It is important in this crop to manage weeds to minimize yield loss within existing fields.

Plants that damage cropping systems, natural ecosystems, or human activities and that are unusually persistent are referred to as weeds (Radosevich et al. 2007). Weeds are a major limiting factor in wild blueberry production and compete with wild blueberries for space, light, moisture, and nutrients. In a weed survey conducted in 1984-1985 in Nova Scotia, red sorrel was the fourth most abundant weed species present in wild blueberry fields (McCully et al. 1991) and has been reported as a major weed problem in wild blueberry fields in recent years (Sangster 2007). In early 1980's hexazinone was widely sprayed in wild blueberry production to control weeds and was widely adopted when research showed a two-fold blueberry yield increase (Yarborough 2004). Initially, hexazinone , the primary herbicide used in wild blueberry production, controlled red sorrel (Jensen 1984), but eventually blueberry growers in Nova Scotia found hexazinone efficacy declined over time (Kennedy et al. 2010). This plant has recently been documented to have developed resistance to this herbicide (Li et al. 2014). Perennial weeds are most commonly seen in wild blueberry fields. They take longer to become resistant possibly due to vegetative propagation, but repeated applications to large weed populations with single herbicide chemistry may result in resistance over time. The distribution of hexazinone-resistant red sorrel throughout the dominant blueberry producing regions of Nova Scotia, however, is currently unknown, and alternative management strategies for this weed are currently lacking.

1.2 Wild blueberry field management and general weed flora

Wild blueberry is a member of the Ericaceae family, genus *Vaccinium*, subgenus Cyanococcus. Commercially there are three main species grown: (1) the highbush blueberry, *V. corymbosum* L., (2) the lowbush blueberry, *V. angustifolium* Aiton, and (3) the rabbiteye blueberry, *V. ashei* Reade (Gough and Korcak 1996). Flowers of blueberries are bell-shaped, white to pinkish-white in color, its fruit are bright blue with a greyish casting and are borne in clusters (Vander Kloet 1988). Wild blueberry is a cryptophytic, low-growing rhizomatous shrub that grows up to 25 cm tall, spreads by underground rhizomes, and grows in well-drained, acidic soils (Kinsman 1993). New blueberry shoots are produced from dormant buds present on the rhizome, and blueberry plants are very hardy due in part to their rhizomes. With sufficient roots one solitary piece of rhizome can grow to be a new separate blueberry plant (Kinsman 1993). McIsaac (1997) reported that in unmanaged fields, the rate of spread of rhizomes can vary from 5-8 cm per year, to 38 cm in one growing season, where competition had been reduced.

Commercial wild blueberry fields are not planted but rather are developed from abandoned farmland or cleared woodland where native blueberry stands already exist (Jensen and Yarborough 2004). These stands are comprised of variable clones which usually spread by underground rhizomes (Hall and Aalders 1961). Each clone is a unique individual that established naturally from seed and the individual shoots, or ramets, that emerge from the rhizomes of each genet constitute the aboveground portion of each plant (Eriksson 1989). Fields are generally managed on a two-year cycle. During the first, or vegetative year, fields are pruned in previous autumn or spring by burning or flail mowing to near ground level which helps to enhance new shoots (Kinsman 1993), grow vegetative, and develop floral buds in late summer and autumn (Jensen and Specht 2002). During the second, or crop year, the shoots flower, produce berries, and harvest generally occurs in August. Fields are then pruned by mowing or burning (Ismail et al. 1981) to promote crown expansion, root development, and increase the number of shoots in the following vegetative year (Smagula and Yarborough 1990).

Due to the nature of wild blueberry field management, weeds are a persistent problem for growers (Kennedy et al. 2011). Most weeds are woody and herbaceous perennials (McCully et al. 1991) which live for more than 2 yr and they are very hard to control (McCully et al.2005) as they reproduce from underground rhizomes, roots, or other vegetative structures (Hall 1959; Yarborough and Ismail 1985; Yarborough and Bhowmik 1989). Blueberries are also perennials, which may have similar growth dynamics as these perennial weeds. In fact, some of the production practices that promote blueberries growth and spread also promote those of these weeds (Kinsman 1993; McCully et al. 2005).

1.2.3 Approaches to the Management of Perennial Weeds

Traditionally, herbaceous perennial weeds are a problem in wild blueberry fields (Kinsman 1993). Successful control of creeping perennials is rarely achieved with one-time effort due to their vegetative reproductive structures and repeated treatments are typically needed to exhaust the root buds and the stored food reserves within the vegetative reproductive structures (Ross and Lembi 1999). An efficient way to control perennial weeds is to initiate control measures at the seedling and early vegetative stages because once the weed begins to develop its perennial reproductive structures the weeds are more difficult to control (Hakansson 1982).

The aggressive spread and persistence of perennials is due to stored carbohydrate reserves in root and rhizome system (Becker and Fawcett 1998). After adequate aboveground photosynthetic structures develop, carbohydrates start to move downward to the underground structures (Becker and Fawcett 1998; Ross and Lembi 1999). Therefore, the most effective time to control perennials is when the plant is moving sugars and other carbohydrates back down into the roots. At this particular time, the weed attempts to generate new underground structures and the implementation of chemical control at that point in time leads to the herbicide translocation along with the carbohydrate into rhizomes, roots or other vegetative reproductive structures (Ross and Lembi 1999; McWhorter 1961). This timing usually coincides with the early flower bud stage, or when the plant is approximately one-fourth of its total height (Ross and Lembi 1999).

Physical and mechanical control of weeds using tillage or hand-pulling are not possible or economically viable on large farms (Jensen and Yarborough 2004). Mowing above blueberry plants can reduce seed production by weeds, but rarely provides complete control of weeds (Yarborough 1996).

Herbicides are the primary method of weed control in wild blueberry production (Jensen and Yarborough 2004). Several pre- and post-emergence herbicides are currently registered for use in wild blueberry (Jensen and Yarborough 2004), but pre-emergence applications of hexazinone continue to be important for general, broad-spectrum weed control. In recent years, however, hexazinone has failed to control an increasing number of weed species, including several species of grasses (Jensen and Yarborough 2004) and the creeping herbaceous perennial red sorrel (Li et al. 2014). Red sorrel is now widespread (Jensen and Sampson, unpubl. data) and difficult to manage in wild blueberry fields, requiring new management strategies (White 2013).

1.3 Red sorrel taxonomy and biology

Red sorrel (*Rumex acetosella* L.) is a common herbaceous perennial plant that belongs to the Polygonaceae family and is native to Europe and Asia but has become naturalized throughout most of North America (Gleason and Cronquist 1963). It has several common names, including sheep sorrel, sour weed, mountain sorrel, and field sorrel (Nijs 1984). The plant occurs as a weed in pastures (Archer and Auld 1982), roadsides, wild blueberry fields (Sampson et al. 1990), abandoned fields, and disturbed sites (Escarre and Houssard 1991). In particular, the plant thrives in areas that have acidic and nutrient-deficient soils (Love 1983), poor drainage, and little competition from other plants (Uva et al. 1997).

Red sorrel is a dioecious plant and reproduces by both seeds and adventitious shoots that arise from the roots (Putwain et al. 1968). The seeds are achenes and vegetative shoots that emerge from the roots are referred to as ramets, or single units of clonal growth (Harper 1977). Both seeds and vegetative shoots contribute to an increase in population (Putwain et al. 1968; Escarre et al. 1994), though most populations of this plant are maintained primarily by vegetative reproduction due to poor seedling survival (Putwain et al. 1968; Meyer and Schmid 1999). Seedlings emerge throughout the growing season in wild blueberry fields, with survival rates ranging from 6 to 51% (White et al. 2014). Similarly, ramets emerge from the creeping root system throughout the entire growing season in wild blueberry fields, with ramet population density peaking in mid to late autumn (White et al. 2014; 2015). Ramets remain vegetative and persist below the blueberry canopy in the year of emergence. Flowering occurs primarily in overwintered ramets (White et al. 2014) and is induced by vernalization and subsequent exposure to long days (White et al. 2015). These flowering ramets bolt and grow taller than established blueberry stems, inhibiting harvest (Kennedy et al. 2011) and potentially interfering with pollination during the crop year (Hughes 2012). Flowering stems can grow up to 60 cm in height and the inflorescences are reddish-brown in color (Alex and Switzer 1977; Uva et al. 1997).

1.4 Herbicide resistance and approaches to the management of herbicide-resistant weeds

Herbicide resistance is the inherited ability of a plant to survive a typically lethal herbicide dose and pass this trait to successive generations (Yang et al. 2009). Herbicide resistance often develops when one or more herbicides with the same mode of action are applied to the same field or weed population for several years (Beckie and Reboud 2009). In this situation, the susceptible portion of the weed population is reduced, and the resistant plants increase in number (Martin et al. 2000). There are 210 weed species (123 dicots and 87 monocots) that have evolved resistance to one or more herbicides (Heap 2014).

The herbicide hexazinone has been applied to commercial wild blueberry fields for many years (Yarborough 2004) at a recommended rate of 1.44 to 1.92 kg ai ha^{-1} (McCully et al. 2005). These application rates previously controlled red sorrel (Jensen 1984), but suspected hexazinone-resistant populations have been reported throughout Atlantic Canada (McCully et al. 2005; Kennedy et al. 2011) and have been confirmed in two red sorrel populations in Nova Scotia (Li et al. 2014). Li et al. (2014) reported that resistance is due to a mutation in a portion of the chloroplast psbA gene and resistant plants had a substitution of Phe to Val at position 255 in the D1 protein, which confers resistance. Management of herbicide-resistant weeds requires a holistic look at all aspects of crop production. To date, management of herbicide-resistant weeds has relied primarily on monitoring, cultural techniques, mechanical management (Heap 2014), and chemical management practices (Prather et al. 2000).

Monitoring of herbicide-resistant weeds is done to identify the presence and absence of resistance in defined geographical areas at a single point in time or across multiple years (Davis et al. 2008). This has traditionally been conducted to determine the scope and distribution of resistance across a region, province, or other defined local areas (Tucker et al. 2006). This work helps to determine potential relationships between resistance and crop production variables and helps develop an improved understanding of farming practices that are associated with resistance development (Legere et al. 2000; Hanson et al. 2009).

Cultural techniques, such as crop rotations, are also tools for preventing resistance. Rotation to another crop facilitates use of both chemical and non-chemical control methods (Ross and Lembi 1985). Manipulation of planting time, cultivation techniques, competitiveness of the crop, hand weeding, and application of herbicides with different modes and sites of action are all possible in a crop rotation system (Prather et al. 2000). For example, crop rotations have been used to control sun hemp (*Crotalaria juncea* L.) plants in corn and soybean (Edwards et al. 1988), because triazine-resistant sunhemp had developed in fields where atrazine was used for several consecutive years (Martin et al. 2000). Crop rotation can be a logical cultural weed management tool for managing herbicide resistance (Martin et al. 2000), however, crop rotation cannot be practiced in wild blueberries to control red sorrel as this crop is a woody perennial and cannot be rotated.

Cultural practices like mulching may help to control weeds. A surface layer of mulch over the blueberry plants or between the clones will smother small weeds and inhibit seed germination. A mulch layer will help modify the microenvironment by maintaining or moderating the soil temperature, reduce light intensity, increase soil moisture, and reduce frost heaving so that the environment is more conducive to rhizome growth and spread. Each of these factors may encourage clonal spread and helps in more efficient use of herbicides (Drummond et al. 2009). Use of wood chips and bark mulch could encourage rhizome development and to cover bare spots within fields and planting blueberry plants in bare spots also helps them fill in more rapidly and out-compete weeds (Degomez and Smaula 1990). Consistent blueberry cover in bare spots will reduce weed establishment (Yarborough 1996).

Physical control of weeds includes burning. Prior to 1980, almost all wild blueberry fields were pruned by burning using straw or tractor-drawn oil burners (Ismail and Yarborough 1979). Burning will control some shallow rooted grasses, coniferous species, reduce the return of many weed seeds from mature plants to the soil, and also kills weed seeds present near the soil surface. Most burning methods, however, provide only partial or erratic weed control (McCully et al. 2005). In addition, periodic burning of blueberry fields leads to the destruction of the surface organic matter and the A1 horizon where most of the blueberry rhizomes are located (Trevett 1956). Loss of soil organic matter leads to a severe impact on the biological, physical, and chemical properties of the soil as well as soil-plant relationships (Warman 1987). Research indicated that mowing emerged blueberry stems to within 1 cm of the soil would produce equivalent yields to burning (Ismail and Yarborough 1979). Flail mowing, therefore, has been introduced as an alternative management technique (Ismail et al. 1981).

Mechanical methods of weed control include tillage and mowing. The use of tillage helps in aeration of soil, also has been cited as an important practice to control weeds (Cardina et al. 2002). It may substitute for herbicide usage and helps to bury weed seeds to reduce seed germination and emergence (Moss 1997). Pruning with mowers is done to remove blueberry stems and stimulate new shoot emergence from rhizomes, but also aids in control of some weeds (Eaton et al. 2004). Flail mowing, therefore, has been introduced as an alternative weed control technique. Mowing in blueberries is usually conducted in the late autumn of the crop year or early spring of the sprout phase of production when the plants are dormant (Warman 1987). Mowing is not recommended as the sole method of weed control, but it helps for the short-term suppression of perennial weeds. Stems chopped at ground level by the mower could reduce the hindrance to harvest by promoting the growth of single vertical stems in the crop year which helps in increasing the quality of the harvest (Chiasson and Argall 1995b). In addition to good weed control, the plant residues left on the soil surface after mowing improves soil temperature, water holding capacity and organic matter of the field (Degomez 1988). However, these herbicide-resistant weeds spread from one field to another through farm machinery such as harvesters and mowers, which must be cleaned before using in the field (Martin et al. 2000; Boyd and White 2009).

While cultural and mechanical methods are important for managing herbicide resistance, herbicides also play a role if used in mixtures or in rotation (Beckie et al. 2001). Mixing two herbicides with different modes of action will delay the development of resistance in weeds, provided that both herbicides have activity on the target weeds (Ross and Lembi 1985). For example, *Chenopodium* spp. and *Amaranthus* spp. have developed resistance to triazine herbicides when triazines were used alone in corn, but have never been reported to evolve resistance where triazine herbicides were used in conjunction with chloroacetamide herbicides because chloroacetamides have some activity on these two genera (Wrubel and Gressel 1994).

A lack of herbicide group rotation often leads to herbicide resistance (Beckie 2006). To avoid the selection of herbicide-resistant weeds, it is important to rotate effective herbicide groups with the goal of reducing the resistant weed population (Beckie and Reboud 2009). There is epidemiological evidence for the utility of herbicide group rotations in delaying the evolution of target-site resistance, including triazine-herbicide resistant weeds (Stephenson et al. 1990) and ACCase inhibitor-herbicide resistant weeds (Legere et al. 2000). Given that red sorrel ramets emerge all season in wild blueberry fields, reach peak ramet density occurs in autumn (White et al. 2014, 2015) and flower by undergoing vernalization in winter, the most logical timings for evaluating herbicides for rotational use on red sorrel are in autumn prior to overwintering (to control overwintering ramets and reduce flowering) and in spring prior to ramet emergence to help suppress season long ramet emergence and re-establishment of vegetative ramets. Based on this information, some objectives have been considered to control hexazinone-resistant red sorrel populations in wild blueberry.

1.5 Objectives

The overall objective of this research is to estimate the occurrence of hexazinone-resistant red sorrel in Nova Scotia and develop new management strategies for this weed species. Specific objectives of the research are to:

(1) Determine the occurrence of hexazinone-resistant red sorrel (*Rumex acetosella* L.) in wild blueberry (*Vaccinium angustifolium* Ait.) fields in Nova Scotia,

(2) Evaluate spring herbicide applications for non-bearing year red sorrel management in wild blueberry fields,

(3) Evaluate autumn herbicide applications for red sorrel management in wild blueberry fields,

(4) Evaluate the effect of autumn mowing and application timing on herbicide efficacy on red sorrel in wild blueberry fields.

My hypotheses are as follows

(1) Hexazinone-resistant biotypes of red sorrel are widely distributed in the wild blueberry producing regions in Nova Scotia.

(2) Spring application of herbicides can be used to reduce non-bearing year ramet density by suppressing ramet and seedling emergence in wild blueberry fields.

(3) Control of ramets prior to overwintering with herbicides will reduce flowering ramet density in the following year and would reduce total ramet density in the following year.

(4) Pre-pruning herbicide applications would be as effective as post-pruning herbicide applications and applications of herbicides in mid-November will give better control than applications in mid-October.

Chapter 2.0 Occurrence of hexazinone-resistant red sorrel (*Rumex acetosella* L.) in wild blueberry (*Vaccinium angustifolium* Ait.) fields in Nova Scotia

2.1 Introduction

Commercial wild blueberry fields are developed from abandoned farmland or deforested areas (Hall et al. 1979) where blueberry plants establish naturally from seed and spread by rhizomatous growth (Hall 1957; Barker et al. 1964). Commercial blueberry production occurs on a 2-year production cycle in which fields are pruned in the first year (non-bearing year) by burning or flail mowing to stimulate vegetative growth and flowering, while fruit development and harvest occurs in the second year (bearing year) (Barker et al. 1964).

Weeds are the major yield limiting factor in commercial blueberry production (Jensen 1984). Although several herbicides are currently registered for use in lowbush blueberry fields (Anonymous 2018), weed control in this crop has relied heavily on preemergence non-bearing year hexazinone applications since initial registration of this herbicide in the early 1980's (Yarborough 2004). Hexazinone is a triazine herbicide that controls weeds by inhibiting electron flow in photosystem II (Shukla and Devine 2008). The site of action of these herbicides is the plastoquinone-binding pocket on the D1 protein in the PSII reaction center of the photosynthetic electron transport chain. Transfer of electrons from Q_A to Q_B is blocked when the herbicide binds, and photosynthesis lacks NADPH for CO_2 fixation (Gardner 1981). Subsequent photo-oxidation of membrane lipids leads to plant death (Shukla and Devine 2008). The herbicide has traditionally controlled a range of herbaceous and woody weed species in lowbush blueberry fields

(Yarborough and Bhowmik 1989; McCully et al. 2005) and registration and use of this herbicide contributed to increased yields, improved use of fertility inputs, and even mechanical harvesting (Yarborough 2004). Continued use of this herbicide, however, has potentially selected for resistant biotypes of some weed species (Jensen and Yarborough 2004), including red sorrel (Li et al. 2014).

