Management of perennial grasses in wild blueberry (*Vaccinium augustifolium* Ait.) fields

By

Linshan Zhang

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ABSTRACT

Weeds are a major yield limiting factor, and perennial grass has become an increasingly serious weed problem in wild blueberry fields. Herbicides are still the primary means of weed control in wild blueberry fields. However, the availability of herbicides for perennial grasses in wild blueberry fields is limited, and some native perennial grasses have developed resistance to several herbicides. Multiple experiments were conducted to introduce new herbicides (foramsulfuron, glufosinate, and flazasulfuron) and develop new herbicide use patterns to limit spread and negative effects of perennial grasses in wild blueberry fields. Our results indicated that foramsulfuron can be an alternative to fluazifop-p-butyl or sethoxydim in controlling tickle grass and bluegrass, and the foramsulfuron efficacy was not affected when tank mixed with mesotrione. Non-bearing year fescue suppression with spring foramsulfuron was generally higher when applications were preceded by fall applications of dichlobenil or glufosinate verses just the fall herbicide applications alone. The glufosinate and terbacil tank mixture, followed by foramsulfuron, provided efficacy similar to propyzamide, and so could be an alternative treatment to propyzamide to suppress hair fescue in the non-bearing year. Among all experiments, dramatic recovery of fescue occurred in the bearing year in all treatments lacking a fall non-bearing year propyzamide or flazasulfuron application. Additional research should be conducted to determine alternative treatments for fall non-bearing year fescue grass management in wild blueberry.

LIST OF ABBREVIATIONS USED

% Percent

°C Degrees Celsius

CO_2 Carbon dioxide

cm Centimeter

fb Followed by

FBY Fall Bearing Year

FNBY Fall Non-Bearing Year

g Gram

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

kPa Kilopascal

kg Kilogram

l Liter

m Meter

m^{-2} Per square meter

I_{50} The dose required for 50% reduction in the response variable

SBY Spring bearing year

SMNBY Summer non-bearing year

SNBY Spring non-bearing year

tuft^{-1} Number per tuft

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Chapter 1 Introduction

General Introduction to the Problem

Canada is the world's largest producer of wild blueberry (*Vaccinium augustifolium* Ait.), and most of them are commercially produced in Quebec and the Atlantic provinces (AAFC 2016; PRRP 2017). In Nova Scotia, wild blueberry is the most important fruit crop in terms of acreage, export sales, and value (Anonymous 2017a; McIsaac 1997). Over 40,000 acres of wild blueberries are managed in Nova Scotia and the province produces approximately 40 million pounds of fruit worth more than 70 million dollars in worldwide exports annually (Anonymous 2017a).

Wild blueberry is unique from other crops in that it is not planted, but is developed and managed from natural stands (PRRP 2017; McIsaac 1997). From 1992 to 2013, approximately 49,853 new acres of wild blueberry field were developed in Canada, with Nova Scotia accounting for 25.3% of the total expanded area (Strik and Yarborough 2005). It should be noticed that, only half of these fields are harvested annually, due to the crop's two-year production cycle. From 1984 to 2004, blueberry production increased approximately by 3.5-fold, but only 1.5-fold came from the land-based increases, and the rest of the increasing crop yield came from improved management of previously developed fields (Jensen and Yarborough 2004). A good field management strategy can increase the blueberry yield from 1.3 tons acre^{-1} to 5 tons acre^{-1} (Strik and Yarborough 2005). Therefore, field management is very important for wild blueberry to improve the crop yield. Studies have shown that production has dramatically increased since the 1980s by advancements in field management, including improved weed management (PRRP 2017; Yarborough 2004).

Weeds are a major yield limiting factor in wild blueberry fields since they compete with the crop for resources, affect berry quality and interfere with harvesting (Anonymous 2016a; McCully et al. 1991; McIsaac 1997). Many weeds occur in wild blueberry fields, with perennial grasses becoming an increasingly serious weed problem (Jensen and Yarborough 2004; Lapointe and Rochefort 2001; McCully et al. 1991). The perennial grasses cause problems because they are invasive, rank and can produce a large number of seeds each year (Jensen and Yarborough 2004). With the implementation of herbicides and other production practices, there has been a dramatic increase in perennial grass diversity (Jensen and Yarborough 2004). Weed surveys of wild blueberry fields conducted in Nova Scotia showed an increase of 83% in perennial weed species from 1984 to 2002 (Jensen and Yarborough 2004; McCully et al. 1991; Jensen and Sampson, unpublished data).

Weed control practices in wild blueberry fields are limited due to the nature of the crop, and herbicides are still the primary means of weed control (Jensen and Yarborough 2004). However, the availability of herbicides for perennial grasses in wild blueberry fields is limited, with only 3 groups of herbicides registered (Anonymous 2016a). Repeated used of herbicides with a similar mode of action could lead to herbicide resistance. Studies showed that some perennial grass species which were controlled by currently registered herbicides, e.g. *Danthonia spicata* L., *Agrostis hyemalis* Britton, Sterns & Poggenb. and *Festuca filiformis* Pourr., have now developed resistance to them (Jensen and Yarborough 2004). Therefore, introduction of new herbicide products and development of new herbicide use patterns are required to limit spread and negative effects of perennial grasses in wild blueberry fields.

This project was mainly focused on four perennial grasses in wild blueberry fields, namely hair fescues (*Festuca filiformis* Pourr), poverty oat grass (*Danthonia spicata* L.), tickle grass (*Agrostis hyemalis* Britton, Sterns & Poggenb.) and Canada bluegrass (*Poa compressa* L.*).* Three new herbicides, foramsulfuron (Option^{TM}), glufosinate ammonium (Ignite^{TM}), and flazasulfuron (Mission^{TM}), were evaluated for perennial grass control in wild blueberry fields.

Introduction to Wild Blueberry

Wild blueberry industry overview. Wild blueberry is a perennial, native fruit in North America (Wood 2004; Vander Kloet 1998). Native people harvested and enjoyed the berries before European settlers arrived in North America (Wood 2004). Later, they introduced the practice of deliberately setting fires to encourage continuing production, which resulted in improved growth and increased fruit yield (Wood 2004). In Canada, the wild blueberry industry began during the early 1800's (Wood 2004). At that time, there were many treeless open barrens with sandy acidic soil where repeatedly burned-over forest regions offered great opportunity for wild blueberry to grow (Wood 2004). Because of that, the land was slow to regenerate back to forest (Wood 2004). In Yarmouth County, back to the 1800's, the fruit was harvested not only for personal use, but also for local distribution (Kinsman 1986). In the mid-1800's, following improvements in marketing, shipping, and establishment of canneries in Maine and along the Canada-US border, the wild blueberry market was expanded (Kinsman 1986). In the 20th century, wild blueberry production grew dramatically because of improved harvesting methods and field management. Introduction of herbicides to this industry since the 1940s was one of the greatest field management revolutions, which led to changes in other production practices, including the further development of mechanical harvesters and increased application of fertilizer (Jensen and Yarborough 2004). This improved field management resulted in rapidly increases in yields. The average wild blueberry yields were 1.3 tons acre^{-1}, while yield can be achieved up to 5 tons acre^{-1} in a well-managed field (Strik and Yarborough 2005).

Now, the wild blueberry is commercially grown in Maine in the United States, and in eastern Canada (McIsaac 1997). In Canada, wild blueberry is mostly cultivated in Quebec, Nova Scotia, Newfoundland, New Brunswick, and Prince Edward Island (McIsaac 1997). In Nova Scotia, wild blueberry has become one of the most important crops and accounts for more than half of the value of all fruit production in the province, contributing 34.1 million dollars to farm-gate value in 2014 (Government of Canada 2015). Over 40,000 acres of wild blueberries are managed in Nova Scotia and the province produces approximately 40 million pounds of fruit worth more than 70 million dollars in worldwide exports annually (Anonymous 2017a). They are exported to many countries, including the United States, Japan, Germany, and the United Kingdom (Anonymous 2017a).

