Weed Survey of Nova Scotia Lowbush Blueberry (*Vaccinium augustifolium* Ait.) Fields and Development of Management Strategies for Spreading Dogbane (*Apocynum androsaemifolium* L.)

By

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ABSTRACT

Weeds are a key limiting factor in lowbush blueberry production and creeping perennials are the most problematic weed species to manage. Weed surveys in lowbush blueberry fields are important and they provide the basis for vegetation management research in lowbush blueberries. A total of 165 bearing year lowbush blueberry fields were surveyed from 2017 to 2019, within which approximately 211 weed species were identified. The most common weed species were herbaceous perennials and woody perennials. The top 10 abundant weeds were red sorrel (*Rumex acetosella* L.), poverty oat grass (*Danthonia spicata* L.), haircap moss (*Polytrichum commune* Hedw.), hair fescue (*Festuca filiformis* Pourr.), narrow-leaved goldenrod (*Euthamia graminifolia* (L) Nutt.), rough hair grass (*Agrostis hyemalis* (Walter) BSP.), woolly panicum (*Dichanthelium acuminatum* Ell.), cow wheat (*Melampyrum lineare* Desr.), bunchberry (*Cornus canadensis* L.), and yellow hawkweed (*Hieracium caespitosum* Dumort). Results are guiding future research priorities for weed management in lowbush blueberry fields. Spreading dogbane is an increasingly troublesome weed in lowbush blueberries. Field studies were conducted from 2017 to 2019 to evaluate the 1) efficacy of a range of broadcast and spot herbicide applications and 2) mechanical and chemical control strategies for spreading dogbane. Results indicated dicamba and glyphosate continue to be the most effective herbicide spot treatments for spreading dogbane. Spot applications of foramsulfuron and flazasulfuron caused >85% injury to spreading dogbane and could be explored further as potential spot treatments. Dicamba was more effective than cutting when the herbicide was applied at the early-bud and flowering stages. Our recommendation for lowbush blueberry growers to control spreading dogbane is to apply dicamba (1.92 g a.e. L water $^{-1}$) in the early bud stage.

LIST OF ABBREVIATIONS USED

% Percent

°C Degrees Celsius

CO_2 Carbon dioxide

cm Centimeter

fb Followed by

g Gram

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

kg Kilogram

l Liter

m Meter

m^{-2} Per square meter

psi Pound per square inch

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AGGIES ONCE, AGGIES TWICE!

Chapter 1- General Introduction

Introduction

The lowbush, or wild, blueberry (*Vaccinium angustifolium* Ait.) is a perennial deciduous shrub, native to northeastern North America (Anonymous 2019). In 2018, there were 65, 642 ha of cultivated area in Canada and produced 85, 092 t of lowbush blueberries (Statistics Canada 2019). Nova Scotia is an important production region in Canada, with 15, 260 ha cultivated commercially and 11, 585 t of fruit produced in 2018 (Statistics Canada 2019). The farm gate value of lowbush blueberries in 2018 was over Cdn $66.5m nationally and about 14.2% (Cdn $9 m) was contributed by Nova Scotia (Statistics Canada 2019).

Unlike other crops, lowbush blueberry fields are not planted but are rather developed and managed from natural stands (McIsaac 1997; Moreau and Savard 2013). From 1992 to 2003, 20, 174 new ha of lowbush blueberry fields were developed in Canada (Strik and Yarborough 2005). Lowbush blueberries are managed by various management practices under this crop's unique 2-year production cycle (Jensen and Yarborough 2004). Fields are pruned by burning or mowing in the first, or nonbearing, year to remove old plant growth and encourage vegetative growth and flower bud formation (Kennedy et al. 2010). Flowers open and come into bloom in the second year, or bearing year, with fruit harvest occurring during late summer (Anonymous 2019; McIsaac 1997). Fields are pruned after the crop is harvested, and the two-year cycle begins again. Among all management practices, weed management is a major production challenge due to the lack of tillage and crop rotation (Jensen and Yarborough 2004). Weeds are a key limiting factor in lowbush blueberry production and contribute significant variation to annual yields (McCully et al. 1991; Yarborough 2011). Yarborough and Bhowmik (1993) reported that blueberry fruit count and yield decreased as weed density increased. In addition, weeds reduce berry quality and interfere with the harvesting process (Yarborough 2011). Therefore, it is essential to understand the weed composition in lowbush blueberry fields.

Creeping perennials are among the most problematic weed species in lowbush blueberry fields and are successful in cropland due to several reproductive and survival mechanisms and, in some instances, cropping and management practices that help these plants spread (Ross and Lembi 2009; Wu and Boyd 2012). Herbicides have been used as the primary weed control tool in lowbush blueberry fields for more than 50 years (Jensen and Yarborough 2004). An integrated weed management plan, however, that involves multiple strategies, such as physical, cultural, biological, and chemical practices, is more adept in controlling perennial plants (Anderson 1996; Benz et al. 1999; Miller 2016).

Spreading dogbane (*Apocynum androsaemifolium* L.) is a creeping herbaceous perennial which reproduces by seeds and prolific underground roots (Bergweiler and Manning 1999; Sampson et al. 1990). Spreading dogbane is a common weed in lowbush blueberry fields. It infested 87.5% of lowbush blueberry fields surveyed in the Saguenay-Lac-Saint-Jean region (Lapointe and Rochefort 2001) and McCully et al. (1991) reported that 3.6% of 115 fields surveyed were affected by spreading dogbane in Nova Scotia. Small patches of spreading dogbane can develop into a serious problem in commercial lowbush blueberry fields, necessitating control actions as soon as possible after the weed is identified (Sampson et al. 1990). The most recent study on spreading dogbane was conducted by Wu and Boyd (2012). However, more research on controlling this troublesome weed species is needed as recent herbicide registrations provide new opportunities for management and growers do not have a truly integrated management plan for this weed species.

Introduction of Lowbush Blueberry

Taxonomy and Biology of Lowbush Blueberry

The lowbush blueberry belongs to the *Ericaceae*, or Heath family, and is a deciduous perennial shrub native to North America. *Vaccinium angustifolium* and *V. myrtiloides* are the dominant lowbush blueberry species in commercially managed fields (Anonymous 2019). *Vaccinum angustifolium*, also known as the low sweet blueberry, can grow from 10 to 38 cm in height and has smooth stems, dark green leaves, and bell-shaped white or pinkish-white blossoms that give way to dark blue fruits. This species comprises most of the harvested lowbush blueberries in Canada. Sour top blueberry, or velvet leaf blueberry, *Vaccinium myrtilloides*, can reach from 15 to 61 cm in height and is distinguished by its stems and leaves that are covered with tiny hairs. Blossoms are also bell-shaped but greenish-white and sour top blueberry produces smaller and less sweet berries than low sweet blueberry (Anonymous 2019; Yarborough 2015). Lowbush blueberries grow best in sandy, well-drained, acidic soil with pH ranging from 4.0 to 5.5, which is not suitable for many other agricultural crops (McIsaac 1997).

Field development

Commercial lowbush blueberry fields are developed from abandoned farmland or cleared forest areas, though blueberry growers prefer the former option as it is easier to manage blueberry fields developed from abandoned farmland (Hall 1959). Fields developed from woodland normally require initial development to remove trees and usually require several years to reach full production (McIsaac 1997). Native blueberry presence should be first considered to develop a woodland area into a blueberry field (McIsaac 1997). After site selection, a development plan will follow to improve growing conditions for blueberries, such as clearing, leveling, and weed control (McIsaac 1997).

Industry overview

In 2016, global lowbush blueberry production increased by 24.5% to a total of 206, 500 metric tonnes and North America (Canada and the United States) accounted for over 90% of world lowbush blueberry production (Anonymous 2017). In 2018, there was a total of 65, 642 ha of cultivated lowbush blueberry fields in Canada in the following production regions: Quebec, 29, 275 ha (44%); New Brunswick, 15, 439 ha (24%); Nova Scotia, 15, 260 ha (23%); Prince Edward Island, 5, 398 ha (8%) (Statistics Canada 2019). In Nova Scotia, lowbush blueberry is an important crop and ranks as the second fruit crop in terms of marketed production, farm gate value, and total cultivated area (Statistics Canada 2019). The main lowbush blueberry production areas in Nova Scotia are shown in Table 1-1.

Table 1- 1. Lowbush blueberry production areas in Nova Scotia

Production zone	Counties and locations included in production zone
Cumberland County	Parrsboro, Oxford, and Collingwood
Central Nova Scotia	Halifax, Colchester, and Hants Counties
Eastern Nova Scotia	Guysborough, Antigonish, and Pictou Counties
Western Nova Scotia	Kings, Yarmouth, Digby, Lunenburg, Queens, Shelburne, and Annapolis Counties
Island of Cape Breton	Island of Cape Breton

Commercial lowbush blueberry production cycle and field management

Commercial lowbush blueberry fields are typically managed under a 2-year production cycle consisting of a nonbearing year followed by a bearing year (McIsaac 1997). Cultural practices and pest management are the two main field management strategies used to stimulate blueberry growth, increase production, and reduce yield loss (Yarborough 2015). Cultural practices include pruning, pollination, fertilization, managing soil acidity, irrigation, and propagation whereas pest management is focused on reducing the risk of insects, diseases, and weeds on yields and berry quality (Yarborough 2015).

Weed Flora of Lowbush Blueberry Fields

The weed community of lowbush blueberry fields has increased in diversity since the early 1980's (McCully et al. 1991; Jensen and Sampson, unpublished data). According to the two weed surveys conducted in Nova Scotia's lowbush blueberry fields from 1984-1985 and 2000-2001, the total weed species increased from 141 (1984-1985) to 191 (2000-2001) (McCully et al. 1991; Jensen and Sampson, unpublished data). The summary information and each weed class from both weed surveys are shown in Table 1-

2. Among all weed species, herbaceous and woody perennials were the dominant species in lowbush blueberry fields (Jensen and Yarborough 2004; table 1-2). The use of herbicide hexazinone and the development of herbicide resistance, reduction in the use of thermal pruning methods, and the use of mechanical machines resulted in increase of herbaceous and woody perennial species (Boyd and White 2009: Li et al. 2014). Jensen and Yarborough (2004) reported there was an obvious trend with increasing species of annual broadleaf and annual grass species in lowbush blueberry fields.

Table 1- 2. Number of weed species in main weed classes in Nova Scotia lowbush blueberry fields conducted in 1984-1985 and in 2000-2001 (McCully et al. 1991; Jensen and Sampson, unpublished data).

Weed classification	Species richness	
	1984-1985	2000-2001
Annual grass	0	9
Orchid	1	4
Fern	4	6
Biennial	3	1
Sedge/rush	5	5
Perennial grass	13	22
Annual broadleaf	17	33
Woody perennial	23	39
Herbaceous perennial	44	71
Total Species	110	190

Weed Survey

A weed survey consists of surveying crop fields within a given geographic area to obtain quantitative and qualitative information about weed community composition that can be useful for identifying species shifts and guiding research priorities (Frick and Thomas 1992; Webster and Coble 1997). Climate change, field management techniques, and herbicide use will affect species composition and distribution (Boyd and White 2009; Drummond and Yarborough 2014), lending utility to repeating weed surveys of a crop at regular intervals. Over time, data from consecutive surveys provide the basis for assessing changes in weed floras, understanding factors driving changes in the weed flora, and anticipating future problem species and research priorities (Andreasen and Streibig 2011). The number of weed species in Nova Scotia lowbush blueberry fields doubled between 1984-1985 and 2000-2001, and over 200 weed species occur in this crop (McCully et al. 1991; Jensen and Sampson, unpublished data; Table 1-2). Since the 2000-2001 weed survey, shifts in weed community composition are undocumented. Therefore, it is important to conduct a new weed survey which improves our knowledge of weed community composition in lowbush blueberries. The ten most common weed species from 1984-1985 and 2000-2001weed surveys are shown in Table 1-3.

Table 1- 3. Ten most common weed species in Nova Scotia lowbush blueberry fields in 1984-1985 and 2000-2001 (McCully et al. 1991; Jensen and Sampson, unpublished data).

	1984-1985 weed survey		2000-2001 weed survey	
Ranking by relative abundance	Common name	Scientific name	Common name	Scientific name
1	Bunchberry	*Cornus Canadensis* L.	Red sorrel	*Rumex acetosella* L.
2	Colonial bentgrass	*Agrostis tenuis* Sibth.	Poverty oat grass	*Danthonia spicata* (L.) Beauv. Ex Roem. & Schult
3	Poverty oat grass	*Danthonia spicata* (L.) Beauv. Ex Roem. & Schult	Bunchberry	*Cornus Canadensis* L.
4	Red sorrel	*Rumex acetosella* L.	Canada bluegrass	*Poa compressa* L.
5	False lily-of-the-valley	*Maianthemum canadense* Desf.	Cow wheat	*Melampyrum lineare* Desr.
6	Goldenrods	*Solidago* spp.	Violet	Viola spp.
7	Hawkweeds	*Hieracium* spp.	Wooly panicum	*Panicum languinosum* Ell.
8	Wooly panicum	*Panicum languinosum* Ell.	Canadian St. John's wort	*Hypericum canadense* L.
9	Common woodrush	*Luzula multiflora* (Ehrh. Ex Huffm.)	Narrow-leave goldenrod	*Euthamia graminifolia* (L.) Nutt.
10	Kentucky bluegrass	*Poa pratensis* L.	Sedge	*Carex* spp.

Creeping Herbaceous Perennials

Physiological Basis of Management Strategies for Creeping Herbaceous Perennial Weeds

Creeping herbaceous perennials reproduce sexually from seed and asexually from vegetative reproductive organs such as stolons, rhizomes, tubers, bulbs, corms, roots, and stems (Bhowmik 1997; Radosevich et al. 2007). Successful management of these weeds, therefore, requires strategies that reduce seedling recruitment (if frequent) and vigour and growth of established plants.

Reducing the vigour and growth of established creeping perennial weeds requires strategies that damage vegetative reproductive structures and reduce stored carbohydrate reserves contained in these structures, which, in turn, requires knowledge of carbohydrate dynamics during the growing season. At the start of the season, early shoot development uses carbohydrate reserves from vegetative reproductive structures, which depletes these resources and reduces vegetative reproductive structure biomass (Becker and Fawcett1998; Bradbury and Hofstra 1977). Once emerged shoots become physiologically independent, they will replenish carbohydrate reserves by transporting new carbohydrates back to the vegetative reproductive structures, usually at the flower bud stage and again at the end of the growing season following seed set (Miller 2016). These timings generally correspond to periods of low vegetative reproductive biomass, increasing susceptibility of these plants to management by reducing shoot regeneration capabilities or facilitating herbicide translocation to vegetative reproductive structures (D'Hertefeldt and Jonsdottir 1999).

Approaches to the Management of Creeping Herbaceous Perennial Weeds

Creeping perennials are very successful under various conditions, especially in perennial crops due to their similar growth patterns (Holm 1977). Management of creeping perennial weeds in these systems can involve the use of physical, mechanical, cultural, biological, and chemical controls, all of which may vary in both efficacy and practicality depending on the weed being managed and the cropping system in which the weed occurs.

Physical and mechanical controls use field equipment, such as hand hoeing, tillage, and mowing (Huiting et al. 2011). Mowing and cutting is a common practice to control tall growing weeds, but it has limited effects on creeping herbaceous perennial weeds (Amor and Harris 1977). Damage from mowing is generally limited to aboveground biomass and requires a cropping system that can support the repeated mowing required to exhaust underground vegetative reproductive structures (Amor and Harris 1977; Huiting et al. 2011). An effective stage to mow is around full leaf development and before flowering as the carbohydrate reserve is at a low level during these two stages (Miller 2016). Tillage is very effective in controlling perennial weeds as it physically damages the vegetative reproductive parts (Monaco et al. 2002). This approach is useful in annual cropping systems and some perennial crops but is unfortunately of limited applicability in a perennial crop such as lowbush blueberries. Other methods are useful for some particular weeds and management systems, but there are limitations to these methods. For example, flame weeding can kill green shoots, but it has no effect on buried plant parts (Zimdahl 2007). Although physical and mechanical controls are effective, it is suggested to combine this method with other control means to manage perennial weeds (Lowday and Marrs 1922). For example, treating Canada thistle (*Cirsium arvense* L.) rosettes with a half-rate of glyphosate following late-July tillage gave 98% control of this weed species (Hunter 1996).

Cultural weed management includes cover crop, plant competition and soil preparation. Cover crops have many advantages, and they are also useful as a weed control method. For example, in organic kale production, hairy vetch (*Vicia villosa* L.) was able to suppress the emergence of weeds up to 56 days following incorporation. In addition, total kale yield in hairy vetch treatments was more than double compared to other treatments lacking cover crops (Mennan et al. 2009). Bicksler and Masiunas (2009) reported that sudangrass (*Sorghum* × *drummondi* (Nees ex. Steud.) Millsp. & Chase) reduced Canada thistle shoot density. Currently, there is limited use of cover crops in lowbush blueberry fields, as previous attempts at this strategy resulted in problematic weed introductions (Jordan 2001). Cultural control of creeping perennial weeds generally requires use of diverse crop rotations containing competitive crops (Radosevich et al. 1997). Stilmant et al. (2012) suggested that an increase in sowing density resulted in stronger crop growth and better soil cover which can reduce weed pressures in cropland.

Soil pH can also affect herbicide efficacy and influence weed control results. Atrazine was reported to have better phytotoxicity when soil pH is in higher level, therefore adding lime to an acid soil can increase atrazine efficacy and achieve better weed control (Armstrong et al. 1967; Best et al. 1975; Harrison et al. 1976; Kells et al. 1980). Cultural techniques specific to lowbush blueberry, such as soil pH adjustment to favor blueberry growth, have been attempted (Smagula and Mitten 2003; Yarborough 2004) and can reduce weed cover (Smagula et al. 2009). Results following sulfur applications are not consistent, however, and research conducted in Nova Scotia did not find significant reductions in weed growth following sulfur applications (Kuwar 2012).

Biological control of creeping herbaceous perennial weeds can be effective if appropriate biocontrol organisms can be identified (MacEachern 2012; Radosevich et al. 1997). Biological control has been used successfully for some important perennial weeds, such as Canada thistle and Canada goldenrod (*Solidago canadensis* L.). Some parasitic fungi, bacteria, and insects have been evaluated and used as a biological control method in Canada thistle (Berner et al. 2013; Bourdot et al. 2006; Cripps et al. 2012; Green and Bailey 2000; Gronwald et al. 2002). *Puccinia punctiformis*, a rust fungus, has been shown to effectively control Canada thistle (Berner et al. 2013). Using fungal isolate *Sclerotium rolfsii* SC 64, Tang et al. (2013) achieved 70% control of Canada goldenrod. Although biological control can be effective, the effect of this method can vary, and few commercially viable options are currently available for lowbush blueberry. The dogbane beetle (*Chrysochus auratus* Fabricius) is present in Nova Scotia and feeds on spreading dogbane, but natural populations do not reach density thresholds which provide acceptable control (MacEachern et al. 2017).

Chemical control is generally effective for creeping perennial weeds and used successfully on a range of weed species in a wide range of cropping systems (Miller 2016). Symplastic herbicide applications to aboveground growth and subsequent translocation to underground reproductive structures generally provide the best control of perennial weeds (Farooq et al. 2019; Wu and Boyd 2009). Application timing is important for ensuring basipetal herbicide translocation, with the most effective timings generally at the flower bud stage or the end of the growing season following seed set (Miller 2016; Ross and Lembi 2009). For example, foliar applications of glyphosate successfully controlled Canada thistle (*Cirsium arvense*) (Glenn and Heimer 1994; Hunter 1996), common milkweed (Bhowmik 1994), and quackgrass (Doll 1993) when applied at early bud stage. Spot applications of glyphosate on red fescue (*Festuca rubra* L.) provided up to 80% control of this rhizomatous grass (Sikoriya 2014). Farooq et al. (2019) reported that spot applications of glyphosate (7.24 g ae L water^{-1}) and mesotrione (0.72 g ai L water^{-1}) injured narrow-leaved goldenrod (*Euthamia graminifolia* (L.) Nutt.) aboveground growth and reduced shoot density in both nonbearing and bearing years in lowbush blueberry fields. Given the general efficacy associated with POST symplastic herbicides on creeping herbaceous perennials, it is important to conduct research to evaluate the efficacy of these types of herbicides in lowbush blueberry as perennial weeds dominate the weed flora (Jensen and Yarborough 2004; McCully et al. 1991).

Spreading Dogbane (Apocynum androsaemifolium L.)

Biology of Spreading Dogbane

Spreading dogbane, *Apocynum androsaemifolium* L., also known as wandering milkweed, rheumatism-weed, honey bloom, or milk weed (Sampson et al. 1990), is a showy plant of the dogbane family (Apocynaceae). “Apocynum” means “away from dog”, as the plant is toxic to dogs, but also to humans, livestock, and other mammals

(Dalby 2004). It reproduces by seed and creeping roots, and once present will spread rapidly (Sampson et al. 1990). A very distinguishable characteristic of spreading dogbane is that all parts of the plant produce a milky latex sap (Hoeg and Burgess 2000).

Established spreading dogbane populations are maintained predominantly by shoot emergence from creeping roots as seedling recruitment seems limited under field conditions (Wu 2010). Shoots emerge in late April and early May, with the majority of shoots emerged by mid-June (Wu et al. 2013). Emerged shoots flower in July, with seed set generally occurring by early August (Wu et al. 2013). Although seed production data for spreading dogbane are lacking, hemp dogbane (*Apocynum cannabinum*) seed pods contain up to 200 seeds each (Evetts and Burnside 1972). Spreading dogbane seeds lack dormancy and germinate readily following release from the parent plant (Boyd and Hughes 2011). Hemp dogbane seeds also lack dormancy and germinate within a year of release (Burnside et al. 1981), though similar data for spreading dogbane are lacking.

Description of spreading dogbane biological features

Spreading dogbane leaves are oblong to ovate, arranged oppositely on the stem, and are often drooping on short stalks (Hoeg and Burgess 2000) (Fig. 1-1). The upper surface of the leaves is bright to dark green, and the underside of the leaves is lighter green (Hoeg and Burgess 2000) (Fig. 1-1).

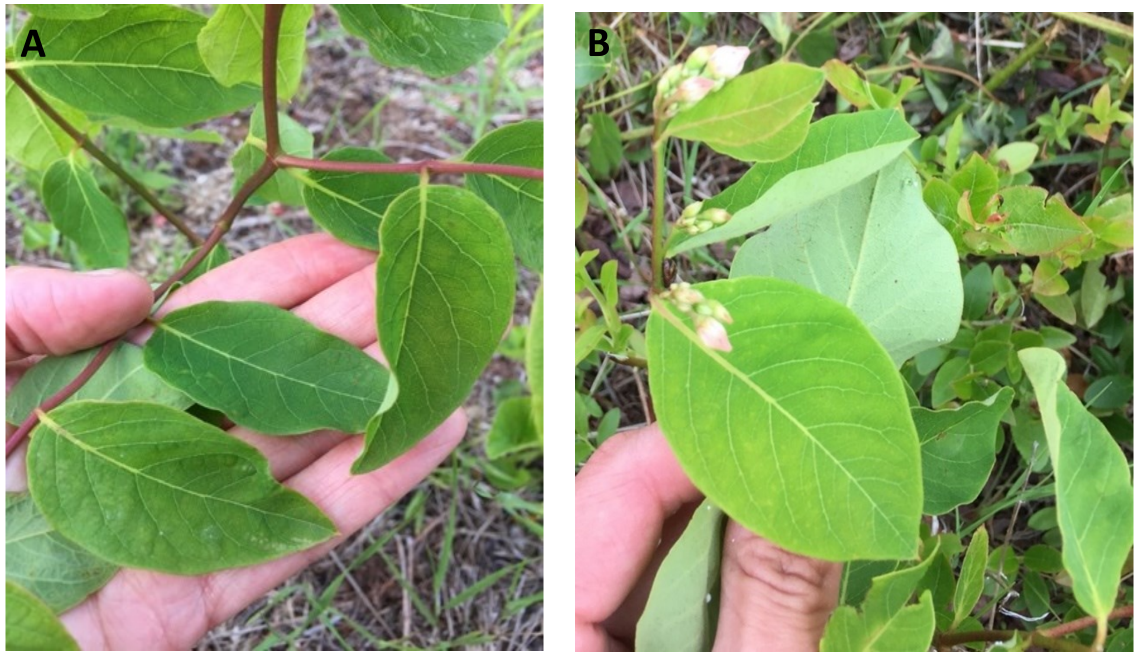

Figure 1- 1. Upper (A) and upper and low (B) surface of spreading dogbane leaves.

Spreading dogbane stems are usually reddish and can reach from 20 to 100 cm high (Boyd and Hughes 2011). The upper stem is usually more branched than the bottom (Sampson et al. 1990) (Fig. 1-2). Stems usually emerge in late April to early May (Wu et al. 2013).

Figure 1- 2. Branched (A) and unbranched (B) spreading dogbane stems.

All species of the genus *Apocynum* have extensive root systems, which can reach 1 to 1.2 m in depth (DiTommaso et al. 2009;Weaver 1926). A related *Apocynum* species, hemp dogbane (*Apocynum cannabinum* L.) has extensive root system with long vertical and horizontal roots and short rhizomes (DiTommaso et al. 2009). From field observation, spreading dogbane also has the same root features (Figures 1-3 and 1-4).

Figure 1- 3. Exhumed spreading dogbane roots in a lowbush blueberry field.

Figure 1- 4. Portion of a spreading dogbane root exhumed from a lowbush blueberry field.

Spreading dogbane flower buds are small and greenish in colour and appear in late June and early July (Wu 2010) (Figure 1-5). Flowers are small, pale pinkish-white with pink stripes, and bell-shaped (Sampson et al. 1990) (Figure 1-5). Flowers form in the upper leaf axils and are found in branched clusters. Flowers are formed from June to August (Wu 2010).

Figure 1- 5. Spreading dogbane flower buds (A) and flowers (B).

Each mature flower will produce two slender, slightly curved, pencil-like seed pods which are between 5 and 15 cm in length (Figure 1-6). Seed pods turn reddish when mature, and seeds are released as seed pods break. Each seed pod contains abundant seeds which are spike-shaped with a white pappus to allow for wind dispersal (Figure 1-6). Seed pods are usually set in the late summer and mature in the early fall (Boyd and Hughes 2011; Sampson et al. 1990; Wu 2010).