Red sorrel (*Rumex acetosella* L.) is a common perennial weed in lowbush blueberry fields (McCully et al. 1991) that reproduces both sexually by setting seed and vegetatively by reproducing from creeping roots (Uva et al. 1997). Red sorrel seeds are also common contaminants on harvesting equipment (Boyd and White 2009), potentially contributing to spread of this weed species. Red sorrel was traditionally controlled by hexazinone (Jensen 1984; Jensen and Specht 2002; McCully et al. 2005), though recent research indicates variability in control across sites (Kennedy et al. 2011; Li 2013) and populations resistant to hexazinone have been identified in lowbush blueberry fields in Nova Scotia (Li et al. 2014). The occurrence and distribution of hexazinone-resistant red sorrel biotypes in lowbush blueberry fields in Nova Scotia, however, is not clear.

The objective of this experiment was to estimate the distribution of hexazinone-resistant red sorrel in wild blueberry in Nova Scotia. I hypothesized that hexazinone-resistant biotypes of red sorrel are widely distributed in the wild blueberry producing regions in Nova Scotia.

2.2 Materials and methods

The objective of this experiment was to determine the occurrence of hexazinone-resistant red sorrel in Nova Scotia. Red sorrel seeds were collected from 44 wild blueberry fields throughout Nova Scotia in August 2016 for use in this experiment (Table 2.1). All seeds collected from the fields were placed in paper envelopes and stored in the dark at room temperature in the laboratory until use. Seeds were stored for 1 to 6 months prior to use. Seeds were stimulated to germinate by submersing them in sulfuric acid for 3 min followed by rinsing with distilled water. Rinsed seeds were then placed in petri dishes lined with 2 pieces of Whatman No. 9 filter paper moistened with distilled water. Dishes were sealed with Parafilm and stored at 4^0C for 72 hours prior to placement in an incubator maintained at 12 hour photo period at 19^0C and 60% RH. Six germinated seeds were then sown in 715 cm^3 pots filled with ProMix growing medium (Pro-Gro® Premium Organic Top Soil, Annapolis Valley Peat Moss Co. Ltd., Berwick, NS) and thinned to 3 seedlings per pot at 2 weeks after emergence. A pot containing 3 seedlings was considered a replicate, and 14 replications were used for each site. Seedlings were treated with a foliar hexazinone application at a rate of 3,840g a.i. ha^{-1} (twice label rate) at 5 wk after emergence using a hand held, CO_2-pressurized single nozzle sprayer equipped with a single Teejet 8002 nozzle and calibrated to deliver 300 L water ha^{-1} at 276 kPa.

Data collection included visual injury rating of hexazinone efficacy on red sorrel at 7, 14, 21, and 28 d after spraying (DAS) and living shoot density in each pot at 42 DAS. Visual injury ratings were conducted using a damage rating scale from 0 to 10, where 0 represents no damage and 10 complete death of all above ground red sorrel shoots.

2.3. Results and discussion

Red sorrel populations collected from 42 of the 44 sites used in this study were controlled by hexazinone (Table 2.1), indicating low occurrence of hexazinone-resistant red sorrel biotypes in lowbush blueberry fields in Nova Scotia. However, 12 and 5% of the red sorrel plants from the Debert and Base Line Road fields, respectively, survived the hexazinone application, indicating potential presence of hexazinone resistant biotypes at these sites.

Table 2.1. Effect of hexazinone applications on red sorrel visual injury rate in 28 days after herbicide application in the greenhouse experiment.

Site	Production year	Coordinates	Damage ratings				Surviving plants (#)
			7th day	14th day	21st day	28th day	
Debert	Non-bearing year	45^{0}28'48"N 63^{0}27'58"W	80.7 ± 4.7[a]	100 ± 0	100 ± 0	100 ± 0	0
Pigeon hill	Non-bearing year	45^{0}33'44"N 63^{0}51'41"W	74.2 ± 5.6	94 ± 5.6	100 ± 0	100 ± 0	0
Pigeon hill	Bearing year	45^{0}34'19"N 63^{0}51'28"W	72.1 ± 6.8	92.1 ±3.8	100 ± 0	100 ± 0	0
Mt. Thom	Non-bearing year	45^{0}29'35"N 62^{0}59'20"W	84.2 ± 3.4	100 ± 0	100 ± 0	100 ± 0	0
Portapique	Bearing year	45^{0}24'26"N 63^{0}63'51"W	65.7 ± 4.8	84 ± 5.1	100 ± 0	100 ± 0	0
Webb road	Non-Bearing year	45^{0}34'19"N 63^{0}71'22"W	29.2 ± 2.2	82.8 ± 3.0	100 ± 0	100 ± 0	0
Milne Mt	Bearing year	45^{0}7'33.22"N 63^{0}6'68.33"W	74.2 ± 6.6	92.8 ± 4.2	100 ± 0	100 ± 0	0
Upper Rawdon	Non-bearing year	45^{0}51'17"N 63^{0}42'49"W	77.8 ± 4.2	98.5 ± 0.9	100 ± 0	100 ± 0	0
Mt. Thom	Bearing year	45^{0}29'35"N 62^{0}59'20"W	82.5 ± 4.1	96.4 ± 2.2	100 ± 0	100 ± 0	0

Glusboro	Bearing year	$45^0$20'55.788"N $62^0$17'52.701"W	79.2 ± 6.4	92.1 ± 5.9	100 ± 0	100 ± 0	0
Debert	Bearing year	$45^0$26'17"N $63^0$27'12"W	47.1 ± 6.4	75.0 ± 6.1	88.5 ± 5.5	90.0 ± 5.1	5
Glennmore	Non-bearing year	45^0 101' 557"N 63^0 154' 256"W	81.4 ± 4.7	96.4 ± 2.4	100 ± 0	100 ± 0	0
Baseline road	Bearing year	$45^0$29'41"N $63^0$32'37"W	62.8 ± 9.2	83.5 ± 5.7	94.2 ± 3.2	96.4 ± 2.4	2
Upper Rawdon-Rainbow field	Non-bearing year	$45^0$51'17"N $63^0$42'49"W	15.7 ± 3.0	95.7 ± 1.3	100 ± 0	100 ± 0	0
Sherbrooke road	Non-bearing year	$45^0$26'60"N $62^0$17'16"W	15.7 ± 1.7	92.1 ± 1.5	100 ± 0	100 ± 0	0
Westchester Mt. Road	Bearing year	$45^0$35'34"N $63^0$50'48"W	40 ± 6.6	100 ± 0	100 ± 0	100 ± 0	0
South Hampton	Non-bearing year	$45^0$35'31"N $63^0$50'53"W	12.8 ± 1.6	91.4 ± 2.3	100 ± 0	100 ± 0	0
Collingwood road	Non-Bearing year	$45^0$35'28"N $63^0$44'56"W	45.7 ± 6.4	95 ± 5.1	100 ± 0	100 ± 0	0
Glenmore	Bearing year	$45^0$101'266"N $63^0$157'275"W	84.7 ± 6.5	98 ± 3.4	100 ± 0	100 ± 0	0
Pigeon hill	Bearing year	$45^0$34'43"N $63^0$51'60"W	20.0 ± 3.4	82.1 ± 4.0	100 ± 0	100 ± 0	0
Webb road	Bearing year	$45^0$34'19"N $63^0$41'22"W	19.2 ± 2.2	92.8 ± 3.0	100 ± 0	100 ± 0	0
Westchester Mt. Road	Non-bearing year	$45^0$35'11"N $63^0$43'28"W	32.1 ± 4.9	87.8 ± 2.8	100 ± 0	100 ± 0	0

Webb road	Bearing year	45^{0}34'41"N 63^{0}41'10"W	28.5 ± 5.5	92.8 ± 3.5	100 ± 0	100 ± 0	0
Mt. Thom	Bearing year	45^{0}29'35"N 62^{0}59'20"W	30 ± 2.0	98.5 ± 0.9	100 ± 0	100 ± 0	0
Mt. Thom	Bearing year	45^{0}29'35"N 62^{0}59'20"W	27.1 ± 2.6	92.1 ± 2.8	100 ± 0	100 ± 0	0
Westchester Mt. Road	Bearing year	45^{0}32'27"N 63^{0}42'53"W	43.5 ± 7.8	97.1 ± 1.9	100 ± 0	100 ± 0	0
South hampton	Bearing year	45^{0}5'31.58"N 64^{0}2'70.42"W	47.1 ± 8.1	99.2 ± 0.7	100 ± 0	100 ± 0	0
Greenfield road	Bearing year	45^{0}21'51"N 63^{0}10'56"W	54.2 ± 8.6	98.5 ± 0.9	100 ± 0	100 ± 0	0
Upper Rawdon	Bearing year	45^{0}41'56"N 63^{0}43'44"W	25.7 ± 6.2	95 ± 2.5	100 ± 0	100 ± 0	0
Pigeon hill	Bearing year	45^{0}34'59"N 63^{0}50'56"W	33.5 ± 7.9	100 ± 0	100 ± 0	100 ± 0	0
Milne Mt	Bearing year	45^{0}7'33.22"N 63^{0}6'62.33"W	34.2 ± 7.6	92.1 ± 4.2	100 ± 0	100 ± 0	0
Upper Rawdon	Bearing year	45^{0}41'56"N 63^{0}43'44"W	80.7 ± 4.8	97.1 ± 2.2	100 ± 0	100 ± 0	0
Greenfield road	Non-bearing year	45^{0}20'48"N 63^{0}50'45"W	78.5 ± 5.4	97.8 ± 1.5	100 ± 0	100 ± 0	0
Baseline Rd	Bearing year	45^{0}28'45"N 63^{0}35'14"W	64.2 ± 5.9	94.2 ± 3.4	100 ± 0	100 ± 0	0
Collingwood road	Bearing year	45^{0}35'28"N 63^{0}48'56"W	55.7 ± 6.4	85 ± 5.1	100 ± 0	100 ± 0	0
Portapique	Bearing year	45^{0}24'26"N 63^{0}43'41"W	35.7 ± 5.8	80 ± 4.1	100 ± 0	100 ± 0	0
Pigeon hill	Non-bearing year	45^{0}34'35"N 63^{0}51'14"W	70 ± 6.3	95 ± 3.4	100 ± 0	100 ± 0	0

Glenmore	Bearing year	45^{0}101'266"N 63^{0}157'75"W	80.7 ± 6.5	95 ± 3.4	100 ± 0	100 ± 0	0
Greenfield road	Non-Bearing year	45^{0}21'51"N 63^{0}20'46"W	64.5 ± 7.6	88.5 ± 0.9	100 ± 0	100 ± 0	0
Webb road	Bearing year	43^{0}32'53"N 63^{0}42'41"W	56.4 ± 4.5	92.8 ± 2.8	100 ± 0	100 ± 0	0
Sherbrooke road	Non-bearing year	45^{0}26'60"N 62^{0}27'26"W	35.7 ± 1.9	82.1 ± 1.7	100 ± 0	100 ± 0	0
Debert	Non-Bearing year	45^{0}26'17"N 63^{0}27'68"W	67.1 ± 5.4	85 ± 5.1	100 ± 0	100 ± 0	0
Milne Mt	Non-bearing year	45^{0}7'40.22"N 63^{0}6'58.33"W	44.2 ± 6.6	72.1 ± 6.2	100 ± 0	100 ± 0	0
Collingwood road	Bearing year	45^{0}35'45"N 63^{0}48'46"W	62.7 ± 6.8	78 ± 6.1	100 ± 0	100 ± 0	0

[a] Values represent the mean ± SE.

[b] Visual estimates of damage were conducted using a 0 to 10 integer scale, where 0 meant no damage and 10 meant complete plant death.

Assuming red sorrel survival is indicative of presence of hexazinone-resistant biotypes, our results indicate that hexazinone-resistant biotypes are not common in lowbush blueberry fields in Nova Scotia. Other factors, therefore, must contribute to lack of hexazinone efficacy in lowbush blueberry fields. Hexazinone efficacy is reduced on fine textured soils and soils high in organic matter (Minogue et al. 1988), and so variability in field efficacy can likely be expected across sites based on variable soil conditions. Hexazinone is also highly water soluble (Bouchard and Lavy 1985), and heavy rainfall after application can leach hexazinone out of the root zone of target weeds (Dos Reis et al. 2017). Red sorrel roots are confined to the upper 5 cm of soil (White 2014), and so variations in spring rainfall may affect efficacy in some years. Proper calibration and operation of spray equipment is also essential for effective weed control with herbicides, and grower surveys indicate a wide range of calibration practices (Stover et al. 2002; Beaulieu et al. 2008; Jasinski and Haley 2014) and sprayer maintenance regimes (Rice 1971) among growers that ultimately affect pesticide efficacy. Use of reduced hexazinone rates by growers is also considered to contribute to reduced control of weeds such as red sorrel (Jensen and Yarborough 2004). Red sorrel is also a creeping herbaceous perennial weed that undergoes extensive amounts of vegetative growth each year (White et al. 2014). Individual genets in established populations are therefore likely large (Kennedy et al. 2011), potentially contributing ability of plants in field populations to recover from initial hexazinone injury. In addition, prolonged use of soil applied triazine herbicides can alter soil microbial communities such that herbicides undergo enhanced microbial degradation due to accumulation of microorganisms adapted to metabolizing the compound (Abit et al. 2012a; 2012b). Hexazinone has been used for over 30 y in lowbush blueberry (McCully et al. 1991), and similar response of blueberry soils to hexazinone may have occurred in some fields.

All triazine resistance is due to target site mutation reported thus far in whole plants is a result of substitution of serine to glycine in the D1 protein in photo-system II (PSII) (Hirschberg and McIntosh 1983), and the mutation responsible for hexazinone resistance in red sorrel has been reported (Li et al. 2014). A major limitation to our study, therefore, was lack of assessment of the presence of the mutation responsible for resistance in the populations that we sampled. This information would have provided insight into the true presence of resistance prior to treatment applications and, more importantly, would have provided confirmation of resistance in the surviving plants from Debert and Baseline Road (Table 2.1). Future assessments of resistance distribution should therefore test for presence or absence of resistance mutations in the populations sampled. Another limitation of the study was the inability to obtain information about prior management practices in the wild blueberry fields from which the seeds used in this study were collected as a history of hexazinone resistance would provide insight into presence or absence of resistance in a given field.

2.4 Conclusion

In conclusion, results of our survey indicate that red sorrel plants in most lowbush blueberry fields are susceptible to hexazinone despite the occurrence of resistant biotypes of this weed species. Reasons for lack of control of this weed by hexazinone are unclear, but factors other than resistance need to be considered.

Chapter 3.0 Evaluation of spring herbicide applications for non-bearing year red sorrel (*Rumex aceotsella* L.) management in wild blueberry (*Vaccinium angustifolium* Ait.) fields

3.1 Introduction

The lowbush, or wild blueberry (*Vaccinium angustifolium* Ait.) is a native fruit crop which grows naturally in eastern North America (Hall et al. 1979). It is a low-growing rhizomatous shrub that grows up to 25 cm tall, spreads by underground rhizomes, and grows in well-drained, acidic soils (Kinsman 1993). The crop is managed under a 2-year production cycle where the shoots are pruned to ground level in the first year (non-bearing year), and the shoots flower and produce berries in the second year (bearing year) (Wood 2004). Controlling weeds is a major challenge in blueberry production as these plants decrease blueberry yield and quality, and also inhibit harvest operations (Kinsman 1993; Kennedy et al. 2010).

Red sorrel (*Rumex acetosella* L.) is a common herbaceous perennial plant found in turf grass, pastures (Ito 1992), landscapes, nursery crops (Uva et al. 1997), roadsides, and perennial crops such as wild blueberry (Sampson et al. 1990; McCully et al. 1991). It reproduces sexually by seed and vegetatively by creeping roots (Uva et al. 1997; Kennedy et al. 2010). Seedlings and ramets can contribute to increases in established populations, but established populations are maintained predominately by vegetative production of ramets (Putwain et al. 1968). Kennedy et al. (2010) reported that red sorrel ramet populations peak in early to late spring and decline throughout the season in lowbush blueberry fields. However, a demographic study conducted by White et al. (2014) found that new ramets actually emerge throughout the growing season (April to December), with the net ramet density dependent upon mortality of emerged ramets. New ramets remain vegetative in the year of emergence, and flowering occurs primarily in overwintered ramets (White et al. 2014) due to a vernalization requirement for flowering (White et al. 2015).

Wild blueberry growers rely heavily on herbicides for weed management as alternative forms of weed control, such as tillage and crop rotation, are not possible. Hexazinone is the traditional herbicide used in wild blueberry production and has controlled red sorrel (McCully et al. 2005; Kennedy et al. 2010). Hexazinone efficacy on red sorrel, however, has declined over time (Li et al. 2014), potentially due to presence of hexazinone-resistant red sorrel biotypes in wild blueberry fields in Nova Scotia (Li et al. 2014). Autumn applications of propyzamide can control red sorrel (Hughes 2012), but climatic conditions have to be favourable for successful weed control with this product and it is an expensive herbicide to use in wild blueberry fields. Alternatives to hexazinone and propyzamide are currently lacking, limiting the ability of growers to develop effective and economical management plans for red sorrel.

Given that new red sorrel ramets emerge throughout the growing season in wild blueberry fields, control of this weed species will rely, at least in part, on use of spring herbicide applications to suppress season-long ramet emergence. The objective of this research is to evaluate spring non-bearing year herbicide applications for suppression of season-long red sorrel ramet emergence in wild blueberry fields. I hypothesized that spring application of herbicides can be used to reduce final non-bearing year ramet density by suppressing ramet and seedling emergence in wild blueberry fields.

3.2 Materials and Methods

3.2.2 Experimental Design

This experiment was established in autumn of 2015 in pruned wild blueberry fields at Greenfield (45^{0}20'48"N; 63^{0}50'45"W), East Mountain (45^{0}29'35"N; 62^{0}59'20"W), and Sherbrooke (45^{0}26'60"N; 62^{0}17'16"W), Nova Scotia. The experimental design was a randomized complete block design with six blocks in Greenfield and five blocks in East Mountain and Sherbrooke. Plot size was 2 m x 6 m, and the experiment consisted of 14 treatments at each site (Table 3.1). Herbicides were applied using a CO_2 pressurized research plot sprayer equipped with four XR8002VS Teejet nozzles operated at a spray pressure of 275 KPa and height of 50 cm from the soil surface. Herbicide applications and associated weather conditions are provided in (Table 3.2).