Wild blueberry management. Wild blueberry is a perennial shrub which grows on sandy, well-drained, acidic soils with pH between 4.2 and 5.5. (AAFC 2016). In contrast to other crops, wild blueberry fields are developed from existing native stands rather than being planted (McIsaac 1997). From 1984 to 2004, blueberry production was increased approximately by 3.5 times, and much of the rising yield has come from improvements in field management (Jensen and Yarborough 2004; Yarborough 1997).

Wild blueberry produces viable and non-dormant seeds, but seedlings are rare, with less than one per square meter (Wesley et al. 1986). Therefore, the crop density expansion relies entirely on the slow rhizome growth of established plants (Trevett 1972). Rhizomes spread faster with proper weed control practices that do not disturb the ground (McIsaac 1997). In unmanaged fields, rhizomes could spread only 5 to 8 cm per year, while as much as 38 cm of rhizome growth occurs per season with a well weed management (McIsaac 1997). To cultivate without disturbing the fields, management methods are limited to pruning, fertilizing, and controlling weeds, pests and diseases (PRRP 2017). Controlling weeds is mainly achieved using herbicides (Jensen and Yarborough 2004).

In commercial fields, wild blueberries are primarily managed on a two-year cycle (AFFC 2016). In the first year, fields are completely pruned, by mowing or burning, to ground level (AAFC 2016). Fields can be pruned any time when the plants are dormant, and it is usually from the first killing frost until growth resumes in the spring (Eaton 1997; DeGomez 1988). The flower buds which grow from new shoots are more winter hardy and are able to produce more individual flowers as compared to flowers from two or three-year-old shoots (McIsaac 1997). If pruned by burning, the heat eliminates some weed species (Penny et al. 2008; DeGomez 1988). However, the occurrence of several perennial weed species, including poverty oat grass and hair fescue, was not reduced by burning, and they recovered over the two-year cycle (Penny et al. 2008). Besides pruning, herbicides are used during the first-year field management to reduce weed competition (PRRP 2017). In the second year, the shoots bloom and produce berries (PRRP 2017). Harvesting usually occurs during August, and today, it is mostly conducted by machines (PRRP 2017).

Herbicide application, as the major weed management strategy, is still practiced throughout the crop year, and varies, depending on weed species.

General Weed Flora of Wild Blueberry Fields. The traditional weed flora of wild blueberry fields has been woody and creeping herbaceous perennial weeds, depending on the origins of the fields (Hall 1959). However, because of production practices and herbicide use, the weed flora in wild blueberry fields has been changing (Jensen and Yarborough 2004). Burning suppresses many woody species and weed seeds (Jensen and Yarborough 2004). Therefore, long-term application of burning changes the weed species towards perennial herbaceous species that regenerate quickly from their vegetative structures (Jensen and Yarborough 2004). Since the introduction of hexazinone (Velpar^{TM}) in the early 1980s, the trend has been towards species that spread by seed, in contrast to the traditional perennial weeds that spread slowly through underground vegetative reproductive structures (Jensen and Kimball 1985; Yarborough and Bhowmik 1989; Jensen and Yarborough 2004). Also, burning is not a common practice today because of increasing fuel costs. It has largely been replaced by mowing, which contributes to the dissemination of seeds and results in greater seedbanks (Jensen and Yarborough 2004).

Many perennial grasses in wild blueberry reproduce and spread by seeds and have become a major weed problem in wild blueberry fields (Jensen and Yarborough 2004). From 1984 to 2002, the number of perennial grass species increased by more than half in wild blueberry fields (McCully et. al 1991; Jensen and Yarborough 2004; Jensen and Sampson, unpublished data). Approximately 22 perennial grass species were found in Nova Scotia wild blueberry fields in 2001-2002 (Jensen and Yarborough 2004; Jensen and Sampson, unpublished data). Common perennial grass species in wild blueberry in Nova Scotia include several *Festuca spp.,* poverty oat grass, tickle grass and Canada bluegrass. Given the increasing occurrence of perennial grasses in wild blueberry fields, research is therefore needed to develop proper weed management strategies to limit negative effects of perennial grasses in this crop.

Perennial grass management in wild blueberry fields

As previously mentioned, weed control options for wild blueberry are limited due to the nature of this crop, and the application of herbicides is still the primary weed control method in wild blueberry fields (Jensen and Yarborough 2004). Common selective herbicides registered for use on perennial grasses in wild blueberry fields are mainly from three herbicide groups: Groups 1, 3, and 5 (Anonymous 2016a). Herbicides are classified by their mode of action, and herbicides that are from the same group share a similar mode of action.

Herbicide Group 1 - fluazifop-p-butyl (Venture^{TM}) and sethoxydim (Poast^{TM}). Herbicides in Group 1 function by inhibiting an enzyme called acetyl Co-enzyme-A carboxylase (ACCase) (Shaner 2014). This enzyme promotes the formation of lipids in the roots of grass plants (Shaner 2014). Susceptible weeds die following treatment due to lack of lipids. Group 1 herbicides that are used in wild blueberry fields to control perennial grasses include fluazifop-P-butyl and sethoxydim (Shaner 2014; Anonymous 2016a; Jensen and Yarborough 2004).

Fluazifop-P-butyl and sethoxydim are selective, postemergence herbicides that are both rapidly absorbed by leaves (Shaner 2014). They both exhibit excellent crop tolerance in blueberry, and can be applied at any time without damage to the crop (Jensen and

Yarborough 2004; Anonymous 2016a). However, the efficacy on native perennial grasses is variable (Jensen and Yarborough 2004; Anonymous 2016a). Both products control tickle grass but only suppress poverty oat grass and bluegrass (Jensen and Yarborough 2004; Anonymous 2016a). Other grasses, particularly *Festuca* spp., are highly tolerant to these herbicides (Jensen and Yarborough 2004; Anonymous 2016a; Stoltenberg et. al 1989; Catanzaro et. al 1993). Hair fescue is tolerant to fluazifop-p-butyle and sethoxydim because of the insensitive form of ACCase (Stoltenberg et al.1989; Catanzaro et al. 1993).

Herbicide Group 3 - propyzamide (Kerb^{TM}). Herbicides in Group 3 inhibit microtubule assembly and disrupt cell division in the late prometaphase of mitosis (Shaner 2014). Propyzamide is a selective, preemergence herbicide in this group that is used to control *Festuca* spp. in wild blueberry fields (Shaner 2014; Anonymous 2016a), which are highly tolerant to other grass control herbicides in the crop (Jensen and Yarborough 2004). However, this herbicide is expensive and requires application to cold soil in the fall to prevent volatilization (Anonymous 2016a). Variability in weed control with this herbicide occurs due to the poor weather at application (Anonymous 2016a). Therefore, development of new use patterns is required to improve the efficacy of propyzamide on perennial grass control in wild blueberry fields.

Herbicide Group 5 - hexazinone (Velpar^{TM}) and terbacil (Sinbar^{TM}). Herbicides in Group 5 inhibit photosystem II, which interferes with photosynthesis and disrupts plant growth, leading to susceptible plant death (Shaner 2014). Hexazinone and terbacil are two herbicides in this group that are used to control certain perennial grasses in wild blueberry fields (Anonymous 2016a).

Terbacil is a selective, preemergence herbicide (Yarborough 2004; Shaner 2014). It is mainly absorbed by roots and less by leaves (Shaner 2014). Terbacil was one of the principle herbicides registered in wild blueberry fields that gives good control of many native grasses, including poverty oat grass (Jensen and Yarborough 2004). However, it has variable control on several species in Nova Scotia (White, personal communication). Also, this herbicide is not recommended for continuous application, since it may promote growth of some common broadleaf weed species, especially sheep sorrel (*Rumex acetosella*), *Solidago* spp., and *Aster* spp. (Anonymous 2016a; Yarborough 2004).