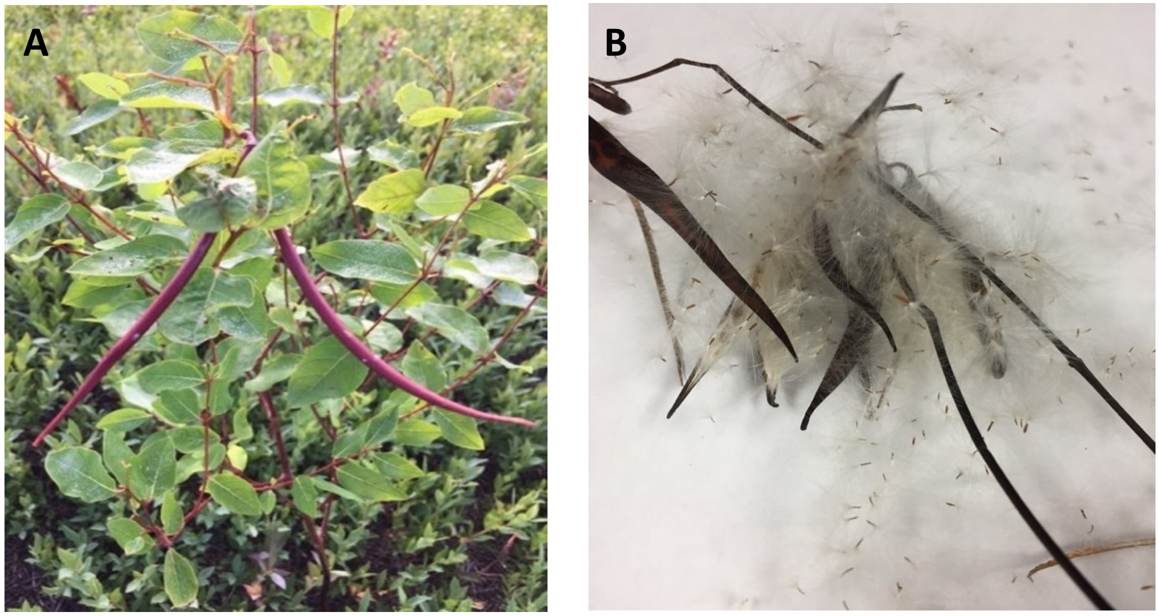

Figure 1- 6. Spreading dogbane seed pod (A) and seeds (B).

Spreading Dogbane Control

There are limited management options for spreading dogbane control in lowbush blueberries (Boyd and Hughes 2011). Recent work by Wu (2010), however, identified several potential broadcast and spot-application herbicide options. Summer broadcast applications of nicosulfuron (25 g a.i. ha^{-1}), nicosulfuron + rimsulfuron tank-mixed with mesotrione (13+13+101 g a.i. ha^{-1}), and nicosulfuron+ rimsulfuron (13+13 g a.i. ha^{-1}) controlled spreading dogbane >83% (Wu and Boyd 2012). Results were, however, variable across sites, and growers have failed to widely adopt these treatments due to risk of crop injury associated with broadcast applications of nicosulfuron + rimsulfuron (Jensen and Specht 2004). Foramsulfuron, a recently registered herbicide in the same chemical group as nicosulfuron and rimsulfuron, has good crop tolerance but has not been evaluated for efficacy on spreading dogbane. Mesotrione applications alone are generally ineffective on spreading dogbane, though multiple applications per season have been registered in lowbush blueberries in Maine, USA (Yarborough and D'Appollonio 2009). Multiple applications per season have not been extensively evaluated in blueberries in Canada, and additional research to identify potential new treatments is required. In addition, alternative herbicides with a similar mode of action to mesotrione could also be considered for lowbush blueberries as this crop exhibits good tolerance to this herbicide mode of action and alternative products that may be more effective on perennial weeds like spreading dogbane are available. Spot applications of dicamba (1 kg a.e. ha^{-1}) provided effective control (> 80%) of spreading dogbane and minimal blueberry damage (Wu 2010). Glyphosate (5 g a.e. ha^{-1}) spot applications were also effective, but injury to blueberry plants was more severe than that observed with dicamba (Wu 2010). Additional herbicides have been registered in lowbush blueberries since this work was completed, however, and there is opportunity to further reduce crop injury associated with spot applications of herbicides on spreading dogbane. Furthermore, evaluation of mechanical control, either alone or as part of an integrated management plan, has been limited, and field-based identification of optimum timing for mechanical and chemical controls have not been determined. Spreading dogbane seedling recruitment in the field is not well documented, but it is thought to be minimal (Wu 2010). As such, management strategies focused on reducing vigour and growth of established plants is more likely to reduce established populations.

Objectives

The two main objectives of this thesis are to i) conduct a weed survey of lowbush blueberry fields in Nova Scotia, and ii) develop management strategies for spreading dogbane in lowbush blueberry fields. Specific hypotheses, where applicable, are provided with each experiment description.

Chapter 2 - Weed Survey of Nova Scotia Lowbush Blueberry (*Vaccinium angustifolium* Ait.) Fields

Abstract

Weed surveys in lowbush blueberry fields are important and they provide the basis for vegetation management research in lowbush blueberries. Weed surveys have not been conducted in lowbush blueberry fields since 2001 in Nova Scotia, Canada. Studies have been conducted on vegetation management in lowbush blueberry fields in various problematic weed species and there have been documented declines in herbicide efficacy, loss and/or acquisition of herbicide active ingredients, confirmation of herbicide-resistant biotypes of important weed species, and documented vectoring of weed seeds by machinery. A weed survey was conducted in 2017 to assess potential changes in the weed flora of lowbush blueberry fields in Nova Scotia. A total of 165 bearing year lowbush blueberry fields were surveyed from 2017 to 2019, within which approximately 211 weed species were identified. Most weed species were herbaceous perennials (89 species) and woody perennials (49 species), followed by annual broadleaf (24 species) and perennial grass weeds (20 species). The remaining flora consisted of a range of ferns, biennials, sedges and rushes, and orchids. The most common weed species (top 10 abundant weeds) were red sorrel (*Rumex acetosella* L.), poverty oat grass (*Danthonia spicata* L.), haircap moss (*Polytrichum commune* Hedw.), hair fescue (*Festuca filiformis* Pourr.), narrow-leaved goldenrod (*Euthamia graminifolia* (L) Nutt.), rough hair grass (*Agrostis hyemalis* (Walter) BSP.), woolly panicum (*Dichanthelium acuminatum* Ell.), cow wheat (*Melampyrum lineare* Desr.), bunchberry (*Cornus canadensis* L.), and yellow hawkweed

(*Hieracium caespitosum* Dumort). When compared to previous weed surveys, increased occurrence of these weed species is likely the result of documented or observed reductions in hexazinone and terbacil efficacy, and common occurrence of seeds of these weed species on machinery. After the top 10 most abundant weeds, there are other weed species that are less common, but they are potentially developing into management challenges and becoming problematic. Those weed species are herbaceous perennial weeds, such as Common St. John's wort (*Hypericum perforatum* L.), spreading dogbane (*Apocynum androsaemifolium* L.) and downey goldenrod (*Solidago puberula* Nutt.), woody perennials, perennial grass and sedges and rushes. An additional 28 weed species were observed outside the quadrat but within surveyed fields and most of them were herbaceous and woody perennial species. Results are guiding future research priorities for weed management in lowbush blueberry fields.

Introduction

The lowbush, or wild, blueberry (*Vaccinium angustifolium* Ait.) is a perennial deciduous shrub that is native to northeastern North America (Anonymous 2019a). In 2018, there were 65, 642 ha of cultivated area in Canada producing 85, 092 t of lowbush blueberries (Statistics Canada 2019). Nova Scotia is an important production region in Canada, with 15, 260 ha cultivated commercially and 11, 585 t of fruit produced in 2018 (Statistics Canada 2019). The farm gate value of lowbush blueberries in 2018 was over Cdn $66.5m nationally and about 14.2% (Cdn $9m) was contributed by Nova Scotia (Statistics Canada 2019).

Lowbush blueberry fields are not planted but managed by various management practices under this crop's unique 2-year production cycle (Jensen and Yarborough 2004; Moreau and Savard 2013). Fields are pruned by burning or mowing in the first, or nonbearing year to remove old plant growth and encourage vegetative growth and flower bud formation (McIsaac 1997). Flowers open and come into bloom in the second, or bearing year, with fruit harvest occurring during late summer (Anonymous 2019a; McIsaac 1997). Fields are pruned after the crop is harvested, and the two-year cycle begins again. Weed management is a major production challenge (Jensen and Yarborough 2004). Weeds are a key limiting factor in lowbush blueberry production (McCully et al. 1991) and contribute significant variation to annual yields (Yarborough 2011). Weeds also reduce berry quality and interfere with the harvesting process, as most of the crop is mechanically harvested (Yarborough 2011). Weed surveys have traditionally been used to assess the weed flora of lowbush blueberry fields and guide weed management research priorities (Jensen and Yarborough 2004), but have not been conducted for over 15 years.

A weed survey consists of surveying crop fields within a given geographic area to obtain quantitative and qualitative information about weed community composition that can be useful for identifying species shifts and guiding research priorities (Frick and Thomas 1992; Webster and Coble 1997). Climate change, field management techniques, and herbicide use will affect species composition and distribution (Drummond and Yarborough 2014; Jensen and Yarborough 2004), lending utility to repeating weed surveys of a crop at regular intervals. Over time, data from consecutive surveys provide the basis for assessing changes in weed floras, understanding factors driving changes in the weed flora, and anticipating future problem species and research priorities (Andreasen and Streibig 2011).

The number of weed species in Nova Scotia lowbush blueberry fields doubled between 1984-1985 (McCully et al. 1991) and 2000-2001 (Jensen and Sampson, unpublished data), and over 200 weed species are now estimated to occur in this crop. Since the last weed survey in 2000-2001 there has been documented movement of weed seeds on machinery (Boyd and White 2009) and several changes in herbicide registrations that may have affected the weed community composition in lowbush blueberry fields in Nova Scotia. These shifts, however, have gone undocumented and it is therefore important to conduct a new weed survey which improves our knowledge of weed community composition in lowbush blueberry fields in Nova Scotia. The objective of this study was to conduct a weed survey to assess the current weed community composition of lowbush blueberry fields in Nova Scotia.

Materials and Methods

A total of 165 lowbush blueberry fields (84 in 2017, 49 in 2018, and 32 in 2019) were surveyed during July and August of the bearing year prior to field harvest (Figure 2-1). Bearing year fields were surveyed as they are rarely treated with herbicides and therefore tend to contain more weeds than nonbearing year fields. Fields were chosen by contacting growers and local field extension specialists in the major production areas to identify fields that were in production (not "resting", or taken out of production) and in the bearing year at the time of the survey. A random field selection from a complete list of fields was attempted, but we encountered significant difficulty obtaining a complete list that was not biased towards a given processor or that gave clear indication of fields that were being actively farmed. A significant number of fields were not being actively farmed during the survey due to low crop prices, and these needed to be avoided to ensure survey results reflected the weed species that are surviving and occurring in actively farmed lowbush blueberry fields.

There are five main lowbush blueberry production areas in Nova Scotia, including Cumberland County, Central Nova Scotia, Eastern Nova Scotia, Western Nova Scotia, and the Island of Cape Breton. This survey was mainly focused on the first four regions due to limited lowbush blueberry acreage in Cape Breton relative to mainland Nova Scotia and practical limitations of traveling to fields in this region (Table 2-1).

The methodology used in this weed survey was similar to McCully et al. (1991). Weed species density and identification, as well as crop density, were determined in twenty 1 m^2 quadrats in each field. Quadrats were placed along a "W" in each field with five quadrats in each transect. Distance between quadrats in each transect was determined by the size and shape of the field, with more distance between quadrats in larger fields and less distance between quadrats in smaller fields. Weed species observed in fields, but outside of quadrats, were recorded as well.

Data were summarized into the quantitative measures of frequency (unadjusted and adjusted), field uniformity (all fields and occurrence fields), density (all fields and occurrence fields), and relative abundance. Unadjusted frequency indicates the percentage of the total number of fields surveyed that contained a weed within at least one quadrat, whereas adjusted frequency includes fields in which the weed was observed outside the quadrats as well. Field uniformity (all fields) indicates the percentage of the total number of quadrats sampled that contained a weed, whereas field uniformity (occurrence fields) is expressed as the percentage of quadrats that contained a weed, but only when considering the fields in which the weed occurred. Density, defined as, the mean density of a weed species, with the expression of the density (all fields) and density (occurrence fields) similar to that as indicated for field uniformity.

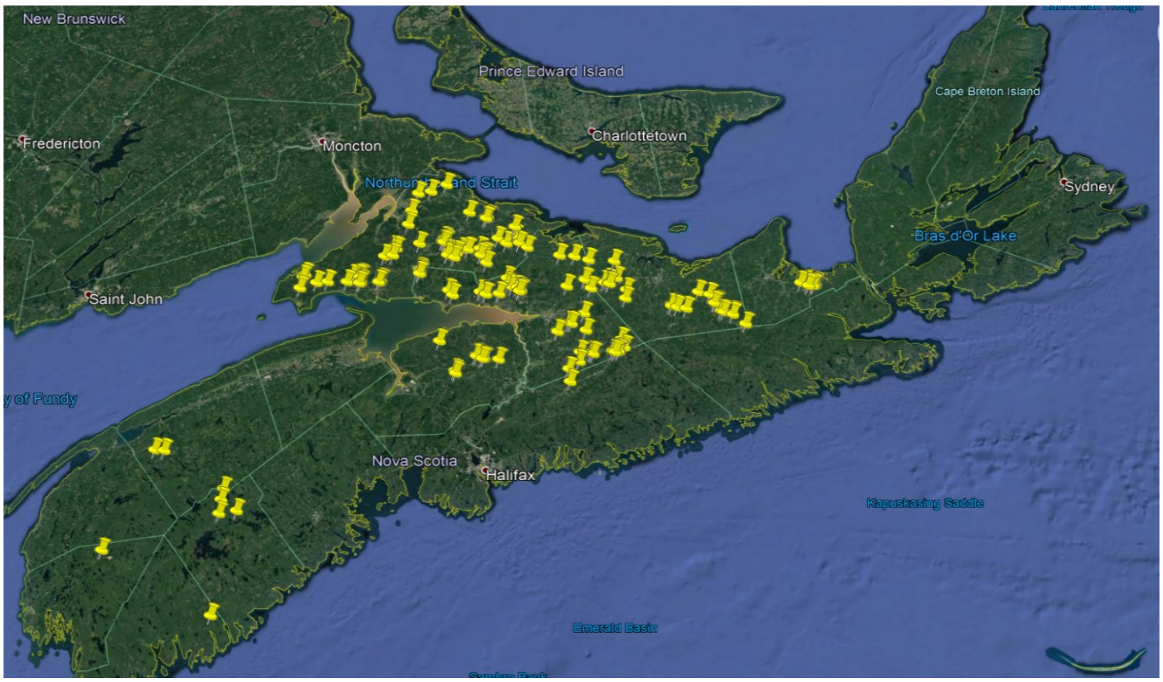

Figure 2- 1. Distribution of bearing year lowbush blueberry fields included in a weed survey in 2017, 2018, and 2019.

Table 2- 1. Summary of bearing year lowbush blueberry fields surveyed in the major lowbush blueberry producing regions of Nova Scotia in 2017, 2018, and 2019.

County	# of fields surveyed
Cumberland	66
Colchester	39
Pictou	21
Antigonish	10
South Shore Counties (Queens, Shelburne, Yarmouth, Annapolis)	10
Halifax	9
Hants	9
Guysborough	1

Relative abundance is a measurement that compares the individual weed species relative to each other. This measurement was calculated from the frequency (unadjusted), field uniformity (all fields), and mean density (all fields) using the formula provided by McCully et al. (1991). The calculation is shown as follows:

The relative frequency for species A (RF_A) $= \frac{\text{frequency value of species A}}{\text{frequency values for all species}} \times 100$

Relative field uniformity for species A (RU_A) $= \frac{\text{field uniformity value of species A}}{\text{field uniformity values for all species}} \times 100$

Relative mean density for species A (RD_A) $= \frac{\text{mean field density value of species A}}{\text{mean field density values for all species}} \times 100$

Relative abundance for species A (RA_A) = RF_A+ RU_A+ RD_A.

Relative abundance was used as the primary factor for ranking importance of weed species identified in the survey, with frequency, field uniformity, and density considered on an individual weed basis.

Results and Discussion

A total of 211 weed species were found in this weed survey, with 183 weed species identified within the quadrats (Table 2-2) and an additional 28 species observed outside the quadrats (Table 2-3). A total of 141 weed species (119 weed species within quadrats and 22 weed species outside the quadrats) were found in the1984-1985 weed survey (McCully et al. 1991), with a total of 191 weed species (125 weed species within quadrats and 66 weed species outside the quadrats) found in the 2000-2001 weed survey

(Jensen and Sampson, unpublished data) (Table 2-2). Herbaceous and woody perennials dominated the weed flora, similar to the previous surveys, followed by annual broadleaf and perennial grass weeds (Tables 2-2 and 2-3). Sedges and rushes continue to be common and are likely more numerous than indicated in these surveys due to difficulty in identifying all samples to species. A small range of biennial weeds, ferns, orchids, and annual grasses comprised the remainder of the weed flora (Tables 2-2 and 2-3).

Table 2- 2. Number of weed species in dominant weed classes found in Nova Scotia lowbush blueberry fields in weed surveys conducted in 1984-1985, 2001-2002 and 2017-2019.

Weed classification	Total number of weed species		
	1985-1985[a]	2001-2002[b]	2017-2019
Annual grass	0	9	5
Orchid	1	4	4
Fern	4	6	5
Biennial	3	1	6
Sedge/rush	5	5	8
Perennial grass	13	22	20
Annual broadleaf	17	33	24
Woody perennial	23	39	49
Herbaceous perennial	44	71	89
Total species	110	190	210

[a]McCully et al. 1991
[b]Jensen and Samspon, unpubl. data

Table 2- 3. Weed species observed within Nova Scotia lowbush blueberry fields but outside the quadrats in a weed survey conducted between 2017-2019.

Weed classification	Total number of weed species
Fern	1
Biennial	1
Perennial grass	2
Annual broadleaf	2
Woody perennial	8
Herbaceous perennial	14
Total species	28

Common weeds in 2017-2019 weed survey of lowbush blueberry fields

The 10 most abundant weed species in lowbush blueberry fields were red sorrel (*Rumex acetosella* L.), poverty oat grass (*Danthonia spicata* (L.) Beauv.), haircap moss

(*Polytrichum commune* Hedw.), hair fescue (*Festuca filiformis* Pourr.), narrow-leaved goldenrod (*Euthamia graminifolia* (L.) Nutt.), rough hair grass (*Agrostis hyemalis* (Walter) BSP.), woolly panicum (*Dichanthelium acuminatum* Ell.), cow wheat (*Melampyrum lineare* Desr.), bunchberry (*Cornus canadensis* L.), and yellow hawkweed (*Hieracium caespitosum* Dumort) (Table 2-4).

The most abundant weed species identified was red sorrel. Red sorrel had the highest frequency (both unadjusted and adjusted), field uniformity (both all and occurrence fields) and density (both all and occurrence fields) (Table 2-4). In terms of relative abundance, red sorrel was two times more abundant (39.80) than the next abundant weed species, poverty oat grass (18.56). When compared to the other two weed surveys, the relative abundance of red sorrel increased from 16.6 (ranked at fourth) in the early 1980's (McCully et al. 1991) to 38.2 (ranked at first) in the early 2000's (Jensen and Sampson, unpublished data), indicating that factors contributing to increased occurrence of red sorrel occurred prior to our survey as there has been little change in the relative abundance of this weed since 2001. Other parameters, however, have increased steadily across surveys. The unadjusted frequency of red sorrel increased from 73% in the 1984-1985 weed survey to 80.5% in the 2000-2001 weed survey to 97.6% in our survey (Table 2-4). Red sorrel seed is a common contaminant on harvesting equipment (Boyd and White 2009), likely contributing to the increased frequency of this weed species. Field uniformity for red sorrel (all fields) was below 30% in the early 1980's and 2000's but increased to 62.9% in our survey. Similarly, density of red sorrel (all fields) increased from 6 and 1 plants m^{-2} in 1984-1985 and 2000-2001, respectively, to 72.1 plants m^{-2} in our survey (Table 2-4). Red sorrel was traditionally controlled with PRE hexazinone applications (Jensen 1985a; Jensen and Specht 2002), though control by this herbicide has become increasingly variable (Kennedy et al. 2010, 2011) and hexazinone-resistant populations have been identified in lowbush blueberry fields in Nova Scotia (Li et al. 2014). Growers generally report limited control of red sorrel from hexazinone as well, and this lack of control no doubt has contributed to the increase in field uniformity and density of red sorrel within fields. Red sorrel can be suppressed with fall pronamide applications (Hughes et al. 2016), though cost of his herbicide precludes its use by most growers, again limiting control of this weed and facilitating spread. The basic biology of red sorrel has also likely contributed to the increased occurrence of this weed species. Red sorrel spreads by seeds and a shallow creeping root system (Kennedy 2009; White et al. 2014). Seedlings emerge throughout the growing season and contribute to established red sorrel populations in wild blueberry fields (White et al. 2014), but vegetative reproduction of ramets from the creeping root system is the primary means of population maintenance (Kennedy 2009; White et al. 2014). Ramets emerge throughout the entire growing season in Nova Scotia, with ramet populations peaking in mid to late autumn (White et al. 2015). Emerged ramets remain as vegetative rosettes below the blueberry canopy in the year of emergence as flowering occurs primarily in overwintering ramets (White et al. 2014) and is induced by vernalization (White et al. 2015b). This growth pattern indicates prolonged periods of indeterminate vegetative growth in this weed species which, when coupled with lack of adequate control from hexazinone, seed spread on machinery, and documented increases in growing season length in lowbush blueberry production regions (Drummond and Yarborough 2014), would account for the large increase in field uniformity and density that have occurred since 2000-2001. Red sorrel reduces lowbush blueberry yield (Hughes et al. 2016), may increase occurrence of

Botrytis cineara blight (Hughes at el. 2016) and interferes with pollination (Hughes 2012), and becomes prolific if not controlled following fertilizer applications (Kennedy et al. 2010, 2011). Development of control strategies for this weed species should therefore be a major component of future research activities.

Poverty oat grass was the second most abundant weed (Table 2-4). Poverty oat grass is a common tuft-forming perennial grass in lowbush blueberry fields (Hall et al. 1979; Yarborough and Bhowmik 1989; Jensen and Yarborough 2004) and was the third and second most common weed species found in 1984-1895 and 2000-2001, respectively. The relative abundance of poverty oat grass declined from 27.5 in 2000-2001 to 18.6 in our survey (Table 2-4), indicating reduced importance of this weed species. The frequency of fields containing this weed species, however, increased from 65.6% to 92.7% and density and field uniformity increased from 0.7 to 5.7 plants m^{-2} and 18 to 43.4, respectively (Table 2-4). Although traditionally controlled by hexazinone (Jensen 1985a; Yarborough et al. 1986; Yarborough and Bhowmik 1989; Jensen and Specht 2002) and terbacil (Smagula and Ismail 1981; Trevett and Durgin 1972), hexazinone-tolerant biotypes have been identified (Burgess 2002; Jensen and Hainstock 2000); Jensen et al. 2003) that may limit efficacy of this herbicide and facilitate increased occurrence of this weed. Terbacil use has also declined due to product cost and grower concern of erosion following aggressive removal of grass species from fields. Poverty oat grass serves as a good living mulch in blueberry fields if properly suppressed (Burgess 2002), and research indicates that densities of <15 poverty oat grass plants m^{-2} are not competitive for nitrogen in lowbush blueberry fields (Marty et al. 2019). Average density in our survey was almost three times lower than this threshold, so it is likely that poverty oat grass is not competitive with lowbush blueberry in many fields where it occurs. Dense populations of flowering poverty oat grass plants can, however, impede harvesting (Jensen and Hainstock 2000; Jensen and Specht 2002) unless suppressed with fluazifop-p-butyl or sethoxydim, and prolonged use of these ACCase-inhibiting herbicides is a concern due to potential resistance development and current lack of alternative POST herbicides (White and Zhang 2019). Future research should therefore focus on identification of new POST herbicides for poverty oat grass to ensure long term capability of supressing this weed while simultaneously benefitting from the presence of this grass as a living mulch.

Haircap moss was the third most abundant weed species in our survey. This plant species was not included in the previous two weed surveys and, as such, trends over time are not possible to assess. The relative abundance of haircap moss was 17 and this weed species was found in 53.9% of fields surveyed (Table 2-4). Field uniformity, however, was low (Table 2-4) and indicates patchy distribution of this weed species in lowbush blueberry fields. Haircap moss is nonetheless a concern to growers as dense patches of moss reduce lowbush blueberry stem density and yield (Percival and Garbary 2012). Flumioxazin is currently registered for control of haircap moss (Percival and Garbary 2012) and recent advances in precision agriculture technology in lowbush blueberries (Esau et al. 2014; 2018) have greatly improved control of this weed species. Future research needs for this weed species seem limited at this time, though flumioxazin is limited to fall applications (Percival and Garbary 2012) and therefore identification of a spring treatment for haircap moss suppression would be beneficial for lowbush blueberry producers unable to conduct fall herbicide applications.

Hair fescue was the fourth most common weed species that we found (Table 2-4) and is a tuft-forming perennial grass of great concern to lowbush blueberry growers. Yield losses of 50% or more are common in dense sods (White 2019; Zhang et al. 2018, Zhang 2017), and many growers are unable to harvest fields with heavy hair fescue infestations due to inability of mechanical harvesters to move through dense tufts. Frequency, field uniformity, and density of this weed decreased dramatically between 1984-1985 and 2000-2001 (McCully et al. 1991; Jensen and Sampson unpubl. data), likely due to control of this species by hexazinone and terbacil (Jensen 1985a; Jensen 1985b; Sampson et al. 1990; Smagula and Ismail 1981). Hexazinone resistance, however, is suspected in hair fescue (Jensen and Yarborough 2004) and hexazinone has failed to control hair fescue in recent research trials (White 2019; Zhang 2017). Recent research also indicates that hair fescue from lowbush blueberry fields is 14 times more tolerant to hexazinone than hair fescue from a roadside population (White and LaForest, unpubl. data), further supporting the lack of hexazinone efficacy on this weed species. Terbacil efficacy is also variable (Zhang 2017; Zhang et al. 2018) and generally limited to single-season suppression (White 2019). Hair fescue frequency, field uniformity, and density increased from 7, 1.4, and 0.1 in 2000-2001to 67.9, 25.4, and 3 in 2017-2019, and declining hexazinone and terbacil efficacy have likely contributed to this. Hair fescue seed is common on wild blueberry harvesters as well (Boyd and White 2019), likely contributing to the large increase in occurrence of this weed as hair fescue seeds lack primary dormancy and readily germinate after dispersal in late summer and early fall (White 2018). Although burn pruning does not eliminate established tufts (Penney et al. 2008), hair fescue seeds are killed by short-term exposure to temperatures of 200 and 300 °C (White and Boyd 2016). The replacement of burning by flail mowing for pruning

(Eaton et al. 2004; Yarborough 2004) may therefore be contributing to increased seed survival and dispersal of this weed species as well. The most effective control for hair fescue is currently fall pronamide applications (White 2019; Zhang et al. 2018), which many growers have not been able to utilize due to the high product cost (Cdn \$500.00 ha^{-1}) and low farm gate value of lowbush blueberries. Precision agriculture technologies can reduce pronamide costs (Esau et al. 2014), though growers have been slow to adopt this technology despite short pay back periods associated with investment in the required equipment (Esau et al. 2016). The ALS/AHAS-inhibiting herbicide foramsulfuron was recently registered for suppression of hair fescue and nonbearing year applications of this herbicide reduce hair fescue flowering and seed production (White and Kumar 2017; Zhang 2017). Levels of suppression are variable, however (Zhang et al. 2018), and the grass recovers and grows normally in the bearing year, necessitating use in conjunction with fall nonbearing year pronamide applications to maintain control over the 2-yr production cycle (White 2019). Recent research has identified promising new herbicides for management of this weed species (Yarborough and Cote 2014; Zhang et al. 2018), though most promising new herbicides are also ALS/AHAS-inhibitors, leading to concerns about the long-term sustainability of new herbicide products for management of this weed species. Emphasis on development of new management strategies for this weed species must continue as pronamide and ALS/AHAS-inhibiting herbicide resistance is an ongoing concern and recently identified herbicides that improve hair fescue control have yet to be registered for use in Canada.