Table 3.1. Herbicides evaluated for non-bearing year red sorrel management in wild blueberry fields.

Trade name	Active ingredient(s)	Applications rate(s) (g a.i. ha^{-1})
Control	Control	
Kerb	Propyzamide	2240
Velpar	Hexazinone	1920
Simplicity	Pyroxsulam	15
Spartan 4F	Sulfentrazone	280
Eragon	Saflufenacil	10
Ignite	Glufosinate	750
Alion	Indaziflam	74
Velpar+simplicity	Hexazinone+pyroxsulam	1920+15
Velpar+saflufenacil	Hexazinone+saflufenacil	1920+10
Velpar+ignite	Hexazinone+glufosinate	1920+750
Velpar+alion	Hexazinone+indaziflam	1920+74
Velpar+spartan 4F	Hexazinone+sulfentrazone	1920+50
Lontrel	Clopyralid	152

Table 3.2. Herbicide application dates and related weather conditions at each wild blueberry site in NS.

Site	Application timing	Date of treatment application	Temp (^{0}C)	Humidity (%)	Average wind speed (km h^{-1})
Sherbrooke	Autumn 2015[a]	12-Nov-2015	12.7	60	2.9
	Spring 2016	3-May-2016	10	74	2.6
East Mountain	Autumn 2015	12-Nov-2015	17.2	55	1.3
	Spring 2016	2-May-2016	18.8	47	2.3
Greenfield	Autumn 2015	9-Nov-2015	12.7	55	3.6
	Spring 2016	3-May-2016	23.8	33	1.3

[a] Propyzamide was applied in autumn 2015 and all other herbicides were applied in spring 2016.

3.2.3 Data collection

Data collection included initial vegetative red sorrel ramet density at each site prior to treatment applications, red sorrel vegetative and flowering ramet density in June and August of the non-bearing year and July of the bearing year, red sorrel vegetative ramet density in autumn of the non-bearing and spring of the bearing year, red sorrel seedling density in June and August of the non-bearing year, blueberry stem density, stem height, and floral bud number per stem in autumn of the non-bearing year, and harvestable blueberry fruit yield in August of the bearing year. Red sorrel ramet data were expressed as total ramet density (vegetative or vegetative + flowering) and flowering ramet density for analysis.

Red sorrel seedling density was determined in three 0.25 m x 0.25 m quadrats per plot and vegetative and flowering ramet density were determined in three 0.3 m x 0.3 m quadrats per plot. Blueberry stem density was determined in three 0.3 m x 0.3 m quadrats. Blueberry stem length and floral bud number were determined on 30 randomly selected blueberry stems in each plot. Stems were clipped at ground level in each plot, bagged in the field, and brought back to the laboratory for data collection. Harvestable blueberry yield was determined in two 1 m x 1 m quadrats per plot. All berries within the quadrat were harvested and cleaned in the field using wind to remove leaves. Yield data were not collected at East Mountain due to presence of wasps within the trial area. Red sorrel initial ramet density was collected on 5-Nov-2015, 12-Nov-2015, and 9-Nov-2015 at Sherbrooke, East Mountain, and Greenfield, respectively. Total ramet density was determined on 10-June-2016, 3-Aug-2016, and 18-Oct-2016 at Sherbrooke, 14-June-2016, 2-Aug-2016, and 12-Oct-2016 at East Mountain, 9-June-2016, 25-July-2016, and 18-Oct-2016 at Greenfield. Red sorrel seedling density was determined on 10-June-2016, 3-Aug-2016, and 17-Oct-2016 at Sherbrooke, 14-June-2016, 2-Aug-2016, and 12-Oct-2016 at East Mountain, 9-June-2016, 25-July-2016, and 18-Oct-2016 at Greenfield. Red sorrel flowering ramet density was determined on 10-June-2016 and 3-Aug-2016 at Sherbrooke, 14-June-2016 and 2-Aug-2016 at East Mountain, 9-June-2016 and 25-July-2016 at Green field. In the bearing year, vegetative red sorrel ramet density was determined on 25-May-2017, and red sorrel vegetative and flowering ramet density were determined at each site on 26-June-2017. Blueberry yield was determined on 8-Aug-2017 at Sherbrooke and Greenfield.

3.2.4 Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) in PROC MIXED in SAS system for windows (Statistical Analysis System, version 9.4, SAS Institute, Cary, NC). In the Mixed Model, treatments were used as fixed effects, while blocks within each trial were considered as random effects. The assumption of constant variance was tested to ensure that residuals had constant variance with a normal distribution. Data were LOG(Y) or SQRT(Y) transformed to achieve normality and constant variance where necessary. Significant differences among treatments were determined using Tukey's multiple means comparison test at a probability level of $P = 0.05$

3.3 Results and Discussion

Data were analyzed separately for each site due to differences in number of blocks and variation in initial ramet density across sites. Initial ramet density at East Mountain, Sherbrooke, and Greenfield did not vary across treatments ($P \geq 0.43$) and was 710 ± 88, 360 ± 92, and 340 ± 103 ramets m^{-2}, respectively. Total ramet density was significantly affected by herbicide treatment at each site ($p \leq 0.0001$). Hexazinone did not reduce total ramet density at any site in the non-bearing year (Tables 3.3, 3.4, and 3.5). Kennedy (2009) found that hexazinone reduced red sorrel ramet density in blueberry fields, and this weed species has historically been considered susceptible to hexazinone (Jensen 1985; Jensen and Specht 2002). Our results are, however, similar to typical responses of red sorrel to hexazinone reported by growers, but it is not clear if this response is due to presence of resistant biotypes (Li et al. 2014) or other factors. Propyzamide reduced total ramet density early in the season at Sherbrooke (Table 3.3) and reduced total ramet density throughout the growing season at Greenfield (Table 3.4). This herbicide was, however, ineffective at East Mountain (Table 3.5), potentially due to the higher air temperature at the time of propyzamide application at this site (Table 3.2). Hughes (2012) also found that propyzamide reduced above ground shoot growth of red sorrel, and our data further confirm general efficacy of this herbicide on red sorrel in wild blueberry.

Pyroxsulam and hexazinone+pyroxsulam reduced total ramet density early in the season at Sherbrooke (Table 3.3), though pyroxsulam was ineffective at Greenfield and East Mountain (Tables 3.4 and 3.5). Li (2013) indicated that hexazinone+pyoxsulam reduced goldenrod biomass by 93% whereas pyroxsulam was not effective, suggesting that there was synergy between these two products on this weed species. Our data, however, do not indicate similar synergy on red sorrel, and pyroxsulam appears to be ineffective on red sorrel.

Sulfentrazone and hexazinone+sulfentrazone reduced red sorrel density in June at East Mountain (Table 3.5), though sulfentrazone applied alone or in combination with hexazinone was generally ineffective at Sherbrooke and Greenfield (Tables 3.3 and 3.4). Li et al. (2014) also found that sulfentrazone did not affect broad leaf weeds and grasses and it was not an effective herbicide to control weeds in blueberry fields.

None of the other herbicides evaluated reduced total red sorrel ramet density in the non-bearing year (Tables 3.3, 3.4, and 3.5), indicating lack of effectiveness of these herbicides on red sorrel.

Table 3.3. Total red sorrel ramet density in various herbicide treatments applied preemergence to wild blueberry in spring of the non-bearing year at Sherbrooke, NS, Canada in 2016.

	Total ramet density (ramets m^{-2})		
Treatment	10 June[a]	3 August[b]	18 October[c]
Control	21.3 ± 2.3ab[d] (478)	23.0 ± 1.9a (541)	17.2 ± 2.0b (303)
Clopyralid	18.8 ± 2.3ab (365)	15.9 ± 1.9ab (276)	18.0 ± 2.0b (349)
Glufosinate ammonium	15.3 ± 2.3abc (271)	18.9 ± 1.9ab (365)	27.9 ± 2.0a (797)
Hexazinone	16.3 ± 2.3abc (302)	18.5 ± 1.9ab (380)	21.1 ± 2.0ab (473)
Hexazinone+pyroxsulam	10.2 ± 2.3c (154)	18.0 ± 1.9ab (352)	21.7 ± 2.0ab (197)
Hexazinone+saflufenacil	18.6 ± 2.3a (353)	19.3 ± 1.9ab (381)	25.0 ± 2.0ab (631)
Hexazinone+glufosinate ammonium	15.9 ± 2.3abc (282)	19.3 ± 1.9ab (397)	23.2 ± 2.0ab (566)
Hexazinone+indaziflam	17.6 ± 2.3abc (332)	19.6 ± 1.9ab (390)	23.1 ± 2.0ab (537)
Hexazinone+sulfentrazone	15.7 ± 2.3abc (263)	16.0 ± 1.9ab (271)	22.9 ± 2.0ab (548)
Indaziflam	17.3 ± 2.3abc (310)	17.5 ± 1.9ab (322)	20.0 ± 2.0ab (419)
Pyroxsulam	13.3 ± 2.3bc (194)	13.4 ± 1.9b (194)	19.5 ± 2.0ab (414)
Propyzamide	13.0 ± 2.3bc (178)	15.9 ± 1.9ab (266)	19.6 ± 2.0ab (412)
Saflufenacil	22.0 ± 2.3a (517)	21.0 ± 1.9ab (448)	21.2 ± 2.0ab (462)
Sulfentrazone	15.0 ± 2.3abc (234)	15.4 ± 1.9ab (248)	20.1 ± 2.0ab (413)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.4. Total red sorrel ramet density in various herbicide treatments applied preemergence to wild blueberry in spring of the non-bearing year at Greenfield, NS, Canada in 2016.

	Total ramet density (ramets m^{-2})		
Treatment	9 June[a]	25 July[b]	18 October[c]
Control	5.2 ± 0.3a[d] (264)	5.5 ± 0.2a (269)	5.9 ± 0.1a (398)
Clopyralid	5.7 ± 0.3a (307)	5.1 ± 0.2abc (185)	5.7 ± 0.1a (314)
Glufosinate ammonium	5.2 ± 0.3a (203)	4.9 ± 0.2abc (141)	5.4 ± 0.1ab (254)
Hexazinone	5.0 ± 0.3a (241)	5.1 ± 0.2abc (189)	5.5 ± 0.1ab (298)
Hexazinone+pyroxsulam	4.9 ± 0.3ab (173)	4.9 ± 0.2abc (172)	5.4 ± 0.1ab (272)
Hexazinone+saflufenacil	5.1 ± 0.3ab (175)	4.9 ± 0.2abc (162)	5.5 ± 0.1a (295)
Hexazinone+glufosinate ammonium	5.1 ± 0.3ab (173)	4.8 ± 0.2abcd (141)	5.3 ± 0.1ab (233)
Hexazinone+indaziflam	4.8 ± 0.3ab (137)	4.4 ± 0.2bcd (95)	5.0 ± 0.1ab (197)
Hexazinone+sulfentrazone	4.9 ± 0.3ab (156)	4.1 ± 0.2cd (71)	5.2 ± 0.1ab (208)
Indaziflam	5.5 ± 0.3a (308)	5.2 ± 0.2ab (214)	5.5 ± 0.1ab (283)
Pyroxsulam	5.0 ± 0.3ab (172)	4.8 ± 0.2abc (148)	5.4 ± 0.1ab (234)
Propyzamide	3.7 ± 0.3b (43)	4.9 ± 0.2d (50)	4.6 ± 0.1b (106)
Saflufenacil	5.2 ± 0.3ab (225)	5.2 ± 0.2abc (196)	5.6 ± 0.1a (279)
Sulfentrazone	4.9 ± 0.3ab (188)	4.8 ± 0.2abc (155)	5.5 ± 0.1ab (283)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.5. Total red sorrel ramet density in various herbicide treatments applied preemergence to wild blueberry in spring of the non-bearing year at East Mountain, NS, Canada in 2016.

Treatment	Total ramet density (ramets m^{-2})		
	14 June[a]	2 August[b]	12 October[c]
Control	24.9 ± 2.2a[d] (631)	23.2 ± 2.7a (562)	27.5 ± 3.5a (831)
Clopyralid	23.0 ± 2.2ab (548)	26.1 ± 2.7a (723)	27.7 ± 3.5a (799)
Glufosinate ammonium	21.6 ± 2.2abc (484)	23.4 ± 2.7a (574)	23.5 ± 3.5a (609)
Hexazinone	20.8 ± 2.2abc (445)	20.1 ± 2.7a (411)	28.2 ± 3.5a (822)
Hexazinone+pyroxsulam	17.3 ± 2.2abc (310)	22.8 ± 2.7a (641)	27.7 ± 3.5a (923)
Hexazinone+saflufenacil	21.0 ± 2.2abc (471)	22.9 ± 2.7a (583)	30.2 ± 3.5a (934)
Hexazinone+glufosinate ammonium	21.6 ± 2.2abc (524)	25.2 ± 2.7a (682)	33.4 ± 3.5a (1177)
Hexazinone+indaziflam	19.9 ± 2.2abc (447)	19.1 ± 2.7a (368)	23.3 ± 3.5a (588)
Hexazinone+sulfentrazone	13.7 ± 2.2bc (206)	16.6 ± 2.7a (284)	22.7 ± 3.5a (534)
Indaziflam	22.4 ± 2.2ab (533)	21.8 ± 2.7a (491)	26.8 ± 3.5a (757)
Propyzamide	24.3 ± 2.2a (612)	26.8 ± 2.7a (751)	33.9 ± 3.5a (1215)
Pyroxsulam	18.1 ± 2.2abc (341)	20.7 ± 2.7a (477)	24.3 ± 3.5a (665)
Saflufenacil	21.9 ± 2.2abc (489)	21.8 ± 2.7 a (491)	31.1 ± 3.5a (987)
Sulfentrazone	12.0 ± 2.2c (148)	17.1 ± 2.7a (294)	24.9 ± 3.5a (650)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey’s mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

There was a significant effect of herbicide treatment on red sorrel flowering ramet density in the non-bearing year at Sherbrooke and Greenfield (p =0.0181) but not East Mountain (p = 0.13. Hexazinone did not reduce flowering ramet density (Tables 3.6, 3.7, and 3.8), further confirming lack of hexazinone efficacy on red sorrel under field conditions. Propyzamide reduced flowering ramet density at Sherbrooke and Greenfield (Tables 3.6 and 3.7), and these results reflect the reduction in total ramet density caused by propyzamide at these sites. When effective, propyzamide therefore reduces ramet density, but likely contributes to reduced seed bank as well due to reductions in flowering ramet density. Pyroxsulam caused enough injury to reduce flowering ramet density at Sherbrooke and Greenfield (Tables 3.6 and 3.7), but not at East Mountain (Table 3.8), and tank mixture with hexazinone did not improve efficacy. Eriavbe (2015) found that pyroxsulam caused about 30% injury of hawkweed rosettes and visual observation indicated this herbicide inhibited flower bud development as well. Sulfentrazone and glufosinate caused enough injury to reduce flowering ramet density at Sherbrooke (Table 3.6), with glufosinate injury also reducing flowering ramet density early in the season at Greenfield (Table 3.7). Tank mixture of these herbicides with hexazinone did not generally improve efficacy (Tables 3.6, 3.7, and 3.8), though flowering density was reduced early in the season by the hexazinone+sulfentrazone tank mixture at Greenfield (Table 3.7). Indaziflam and hexazinone+indaziflam reduced flowering ramet density late in the season at Sherbrooke (Table 3.6), with the indaziflam+hexazinone tank mixture also reducing flowering ramet density early in the season at Greenfield (Table3.7). Indaziflam may therefore have some efficacy on red sorrel, though results of this research indicate this efficacy is inconsistent across sites. Saflufenacil and clopyralid did not reduce flowering ramet density (Tables

3.6, 3.7, and 3.8), and these results are consistent with lack of total ramet reductions from these herbicides as well (Tables 3.3, 3.4, and 3.5).

Table 3.6. Red sorrel flowering ramet density in various herbicide treatments applied pre-emergence to wild blueberry in the non-bearing year at Sherbrooke, NS, Canada in 2016.

Treatment	Flowering ramet density (ramets m^{-2})	
	10 June[a]	3 August[b]
Control	15.8 ± 2.2a[c] (262)	19.4 ± 1.6a (382)
Clopyralid	10.5 ± 2.2abcd (142)	11.4 ± 1.6bc (154)
Glufosinate ammonium	3.7 ± 2.2bcde (19)	8.1 ± 1.6bc (67)
Hexazinone	8.5 ± 2.2abcd (109)	12.8 ± 1.6ab (188)
Hexazinone+pyroxsulam	1.2 ± 2.2e (0)	5.2 ± 1.6bc (42)
Hexazinone+saflufenacil	7.8 ± 2.2abcde (88)	10.2 ± 1.6abc (111)
Hexazinone+glufosinate ammonium	2.7 ± 2.2de (11)	8.1 ± 1.6bc (42)
Hexazinone+Indaziflam	12.0 ± 2.2ab (165)	12.1 ± 1.6b (165)
Hexazinone+Sulfentrazone	5.2 ± 2.2abcde (40)	7.4 ± 1.6bc (77)
Indaziflam	9.4 ± 2.2abcd (111)	10.1 ± 1.6bc (118)
Propyzamide	1.3 ± 2.2e (1)	6.8 ± 1.6bc (47)
Pyroxsulam	1.5 ± 2.2e (2)	5.2 ± 1.6c (28)
Saflufenacil	14.7 ± 2.2abc (298)	13.3 ± 1.6ab (191)
Sulfentrazone	3.6 ± 2.2cde (22)	7.4 ± 1.6bc (72)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.7. Red sorrel flowering ramet density in various herbicide treatments applied pre-emergence to wild blueberry in the non-bearing year at Greenfield, NS, Canada in 2016.