Hexazinone is a selective, preemergence herbicide which was registered in 1982 in wild blueberry in Canada (Yarborough 1989; Jensen and Yarborough 2004). It is absorbed by roots and leaves (Shaner 2014). Hexazinone initially provided very good control of many grasses in wild blueberry fields, and it provides a wider spectrum of weed control than terbacil (Yarborough 2004; Jensen 1985; Yarborough and Bhowmik 1989). However, widespread use of hexazinone has resulted in the development of herbicide resistance in many native perennial grass species, including poverty oat grass, several *Festuca spp.*, and *Agrostis spp.* (Jensen and Yarborough 2004). It has been observed that grasses, including poverty oat grass, are the most frequent weed species in wild blueberry fields which have received at least one hexazinone application (Yarborough and Bhowmilk 1989; McCully 1991).

Though there are several herbicides available for perennial grass management in wild blueberry, efficacy varies across species. In addition, currently available herbicides are limited to Groups 1, 5, and 3. Some perennial grasses have developed resistance to these, which reduces the long-term sustainability of currently registered herbicides. For perennial grasses, like fescue grass, which are highly tolerant to most registered herbicides, propyzamide is the only option to provide control. However, sustained use of the same herbicide, or the same application pattern, may lead to new cases of herbicide resistance. Therefore, introduction of new herbicides and development of new herbicide use patterns are important for ensuring sustainable perennial grass management in wild blueberry.

Important perennial grasses in wild blueberry fields

Hair, or Fine-Leaved Fescue (*Festuca filiformis* Pourr.). Hair fescue is a perennial, tuft-forming grass which spreads by seeds. It is native to Europe, and is now established in eastern and northwestern North America (USDA 2016c). Hair fescue is a common weed in wild blueberry fields, and the very dense, sod-forming tufts compete with the crop for resources and interfere with harvesting (Personal observation). Hair fescue can produce over 2700 seeds in each plant (White and Kumar 2017), which forms large soil seedbanks for population maintenance. Most of *Festuca filiformis* seeds were present in the 0-5cm soil layer, and over 80% of these seeds can germinate, while 13.9% to 27.9% seeds in the 6 -10 cm soil layer can germinate (Smith et al. 2002).

Herbicide-resistant populations of hair fescue occurs in wild blueberry fields in North America, and the abundance of this species has increased in Nova Scotia (Yarborough and Cote 2014). It is highly resistant to hexazinone and fluazifop-P-butyl, and terbacil efficacy is variable in wild blueberry fields in Nova Scotia (Anonymous 2016a). Propyzamide is currently the only registered herbicide that provides good control of hair fescue in wild blueberry fields in Canada (Yarborough and Cote 2014), but the herbicide efficacy varies depending on the weather conditions at application. In addition, propyzamide is expensive to apply. When only a single herbicide is used, herbicide resistance will eventually occur.

Therefore, evaluation of alternative herbicide products, and development of new use patterns that combine propyzamide use with recently registered herbicides are now required to limit the increase of this species in wild blueberry fields and to prevent development of herbicide resistance. Another option to prevent the hair fescue resistance to propyzamide is to introduce new herbicide products with different modes of action to alternate with or to apply in combination with herbicides that are currently used. There have been few studies on two new herbicides, foramsulfuron and glufosinate, for controlling hair fescue in wild blueberry (White and Kumar 2017). Yarborough and Cote (2014) found that foramsulfuron did not completely suppress this species when applied alone in spring. The plants recovered from the treatment by August (Yarborough and Cote 2014). However, when fescues were treated with glufosinate followed by foramsulfuron, a trend of significantly lower seed production and tuft height was observed (White and Kumar 2017). Due to the lack of studies on foramsulfuron and glufosinate in wild blueberry, research should be conducted to determine the effect and to develop new use patterns for these two new herbicides.

Poverty oat grass (*Danthonia spicate* L.). Poverty oat grass is native to North America and was one of the most common perennial grasses found in *wild blueberry fields (Darbyshire and Cayouette 1989; McCully et. al 1991).* In Canada, Poverty oat grass was found in all provinces and territories (Darbyshire and Cayouette 1989). The plant spreads entirely by seeds (Muenscher 1955; Dabyshire and Cayouette 1989). Seeds form a persistent seedbank, and dormant seeds can remain viable in soil for several decades (Livingstone and Allessio 1968). Hexazinone has been used to control this species in wild blueberry (Yarborough and Bhomik 1986). However, hexazinone resistance occurred when this herbicide was used for decades. A weed survey showed that poverty oat grass was one of the most frequent weeds in Nova Scotian wild blueberry fields where hexazinone had been applied at least one time (McCully et al. 1991). Poverty oat grass is currently controlled with fluzifop-p-butyl and sethoxydim in wild blueberry fields in Canada (Anonymous 2016a). However, with repeated use of the same herbicides, resistance might occur again. Therefore, introduction of new herbicides is essential to limit the spread and impact of this species in wild blueberry fields.

Tickle grass (*Agrostis hyemalis* Britton, Sterns & Poggenb.). Tickle grass is native to North America but is mostly found in the eastern United States and some provinces of Canada (USDA 2016a). It is an increasingly common perennial grass in wild blueberry fields in eastern Canada. The plant produces copious amount of seeds, with over 16,000 seeds produced by each plant (Steven 1932). The seed is a common contaminant of mechanical blueberry harvesters (Boyd and White 2009), which also is a factor likely led to the increased infrequency of this species in recent weed surveys. Tickle grass was found in 36% of fields sampled during a similar survey in 2001 (Boyd et. al 2014; Jensen and Sampson, unpublished data). In wild blueberry fields, tickle grass can be easily controlled by fluazifop-p-butyl and sethoxydim (Anonymous 2016a). Since the overuse of the same chemicals may lead to herbicide resistance, introduction of new herbicides is essential to prevent herbicide resistance.

Bluegrass (*Poa compressa* L.). Canada bluegrass was introduced to North America from Europe (USDA 2016b). This perennial grass is currently widespread in North America, with the exception of the state of Florida, and it has become a common weed species in Nova Scotian wild blueberry fields (USDA 2016b; McCully et. al 1991). The plant spreads by seeds and rhizomes (IPANE 2016). The rhizomes contribute to establishment and spread locally, whereas the production of seeds allows the species to disperse over long distances (IPANE 2016). In wild blueberry fields, bluegrass is mainly managed by fluazifop-P-butyl, sethoxydim, and hexazinone. However, bluegrass has developed hexazinone tolerance, and the other two herbicides only suppress this species, but not completely control it (Anonymous 2016a). Therefore, it is essential to test and introduce new herbicides for bluegrass management in blueberry fields.

Introduction of new herbicides for perennial grass management in wild blueberry

Based on the discussions above, perennial grasses have become increasingly common in wild blueberry fields. Due to limitations associated with existing herbicides for perennial grass management in wild blueberry fields, it is essential to introduce new herbicides that control perennial grasses in both the sprout and crop years. This project focused on three new herbicides for perennial grass control, which were foramsulfuron, glufosinate ammonium, and flazasulfuron.

Foramsulfuron (Option^{TM}). Foramsulfuron is a selective, postemergence Group 2 herbicide. It functions by inhibiting the enzyme acetolactate synthase (ALS) or acetohydroxy acid synthase (AHAS), which blocks branched chain amino acid production. Foramsulfuron is now registered for wild blueberry in Eastern Canada, primarily for suppressing fescue grasses (Anonymous 2016b).

A few studies on the use of foramsulfuron for controlling fescue grass in wild blueberry showed that foramsulfuron could suppress fescue grass, but not completely control the species (White and Kumar 2017; Yarborough and Cote 2014). When fescue grass was treated with glufosinate ammonium followed by foramsulfuron, the herbicide combination gave a better grass control, in terms of the lower seed production and tuft height (White and Kumar 2017). Therefore, it is important to conduct further research on the efficacy of foramsulfuron.