Narrow-leaved goldenrod was the fifth most abundant weed species in our survey and, based on our data, has become the dominant goldenrod species in lowbush blueberry fields in Nova Scotia (Table 2-4). Goldenrods are common in sites lacking tillage (Blackshaw 2005; Kapusta and Krausz 1993) and are therefore very common weeds in lowbush blueberry fields (Jensen 1985a; Jensen 1985b; LaPointe and Rochefort 2001; Yarborough et al. 1986), particularly those developed from abandoned farmland (Hall 1959). Goldenrods were surveyed collectively under the *Solidago* genus in 1984-1985 and occurred in 69% of fields surveyed (McCully et al. 1991). When separated by species, narrow-leaved goldenrod occurred in 31.3% of fields surveyed in 2000-2001 and had a field uniformity and density of 13.9 and 0.2 plants m^{-2}, respectively. Our data therefore indicate a large increase in the occurrence of this weed species in lowbush blueberry fields in Nova Scotia (Table 2-4). Goldenrods are generally susceptible to hexazinone (Jensen 1985a; Jensen 1985b; Yarborough et al. 1986), and >80% control of narrow-leaved goldenrod was reported following bearing year applications of 1 kg ha^{-1} of hexazinone (Jensen and Specht 2002). Boyd and White (2010), however, reported incomplete control of goldenrods with hexazinone and White et al (2016) found that hexazinone did not control narrow-leaved goldenrod. Given the low frequency of all other goldenrod species in our survey (Table 2-4), it seems that reduced hexazinone efficacy on narrow-leaved goldenrod specifically has contributed to the increased occurrence of this weed species and future research to assess potential development of hexazinone resistance in this weed species should be conducted. Narrow-leaved goldenrod can be controlled by a range of spot herbicide applications (Farooq et al. 2019) and is suppressed by broadcast mesotrione applications (Boyd and White 2010; Farooq et al. 2019; White et al. 2016). Suppression is improved when mesotrione is applied in conjunction with PRE hexazinone applications (Boyd and White 2010) or when sequential mesotrione applications are used (Farooq et al. 2019). Sequential nonbearing year mesotrione applications reduce bearing year shoot density of narrow-leaved goldenrod (Farooq et al. 2019) and reduce the need for bearing year herbicide applications, and the lowbush blueberry industry should continue to pursue registration of this use pattern in light of declining hexazinone efficacy as tall weeds like goldenrods can shade blueberry plants (Yarborough and Marra 1997) and interfere with harvest (Jensen and Specht 2002) and must therefore be managed effectively.

The sixth and seventh most abundant weed species were the tuft-forming perennial grasses, rough hair grass and woolly panicum (Table 2-4). Rough hair grass was not documented in the 1984-1985 weed survey (McCully et al. 1991) but was found in the 2000-2001 weed survey (Jensen and Sampson, unpublished data). Frequency, field uniformity, and density of this weed increased in our survey relative to 2000-2001, likely due to the occurrence of dense stands of presumably hexazinone tolerant biotypes of this grass species and deregistration of atrazine (Jensen and Hainstock 2000; Jensen and Yarborough 2004). Rough hair grass is, however, susceptible to terbacil (Jensen and Hainstock 2000), the commonly used ACCase-inhibiting herbicides fluazifop-p-butyl and sethoxydim (Boyd et al. 2014; White and Zhang 2019), and foramsulfuron (White and Zhang 2019) and is therefore quite easily managed in lowbush blueberry fields. This grass species does, however, become abundant in bearing year fields (White, personal observation) and recent changes in lowbush blueberry processor policies on pesticide use have routinely limited bearing year applications of herbicides such as fluazifop-p-butyl and sethoxydim. Individual rough hair grass plants can produce upwards of 16 000 seeds plant $^{-1}$ (Stevens 1932) which commonly occur on harvesting equipment (Boyd and White 2009) if plants are not suppressed with herbicides in the bearing year. Density of this grass was, however, low (Table 2-4), and growers should therefore monitor fields and use rotations or tank mixtures of fluazifop-p-butyl or sethoxydim and foramsulfuron to manage this grass effectively and reduce likelihood of herbicide resistance development.

Woolly panicum has been a consistently common grass across all weed surveys in lowbush fields in Nova Scotia, but is generally of little concern to growers due to the low field uniformity and density of this grass species (Table 2-4). Frequency of this grass increased from 35 to 49% between 2000-2001 and 2017-2019, however, and field uniformity and density were higher in our survey than in previous surveys. This grass species is therefore increasing in occurrence in lowbush blueberry fields in Nova Scotia, though implications of this are unclear as limited research has been conducted to date on this grass species and general effects of this grass on lowbush blueberry plants or susceptibility to commonly used herbicides is not known. *Panicum* spp. in general are quite susceptible to ACCase-inhibiting herbicides such as fluazifop-p-butyl and sethoxydim and ALS/AHAS-inhibiting herbicides that have activity on grasses (Jensen and Yarborough 2004; Zandstra et al. 2004) and so this species is likely easily managed in lowbush blueberry fields. Future research should, however, be conducted to improve knowledge of general herbicide susceptibility of this grass species and to improve understanding of any potential impacts of this grass species on lowbush blueberry.

Cow wheat was the eighth most common weed species in lowbush blueberry fields in our survey (Table 2-4). Frequency, field uniformity, and density of this weed have increased steadily since the 1984-1985 survey and are the highest ever recorded in our survey. Cow wheat is a facultative root hemiparasitic annual plant that grows to about 30 cm in height and occurs widely in North America (Cantlon et al. 1963; Nave et al.

2018). Increased occurrence of this weed species is therefore a concern as hemiparasitic species generally withdraw resources from host plants via haustoria connections (Těšitel et al. 2010), potentially reducing growth of the host plant. For example, cow wheat removed radiolabelled phosphate from jack pine (*Pinus banksiana*) seedlings (Cantlon et al. 1963). Parasitism of lowbush blueberry by cow wheat has not been documented in commercial fields, but has been observed in jack pine stands (Cantlon et al. 1963). Common cow wheat (*Melampyrum pretense* L) parasitizes *Vaccinium* spp. as well (Masselink 1980), indicating potential preference of the genus *Melampyrum* for *Vaccinium* spp. Growers observe yield losses in dense patches of cow wheat, though the mechanism of yield loss is not clear. Cow wheat can be easily managed with mesotrione (Anonymous 2015a) and foramsulfuron (Gavin Graham, personal communication; White, personal observation), but can become lodged in the teeth of mechanical harvesters and hinder harvest operations if not controlled in the bearing year. Future research should be conducted to determine potential parasitic interactions between cow wheat and lowbush blueberry as this may be contributing to yield losses in lowbush blueberry fields.

The ninth most common weed species was bunchberry (Table 2-4). Bunchberry was the most common weed species found in 1984-1985 (McCully et al. 1991) but frequency, field uniformity, and density have generally declined between 1984-1985 and 2017-2019. Research efforts implemented following the 1984-1985 weed survey resulted in identification of the ALS/AHAS-inhibiting herbicide tribenuron methyl as an effective herbicide on bunchberry (Howatt 1992). Tribenuron methyl was registered for bunchberry control in lowbush blueberries in Canada in 1994 (Jensen and Specht 2004), and additional research conducted since 1994 has resulted in both spring nonbearing year and fall bearing year application timings being registered for use (Anonymous 2015b). Both application timings are routinely used by growers, likely contributing to the decline in survey parameters over time for this weed species. To date, no evidence or suspicion of resistance has occurred, though identification of an alternative to tribenuron methyl for bunchberry control would be advisable as this plant competes with lowbush blueberry for space (Yarborough and Bhowmik 1993) and must be managed to prevent contamination of harvested blueberries by bunchberry fruit (McCully et al. 1991).

The tenth most abundant weed species in this survey was yellow hawkweed (Table 2-4). Surveyed collectively under the *Hieracium* genus in the past, hawkweeds were found in 48% of fields surveyed in 1984-1985 but declined to <5% of fields surveyed in 2000-2001, presumably due to susceptibility of these weeds to hexazinone and atrazine (Jensen 1985a; Jensen 1985b; Penney and McRae 2000) and possibly terbacil (Anonymous 2017). The trend of increasing frequency, field uniformity, and density between 2000-2001 and 2017-2019 is a concern as it suggests selection of hexazinone-resistant biotypes of this weed species. Eriavbe (2014) reported short-term suppression of *Hieracium* spp. with hexazinone, indicating a decline in hexazinone efficacy on this genus. Synthetic auxin herbicides, however, gave good control (Eriavbe 2014) and many growers are now using clopyralid to manage hawkweeds. Terbacil also continues to provide suppression of hawkweeds (Anonymous 2017), though this herbicide is not routinely used for hawkweed management due to product cost and concern of erosion following grass removal by terbacil. Future research should combine additional herbicide screening activities with focus on evaluating various clopyralid application timings, rates, and tank mixture partners for improved control of this increasingly common weed complex.

Other less common but potentially problematic weeds

Although less common than the weed species discussed above, many other weed species identified in the quadrats during the survey should be of concern to growers and of priority for future research activities due to trends in survey responses, lack of adequate control measures, or potential for future problems.

Other herbaceous perennial weeds identified in the survey that should be of concern are Common St. John’s wort (*Hypericum perforatum* L.), spreading dogbane (*Apocynum androsaemifolium* L.), and downey goldenrod (*Solidago puberula* Nutt.). Although the field uniformity indicates common St. John’s wort is patchy in the fields where it occurs, frequency of this weed increased from 11.3 in 1984-1985 to 43.6 in 2017-2019 (Table 2-4). Common St. John’s wort is invasive in Canada (Clark 1953) and produces an abundance of highly viable seeds (Crompton et al. 1988) and rhizomes (Crompton et al. 1988; Sampson et al. 1990). Stems can reach 90 cm in height (Crompton et al. 1988), providing opportunity to shade blueberry plants and interfere with harvesting. The plant is not controlled by s-triazine herbicides such as hexazinone (Crompton et al. 1988) and glyphosate is considered the most effective herbicide for this weed species (Campbell et al. 1975; Campbell et al. 1979). Growers will therefore, likely need to rely on careful spot applications or wiper applications of glyphosate until an alternative treatment can be developed.

Frequency of fields containing spreading dogbane increased from 1.7 in 1984-1985 to 16.4 in 2017-2019 (Table 2-4). The plant reproduces by seeds and its prolific underground roots (Bergweiler and Manning 1999; Sampson et al. 1990). Stems can reach 75 cm in height (Sampson et al. 1990) and shading from this weed species can reduce lowbush blueberry yield by >80% (Yarborough and Marra 1997). Broadcast herbicide applications provide variable levels of control of spreading dogbane in lowbush blueberry (Wu and Boyd 2012), though recent research indicates that a tank mixture of foramsulfuron + flazasulfuron is an effective broadcast treatment that could be considered for lowbush blueberry (Chapter 3, Table 3-14). The most reliable control of spreading dogbane in lowbush blueberry is generally obtained with spot applications of dicamba (Wu and Boyd 2012) and applications at the early flower bud to flowering stage of the weed are most effective (Chapter 4, Table 4-7). Recent research efforts to identify an alternative spot treatment for this weed have not been successful (Chapter 3, Table 3-16 and Table 3-18), though tank mixtures of dicamba with ALS/AHAS-inhibiting herbicides may improve control (Chapter 3, Table 3-19) and recent results warrant additional research.

Downey goldenrod is an increasing concern to growers and is a weed species for which little information is available in lowbush blueberry fields. It is unclear if this goldenrod species was found in the 1984-1985 survey, and the plant was not indicated in the 2000-2001 survey. We are unable to find research reports on management of this species, and no information on susceptibility to herbicides used in lowbush blueberry could be found. As such, future research should be conducted to better understand the impacts of this weed species in lowbush blueberries and identify potential management options for the weed.

Other woody perennials include red and black chokeberry (*Aronia arbutifolia* (L.) Pers. and *Aronia melanocarpa* (Michx.) Elliott), black huckleberry (*Gaylussacia baccata* (Wangenh.) K. Koch), glossy buckthorn (*Frangula alnus* Mill.), and spireas (*Spiraea tomentosa* L., *Spiraea alba* var. *latifolia*, and *Spiraea* spp.). Chokeberries, black huckleberry, and glossy buckthorn are a concern due to lack of hexazinone efficacy (Jensen 1985a; Yarborough and Bhowmik 1989), limited selective control options for these species (Jensen and Specht 2004; Jensen and Yarborough 2004), and the potential contribution of fruit contaminants to harvested blueberries (Yarborough and Ismail 1979; Yarborough and Ismail 1980). Although some growers delay pruning an extra year to allow these weeds to grow above blueberry plants to facilitate selective weed wiper applications, this is not a common practice and there are little to no experimental data to support this management approach. Spot applications of chlorimuron selectively controlled black chokeberry (Jensen and Yarborough 2004), indicating that selective treatments can likely be found for these species if these activities are deemed a research priority. Glossy buckthorn in particular should be of high priority due to potential dispersal of seeds by birds (Craves 2015), increasing prevalence of this invasive species throughout Nova Scotia (Belliveau 2012), and personal observation of this species occurring in lowbush blueberry fields taken out of production during periods of low crop prices (White, personal observation).

The other major perennial grass weed identified in the survey was red fescue (*Festuca rubra* L.), a rhizomatous perennial grass presumably introduced into lowbush blueberry fields as a contaminant in straw used for burning. This grass was first recorded in 2000-2001 when it occurred in <1% of fields surveyed. It occurred in about 8% of fields we surveyed from 2017-2019 and has a very high field uniformity and density in fields where it occurs (Table 2-4). This grass forms dense sods that reduce lowbush blueberry growth and yield (Sikoriya 2014) and is only known to be adequately controlled by pronamide, dichlobenil, or glyphosate (Sikoriya 2014). Costs associated with pronamide and dichlobenil, however, limit grower use of these herbicides, and glyphosate poses a significant crop injury risk. Nonbearing year suppression with foramsulfuron, however, increased yields (Sikoriya 2014) and therefore provides growers with a registered suppressive treatment until additional research can be conducted to identify new control strategies. Flazasulfuron provides better suppression of hair fescue than foramsulfuron (Zhang et al. 2018) and should be evaluated on red fescue as well. Given the increased occurrence and extensive distribution of this weed in infested fields, future research must identify new control strategies for this weed species.

Of the sedges and rushes identified, black bulrush (*Scirpus atrovirens* Willd.) continues to be common in lowbush blueberry fields and toad rush (*Juncus bufonius* L.) was also very common in our survey from 2017-2019 (Table 2-4). Black bulrush occurred in 3.5% of fields surveyed in 1984-1985 but occurred in 30.9% of fields in our survey from 2017-2019. The presence of black bulrush can reduce blueberry yield and the thick tufts of this weed species also hamper mechanical harvesting (Anonymous 2017; Boyd and White 2010). Hexazinone does not control black bulrush (Jensen and Specht 2004; Anonymous 2017) and terbacil efficacy is variable (Boyd and White 2010). Spot applications of nicosulfuron + rimsulfuron, however, are effective (Jensen and Specht 2004) and have been registered for control of this weed for some time (Jensen et al. 2003). This treatment is effective (Boyd and White 2010; Jensen and Specht 2004) and increased occurrence of this weed therefore indicates reluctance of growers to utilize this spot application for this weed species. Field uniformity in occurrence fields is high enough that spot applications may be impractical in many fields though, potentially forcing growers to rely on less effective broadcast applications of herbicides such as mesotrione (Boyd and White 2010). Black bulrush plants produce thousands of viable seeds (Jensen et al. 2003), and our results suggest that growers must be more aggressive with nicosulfuron + rimsulfuron spot applications in fields where this weed occurs. Limited data are available on potential negative effects of toad rush on lowbush blueberry or susceptibility of this species to commonly used herbicides, though the frequency of this species and field uniformity in fields containing the plant (Table 2-4) warrant additional research to improve understanding of this species in lowbush blueberry fields.

Other annual weeds that should be emphasized include hemp nettle (*Galeopsis tetrahit* L.), horseweed (*Conyza canadensis* (L.) Cronquist), and American burnweed (*Erechtites hieraciifolius* (L.) Raf. Ex DC.) (Table 2-4). Hemp nettle is a common weed of arable crops such as cereals (Thomas et al. 1994) where it can reduce yield by up to 50% at densities of 28-248 plants m^{-2} (Légère and Deschênes 1991). Hemp nettle frequency has remained between 15 and 20% since 1984-1985 and average density in lowbush blueberry fields (Table 2-4) is much lower than that reported in arable crops. Effects of this weed on lowbush blueberry growth and development under typical field densities is therefore unclear, though plants can reach 75 cm in height (O'Donovan and Sharma 1987) and therefore pose a risk of shading blueberry plants or hindering harvest operations at high densities. Hemp nettle is sensitive to synthetic auxin herbicides (Frost 1982) but limited data on susceptibility to commonly used herbicides in lowbush blueberry are available. Future research should focus on susceptibility of this weed to commonly used PRE and POST herbicides in lowbush blueberry to provide basis for recommendations to growers.

Horseweed and American burnweed are relatively new weeds in lowbush blueberry fields and should be of concern to growers due to issues caused by these weeds in other crops or in other lowbush blueberry production regions. Horseweed is a facultative winter annual that was found in 2000-2001 and occurred in <1% of fields surveyed. This weed occurred in 1.8% of fields surveyed in 2017-2019, indicating that distribution is increasing but is still very low. This weed is nonetheless a concern as it is a common weed in no-till farming systems (Brown and Whitwell 1988) and is a prolific producer of wind-borne seeds that can potentially be dispersed up to 500 km away from the parent plant (Bhowmik and Bekech 1993; Shields et al. 2006). This weed has also developed resistance to several herbicides in other cropping systems (Koger et al. 2004; Lehoczki et al. 1984), indicating potential for similar problems in lowbush blueberry. Growers should monitor for this weed species and hand-pull or spot treat plants as they are found to prevent seed production and further dispersal, and future research should assess the sensitivity of this weed species to commonly used herbicides in lowbush blueberry.

American burnweed was not documented in previous weed surveys in Nova Scotia and occurred in 4.2% of fields surveyed in 2017-2019 (Table 2-4). The plant is a summer annual native to deciduous forest regions of North America (Darbyshire et al. 2012) and is abundant in areas of recently cleared forest (Eaton 1824; Pursh 1814; Torrey 1843) or turfgrass areas adjacent to woodlands (Atkinson et al. 2014). Plants can produce up to 32,000 wind-borne seeds (Csiszár 2006) that form persistent seed banks (Baskin and Baskin 1996). Seeds of plants collected from lowbush blueberry fields exhibit dormancy mechanisms similar to many summer annual weeds (White et al. 2017), indicating seed banks may be formed in these fields as well. The plant was first reported as a weed in lowbush blueberry fields in Maine, USA where it formed very dense stands that reduced yield and hindered harvest in some fields (David Yarborough, personal communication). The plant is, however, susceptible to many currently registered herbicides in lowbush blueberry (White and Webb 2017) and POST applications of the commonly used herbicides mesotrione and foramsulfuron should provide control (White and Webb 2018). Efficacy does, however, decline with increasing plant size (White and Webb 2018), so growers need to monitor fields closely to ensure timely herbicide applications. Future research should focus on field-based evaluations of herbicide programs to manage this weed.

Weeds present outside the quadrats within surveyed fields

There were 28 additional weeds found in at least one field but never within the quadrats. Most of these weeds were herbaceous and woody perennials (Table 2-3) that occurred in 0.6 to 3% of fields surveyed (Table 2-5). Some potentially problematic species were identified, though potential for them to become widespread problems seems unlikely. Many of the woody perennials found are common tree and shrub species in Nova Scotia, several of which are readily controlled with hexazinone or spot applications of other registered herbicides (Jensen 1985a; Sampson et al. 1990). Although herbaceous perennials such as Canada thistle (*Cirsium arvense* L.) cause significant problems in arable crops and pastures, this weed has always been of low frequency in lowbush blueberry weed surveys (McCully et al 1991; Jensen and Sampson upubl data), indicating unsuitability of lowbush blueberry fields for proliferation of this weed species. Others, such as rough cinquefoil (*Potentilla norvegica* L.) and common boneset (*Eupatorium perfoliatum* L.), are likely controlled by hexazinone. The identification of sheep fescue (*Festuca ovina* L.) in one field indicates that this grass species is still present in some areas, though potential for this species to become as prolific as hair fescue is unclear. Low occurrence of this grass would suggest susceptibility to herbicides such as hexazinone and terbacil, though occurrence of this weed should nonetheless be noted so that any changes in frequency can be detected early to avoid widespread problems similar to those being caused by hair and red fescue.

Table 2- 4. Weed survey result of Nova Scotia lowbush blueberry fields 2017-2019.

Scientific name	Common name	Frequency		Field Uniformity		Density		Relative abundance
		Unadjusted	Adjusted	All fields	Occurrence fields	All fields	Occurrence fields	
		----------%----------		----------%----------		---- shoots m^{-2}----		
Vaccinium angustifolium Ait.	Lowbush blueberry	100.00	100.00	95.24	95.24	262.35	262.35	94.03
Rumex acetosella L.	Red sorrel	97.58	97.58	62.88	64.44	72.05	73.84	39.80
Danthonia spicata L.	Poverty oat grass	92.73	93.33	43.36	46.76	5.70	6.14	18.56
Polytrichum commune Hedw.	Haircap moss	53.94	53.33	10.94	20.56	43.82	20.56	16.99
Festuca filiformis Pourr.	Hair fescue	67.88	74.55	25.36	37.37	3.00	4.41	11.70
Euthamia graminifolia (L.) *Nutt.*	Narrow-leaved goldenrod	78.79	86.06	17.00	21.58	2.66	3.38	10.27
Agrostis hyemalis (Walter) BSP.	Rough hair grass	67.88	69.09	16.97	25.00	1.81	2.66	9.31
Panicum lanugosum Ell.	Woolly panicum	49.09	50.91	10.73	21.85	4.10	8.36	7.02
Melampyrum lineare Desr.	Cow wheat	43.03	44.24	10.42	24.23	1.84	4.27	5.98
Cornus canadensis L.	Bunchberry	41.82	43.64	7.48	17.90	3.12	7.47	5.48
Hieracium caespitosum Dumort	Yellow hawkweed	34.55	40.00	8.15	23.60	2.23	6.45	4.93
Hypericum perforatum L.	Common St John’s wort	43.64	58.18	5.97	13.68	0.33	0.75	4.54
Hypericum canadense L.	Canada St John’s wort	40.00	47.27	5.12	12.80	1.30	3.24	4.32
Scirpus atrovirens Willd.	Black bulrush	30.91	38.18	4.67	15.00	0.23	0.76	3.33
Juncus bufonius L.	Toad rush	27.88	33.94	4.55	16.30	0.59	2.13	3.18
Vicia cracca L.	Tufted vetch	30.91	41.82	3.91	12.65	0.24	0.76	3.14
Poa compressa L.	Canada bluegrass	23.64	29.70	4.67	19.74	1.07	4.53	3.04
Luzula multiflora (Retz.) Lejeune	Wood rush	21.82	21.82	4.18	19.17	0.15	0.71	2.57
Viola spp.	Viola	19.39	20.61	3.12	16.09	0.56	2.88	2.24
Maianthemum canadense Desf.	False lily of the valley	20.61	20.61	2.24	10.88	0.78	3.76	2.15
Viola arvensis Murray	Field violet	17.58	20.61	2.47	12.76	0.31	1.74	1.89
Galeopsis tetrahit L.	Hemp nettle	19.39	24.24	1.55	7.97	0.08	0.40	1.73
Festuca rubra L.	Red fescue	7.88	9.09	3.39	43.08	1.25	15.85	1.69
Apocynum androsaemifolium L.	Spreading dogbane	16.36	18.79	1.73	10.56	0.14	0.87	1.58
Panicum capillaire L.	Witch grass	13.94	15.76	2.09	15.00	0.44	3.12	1.58

Solidago puberula Nutt.	Downey goldenrod	12.73	14.55	2.42	19.05	0.35	2.74	1.56
Pteridium aquilinum (L.) Kuhn.	Bracken fern	15.15	17.58	1.61	10.60	0.11	0.74	1.46
Potentilla simplex Michx.	Five finger cinquefoil	13.94	20.61	1.79	12.83	0.18	1.28	1.44
Carex spp.	Sedge	10.91	12.12	1.70	15.56	0.12	1.11	1.20
Lobelia inflata L.	Indian tobacco	12.73	18.79	1.27	10.00	0.04	0.31	1.19
Oxalis stricta L.	Wood sorrel	12.12	15.76	0.82	6.75	0.11	0.88	1.06
Gaultheria procumbens L.	Teaberry	9.09	9.70	1.24	13.67	0.51	5.62	1.05
Betula populifolia Marshall	Wire birch	10.30	20.00	1.15	11.18	0.03	0.31	1.00
Aster spp.	Asters	9.09	11.52	1.12	12.33	0.06	0.68	0.91
Kalmia angustifolia L.	Lambkill	7.27	8.48	1.39	21.67	0.23	3.22	0.90
Plantanthera hyperborea (L.) Lindl.	Green orchid	10.30	12.12	0.76	7.35	0.01	0.11	0.89
Elytrigia repens (L.) Desv ex B.D. Jacks	Quack grass	8.48	10.91	0.67	7.86	0.13	1.58	0.78
Rosa spp.	Wild rose	8.48	15.76	0.67	7.86	0.03	0.31	0.75
Tragopogon pratensis L.	Meadow goats's-beard	8.48	13.33	0.64	7.50	0.02	0.29	0.74
Solidago flexicaulis L.	Broadleaf goldenrod	6.06	8.48	0.97	16.00	0.05	0.76	0.67
Muhlenbergia mexicna (L.) Trin.	Muhly grass	5.45	6.67	0.82	15.00	0.16	3.02	0.62
Betula spp.	Birch	6.06	6.06	0.73	12.00	0.02	0.39	0.60
Viola sagittata Aiton	Arrow-leaved violet	4.51	4.51	1.12	31.43	0.05	1.83	0.60
Lysimachia terrestris (L.) BSP.	Yellow loosestrife	6.06	10.91	0.45	6.00	0.05	0.76	0.54
Equisetum arvense L.	Field horsetail	6.06	6.67	0.42	7.00	0.03	0.54	0.53
Acer rubrum (L.)	Red maple	6.06	12.73	0.36	6.00	0.01	0.21	0.51
Abies balsamea (L.) Mill.	Balsam fir	5.45	6.06	0.45	8.33	0.03	0.63	0.49
Picea spp.	Spruce	4.85	6.67	0.61	12.50	0.01	0.14	0.48
Daucus carota L.	Wild carrot	4.85	6.06	0.55	11.25	0.06	1.21	0.48
Prenanthes trifoliolata (Cass.) Fern.	Lions paw	5.45	8.27	0.42	7.50	0.01	0.16	0.48
Potentilla tridentata Ait.	Three finger cinquefoil	5.45	6.06	0.33	6.11	0.09	1.63	0.48
Symphyotrichum lateriflorum (L.) Á. Löve & D. Löve	Calico aster	4.85	6.06	0.48	10.00	0.02	0.50	0.46
Spiraea spp.	Spirea	4.85	13.33	0.45	9.38	0.01	0.30	0.45
Stellaria graminea L.	Grass-leaved stitchwort	4.85	7.88	0.42	8.75	0.03	0.59	0.44