	Flowering density (ramets m^{-2})	
Treatment	9 June[a]	25 July[b]
Control	3.2 ± 0.5ab[c] (60)	4.2 ± 0.4ab (85)
Clopyralid	3.0 ± 0.5abc (43)	4.1 ± 0.4ab (70)
Glufosinate ammonium	0.5 ± 0.5bc (1)	2.4 ± 0.4ab (21)
Hexazinone	3.4 ± 0.5a (53)	4.5 ± 0.4a (103)
Hexazinone+pyroxsulam	1.1 ± 0.5abc (6)	3.9 ± 0.4ab (85)
Hexazinone+saflufenacil	0.8 ± 0.5abc (2)	3.4 ± 0.4ab (43)
Hexazinone+glufosinate ammonium	1.0 ± 0.5abc (4)	3.3 ± 0.4ab (46)
Hexazinone+indaziflam	0.6 ± 0.5bc (1)	3.1 ± 0.4ab (37)
Hexazinone+sulfentrazone	0.2 ± 0.5c (0)	2.6 ± 0.4ab (85)
Indaziflam	2.5 ± 0.5abc (42)	3.7 ± 0.4ab (53)
Pyroxsulam	0.4 ± 0.5bc (1)	3.2 ± 0.4ab (43)
Propyzamide	0.2 ± 0.5c (0)	2.1 ± 0.4b (19)
Saflufenacil	2.0 ± 0.5abc (17)	4.0 ± 0.4ab (69)
Sulfentrazone	2.6 ± 0.5abc (53)	3.7 ± 0.4ab (63)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.8. Red sorrel flowering ramet density in various herbicide treatments applied pre-emergence to wild blueberry in the non-bearing year at East Mountain, NS, Canada in 2016.

	Flowering density (ramets m^{-2})	
Treatment	14 June[a]	2 August[b]
Control	10.5 ± 2.6a[c] (134)	11.9 ± 1.0a (143)
Clopyralid	10.3 ± 2.6a (131)	11.9 ± 1.0a (143)
Glufosinate ammonium	5.7 ± 2.6a (40)	11.9 ± 1.0a (146)
Hexazinone	11.0 ± 2.6a (131)	12.4 ± 1.0a (156)
Hexazinone+pyroxsulam	3.7 ± 2.6a (22)	8.3 ± 1.0a (71)
Hexazinone+saflufenacil	12.8 ± 2.6a (206)	11.7 ± 1.0a (140)
Hexazinone+glufosinate ammonium	6.4 ± 2.6a (86)	11.6 ± 1.0a (140)
Hexazinone+indaziflam	9.3 ± 2.6a (194)	13.3 ± 1.0a (177)
Hexazinone+sulfentrazone	7.2 ± 2.6a (73)	10.5 ± 1.0a (115)
Indaziflam	10.9 ± 2.6a (151)	12.6 ± 1.0a (160)
Propyzamide	11.1 ± 2.6a (171)	11.9 ± 1.0a (153)
Pyroxsulam	2.5 ± 2.6a (9)	9.1 ± 1.0a (89)
Saflufenacil	7.8 ± 2.6a (67)	11.2 ± 1.0a (128)
Sulfentrazone	5.0 ± 2.6a (28)	12.2 ± 1.0a (153)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Red sorrel seedling density was significantly affected by herbicide treatment at each site ($P \leq 0.0001$). Hexazinone reduced seedling density in July and October at Greenfield (Table 3.10), indicating that hexazinone may provide control red sorrel seedlings, but not established plants, at some sites. This may also partially explain the generally high hexazinone efficacy on red sorrel in the greenhouse resistance screening experiment. Hexazinone+pyroxsulam, hexazinone+glufosinate, hexazinone+indaziflam and hexazinone+sulfentrazone also reduced seedling density in July and October, indicating that hexazinone used as a component of spring herbicide tank mixtures may contribute to red sorrel management through residual control of seedlings. Propyzamide reduced seedling density throughout the non-bearing year at Greenfield (Table 3.10). Pyroxsulam, glufosinate, sulfentrazone, and clopyralid reduced seedling density in July and October as well (Table 3.10) indicating potential residual activity from these herbicides in lowbush blueberry fields.

While sulfentrazone appears promising for management of red sorrel seedlings in wild blueberry fields, results are inconsistent across sites and additional research is required to assess potential of this herbicide in wild blueberry. None of the other treatments evaluated appear to contribute to red sorrel seedling reduction in wild blueberry fields.

Table 3.9. Red sorrel seedling density in various herbicide treatments applied pre-emergence to wild blueberry in the non-bearing year at Sherbrooke, NS, Canada in 2016.

	Seedling density (seedlings m^{-2})		
Treatment	10 June[a]	3 August[b]	17 October[c]
Control	6.5 ± 2.0a[d] (55)	3.6 ± 0.5a (38)	2.2 ± 0.6a (6)
Clopyralid	5.7 ± 2.0a (60)	1.7 ± 0.5ab (17)	1.0 ± 0.6a (0)
Glufosinate ammonium	2.7 ± 2.0a (9)	1.6 ± 0.5ab (6)	2.8 ± 0.6a (14)
Hexazinone	3.1 ± 2.0a (16)	2.2 ± 0.5ab (9)	1.0 ± 0.6a (0)
Hexazinone+pyroxsulam	7.7 ± 2.0a (85)	1.2 ± 0.5ab (4)	1.6 ± 0.6a (3)
Hexazinone+saflufenacil	4.1 ± 2.0a (21)	1.3 ± 0.5ab (5)	2.7 ± 0.6a (7)
Hexazinone+glufosinate ammonium	7.5 ± 2.0a (108)	2.0 ± 0.5ab (11)	1.7 ± 0.6a (3)
Hexazinone+indaziflam	2.2 ± 2.0a (5)	0.9 ± 0.5ab (4)	1.4 ± 0.6a (2)
Hexazinone+sulfentrazone	2.6 ± 2.0a (8)	1.8 ± 0.5ab (5)	2.4 ± 0.6a (7)
Indaziflam	2.7 ± 2.0a (9)	1.1 ± 0.5ab (3)	1.6 ± 0.6a (2)
Propyzamide	5.7 ± 2.0a (70)	1.8 ± 0.5ab (13)	1.0 ± 0.6a (0)
Pyroxsulam	3.9 ± 2.0a (24)	12 ± 0.5ab (12)	2.7 ± 0.6a (9)
Saflufenacil	6.8 ± 2.0a (89)	1.9 ± 0.5ab (17)	1.4 ± 0.6a (2)
Sulfentrazone	2.9 ± 2.0a (10)	0.7 ± 0.5b (2)	2.7 ± 0.6a (7)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.10. Red sorrel seedling density in various herbicide treatments applied pre-emergence to wild blueberry in the non-bearing year at Greenfield, NS, Canada in 2016.

	Seedling density (seedlings m^{-2})		
Treatment	9 June[a]	25 July[b]	18 October[c]
Control	2.8 ± 0.5ab[d] (27)	4.4 ± 0.4a (107)	4.6 ± 0.4a (21)
Clopyralid	2.2 ± 0.5ab (14)	2.4 ± 0.4ab (11)	1.5 ± 0.4b (1)
Glufosinate ammonium	2.6 ± 0.5ab (24)	1.7 ± 0.4b (17)	1.8 ± 0.4b (3)
Hexazinone	3.3 ± 0.5a (43)	2.1 ± 0.4b (20)	1.6 ± 0.4b (3)
Hexazinone+pyroxsulam	2.3 ± 0.5ab (19)	1.0 ± 0.4b (3)	2.1 ± 0.4b (5)
Hexazinone+saflufenacil	2.3 ± 0.5ab (18)	2.4 ± 0.4ab (11)	2.1 ± 0.4ab (5)
Hexazinone+glufosinate Ammonium	2.4 ± 0.5ab (11)	1.9 ± 0.4b (17)	1.5 ± 0.4b (1)
Hexazinone+indaziflam	1.5 ± 0.5ab (8)	0.7 ± 0.4b (2)	1.9 ± 0.4b (3)
Hexazinone+sulfentrazone	1.2 ± 0.5ab (6)	0.7 ± 0.4b (2)	1.5 ± 0.4b (1)
Indaziflam	3.0 ± 0.5ab (27)	2.6 ± 0.4ab (2)	2.1 ± 0.4ab (5)
Propyzamide	0.5 ± 0.5b (4)	1.3 ± 0.4b (9)	1.9 ± 0.4b (3)
Pyroxsulam	2.5 ± 0.5ab (23)	1.2 ± 0.4b (6)	1.6 ± 0.4b (2)
Saflufenacil	1.8 ± 0.5ab (12)	2.8 ± 0.4ab (17)	2.5 ± 0.4ab (6)
Sulfentrazone	1.7 ± 0.5ab (10)	1.8 ± 0.4b (8)	2.4 ± 0.4ab (6)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.11. Red sorrel seedling density in various herbicide treatments applied pre-emergence to wild blueberry in the non-bearing year at East Mountain, NS, Canada in 2016.

	Seedling density (seedlings m^{-2})		
Treatment	14 June[a]	2 August[b]	12 October[c]
Control	6.9 ± 0.5a[d] (1138)	16.6 ± 1.9a (286)	3.2 ± 0.5a (78)
Clopyralid	6.6 ± 0.5a (1172)	8.8 ± 1.9a (90)	3.2 ± 0.5a (27)
Glufosinate ammonium	6.2 ± 0.5a (601)	7.3 ± 1.9a (64)	3.1 ± 0.5a (27)
Hexazinone	6.2 ± 0.5a (994)	9.1 ± 1.9a (94)	3.9 ± 0.5a (57)
Hexazinone+pyroxsulam	5.8 ± 0.5a (791)	11.2 ± 1.9a (192)	3.5 ± 0.5a (52)
Hexazinone+saflufenacil	5.2 ± 0.5ab (405)	8.7 ± 1.9a (77)	4.0 ± 0.5a (57)
Hexazinone+glufosinate ammonium	5.9 ± 0.5a (624)	9.2 ± 1.9a (99)	3.8 ± 0.5a (48)
Hexazinone+indaziflam	5.0 ± 0.5ab (178)	8.2 ± 1.9a (77)	2.1 ± 0.5a (12)
Hexazinone+sulfentrazone	3.4 ± 0.5b (61)	8.6 ± 1.9a (93)	3.2 ± 0.5a (33)
Indaziflam	5.4 ± 0.5ab (339)	8.4 ± 1.9a (81)	1.8 ± 0.5a (13)
Propyzamide	6.2 ± 0.5a (680)	9.0 ± 1.9a (88)	3.9 ± 0.5a (61)
Pyroxsulam	5.4 ± 0.5ab (664)	10.7 ± 1.9a (129)	2.7 ± 0.5a (27)
Saflufenacil	6.1 ± 0.5a (664)	10.5 ± 1.9a (112)	3.5 ± 0.5a (38)
Sulfentrazone	4.9 ± 0.5ab (304)	9.8 ± 1.9a (113)	4.3 ± 0.5a (102)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d]Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

There was a significant herbicide treatment effect on overwintered ramet density in the bearing year at Sherbrooke ($p \leq 0.0143$) and Greenfield ($p \leq 0.0059$) but not East Mountain ($p = 0.3825$). There was, however, no significant effect of herbicide treatment on vegetative and flowering ramet densities across sites. Red sorrel recovered in the propyzamide treatment at Sherbrooke (Table 3.12) but continued to be suppressed by this herbicide early in the bearing year at Greenfield (Table 3.13). Overwintered ramet density was reduced by pyroxsulam at Sherbrooke and Greenfield, though red sorrel recovered in this treatment later in the bearing year (Tables 3.12 and 3.13). Hexazinone+glufosinate, hexazinone+indaziflam, and hexazinone+sulfentrazone also reduced overwintering ramet density at Greenfield (Table 3.13). Overall, these results indicate that, while some herbicides reduced non-bearing year red sorrel density, few maintained suppression of this weed into the bearing year. Further studies are therefore needed to determine the optimum spring non-bearing year red sorrel management strategies in wild blueberry fields.

Table 3.12. Overwintered, vegetative, and flowering red sorrel ramet density in the bearing year at Sherbrooke, NS, Canada in 2017.

Treatment	Overwintered ramet density (ramets m^{-2})[a]	Vegetative ramet density (ramets m^{-2})[b]	Flowering ramet density (ramets m^{-2})[c]
Control	18.1 ± 1.8a[d] (328)	4.5 ± 0.1a (97)	4.7 ± 0.2a (122)
Clopyralid	11.3 ± 1.8ab (169)	4.5 ± 0.1a (94)	4.7 ± 0.2a (135)
Glufosinate ammonium	15.7 ± 1.8ab (266)	4.6 ± 0.1a (109)	5.3 ± 0.2a (250)
Hexazinone	14.4 ± 1.8ab (288)	4.5 ± 0.1a (94)	5.3 ± 0.2a (224)
Hexazinone+pyroxsulam	14.0 ± 1.8ab (205)	4.6 ± 0.1a (106)	5.2 ± 0.2a (202)
Hexazinone+saflufenacil	15.5 ± 1.8a (242)	4.7 ± 0.1a (123)	5.3 ± 0.2a (214)
Hexazinone+glufosinate ammonium	13.1 ± 1.8ab (179)	4.6 ± 0.1a (117)	5.1 ± 0.2a (180)
Hexazinone+indaziflam	16.5 ± 1.8a (288)	4.8 ± 0.1a (124)	5.1 ± 0.2a (200)
Hexazinone+sulfentrazone	15.5 ± 1.8ab (260)	4.7 ± 0.1a (122)	5.3 ± 0.2a (229)
Indaziflam	12.6 ± 1.8ab (162)	4.7 ± 0.1a (125)	5.1 ± 0.2a (174)
Propyzamide	12.1 ± 1.8ab (154)	4.6 ± 0.1a (117)	4.8 ± 0.2a (140)
Pyroxsulam	7.7 ± 1.8b (73)	4.4 ± 0.1a (98)	4.7 ± 0.2a (128)
Saflufenacil	14.0 ± 1.8ab (202)	4.5 ± 0.1a (97)	4.7 ± 0.2a (170)
Sulfentrazone	14.5 ± 1.8ab (228)	4.3 ± 0.1a (85)	4.8 ± 0.2a (134)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.13. Overwintered, vegetative, and flowering red sorrel ramet density in the bearing year at Greenfield, NS, Canada in 2017.

Treatment	Overwintered ramet density (ramets m^{-2})[a]	Vegetative ramet density (ramets m^{-2})[b]	Flowering ramet density (ramets m^{-2})[c]
Control	5.8 ± 0.3a[d] (348)	4.8 ± 0.1a (146)	4.5 ± 0.3a (149)
Clopyralid	4.6 ± 0.3abc (124)	4.7 ± 0.1a (121)	3.8 ± 0.3a (62)
Glufosinate ammonium	4.6 ± 0.3abc (124)	4.9 ± 0.1a (148)	4.5 ± 0.3a (100)
Hexazinone	4.7 ± 0.3abc (128)	4.8 ± 0.1a (152)	4.4 ± 0.3a (112)
Hexazinone+pyroxsulam	5.0 ± 0.3ab (163)	4.7 ± 0.1a (120)	4.7 ± 0.3a (141)
Hexazinone+saflufenacil	4.7 ± 0.3abc (127)	4.6 ± 0.1a (116)	4.5 ± 0.3a (129)
Hexazinone+glufosinate ammonium	4.2 ± 0.3bc (100)	4.8 ± 0.1a (139)	4.5 ± 0.3a (101)
Hexazinone+indaziflam	4.0 ± 0.3bc (74)	4.9 ± 0.1a (85)	3.5 ± 0.3a (64)
Hexazinone+sulfentrazone	4.4 ± 0.3bc (104)	4.6 ± 0.1a (112)	4.4 ± 0.3a (94)
Indaziflam	4.5 ± 0.3abc (101)	4.9 ± 0.1a (154)	4.2 ± 0.3a (74)
Propyzamide	3.5 ± 0.3c (46)	4.5 ± 0.1a (96)	3.4 ± 0.3a (36)
Pyroxsulam	4.0 ± 0.3bc (64)	4.7 ± 0.1a (76)	3.2 ± 0.3a (46)
Saflufenacil	4.4 ± 0.3abc (111)	4.8 ± 0.1a (137)	4.0 ± 0.3a (72)
Sulfentrazone	4.5 ± 0.3abc (112)	4.8 ± 0.1a (130)	4.6 ± 0.3a (104)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 3.14. Overwintered, vegetative, and flowering red sorrel ramet density in the bearing year at East Mountain, NS, Canada in 2017.

Treatment	Overwintered ramet density (ramets m^{-2})[a]	Vegetative ramet density (ramets m^{-2})[b]	Flowering ramet density (ramets m^{-2})[c]
Control	6.0 ± 0.2a[d] (477)	4.5 ± 0.1a (98)	5.1 ± 0.1a (182)
Clopyralid	5.8 ± 0.2a (360)	4.6 ± 0.1a (102)	5.1 ± 0.1a (168)
Glufosinate ammonium	5.9 ± 0.2a (380)	4.2 ± 0.1a (76)	5.3 ± 0.1a (228)
Hexazinone	5.9 ± 0.2a (384)	4.4 ± 0.1a (85)	5.3 ± 0.1a (214)
Hexazinone+pyroxsulam	5.8 ± 0.2a (372)	4.5 ± 0.1a (103)	5.1 ± 0.1a (186)
Hexazinone+saflufenacil	6.3 ± 0.2a (608)	4.4 ± 0.1a (94)	5.7 ± 0.1a (314)
Hexazinone+glufosinate ammonium	6.0 ± 0.2a (474)	4.4 ± 0.1a (88)	5.3 ± 0.1a (227)
Hexazinone+indaziflam	6.2 ± 0.2a (556)	4.6 ± 0.1a (108)	5.6 ± 0.1a (299)
Hexazinone+sulfentrazone	6.0 ± 0.2a (434)	4.2 ± 0.1a (74)	5.4 ± 0.1a (248)
Indaziflam	6.1 ± 0.2a (525)	4.5 ± 0.1a (94)	5.2 ± 0.1a (235)
Propyzamide	6.1 ± 0.2a (488)	4.4 ± 0.1a (97)	5.4 ± 0.1a (238)
Pyroxsulam	5.7 ± 0.2a (369)	4.5 ± 0.1a (94)	5.2 ± 0.1a (218)
Saflufenacil	5.7 ± 0.2a (314)	4.4 ± 0.1a (91)	5.3 ± 0.1a (223)
Sulfentrazone	5.7 ± 0.2a (402)	4.3 ± 0.1a (80)	5.2 ± 0.1a (214)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Herbicide applications did not have significant effects on blueberry stem density ($P \geq= 0.63$), stem height ($P = 0.50$), flower bud density ($P = 0.42$), and blueberry yield ($P = 0.95$) at any site. Blueberry stem density averaged 296 ± 49 stems m^{-2}, 601 ± 63 stems m^{-2}, and 239 ± 42 stems m^{-2} at Sherbrooke, Greenfield, and East Mountain, respectively. Blueberry stem height averaged 16.3 ± 0.4 cm, 15.5 ± 0.6 cm, and 15.9 ± 1.8 cm at Sherbrooke, Greenfield, and East Mountain, respectively. Blueberry floral bud numbers average 4.3 ± 0.2 buds $stem^{-1}$, 4.7 ± 0.1 buds $stem^{-1}$, and 4.1 ± 0.4 buds $stem^{-1}$ at Sherbrooke, Greenfield, and East Mountain, respectively. Blueberry yield averaged 3410 ± 779.2 kg ha^{-1} and 5090.4 ± 633.6 kg ha^{-1} at Sherbrooke and Greenfield, respectively. Treatments evaluated did not cause blueberry injury and did not affect blueberry yield. The lack of density, flower bud or yield increases may be due to incomplete control of red sorrel from most of the treatments. Red sorrel is suspected to be competitive with wild blueberry as Kennedy et al. (2010) found that reduction in red sorrel density following hexazinone application increased yield.