This product was originally used to control grasses and several broadleaved weeds in corn (Shaner 2014). Since foramsulfuron controls many grass species in corn (Nurse et. al 2007), it is possible that it could control additional grass species in wild blueberry fields. Due to limitations of currently registered herbicides on poverty oat grass, tickle grass and bluegrass, the efficacy of this new product on these common perennial grasses in wild blueberry should be tested. Since foramsulfuron demonstrated poor activity on some common broadleaved species, blueberry growers currently apply it in tank-mixtures with broadleaf herbicides, such as mesotrione. An antagonistic study showed that the addition of mesotrione to foramsulfuron resulted in decreased efficacy of foramsulfuron on green foxtail, yellow foxtail, and shattercane (Schuster et. al 2008; Bunting et al. 2005). However, the effects of tank mixtures with foramsulfuron on perennial grasses in wild blueberry are unknown.

Glufosinate ammonium (Ignite™). Glufosinate ammonium is a non-selective, Group 10 herbicide (Shaner 2014). It functions by inhibiting glutamine synthetase activity and the production of glutamine (Shaner 2014). This contact herbicide "burns down" green tissue. Glufosinate ammonium does not translocate into the root system (Shaner 2014), and therefore, cannot completely control perennial weeds. However, spring applications after mowing to desiccate green plant tissue may be a potential weed control strategy when combined with additional herbicides (White and Kumar 2017). New use patterns of combinations of glufosinate ammonium and other herbicides can be developed, which could potentially control fescue grasses more effectively.

Flazasulfuron (Mission^{TM}). Flazasulfuron is a selective, Group 2 herbicide which controls grasses, broadleaf weeds, and sedges (Shaner 2014). Flazasulfuron controls several *Festuca* spp. in turf grass (Ferrell et al 2004). Because of its good performance in controlling *Festuca spp*. in turf grass, it is possible that this product could control *Festuca. spp* in wild blueberry fields. In addition, flazasulfuron has not been widely evaluated in wild blueberry, with the potential damage to the crop relatively unknown at this time. Therefore, effect of flazasulfuron on hair fescue in wild blueberry fields should be studied.

In conclusion, currently registered herbicides have limitations for suppressing important perennial grasses in wild blueberry fields. Introduction of new herbicides and development of new herbicide use patterns are now required to limit the yield limiting effects of these perennial species and to prevent development of herbicide resistance. This project was mainly focused on evaluating and developing use patterns of foramsulfuron, glufosinate ammonium and flazasulfuron for controlling perennial grasses in wild blueberry fields.

Chapter 2 - Potential role of foramsulfuron for management of non-fescue grasses in wild blueberry

Abstract

Perennial grasses are an increasingly common problem in wild blueberries in Nova Scotia. However, the availability of herbicide options for controlling perennial grasses in wild blueberry fields is limited. Also, overuse of certain herbicides has already caused herbicide resistance. Therefore, the introduction of new herbicide products is required to limit spread and impact of perennial grasses in wild blueberry fields. Two experiments were conducted in this chapter to explore the potential role of foramsulfuron for managing important perennial grasses in wild blueberry fields. The objective of experiment 1 was to evaluate a new herbicide product, foramsulfuron (Option^{TM}), for postemergence perennial grass management in wild blueberry. Field and greenhouse studies were conducted in 2016 and 2017, respectively. Treatments for the dose response were 0, 3.75, 7.5, 15, 30, 60, 120 and 240 g a.i. ha^{-1}. Target species were ticklegrass (*Agrostis hyemalis*), poverty oat grass (*Danthonia spicata*), and Canada bluegrass (*Poa compressa*) in field experiments and ticklegrass and poverty oat grass in greenhouse experiments. Foramsulfuron suppression efficacy varied across grass species. Poverty oat grass was most tolerant to foramsulfuron, and approximately 43 g a.i. ha^{-1} foramsulfuron was required to reduce inflorescence number by half. Canada bluegrass and ticklegrass were very susceptible to the herbicide, and only required approximately 7.8 and 5.4 g a.i. ha^{-1} respectively, to reduce inflorescence number by half. In the greenhouse experiment, 5.0 and 4.2 g a.i ha^{-1} foramsulfuron were required to reduce poverty oat grass and ticklegrass biomass by 50%, respectively, at 28 days after application. Visual injury occurred more rapidly in ticklegrass as compared with poverty oat grass, further indicating greater susceptibility of ticklegrass to foramsulfuron. The objective of experiment 2 was to determine if mesotrione antagonizes foramsulfuron efficacy on poverty oat grass and ticklegrass. Results showed that there were no antagonistic effects of mesotrione on foramsulfuron. Based on these results, foramsulfuron could be a potential herbicide for controlling perennial grasses in wild blueberry fields, but the degree of control depends on grass species and foramsulfuron application rate. Also, growers should consider use of this tank mixture when both susceptible broadleaf and grass weeds are present.

Introduction

Wild blueberry (*Vaccinium augustifolium* Ait.) is one of the largest industries in Nova Scotia, Canada, contributing more than $34 million to farm gate value in 2014 (Government of Canada 2015; McIsaac 1997). The development of the crop yield can be severely influenced by numerous factors; one of the most important challenges is weed management (McCully et al. 1991; Jensen and Yarborough 2004). Unlike other crops that are planted, wild blueberry is developed from native stands on deforested or abandoned agricultural land (Hall 1959). This complicates weed management in wild blueberry fields in terms of diverse weed species and limited weed control options.

Depending on the origins of the field, weed flora in wild blueberry consists of almost the entire native species, including grasses and herbaceous broadleaves (Jensen and Yarborough 2004). With the implementation of herbicides and other production practices, species that rely on seeds and vegetative structures for establishment and spread, such as perennial grass species, have become one of the major weed problems. (Jensen and

Yarborough 2004). According to weed surveys of wild blueberry fields conducted in Nova Scotia from 1985 to 2002, the number of perennial grass species almost doubled (McCully et al. 1991; Jensen and Yarborough 2004; Jensen and Sampson, unpublished data). A significant blueberry yield increase was observed after perennial grass species, such as, poverty oat grass and tickle grass, were reduced (Boyd et al. 2014; Yarborough and Bhowmik 1989). Also, the large amount of seeds produced by perennial grasses badly interfere with harvest operations and could be contaminants of mechanical blueberry harvesters (Boyd and White 2009). When developing weed control strategies in other agricultural crop fields, many weed management options can be considered, including chemical control, physical and mechanical control, cultural control, as well as biological control. However, because of the perennial nature of wild blueberry, weed control options are limited, and application of herbicides is still the primary management strategy to control weeds (Jensen and Yarboroughs 2004).

Several selective herbicides are registered for perennial grass control in wild blueberry fields, but fluazifop-p-butyl (Venture^{TM}) and sethoxydim (Poast^{TM}) are the only two herbicides currently registered for general postemergence grass control in wild blueberry fields (Anonymous 2016a). Fluazifop-P-butyl and sethoxydim both function by inhibiting acetyl-Co-enzyme A carboxylase (ACCase), which disrupts lipid synthesis (Shaner 2014). These two products control tickle grass but only suppress poverty oat grass and Canada bluegrass (Anonymous 2016a). Neither of these two herbicides control any non-grass weed flora in wild blueberry fields, such as broad-leaved weeds (Anonymous 2016a). Also, repeated application of herbicides with the same mode of action in the same fields may lead to herbicide resistance, resulting in resistant biotypes dominating the weed population.

Therefore, it is necessary to introduce new herbicides to perennial grass management in wild blueberry, prevent development of herbicide resistant perennial grasses, and control a wider spectrum of weed species.