Erechtites hieraciifolius (L.) Raf. Ex DC.	American burn weed	4.24	4.24	0.52	12.14	0.02	0.39	0.42
Hypericum ellipticum Hook.	Creeping St John wort	4.24	4.24	0.42	10.00	0.07	1.60	0.41
*Veronica officinalis*L.	Common speedwell	4.24	4.24	0.42	10.00	0.03	0.79	0.40
Cerastium vulgatum L.	Mouse-eared chickweed	4.85	5.45	0.27	5.63	0.02	0.34	0.40
Rubus hispidus L.	Trailing blackberry	4.24	12.73	0.36	8.57	0.02	0.49	0.38
Centaurea nigra L.	Black knapweed	3.64	6.67	0.36	10.00	0.03	0.84	0.35
Aronia arbutifolia (L.) Pers.	Red chokeberry	3.64	4.85	0.24	6.67	0.06	1.63	0.32
Berberis canadensis Mill.	Barberry	3.03	4.24	0.39	13.00	0.05	1.56	0.32
Agrostis gigantea Roth	Red top	3.64	3.64	0.18	5.00	0.02	0.42	0.30
Gaylussacia baccata (Wangenh.) K. Koch	Black huckleberry	3.03	6.67	0.30	10.00	0.03	1.15	0.29
Nuttallanthus canadensis (L.) D.A. Sutton	Canada toadflax	3.03	6.06	0.21	7.00	0.03	1.10	0.27
Aronia melanocarpa (Michx.) Elliott	Black chokeberry	3.03	3.64	0.21	7.00	0.01	0.21	0.26
Spiraea tomentosa L.	Hardhack	2.42	3.64	0.36	15.00	0.01	0.40	0.26
Juncus effusus L.	Soft rush	2.42	3.64	0.30	12.50	0.05	2.18	0.25
Amelanchier spp.	Service berry	3.03	5.45	0.15	5.00	0.00	0.14	0.25
Spergula arvensis L.	Corn spurry	2.42	2.42	0.27	11.25	0.04	1.64	0.24
Sisyrinchium montanum Greene	Common blue-eyed grass	2.42	2.42	0.24	10.00	0.01	0.53	0.23
Eurybia spectabilis (Aiton) G.L. Nesom	Showy aster	2.42	3.03	0.21	8.75	0.02	0.95	0.22
Coptis trifolia (L.) Salisb.	Goldthread	2.42	2.42	0.18	7.50	0.05	2.24	0.22
Prunella vulgaris L.	Heal all	2.42	2.42	0.18	7.50	0.02	0.71	0.21
Hieracium praealtum Vill. Ex Gochnat	Tall hawkweed	1.82	3.64	0.30	16.67	0.04	2.17	0.21
Epilobium ciliatum Raf.	Northern willow herb	2.42	4.24	0.15	6.25	0.01	0.45	0.21
Rosa virginiana Mill.	Virginia rose	2.42	2.42	0.15	6.25	0.01	0.43	0.21
Solidago rugosa Mill.	Rough-stemmed goldenrod	2.42	5.45	0.15	6.25	0.01	0.26	0.20
Viburnum spp.	Viburnum	2.42	3.03	0.15	6.25	0.01	0.24	0.20
Leucanthemum vulgare Lam.	Oxeye daisy	2.42	10.30	0.15	6.25	0.00	0.20	0.20
Achillea millefolium L.	Common yarrow	2.42	5.45	0.12	5.00	0.02	0.76	0.20
Spiraea alba var. *latifolia*	Meadowsweet	2.42	3.64	0.12	5.00	0.01	0.25	0.20

Rubus idaeus L.	Red raspberry	1.82	3.03	0.27	15.00	0.01	0.28	0.19
Solidago macrophylla Pursh	Largeleaf goldenrod	1.82	3.64	0.24	13.33	0.01	0.38	0.19
Diervilla lonicera Mill.	Bush honeysuckle	1.82	2.42	0.24	13.33	0.01	0.32	0.19
Houstonia caerulea (L.) Hook.	Bluets	1.82	1.82	0.21	11.67	0.01	0.65	0.18
Conyza canadensis (L.) Cronquist	Horseweed	1.82	3.03	0.21	11.67	0.01	0.43	0.18
Digitaria sanguinalis (L.) Scop.	Large crab grass	1.82	1.82	0.21	11.67	0.01	0.33	0.18
Monotropa uniflora L.	Indian pipe	1.82	1.82	0.15	8.33	0.01	0.82	0.17
Trifolium campestre Schreb.	Hop clover	1.82	4.85	0.15	8.33	0.01	0.63	0.16
Betula papyrifera Marshall	White birch	1.82	4.85	0.15	8.33	0.00	0.15	0.16
Viola sororia Willd.	Blue violet	1.21	1.21	0.27	22.50	0.03	2.13	0.16
Anaphalis margaritacea (L.) Benth. & Hook.	Pearly everlasting	1.82	4.85	0.12	6.67	0.01	0.55	0.16
Sonchus oleraceus L.	Annual sow-thistle	1.82	1.82	0.12	6.67	0.01	0.40	0.16
Viburnum nudum L. var. cassinoides (L.) Torr. & A. Gray	Wild raisin	1.82	4.24	0.12	6.67	0.00	0.17	0.15
Aralia hispida Vent.	Bristly aralia	1.82	2.42	0.09	5.00	0.00	0.15	0.15
Oenothera biennis L.	Evening primrose	1.82	6.67	0.09	5.00	0.00	0.07	0.15
Alnus spp.	Alder	1.82	6.67	0.09	5.00	0.00	0.07	0.15
Hybanthus concolor (T.F. Forst.) Spreng.	Green violet	1.82	1.82	0.09	5.00	0.00	0.05	0.15
Mitchella repens L.	Partridge berry	0.61	0.61	0.18	30.00	0.15	24.30	0.12
Rhinanthus minor L. *ssp. minor*	Yellow rattle	1.21	1.21	0.12	10.00	0.02	1.38	0.12
Solidago canadensis L.	Canada goldenrod	1.21	1.21	0.12	10.00	0.00	0.40	0.11
Potentilla canadensis L.	Dwarf cinquefoil	1.21	1.21	0.12	10.00	0.00	0.38	0.11
Epilobium coloratum Biehler	Purple leaf willow herb	1.21	1.82	0.12	9.76	0.00	0.35	0.11
Viola primulifolia L. (pro sp.) [*lanceolata X macloskeyi]*	Primrose-leaved violet	1.21	1.21	0.12	10.00	0.00	0.33	0.11
Dichanthelium boreale (Nash) Freckmann	Northern panicgrass	1.21	1.21	0.12	10.00	0.00	0.30	0.11
Frangula alnus Mill.	Glossy buckthorn	1.21	3.03	0.12	10.00	0.00	0.13	0.11
Gnaphalium uliginosum L.	Low cudweed	1.21	1.21	0.09	7.50	0.01	1.23	0.11
Plantago major L.	Broadleaf plantain	1.21	3.03	0.09	7.50	0.00	0.15	0.11

Platanthera leucophaea (Nutt.) Lindl.	White prairie fringed orchid	1.21	2.42	0.09	7.50	0.00	0.10	0.11
Scorzoneroides autumnalis (L.) Moench	Fall dandelion	1.21	1.82	0.09	7.50	0.00	0.08	0.11
Trifolium repens L.	White clover	1.21	1.82	0.06	5.00	0.03	2.10	0.10
Poa saltuensis (Fern. & Wieg)	Forest meadow grass	1.21	1.21	0.06	5.00	0.00	0.25	0.10
Populus grandidentata Michx.	Large toothed aspen	1.21	1.82	0.06	5.00	0.00	0.20	0.10
Populus spp.	Aspen	1.21	3.64	0.06	5.00	0.00	0.18	0.10
Centaurea jacea L.	Brown knapweed	1.21	4.85	0.06	5.00	0.00	0.13	0.10
Spiranthes lacera Raf.	Slender lady's tresses	1.21	1.82	0.06	5.00	0.00	0.10	0.10
Picea glauca (Moench) Voss	White spruce	1.21	6.06	0.06	5.00	0.00	0.10	0.10
Prunus pensylvanica L. f.	Pincherry	1.21	3.03	0.06	5.00	0.00	0.05	0.10
Platanthera blephariglottis (Willd .) Lindl.	White fringed bog orchid	1.21	1.21	0.06	5.00	0.00	0.05	0.10
Solidago speciosa Nutt.	Showy goldenrod	1.21	1.21	0.06	5.00	0.00	0.05	0.10
Doellingeria umbellata (P.Mill.) Nees	Tall white aster	1.21	4.85	0.06	5.00	0.00	0.05	0.10
Lactuca canadensis L.	Canada lettuce	1.21	3.03	0.06	2.50	0.00	0.05	0.10
Hieracium pilosella L.	Mouse-ear hawkweed	0.03	1.21	0.15	25.00	0.18	30.00	0.08
Phleum pratense L.	Timothy grass	0.61	2.42	0.15	25.00	0.00	0.45	0.08
Piptatheropsis pungens (Torr.) Romasch., P.M. Peterson & R.J. Soreng	Mountain rice grass	0.61	0.61	0.12	20.00	0.00	0.50	0.07
Panicum dichotomiflorum (L.) Michx.	Fall panicum grass	0.61	0.61	0.09	15.00	0.03	5.30	0.07
Plantago lanceolata L.	Narrow leaf plantain	0.61	0.61	0.09	15.00	0.01	1.90	0.07
Pinus strobus L.	Eastern white pine	0.61	0.61	0.09	15.00	0.00	0.20	0.06
Acer spp.	Maple	0.61	1.82	0.09	15.00	0.00	0.15	0.06
Piptatheropsis canadensis (Poir.) Romasch., P.M. Peterson & R.J. Soreng	Canada rice grass	0.61	0.61	0.09	15.00	0.00	0.15	0.06
Oxalis stricta L.	Common yellow woodsorrel	0.61	0.61	0.06	10.00	0.03	4.20	0.06
Lindernia dubia (L.) Pennell	False pimpernel	0.61	1.21	0.06	10.00	0.01	2.20	0.06
Stellaria media (L.) Vill.	Common starwort	0.61	0.61	0.06	10.00	0.01	0.90	0.06

Polygonum sagittatum L.	Arrow-leaved tearthumb	0.61	0.61	0.06	10.00	0.00	0.80	0.06
Stenaria nigricans (Lam.) Terrell var. nigricans	Baby's breath	0.61	0.61	0.06	10.00	0.00	0.60	0.06
Artemisia campestris L.	Tall wormwood	0.61	0.61	0.06	10.00	0.00	0.55	0.06
Lycopus americanus Muhl. ex W.P.C. Barton	Water horehound	0.61	0.61	0.06	10.00	0.00	0.50	0.06
Viola sagittata Aiton	Ovate-leaved violate	0.61	0.61	0.06	10.00	0.00	0.10	0.06
Polygala lindheimeri A. Gray	Purple milkwort	0.61	0.61	0.03	5.00	0.01	1.20	0.05
Setaria glauca (L.) Beauv.	Yellow foxtail	0.61	0.61	0.03	5.00	0.01	0.95	0.05
Salix spp.	Willow	0.61	2.42	0.03	5.00	0.00	0.55	0.05
Raphanus raphanistrum L.	Wild radish	0.61	0.61	0.03	5.00	0.00	0.55	0.05
Lactuca serriola L.	prickly lettuce	0.61	1.21	0.03	5.00	0.00	0.40	0.05
Amelanchier canadensis (L.) Medik.	Shadbush	0.61	1.21	0.03	5.00	0.00	0.40	0.05
Solidago hispida Muhl. ex Willd.	Hairy goldenrod	0.61	2.42	0.03	5.00	0.00	0.35	0.05
Chenopodium album L.	Lambsquarters	0.61	1.82	0.03	5.00	0.00	0.30	0.05
Epilobium angustifolium L.	Fireweed	0.61	2.42	0.03	5.00	0.00	0.30	0.05
Hypericum boreale (Britton) E.P. Bicknell	Northern St John's Wort	0.61	0.61	0.03	5.00	0.00	0.30	0.05
Solidago nemoralis Aiton	Gray goldenrod	0.61	0.61	0.03	5.00	0.00	0.30	0.05
Arctostaphylos uva-ursi (L.) Spreng	Bear berry	0.61	0.61	0.03	5.00	0.00	0.30	0.05
Carex crawfordii Fernald	Crawford's sedge	0.61	0.61	0.03	5.00	0.00	0.30	0.05
Comptonia peregrina (L.) J.M. Coult.	Sweet fern	0.61	0.61	0.03	5.00	0.00	0.25	0.05
Solidago stricta Aiton	Wand-like goldenrod	0.61	0.61	0.03	5.00	0.00	0.20	0.05
Rumex crispus L.	Curly dock	0.61	2.42	0.03	5.00	0.00	0.20	0.05
Hieracium longipilum Torr.	Hairy hawkweed	0.61	0.61	0.03	5.00	0.00	0.20	0.05
Ilex mucronata (L.) Powell, Savolainen & Andrews	Mountain holly	0.61	1.82	0.03	5.00	0.00	0.20	0.05
Polygonum convolvulus (L.) Á.Löve	Wild buckwheat	0.61	0.61	0.03	5.00	0.00	0.15	0.05
Thelypteris noveboracensis (L.) Nieuwl.	New York fern	0.61	0.61	0.03	5.00	0.00	0.15	0.05
Hieracium aurantiacum (L.) F.W.Schultz & Sch.Bip.	Orange hawkweed	0.61	0.61	0.03	5.00	0.00	0.15	0.05

Trientalis borealis Raf.	Star flower	0.61	0.61	0.03	5.00	0.00	0.15	0.05
Doellingeria umbellata (Mill.) Nees	Flat topped aster	0.61	1.21	0.03	5.00	0.00	0.10	0.05
Agrostis stolonifera L.	Creeping bent grass	0.61	0.61	0.03	5.00	0.00	0.10	0.05
Taraxacum officinale F.H. Wigg.	Dandelion	0.61	0.61	0.03	5.00	0.00	0.10	0.05
Sambucus racemosa L. *var. melanocarpa (A. Gray) McMinn*	Black elderberry	0.61	1.82	0.03	5.00	0.00	0.10	0.05
Carex tribuloides Wahlenb. var. *tribuloides*	Broom sedge	0.61	0.61	0.03	5.00	0.00	0.10	0.05
Anthoxanthum odoratum L.	Sweet vernal grass	0.61	1.21	0.03	5.00	0.00	0.05	0.05
Ranunculus acris L.	Tall buttercup	0.61	1.21	0.03	5.00	0.00	0.05	0.05
Poa annua L.	Annual bluegrass	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Lotus corniculatus L.	Common bird's-foot trefoil	0.61	1.82	0.03	5.00	0.00	0.05	0.05
Ajuga reptans L.	Bugleweed	0.61	1.21	0.03	5.00	0.00	0.05	0.05
Sambucus racemosa L.	Red berried elder	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Bellis perennis L.	Common daisy	0.61	3.03	0.03	5.00	0.00	0.05	0.05
Cuphea viscosissima Jacq.	Clammy cuphea	0.61	1.21	0.03	5.00	0.00	0.05	0.05
Fragaria virginiana Duchesne	Wild strawberry	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Thelypteris palustris Rich.	Marsh fern	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Quercus spp.	Oak	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Erigeron annuus (L.) Pers.	Annual fleabane	0.61	1.21	0.03	5.00	0.00	0.45	0.05
Pinus spp.	Pine	0.61	1.21	0.03	5.00	0.00	0.05	0.05
Verbascum thapsus L.	Mullein	0.61	1.82	0.03	10.00	0.00	0.10	0.05
Dichanthelium depauperatum (Muhl.) Gould	Starved panic grass	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Hypochaeris radicata L.	Cat's ear	0.61	1.21	0.03	5.00	0.00	0.05	0.05
Carex arctata Boott ex Hook.	Dropping woodland sedge	0.61	0.61	0.03	5.00	0.00	0.05	0.05
Veronica serpyllifolia L.	Thymeleaf speedwell	0.61	0.61	0.03	5.00	0.00	0.05	0.05

Table 2- 5. Frequency of weed species observed within Nova Scotia lowbush blueberry fields but outside the quadrats 2017-2019.

Scientific name	Common name	Frequency
Alnus serrulata (Aiton) Willd.	Black alder	3.03
Trifolium arvense L.	Rabbit foot clover	1.81
Alnus serrulata (Aiton) Willd.	Smooth alder	1.81
Rudbeckia hirta Var. pulcherrima Farw.	Black-eyed Susan	1.21
Rudbeckia triloba L.	Brown-eyed Susan	1.21
Cirsium arvense L.	Canada Thistle	1.21
Dennstaedtia punctilobula (Michx.) Moore	Hay scented fern	1.21
Acer saccharum Marshall	Sugar maple	1.21
Malus coronaria (L.) Mill.	Wild apple	1.21
Silene vulgaris (Moench) Garcke	Bladder campion	0.60
Solidago caesia L.	Blue stem goldenrod	0.60
Andromeda polifolia L.	Bog rosemary	0.60
Galium aparine L.	Common Bedstraw	0.60
Eupatorium perfoliatum L.	Common boneset	0.60
Heracleum spp.	Cow Parsnip	0.60
Poa palustris L.	Fowl meadow grass	0.60
Ranunculus recurvatus Poir.	Hooked crowfoot	0.60
Lupinus albus L.	Lupin	0.60
Lilium bulbiferum L.	Orange lily	0.60
Quercus rubra L.	Red oak	0.60
Pinus resinosa Ait.	Red pine	0.60
Ribes spp.	Currants	0.60
Potentilla norvegica L.	Rough cinquefoil	0.60
Oenothera humifusa Nutt.	Seabeach evening primrose	0.60
Festuca ovina L.	Sheep fescue	0.60
Lilium lancifolium Kellogg	Tiger lily	0.60
Lysimachia quadrifolia L.	Whorled loosestrife	0.60
Origanum majorana L.	Wild marjoram	0.60

Chapter 3 - Evaluation of broadcast and spot herbicide applications for spreading dogbane (*Apocynum androsaemifolium* L) management in lowbush blueberry fields

Abstract

Spreading dogbane is an increasingly troublesome weed in lowbush blueberry fields. Field studies were conducted from 2017 to 2019 to evaluate the efficacy of a range of broadcast and spot herbicide applications on spreading dogbane. Results indicated that broadcast mesotrione [(144g a.i. ha^{-1}) + 0.2% NIS] and foramsulfuron [(35 g a.i. ha^{-1}) + UAN (2.5 L ha^{-1})] applications did not control spreading dogbane, and control was not improved by sequential applications of either herbicide. Foramsulfuron tank mixture with flazasufuron [(50g a.i. ha^{-1}) + 0.2% NIS] and foramsulfuron tank mixture with mesotrione reduced shoot density in both nonbearing and bearing years in one of the two sites, suggesting broadcast tank mixtures may improve control, warranting further exploration. Significant variation within treatments was found across years and experimental sites. Results indicated dicamba and glyphosate continue to be the most effective herbicide spot treatments for spreading dogbane. Spot applications of foramsulfuron and flazasulfuron caused >85% injury to spreading dogbane and could be explored further as potential spot treatments. Fall spot applications did not control spreading dogbane due to the early senescence of spreading dogbane shoots at trial sites. Spot applications of dicamba at 0.96 or 1.92 g a.e. L $water^{-1}$ in tank mixture with foramsulfuron or flazasulfuron improved consistency of nonbearing year spreading dogbane shoot density reductions and these

tank mixtures should be explored further for management of spreading dogbane in lowbush blueberry.

Introduction

Lowbush, or wild blueberry (*Vaccinium angustifolium* Ait.) is a perennial deciduous shrub that is native to northeastern North America (Anonymous 2019). In general, lowbush blueberry fields are developed from abandoned farmland or cleared forest areas (Hall 1959). The uniquess of lowbush blueberries are managed under a 2-year production cycle (Jensen and Yarborough 2004). In the first year (nonbearing year), fields are pruned by burning or mowing to remove old plant growth and encourage vegetative growth and flower bud formation (Anonymous 2019; Jensen and Yarborough 2004). In the second year (bearing year), flowers open and bloom occurs and fruit harvest occurring during late summer (Anonymous 2019; McIsaac 1997). Weed management is a major production challenge (Jensen and Yarborough 2004) and weeds contribute significant variation to annual yields (McCully et al. 1991; Yarborough 2011).

Creeping perennials are among the most problematic weed species in lowbush blueberry fields and are successful in cropland due to several reproductive and survival mechanisms and, in some instances, cropping and management practices that help these plants spread (McCully et al. 1991; Jensen and Yarborough 2004; Ross and Lembi 2009). Spreading dogbane (*Apocynum androsaemifolium* Ait) is a creeping herbaceous perennial which reproduces by seeds and creeping roots (Bergweiler and Manning 1999; Sampson et al. 1990). Similar to the related hemp dogbane (*Apocynum cannabinum* L.), spreading dogbane infestation in lowbush blueberry fields is primarily by creeping roots (Ransom and Kells 1998; H Lyu personal observation). Spreading dogbane is a common weed in lowbush blueberry fields, though occurrence varies across production regions. Spreading dogbane occurred in 87.5% of lowbush blueberry fields in the Saguenay-Lac-Saint-Jean region (Lapointe and Rochefort 2001), though occurrence is somewhat lower in Nova Scotia. McCully et al. (1991) reported that 3.6% of fields surveyed in 1991 contained spreading dogbane in Nova Scotia, with the occurrence increasing to 8% of fields in 2000-2001 (Jensen and Sampson, unpubl. data) and 16.4% of fields in 2017-2019 (Chapter 2, Table 2-4). This suggests spreading dogbane is increasing in occurrence in Nova Scotia lowbush blueberry fields.

Recent research on spreading dogbane management in lowbush blueberry is somewhat limited, though broadcast and spot applications of herbicides have been evaluated. Wu and Boyd (2012) found broadcast applications of nicosulfuron at 25 g ai ha^{-1} with 0.5% v/v blend of surfactant with petroleum hydrocarbons gave > 60% control of spreading dogbane. Wu and Boyd (2012) also reported broadcast applications of nicosulfuron (13 g a.i. ha^{-1}) plus rimsulfuron (13 g a.i. ha^{-1}) applied alone or in tank mixture with mesotrione (101 g a.i. ha^{-1}) gave > 80% control of spreading dogbane, though control varied across study sites. D'Appollonio and Yarborough (2018) found mesotrione and hexazinone tank mixes provided 93% control of spreading dogbane and mesotrione alone provided 98% control, though spreading dogbane regrowth occurred in each treatment.

Spreading dogbane control with spot applications has generally been more effective than broadcast applications. Spot applications of dicamba (1 kg ae ha^{-1} in 550 L ha^{-1} water) and glyphosate (5 g ae L^{-1} water) controlled spreading dogbane (Wu and Boyd 2012), though dicamba caused less blueberry injury than glyphosate. The related hemp dogbane is similarly susceptible to POST herbicides such as glyphosate, 2, 4-D plus dicamba, nicosulfuron, and primisulfuron (Curran et al. 1997; DiTommaso et al. 2009; Dobbels and Kapusta 1993; Doll 1997; Glenn et al. 1997; Orfanedes and Wax 1991; Schultz and Burnside 1979; Webster and Cardina 1999). Tank mixtures of nicosulfuron with dicamba provided greater control of hemp dogbane than either herbicide applied alone (Glenn and Anderson 1993; Glenn et al. 1997; Ransom and Kells 1998). This is likely due to increased translocation of sulfonylurea herbicides when tank mixed with dicamba (Kalnay and Glenn 2000).

The objective of this research was to evaluate a range of broadcast and spot herbicide applications for control of spreading dogbane in lowbush blueberry fields. Specific objectives of this research were to determine (1) efficacy and optimal application interval between sequential POST mesotrione applications on spreading dogbane, (2) the effect of sequential mesotrione and foramsulfuron applications on spreading dogbane, (3) the effect of various broadcast herbicide tank mixtures on spreading dogbane, (4) the effect of various summer and fall spot herbicide applications on spreading dogbane, and (5) the effect of spot applications of dicamba tank mixtures with sulfonylurea herbicides mixtures on spreading dogbane.

Materials and Methods

Study Sites

Experiments were conducted in commercial lowbush blueberry fields in Nova Scotia between 2017 and 2019 (Table 3-1; Figure 3-1).

Table 3- 1. Study sites used for evaluation of broadcast and spot herbicide applications on spreading dogbane in lowbush blueberry fields in Nova Scotia, Canada.

Site, year	Production year	Latitude	Longitude	Elevation
				m
Collingwood Corner, 2017	Nonbearing	45° 34' 25.32" N	63° 53' 52.44" W	270
Collingwood Corner, 2018	Bearing			
Greenfield, 2017	Nonbearing	45° 18' 6.48" N	63° 10' 56.64" W	163
Greenfield, 2018	Bearing			
Parrsboro, 2017	Nonbearing	45° 30' 33.12" N	63° 44' 40.92" W	191
Parrsboro, 2018	Bearing			
Rawdon, 2017	Nonbearing	45° 5' 16.44" N	63° 44' 40.92" W	143
Rawdon, 2018	Bearing			
Westchester Mt., 2018	Nonbearing	45° 34' 57" N	63° 43' 26.4" W	265
Westchester Mt., 2019	Bearing			
Windham Hill, 2017	Nonbearing	45° 37' 30.36" N	63° 58' 27.84" W	244
Windham Hill, 2018	Bearing			

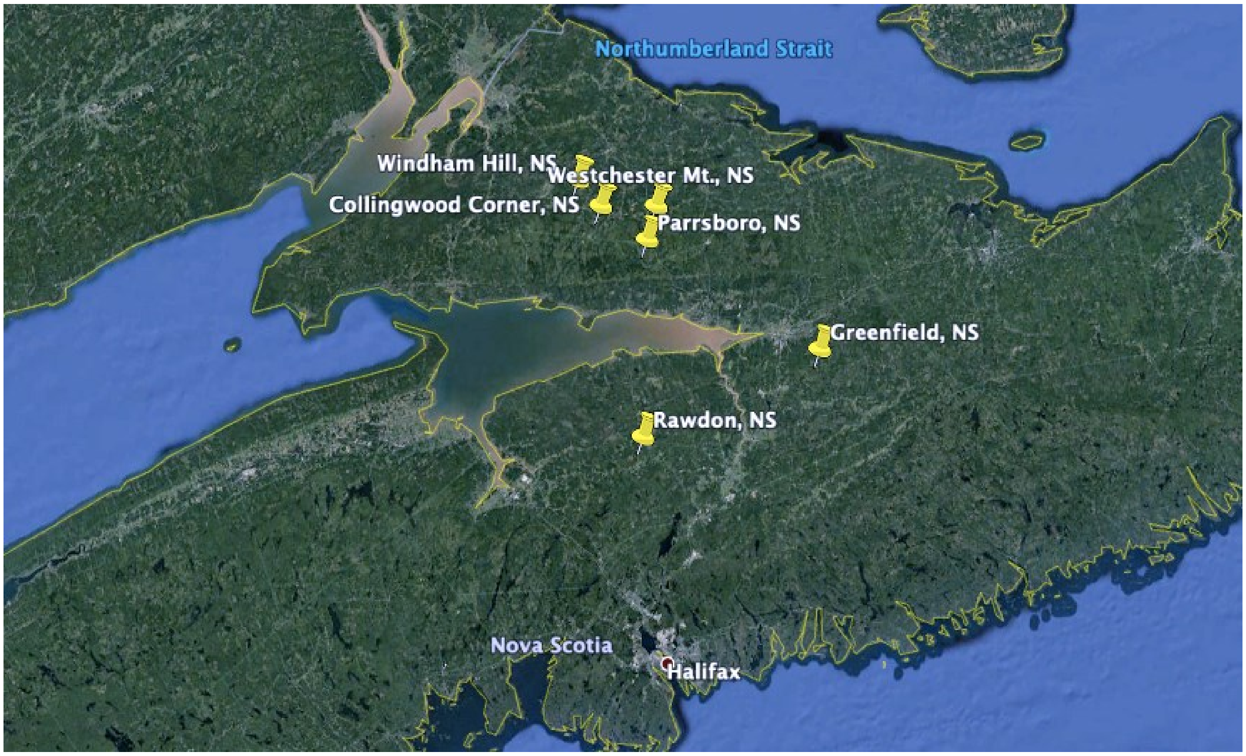

Figure 3- 1. Study sites used for evaluation of broadcast and spot herbicide applications on spreading dogbane in lowbush blueberry fields in Nova Scotia, Canada.