3.4 Conclusion

From this study it can be concluded that all the herbicide applications evaluated did not affect blueberry density, plant height, floral buds, and yield. Propyzamide was the most effective herbicide evaluated for non-bearing year control of red sorrel in blueberry fields. Propyzamide reduced total ramet, seedling, and flowering ramet density in Greenfield and Sherbrooke in the non-bearing year and reduced over-wintered ramet density at Greenfield in the bearing year. Seedling and flowering density recovered in bearing year in this treatment, however, at Sherbrooke and East Mountain.

Pyroxsulam and hexazinone+pyroxsulam reduced total ramet density initially at Sherbrooke, and sulfentrazone and hexazinone+sulfentrazone reduced total ramet density initially at East Mountain. Red sorrel recovered in these treatments, however, and density increased in the non-bearing year. Pyroxsulam and glufosinate reduced flowering ramet density throughout the non-bearing year and densities increased in the bearing year at Shrebrooke and Greenfield, whereas in Greenfield hexazinone+indaziflam, hexazinone+sulfentrazone, pyroxsulam and glufosinate ammonium reduced red sorrel flowering ramet density initially and densities recovered in the non-bearing year. Herbicides evaluated in this study, therefore, did not provide adequate control of red sorrel in wild blueberry following spring applications. Additional spring-applied herbicides should be evaluated for non-bearing year red sorrel suppression in wild blueberry.

Chapter 4.0 Evaluation of autumn herbicide applications for red sorrel (*Rumex acetosella* L.) management in wild blueberry (*Vaccinium angustifolium* Ait.) fields.

4.1 Introduction

Wild blueberry (*Vaccinium augustifolium* Ait.) is an important fruit crop in Nova Scotia, Canada, contributing more than $34 million to the farm gate value in 2014 (Government of Canada. 2015). Wild blueberry is unique from other crops in that it is not planted but is developed and managed from natural stands (McIssac 1997). The crop is managed under a 2-year production cycle where the shoots are pruned to ground level in the first year (non-bearing year), and the shoots flower and produce berries in the second year (bearing year) (Wood 2004). Weeds compete with wild blueberries, decrease blueberry yield and quality, and also inhibit harvest operations.

Red sorrel is a dioecious, creeping herbaceous perennial plant found as a weed in wild blueberry fields in Atlantic Canada (McCully et al. 1991). It reproduces vegetatively from creeping roots (Escarre et al. 1994) and sexually through seeds (Putwain et al. 1968). Both seeds and ramets can contribute to an increase in population size (Putwain et al. 1968), but established populations in wild blueberry fields are maintained predominantly by vegetative reproduction of ramets from the creeping root system (White et al. 2014a). New ramets emerge throughout the growing season (White et al. 2014), with net ramet populations peaking in autumn (White et al. 2015). New ramets emerging within a given season, however, remain as vegetative rosettes due to a vernalization requirement for flowering (White et al. 2015). As such, flowering occurs primarily in overwintered ramets in wild blueberry fields (White et al. 2014), with an opportunity for reducing flowering ramet density in subsequent years through management of peak ramet populations in autumn. In addition, perennial weeds generally transport carbohydrates to the roots in autumn before winter dormancy (Becker and Fawcett 1998), providing an opportunity for symplastic herbicide movement to the roots with the products of photosynthesis (Bhowmik 1997).

The objective of this research was to evaluate autumn herbicide applications for red sorrel management in wild blueberry fields. I hypothesized that i) control of ramets prior to overwintering with herbicides will reduce flowering ramet density in the following year, and ii) that application of symplastic herbicides in autumn would reduce total ramet density in the following year.

4.2 Materials and Methods

4.2.2 Experimental Design

This experiment was established in autumn of 2015 in pruned wild blueberry fields at Rawdon ($45^05'13.95"$N; $63^042'50.60"$W), Greenfield ($45^020'48"$N; $63^050'45"$W), and Stewiacke ($45^016'18.68"$N; $63^04'36.49"$W), Nova Scotia. The experimental design was a randomized complete block design with five blocks in Rawdon and four blocks in Greenfield and Stewiacke. Plot size was 2 m x 6 m, and the experiment consisted of 14 treatments at each site (Table 4.1). Herbicides were applied using a CO_2 pressurized research plot sprayer equipped with four XR8002VS Tee jet nozzles operated at a spray pressure of 275 KPa. Herbicide application dates and weather conditions during application are provided in (Table 4.2).

Table 4.1. Herbicides evaluated and applied in autumn for red sorrel management in pruned wild blueberry fields.

Herbicide treatment	Active ingredient(s)	Application rate(s) g a.i. or a.e. ha^{-1}
Control	-	-
Kerb (as industry standard)	Propyzamide	2240
Ignite	Glufosinate	750
Banvel	Dicamba	2200
Chateau	Flumioxazin	140
Chateau + Velpar	Flumioxazin + hexazinone	140 + 1920
Spartan[a]	Tribenuron methyl	30
RoundUp WeatherMax	Glyphosate	1800
Lontrel	Clopyralid	150
Ultim[a]	Nicosulfuron+rimsulfuron	13 + 13
Simplicity[a]	Pyroxsulam	15
Casoron	Dichlobenil	7,000
Distinct[a]	Dicamba + diflufenzopyr	143 + 57
Spartan 4F	Sulfentrazone	280

[a] Spartan, Ultim, Simplicity, and Distinct were applied in conjunction with a non-ionic surfactant at 0.2% v/v basis.

Table 4.2. Herbicide application dates and related weather conditions at each site.

Site	Application timing	Date of treatment of application	Temp (^{0}C)	Humidity (%)	Average wind speed (km h^{-1})
Rawdon	Autumn 2015	19-Nov-2015	5.5	66.0	2.2
	Spring 2016	26-May-2016	18.4	66.5	2.4
Greenfield	Autumn 2015	29-Nov-2015	4.8	56.0	3.2
	Spring 2016	26-May-2016	18.8	62.0	2.3
Stewiacke	Autumn 2015	19-Nov-2015	5.4	66.0	2.2
	Spring 2016	26-May-2016	23.2	63.2	1.6

4.2.3 Data collection

Data collection included initial vegetative red sorrel ramet density at each site prior to treatment applications, overwintered ramet density in April of the non-bearing year, red sorrel vegetative and flowering ramet density in June and July of the non-bearing year and June of the bearing year, red sorrel seedling density in June, July, and October of the non-bearing year, and harvestable blueberry fruit yield in August of the bearing year. Ramet data were expressed as total ramet density (vegetative or vegetative + flowering) on each counting date for analysis.

Red sorrel seedling density was determined in three 0.25 m x 0.25 m quadrats per plot and vegetative and flowering ramet density were determined in three 0.3 m x 0.3 m quadrats per plot. Blueberry stem density was determined in three 0.3 m x 0.3 m quadrats in autumn of the non-bearing year. Blueberry stem length and floral bud number were determined on 30 randomly selected blueberry stems in each plot in autumn of the non-bearing year. Stems were clipped at ground level in each plot, bagged in the field, and brought back to the laboratory for data collection. Harvestable blueberry yield was determined in two 1 m x 1 m quadrats per plot in late summer of the bearing year using hand rakes. All berries within the quadrat were harvested and cleaned in the field using wind to remove leaves. Final yield data were not collected at Rawdon due to the field being mowed by the grower on 1-Oct-2016. Red sorrel initial ramet density was determined on 30-Oct-2015, 12-Nov-2015 and 5-Nov-2015 at Rawdon, Greenfield, and Stewiacke respectively. Total ramet density was determined on 10-June-2016, 19-July-2016 and 3-Oct-2016 at Rawdon, 9-June-2016, 28-July-2016 and 19-Oct-2016 at Greenfield, 9-June-2016, 28-July-2016 and 28-Oct-2016 at Stewiacke. Red sorrel flowering density was determined on 10-June-2016 and 19-July-2016 at Rawdon, 9-June-2016 and 28-July-2016 at Greenfield, 9-June-2016 and 28-July-2016 at Stewiacke. In bearing year, red sorrel ramet density was determined on 23-May-2017 at each site, and red sorrel vegetative and flowering ramet density were determined at each site on 19-June-2017 at Rawdon and 23-June-2016 at Greenfield and Stewiacke. Blueberry yield was determined on 3-Aug-2017 at Greenfield and Stewiacke.

4.2.4 Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) in PROC MIXED in SAS for windows (Statistical Analysis System, version 9.4, SAS Institute, Cary, NC). In the Mixed Model, treatment was considered as a fixed effect, while blocks within each trial were considered as random effects. The assumption of constant variance was tested to ensure that residuals had constant variance with a normal distribution. Data were LOG(Y) or SQRT(Y) transformed when necessary to achieve normality and constant variance where necessary. Significant differences among treatments were determined using Tukey's multiple means comparison test at a probability level of $P = 0.05$.

4.3 Results and Discussion

Data were analyzed separately for each site due to differences in block number and variation in initial ramet density. Initial ramet density at Rawdon, Greenfield, and Stewiacke was 420 ± 142, 566 ± 211, and 631 ± 137 ramets m^{-2}, respectively, and did not vary across treatments ($p = 0.12$). Over wintered ramet density was significantly affected by herbicide treatment at each site ($p < 0.0001$). Dicamba, tribenuron-methyl, and dichlobenil consistently reduced overwintered ramet density across sites (Tables 4.3, 4.4, and 4.5). Dicamba controlled red sorrel in alpine grasslands (Kim et al. 1999) and Canode and Robocker (1967) found that red sorrel was controlled by autumn application of dicamba in Kentucky bluegrass (*Poa pratensis* L.) seed fields. Our results indicate that this herbicide could be considered for autumn red sorrel control in wild blueberry. Autumn dicamba applications are registered for woody weed control (Anonymous 2019), and our results indicate that these applications could potentially be considered for red sorrel control as well. Tribenuron-methyl is currently registered for control of a wide range of weed species in wild blueberry (Jensen and Specht 2004), and our data also provide basis for use of this herbicide for red sorrel management as well. Skroch et al. (1975) found that dichlobenil applications of 4500 g a.i. ha^{-1} gave commercially acceptable control of broad-leaved weeds early in the season in apple orchards, but that control became less effective as the season progressed. Our results indicate longer of periods of weed control from dichlobenil in wild blueberry fields, and this herbicide should be evaluated further to identify economical uses of this herbicide for weed control.

Propyzamide reduced overwintered ramet density at Greenfield and Stewiacke (Tables 4.4 and 4.5), but not at Rawdon (Table 4.3). Propyzamide controls red sorrel (Hughes et al. 2016), though variability in efficacy does occur. We also observed variability in propyzamide efficacy across sites in spring non-bearing year herbicide experiments (Tables 3.3, 3.4, and 3.5). Given the cost of propyzamide (approximately \$500 ha^{-1}), the lack of consistent control, and potential identification of alternative herbicides from this study, this product should not be used for red sorrel management in lowbush blueberry. Growers can, however, likely expect suppression of red sorrel from propyzamide when this herbicide is used for management of other weed species (such as fescue grasses) in wild blueberry.

Glufosinate and glyphosate reduced over-wintered ramet density at Rawdon and Stewiacke (Tables 4.3 and 4.5) but not at Greenfield (Table 4.4). These herbicides may therefore contribute to autumn red sorrel management, but efficacy is less consistent than that associated with dicamba, tribenuron methyl, and dicholobenil. Frank and Simon (1981) found that glyphosate application twice a year for 3 y effectively controlled perennial weeds including red sorrel, dandelion (*Taraxacum officinale* L.), and broadleaf dock (*Rumex obtusifolius* L.), indicating potential use of autumn applications of this herbicide for red sorrel management. Kim et al. (1999) found that glufosinate and glyphosate controlled red sorrel, suggesting these herbicides could be applied for red sorrel control at Kangwon alpine grasslands. However, there are risks associated with broadcast application of glyphosate. Yarborough and Ismail (1979) found that high rates of glyphosate reduced the height of blueberry stems, and this herbicide can cause severe injury when the blueberry crop is contacted by broadcast application (Jensen and Specht 2004). This herbicide is therefore used primarily as a directed spot application or for fall weed control during the early stages of field development (Anonymous 2016).

Flumioxazin, flumioxazin+hexazinone, dicamba+diflufenzopyr, and sulfentrazone reduced over-wintered ramet density at Stewiacke only (Table 4.5), indicating limited potential for autumn red sorrel management using these herbicides. Autumn flumioxazin applications, however, damage red sorrel (Percival et al. 2014), so additional work could be conducted with this herbicide to determine potential use for red sorrel management, particularly given the current autumn registration of this herbicide for hair cap moss

(*Polytrichum commune*) management in wild blueberry (Anonymous 2019). Dicamba+diflufenzopyr was less effective than dicamba alone and this herbicide mixture therefore appears to have limited utility for red sorrel management in lowbush blueberry. Farooq et al. (2019) also found that dicamba+diflufenzopyr was not superior to dicamba alone for controlling narrowleaved goldenrod, and so the future potential of dicamba+diflufenzopyr for weed control in lowbush blueberry is not clear. Spring sulfentrazone applications were also inconsistent on red sorrel (Tables 3.3, 3.4 and 3.5), further indicating variable activity of this herbicide on red sorrel in lowbush blueberry fields.

Clopyralid and pyroxsulam did not reduce over wintered ramet density at any site (Tables 4.3, 4.4, 4.5), indicating limited potential for these herbicides to be utilized for autumn red sorrel management in lowbush blueberry. Autumn clopyralid applications do, however, contribute to management of perennial weeds such as meadow hawkweed (*Hieracium caespitosum*) in blueberry fields (Eriavbe 2015), and this herbicide could be considered for use in future tank mixtures to broaden the spectrum of weed control obtained.

Herbicide treatment had a significant effect on total ramet density at Rawdon and Greenfield ($p \leq 0.0046$) but not Stewiacke ($p < 0.1104$), though reductions in total ramet density were limited to a few treatments and were not consistent across sites. Tribenuron-methyl and glufosinate reduced total ramet density in the non-bearing year at Rawdon, though red sorrel had begun to recover in the glufosinate treatment by October (Table 4.3). These treatments therefore reduced overwintering ramet density (Table 4.3), but also provided suppression of red sorrel during the non-bearing year. Although dicamba, glyphosate, and dichlobenil reduced overwintering ramet density at Rawdon, red sorrel recovered in these treatments and total ramet density during the remainder of the non-bearing year was not reduced (Table 4.3). None of the other herbicides evaluated reduced total ramet density in the non-bearing year at Rawdon. Propyzamide and dichlobenil reduced both overwintering ramet density and total ramet density throughout the non-bearing year at Greenfield (Table 4.4) whereas red sorrel recovered in all other treatments evaluated at this site. Results therefore indicate that while several treatments consistently reduced overwintering ramet density, reductions in total ramet density throughout the remainder of the non-bearing year were much less consistent across treatments and sites. Additional research will therefore need to focus on combining both autumn and spring herbicide applications to maintain red sorrel suppression in wild blueberry fields.

Table 4.3. Over wintered and total red sorrel ramet density in various herbicide treatments applied on 19 November to wild blueberry in bearing year at Rawdon, NS, Canada in 2016.

Treatment	Overwintered ramets (ramets m^{-2})	Total ramet density (ramets m^{-2})		
	29 April[a]	10 June[b]	19 July[c]	3 October[d]
Control	6.1 ± 0.5a[e] (538)	5.6 ± 0.3a (333)	18.7 ± 1.6a (353)	15.0 ± 1.9a (230)
Clopyralid	5.5 ± 0.5ab (290)	4.4 ± 0.3a (161)	12.6 ± 1.6ab (177)	9.1 ± 1.9ab (106)
Dicamba	1.0 ± 0.5d (0)	4.2 ± 0.3a (125)	8.8 ± 1.6b (101)	6.4 ± 1.9ab (51)
Dichlobenil	3.5 ± 0.5bc (50)	4.9 ± 0.3a (157)	11.3 ± 1.6ab (133)	11.0 ± 1.9ab (134)
Dicamba+diflufenzopyr	4.5 ± 0.5abc (93)	4.9 ± 0.3a (163)	15.1 ± 1.6ab (236)	12.5 ± 1.9ab (165)
Flumioxazin	4.8 ± 0.5ab (156)	5.7 ± 0.3a (337)	15.0 ± 1.6ab (227)	12.7 ± 1.9ab (182)
Flumioxazin+hexazinone	4.4 ± 0.5abc (111)	5.1 ± 0.3a (181)	11.7 ± 1.6ab (149)	8.9 ± 1.9ab (110)
Glufosinate	2.4 ± 0.5c (20)	3.9 ± 0.3b (146)	9.9 ± 1.6b (100)	7.8 ± 1.9ab (71)
Glyphosate	2.2 ± 0.5c (33)	5.4 ± 0.3a (359)	12.2 ± 1.6ab (186)	10.0 ± 1.9ab (129)
Nicosulfuron/rimsulfuron	5.7 ± 0.5ab (352)	5.7 ± 0.3a (342)	13.7 ± 1.6ab (196)	12.8 ± 1.9ab (184)
Propyzamide	3.9 ± 0.5abc (163)	5.1 ± 0.3a (244)	13.0 ± 1.6ab (176)	10.8 ± 1.9ab (122)
Pyroxsulam	3.9 ± 0.5abc (151)	4.8 ± 0.3a (134)	12.6 ± 1.6ab (182)	11.0 ± 1.9ab (154)
Sulfentrazone	4.3 ± 0.5ab (169)	5.7 ± 0.3a (379)	5.3 ± 1.6ab (231)	5.05 ± 1.9a (179)
Tribenuron-methyl	3.8 ± 0.5bc (73)	4.7 ± 0.3b (167)	7.6 ± 1.6b (59)	4.2 ± 1.9b (31)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[e] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.4. Over wintered and total red sorrel ramet density in various herbicide treatments applied on 29 November to wild blueberry in bearing year at Greenfield, NS, Canada in 2016.