Foramsulfuron has recently been registered for weed management in wild blueberry in Nova Scotia (Anonymous 2016b). It is primarily registered for post-emergence suppression of *Festuca spp.* at a rate of 35 g ai ha^{-1} (Anonymous 2016b). Foramsulfuron functions by inhibiting the enzyme acetolactate synthase (ALS) or acetohydroxy acid synthase (AHAS), which prevents the production of branch-chained amino acids (Shaner 2014). Foramsulfuron controls many grass species in corn, including barnyard grass (*Echinochloa crus-galli* Beauv.), large crabgrass (*Digitaria sanguinalis* Scop.), *Panicum* spp., as well as the perennial grass quack grass (*Elytrigia repens* Nevski.) (Nurse et. al 2007; Anonymous. 2016b). In addition, foramsulfuron applied at 25 g a.i. ha^{-1} gave good control of green foxtail (*Setaria viridis* Beauv.) (Nurse et al. 2007; Bunting 2004), indicating potential efficacy of this product over a range of application rates. Therefore, the registered application rate of 35 g a.i ha^{-1} in wild blueberry may be higher or lower than the rate required for acceptable control of other important perennial grasses in wild blueberry fields. However, there is limited information about the response of common perennial grasses to varying rates of foramsulfuron in wild blueberry.

Foramsulfuron also suppresses certain broadleaf weed species, including hawkweed (*Hieracium caespitosum* Dumort.), lamb's quarters (*Chenopodium album* L.), sheep sorrel (*Rumex acetosella* L.), and spreading dogbane (*Apocynum androsaemifolium* L.) (Anonymous 2016b). However, this herbicide generally has poor and inconsistent control of broadleaf weed species (Anonymous 2016a; Nurse et al. 2007). To broaden the spectrum of weed control, applying foramsulfuron in tank mixtures with a broadleaf herbicide may help to obtain additional broadleaf weed control and protect the full yield potential of crops (Nurse et al. 2007; Bunting et al. 2005; Schuster et al. 2007).

Mesotrione is a selective, pre- and post-emergence herbicide in Group 27 (Anonymous 2015; Shaner 2014). It functions by inhibiting 4-hydroxyphenyl pyruvate dioxygenase (HPPD), which is a key compound in plastoquinone biosynthesis (Mitchell et. al 2001; Shaner 2014). Without the involvement of plastoquinone, carotenoid biosynthesis is disrupted (Shaner 2014). In wild blueberry fields, pre- or post-emergence application of mesotrione is considered when developing weed control strategies of a variety of broadleaf weed species, including lamb's quarters, American burnweed (*Erechtites hieraciifolius* L.), and wild mustard (*Sinapis arvensis* L.) (Anonymous 2016a). Application of mesotrione post-emergence was very effective on broadleaf weeds control, while less so on grasses (James et al. 2006; Stephenson et. al 2004). Blueberry growers currently apply grass herbicides as tank mixtures with mesotrione for improved weed control, but the effects of tank mixtures of mesotrione and foramsulfuron for grass species in wild blueberry fields are unknown. Herbicide combinations of sulfonylurea herbicides with mesotrione were demonstrated to have antagonistic effects when target species were several monocot species, including green foxtail (*Setaria viridis* L.), yellow foxtail (*Setaria pumila* Poir.), and shattercane (*Sorghum bicobr* L.) (Schuster et al. 2008). The decreased absorption and/or translocation on the targeted species caused by mesotrione could be a reason for the sulfonylurea efficacy reduction (Schuster et al. 2007; Schuster et al. 2008). However, antagonistic effect of mesotrione on sulfonylurea is species specific and it was not observed on many other species, such as large crabgrass (*Digitaria sangunalis* Scoup.) or velvetleaf (*Abutilon theophrasti* Medicus.) (Schuster et al. 2008). There is little information on the effects of tank mixtures of mesotrione and foramsulfuron for important grass species in wild blueberry fields, such as tickle grass, poverty oat grass, and Canada bluegrass. Therefore, it is important to determine if efficacy of foramsulfuron on these grass species is affected in the tank mixing with mesotrione.

The objective of this chapter was to explore the potential role of foramsulfuron in managing non-fescue perennial grasses in wild blueberry fields. Specific objectives were to 1) determine the susceptibility of poverty oat grass, ticklegrass, and Canada bluegrass to foramsulfuron, and 2) determine if the addition of mesotrione to foramsulfuron affects foramsulfuron efficacy on poverty oat grass and ticklegrass.

Materials and Methods

Foramsulfuron efficacy on poverty oat grass, ticklegrass, and Canada bluegrass. Experiments were conducted in both the field and greenhouse to determine foramsulfuron (Option^{TM} 2.25 OD herbicide, Bayer CropScience) efficacy on poverty oat grass, ticklegrass, and Canada bluegrass. The experiment was conducted as a dose response with treatments consisting of 0X, 0.25X, 0.5X, 1X, 2X, 4X, 8X and 16 X, where X = 15 g a.i. ha^{-1}. Foramsulfuron was applied with a liquid nitrogen fertilizer (Urea-Ammonium Nitrate, 28% UAN, BASF Canada Inc.) at a rate of 2.5 L ha^{-1}. The experiment was arranged in a randomized complete block design with four blocks in the field and in a completely randomized design with 6 replicates in the greenhouse. Field experiments were established in the fall after mowing or in the spring year in wild blueberry fields located in Rawdon (45°5'13.95"N; 63°42'50.60"W), Londonderry (45°28'53.44"N; 63°33'59.73"W), Portapique (45°24'36.85"N; 63°43'28.07"W) and Tatamagouche (45°37'45.87"N;

63°28'39.59"W) in Nova Scotia, Canada. Poverty oat grass trials were established at Rawdon, Tatamagouche and Portapique. The Canada bluegrass trial was established at Londonderry. The tickle grass trial was established at Rawdon. In addition to the foramsulfuron doses outlined above, trials at Rawdon and Tatamagouche also included fluazifop-p-butyl (Venture^{TM} L herbicide, Syngenta Canada Inc.) and sethoxydim (Poast Ultra herbicide, BASF Canada Inc.) to evaluate foramsulfuron efficacy against currently available industry standard herbicides. Fluazifop-p-butyl and sethoxydim were applied at rates of 250 g a.i ha^{-1} and 495 g a.i ha^{-1}, respectively. Sethoxydim was applied with Merge surfactant (50% surfactant blend and 50% petroleum hydrocarbons, BASF Canada Inc.), at a rate of 2 L ha^{-1}. However, these two treatments were not included at Portapique as the limited space available for trial establishment. All herbicides were applied postemergence in May or June of the non-bearing year (Table 2-1). Plot size was 2 m X 6 m, with a 1-m-wide unsprayed strip between each block. Herbicides were applied with a CO_2 pressurized research plot sprayer outfitted with four 11002 XR nozzles, calibrated to deliver a water volume of 200 L ha^{-1} at a pressure of 276 kPa.

Data collection included damage ratings of blueberry and target grasses, grass density (stems or tufts) prior to treatment applications and in late summer of the year of herbicide applications, grass inflorescence number and height following treatment applications, and wild blueberry stem density, stem height and flower bud number per stem at the end of the non-bearing year. Damage ratings were conducted for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 45 days after the initial herbicide application. Inflorescence number and height of all target grasses were counted and measured in the field by randomly selecting 10 grass stems per plot. Canada bluegrass stem density was counted in three 0.3 m X 0.3 m quadrats per plot. Tuft density of poverty oat grass and tickle grass were determined in two 1 m X 1 m quadrats per plot. Blueberry shoot were counted in two 30 cm X 30 cm quadrats per plot. In each plot, 30 randomly selected blueberry stems were clipped at ground level, bagged in the field, and brought back to the laboratory in late autumn. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Initial grass density for poverty oat grass, blue grass and tickle grass were determined on May 31, 2016, May 16, 2016 and May 25, 2016, respectively. Bluegrass total stem density, flowering stem density, and stem height were determined on June 20, 2016. Tickle grass total tuft density, flowering tuft density, inflorescence height, and inflorescence number were counted on July 18, 2016. Poverty oat grass total tuft density, flowering tuft density, inflorescence height, and inflorescence number were determined from July 14 to 18, 2016. Blueberry stem counts and stem collection were completed in Rawdon, Tatamagouche, Portapique, and Londonderry on October 15, 2016, September 29, 2016, October 20, 2016 and October 6, 2016, respectively.