Experiment 1: Evaluation of sequential mesotrione applications on spreading dogbane

Experiments were conducted in three commercial lowbush blueberry fields located in Collingwood Corner (2017-2018), Rawdon (2017-2018) and Westchester Mt. (2018 and 2019), Nova Scotia (Table 3-1), Canada. The experiment was designed to evaluate sequential mesotrione (Callisto herbicide; Syngenta, Platsville, ON, Canada) applications on spreading dogbane. The experiment was arranged as a randomized complete block design with five blocks at all three sites. Plot size was 2 m X 4 m, with a 1 m buffer between each block. Treatments consisted of (1) nontreated control, (2) mesotrione application at the early-bud stage, (3) mesotrione application at the early-bud stage followed by a sequential mesotrione application at 7 d after initial treatment (DAIT), (4) mesotrione application at the early-bud stage followed by a sequential mesotrione application at 14 DAIT, (5) mesotrione application at the early-bud stage followed by a sequential mesotrione application at 21 DAIT, and (6) mesotrione application at the early-bud stage followed by a sequential mesotrione application at 28 DAIT. Mesotrione was applied at a rate of 144 g ai ha^{-1} in 200 L ha^{-1} water with 0.2% v/v nonionic surfactant using a CO_2 pressurized research plot sprayer equipped with four Hypro ULD120-02 Ultra Lo-Drift Tip nozzles and operated at a spray pressure of 275 kPa. Mean spreading dogbane shoot height at the first application was 45 ± 6 cm, 55 ± 6 cm, and 47 ± 6 cm at Collingwood Corner, Rawdon, and Westchester Mt., respectively. Weather conditions at the time of treatment applications for each site are reported in Table 3-2.

Table 3- 2. Application dates and weather conditions at the time of mesotrione herbicide applications at Collingwood Corner, Rawdon, and Westchester Mt., Nova Scotia, Canada

Site	Treatment	Application date	Temperature	Relative humidity	Mean wind speed
			---°C---	---%---	-Km h^{-1}-
Collingwood Corner	Nontreated control	N/A[a]	N/A	N/A	N/A
	Mesotrione (all treated plots)	June 22, 2017	18	56	16
	Mesotrione (7 DAIT)	June 29, 2017	18	62.9	10.3
	Mesotrione (14 DAIT)	July 5, 2017	19	49	6
	Mesotrione (21 DAIT)	July 12, 2017	19	72	10
	Mesotrione (28 DAIT)	July 19, 2017	20	60	10
Rawdon	Nontreated control	N/A	N/A	N/A	N/A
	Mesotrione (all treated plots)	June 21, 2017	25	52	21
	Mesotrione (7 DAIT)	June 28, 2017	17	70	10
	Mesotrione (14 DAIT)	July 5, 2017	25	36	14
	Mesotrione (21 DAIT)	July 11, 2017	25	40	10
	Mesotrione (28 DAIT)	July 18, 2017	19	83	6
Westchester Mt.	Nontreated control	N/A	N/A	N/A	N/A
	Mesotrione (all treated plots)	July 5, 2018	20	50	10.6
	Mesotrione (7 DAIT)	July 11, 2018	18	40	6
	Mesotrione (14 DAIT)	July 19, 2018	21	70	5
	Mesotrione (21 DAIT)	July 25, 2018	25	65	10
	Mesotrione (28 DAIT)	August 1, 2018	22	55	10

[a]Abbreviations: N/A, not applicable; DAIT, days after initial treatment.

Experiment 2: Evaluation of sequential mesotrione and foramsulfuron applications on spreading dogbane

Experiments were conducted in three commercial lowbush blueberry fields located in Parrsboro (2017-2018), Windham Hill (2017-2018) and Westchester Mt. (2018 and 2019), Nova Scotia (Table 3-1). The experiment was designed to evaluate sequential mesotrione and foramsulfuron (Option herbicide, Bayer CropScience Inc., Calgary, AB, Canada) applications on spreading dogbane. The experiment was a 3 × 3 factorial arrangement of early herbicide application (none, mesotrione, foramsulfuron) and late herbicide application (none, mesotrione, foramsulfuron) arranged in a randomized complete block design with six blocks at all three sites. Plot size was 2 m by 4 m, with a 1 m buffer between each block. Early and late herbicide applications were applied at the pre-bud and bud stage, respectively. Mesotrione was applied at a rate of 144 g a.i ha^{-1} in 200 L ha^{-1} water with 0.2% v/v nonionic surfactant (NIS) and foramsulfuron was applied at a rate of 35 g a.i ha^{-1} in 200 L ha^{-1} water with 28% urea ammonium nitrate (UAN) at a rate of 2.5 L ha^{-1}. Treatments were applied using a CO_2 pressurized research plot sprayer equipped with four Hypro ULD120-02 Ultra Lo-Drift Tip nozzles and operated at a spray pressure of 275 kPa. Mean spreading dogbane shoot height at the early application timing was 40 ± 8 cm, 27 ± 5 cm, and 32 ± 4 cm at Parrsboro, Windham Hill, and Westchester Mt., respectively. Mean spreading dogbane shoot height at the late application timing was 39 ± 9 cm, 29 ± 7 cm, and 43 ± 7 cm at Parrsboro, Windham Hill, and Westchester Mt., respectively. Weather conditions at the time of treatment applications for each site are reported in Table 3-3.

Table 3- 3. Application dates and weather conditions at the time of sequential mesotrione and foramsulfuron herbicide applications at Parrsboro, Windham Hill, and Westchester Mt., Nova Scotia, Canada.

Site	Application timing	Application date	Temperature	Relative humidity	Wind speed
			---°C---	---%---	---Km h^{-1}---
Parrsboro	Early	June 13, 2017	30.0	51.4	4.9
	Late	June 27, 2017	25.5	45.4	14.2
Windham Hill	Early	June 12, 2017	25.0	58.2	6.6
	Late	June 27, 2017	24.3	80.4	10.5
Westchester Mt.	Early	June 27, 2018	19.0	55	16
	Late	July 3, 2018	22.0	49.1	9.7

Experiment 3: Evaluation of broadcast herbicide tank mixtures on spreading dogbane

Experiments were conducted in two commercial lowbush blueberry fields located in Westchester Mt. (Bragg field and Staple field), Nova Scotia (Table 3-1) in 2018 and 2019 to evaluate broadcast herbicide tank mixtures on spreading dogbane. The experiment was arranged as a randomized complete block design with 5 blocks and 9 treatments. Plot size was 2 m by 4 m, with a 1 m buffer between each block. Treatments consisted of (1) nontreated control, (2) foramsulfuron (35 g a.i. ha^{-1}) + UAN (2.5 L ha^{-1}), (3) flazasulfuron (50 g a.i. ha^{-1}) + 0.2% nonionic surfactant (NIS), (4) mesotrione (144g a.i. ha^{-1}) + 0.2% NIS, (5) foramsulfuron + UAN + flazasulfuron + 0.2% NIS, (6) foramsulfuron + UAN + mesotrione + 0.2% NIS, (7) flazasulfuron + mesotrione + 0.2% NIS, (8) mesotrione + 0.2% NIS followed by foramsulfuron + UAN, and (9) mesotrione + 0.2% NIS followed by flazasulfuron + 0.2% NIS. Sequential foramsulfuron and flazasulfuron applications were applied 7 d after initial mesotrione applications. Treatments were applied using a CO_2 pressurized research plot sprayer equipped with four Hypro ULD120-02 Ultra Lo-Drift Tip nozzles and operated at a spray pressure of

275 kPa. Mean spreading dogbane shoot height at the application was 32 ± 5 cm and 36 ± 7 cm at Bragg and Staple, respectively. Weather conditions at the time of treatment applications for each site are reported in Table 3-4.

Table 3- 4. Application dates and the weather conditions at the time of broadcast herbicide tank mix applications at Westchester Mt. Bragg and Staple fields.

Site	Application timing	Application date	Temperature	Relative humidity	Wind speed
			---°C---	---%---	-Km h^{-1}-
Bragg field	Applications at early bud stage	July 3, 2018	25	45	5
	Sequential applications	July 17, 2018	26	66	8
Staple field	Applications at early bud stage	July 5, 2018	20	60	10
	Sequential applications	July 11, 2018	22	55	10

Experiment 4: Effect of summer and fall spot herbicide applications on spreading dogbane

Experiments were conducted in 2017-2018 to evaluate nonbearing year summer and fall spot herbicide applications on spreading dogbane (Table 3-5). Dicamba and glyphosate were included as industry standard spot herbicide treatments for spreading dogbane (Wu and Boyd 2012). Foramsulfuron, tribenuron-methyl, nicosulfuron+ rimsulfuron, clopyralid, and triclopyr were included as they are currently registered for use in lowbush blueberry and would therefore be readily available for use by growers if effective. Pyroxsulam, flazasulfuron, halosulfuron, and dicamba+diflufenzopyr were included as new products that may have potential for weed control in lowbush blueberries but are not currently registered for use in lowbush blueberries in Canada.

The summer spot herbicide application experiment was conducted at Greenfield, Parrsboro, and Rawdon from 2017-2018, and the fall spot herbicide application experiment was conducted at Collingwood Corner, Parrsboro, and Rawdon from 2017-

2018 (Table 3-1). Experiments were arranged as a completely randomized design with 5 replications and 10 and 12 treatments in the summer and fall spot application experiments, respectively (Table 3-5). Plot size was 1 m X 1 m, and plots were established in various spreading dogbane patches at each site. Herbicides were applied when spreading dogbane was at the early-bud and post-seed stage for the summer and fall spot application treatments, respectively. Herbicides were applied with a CO_2 pressurized research plot sprayer equipped with a single AI11002-VS AI TeeJet Air Induction Flat Fan nozzle operated at a spray pressure of 275 KPa. Herbicides were applied to spreading dogbane leaves until initial runoff of herbicide solution occurred. Mean spreading dogbane shoot heights at the time of herbicide applications in the summer spot application experiment were 43.7 ± 8 cm, 37.6 ± 8 cm, and 43.5 ± 9 cm at Greenfield, Parrsboro, and Rawdon, respectively. Mean shoot heights at the time of herbicide applications in the fall spot application experiment were 36 ± 5 cm, 48 ± 5 cm, and 40 ± 5 cm at Collingwood Corner, Parrsboro, and Rawdon, respectively. The weather conditions at the time of treatment applications for each site are reported in Table 3-6.

Table 3- 5. POST herbicides evaluated as summer and fall spot applications to spreading dogbane in lowbush blueberry fields located at Collingwood Corner, Greenfield, Parrsoboro, and Rawdon, Nova Scotia.

Common name	Trade name	Application rate	Surfactant	Manufacturer, city, state or province, country
		g ai or ae L water^{-1}		
Nontreated control	N/A[a]	N/A	N/A	N/A
Dicamba	Banvel	1.92	0.2% Non-ionic surfactant (NIS)	BASF, Mississauga, ON, Canada
Glyphosate	Roundup Weathermax	7.236	N/A	Monsanto, Winnipeg, MB, Canada
Foramsulfuron	Option	0.18	28% UAN[b]	Bayer CropScience, Regina, SK, Canada
Tribenuron-methyl	Spartan	0.1875	0.2% NIS	DuPont, Mississauga, ON, Canada
Nicosulfuron+ rimsulfuron	Ultim	0.03225	0.2% NIS	DuPont, Mississauga, ON, Canada
Clopyralid	Lontrel	0.756	0.2% NIS	Dow AgroSciences, Calgary, AB, Canada
Triclopyr	Garlon	6.24	0.2% NIS	DuPont, Mississauga, ON, Canada
Pyroxsulam	Simplicity	0.075	0.2% NIS	Dow AgroSciences, Calgary, AB, Canada
Flazasulfuron	Mission	0.25	0.2% NIS	ISK BioSciences, Concord, OH, USA
Halosulfuron[c]	Sandea	0.17424	0.2% NIS	Gowan Canada, Winnipeg, MB, Canada
Dicamba+ diflufenzopyr[c]	Distinct	1.0682	0.2% NIS	BASF, Mississauga, ON, Canada

[a]Abbreviation: N/A, not applicable.
[b]28% urea-ammonium nitrate was applied at a rate of 12.5 mL L^{-1}.
[c]Halosulfuron and dicamba+diflufenzopyr were only applied in fall spot application experiment.

Table 3- 6. Application date and weather conditions at the time of herbicide spot applications at Collingwood Corner, Greenfield, Parrsoboro, and Rawdon, Nova Scotia in 2017.

Experiment	Site	Application date	Temperature	Relative humidity	Wind speed
			---°C---	---%---	---Km h^{-1}---
Summer spot application	Greenfield	June 28	20	50	5
	Parrsboro	June 27	26	42	10
	Rawdon	June 21	23	64	14
Fall spot application	Collingwood Corner	September 17	15	87	6
	Parrsboro	September 17	16	82	8
	Rawdon	September 18	18	92	5

Experiment 5: Effect of spot applications of dicamba tank mixtures with sulfonylurea herbicides on spreading dogbane

The experiment was conducted at Westchester Mt. (Bragg and Staple) in 2018-2019 (Table 3-1). Experiments were arranged as a completely randomized design with 5 replications and 1 m X 1 m plot size and were established in various spreading dogbane patches across each site. The experiment was a 3 × 4 factorial arrangement of dicamba rate (0, 0.96 and 1.92 g a.e. L water $^{-1}$) and sulfonylurea herbicides (none, foramsulfuron at 0.18 g a.i. L water $^{-1}$, flazasulfuron at 0.25 g a.i. L water $^{-1}$, and nicosulfuron+ rimsulfuron at 0.03 g a.i. L water $^{-1}$). Herbicides were applied to the experimental plots when spreading dogbane was at the early-bud stage. Herbicides were applied with a CO_2 pressurized research plot sprayer equipped with a single AI11002-VS AI TeeJet Air Induction Flat nozzle operated at a spray pressure of 275 KPa. Herbicides were applied to spreading dogbane leaves until the initial runoff of herbicide solution occurred. Mean spreading dogbane shoot heights at application were 29 ± 4 cm and 35 ± 4 cm in Westchester Mt. Bragg and Staple, respectively. The weather conditions at the time of treatment applications for each site are reported in Table 3-7.

Table 3- 7. Application date and the weather conditions at the time of herbicide tank mix spot applications at Westchester Mt. Bragg and Staple fields, Nova Scotia in 2018.

Site	Application date	Temperature	Relative humidity	Wind speed
		---°C---	---%---	---Km h^{-1}---
Westchester Mt. (Bragg field)	July 5, 2018	20	50	6
Westchester Mt. (Staple field)	July 5, 2018	20	50	6

Data collection

Data collection in all experiments included spreading dogbane shoot density and height measurements and visual injury ratings on spreading dogbane and lowbush blueberry, where possible. Lowbush blueberry stem length, floral bud number, and yield data were collected in the broadcast herbicide experiments at sites with sufficient blueberry coverage across the experimental area.

Spreading dogbane shoot density in the broadcast and summer spot application experiments was determined at the time of treatment applications, at the end of the nonbearing year, and in early summer of the bearing year. Spreading dogbane shoot density in the fall spot application experiment was determined at the time of fall herbicide applications and in early summer of the bearing year. Spreading dogbane shoot density was determined in two 1 m^2 quadrats in all broadcast experiments and on a whole-plot basis for spot application experiments. Spreading dogbane height in all broadcast experiments was determined on 30 randomly selected spreading dogbane shoots across the entire trial area. Spreading dogbane height in all spot application experiments was determined on 5 shoots in each treatment plot. Visual injury ratings were collected in all experiments except the fall herbicide spot application experiment at 7, 21, and 35 d after treatment (DAT). Visual injury ratings were conducted using a scale from 0 to 100, where 0 meant no plant injury and 100 was complete plant death. To ensure consistency, all visual injury ratings were conducted by the same person on each evaluation.

Lowbush blueberry stem length and floral bud number were determined on thirty randomly selected blueberry stems from each plot and data were collected at the end of the nonbearing year. Lowbush blueberry yield was determined in two 1 m^2 quadrats per plot using hand rakes in mid-August.

Lowbush blueberry stem length and floral bud number in experiment 1 were determined on thirty randomly selected blueberry stems from each plot and data were collected at the end of the nonbearing year on October 2, 2017 (Collingwood Corner), September 22, 2017 (Rawdon), and November 12, 2018 (Westchester Mt.). Lowbush blueberry yield was determined in two 1 m^2 quadrats per plot using hand rakes in on August 14^{th} and 15^{th} in 2018 at Westchester Mt, Collingwood Corner and Rawdon, respectively.

Lowbush blueberry stem length and floral bud number in experiment 2 were determined on thirty randomly selected blueberry stems from each plot and data were collected at the end of the nonbearing year on October 2, 2017 (Windham Hill) and November 12, 2018 (Westchester Mt.). The lowbush blueberry yield was determined in two 1 m^2 quadrats per plot using hand rakes on August 14, 2019, at Westchester Mt.

Lowbush blueberry stem length and floral bud number in experiment 3 were determined on thirty randomly selected blueberry stems from each plot and data were collected at the end of the nonbearing year on November 12, 2018, at both sites. Lowbush blueberry yield was determined in two 1 m^2 quadrats per plot using hand rakes on August 14, 2019, in both sites.

Statistical analysis

SAS (version 9.4, SAS Institute, Raleigh, NC) was used for all analyses. All experimental data were analysed with a mixed effects model using PROC MIXED. Herbicide treatment and main and interactive effects were modeled as fixed effects in all analyses and blocks, where used, were modeled as random effects. ANOVA assumptions were evaluated with PROC UNIVARIATE. Differing data transformations (i.e., square root, common log) were used when needed to meet the normality and constant variance assumptions, and transformations used are indicated in results tables. Subjective data (e.g., damage ratings) were analyzed using nonparametric analysis in PROC NPAR-1-WAY, and treatment effects were determined using the Kruskal-Wallis test. Means were determined using the LS MEANS statement, and mean separation, where necessary, was conducted using Tukey's HSD multiple means comparison test with significance set at $\alpha = 0.05$.

Results and Discussion

Experiment 1: Evaluation of sequential mesotrione applications on spreading dogbane

Initial spreading dogbane shoot density did not vary across treatments at Collingwood Corner or Rawdon ($P \geq 0.0599$), though initial density did vary across treatments at the Westchester Mt. site ($P = 0.0095$) (Table 3-8). Herbicide treatment had a significant effect on spreading dogbane visual injury ratings at each site ($P \leq 0.0014$) (Table 3-8). There was no significant herbicide treatment effect on nonbearing year spreading dogbane density at Westchester Mt. ($P = 0.2363$) and no significant herbicide treatment effect on spreading dogbane shoot density at any site in the bearing year ($P \geq 0.1675$). Single mesotrione applications caused 25-31% injury to spreading dogbane by 35 DAS but did not reduce nonbearing year density at Westchester Mt. or bearing year density at any of the sites (Table 3-8). Sequential mesotrione applications caused greater injury than single applications, though injury varied across sites. Sequential mesotrione applications at 7 and 14 DAIT caused 56-67 % injury to spreading dogbane by 35 DAS at Collingwood Corner, with applications at 21 and 28 DAIT causing less injury at this site (Table 3-8). Sequential mesotrione applications at 7, 14, and 21 DAIT all caused >80% injury at Rawdon, whereas injury was highest when sequential applications occurred at 7 DAIT at Westchester Mt. (Table 3-8). Variation in both spreading dogbane (Wu and Boyd 2012) and hemp dogbane (Ransom and Kells 1998) response to herbicides across sites has been reported and factors affecting this variation should be explored further in future research. Bearing year density, regardless of extent of nonbearing year injury from sequential applications, was not reduced at any site (Table 3-8). These results therefore suggest that mesotrione, applied alone or as sequential applications, is not an effective herbicide treatment for spreading dogbane. Sequential mesotrione applications are, however, effective on other perennial weeds, including horsenettle (*Solanum carolinense* L.) in corn (*Zea mays*) (Armel et al.2003) and narrowleaf goldenrod [*Euthamia graminifolia* (L.) Nutt.)] in lowbush blueberries (Farooq et al. 2019), indicating utility of sequential applications for control of perennial weeds other than spreading dogbane. Tank mixtures of mesotrione with other herbicides (nicosulfuron+rimsulfuron) may improve control of spreading dogbane as well (Wu and Boyd 2012), indicating that future research should consider opportunities for mesotrione tank mixtures in sequential applications.

There was a minimal lowbush blueberry injury from mesotrione applications (0-5%) across sites (data not shown). There was no significant effect of treatment on blueberry stem length ($P \geq 0.1625$), blueberry floral bud number stem^{-1} ($P \geq 0.2043$), or yield ($P \geq 0.1368$) across sites. Mean blueberry stem length at Collingwood Corner, Rawdon, and Westchester Mt. was 19 ± 5 cm, 23 ± 2 cm, and 22 ± 8 cm, respectively. Mean blueberry flower bud number at Collingwood Corner, Rawdon, and Westchester Mt. was 3 ± 1, 3 ± 1, and 4 ± 2 buds stem^{-1}, respectively. Mean blueberry yield at Collingwood Corner, Rawdon, and Westchester Mt. was 1600.0 ± 0.1 kg·ha^{-1}, 900.0 ± 0.1 kg·ha^{-1}, and 300.0 ± 0.1 kg·ha^{-1}, respectively.

Table 3- 8. Effect of single and sequential mesotrione applications on spreading dogbane visual injury ratings and shoot density at lowbush blueberry fields in Collingwood Corner, Rawdon, and Westchester Mt., Nova Scotia, Canada.

Site	Treatment	Density at initial application[a]	Visual injury ratings[b] 7 DAT[c]	21 DAT	35 DAT	Nonbearing-year shoot density	Bearing-year shoot density
		-shoots m^{-2}-	----------------%--------------			----------shoots m^{-2}-------	
Collingwood Corner	Nontreated control	2.6 ± 0.2[d] a[e] (14)	0	0	0	*[f]	10.3 ± 2 a
	Mesotrione	2.8 ± 0.2 a (16)	14 ± 2	26 ± 2	25 ± 5	*	12.0 ± 2 a
	Mesotrione fb mesotrione (7 DAIT)	2.8 ± 0.2 a (16)	13 ± 3	52 ± 5	56 ± 8	*	13.8 ± 2 a
	Mesotrione fb mesotrione (14 DAIT)	2.8 ± 0.2 a (18)	12 ± 3	61 ± 3	67 ± 5	*	10.3 ± 1 a
	Mesotrione fb mesotrione (21DAIT)	2.6 ± 0.2 a (14)	16 ± 4	31 ± 6	48 ± 9	*	11.8 ± 2 a
	Mesotrione fb mesotrione (28 DAIT)	2.3 ± 0.2 a (10)	16 ± 2	32 ± 3	28 ± 5	*	9.3 ± 2 a
	P value[g]		0.0014	<.0001	<.0001		
Rawdon	Nontreated control	8.2 ± 2 a	0	0	0	*	4.9 ± 1 a
	Mesotrione	7.3 ± 1 a	25 ± 3	30 ± 4	31 ± 2	*	3.8 ± 1 a
	Mesotrione fb mesotrione (7 DAIT)	10.1 ± 3 a	29 ± 2	62 ± 5	90 ± 3	*	4.1 ± 1 a
	Mesotrione fb mesotrione (14 DAIT)	5.2 ± 1 a	29 ± 1	50 ± 4	88 ± 6	*	3.6 ± 1 a
	Mesotrione fb mesotrione (21DAIT)	11.6 ± 1 a	28 ± 4	34 ± 2	85 ± 4	*	5.0 ± 1 a
	Mesotrione fb mesotrione (28 DAIT)	10.1 ± 1 a	28 ± 3	30 ± 3	46 ± 13	*	4.2 ± 1 a
	P value		<.0001	<.0001	<.0001		
Westchester Mt.	Nontreated control	12.2 ± 4 b	0	0	0	13.1 ± 2 a	9.7 ± 2 a
	Mesotrione	21.3 ± 5 ab	20 ± 0	24 ± 2	25 ± 3	12.9 ± 4 a	13.3 ± 2 a
	Mesotrione fb mesotrione (7 DAIT)	31.9 ± 6 a	20 ± 0	65 ± 6	71 ± 3	8.1 ± 1 a	16.5 ± 2 a
	Mesotrione fb mesotrione (14 DAIT)	17.3 ± 5 b	20 ± 0	47 ± 5	51 ± 4	11.1 ± 2 a	15.3 ± 3 a
	Mesotrione fb mesotrione (21DAIT)	23.1 ± 3 ab	20 ± 0	26 ± 2	48 ± 3	8.8 ± 3 a	13.5 ± 3 a
	Mesotrione fb mesotrione (28 DAIT)	21.7 ± 3 ab	20 ± 0	24 ± 2	52 ± 7	8.2 ± 2 a	16.0 ± 2 a
	P value		<.0001	<.0001	<.0001		

[a]Density at application at Collingwood Corner were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.
[b]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.
[c]Abbreviations: DAT, days after treatment; fb, followed by; DAIT, days after initial treatment.
[d]Values represent the mean ± 1 SE.
[e]Means within columns followed by different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.
[f]Shoot density data could not be determined at the end of the nonbearing year due to unexpected early senescence of shoots in all treatment plots.
[g]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Experiment 2: Evaluation of sequential mesotrione and foramsulfuron applications on spreading dogbane

Spreading dogbane density prior to initial herbicide applications did not vary across treatments at any site ($P \geq 0.2586$) (Table 3-9). There was no significant effect of early herbicide application ($P \geq 0.4202$) or the early by late herbicide interaction ($P \geq 0.0846$) on nonbearing year spreading dogbane shoot density at Windham Hill and Westchester Mt. (Table 3-9). There was a significant effect of late herbicide application on nonbearing year spreading dogbane shoot density at Westchester Mt. ($P = 0.0185$) but not the Windham Hill site ($P = 0.2399$) (Table 3-9). There was no significant effect of early herbicide application ($P \geq 0.3633$), late herbicide application ($P \geq 0.6954$), or the early by late herbicide interaction ($P \geq 0.6105$) on bearing year spreading dogbane shoot density at each site (Table 3-9). There was a significant effect of herbicide treatment on spreading dogbane visual-injury rating ($P < 0.0001$) at all three sites (Table 3-9).