Treatment	Overwintered ramets (ramets m^{-2})	Total ramet density (ramets m^{-2})		
	28 April[a]	9 June[b]	28 July[c]	19 October[d]
Control	31.5 ± 4.0a[e] (26)	18.3 ± 1.9ab (341)	22.5 ± 1.9a (512)	21.3 ± 1.3a (456)
Clopyralid	16.7 ± 4.0abc (326)	15.4 ± 1.9ab (241)	17.2 ± 1.9ab (300)	17.6 ± 1.3ab (312)
Dicamba	7.1 ± 4.0c (122)	17.0 ± 1.9ab (306)	21.1 ± 1.9ab (455)	19.8 ± 1.3a (396)
Dichlobenil	2.4 ± 4.0c (6)	4.5 ± 1.9c (24)	7.3 ± 1.9c (61)	5.8 ± 1.3c (37)
Dicamba+diflufenzopyr	20.2 ± 4.0abc (455)	16.8 ± 1.9ab (301)	19.9 ± 1.9ab (419)	17.8 ± 1.3ab (320)
Flumioxazin	16.3 ± 4.0abc (302)	15.5 ± 1.9ab (249)	18.2 ± 1.9ab (353)	19.6 ± 1.3a (389)
Flumioxazin+hexazinone	16.4 ± 4.0abc (323)	18.0 ± 1.9ab (334)	19.0 ± 1.9ab (363)	20.3 ± 1.3a (425)
Glufosinate	13.7 ± 4.0abc (220)	18.5 ± 1.9ab (364)	18.8 ± 1.9ab (369)	21.8 ± 1.3a (488)
Glyphosate	14.0 ± 4.0abc (208)	22.1 ± 1.9a (493)	19.5 ± 1.9ab (401)	21.9 ± 1.3a (491)
Nicosulfuron/rimsulfuron	14.6 ± 4.0abc (319)	18.1 ± 1.9ab (333)	16.2 ± 1.9abc (268)	20.4 ± 1.3a (418)
Propyzamide	11.0 ± 4.0bc (183)	9.2 ± 1.9bc (93)	12.6 ± 1.9bc (170)	11.9 ± 1.3bc (145)
Pyroxsulam	26.3 ± 4.0ab (729)	21.5 ± 1.9a (729)	19.4 ± 1.9ab (396)	20.5 ± 1.3a (423)
Sulfentrazone	18.3 ± 4.0abc (413)	19.6 ± 1.9a (400)	20.8 ± 1.9ab (268)	20.7 ± 1.3a (437)
Tribenuron-methyl	7.9 ± 4.0bc (63)	14.5 ± 1.9ab (222)	14.2 ± 1.9abc (226)	19.0 ± 1.3a (375)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[e] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.5. Overwintered and total red sorrel ramet density in various herbicide treatments applied on 19 November to wild blueberry in bearing year at Stewiacke, NS, Canada in 2016.

Treatment	Overwintered ramets (ramets m^{-2})	Total ramet density (ramets m^{-2})		
	29 April[a]	9 June[b]	28 July[c]	5 October[d]
Control	32.4 ± 2.8a[e] (1079)	12.8 ± 2.2a (183)	5.7 ± 0.3a (338)	18.2 ± 2.4a (348)
Clopyralid	20.7 ± 2.8abc (468)	15.1 ± 2.2a (243)	5.1 ± 0.3a (209)	16.2 ± 2.4a (278)
Dicamba	1.2 ± 2.8e (0)	13.8 ± 2.2a (200)	5.2 ± 0.3a (201)	12.0 ± 2.4a (153)
Dichlobenil	2.8 ± 2.8de (11)	14.5 ± 2.2a (224)	5.4 ± 0.3a (248)	8.2 ± 2.4a (80)
Dicamba+diflufenzopyr	15.8 ± 2.8bcd (252)	16.9 ± 2.2a (295)	5.5 ± 0.3a (282)	16.8 ± 2.4a (297)
Flumioxazin	8.9 ± 2.8cde (83)	14.7 ± 2.2a (239)	5.4 ± 0.3a (249)	16.0 ± 2.4a (263)
Flumioxazin+hexazinone	7.8 ± 2.8cde (126)	12.3 ± 2.2a (165)	5.0 ± 0.3a (211)	15.7 ± 2.4a (262)
Glufosinate	7.8 ± 2.8cde (80)	17.0 ± 2.2a (302)	5.6 ± 0.3a (333)	11.7 ± 2.4a (167)
Glyphosate	8.7 ± 2.8cde (91)	16.0 ± 2.2a (269)	5.3 ± 0.3a (223)	14.3 ± 2.4a (243)
Nicosulfuron/rimsulfuron	20.9 ± 2.8abc (441)	17.7 ± 2.2a (334)	5.3 ± 0.3a (228)	13.4 ± 2.4a (200)
Propyzamide	12.2 ± 2.8bcde (189)	18.4 ± 2.2a (379)	5.6 ± 0.3a (347)	18.1 ± 2.4a (338)
Pyroxsulam	22.4 ± 2.8ab (535)	19.1 ± 2.2a (391)	5.9 ± 0.3a (442)	17.2 ± 2.4a (326)
Sulfentrazone	17.8 ± 2.8bc (392)	15.1 ± 2.2a (233)	5.1 ± 0.3a (193)	16.0 ± 2.4a (273)
Tribenuron-methyl	3.0 ± 2.8de (12)	10.9 ± 2.2a (128)	4.7 ± 0.3a (93)	13.0 ± 2.4a (187)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[e] Means within columns followed by the same letter do not differ significantly according to a Tukey’s mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

There was a significant effect of herbicide treatment on red sorrel flowering ramet density in the non-bearing year at each site ($p < 0.0179$). Dicamba and tribenuron-methyl gave consistent reductions in flowering ramet density throughout the non-bearing year at Rawdon and Stewiacke (Tables 4.6 and 4.7) but flowering ramet density increased in these treatments late in the season at Greenfield (Table 4.8). Flowering in red sorrel primarily occurs in overwintering ramets (White et al. 2014) and reductions in overwintering ramets should therefore reduce flowering ramet density.

Dichlobenil reduced flowering ramet density at Rawdon and Greenfield (4.6 and 4.8), though flowering ramets recovered later in the season. Zhang (2018) also found that application of dichlobenil in autumn reduced hair fescue (*Festuca filiformis*) flowering tuft density in more than one wild blueberry fields and indicated that suppression could last for two years.

Glyphosate and pyroxsulam reduced flowering ramet density early in the season at Rawdon (Table 4.6), though density increased in these treatments by the later counting date. These results are in agreement with the reduced over wintered ramet density observed after application of these treatments (Table 4.3). Doll (1997) found that glyphosate application in autumn was effective on hemp dogbane (*Apocynum cannabinum* L.) and Wu (2011) found that spot sprays with glyphosate effectively controlled spreading dogbane (*Apocynum androsaemifolium* L.) in the year after application in wild blueberry fields. Application of pyroxsulam damaged hawkweed rosettes (*Hieracium* spp.) but did not provide complete control in wild blueberry fields (Eriavbe 2015).

Propyzamide reduced flowering ramet density in June, though flowering ramet density increased in these treatments during the remainder of the non-bearing year at

Greenfield (Table 4.8). Propyzamide had also shown reductions in flowering ramet density in the spring herbicide trial at Greenfield and Sherbrooke (Tables 3.6 and 3.7). However, propyzamide is a potential herbicide that can control red sorrel in wild blueberry fields.

Table 4.6. Red sorrel flowering ramet density in various herbicide treatments applied pre-emergence to wild blueberry in bearing year at Rawdon, NS, Canada in 2016.

Treatment	Flowering ramet density (ramets m^{-2})	
	10 June[a]	19 July[b]
Control	13.7 ± 2.2ab[c] (214)	13.1 ± 1.3a (171)
Clopyralid	5.4 ± 2.2abc (61)	10.5 ± 1.3abc (122)
Dicamba	1.0 ± 2.2c (0)	2.7 ± 1.3d (12)
Dichlobenil	4.8 ± 2.2bc (33)	7.4 ± 1.3abcd (57)
Dicamba+diflufenzopyr	5.0 ± 2.2abc (35)	10.8 ± 1.3abc (120)
Flumioxazin	14.4 ± 2.2ab (214)	11.7 ± 1.3ab (138)
Flumioxazin+hexazinone	6.7 ± 2.2abc (59)	9.1 ± 1.3abcd (90)
Glufosinate	6.1 ± 2.2abc (54)	6.2 ± 1.3abc (40)
Glyphosate	3.1 ± 2.2c (27)	7.4 ± 1.3abcd (68)
Nicosulfuron+rimsulfuron	15.0 ± 2.2a (245)	10.4 ± 1.3abc (113)
Propyzamide	8.8 ± 2.2abc (131)	9.5 ± 1.3abc (95)
Pyroxsulam	1.4 ± 2.2c (2)	9.5 ± 1.3abc (115)
Sulfentrazone	13.8 ± 2.2ab (232)	10.9 ± 1.3abc (127)
Tribenuron-methyl	3.2 ± 2.2c (30)	4.9 ± 1.3cd (28)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.7. Red sorrel flowering ramet density in various herbicide treatments applied pre-emergence to wild blueberry in bearing year at Stewiacke, NS, Canada in 2016.

Treatment	Flowering ramet density (ramets m^{-2})	
	9 June[a]	28 July[b]
Control	8.0 ± 2.3a[c] (100)	13.5 ± 2.0a (193)
Clopyralid	6.3 ± 2.3a (50)	8.8 ± 2.0abc (98)
Dicamba	1.6 ± 2.3b (2)	4.7 ± 2.0bc (26)
Dichlobenil	3.9 ± 2.3a (25)	10.9 ± 2.0abc (119)
Dicamba+diflufenzopyr	2.5 ± 2.3a (8)	9.2 ± 2.0abc (86)
Flumioxazin	5.7 ± 2.3a (44)	7.9 ± 2.0abc (70)
Flumioxazin+hexazinone	4.1 ± 2.3a (26)	6.3 ± 2.0abc (73)
Glufosinate	6.4 ± 2.3a (47)	9.3 ± 2.0abc (95)
Glyphosate	4.2 ± 2.3a (28)	7.8 ± 2.0abc (67)
Nicosulfuron/rimsulfuron	11.0 ± 2.3a (156)	9.8 ± 2.0abc (108)
Propyzamide	10.0 ± 2.3a (162)	9.3 ± 2.0abc (115)
Pyroxsulam	5.9 ± 2.3a (53)	12.8 ± 2.0ab (197)
Sulfentrazone	5.3 ± 2.3a (42)	9.1 ± 2.0abc (86)
Tribenuron-methyl	1.0 ± 2.3b (0)	3.7 ± 2.0c (20)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.8. Red sorrel flowering ramet density in various herbicide treatments applied pre-emergence to wild blueberry in bearing year at Greenfield, NS, Canada in 2016.

Treatment	Flowering ramet density (ramets m^{-2})	
	9 June[a]	28 July[b]
Control	3.6 ± 1.7bcd[c] (34)	5.0 ± 0.3a (176)
Clopyralid	4.6 ± 1.7bcd (23)	4.6 ± 0.3a (117)
Dicamba	3.2 ± 1.7bcd (17)	4.4 ± 0.3a (98)
Dichlobenil	1.4 ± 1.7cd (1)	3.8 ± 0.3a (51)
Dicamba+diflufenzopyr	4.5 ± 1.7bcd (21)	4.7 ± 0.3a (145)
Flumioxazin	5.1 ± 1.7abcd (34)	4.3 ± 0.3a (104)
Flumioxazin+hexazinone	4.4 ± 1.7bcd (19)	5.1 ± 0.3a (186)
Glyphosate	9.9 ± 1.7abc (102)	4.7 ± 0.3a (129)
Glufosinate	5.2 ± 1.7abcd (33)	4.4 ± 0.3a (102)
Nicosulfuron/rimsulfuron	6.4 ± 1.7abcd (56)	4.4 ± 0.3a (95)
Propyzamide	1.0 ± 1.7d (0)	4.5 ± 0.3a (111)
Pyroxsulam	13.1 ± 1.7ab (225)	4.9 ± 0.3a (163)
Sulfentrazone	11.4 ± 1.7ab (140)	5.2 ± 0.3a (193)
Tribenuron-methyl	1.7 ± 1.7cd (2)	3.9 ± 0.3a (60)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Red sorrel seedling density was significantly affected by herbicide treatment at Greenfield and Stewiacke ($p \leq 0.0001$), but not at Rawdon ($p = 0.1681$). Dichlobenil was the only herbicide that reduced seedling density throughout the non-bearing year at Greenfield (Table 4.10) and also reduced seedling density in June and July at Stewiacke (Table 4.11). These results are in agreement with previous studies which indicate the presence of phytotoxic levels of dichlobenil in soil one year after application (Sheets et al. 1968). Propyzamide, dicamba, flumioxazin, and flumioxazin+hexazinone also reduced seedling density early in the season at Stewiacke (Table 4.11), however, seedling density increased as the season progressed. This can be attributed to the limited persistence of these herbicides in the soil. The approximate half-life of propyzamide, dicamba, and flumioxazin were found to be 40-60 days, 16 days, and 12-17days, respectively (Smith 1984; Ferrell and Vencill 2003; Zhao et al. 2015). None of the other treatments reduced seedling density in non-bearing year at Stewiacke.

Table 4.9. Red sorrel seedling density in various herbicide treatments applied pre-emergence to wild blueberry in bearing year at Rawdon, NS, Canada in 2016.

Treatment	Seedling density (seedlings m^{-2})		
	10 June[a]	19 July[b]	3 October[c]
Control	2.6 ± 0.7a[d] (34)	3.7 ± 0.6a (44)	2.6 ± 0.4a (13)
Clopyralid	2.0 ± 0.7a (11)	0.9 ± 0.6a (4)	0.8 ± 0.4a (3)
Dicamba	1.7 ± 0.7a (40)	1.8 ± 0.6a (19)	0.3 ± 0.4a (2)
Dichlobenil	2.5 ± 0.7a (14)	1.0 ± 0.6a (5)	0.9 ± 0.4a (4)
Dicamba+diflufenzopyr	1.7 ± 0.7a (13)	1.6 ± 0.6a (11)	0.7 ± 0.4a (2)
Flumioxazin	2.0 ± 0.7a (12)	1.6 ± 0.6a (9)	0.8 ± 0.4a (3)
Flumioxazin+hexazinone	0.4 ± 0.7a (2)	0.6 ± 0.6a (5)	0.3 ± 0.4a (1)
Glufosinate	2.4 ± 0.7a (22)	2.8 ± 0.6a (36)	0.7 ± 0.4a (2)
Glyphosate	3.6 ± 0.7a (110)	2.3 ± 0.6a (56)	0.9 ± 0.4a (4)
Nicosulfuron/rimsulfuron	3.3 ± 0.7a (37)	2.7 ± 0.6a (26)	1.1 ± 0.4a (6)
Propyzamide	1.4 ± 0.7a (16)	1.2 ± 0.6a (8)	0.4 ± 0.4a (2)
Pyroxsulam	1.0 ± 0.7a (5)	2.3 ± 0.6a (16)	0.4 ± 0.4a (2)
Sulfentrazone	2.2 ± 0.7a (12)	2.0 ± 0.6a (10)	1.3 ± 0.4a (1)
Tribenuron-methyl	3.0 ± 0.7a (59)	1.8 ± 0.6a (12)	0.3 ± 0.4a (1)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.10. Red sorrel seedling density in various herbicide treatments applied pre-emergence to wild blueberry in bearing year at Greenfield, NS, Canada in 2016.

Treatment	Seedling density (seedlings m^{-2})		
	9 June[a]	28 July[b]	19 October[c]
Control	5.0 ± 1.1a[d] (26)	4.0 ± 0.4a (56)	6.1 ± 0.4a (37)
Clopyralid	2.9 ± 1.1a (9)	1.9 ± 0.4ab (6)	1.3 ± 0.4b (1)
Dicamba	5.1 ± 1.1a (32)	2.1 ± 0.4ab (13)	1.7 ± 0.4b (4)
Dichlobenil	1.0 ± 1.1b (0)	0.6 ± 0.4b (0)	1.3 ± 0.4b (1)
Dicamba+diflufenzopyr	4.9 ± 1.1a (25)	2.6 ± 0.4ab (14)	1.0 ± 0.4b (0)
Flumioxazin	1.7 ± 1.1a (2)	2.6 ± 0.4a (12)	1.6 ± 0.4b (2)
Flumioxazin+hexazinone	1.7 ± 1.1a (49)	2.4 ± 0.4ab (16)	1.9 ± 0.4b (4)
Glufosinate	4.1 ± 1.1a (17)	2.1 ± 0.4ab (12)	1.0 ± 0.4b (0)
Glyphosate	5.7 ± 1.1a (34)	3.0 ± 0.4a (21)	1.7 ± 0.4b (2)
Nicosulfuron/rimsulfuron	5.5 ± 1.1a (36)	2.9 ± 0.4ab (20)	1.0 ± 0.4b (0)
Propyzamide	4.1 ± 1.1a (16)	2.1 ± 0.4ab (8)	1.3 ± 0.4b (1)
Pyroxsulam	5.8 ± 1.1a (34)	3.0 ± 0.4a (30)	1.0 ± 0.4b (0)
Sulfentrazone	3.6 ± 1.1a (13)	3.1 ± 0.4a (20)	1.0 ± 0.4b (0)
Tribenuron-methyl	3.7 ± 1.1a (21)	2.5 ± 0.4ab (13)	2.3 ± 0.4b (6)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.11. Red sorrel seedling density in various herbicide treatments applied pre-emergence to wild blueberry in bearing year at Stewiacke, NS, Canada in 2016.