Table 2-1. Herbicide application dates and related weather conditions in each trial for foramsulfuron dose response experiment

Weed species	Site	Date of application	Temp. (°C)	Humidity (%)	Wind speed (km h^{-1})
Poverty oat grass	Rawdon	02-Jun-16	18.4	49.7	5.8
	Tatamagouche	02-Jun-16	19.5	39.3	5.1
	Portapique	07-Jun-16	14.9	67.8	1.5
Blue grass	Londonderry	18-May-16	15.7	63.5	2.6
Tickle grass	Rawdon	25-May-16	22.8	58.0	7.4

For the greenhouse experiments, target species were poverty oat grass and tickle grass. The greenhouse experiment was repeated once for each species. Plants were established from seeds collected from growers' fields in Nova Scotia during summer of 2016. Poverty oat grass seeds were collected from Rawdon and Portapique. Tickle grass seeds were collected from Rawdon. All seeds collected from the fields were placed in paper envelopes and stored in the dark at room temperature in the laboratory until use. All seeds went through cold moist stratification for seed dormancy-breaking. Moist environment was provided by mixing seeds with a cup of wet sand in 16 cm X 14 cm zipper bags. The cold moist stratification process was conducted by placing seeds in a refrigerator which exposed seed to a constant temperature of 4 - 5 ºC for 45 days. Then, the mixture of seeds and sand was planted in 893cm^3 plastic pots filled with 1: 2 mixtures of sand and Pro-mix on June 29, 2017. Emerging grasses were thinned to one plant in each pot two weeks after planting. Foramsulfuron application was made at 30 days after planting for both tickle grass and poverty oat grass. Foramsulfuron was applied using a hand-held, CO_2-pressurized single nozzle sprayer outfitted with a Teejet XR 11002 nozzle and calibrated to deliver a water volume of 200L ha^{-1} at a pressure of 276 kPa.

Data collection included target species visual injury rating and final aboveground grass biomass in each pot at the end of the experiment. Visual injury rating was conducted by using a standard 0-10 visual system (0 = no damage, 10 = complete plant death) at 7, 14, 21 and 28 days after herbicide application. For biomass collection, all aboveground plant material was clipped to the soil surface level. Plant material was placed in paper bags and dried in an oven at 70 ºC for 48 hours prior to weighing.

Potential Antagonistic effect of mesotrione on foramsulfuron. All experiments were established in the fall after mowing or in the spring in wild blueberry fields located in Rawdon, Portapique, and Tatamagouche in Nova Scotia, Canada. The objective of the experiment was to determine if the addition of mesotrione (Callisto^{TM} 480SC Herbicide, Syngenta Canada Inc.) to foramsulfuron alters foramsulfuron efficacy of controlling poverty oat grass and tickle grass as these two grasses are most commonly treated with a mesotrione tank mixture with graminicides. Poverty oat grass trials were established at Portapique, Tatamagouche and Rawdon. The tickle grass trial was established at Rawdon. The experiment was designed as a 2 X 4 factorial arrangement of mesotrione application (no, yes) and grass herbicide (none, fluazifop-p-butyl, sethoxydim, foramsulfuron) arranged in a randomized complete block design, with four blocks at all poverty oat grass trials and five blocks at the Rawdon tickle grass trial. Mesotrione was applied at a rate of 144 g a.i. ha^{-1}. Fluazifop-p-butyl (Venture^{TM} L herbicide, Syngenta Canada Inc.), sethoxydim (Poast^{TM} Ultra herbicide, BASF Canada Inc.), and foramsulfuron were applied at rates of 250, 495, and 35 g a.i. ha^{-1}, respectively. Foramsulfuron was applied with a liquid nitrogen fertilizer (28 % UAN, Urea-Ammonium Nitrate, BASF Canada Inc.) at a rate of 2.5 L ha^{-1}. Sethoxydim was applied with a surfactant, Merge (50% surfactant blend and 50% petroleum hydrocarbons, BASF Canada Inc.), at a rate of 2 L ha^{-1}. Mesotrione was applied with a surfactant, Activate Plus^{TM} (Alkylarylpolyoxyethylene glycols, free fatty acids & IPA, Winfield Solution LLC.), at a rate of 0.4 L ha^{-1}. The size of each treatment plot was 2 m X 6 m with a 1-m-wide unsprayed strip in between each block. All herbicides were applied post emergence to the wild blueberry and target grass species. The detailed herbicide application timings and the weather at application in each trial are shown in Table 2-2. Herbicides were applied with a CO_2-pressurized research plot sprayer outfitted with four 11002 XR nozzles, calibrated to deliver a water volume of 200 L ha^{-1} at a pressure of 276 kPa.

Data collection included damage ratings of blueberry and target grasses, grass tuft density prior to treatment applications and in late summer of the year of herbicide applications, grass inflorescence number and height following treatment applications, and wild blueberry stem density, stem height, and flower bud number per stem at the end of the sprout year. Damage ratings were conducted for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 45 days after herbicide application. Tuft densities of poverty oat grass and tickle grass were determined in two 1 m X 1 m quadrats per plot. Inflorescence number and height of all target grasses were counted and measured in the field by randomly selecting 10 grasses per plot. Blueberry shoot counts were conducted in two 30 cm X 30 cm quadrats per plot. In each plot, 30 randomly selected blueberry stems were clipped at ground level, bagged in the field, and brought back to the laboratory in late autumn. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Initial grass density for poverty oat grass and tickle grass were determined on May 31, 2016 and May 25, 2016, respectively. Grass response data (flowering and total tuft density, inflorescence number and height) for poverty oat grass were determined on July 4, 2016 at both Portapique and Tatamagouche, and on July 18, 2016 at Rawdon. Grass response data for tickle grass were determined on July 18, 2016 at Rawdon. Blueberry stem density counts and stem collection were completed on October 20, 2016, September 29, 2016 and October 15, 2016 at Portapique, Tatamagouche, and Rawdon, respectively.

Table 2-2. Herbicide application dates and related weather conditions in each trial for foramsulfuron antagonistic effect experiment

Weed species	Site	Date of spraying	Temp (°C)	Humidity (%)	Wind speed (km h^{-1})
Poverty oat grass	Portapique	07-Jun-2016	14.9	67.8	1.3
	Tatamagouche	02-Jun-2016	19.5	39.3	7.1
	Rawdon	02-Jun-2016	18.4	49.7	9.1
Tickle grass	Rawdon	25-May-2016	22.8	58.0	7.4

Statistical analysis

For all data, firstly, a test of main and interactive effects of treatment and experimental site was conducted to determine if the data could be combined across sites. When the data conformed to the assumptions for ANOVA and the interaction effect of site by treatment was not significant after analysis, these data were pooled by experimental sites for further analysis. Otherwise, data were analyzed separately by sites. Damage rating data for wild blueberry and target species were analyzed in PROC NPAR1WAY in SAS system for Windows (Statistical Analysis System, Version 9.2, SAS Institute, Cary, NC). Other data were analyzed by using analysis of variance (ANOVA) in PROC MIXED in SAS for Windows. In the Mixed Model, treatments and experimental sites were used as fixed effects, while blocks within each trial were used as random effects. The assumptions of constant variance were tested to ensure that residuals had constant variance with a normal distribution. Some data were transformed to achieve normality and constant variance, with transformations indicated in the data table. Significant differences among treatments were determined using Tukey's multiple means comparison test at a probability level of $P < 0.05$.