Single mesotrione and foramsulfuron applications, regardless of application timing, caused 40-63% injury (Table 3-9) but did not reduce shoot density at any site (Table 3-9). Injury from sequential mesotrione and sequential foramsulfuron applications was < 60% across sites (Table 3-9), further indicating lack of sequential mesotrione efficacy but also indicating lack of sequential foramsulfuron efficacy. Early mesotrione applications followed by late foramsulfuron applications, as well as early foramsulfuron applications followed by late mesotrione applications, generally caused < 60% injury and were also generally ineffective on spreading dogbane (Table 3-9). These results suggest that mesotrione and foramsulfuron, applied alone or as sequential application, are not effective herbicides for spreading dogbane.

There was minimal injury on lowbush blueberry from all treatment application (5%) across sites. Blueberry stem length, floral bud number and yield data were unable to obtain at Parrsboro site. There was no significant effect of early herbicide application ($P \geq 0.1010$), late herbicide application ($P \geq 0.2073$) or the early by late herbicide interaction ($P \geq 0.2808$) on blueberry stem length at Westchester Mt. and Windham Hill (data not shown). There was no significant effect of early herbicide application ($P \geq 0.2915$), late herbicide application ($P \geq 0.9283$) or the early by late herbicide interaction on blueberry floral bud number stem^{-1} at Westchester Mt. and Windham Hill ($P \geq 0.0961$) (data not shown). Yield data were only obtained at Westchester Mt., but data were not able to be made to conform to the assumptions of the normality of residuals and constant variance after data transformation. Mean blueberry stem length at Windham Hill and Westchester Mt. was 17 ± 3 cm and 24 ± 4 cm, respectively. Mean blueberry flower bud number at Windham Hill and Westchester Mt. was 2 ± 1 and 5 ± 1 buds stem^{-1}, respectively. Mean blueberry yield at Westchester Mt. was 160.0 ± 0.1 kg·ha^{-1}.

Table 3- 9. Effect of sequential mesotrione and foramsulfuron applications on spreading dogbane shoot density and visual injury ratings at lowbush blueberry fields in Windham Hill, Parrsboro, and Westchester Mt., Nova Scotia, Canada.

Site	Early herbicide application	Late herbicide application	Density at application	Visual injury ratings[a] 7 DAT[b]	21 DAT	35 DAT	Nonbearing-year shoot density	Bearing-year shoot density
			-shoots m^{-2}-	----------------%----------------			----------shoots m^{-2}---------	
Windham Hill	None	None	11.5 ± 2[c] a[d]	0	0	0	2.8 ± 1a	7.9 ± 2 a
	None	Mesotrione	8.1 ± 3 a	0	20 ± 4	40 ± 6	2.6 ± 1 a	5.8 ± 1 a
	None	Foramsulfuron	9.7 ± 3 a	0	20 ± 0	42 ± 4	3.6 ± 1 a	6.3 ± 1 a
	Mesotrione	None	8.3 ± 1 a	16.7 ± 8	37.5 ± 3	40 ± 8	2.7 ± 1 a	5.7 ± 1 a
	Mesotrione	Mesotrione	6.2 ± 2 a	23.3 ± 4	50.8 ± 2	54.2 ± 2	2.5 ± 1 a	5.6 ± 2 a
	Mesotrione	Foramsulfuron	4.3 ± 1 a	30.8 ± 3	42.5 ± 3	54.2 ± 2	4.1 ± 1 a	5.7 ± 1 a
	Foramsulfuron	None	5.0 ± 1 a	9.2 ± 2	29.2 ± 2	45.0 ± 5	3.3 ± 1 a	4.8 ± 1 a
	Foramsulfuron	Mesotrione	9.0 ± 2 a	15.8 ± 2	43.3 ± 5	55.0 ± 2	3.8 ± 2 a	5.6 ± 1 a
	Foramsulfuron	Foramsulfuron	8.0±1a	11.7 ± 2	39.2 ± 5	49.2 ± 6	5.0 ± 1 a	6.8 ± 1 a
		P value[e]		<.0001	<.0001	<.0001		
Parrsboro	None	None	13.3 ± 4 a	0	0	0	*[f]	12.1 ± 3 a
	None	Mesotrione	11.0 ± 4 a	0	20 ± 4	40 ± 6	*	9.2 ± 2 a
	None	Foramsulfuron	16.3 ± 4 a	0	20 ± 0	42 ± 4	*	13.0 ± 3 a
	Mesotrione	None	12.3 ± 3 a	16.7 ± 8	37.5 ± 3	40 ± 8	*	10.3 ± 1 a
	Mesotrione	Mesotrione	11.3 ± 3 a	23.3 ± 4	50.8 ± 2	54.2 ± 2	*	10.4 ± 2 a
	Mesotrione	Foramsulfuron	11.3 ± 2 a	30.8 ± 3	42.5 ± 3	54.2 ± 2	*	11.1 ± 1 a
	Foramsulfuron	None	11.3 ± 2 a	9.2 ± 2	29.2 ± 2	45.0 ± 5	*	13.0 ± 2 a
	Foramsulfuron	Mesotrione	16.3 ± 6 a	15.8 ± 2	43.3 ± 5	55.0 ± 2	*	12.0 ± 3 a
	Foramsulfuron	Foramsulfuron	15.2 ± 4 a	11.7 ± 2	39.2 ± 5	49.2 ± 6	*	10.1 ± 2 a
		P value		<.0001	<.0001	<.0001		
Westchester Mt.	None	None	17.7 ± 3 a	0	0	0	16.0 ± 2 a	16.8 ± 2 a
	None	Mesotrione	17.0 ± 1 a	0	50.0 ± 6	60.8 ± 4	9.0 ± 2 a	17.2 ± 2 a
	None	Foramsulfuron	28.5 ± 4 a	0	60.8 ± 3	63.3 ± 5	11.7 ± 1 a	21.3 ± 4 a
	Mesotrione	None	19.8 ± 3 a	28.3 ± 3	30.8 ± 8	40.8 ± 6	14.8 ± 2 a	19.1 ± 2 a
	Mesotrione	Mesotrione	20.2 ± 3 a	35.8 ± 1	47.5 ± 6	44.2 ± 5	11.5 ± 1 a	14.6 ± 3 a
	Mesotrione	Foramsulfuron	18.1 ± 2 a	32.5 ± 3	54.2 ± 8	63.3 ± 3	8.3 ± 2 a	14.7 ± 1 a
	Foramsulfuron	None	18.3 ± 2 a	25.8 ± 4	35 ± 11	48.3 ± 6	10.2 ± 1 a	17.6 ± 2 a
	Foramsulfuron	Mesotrione	22.0 ± 3 a	23.3 ± 2	44.2 ± 7	35.8 ± 6	11.8 ± 2 a	18.9 ± 2 a
	Foramsulfuron	Foramsulfuron	19.1 ± 4 a	27.5 ± 2	66.7 ± 3	49.2 ± 4	9.3 ± 1 a	13. 5± 1 a

P value	<.0001	<.0001	<.0001

[a]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.
[b]Abbreviations: DAT, days after treatment.
[c]Values represent the mean ± 1 SE.
[d]Means within columns followed by different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.
[e]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.
[f]Shoot density data could not be determined at the end of the nonbearing year due to unexpected early senescence of shoots in all treatment plots.

Experiment 3 Evaluation of broadcast herbicide tank mixtures on spreading dogbane

Initial spreading dogbane shoot density did not vary across treatments at each site ($P \geq 0.0563$) (Table 3-10). There was a significant herbicide treatment effect on visual injury ratings ($P < 0.0001$) on all rating dates at each site (Table 3-10). There was a significant herbicide treatment effect on spreading dogbane shoot density in both the nonbearing year ($P = 0.0003$) and bearing year ($P = 0.0016$) at Staple field but not in either year at the Bragg field ($P \geq 0.2451$) (Table 3-10). There was a significant herbicide treatment effect on blueberry stem length ($P = 0.0003$) and yield ($P = 0.0257$) at Staple field and blueberry stem length ($P < 0.0001$) and floral bud number ($P = 0.0299$) at the Bragg field (Table 3-11).

Mesotrione caused 32-57% injury to spreading dogbane but did not reduce nonbearing or bearing year shoot density at either site (Table 3-10). Similar levels of injury and lack of shoot density reduction occurred following single mesotrione applications in the sequential mesotrione experiment (Table 3-8) and early and late mesotrione applications (Table 3-9), further indicating limited utility of mesotrione applications alone to control spreading dogbane. Foramsulfuron caused 45-65% injury across sites but did not reduce nonbearing or bearing year spreading dogbane shoot density at either site (Table 3-10). These results are similar to those obtained from both early and late foramsulfuron applications (Table 3-9) and indicate that foramsulfuron applications alone injure spreading dogbane but do not provide adequate control. Injury from flazasulfuron was generally similar to that of foramsulfuron, though flazasulfuron reduced nonbearing year shoot density at the Staple field (Table 3-10). Bearing year density, however, was not reduced by this herbicide at either site (Table 3-10), indicating that injury and potential nonbearing year density reductions do not contribute to long-term control of spreading dogbane. Mesotrione + foramsulfuron caused similar levels of visual injury as these herbicides applied alone, but this tank mixture reduced both nonbearing and bearing year shoot density at the Staple field (Table 3-10). Although similar density reductions did not occur at Bragg, these results indicate potential improvements in spreading dogbane control from mesotrione + foramsulfuron tank mixtures relative to applications of these herbicides alone or as sequential applications. The mesotrione + flazasulfuron tank mixture caused ≥ 70% injury to spreading dogbane, though nonbearing and bearing year density were not reduced. The increased injury to spreading dogbane, however, would indicate that this tank mixture could be considered further for potential management of spreading dogbane. The foramsulfuron + flazasulfuron tank mixture caused > 80% injury to spreading dogbane and reduced both nonbearing and bearing year density at Staple field (Table 3-10). Although density reductions were not consistent across sites, the level of control obtained at Staple warrants additional research with this tank mixture as flazasulfuron provides effective suppression or control of other perennial weeds in lowbush blueberry fields (Zhang et al. 2018; Farooq et al. 2019). Treatments containing flazasulfuron, however, caused >60% crop injury and reduced stem length (Table 3-11), indicating that this herbicide should be limited to spot applications for spreading dogbane control. Sequential applications of mesotrione and foramsulfuron or mesotrione and flazasulfuron injured spreading dogbane and reduced nonbearing year density at Staple, though bearing year density was not reduced at either site (Table 3-10). Collectively, these results indicate that herbicide tank mixtures, rather than single or sequential applications, may be more effective for spreading dogbane management.

There was minimal injury on lowbush blueberry from mesotrione application (5-20%) across sites. There was a significant effect of treatment on blueberry stem length ($P \leq 0.0003$) across sites. There was a significant negative effect of treatment on blueberry floral bud number stem^{-1} at staple site ($P = 0.0336$), but no significant effect of treatments at Bragg site ($P = 0.6491$). There was a significant effect of treatment on yield ($P = 0.0257$) at Bragg site, but no significant effect of treatment at Staple site ($P = 0.2127$).

Table 3-10. Effect of broadcast herbicide tank mix and sequential applications on spreading dogbane visual injury ratings and shoot density at lowbush blueberry fields in Westchester Mt., Nova Scotia, Canada in 2018 and 2019.

Site	Treatment	Density at application	Visual injury ratings[a]			Nonbearing-year density	Bearing-year density
			7 DAT[b]	21 DAT	35 DAT		
		--shoots m^{-2}--	----------------%----------------			-----------shoots m^{-2}----------	
Westchester Staple Field	Non-treated Control	16.3 ± 2[c] a[d]	0	0	0	14.6 ± 1 a	18.0 ± 1 a
	Mesotrione	8.4 ± 2 a	19 ± 1	51 ± 4	57 ± 1	10.1 ± 1 ab	11.7 ± 2 abc
	Foramsulfuron	13.9 ± 2 a	12 ± 2	49 ± 4	65 ± 4	10.7 ± 1 ab	14.1 ± 1 ab
	Flazasulfuron	13.5 ± 2 a	19 ± 1	51 ± 4	57 ± 1	8.3 ± 2 b	14.7 ± 2 ab
	Mesotrione+ Foramsulfuron	11.5 ± 4 a	17 ± 3	56 ± 2	56 ± 1	7.8 ± 1 b	10.7 ± 3 bc
	Mesotrione+ Flazasulfuron	12.8 ± 1 a	16 ± 2	55 ± 5	70 ± 4	10.4 ± 1 ab	12.5 ± 1 abc
	Foramsulfuron+ Flazasulfuron	10.9 ± 2 a	22 ± 2	80 ± 4	87 ± 5	5.8 ± 1 b	6.9 ± 1 c
	Mesotrione fb Foramsulfuron	14.3 ± 3 a	21 ± 2	53 ± 2	58 ± 2	7.8 ± 1 b	11.0 ± 1 abc
	Mesotrione fb Flazasulfuron	14.2 ± 3 a	21 ± 2	67 ± 5	80 ± 3	7.2 ± 1 b	10.9 ± 1 abc
	P-value[e]		<.0001	<.0001	<.0001		
Westchester Bragg Field	Non-treated Control	10.0 ± 2 a	0	0	0	13.7 ± 2 a	10.8 ± 2 a
	Mesotrione	7.2 ± 1 a	16 ± 3	23 ± 2	32 ± 7	11.3 ± 2 a	9.4 ± 1 a
	Foramsulfuron	9.1 ± 0 a	12 ± 1	24 ± 5	45 ± 4	8.9 ± 1 a	9.6 ± 1 a
	Flazasulfuron	6.0 ± 1 a	12 ± 1	58 ± 3	65 ± 5	9.0 ± 1 a	11.1 ± 1 a
	Mesotrione+ Foramsulfuron	9.4 ± 2 a	13 ± 2	27 ± 3	41 ± 7	10.3 ± 2 a	10.5 ± 2 a
	Mesotrione+ Flazasulfuron	12.7 ± 2 a	14 ± 2	57 ± 6	77 ± 2	12.0 ± 3 a	9.8 ± 2 a
	Foramsulfuron+ Flazasulfuron	9.7 ± 1 a	16 ± 2	69 ± 1	82 ± 3	7.3 ± 1 a	8.4 ± 1 a
	Mesotrione fb Foramsulfuron	6.5 ± 1 a	16 ± 2	28 ± 5	57 ± 5	9.0 ± 2 a	7.4 ± 1 a
	Mesotrione fb Flazasulfuron	10.9 ± 2 a	20 ± 0	63 ± 1	77 ± 4	11.6 ± 1 a	11.0 ± 1 a
	p-value		<.0001	<.0001	<.0001		

[a]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.
[b]Abbreviations: DAT, days after treatment; fb, followed by.
[c]Values represent the mean ± 1 SE.
[d]Means within columns followed by different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.
[e]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Table 3- 11. Effect of broadcast herbicide tank mix and sequential applications on blueberry visual injury ratings, stem length, floral bud number, and yield at lowbush blueberry fields in Westchester Staple and Bragg fields, Nova Scotia, Canada.

Site	Treatment	Visual injury ratings[a]			Blueberry stem length	Blueberry floral bud number	Blueberry yield
		7 DAT[b]	21 DAT	35 DAT			
		----------------%----------------			------cm------		----$kg \cdot ha^{-1}$---
Westchester Staple Field	Non-treated Control	0	0	0	18.3 ± 0.8[c] a[d]	4.1 ± 0.3 ab	140 ± 0.04 a
	Mesotrione	5.0 ± 0	5.0 ± 0	6.0 ± 1. 0	18.0 ± 0.9 ab	3.6 ± 0.1 ab	170 ± 0.03 a
	Foramsulfuron	5.0 ± 0	6.0 ± 1. 0	6.0 ± 1. 0	16.4 ± 1.5 abcd	3.6 ± 0.2 ab	140 ± 0.02 a
	Flazasulfuron	10.0 ± 1.6	11.0 ± 1. 0	8.0 ± 1. 2	13.3 ± 0.5 cd	3.5 ± 0.3 ab	230 ± 0.04 a
	Mesotrione+ Foramsulfuron	7.0 ± 1.2	5.0 ± 0	5.0 ± 0	17.6 ± 0.6 abc	4.4 ± 0.2 ab	230 ± 0.06 a
	Mesotrione+ Flazasulfuron	8.0 ± 1.2	11.0 ± 1.0	8.0 ± 1.2	13.8 ± 1.1 bcd	3.3 ± 0.2 ab	100 ± 0.05 a
	Foramsulfuron+ Flazasulfuron	9.0 ± 1.0	14.1 ± 1.0	9.0 ± 1.0	12.6 ± 0.5d	3.5 ± 0.4 ab	120 ± 0.03 a
	Mesotrione fb Foramsulfuron	5.0 ± 0	5.0 ± 0	5.0 ± 0	18.9 ± 1.4 a	4.7 ± 1.0 a	180 ± 0.07 a
	Mesotrione fb Flazasulfuron	6.0 ± 1.0	11.0 ± 1.0	11.0 ± 1.0	13.4 ± 0.6 cd	2.9 ± 0.2 b	150 ± 0.05 a
	P-value[e]	<.0001	<.0001	<.0001			
Westchester Bragg Field	Non-treated Control	0	0	0	16.9 ± 0.5 abc	3.4 ± 0.2 a	200 ± 0.05 ab
	Mesotrione	5.0 ± 0	5.0 ± 0	5.0 ± 0	17.6 ± 1.8 ab	4.0 ± 0.6 a	200 ± 0.05 ab
	Foramsulfuron	5.0 ± 0	11.0 ± 2.4	5.0 ± 0	18.6 ± 1.4 a	4.2 ± 0.8 a	200 ± 0.05 ab
	Flazasulfuron	5.0 ± 0	11.0 ± 2.4	5.0 ± 0	12.9 ± 0.4 c	3.9 ± 0.3 a	200 ± 0.03 ab
	Mesotrione+ Foramsulfuron	5.0 ± 0	5.0 ± 0	5.0 ± 0	17.8 ± 0.8 ab	3.9 ± 0.4 a	200 ± 0.05 ab
	Mesotrione+ Flazasulfuron	5.0 ± 0	9.0 ± 1	5.0 ± 0	13.6 ± 0.5 bc	4.2 ± 0.3 a	200 ± 0.03 ab
	Foramsulfuron+ Flazasulfuron	5.0 ± 0	17.0 ± 3.0	4.0 ± 1. 0	13.4 ± 0.6 bc	3.3 ± 0.2 a	100 ± 0.02 ab
	Mesotrione fb Foramsulfuron	5.0 ± 0	5.0 ± 0	5.0 ± 0	17.6 ± 1.2 ab	3.9 ± 0.4 a	300 ± 0.09 a
	Mesotrione fb Flazasulfuron	5.0 ± 0	18.0 ± 1.2	5.0 ± 0	14.7 ± 0.6 abc	4.0 ± 0.2 a	100 ± 0.04 b
	p-value	<.0001	<.0001	<.0001			

[a]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.
[b]Abbreviations: DAT, days after treatment; fb, followed by.
[c]Values represent the mean ± 1 SE.
[d]Means within columns followed by different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.
[e]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Experiment 4: Effect of summer and fall spot herbicide applications on spreading dogbane

Summer spot herbicide applications on spreading dogbane

Initial spreading dogbane shoot density did not vary across treatments at each site ($P \geq 0.6996$) (Table 3-12). There was a significant effect of herbicide treatment on visual injury ratings ($P < 0.0001$) on all rating dates (Table 3-12). There was a significant effect of herbicide treatment on nonbearing year shoot density at Greenfield and bearing year shoot density at Greenfield and Parrsboro ($P< 0.0001$) (Table 3-12). There was no a significant effect of herbicide treatment on bearing year shoot density at Rawdon ($P = 0.9680$) (Table 3-12).

Dicamba and glyphosate caused 100% damage to spreading dogbane by 35 DAT at all three sites (Table 3-12) and reduced nonbearing year shoot density at Greenfield (Table 3-12). Nonbearing year density, unfortunately, could not be collected at Parrsboro and Rawdon due to early spreading dogbane shoot senescence at these sites, though the high level of injury at these sites from dicamaba and glyphosate (Table 3-12) indicates similar nonbearing year density reductions could have occurred in these treatments at these sites. Dicamba also reduced bearing year shoot density at Greenfield and Parrsboro (Table 3-12), indicating long term control of spreading dogbane by this herbicide. Injury from foramsulfuron varied across sites but was > 80% at Parrsboro and Rawdon (Table 3-12). Nonbearing year shoot density was also reduced by this treatment at Greenfield (Table 3-12). These results indicate that foramsulfuron may be more effective as a spot treatment rather than a broadcast application for spreading dogbane management. Tribenuron-methyl, nicosulfuron+rimsulfuron, and clopyralid caused variable levels of injury to spreading dogbane and did not reduce nonbearing or bearing year density, indicating that these currently registered herbicides likely will not contribute to spreading dogbane management in lowbush blueberry. Similarly, pyroxsulam and halosulfuron caused minimal injury to spreading dogbane and did not reduce density, indicating limited potential for these non-registered herbicides to contribute to spreading dogbane management. Alternative target weeds should, therefore, be identified if these herbicides are to be considered for registration in lowbush blueberries in Canada. Flazasulfuron, however, caused > 90% injury to spreading dogbane at Parrsboro and Rawdon. Although density was not reduced by this treatment, the high level of injury caused by flazasulfuron spot applications warrant additional work with this herbicide as broadcast applications of a flazasulfuron tank mixtures also caused high levels of injury to spreading dogbane and reduced density (Table 3-12).

Table 3- 12. Effect of various summer herbicide spot treatments on spreading dogbane visual injury ratings at lowbush blueberry fields in Greenfield, Parrsboro and Rawdon, Nova Scotia, Canada in 2017-2018.

Site	Treatment	Density at application[a]	Visual injury ratings[b]			Nonbearing-year density	Bearing-year density
			7 DAT[c]	21 DAT	35 DAT		
		-shoots m^{-2}-	-------------%-------------			-----------shoots m^{-2}----------	
Greenfield	Non-treated control	21 ± 6[d] a[e] (3)	0	0	0	8 ± 3[f]	13 ± 3 a (3)
	Dicamba	16 ± 2 a (3)	18 ± 3	100 ± 0	100 ± 0	3 ± 3	2 ± 1 b (1)
	Glyphosate	14 ± 2 a (3)	67 ± 15	100 ± 0	100 ± 0	0	5 ± 1 ab (2)
	Foramsulfuron	12 ± 2 a (2)	16 ± 2	29 ± 4	35 ± 10	1 ± 1	7 ± 1 ab (2)
	Tribenuron-methyl	19 ± 4 a (3)	14 ± 1	17 ± 2	11 ± 3	12 ± 2	8 ± 1 a (3)
	Nicosulfuron + Rimsulfuron	15 ± 4 a (3)	11 ± 2	12 ± 2	12 ± 4	8 ± 2	12 ± 2 a (3)
	Clopyralid	13 ± 2 a (3)	9 ± 1	7 ± 2	6 ± 1	4 ± 2	10 ± 3 a (2)
	Pyroxsulam	14 ± 3 a (3)	15 ± 2	19 ± 2	14±4	5 ± 1	8 ± 2 ab (2)
	Flazasulfuron	15 ± 3 a (3)	10 ± 2	21 ± 6	20±7	8 ± 2	11 ± 1 a (2)
	Halosulfuron	22 ± 6 a (3)	12 ± 3	13 ± 3	10±2	5 ± 1	14 ± 3 a (3)
	p-value [g]		<.0001	<.0001	<.0001		
Parrsboro	Non-treated control	15 ± 2 a (3)	0	0	0	*[h]	12 ± 2 a (4)
	Dicamba	12 ± 3 a (2)	55 ± 13	100 ± 0	100 ± 0	*	2. ± 1 b (2)
	Glyphosate	23 ± 3 a (3)	92 ± 8	100 ± 0	100 ± 0	*	5 ± 1 ab (2)
	Foramsulfuron	20 ± 4 a (3)	26 ± 2	90 ± 8	96 ± 4	*	8 ± 1 a (3)
	Tribenuron-methyl	22 ± 4 a (3)	10 ± 3	46 ± 6	52 ± 12	*	9 ± 1 a (3)
	Nicosulfuron + Rimsulfuron	18 ± 3 a (3)	13 ± 5	19 ± 3	33 ± 8	*	9 ± 3 a (3)
	Clopyralid	23 ± 6 a (3)	3 ± 2	8 ± 3	16 ± 7	*	7 ± 2 a (7)
	Pyroxsulam	22 ± 9 a (3)	6 ± 1	32 ± 2	42 ± 4	*	11 ± 2 ab (3)
	Flazasulfuron	23± 7 a (3)	22 ± 8	98 ± 1	100 ± 0	*	8 ± 2 ab (3)
	Halosulfuron	14 ± 3 a (3)	13 ± 3	12 ± 3	18 ± 4	*	9 ± 2 a (3)
	p-value		<.0001	<.0001	<.0001		
Rawdon	Non-treated control	12 ± 3a (2)	0	0	0	*	5 ± 2 a (2)
	Dicamba	10 ± 1 a (2)	77 ± 2	100 ± 0	100 ± 0	*	5 ± 2 a (2)
	Glyphosate	10 ± 2 a (2)	65 ± 7	99 ± 1	100 ± 0	*	5 ± 1 a (3)
	Foramsulfuron	9 ± 1 a (2)	14 ± 7	56 ± 14	80 ± 18	*	4 ± 2 a (2)
	Tribenuron-methyl	10 ± 2 a (2)	8 ± 3	18 ± 6	12 ± 6	*	4 ± 1 a (2)
	Nicosulfuron + Rimsulfuron	9 ± 1 a (2)	6 ± 1	21 ± 5	18 ± 2	*	4 ± 1 a (2)
	Clopyralid	15 ± 4 a (3)	5 ± 4	6 ± 2	10 ± 3	*	6 ± 2 a (2)

Pyroxsulam	10 ± 3 a (2)	11 ± 6	28 ± 14	48 ± 19	*	5 ± 2 a (2)
Flazasulfuron	13 ± 2 a (3)	19 ± 6	78 ± 13	90 ± 9	*	7 ± 2 a (3)
Halosulfuron	12 ± 3 a (2)	11 ± 4	19 ± 5	22 ± 6	*	5 ± 1 a (2)
p-value		<.0001	<.0001	<.0001		

[a]Density before application and bearing year shoot density at Greenfield were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Density before application and bearing year shoot density in Parrsboro were LOG(Y) and SQRT(Y) transformed respectively before analysis to meet the assumptions of the ANOVA analysis. Density before application and bearing year shoot density in Rawdon were LOG(Y) and SQRT(Y) transformed respectively before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.

[b]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.

[c]Abbreviations: DAT, days after treatment.

[d]Values represent the mean ± 1 SE.

[e]Means within columns with different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.

[f]Density in nonbearing year and bearing year at Greenfield was not able to be made to conform to the assumptions of normality and constant variance after data transformation. Letter groupings are therefore not provided for these data.

[g]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

[h]Shoot density data could not be determined at the end of the nonbearing year due to unexpected early senescence of shoots in all treatment plots.