Treatment	Seedling density (seedlings m^{-2})		
	9 June[a]	28 July[b]	5 October[c]
Control	4.8 ± 0.5a[d] (172)	4.4 ± 0.4a (85)	4.3 ± 0.5a (18)
Clopyralid	3.6 ± 0.5abc (62)	2.9 ± 0.4ab (18)	1.7 ± 0.5a (2)
Dicamba	2.7 ± 0.5bcd (21)	1.6 ± 0.4b (6)	1.7 ± 0.5a (2)
Dichlobenil	0.4 ± 0.5d (1)	1.6 ± 0.4b (6)	2.3 ± 0.5a (6)
Dicamba+diflufenzopyr	3.8 ± 0.5ab (54)	2.7 ± 0.4ab (17)	2.1 ± 0.5a (5)
Flumioxazin	1.7 ± 0.5bcd (14)	2.6 ± 0.4ab (25)	1.7 ± 0.5a (2)
Flumioxazin+hexazinone	0.8 ± 0.5cd (8)	2.1 ± 0.4ab (14)	2.1 ± 0.5a (5)
Glufosinate	3.2 ± 0.5abcd (28)	3.1 ± 0.4ab (22)	1.7 ± 0.5a (2)
Glyphosate	4.0 ± 0.5ab (69)	2.9 ± 0.4ab (18)	2.3 ± 0.5a (5)
Nicosulfuron/rimsulfuron	4.1 ± 0.5ab (82)	2.6 ± 0.4ab (16)	1.6 ± 0.5a (2)
Propyzamide	2.3 ± 0.5bcd (20)	2.2 ± 0.4ab (9)	2.5 ± 0.5a (6)
Pyroxsulam	3.8 ± 0.5ab (82)	2.7 ± 0.4ab (18)	2.8 ± 0.5a (9)
Sulfentrazone	3.3 ± 0.5abcd (29)	3.0 ± 0.4ab (20)	1.3 ± 0.5a (1)
Tribenuron-methyl	2.6 ± 0.5abcd (18)	2.2 ± 0.4ab (14)	2.3 ± 0.5a (5)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

There was no effect of herbicide treatment on overwintered, vegetative, and flowering ramet density at Rawdon in the bearing year ($p = 0.77$), indicating that red sorrel completely recovered in all herbicide treatments at this site by the bearing year (Table 4.12). There was, however, a significant effect of herbicide treatment on overwintered, vegetative, and flowering ramet density at Greenfield ($p \leq 0.0011$) and on overwintered ramet density ($p = 0.0084$), but not vegetative and flowering ramet density ($p \geq 0.6141$), at Stewiacke in the bearing year. Dichlobenil reduced overwintered, vegetative, and flowering ramet density in the bearing year at Greenfield (Table 4.13), indicating potential for this herbicide to provide production cycle suppression of red sorrel in wild blueberry fields. Lack of recovery in this treatment in the bearing year at Greenfield was likely due to the reduction in seedling density during the non-bearing year (Table 4.10), potentially indicating that seedling management following autumn herbicide applications is essential for maintaining red sorrel control in wild blueberry fields. Additional research should focus on the mechanism of red sorrel recovery following autumn herbicide applications to determine if re-establishment from seed, creeping roots, or both contribute to red sorrel recovery from autumn herbicide applications, particularly given the limited bearing year suppression associated with most other herbicides evaluated.

Dicamba reduced overwintered ramet density in the bearing year at Greenfield and Stewiacke (Tables 4.13 and 4.14), though vegetative and flowering ramet density were not reduced at the later counting dates. This is consistent with the control of red sorrel ramets achieved by autumn dicamba application in alphine grass lands (Kim et al. 1999). Dicamba reduced seedling density initially in the non-bearing year at Greenfield and Stewiacke (Tables 4.10 and 4.11), but density increased in later counting dates. Recovery of vegetative and flowering ramet density in the bearing year might be due to increase in seedling density in the non-bearing year.

Propyzamide reduced vegetative and flowering ramet density in the bearing year at Greenfield only (Table 4.13). Overwintered ramet density was reduced in the tribenuron-methyl treatment at Stewiacke, but ramet density in all treatments increased during the remainder of the bearing year at this site (Table 4.14). Tribenuron-methyl significantly reduced over wintered (Table 4.5) and flowering ramet density (Table 4.8) throughout the non-bearing year but no reduction in seedling density was observed in non-bearing year at Stewiacke. Recovery of ramets in the tribenuron-methyl treatment in the bearing year is therefore likely due to uncontrolled seedling populations during the non-bearing year, and additional research should be conducted to determine combinations of autumn tribenuron methyl and spring herbicide applications.

Table 4.12. Overwintered, vegetative, and flowering red sorrel ramet density in the bearing year at Rawdon, NS, Canada in 2017.

Treatment	Overwintered ramet density (ramets m^{-2})[a]	Vegetative ramet density (ramet m^{-2})[b]	Flowering ramet density (ramets m^{-2})[c]
Control	11.9 ± 1.8a[d] (164)	5.2 ± 0.4a (191)	9.5 ± 1.3a (92)
Clopyralid	7.6 ± 1.8a (72)	3.4 ± 0.4a (30)	10.3 ± 1.3a (108)
Dicamba	8.3 ± 1.8a (88)	3.3 ± 0.4a (36)	7.6 ± 1.3a (62)
Dichlobenil	8.0 ± 1.8a (77)	4.1 ± 0.4a (57)	8.5 ± 1.3a (81)
Dicamba+diflufenzopyr	12.6 ± 1.8a (160)	4.0 ± 0.4a (62)	9.6 ± 1.3a (101)
Flumioxazin	12.9 ± 1.8a (189)	4.1 ± 0.4a (80)	10.8 ± 1.3a (116)
Flumioxazin+hexazinone	9.3 ± 1.8a (126)	3.2 ± 0.4a (55)	10.4 ± 1.3a (122)
Glufosinate	10.8 ± 1.8a (120)	4.1 ± 0.4a (71)	9.6 ± 1.3a (94)
Glyphosate	10.0 ± 1.8a (104)	3.6 ± 0.4a (80)	10.1 ± 1.3a (119)
Nicosulfuron/rimsulfuron	10.0 ± 1.8a (107)	3.8 ± 0.4a (42)	6.8 ± 1.3a (48)
Propyzamide	9.3 ± 1.8a (88)	3.2 ± 0.4a (34)	9.6 ± 1.3a (97)
Pyroxsulam	8.8 ± 1.8a (102)	3.5 ± 0.4a (40)	7.9 ± 1.3a (77)
Sulfentrazone	11.5 ± 1.8a (142)	3.9 ± 0.4a (59)	9.0 ± 1.3a (88)
Tribenuron-methyl	6.6 ± 1.8a (51)	3.4 ± 0.4a (37)	7.9 ± 1.3a (68)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.13. Overwintered, vegetative, and flowering red sorrel ramet density in the bearing year at Greenfield, NS, Canada in 2017.

Treatment	Overwintered ramet density (ramets m^{-2})[a]	Vegetative ramet density (ramet m^{-2})[b]	Flowering ramet density (ramets m^{-2})[c]
Control	5.6 ± 0.3a[d] (296)	12.9 ± 0.9a (169)	7.5 ± 0.1a (1882)
Clopyralid	5.1 ± 0.3ab (167)	11.4 ± 0.9abc (137)	7.2 ± 0.1abc (1522)
Dicamba	4.0 ± 0.3b (62)	12.8 ± 0.9a (166)	7.5 ± 0.1a (1851)
Dichlobenil	1.9 ± 0.3c (14)	7.7 ± 0.9c (62)	6.4 ± 0.1c (689)
Dicamba+diflufenzopyr	5.0 ± 0.3ab (174)	12.2 ± 0.9abc (150)	7.4 ± 0.1a (1666)
Flumioxazin	5.1 ± 0.3ab (175)	12.8 ± 0.9a (167)	7.4 ± 0.1a (1862)
Flumioxazin+hexazinone	4.9 ± 0.3ab (150)	12.1 ± 0.9abc (153)	7.3 ± 0.1ab (1707)
Glufosinate	4.9 ± 0.3ab (139)	12.2 ± 0.9ab (150)	7.4 ± 0.1a (1666)
Glyphosate	4.9 ± 0.3ab (137)	11.0 ± 0.9abc (127)	7.1 ± 0.1abc (1419)
Nicosulfuron/rimsulfuron	5.1 ± 0.3ab (181)	12.1 ± 0.9abc (150)	7.3 ± 0.1ab (1676)
Propyzamide	4.3 ± 0.3ab (83)	8.1 ± 0.9bc (67)	6.5 ± 0.1bc (751)
Pyroxsulam	5.0 ± 0.3ab (193)	11.7 ± 0.9abc (138)	7.3 ± 0.1ab (1543)
Sulfentrazone	5.0 ± 0.3ab (164)	9.9 ± 0.9abc (100)	7.0 ± 0.1abc (1121)
Tribenuron-methyl	4.4 ± 0.3ab (104)	10.4 ± 0.9abc (112)	7.0 ± 0.1abc (1244)

[a] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Table 4.14. Overwintered, vegetative, and flowering red sorrel ramet density in the bearing year at Stewiacke, NS, Canada in 2017.

Treatment	Overwintered ramet density (ramets m^{-2})[a]	Vegetative ramet density (ramets m^{-2})[b]	Flowering ramet density (ramets m^{-2})[c]
Control	18.4 ± 2.5a[d] (344)	4.6 ± 0.3a (135)	5.0 ± 0.6a (183)
Clopyralid	11.1 ± 2.5abc (154)	3.6 ± 0.3a (45)	3.8 ± 0.6a (59)
Dicamba	7.7 ± 2.5c (62)	4.0 ± 0.3a (45)	3.4 ± 0.6a (73)
Dichlobenil	12.6 ± 2.5abc (164)	3.9 ± 0.3a (57)	4.2 ± 0.6a (122)
Dicamba+diflufenzopyr	14.5 ± 2.5abc (253)	4.4 ± 0.3a (96)	4.4 ± 0.6a (144)
Flumioxazin	15.5 ± 2.5abc (251)	4.4 ± 0.3a (83)	5.0 ± 0.6a (156)
Flumioxazin+hexazinone	18.1 ± 2.5a (379)	4.4 ± 0.3a (87)	4.9 ± 0.6a (161)
Glufosinate	9.1 ± 2.5abc (94)	4.1 ± 0.3a (87)	3.8 ± 0.6a (98)
Glyphosate	13.2 ± 2.5abc (175)	4.1 ± 0.3a (73)	4.4 ± 0.6a (123)
Nicosulfuron/rimsulfuron	11.9 ± 2.5abc (151)	4.6 ± 0.3a (121)	4.7 ± 0.6a (128)
Propyzamide	17.6 ± 2.5ab (319)	4.4 ± 0.3a (100)	5.2 ± 0.6a (210)
Pyroxsulam	16.4 ± 2.5abc (331)	4.4 ± 0.3a (103)	4.0 ± 0.6a (184)
Sulfentrazone	11.0 ± 2.5abc (149)	4.2 ± 0.3a (76)	3.7 ± 0.6a (72)
Tribenuron-methyl	8.2 ± 2.5bc (83)	3.1 ± 0.3a (31)	4.0 ± 0.6a (80)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Herbicide applications did not have significant effects on blueberry stem density (P = 0.39), stem height (P = 0.93), flower bud density (P = 0.17), and blueberry yield (P = 0.16) at any site. Blueberry stem density averaged 556 ± 58 stems m^{-2} and 494 ± 62 stems m^{-2} at Greenfield and Stewiacke respectively. Blueberry stem height averaged 16.3 ± 0.6 cm and 14.7 ± 0.6 cm at Greenfield and Stewiacke, respectively. Blueberry floral bud numbers averaged 4.7 ± 0.2 buds stem^{-1} and 4.3 ± 0.5 buds stem^{-1} at Greenfield and Stewiacke, respectively. Blueberry yield averaged 3480 ± 617.2 kg ha^{-1}and 1080 ± 566.4 kg ha^{-1} at Greenfield and Stewiacke, respectively. These observations indicate the crop safety of these herbicides in blueberry fields. Lack of increases in blueberry stem density, height, bud numbers, and yield were unexpected given that red sorrel decreases blueberry yields and interferes with harvest practices once established in the bearing year (Kennedy 2009; Kennedy et al. 2011). Weeds like red sorrel are competitive to blueberries and when the weeds are controlled, blueberry yields can increase (Yarborough and Ismail 1985). Variations in blueberry yields occurred as the blueberry yields were obtained from 1 m x 1 m quadrats in each plot, so it is possible that these were areas with unusually dense blueberry cover.

4.4 Conclusion

Red sorrel ramet densities were significantly affected by autumn herbicide applications. Dicamba, tribenuron-methyl, and dichlobenil gave the most consistent reductions in overwintered ramet density across sites. Glufosinate, glyphosate, propyzamide, flumioxazin, flumioxazin + hexazinone, dicamba+diflufenzopyr and sulfentrazone also reduced overwintered ramet density, however, these treatments were not consistent across sites in the non-bearing year.

Dicamba and tribenuron-methyl gave consistent reductions in flowering ramet density throughout the non-bearing year at Rawdon and Stewiacke, but flowering ramets recovered in the non-bearing year at Greenfield. Glyphosate, pyroxsulam, dichlobenil, and propyzamide reduced flowering ramet density initially and densities recovered in the non-bearing year. However, dichlobenil and propyzamide reduced flowering ramet density throughout the non-bearing year at Greenfield.

None of the treatments reduced seedling density at Rawdon. Dichlobenil gave the greatest reductions in seedling density at Greenfield and Stewiacke throughout the non-bearing year. However, by the end of the non-bearing year, seedling density was low in all the treatments at Greenfield. Dicamba, propyzamide, flumioxazin, flumioxazin+hexazinone also reduced seedling density at Stewiacke, though densities increased in these treatments by the end of the season.

Dichlobenil and propyzamide gave the most consistent reductions in overwintered, vegetative and flowering ramet densities at Greenfield and Stewiacke in the 2017 bearing year. Dicamba and tribenuron-methyl also reduced overwintered ramet density in the 2016 non-bearing year, however red sorrel ramets recovered in these treatments during the 2017 bearing year. Herbicides evaluated in this study reduced red sorrel ramets initially however, ramets recovered later in the season in wild blueberry fields. Additional research should be conducted to evaluate with additional autumn herbicides for prolonged control of red sorrel suppression in wild blueberry fields

Chapter 5.0 Effect of autumn mowing and application timing on herbicide efficacy on red sorrel (*Rumex acetosella* L.) in wild blueberry (*Vaccinium angustifolium* Ait.) fields.

5.1 Introduction

The lowbush, or wild blueberry (*Vaccinium angustifolium* Ait.) is the most important fruit crop in Nova Scotia in terms of export sales and total acreage. (McIsaac 1997). It is a low-growing, perennial shrub from the Ericaceae family. Initial establishment of plants is from seedlings that spread by extensive rhizome systems (Trevett 1956), eventually forming large clones that intermingle with neighboring clones (Barker et al. 1964). The extensive rhizome system in blueberries allows it to withstand destruction of stems and leaves by pruning (Hall et al. 1979). After pruning, the entire aboveground portion of the plant is replaced by vigorous new shoots (Kender and Eggert 1966), which grow vegetatively in the first, or non-bearing year, and bloom and produce fruit in the second, or bearing year (Eck and Childers 1966).

Pruning of lowbush blueberry fields has traditionally been conducted by burning with straw or oil-based burners (Black 1963; Wood 2004), but costs and environmental concerns associated with burning has led to widespread adoption of flail mowing as the main pruning method (Eaton et al. 2004; Yarborough 2004). Lowbush blueberry fields can be pruned in autumn following crop harvest or in early spring (Ismail and Hanson 1982; Eaton et al. 2004), though autumn pruning is more widely practiced due to convenience and reduced lateral branching of blueberry stems associated with autumn pruning (Ismail and Hanson 1982; Vander Kloet and Pither 2000). Autumn pruning should occur after first frost to prevent cumulative reductions in yield with many growers pruning as late as possible due to improved cutting efficiency of blueberry stems hardened off by cold weather (Yarborough and Hess 1998). Autumn pruning may therefore delay post-pruning autumn herbicide applications, potentially reducing efficacy due to prolonged exposure of weeds such as red sorrel to cold conditions. Lowbush blueberry leaf senescence, however, begins soon after harvest (Percival et al. 2012), with potential opportunity for pre-pruning herbicide applications to control weeds such as red sorrel growing beneath the blueberry canopy.

The objectives of this experiment were to determine i) the effect of autumn mowing on herbicide efficacy on red sorrel in wild blueberry fields, and ii) the effect of autumn application timing on herbicide efficacy on red sorrel. I hypothesized that i) pre-pruning herbicide applications would be as effective as post-pruning herbicide applications, and ii) applications of herbicides in mid-November will give better control than applications in mid-October due to increased carbohydrate movement into roots in November relative to October.

5.2 Materials and Methods

5.2.2 Experimental Design

5.2.2.3 Autumn Mowing Experiment

This experiment was established in autumn of 2016 in a wild blueberry field at Mt. Thom, Nova Scotia (45^{0}29'35"N; 62^{0}59'20"W). The experiment was arranged in a completely randomized design with four replications and nine treatments (Table 5.1) and a plot size of 2 m X 4 m. Mowing was conducted using a self-propelled rotary mower. Plots requiring mowing prior to herbicide applications were mowed on September 19, 2016 with all remaining plots mowed on October 11, 2016. Herbicides were applied using a CO_2 pressurized research plot sprayer equipped with four XR8002VS Teejet nozzles operated at a spray pressure of 275 KPa. Herbicides were applied on November 1, 2016. Temperature, relative humidity, and mean wind speed at the time of application were 12.7C, 60%, and 3.6 km hr^{-1}, respectively.