For Experiment 1, when effects of foramsulfuron rates on grass responses were significant, related data were used to develop dose-response curves of foramsulfuron for target weed species control in SigmaPlot (Version 12.0, Systat Software Inc.). To develop dose-response curves of foramsulfuron for target weed species, flowering grass density, total grass density, inflorescence number, and inflorescence height of target species over herbicide rates were presented as percentages of untreated control and the log-logistic model was developed in SigmaPlot. The log-logistic model is of the form:

$$y = f(x) = min + \frac{max - min}{1 + (\frac{x}{I50})^b} \text{ (Seefeldt et al. 1995),}$$

where y is grass response (flowering grass densities, total grass density, inflorescence number and height of target species), min is the lower limit of the response, max is the upper limit of the response, b is slope, and I_{50} is the dose required for 50% reduction in the response variable. The dose-response curve and the log-logistic model were also used to determine the rate of foramsulfuron required for at least 90% control of target species without affecting crop safety.

Results and Discussion

Foramsulfuron efficacy on poverty oat grass, tickle grass, and Canada bluegrass.

Field experiment. Visual injury ratings of wild blueberry plants were unaffected by foramsulfuron application rate at each site ($p \geq 0.1886$), with visual injury rarely exceeding 20%. There were no significant effects of experimental site X foramsulfuron interaction ($P \geq 0.3692$) on blueberry stem height and flower bud number per stem across poverty oat grass experimental sites (Table 2-3). These two blueberry response variables were pooled across locations for analysis.

Table 2-3. Test of main and interactive effects of treatment and experimental site on blueberry potential yield in foramsulfuron dose response trial of poverty oat grass and bluegrass at four sites in Nova Scotia, in 2016-2017.

Weed species	Effects	Blueberry stem density (stems m^{-2})	Blueberry stem height (cm)	Blueberry flower buds (# $stem^{-1}$)
Poverty oat grass	Experimental site	-	NS	NS
	Treatment	-	NS	NS
Bluegrass	Experimental site by treatment	-	NS	NS
	Treatment	NS	NS	NS

[a]Abbreviation: NS, no significant difference
[b]*P < 0.05, **P < 0.01, ***P < 0.001 level of significant obtained with PROC MIXED in SAS

There were no significant effects of foramsulfuron rates on blueberry stem height (p = 0.3265) and flower bud number per stem (p = 0.0802) with stem height and bud number averaging 14.0 ± 2.1 cm and 5 ± 1 flower buds stem $^{-1}$, respectively. There was no significant effect of foramsulfuron rate on blueberry stem height (p = 0. 8571) and flower bud number per stem (p = 0.1806) in the Canada bluegrass experiment, with height and flower bud number averaging 16.9 ± 1.2 cm and 6 ± 0 flower buds stem $^{-1}$, respectively. Blueberry stem density data for tickle grass at Rawdon was not available as the site was accidentally mowed. Therefore, blueberry stem density data were only limited to poverty oat grass sites and the bluegrass site. Site-combined blueberry density data did not conform to the assumptions for normality and constant variance when testing for main and interactive effects of treatment and experimental site, and data for blueberry stem density were analyzed separately across sites. There was no significant effect of foramsulfuron rate on blueberry stem density ($p \geq 0.0547$) at both poverty oat grass and bluegrass sites. The average blueberry stem density at Tatamagouche, Portapique, Rawdon, and Londonderry were 409 ± 86 stem m^{-2}, 286 ± 127 stem m^{-2}, 345 ± 129 stem m^{-2}, and 409 ± 89 stem m^{-2}, respectively. Based on these results, wild blueberry is highly tolerant to foramsulfuron, and these results are similar to tolerance reported previously (White and Kumar 2017). The results also indicated that suppression of target perennial species did not increase blueberry yield potential. Even though initial herbicide experiments found that weed cover significantly influenced blueberry productivity (Jensen 1986; Yarborough et al. 1986; Yarborough and Bhowmik 1989), low impact of weed density on blueberry yield productivity in related experiments were common as well (White and Kumar 2017; Lapointe and Rochefort 2001). This was probably because the weed cover percentage was not as high as that in initial experiments where yield increased dramatically with reduction of grass density (Lapointe and Rochefort 2001). In this study, even though there was reduced density of perennial grasses with increasing foramsulfuron rates, blueberry yield potential did not increase. However, grasses in blueberry fields might interfere with harvest efficiency and may lead to other problems, such as harbouring harmful insects and diseases. Also, rapid seed dispersal rate can result in increased weed density within and across fields (Boyd and White 2009). Therefore, it is still essential to manage perennial grass populations in wild blueberry, and these data suggest that foramsulfuron exhibits excellent crop tolerance in wild blueberry and can be safely used for perennial grass management in wild blueberry.

For poverty oat grass, initial tuft density, flowering tuft density, total tuft density, flowering tuft inflorescence number, and flowering tuft inflorescence height were analyzed separately for each site as data in the combined data set could not be made to conform to the assumptions for normality and constant variance when testing for the effect of experimental site. Trends in results were similar across sites. Poverty oat grass initial tuft densities in Tatamagouche, Portapique, and Rawdon were 8 ± 3, 12 ± 6, and 5 ± 2 tufts m^{-2}, respectively. Flowering tuft density, inflorescence number, and inflorescence height were significantly reduced by foramsulfuron rate at all sites, with total tuft density also reduced significantly at Tatamagouche (Table 2-4). Poverty oat grass control increased with increasing foramsulfuron application rate (Figures 2-1, 2-2, 2-3 and 2-4; Tables 2-5 and 2-6). The foramsulfuron application rate required to obtain 50% reduction in poverty oat grass inflorescence number ranged from 32.9 to 40.9 g a.i ha^{-1} (Table 2-5). More than 280 g a.i ha^{-1} of foramsulfuron was required to obtain a 90% reduction in most of measured response variables (Table 2-5). It required over 35 g a.i ha^{-1} rate of foramsulfuron to reduce poverty oat grass inflorescence number to the level that achieved with application of Sethoxydim (495 g a.i ha^{-1}). To obtain results of poverty oat grass inflorescence number similar to that obtained with industry standard applications of fluazifop-p-butyl (250 g a.i ha^{-1}) required approximately 280 g a.i ha^{-1} rate of foramsulfuron (Table 2-6). These results suggested that foramsulfuron applications at the registered rate (35 g a.i ha^{-1}) cannot control poverty oat grass effectively. Previous research also noted that foramsulfuron could only suppress, but not control, poverty oat grass when applied alone (Anonymous 2016a). Our results, however, indicate limited potential for poverty oat grass control with foramsulfuron given the extremely high application rate required to obtain acceptable control.

Table 2-4. Effect of foramsulfuron application rate on flowering tuft/stem density, total tuft/stem density, inflorescence number and inflorescence/grass height in dose response field experiments.

Species	Site	Mean initial grass density at application (tufts/stems m^{-2})	Flowering tuft/stem density[a] (tufts or stems m^{-2})	Total Tuft/stem density[b] (tufts or stems m^{-2})	Inflorescence number[c] (# $tuft^{-1}$)	Inflorescence/ stem height[d] (cm)
Poverty oat grass	Tatamagouche	NS	***[e]	***	**	***
	Portapique	NS	***	NS	*	***
	Rawdon	NS	*	NS	***	***
Bluegrass	Londonderry	NS	***	NS	-	***
Tickle grass	Rawdon	NS	***	***	***	***

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[a] Flowering tuft density of poverty oat grass and tickle grass; [a] Flowering stem density of blue grass

[b] Total tuft density of poverty oat grass and tickle grass; [b] Total stem density of bluegrass

[c] Inflorescence number of poverty oat grass and tickle grass

[d] Inflorescence height of Poverty oat grass and tickle grass; [d] Stem height of bluegrass

[e] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ level of significance obtained with PROC MIXED in SAS