Fall spot herbicide applications on spreading dogbane

Spreading dogbane shoot density at the time of herbicide applications did not vary across treatments ($P \geq 0.3108$) (Table 3-13). There was no significant treatment effect on spreading dogbane shoot density in the year after application at any site ($P \geq 0.1462$) as no herbicides evaluated reduced density in the year after application (Table 3-13).

Dicamba provided good control of spreading dogbane in the summer spot applications, so lack of efficacy in fall applications was unexpected as fall dicamba applications provide effective control of other perennial weeds such as dandelion (*Taraxacum officinale* F.H. wigg) and Canada Thistle (*Cirsium arvense* L) (Wilson and Michiels 2003). Broadcast dicamba applications in mid-September gave >80% control of spreading dogbane in lowbush blueberry fields (Wu 2012), and Wu (2012) reported high leaf retention on spreading dogbane shoots at this application timing. Fall spot applications in our experiment were conducted in mid-September as well, though we observed leaf chlorosis and leaf loss on some spreading dogbane shoots at the time of herbicide applications. Whaley and VanGessel (2002) reported that leaf chlorosis can reduce fall herbicide efficacy, and this likely contributed to the lack of efficacy of treatments in our experiment as well. Utilization of a fall application timing for spreading dogbane will, therefore, require careful observation of spreading dogbane patches within individual fields as senescence of this weed in fall may be variable across sites.

Table 3- 13. Effect of fall herbicide spot treatments on spreading dogbane shoot density at Collingwood Corner, Parrsboro, and Rawdon, Nova Scotia, Canada, in 2017-2018.

	Collingwood Corner		Parrsboro		Rawdon	
Treatment	Density at application[a]	Density in year after application	Density at application	Density in year after application	Density at application	Density in year after application
	-----------------	-----------------	-----------------	$shoots\ m^{-2}$	-----------------	-----------------
Non-treated control	2.0 ± 0.2[b] a[c] (6)	1.9 ± 0.2 a (7)	22.2 ± 2 a	13.8 ± 1 a	2.9 ± 0.3 a (18)	7.2 ± 1.0 a
Dicamba	2.4 ± 0.2 a (12)	2.5 ± 0.2 a (12)	24.8 ± 2 a	13.4 ± 1 a	2.9 ± 0.3 a (20)	8.6 ± 2.0 a
Glyphosate	1.8 ± 0.2 a (6)	2.4 ± 0.2 a (11)	27.4 ± 4 a	12.8 ± 3 a	3.5 ± 0.3 a (35)	15.0 ± 3.0 a
Foramsulfuron	2.4 ± 0.2 a (10)	2.4 ± 0.2 a (11)	18.6 ± 2 a	13.2 ± 2 a	2.7 ± 0.3 a (15)	5.2 ± 2.0 a
Tribenuron-methyl	2.1 ± 0.2 a (8)	2.3 ± 0.2 a (10)	25.0 ± 2 a	13.2 ± 2 a	3.0 ± 0.3 a (22)	10.4 ± 3.0 a
Nicosulfuron + Rimsulfuron	2.2 ± 0.2 a (11)	2.4 ± 0.2 a (10)	22.8 ± 4 a	11.8 ± 2 a	2.8 ± 0.3 a (16)	8.2 ± 1.0 a
Clopyralid	2.2 ± 0.2 a (11)	2.3 ± 0.2 a (10)	21.4 ± 3 a	11.0 ± 1 a	3.0 ± 0.3 a (27)	6.6 ± 2.0 a
Pyroxsulam	2.3 ± 0.2 a (10)	1.9 ± 0.2 a (7)	23.6 ± 3 a	12.0 ± 2 a	3.0 ± 0.3 a (22)	10.2 ± 2.0 a
Flazasulfuron	2.0 ± 0.2 a (6)	2.1 ± 0.2 a (8)	25.2 ± 3 a	10.6 ± 1 a	2.7 ± 0.3 a (16)	7.0 ± 1.0 a
Halosulfuron	2.1 ± 0.2 a (7)	2.2 ± 0.2 a (8)	27.2 ± 3 a	14.6 ±1 a	3.1 ± 0.3 a (24)	10.6 ± 2.0 a
Triclopyr	2.5 ± 0.2 a (12)	2.4 ± 0.2 a (11)	21.6 ± 4 a	11.4 ± 1 a	3.0 ± 0.3 a (24)	8.6 ± 1.0 a
Dicamba + diflufenzopyr	2.2 ± 0.2 a (9)	2.4 ± 0.2 a (11)	24.8 ± 1 a	15.4 ± 3 a	3.0 ± 0.3 a (16)	10.8 ± 2.0 a

[a]Density before application and bearing year shoot density in Collingwood Corner and density before application in Rawdon were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.

[b]Values represent the mean ± 1 SE.

[c]Means within columns followed by different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.

Experiment 5: Effect of dicamba tank mix spot applications on spreading dogbane

Spreading dogbane shoot density at the time of herbicide applications did not vary across treatments at either site ($P \geq 0.0884$) (Tables 3-14, 3-15). There was a significant effect of dicamba ($P < 0.0001$) and sulfonylurea herbicide ($P \leq 0.0318$), but not the dicamba by sulfonlylurea herbicide interaction ($P \geq 0.1981$) on nonbearing year spreading dogbane shoot density at each site (Tables 3-14, 3-15). There was a significant effect of dicamba ($P \leq 0.0013$), but not sulfonylurea herbicide ($P \geq 0.0838$) or the dicamba by sulfonylurea herbicide interaction ($P \geq 0.3257$) on bearing year shoot density at each site (Tables 3-14, 3-15).

Foramsulfuron and nicosulfuron+rimsulfuron applications without dicamba caused 31-85% injury and did not reduce nonbearing year or bearing year shoot density at either site (Tables 3-14, 3-15). Flazasulfuron applications, however, caused >90% injury to spreading dogbane at each site (Tables 3-14, 3-15) and, given results of the broadcast tank mixture experiment (Table 3-10) and summer spot herbicide application experiment (Table 3-12), indicate that this herbicide may contribute to spreading dogbane management.

Dicamba applications of 0.96 g a.e. L water^{-1} alone caused >85% injury at each site but did not reduce nonbearing or bearing year shoot density (Tables 3-14, 3-15). Tank mixture of 0.96 g a.e. L water^{-1} dicamba with foramsulfuron, however, reduced nonbearing year shoot density at each site (Tables 3-14, 3-15) and tank mixture with flazasulfuron reduced nonbearing year density at the Bragg field (Table 3-14). Bearing year density was not reduced in these treatments (Tables 3-14, 3-15) but results do indicate potential for tank mixtures of dicamba and sulfonylurea herbicides to improve control over dicamba alone. Tank mixture of 0.96 g a.e. L water^{-1} dicamba with nicosulfuron+rimsulfuron did not reduce nonbearing year density at either site (Tables 3-14, 3-15), though bearing year density was reduced by this treatment at Bragg (Table 3-14).

Dicamba applications of 1.92 g a.e. L water^{-1} caused >85% injury but only reduced nonbearing year shoot density at Bragg (Table 3-14) and bearing year shoot density at Staple (Table 3-15). Tank mixture with foramsulfuron and flazasulfuron, however, gave consistent reductions in nonbearing year density at each site (Tables 3-14, 3-15) and tank mixture with nicosulfuron+rimsulfuron reduced nonbearing year density at the Bragg field (Table 3-14). Tank mixture with foramsulfuron and nicosulfuron+rimsulfuron also reduced bearing year density at the Bragg field (Table 3-14), though no bearing year density reductions occurred in these treatments at the Staple field. Dicamba in tank mixture with nicosulfuron improved hemp dogbane and other broadleaf weed control in corn fields relative to dicamba applied alone (Dobbels and Kapusta 1993; Glenn and Anderson 1993; Glenn et al. 1997). In addition. hemp dogbane shoot growth was reduced in the year after application, however, the reasons for this enhanced activity remain unknown (Glenn et al. 1997; Kalnay and Glenn 2000). Results of our experiment suggest that spreading dogbane control can be improved by dicamba tank mixtures with sulfonylurea herbicides, particularly foramsulfuron or flazasulfuron.

Table 3- 14. Effect of dicamba and sulfonylurea herbicide spot applications on spreading dogbane visual injury and shoot density at Westchester Bragg field, Nova Scotia, Canada, in 2018 and 2019.

Dicamba (g a.e. L water^{-1})	Sulfonylurea	Density before application[a]	7 DAT[b]	21 DAT	35 DAT	Nonbearing-year shoot density	Bearing-year shoot density
		---shoots m^{-2}---	-------------%----------------			-----------shoots m^{-2}------------	
0	None	2.3 ± 0.2[c] a[d] (10)	0	0	0	3.2 ± 0.3 a (10)	7.6 ± 2.0 ab
0	Foramsulfuron	2.5 ± 0.2 a (12)	4 ± 3[e]	24 ± 14	31 ± 17	3.3 ± 0.3 a (10)	8.4 ± 1.0 ab
0	Flazasulfuron	2.3 ± 0.2 a (10)	13 ± 1	91 ± 8	99 ± 1	2.8 ± 0.3 ab (7)	6.2 ± 1.0 ab
0	Nicosulfuron + Rimsulfuron	2.5 ± 0.2 a (12)	13 ± 2	25 ± 15	33 ± 17	3.4 ± 0.3 a (10)	9.2 ± 1.0 a
0.96	None	2.6 ± 0.2 a (12)	12 ± 2	60 ± 19	95 ± 5	2.6 ± 0.3 abc (6)	4.6 ± 1.0 ab
0.96	Foramsulfuron	2.4 ± 0.2 a (10)	18 ± 2	99 ± 1	87 ± 13	1.7 ± 0.3 bc (3)	4.2 ± 2.0 ab
0.96	Flazasulfuron	2.9 ± 0.2 a (18)	18 ± 1	100	100	1.5 ± 0.3 c (1)	4.6 ± 1.0 ab
0.96	Nicosulfuron + Rimsulfuron	2.2 ± 0.2 a (8)	15 ± 2	81 ± 16	87 ± 13	2.3 ± 0.3 abc (5)	3.0 ± 1.0 b
1.92	None	2.5 ± 0.2 a (12)	16 ± 2	93 ± 7	99 ± 1	2.0 ± 0.3 bc (3)	4.6 ± 1.0 ab
1.92	Foramsulfuron	2.4 ± 0.2 a (11)	20 ± 2	100	100	1.6 ± 0.3 c (2)	3.2 ± 1.0 b
1.92	Flazasulfuron	2.5 ± 0.2 a (12)	20 ± 2	100	100	1.9 ± 0.3 bc (3)	4.6 ± 1.0 ab
1.92	Nicosulfuron + Rimsulfuron	2.3 ± 0.2 a (9)	17 ± 2	99 ± 1	100	1.7 ± 0.3 bc (2)	3.0 ± 1.0 b
	p-value[f]		<.0001	<.0001	<.0001		

[a]Density before application at Westchester Bragg field were LOG(Y) transformed and nonbearing year shoot density was SQRT(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.

[b]Abbreviations: DAT, days after treatment.

[c]Values represent the mean ± 1 SE.

[d]Means within columns followed by different letters are significantly different at P < 0.05 according to the Tukey honestly significant difference multiple means comparison test.

[e]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.

[f]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Table 3- 15. Effect of dicamba and sulfonylurea herbicide spot applications on spreading dogbane visual injury and shoot density at Westchester Staple field, Nova Scotia, Canada, in 2018 and 2019.

Dicamba (g a.e. L water^{-1})	Sulfonylurea	Density before application[a]	7 DAT[b]	21 DAT	35 DAT	Nonbearing-year shoot density	Bearing-year shoot density
		shoots m^{-2}	--------------%----------------			-----------shoots m^{-2}------------	
0	None	2.6 ± 0.2[c] a[d] (13)	0	0	0	2.2 ± 0.4 a (8)	2.1 ± 0.3 ab (7)
0	Foramsulfuron	3.0 ± 0.2 a (20)	12 ± 3[e]	55 ± 15	85 ± 10	1.0 ± 0.4 ab (3)	1.3 ± 0.3 ab (4)
0	Flazasulfuron	2.5 ± 0.2 a (12)	20 ± 4	94 ± 5	95 ± 5	1.0 ± 0.4 ab (3)	1.6 ± 0.3 ab (5)
0	Nicosulfuron + Rimsulfuron	2.4 ± 0.2 a (11)	12 ± 3	40 ± 14	57 ± 11	2.2 ± 0.4 a (8)	2.2 ± 0.3 a (8)
0.96	None	2.3 ± 0.2 a (10)	16 ± 2	84 ± 16	100	1.0 ± 0.4 ab (1)	1.0 ± 0.3 ab (2)
0.96	Foramsulfuron	2.8 ± 0.2 a (17)	22 ± 2	100	100	0.2 ± 0.4 b (0.4)	1.1 ± 0.3 ab (2)
0.96	Flazasulfuron	2.7 ± 0.2 a (14)	23 ± 2	100	100	0.5 ± 0.4 ab (1)	1.0 ± 0.3 ab (2)
0.96	Nicosulfuron + Rimsulfuron	2.5 ± 0.2 a (13)	16 ± 4	81 ± 19	72 ± 17	1.1 ± 0.4 ab (4)	1.8 ± 0.3 ab (7)
1.92	None	2.6 ± 0.2 a (13)	17 ± 3	81 ± 19	87 ± 13	1.0 ± 0.4 ab (3)	1.0 ± 0.3 b (2)
1.92	Foramsulfuron	2.8 ± 0.2 a (15)	18 ± 4	84 ± 16	100	0 b (0)	1.2 ± 0.3 ab (4)
1.92	Flazasulfuron	2.1 ± 0.2 a (8)	21 ± 3	100	100	0.6 ± 0.4 b (1)	1.1 ± 0.3 ab (3)
1.92	Nicosulfuron + Rimsulfuron	2.8 ± 0.2 a (16)	16 ± 3	87 ± 13	95 ± 5	1.0 ± 0.4 ab (3)	1.1 ± 0.3 ab (4)
	p-value[f]		<.0001	<.0001	<.0001		

[a]Density before application, nonbearing-year shoot density and bearing year shoot density at Westchester Staple field were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.

[b]Abbreviations: DAT, days after treatment.

[c]Values represent the mean ± 1 SE.

[d]Means within columns followed by different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.

[e]Visual injury ratings were estimated on a 0-100 scale, where 0 is no plant death and 100 is complete plant death.

[f]P-value associated with Kuskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Conclusion

In conclusion, broadcast mesotrione and foramsulfuron applications did not control spreading dogbane, and control was not improved by sequential applications of either herbicide. Broadcast tank mixtures of mesotrione+foramsulfuron or foramsulfuron+flazasulfuron, however, may improve control and should be explored further. Dicamba and glyphosate continue to be the most effective herbicide spot treatments for spreading dogbane, though spot applications of foramsulfuron and flazasulfuron caused >85% injury to spreading dogbane and could be explored further as potential spot treatments. Fall spot herbicide applications did not control spreading dogbane due to early senescence of spreading dogbane shoots at trial sites. Spot applications of dicamba at floral bud stage at 0.96 or 1.92 g a.e. L water^{-1} in tank mixture with foramsulfuron or flazasulfuron improved consistency of nonbearing year spreading dogbane shoot density reductions and these tank mixtures should be explored further for management of spreading dogbane in lowbush blueberry.

Chapter 4 - Evaluation of mechanical and chemical control strategies for spreading dogbane (*Apocynum androsaemifolium* L.) management in lowbush blueberry fields

Abstract

Spreading dogbane is a common perennial weed in lowbush blueberry fields in Nova Scotia. Field studies were conducted from 2017 to 2019 to (1) evaluate the effect of repeated cutting on spreading dogbane shoot regrowth, (2) determine the main and interactive effect of cutting and symplastic herbicide (dicamba) application on spreading dogbane shoot regeneration, (3) determine the optimum application timing of symplastic herbicide (dicamba) and cutting treatments. Results indicated that cutting at the floral bud stage was not effective to control spreading dogbane. Spreading dogbane shoots continued to regrow in the bearing year at each site. Dicamba was more effective than cutting when the herbicide was applied at the early-bud and flowering stages. Further research should be developed to evaluate cutting at mid- to late flower stage. Our recommendation for lowbush blueberry growers to control spreading dogbane is to apply dicamba (1.92 g a.e. L water $^{-1}$) in the early bud stage.

Introduction

The lowbush, or wild blueberry (*Vaccinium angustifolium* Ait.) is a perennial deciduous shrub that is native to north-eastern North America (Anonymous 2019). Commercial lowbush blueberry fields are developed from abandoned farmland or cleared forest areas, though blueberry growers prefer the former option as blueberry fields developed from abandoned farmland are easier to manage (Hall 1959). Commercial lowbush blueberry fields are usually managed under a 2-year production cycle consisting of a vegetative (nonbearing) year followed by a bearing year (McIsaac 1997). Fields are pruned by burning or mowing in the nonbearing year to remove old plant growth and encourage vegetative growth and flower bud formation (Baker et al. 1964). Flowers open and come into bloom in the second year, or bearing year, with fruit harvest occurring during late summer (Anonymous 2019; McIsaac 1997). Fields are pruned after the crop is harvested, and the two-year cycle begins again (McIsaac 1997). Among all management practices, weed management is a major production challenge (Jensen and Yarborough 2004). Weeds are a key limiting factor in lowbush blueberry production and contribute significant variation to annual yields (McCully et al. 1991; Yarborough 2011).

Creeping perennials are among the most problematic weed species in lowbush blueberry fields and are successful in cropland due to several reproductive and survival mechanisms and, in some instances, cropping and management practices that help these plants spread (Ross and Lembi 2009; Wu and Boyd 2012). Spreading dogbane (*Apocynum androsaemifolium* Ait.) is a creeping herbaceous perennial which reproduces by seeds and prolific creeping roots (Bergweiler and Manning 1999; Sampson et al. 1990). Spreading dogbane is a common weed in lowbush blueberry fields. The plant occurred in 87.5% of lowbush blueberry fields surveyed in the Saguenay-Lac-Saint-Jean region of Quebec (Lapointe and Rochefort 2001), and McCully et al. (1991) reported that 3.6% of 115 fields surveyed contained spreading dogbane in Nova Scotia. In a recent weed survey conducted from 2017 to 2019, 16.4% of 165 fields surveyed contained spreading dogbane in Nova Scotia (Chapter 2, Table 2-4). Small patches of spreading dogbane can develop into a serious problem in commercial lowbush blueberry fields, and the increased occurrence of this weed is therefore a concern to growers as a true integrated weed management (IWM) plan does not exist for this weed species.

Integrated weed management is a management approach that uses multiple weed control methods to give crops advantages over weeds (Harker and O'Donovan 2013). This approach provides opportunities to maintain weed populations at manageable levels, reduce the environmental impact from certain control methods (e.g., herbicides), maintain cropping system sustainability (Harker and O'Donovan 2013). A plan that combines the advantages of mechanical, cultural, and chemical control methods is most likely to achieve management goals (Smith 1995), and a successful management plan for perennial weed species usually utilizes multiple weed control strategies (Miller 2016) to exploit biological weaknesses.

Creeping herbaceous perennials have advanced underground vegetative structures that store carbohydrates. Shoot emergence and development early in the season depletes stored carbohydrate reserves from vegetative reproductive structures (Bradbury and Hofstra 1977), reducing vegetative reproductive structure biomass and shoot regeneration capability (Becker and Fawcett 1998). Emerged shoots gradually become physiologically independent and replenish carbohydrate reserves by transporting new carbohydrates back to the vegetative reproductive structures during later growing stages (D'Hertefeldt and Jonsdottir 1999). These timings generally correspond to periods of low vegetative reproductive structure biomass, increasing the susceptibility of these plants to management practices by reducing shoot regeneration capabilities or facilitating herbicide translocation to vegetative reproductive structures (D'Hertefeldt and Jonsdottir 1999). Therefore, an opportunity exists to utilise mechanical and chemical control strategies at a range of predicted susceptible timings to manage spreading dogbane. Utilizing dicamba as a chemical control and shoot cutting as a mechanical control, the objectives of this research were to (1) evaluate the effect of repeated cutting on spreading dogbane shoot regeneration, (2) determine the main and interactive effects of cutting and symplastic herbicide application on spreading dogbane shoot regeneration, and (3) determine the optimum application timing of symplastic herbicide and cutting treatments on spreading dogbane control.

Materials and Methods

Study Sites

Experiments were conducted in commercial lowbush blueberry fields in Nova Scotia between 2017 and 2019 (Table 4-1, Figure 4-1).

Table 4- 1. Study sites used for evaluation of chemical and mechanical control of spreading dogbane in lowbush blueberry fields in Nova Scotia, Canada.

Site, year	Production year	Latitude	Longitude	Elevation
				m
Collingwood Corner, 2017	Nonbearing	45° 34' 25.32" N	63° 53' 52.44" W	270
Collingwood Corner, 2018	Bearing			
Greenfield, 2017	Nonbearing	45° 18' 6.48" N	63° 10' 56.64" W	163
Greenfield, 2018	Bearing			
Parrsboro, 2017	Nonbearing	45° 30' 33.12" N	63° 44' 40.92" W	191
Parrsboro, 2018	Bearing			
Rawdon, 2017	Nonbearing	45° 5' 16.44" N	63° 44' 40.92" W	143
Rawdon, 2018	Bearing			
Westchester Mt., 2018	Nonbearing	45° 34' 57" N	63° 43' 26.40" W	265
Westchester Mt., 2019	Bearing			
Windham Hill, 2017	Nonbearing	45° 37' 30.36" N	63° 58' 27.84" W	244
Windham Hill, 2018	Bearing			

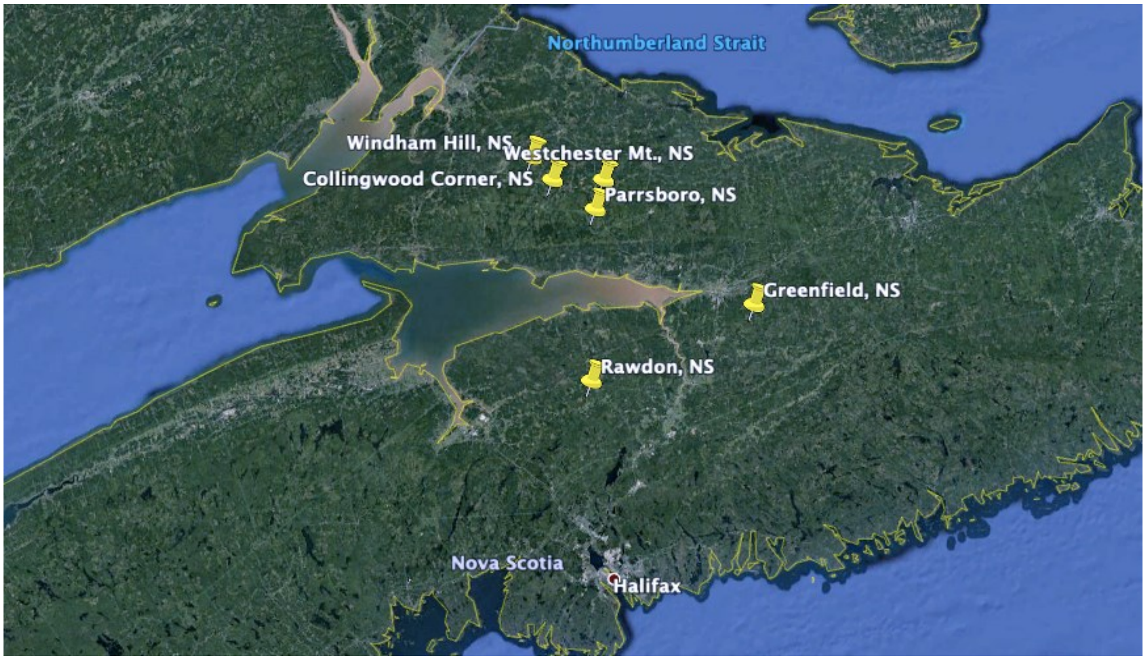

Figure 4- 1. Study sites used for evaluation of mechanical and chemical control strategies for spreading dogbane management in lowbush blueberry fields in Nova Scotia, Canada.

Experiment 1: Effect of repeated cutting on spreading dogbane shoot regeneration

The objective of this experiment was to determine if repeated cutting of spreading dogbane reduces shoot regeneration. Experiments were conducted in three commercial lowbush blueberry fields located in Collingwood Corner, Greenfield, and Rawdon, Nova Scotia (Table 4-1) in 2017-2018 to evaluate the effect of repeated cutting on spreading dogbane shoot regeneration. The experiment was arranged in a Completely Randomized Design (CRD) with 5 replications at all study sites. Plot size was 1 m by 1 m with a 0.5 m buffer between each plot. Treatments consisted of (1) nontreated control, (2) cutting of aboveground stems at soil level at the floral bud stage of spreading dogbane, and (3) cutting of aboveground stems at the soil level at the floral bud stage of spreading dogbane followed by cutting of regenerated shoots when regrowth reached the floral bud stage. Mean spreading dogbane heights on cutting dates across sites for all treatments are given in Table 4-2. Cutting was conducted with manual clippers, and all the aboveground shoot material was removed at each cutting.

Table 4- 2. Cutting dates and mean spreading dogbane shoot height at the time of cutting treatments at Collingwood Corner, Greenfield, and Rawdon, Nova Scotia, Canada, in 2017.

Site	Treatment	Application date	Mean shoot height[a]
			---cm---
Collingwood Corner	Initial cutting	June 29, 2017	60.0 ± 4
	Second cutting	August 8, 2017	36.5 ± 10.0
Greenfield	Initial cutting	June 27, 2017	49.3 ± 4
	Second cutting	August 25, 2017	29.7 ± 9
Rawdon	Initial cutting	June 21, 2017	51.2 ± 6
	Second cutting	August 8, 2017	39.7 ± 7

[a]Values represent the mean ± 1 SE.

Experiment 2: Integrating chemical and mechanical control for management of spreading dogbane

The objective of this experiment was to determine if combining chemical and mechanical control improves control of spreading dogbane. The experiment was conducted in three commercial lowbush blueberry fields located in Parrsboro (2017-2018), Rawdon (2017-2018) and Westchester Mt. (2018-2019), Nova Scotia (Table 1). Treatments consisted of (1) nontreated control, (2) initial control (IC) - cutting followed by (fb) subsequent control (SC) - nothing, (3) IC - cutting fb SC - cutting, (4) IC - cutting fb SC - herbicide, (5) IC - herbicide fb SC - nothing, (6) IC - herbicide fb SC - cutting, (7) IC - herbicide fb SC - herbicide. The experiment was arranged in a Completely Randomized Design (CRD) with 6 replications at each site. Plot size was 2 m by 2 m. Spreading dogbane heights was measured on application dates for initial and subsequent treatments at each site (Table 4-3). Initial control treatments were applied at the floral bud stage and the subsequent control treatments were applied when new growth in the treated plots reached the floral bud stage again. Dicamba was used as the symplastic herbicide due to previous reports of efficacy and crop tolerance (Wu and Boyd 2012) and was applied at 1.92 g a.e. L water $^{-1}$ with a hand-held, CO_2 pressurized research plot sprayer equipped with a single 8002VS nozzle operated at a spray pressure of 275 KPa. The cutting treatments consisted of cutting emerged spreading dogbane shoots as close to the soil surface as possible with clippers.