Table 5.1. Treatments for evaluation of autumn mowing effect on herbicide efficacy on red sorrel in wild blueberry fields.

Trade name	Active ingredient(s)	Mowed prior to herbicide applications	Application rate(s) (g a.i ha^{-1})
Control	-	-	-
Banvel	Dicamba	Yes	2200
Banvel	Dicamba	No	2200
Spartan[a]	Tribenuron-methyl	Yes	30
Spartan	Tribenuron-methyl	No	30
Roundup	Glyphosate	Yes	1800
Roundup	Glyphosate	No	1800
Ignite	Glufosinate	Yes	750
Ignite	Glufosinate	No	750

[a]Spartan was applied in conjunction with a non-ionic surfactant at 0.2% v/v basis.

5.2.2.4 Effect of Autumn Herbicide Application Timing on Red Sorrel

This experiment was established in autumn of 2016 in a wild blueberry field at Mt. Thom, Nova Scotia ($45^0$29'35"N; $62^0$59'20"W) The experiment was arranged in a completely randomized design with four replications and nine treatments (Table 5.2) and a plot size of 2 m X 4 m. Herbicides were applied using a CO_2 pressurized research plot sprayer equipped with four XR8002VS Teejet nozzles operated at a spray pressure of 275

KPa. Herbicide application dates and associated weather conditions during herbicide applications are provided (Table 5.2).

Table 5.2. Herbicides and application timings evaluated for red sorrel management in wild blueberry fields.

Trade name	Active ingredient(s)	Timing	Applications rate(s) (g a.i ha^{-1})
Control	-	-	-
Banvel	Dicamba	Early October[b]	2200
Banvel	Dicamba	Early November[c]	2200
Spartan[a]	Tribenuron-methyl	Early October	30
Spartan	Tribenuron-methyl	Early November	30
Roundup	Glyphosate	Early October	1800
Roundup	Glyphosate	Early November	1800
Ignite	Glufosinate	Early October	750
Ignite	Glufosinate	Early November	750

[a] Spartan was applied with a non-ionic surfactant at 0.2% v/v basis.

[b] Early October herbicide applications were made on October 11, 2016. Air temperature, relative humidity, and mean wind speed at the time of herbicide applications were 19.5 C, 56.2%, and 4.0 km hr^{-1}, respectively.

[c] Early November herbicide applications were made on November 9, 2016. Air temperature, relative humidity, and mean wind speed at the time of herbicide applications were 12.7 C, 60%, and 3.6 km hr^{-1}, respectively.

5.2.3 Data collection

Data collection in each experiment included initial vegetative red sorrel ramet density prior to treatment application, overwintered ramet and seedling density in May of the non-bearing year, red sorrel vegetative and flowering ramet density in July of the non-bearing year, and blueberry stem density and flower bud number in November of the non-bearing year. Ramet data were expressed as total ramet density (vegetative or vegetative + flowering) on each counting date for analysis. Red sorrel seedling density was determined in two 0.25 m x 0.25 m quadrats per plot and total and flowering ramet density were determined in two 0.3 m x 0.3 m quadrats per plot. Seedling and ramet density of red sorrel were determined in spring and summer of the non-bearing year. Blueberry stem length and floral bud number were determined on 30 randomly selected blueberry stems in each plot in autumn of the non-bearing year. Stems were clipped at ground level in each plot, bagged in the field, and brought back to the laboratory for data collection. Red sorrel initial ramet density was determined on 11-Oct-2016. Red sorrel overwintered ramet and seedling density was determined on 16-May-2017. Red sorrel total ramet and flowering ramet density was determined on 6-July-2017.

5.2.4 Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) in PROC MIXED in SAS for windows (Statistical Analysis System, version 9.4, SAS Institute, Cary, NC). In the Mixed Model, herbicide treatments were used as fixed effects. The assumption of constant variance was tested to ensure that residuals had constant variance with a normal distribution. Data were LOG(Y) or SQRT(Y) transformed to achieve normality and constant variance where necessary. Significant differences among treatments were determined using Tukey's multiple means comparison test at probability level of P = 0.05.

5.3 Results and discussion

Average initial ramet density in the autumn mowing experiment was 492 ± 117 ramets m^{-2} and did not vary across treatments (p = 0.18). There was a significant effect of herbicide treatment on overwintered and flowering ramet density ($p \leq 0.0001$), but not on total ramet and seedling density (p = 0.54). Dicamba and tribenuron-methyl gave the greatest reductions in overwintered and flowering ramet density in both mowed and unmowed plots (Table 5.4). Flowering occurs primarily in overwintering ramets (White et al. 2014), and reductions in flowering ramet density in these treatments would be expected given the reduction in overwintering ramet density. Tribenuron-methyl and dicamba reduced overwintering ramet density in the autumn herbicide screening trial as well (Tables 4.3, 4.6). Tribenuron methyl efficacy on red sorrel is not reported in the literature, though dicamba provides control of red sorrel in turfgrass and other systems (Burrill et al. 1989). Glufosinate and glyphosate did not reduce overwintering ramet density and, in turn, did not reduce flowering ramet density (Table 5.4). These treatments were also inconsistent in reducing overwintering and flowering ramet density in the autumn screening trial (Table 4.4, 4.6), further indicating lower efficacy of these herbicides on red sorrel relative to dicamba and tribenuron methyl. The field experiment conducted by Kim et al. (1999), however, found that glufosinate and glyphosate controlled red sorrel in kangwon alpine grasslands, and reasons for lack of control of red sorrel from these herbicides in lowbush blueberry fields is unclear.

Autumn applications of dicamba, glufosinate, glyphosate, and tribenuron-methyl did not reduce seedling density (Table 5.4). This can likely be attributed to limited persistence of these herbicides in soil. The approximate half-life of dicamba, glufosinate, glyphosate, and tribenuron-methyl were found to be 16 days (Smith and Belyk 1989), 60 days (Kotoula-syka et al. 1993), 47days and 32-45 days (Haney et al. 2000), respectively, likely limiting the amount of herbicide retained to provide seedling control in the year after application. Howatt (1991) also found that most sulfonylurea herbicides tested were ineffective in controlling broadleaf weeds when applied pre-emergence in blueberry fields.

Table 5.3. Effect of herbicide and mowing on red sorrel overwintered ramet, vegetative ramet, flowering ramet, and seedling density in the non-bearing year at Mt. Thom, NS in 2017. Plots mowed on September 19, 2016 and herbicides applied on November 1, 2016.

Treatment	Mowing	Overwintered ramet density (ramets m^{-2}) May 16[a]	Flowering ramet density (ramets m^{-2}) July 6[b]	Total ramet density (ramets m^{-2}) July 6[c]	Seedling density (seedlings m^{-2}) May 16[d]
Control	-	21.1 ± 2.1a[e] (481)	10.8 ± 1.2a (126)	17.9 ± 1.6a (331)	4.4 ± 2.1a (22)
Dicamba	Yes	3.8 ± 2.1c (22)	1.0 ± 1.2b (0)	16.2 ± 1.6a (284)	10.0 ± 2.1a (124)
Dicamba	No	3.4 ± 2.1c (14)	1.0 ± 1.2b (0)	12.8 ± 1.6a (198)	6.9 ± 2.1a (54)
Glufosinate	Yes	16.1 ± 2.1ab (282)	5.5 ± 1.2ab (41)	16.5 ± 1.6a (277)	10.0 ± 2.1a (121)
Glufosinate	No	12.6 ± 2.1abc (183)	6.8 ± 1.2ab (56)	16.1 ± 1.6a (261)	9.0 ± 2.1a (107)
Glyphosate	Yes	15.7 ± 2.1ab (284)	7.2 ± 1.2a (61)	14.3 ± 1.6a (218)	9.3 ± 2.1a (136)
Glyphosate	No	13.0 ± 2.1abc (183)	8.9 ± 1.2a (96)	15.1 ± 1.6a (238)	7.5 ± 2.1a (72)
Tribenuron-methyl	Yes	6.9 ± 2.1bc (62)	1.0 ± 1.2b (0)	9.6 ± 1.6a (95)	5.7 ± 2.1a (41)
Tribenuron-methyl	No	3.3 ± 2.1c (12)	1.0 ± 1.2b (0)	11.2 ± 1.6a (136)	5.8 ± 2.1a (49)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[e] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

Initial ramet density in the autumn herbicide application timing experiment was 1408 ± 276 ramets m^{-2} and did not vary across treatments ($p = 0.56$). There was a significant effect of herbicide treatment on overwintered, flowering ramet density, and seedling density ($p \leq 0.0001$), but not on total ramet density ($p \geq 0.55$). All herbicides reduced overwintered and flowering ramet density, with no differences observed between early and late application timings (Table 5.5). Dicamba and tribenuron-methyl reduced overwintered and flowering ramet density in the mowing trial as well (Table 5.4), and similar reductions were observed in the autumn herbicide screening trial (Table 4.3, 4.6). Autumn applications of these herbicides therefore appear to provide consistent reductions in overwintering and flowering red sorrel ramets. Trevett (1961) and Everett et al. (1968) indicated autumn applications of dicamba control sheep laurel (*Kalmia augustifolia* L.) in wild blueberry fields, and Jensen and North (1987) also found that application of dicamba during late fall provided complete control of speckled alder (*Alnus rugosa* Spreng.) in wild blueberry fields. These use patterns of dicamba may therefore also contribute to red sorrel management. Early or late autumn tribenuron methyl applications are also utilized for bunchberry control in lowbush blueberry (Yarborough and Hess 1996), and this provides an additional herbicide use pattern that may contribute to red sorrel management.

Glyphosate and glufosinate reduced overwintering, flowering ramet, and seedling density of red sorrel with the exception of late dicamba and early autumn glufosinate applications, which had no effect on seedling density. These treatments, however, were ineffective in the mowing trial (Table 5.4) and autumn herbicide screening trial (Table 4.4). Mechanisms to explain this inconsistency are unclear. Carlson and Burnside (1984), however, found that glufosinate toxicity was less than glyphosate at equal rates, and four times the application rate of glufosinate was required to achieve equivalent control of weeds compared to glyphosate. Performance of glufosinate and glyphosate is also influenced by environmental factors (McWhorter et al. 1980; Anderson et al. 1993) and can also be affected by timing of herbicide application as well as rate of herbicide applied (Grichar 1997). Glufosinate tends to exhibit limited root translocation in treated plants, which can reduce efficacy of this herbicide on perennial weeds. Bradley and Hagood (2002) reported that there was very limited mugwort (*Artemisia vulgaris*) control with glufosinate due to insufficient movement of glufosinate into rhizomes. Yarborough and Ismail (1981) reported that selective post-emergent applications of glyphosate following blueberry leaf abscission in late autumn provide good control of sheep laurel (*Kalmia augustifolia* L.), and this herbicide is currently registered for this use in wild blueberry fields (Jensen and Yarborough 2004). Our results indicate that these applications may also contribute to red sorrel management, though results will likely be variable and inconsistent.

Table 5.4. Effect of herbicide application timing on overwintered, vegetative, flowering, and seedling ramet density in the non-bearing year at Mt. Thom, NS in 2017. Plots were mowed on September 19, 2016 and herbicides were applied on November 1, 2016.

Treatment	Timing	Overwintered ramet density (ramets m^{-2}) May 16[a]	Flowering ramet density (ramets m^{-2}) July 6[b]	Total ramet density (ramets m^{-2}) July 6[c]	Seedling density (seedling m^{-2}) May 16[d]
Control	-	19.9 ± 2.2a[e] (430)	22.5 ± 1.7a (522)	6.9 ± 0.2a (621)	18.6 ± 2.1a (358)
Dicamba	Early	7.4 ± 2.2b (94)	1.0 ± 1.7c (0)	5.3 ± 0.2a (235)	10.8 ± 2.1b (124)
Dicamba	Late	5.2 ± 2.2b (30)	1.0 ± 1.7c (0)	5.8 ± 0.2a (424)	13.7 ± 2.1ab (219)
Glufosinate	Early	7.8 ± 2.2b (81)	1.6 ± 1.7c (3)	5.2 ± 0.2a (365)	13.3 ± 2.1ab (185)
Glufosinate	Late	11.2 ± 2.2b (156)	4.4 ± 1.7bc (28)	5.7 ± 0.2a (558)	8.8 ± 2.1b (88)
Glyphosate	Early	9.4 ± 2.2b (108)	3.2 ± 1.7bc (12)	5.8 ± 0.2a (438)	11.4 ± 2.1b (155)
Glyphosate	Late	10.1 ± 2.2b (106)	7.8 ± 1.7b (92)	5.6 ± 0.2a (615)	7.3 ± 2.1b (72)
Tribenuron-methyl	Early	11.4 ± 2.2b (122)	5.6 ± 1.7bc (40)	5.9 ± 0.2a (424)	8.4 ± 2.1b (91)
Tribenuron-methyl	Late	9.2 ± 2.2b (120)	4.3 ± 1.7bc (62)	5.1 ± 0.2ab (231)	6.9 ± 2.1b (73)

[a] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[b] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[c] Data were LOG(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[d] Data were SQRT(Y) transformed prior to analysis to meet the assumptions of ANOVA. Transformed means are presented for means comparisons and variance estimates, and means estimated from the non-transformed data are presented in parentheses.

[e] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE.

In the autumn mowing trial, herbicide applications did not have significant effects on blueberry stem height (p = 0.71) and flower bud density (p = 0.69). Blueberry stem height and floral bud number averaged 18.2 ± 0.9 cm and 3.0 ± 0.2 buds stem^{-1} respectively in the autumn mowing trial. Herbicide applications also had no significant effects on blueberry stem height (p = 0.72) and flower bud density (p = 0.57) in the herbicide application trial. Blueberry stem height and floral bud number averaged 17.6 ± 0.8 cm and 4.1 ± 0.4 buds stem^{-1} respectively in the herbicide application trial.

Autumn bearing year herbicide applications of dicamba, tirbenuron-methyl, glufosinate and glyphosate therefore exhibited good crop tolerance, which is consistent with results from the autumn screening experiment. Autumn applications of these herbicides should therefore be considered for various aspects of weed management in wild blueberry field.

5.4 Conclusion

In conclusion, efficacy of fall herbicide applications on red sorrel was not affected by mowing or application timing. Growers can therefore consider pre-pruning herbicide applications to control red sorrel if desired, and applications in both October and November should be effective. Future research, however, should evaluate the effects of mowing and herbicide application timing across a greater range of sites to confirm results of this study.

Chapter 6.0 – Conclusions

6.1 Overview

Red sorrel (*Rumex acetosella* L.) is a common herbaceous creeping perennial species in commercially managed lowbush blueberry (*Vaccinium angustifolium* Ait.) fields (McCully et al. 1991) and is now established in over 90% of the acreage of this crop in Nova Scotia (Jensen and Sampson, unpubl. data). Management of this weeds is difficult due to limited herbicide options. Therefore, it is important to develop herbicide rotation to tackle herbicide resistance, ensure long term management of this species, and requires identification of optimum treatments and their important timings in the wild blueberry production cycle. Research for this thesis was focused on 1) Occurrence of hexazinone-resistant red sorrel in wild blueberry fields in Nova Scotia, 2) Evaluation of spring herbicide applications for non-bearing year red sorrel management in wild blueberry fields, 3) Evaluation of autumn herbicide applications for red sorrel management in wild blueberry fields, and 4) Effect of autumn mowing and application timing on herbicide efficacy on red sorrel in wild blueberry fields.

In chapter 2, we concluded that red sorrel populations collected from 42 of the 44 sites used in this study were controlled by hexazinone. Therefore, it was a good sign that low occurrence of hexazinone-resistant red sorrel biotypes was observed in lowbush blueberry fields in Nova Scotia. Reasons other than resistance are therefore contributing to lack of hexazinone efficacy under field conditions and this should be an important focus of future research. However, 12 and 5% of the red sorrel plants from the Debert and Base

Line Road fields respectively, survived the hexazinone application. This determination concurs with Li et al. (2014), who observed and recorded red sorrel resistance to hexazinone in Atlantic Canada. Results in this experiment indicate that red sorrel plants in most blueberry fields are susceptible to hexazinone other than the occurrence of resistant biotypes of this weed species. Reasons for lack of control of this weed by hexazinone are unclear, but factors other than resistance need to be considered.

Results in chapter 3 indicate that pyroxsulam and sulfentrazone reduced total ramet density in the non-bearing year. Tank mixture of these herbicides with hexazinone reduced total ramet density in the non-bearing year and red sorrel recovered and density increased in the bearing year. Pyroxsulam and glufosinate reduced flowering ramet density throughout the non-bearing year and densities increased in the bearing year at Shrebrooke and Greenfield, whereas in Greenfield hexazinone+indaziflam, hexazinone+sulfentrazone, pyroxsulam and glufosinate ammonium reduced red sorrel flowering ramet density initially and densities recovered in the non-bearing year. Herbicides evaluated in this study did not provide adequate control of red sorrel in blueberry fields following spring applications. Additional research will therefore be required to identify spring non-bearing year herbicides that provide effective control of red sorrel.

In autumn herbicide applications, results indicate that dicamba, tribenuron-methyl, and dichlobenil gave the most consistent reductions in overwintered ramet density across sites in both non-bearing and bearing year. Dicamba and tribenuron-methyl also gave consistent reductions in flowering ramets across sites in non-bearing year and densities recovered and increased in populations later in the season. Tribenuron-methyl currently has a spring application registered for bunchberry (*Cornus Canadensis* L.) control in wild blueberry, and this application timing should also be evaluated for red sorrel management given efficacy of fall applications of this herbicide. Dicamba, propyzamide, flumioxazin, flumioxazin+hexazinone also reduced seedling densities, though densities increased in these treatments by the end of the nonbearing season. Efficacy of fall herbicide applications on red sorrel was also not affected by mowing or application timing. Growers can therefore consider pre-pruning herbicide applications to control red sorrel if desired, and applications in both October and November should be effective. Results indicate that red sorrel will most effectively be managed by fall herbicide applications in wild blueberry. Additional research is required to determine acceptable spring herbicide treatments for this weed species and also alternative treatments to control red sorrel in wild blueberry fields.

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