Table 4- 3. Application dates, mean spreading dogbane shoot height, air temperature, relative humidity, and wind speed at the time of initial and subsequent treatment applications at Parrsboro, Rawdon, and Westchester Mt., Nova Scotia, Canada.

Site	Treatment	Application date	Mean shoot height[a]	Temperature	Relative humidity	Wind speed
			---cm---	--°C--	-%-	-Km h^{-1}-
Parrsboro	Initial treatment	June 22, 2017	38.7 ± 9	18	56	16
	Subsequent treatment	August 25, 2017	26.0 ± 4	25	55	8
Rawdon	Initial treatment	June 15, 2017	46.0 ± 3	16	51	8
	Subsequent treatment	August 11, 2017	30.9 ± 5	25	50	8
Westchester Mt. (Staple field)	Initial treatment	July 5, 2018	34.6 ± 4	20	50	5
	Subsequent treatment	August 7, 2018	31.1 ± 3	23	45	5

[a]Values represent the mean ± 1 SE.

Experiment 3: Effect of cutting and herbicide application timing on spreading dogbane shoot regeneration

The objective of this experiment was to determine the optimum application timing of chemical and mechanical control treatments for control of spreading dogbane. The experiment was conducted in three commercial lowbush blueberry fields located in Collingwood Corner, Rawdon, and Windham Hill, Nova Scotia (Table 4-1) in 2017-2018. Treatments consisted of (1) nontreated control, (2) cutting at the pre-bud stage, (3) cutting at the early bud stage, (4) cutting at the flowering stage, (5) cutting at the post-seed stage, (6) dicamba application at the pre-bud stage, (7) dicamba application at the early bud stage, (8) dicamba application at the flowering stage, and (9) dicamba application at the post-seed stage. The experiment was arranged in a completely randomized design with 6 replications at all study sites. Plot size was 2 m by 2 m, with a 0.5 m buffer between each plot. Mean spreading dogbane shoot heights on application dates at each site are given in Table 4-4. Dicamba was applied at 1.92 g a.e. L water $^{-1}$ with hand-held, CO_2 pressurized research plot sprayer equipped with a single 8002VS nozzle operated at a spray pressure of 275 KPa.

Table 4- 4. Application dates, mean spreading dogbane shoot height, air temperature, relative humidity, and wind speed at the time of cutting and dicamba applications at Collingwood Corner, Rawdon, and Windham Hill, Nova Scotia, Canada.

Site	Treatment	Application date	Mean shoot height[a]	Temperature	Relative humidity	Wind speed
			---cm---	--°C--	-%-	-Km h^{-1}-
Collingwood Corner	Pre-bud stage	June 12, 2017	43.7 ± 9	13	89	8
	Floral bud stage	June 29, 2017	60.3 ± 9	20	63	9.5
	Flowering stage	July 19, 2017	63.7 ± 10.6	19	84	11
	Post-seed stage	August 1, 2017	56.0 ± 10.4	20	60	10
Rawdon	Pre-bud stage	June 14, 2017	41.9 ± 4	20	49	5
	Floral bud stage	June 23, 2017	43.9 ± 3	21	57	8
	Flowering stage	August 1, 2017	46.0 ± 5	21	60	10
	Post-seed stage	September 18, 2017	39.0 ± 3	18	92	5
Windham Hill	Pre-bud stage	June 12, 2017	21.7 ± 3	25	39	3
	Floral bud stage	June 29, 2017	22.6 ± 4	22	45	5
	Flowering stage	July 12, 2017	28.2 ± 7	21	84	14
	Post-seed stage	September 17, 2017	20.9 ± 5	18	70	5

[a]Values represent the mean ± 1 SE.

Data collection

Spreading dogbane shoot densities were determined at the time of treatment applications, at the end of the nonbearing year (mid-August) in which treatments were conducted, and in early summer of the bearing year when regenerating shoots were at the flower bud stage. Spreading dogbane shoot density was determined on a whole-plot basis for all experiments. Spreading dogbane shoot heights were determined on 5 shoots per plot and were collected from each plot before treatment applications.

Statistical analysis

SAS (version 9.4, SAS Institute, Raleigh, NC) was used for all statistical analyses. Spreading dogbane shoot density and height were analyzed with a mixed model and

PROC MIXED. Means were determined using the LS MEANS statement and mean separation, where necessary, was conducted using the Tukey HSD multiple means comparison test with significance of $\alpha = 0.05$. Assumptions of normality, constant variance, and independence were tested using PROC UNIVARIATE. Differing data transformations (i.e., square root, log) were used when needed to meet the assumptions of normality and constant variance, and transformations used are indicated in results tables. Subjective data (e.g., damage ratings) were analyzed using nonparametric analysis in PROC NPAR-1-WAY, and treatment effects were determined using the Kruskal-Wallis test.

Results and Discussion

Experiment 1: Effect of repeated cutting on spreading dogbane shoot regeneration

Initial spreading dogbane shoot density did not vary across treatments at all three sites ($P \geq 0.2765$) (Table 4-5). Unfortunately, nonbearing year shoot density at Collingwood Corner and Rawdon were not able to be collected due to unexpected early senescence of spreading dogbane shoots at these sites. Data from these sites are therefore limited to the bearing year. Nonbearing year data were collected at Greenfield.

There was a significant treatment effect on nonbearing year ($P = 0.0003$) but not bearing year ($P = 0.2854$) spreading dogbane shoot density at Greenfield. Similarly, there was no significant treatment effect on bearing year density at Collingwood Corner or Rawdon ($P \geq 0.3512$). Cutting emerged spreading dogbane stems once did not reduce final nonbearing year density at Greenfield. Two cuttings, however, reduced density by the end of the nonbearing year (Table 4-5). Bearing year density, however, was similar across all treatments at Greenfield, indicating short-term suppression of spreading dogbane by cutting. Bearing year shoot density was similar across treatments at Collingwood Corner and Rawdon as well, further indicating no long-term suppression of spreading dogbane by repeated cutting. Repeated mowing or cutting of gray goldenrod (*Solidago nemoralis* Aiton.) at the floral bud stage only reduced shoot density in the year of cutting as well (Peters and Lowance 1978). Shoot density of other weed species, such as wild chervil (*Anthriscus sylvestris* (L.) (Beaton 2014), common reed (*Phragmites australis* (Cav.) Trin. ex Steud) (Derr 2008), pale swallowwort (*Vincetoxicum rossicum*) (Averill et al. 2008), and narrow-leaved goldenrod (*Euthamia graminifolia* (L.) Nutt.) (Farooq 2018) is also only reduced in the year of cutting. Repeated cutting of tropical soda apple (*Solanum viarum*), however, was more effective than a single cutting (Mislevey et al. 1999), and repeated cutting reduced bermudagrass (*Cynodon dactylon* (L.) Pers.) and Johnsongrass (*Sorghum halepense* (L.) Pers.) rhizome length relative to a single cutting. Effects of this form of mechanical weed control therefore seem to vary across weed species, and perhaps additional work could investigate the effects of repeated cutting on spreading dogbane root biomass before ruling out this form of control for this weed species. In addition, our data show that repeated cutting will reduce short-term density, thus reducing potential shading, harvest interference, or other competitive interactions between spreading dogbane and lowbush blueberry.

Table 4- 5. Effect of repeated cutting on spreading dogbane shoot density at lowbush blueberry fields in Collingwood Corner, Greenfield, and Rawdon, Nova Scotia, Canada.

Site	Treatment	Density before cutting[a]	Nonbearing year shoot density	Bearing year shoot density
		--shoots m^{-2}--	--shoots m^{-2}--	--shoots m^{-2}--
Collingwood Corner	Non-treated control	11.6 ± 1[b] a[c]	*[d]	5.2 ± 1 a
	Cut once at floral bud	10.0 ± 1 a	*	6.0 ± 1 a
	Cut twice at floral bud	11.2 ± 2 a	*	7.0 ± 1 a
Greenfield	Non-treated control	2.5 ± 0.1 a (11)	1.7 ± 0.2 a (5)	4.6 ± 1 a
	Cut once at floral bud	2.5 ± 0.1 a (11)	1.8 ± 0.2 a (6)	5.0 ± 1 a
	Cut twice at floral bud	2.3 ± 0.1 a (9)	0.1 ± 0.2 b (0.2)	6.4 ± 1 a
Rawdon	Non-treated control	16.8 ± 2 a	*	8.0 ± 1 a
	Cut once at floral bud	21.0 ± 3 a	*	4.2 ± 1 b
	Cut twice at floral bud	16.6 ± 3 a	*	4.6 ± 1 b

[a]Density before cutting and nonbearing year shoot density in Greenfield were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.
[b]Values represent the mean ± 1 SE.
[c]Means within columns followed by different letters are significantly different at P < 0.05 according to the Tukey honestly significant difference multiple means comparison test.
[d]Shoot density data were unable to be collected due to unexpectedly early senescence of spreading dogbane shoots.

Experiment 2: Integrating chemical and mechanical control for control of spreading dogbane

Initial spreading dogbane shoot density did not vary among treatments at Parrsboro or Rawdon (P ≥ 0.0536), though initial density did vary across treatments at the Westchester Mt. site (P = 0.0443) (Table 4-6). There was no significant treatment effect on nonbearing year or bearing year (P ≥ 0.3468) spreading dogbane shoot density at any site. Limited effects of cutting on spreading dogbane would be somewhat expected given results of the repeated cutting experiment (Table 4-5), though it is unclear why one or two cuttings did not reduce nonbearing year density in this experiment (Table 4-6). In addition, lack of shoot density reductions following dicamba applications was unexpected given results of the summer spot spray experiment (Chapter 3, Table 3-16) and results of

Wu and Boyd (2012). Year or site effects may explain the results (Random and Kells; 1998Wu and Boyd 2012), but all three sites had similar results and so this seems unlikely. Ultimately, our results may be indicative of a high level of variation in the response of spreading dogbane to management, and underlying factors affecting this variability should be investigated in the future.

Table 4- 6. Effects of mechanical and chemical control on spreading dogbane shoot density at lowbush blueberry fields in Parrsboro, Rawdon, Westchester Mt. Staple field, Nova Scotia, Canada.

Site	Initial control measure	Subsequent control measure	Density prior to initial control[a]	Nonbearing year shoot density	Bearing year shoot density
			-----shoots m^{-2}-----	-----shoots m^{-2}-----	-----shoots m^{-2}-----
Parrsboro	Non- treated control	Non- treated control	4.3 ± 0.2[b] a[c] (83)	9.0 ± 8	23.8 ± 10
	Cutting	Nothing	4.1 ± 0.2 a (79)	1.5 ± 1	17.2 ± 7
	Cutting	Cutting	4.2 ± 0.2 a (76)	7.8 ± 6	21.7 ± 9
	Cutting	Dicamba	4.3 ± 0.2 a (79)	3.3 ± 2	26.0 ± 10
	Dicamba	Nothing	4.0 ± 0.2 a (59)	2.7 ± 2	9.7 ± 6
	Dicamba	Cutting	4.9 ± 0.2 a (149)	0.8 ± 1	25.0 ± 12
	Dicamba	Dicamba	4.9 ± 0.2 a (149)	3.2 ± 3	20.7 ± 8
Rawdon	Non- treated control	Non- treated control	133.5 ± 42 a	*[d]	21.2 ± 7 a
	Cutting	Nothing	147.0 ± 27 a	*	29.7 ± 5 a
	Cutting	Cutting	161.3 ± 29 a	*	37.8 ± 8 a
	Cutting	Dicamba	125.0 ± 17 a	*	40.3 ± 5 a
	Dicamba	Nothing	128.5 ± 19 a	*	34.7 ± 5 a
	Dicamba	Cutting	143.2 ± 34 a	*	37.3 ± 4 a
	Dicamba	Dicamba	123.5 ± 11 a	*	37.3 ± 6 a
Westchester Staples	Non- treated control	Non- treated control	40.2 ± 9 a	22.2 ± 11	2.7 ± 0.5 a (20)
	Cutting	Nothing	45.8 ± 9 a	15.3 ± 5	2.1 ± 0.5 a (10)
	Cutting	Cutting	61.7 ± 6 a	8.5 ± 5	2.5 ± 0.5 a (17)
	Cutting	Dicamba	59.3 ± 7 a	15.2 ± 7	2.6 ± 0.5 a (16)
	Dicamba	Nothing	73.5 ± 8 a	16.5 ± 11	2.4 ± 0.5 a (18)
	Dicamba	Cutting	70.8 ± 7 a	12.2 ± 9	2.9 ± 0.5 a (22)
	Dicamba	Dicamba	70.8 ± 12 a	8.0 ± 5	1.5 ± 0.5 a (18)

[a]Density prior to initial control in Parrsboro and bearing year shoot density in Westchester Staples field were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses. Density in nonbearing year and bearing year at Parrsboro and nonbearing year shoot density at Westchester Staple field were not able to be made to conform to the assumptions of normality and constant variance after data transformation. Letter groupings are therefore not provided for these data.

[b]Values represent the mean ± 1 SE.

[c]Means within columns with different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.

[d]Shoot density data could not be determined at the end of the nonbearing year due to unexpected early senescence of shoots in all treatment plots.

Experiment 3: Effect of cutting and herbicide application timing on spreading dogbane shoot regeneration

There was a significant treatment effect on initial spreading dogbane shoot density at Windham Hill ($P = 0.0179$) but not at Collingwood Corner ($P = 0.1921$) or Rawdon ($P = 0.0996$) (Table 4-7). Initial density was similar across most treatments at Windham Hill, though was lower in the cutting at post-seed timing treatment at this site (Table 4-7). Nonbearing year shoot density data were unable to be obtained at Collingwood Corner and Rawdon due once again to unexpectedly early senescence of spreading dogbane shoots at these sites. There was a significant treatment effect on nonbearing year spreading dogbane shoot density at Windham Hill ($P \leq 0.0001$) and on bearing year shoot density at each site ($P \leq 0.0216$). Cutting spreading dogbane shoots at the pre-bud stage or at the flower bud stage did not reduce final nonbearing year density (Table 4-7). Cutting at the flowering and post-seed stage, however, reduced density relative to the non-treated control (Table 4-7). It is unclear if cutting spreading dogbane this late in the season reduces competitive interactions between lowbush blueberry and spreading dogbane, but the density reduction associated with cutting at the flowering stage may reduce harvest interference if conducted in the bearing year. Dicamba applications at the pre-bud and flower bud stage did not reduce nonbearing year shoot density whereas applications at the flowering and post-seed stage caused density reductions (Table 4-7).

Cutting treatments did not reduce shoot density in the subsequent bearing year (Table 4-7). These results are similar to the repeated cutting experiment (Table 4-5) and in the attempt at integrated cutting with dicamba use (Table 4-6), further indicating limited effects of cutting on spreading dogbane. Dicamba applications reduced bearing year density, but only when applied at the flower bud or flowering stages (Table 4-7). Although neither of these application timings was consistently effective, these results, in combination with nonbearing year results obtained at Windham Hill, indicate that mechanical or chemical control of spreading dogbane is most effective when conducted at either the flower bud or flowering stage of shoot growth. Underlying factors affecting the consistency of these application timings is unclear, though it would seem likely that changes in carbohydrate dynamics occurring during these growth stages can affect efficacy. For example, Becker and Fawcett (1998) showed that hemp dogbane shoots translocated carbohydrates to roots between the early bud and mid-flower stages, but that this pattern of translocation was not consistent across years. Downward translocation of carbohydrates in the second year of their study actually occurred at the onset of the early bud stage rather than between the early bud and mid-flower stage (Becker and Fawcett 1998). Underlying reasons for these differences are unclear, but yearly variation in timing of downward carbohydrate translocation from shoots would help explain variation in cutting and symplastic herbicide efficacy in this plant species. It seems likely that research on patterns of carbohydrate movement in spreading dogbane plants in lowbush blueberry fields is needed to provide some basis for improving application timing of symplastic herbicides to this weed species.

Table 4- 7. Application timing of symplastic herbicide and cutting treatments on spreading dogbane shoot density at lowbush blueberry fields in Collingwood Corner, Rawdon, and Windham Hill, Nova Scotia, Canada.

Site	Management technique	Management technique timing	Density prior to application[a]	Nonbearing year shoot density	Bearing year shoot density
			shoots m^{-2}	shoots m^{-2}	shoots m^{-2}
Collingwood Corner	Non-treated control	Non-treated control	3.5 ± 0.3[b] a[c] (37)	*[d]	2.7 ± 0.3 a (16)
	Cutting	Pre-bud	3.3 ± 0.3 a (29)	*	2.3 ± 0.3 a (11)
	Cutting	Floral Bud	3.4 ± 0.3 a (34)	*	3.0 ± 0.3 a (22)
	Cutting	Flowering	3.5 ± 0.3 a (33)	*	2.6 ± 0.3 a (13)
	Cutting	Post Seed	3.4 ± 0.3 a (31)	*	3.0 ± 0.3 a (19)
	Dicamba	Pre-bud	3.0 ± 0.3 a (26)	*	2.9 ± 0.3 a (18)
	Dicamba	Floral Bud	3.3 ± 0.3 a (31)	*	1.2 ± 0.3 bc (5)
	Dicamba	Flowering	3.0 ± 0.3 a (23)	*	1.0 ± 0.3 c (2)
	Dicamba	Post Seed	2.6 ± 0.3 a (17)	*	2.2 ± 0.3 ab (10)
Rawdon	Non-treated control	Non-treated control	81.3 ± 7 a	*	15.8 ± 2 a
	Cutting	Pre-bud	80.7 ± 20 a	*	12.8 ± 4 ab
	Cutting	Floral Bud	75.2 ± 6 a	*	16.3 ± 1 a
	Cutting	Flowering	54.2 ± 11 a	*	12.5 ± 2 ab
	Cutting	Post Seed	59.2 ± 7 a	*	16.7 ± 1 a
	Dicamba	Pre-bud	81.2 ± 18 a	*	9.5 ± 3 ab
	Dicamba	Floral Bud	76.7 ± 12 a	*	5.2 ± 2 b
	Dicamba	Flowering	87.3 ± 13 a	*	10.5 ± 1 ab
	Dicamba	Post Seed	44.2 ± 4 a	*	14.0 ± 1 ab
Windham Hill	Non-treated control	Non-treated control	5.2 ± 0.5 ab (27)	1.6 ± 0.3 ab (5)	14.7 ± 3 ab
	Cutting	Pre-bud	5.1 ± 0.5 ab (27)	2.6 ± 0.3 a (15)	16.3 ± 2 ab
	Cutting	Floral Bud	5.3 ± 0.5 ab (28)	1.3 ± 0.3 abc (4)	11.5 ± 3 ab
	Cutting	Flowering	4.9 ± 0.5 ab (24)	0.5 ± 0.3 bc (2)	17.8 ± 3 a
	Cutting	Post Seed	3.3 ± 0.5 b (13)	0.2 ± 0.3 bc (0.3)	14.0 ± 4 ab
	Dicamba	Pre-bud	4.7 ± 0.5 ab (22)	2.1 ± 0.3 a (10)	16.0 ± 4 ab
	Dicamba	Floral Bud	5.9 ± 0.5 a (34)	1.5 ± 0.3 abc (6)	7.0 ± 2 ab
	Dicamba	Flowering	5.7 ± 0.5 a (33)	0.6 ± 0.3 bc (2)	3.7 ± 1 b
	Dicamba	Post Seed	4.1 ± 0.5 ab (17)	0 c (0)	11.3 ± 2 ab

[a]Density prior to application and bearing year short density in Collingwood Corner, and nonbearing year shoot density in Windham Hill were LOG(Y) transformed before analysis to meet the assumptions of the ANOVA analysis. SQRT(Y) transformation was performed in density prior to application in Windham Hill. Transformed means are presented for means comparisons and variance estimates, and back-transformed means are presented in parentheses.
[b]Values represent the mean ± 1 SE.
[c]Means within columns different letters are significantly different at $P < 0.05$ according to the Tukey honestly significant difference multiple means comparison test.
[d]Shoot density data could not be determined at the end of the nonbearing year due to unexpected early senescence of shoots in all treatment plots

Conclusion

In conclusion, cutting is not an effective long-term control for spreading dogbane. Short-term reductions in density caused by repeated cutting or a single cutting at the flowering stage may reduce competitive interactions with lowbush blueberry or facilitate harvest and should be considered when other management strategies are not available. Dicamba applications at the early flower bud or flowering stages gave the most consistent reductions in nonbearing and bearing year shoot density and should be considered as a standard treatment for this weed species. Future evaluation of new symplastic herbicides for spreading dogbane control should focus on these applications timings to ensure optimum application timings for product effectiveness. Underlying factors affecting consistency of these application timings need to be identified and investigated. Dicamba applications at the pre-bud and post-seed stages did not reduce density and should likely be avoided by growers and in future research unless an adequate spreading dogbane leaf canopy is retained late in the season to facilitate post seed-stage applications.

Chapter 5 Conclusions

Wild blueberries are an economically important crop in Nova Scotia and weed management is an ongoing challenge in field management. Weeds are a key limiting factor in lowbush blueberry production and creeping perennials are the most problematic weed species to manage.

Weed surveys in lowbush blueberry fields are important and they provide the basis for vegetation management research and contribute important data to guide extension efforts. A weed survey was conducted in 2017 to assess potential changes in the weed flora of lowbush blueberry fields in Nova Scotia. A total of 165 bearing year lowbush blueberry fields were surveyed from 2017 to 2019, within which approximately 211 weed species were identified. Most weed species were herbaceous perennials (89 species) and woody perennials (49 species), followed by annual broadleaf (24 species) and perennial grass weeds (20 species). The remaining flora consisted of a range of ferns, biennials, sedges and rushes, and orchids. The most common weed species (top 10 abundant weeds) were red sorrel (*Rumex acetosella* L.), poverty oat grass (*Danthonia spicata* L.), haircap moss (*Polytrichum commune* Hedw.), hair fescue (*Festuca filiformis* Pourr.), narrow-leaved goldenrod (*Euthamia graminifolia* (L) Nutt.), rough hair grass (*Agrostis hyemalis* (Walter) BSP.), woolly panicum (*Dichanthelium acuminatum* Ell.), cow wheat (*Melampyrum lineare* Desr.), bunchberry (*Cornus canadensis* L.), and yellow hawkweed (*Hieracium caespitosum* Dumort). The steady increase in survey parameters for red sorrel indicate that this weed species is well adapted to lowbush blueberry fields. Although competitive interactions between red sorrel and lowbush blueberries have not been fully investigated, a number of issues associated with this weed species (see Chapter 2) suggest that development of sustainable management strategies for this weed species need to be developed. The continued spread of this weed, combined with the dramatic increase in the occurrence of hair fescue and other weeds lacking wind-borne seeds, also highlight the need for the lowbush blueberry industry to take the movement of weed seeds on machinery seriously moving forward as discovery and registration of new herbicides will not keep pace with the development and subsequent spread of resistant weed biotypes if equipment is not cleaned or approaches to harvesting are not altered.

After the top 10 most abundant weeds, there are other weed species that are less common, but they are potentially developing into management challenges and becoming problematic. Those weed species are herbaceous perennial weeds, such as Common St. John's wort (*Hypericum perforatum* L.), spreading dogbane (*Apocynum androsaemifolium* L.) and downey goldenrod (*Solidago puberula* Nutt.), woody perennials, perennial grass and sedges and rushes. Our data, for example, show a large increase in the occurrence of St. John's wort, indicating that a spot treatment or other management strategy should be developed for this weed species. Our data also provide a basis for considering the adaptation of this weed species to previous biocontrol efforts or potential decline in biocontrol agents that could be investigated.

One of the more important aspects of the weed survey data is that, if truly committed to a proactive approach to weed management, the lowbush blueberry industry in Nova Scotia now has the opportunity to develop solutions for serious weeds before they become wide spread and more difficult to manage. Weeds of particular importance for the development of management startegies now are the perennial grass red fescue, the woody shrub glossy buckthorn, and the annual plants American burnweed and Canada fleabane. Our data, for example, show that red fescue is gradually increasing in occurrence. Although not as common as hair fescue, red fescue is arguably a more problematic fescue as it also tolerant to many herbicides but spreads by rhizomes rather than relying exclusively on seed. Established plants, therefore, will quickly colonize blueberry fields once established as few growers will likely invest in the pronamide applications required to control initial infestations. Glossy buckthorn currently occurs in only 1.2% of fields, but spreads aggressively by animal-mediated dispersal of fruit and seeds and is an incredibly problematic invasive plant. The time to develop an appropriate spot treatment and strategy for dealing with sporadic plants is now so that large populations that cannot be controlled do not become established. Similarly, American burnweed and Canada fleabane occur in relatively few fields, but have the inherent capacity to rapidly become problems. Growers are already asking about these, and other weeds of low occurrence on the list, indicating that it is only a matter of time before some of these become more widespread and difficult to manage. An additional 28 weed species were observed outside the quadrat but within surveyed fields and most of them were herbaceous and woody perennial species. At the moment most of these do not appear to have significant weedy potential relative to some of the other plant species identified. Results are guiding future research priorities for weed management in lowbush blueberry fields.

Spreading dogbane is an increasingly troublesome weed in lowbush blueberries. Fields studies were conducted from 2017 to 2019 to evaluate the 1) efficacy of a range of broadcast and spot herbicide applications and 2) mechanical and chemical control strategies for spreading dogbane. Results indicated dicamba and glyphosate continue to be the most effective herbicide spot treatments for spreading dogbane. Results indicated that broadcast mesotrione [(144g a.i. ha^{-1}) + 0.2% NIS] and foramsulfuron [(35 g a.i. ha^{-1}) + UAN (2.5 L ha^{-1})] applications did not control spreading dogbane, and control was not improved by sequential applications of either herbicide. Foramsulfuron tank mixture with flazasufuron [(50g a.i. ha^{-1}) + 0.2% NIS] and foramsulfuron tank mixture with mesotrione reduced shoot density in both nonbearing and bearing years in one of the two sites, suggesting broadcast tank mixtures may improve control, warranting further exploration. Significant variation within treatments was found across years and experimental sites. Spot applications of foramsulfuron and flazasulfuron caused >85% injury to spreading dogbane and could be explored further as potential spot treatments. Treatments that should also be considered in the future are spot applications of sulfonyl urea tank mixtures. The broadcast application of foramsulfuron+flazasulfuron, for example, caused a high level of dogbane injury, and this treatment applied as a spot application may be even more effective. Mixtures with nicosuluforn+rimsulfuron could also be considered. Although sulfonylurea herbicides are prone to resistance development, use of mixtures on an established perennial weed that is not routinely recruited new plants from seed should pose a low risk to rapid resistance development.

Fall spot applications did not control spreading dogbane due to the early senescence of spreading dogbane shoots at trial sites. We are still unsure of the reasons for the early senescence observed in our trials, but it does indicate that growers should monitor dogbane patches closely for the onset of senescence if considering fall herbicide applications.

Spot applications of dicamba at 0.96 or 1.92 g a.e. L water^{-1} in tank mixture with foramsulfuron or flazasulfuron improved consistency of nonbearing year spreading dogbane shoot density reductions and these tank mixtures should be explored further for management of spreading dogbane in lowbush blueberry. Dicamba was more effective than cutting when the herbicide was applied at the early-bud and flowering stages. Further research should be developed to evaluate cutting at mid- to late flower stage. Our recommendation for lowbush blueberry growers to control spreading dogbane is to apply dicamba (1.92 g a.e. L water $^{-1}$) in the early bud stage.

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