NS, not significant

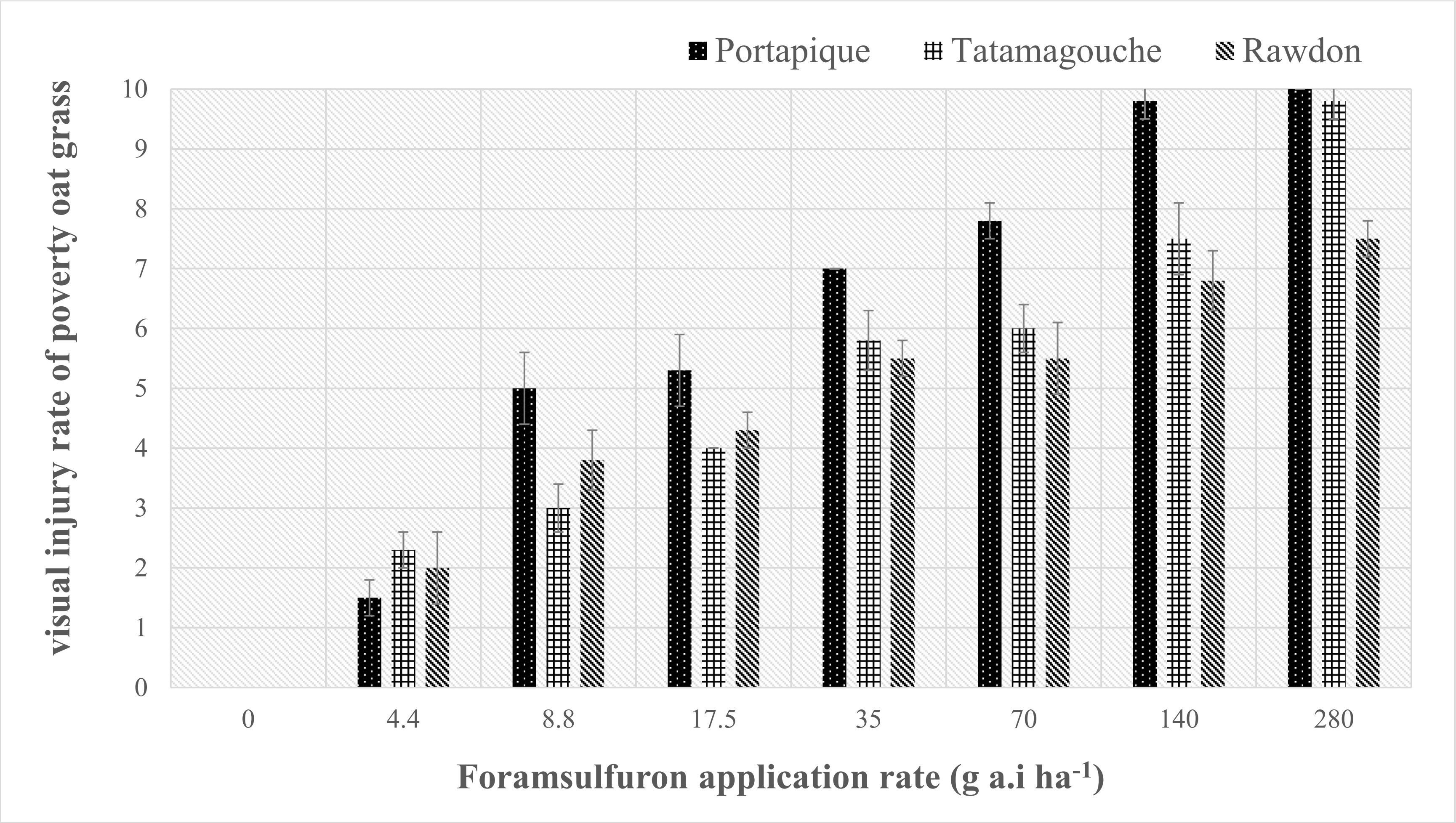

Figure 2-1 Herbicide visual injury rating of poverty oat grass at 45 days after application following treatment with various foramsulfuron application rates at Portapique, Tatamagouche and Rawdon in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

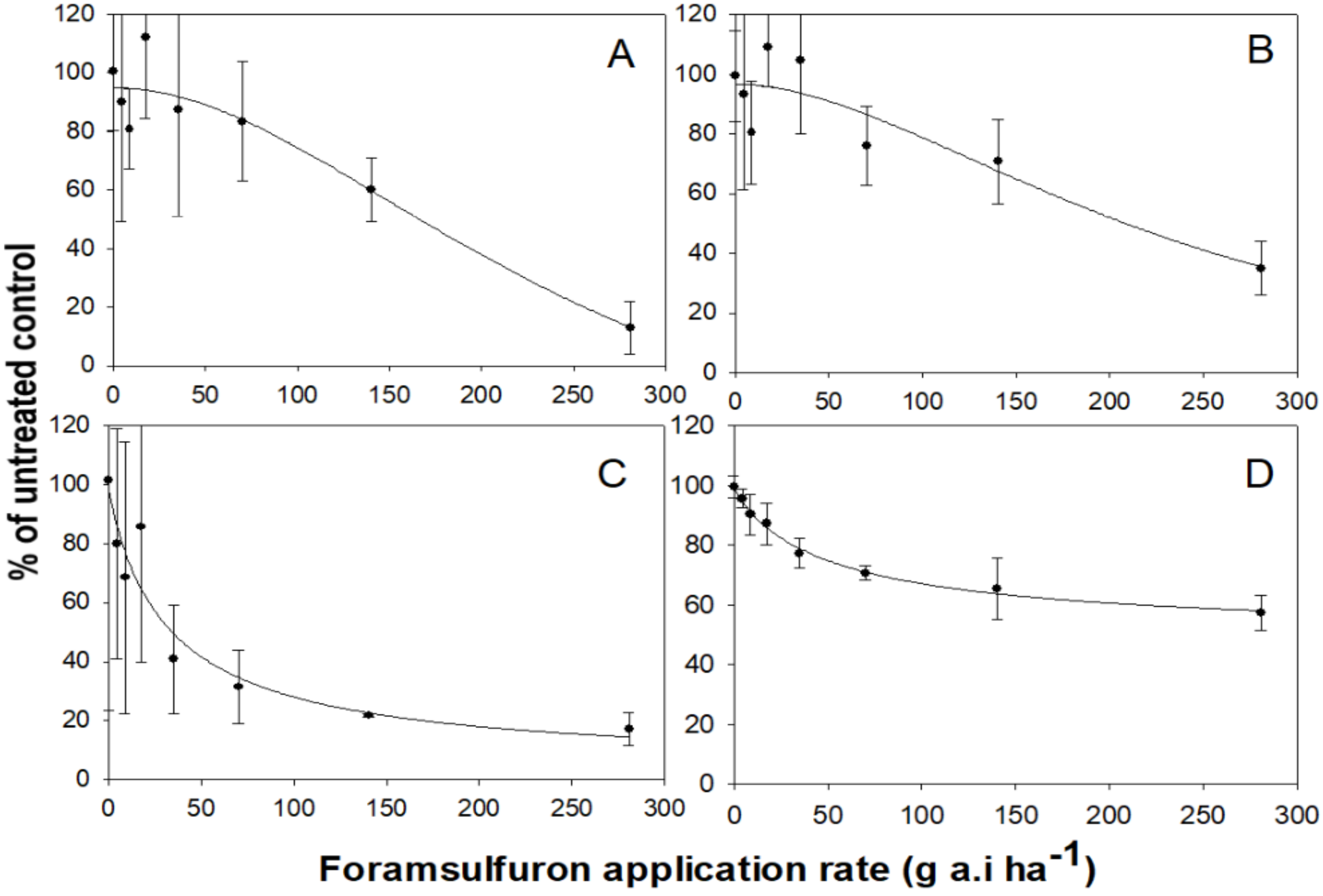

Figure 2-2. Flowering tuft density (A), total tuft density (B), inflorescence number (C), and inflorescence height (D) of poverty oat grass at Tatamagouche as influenced by foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form f (x)= min + (max-min)/ [1 + $(x/I50)^b$]. Parameter estimates for the four-parameter logistic dose response are provided in Table 2-5

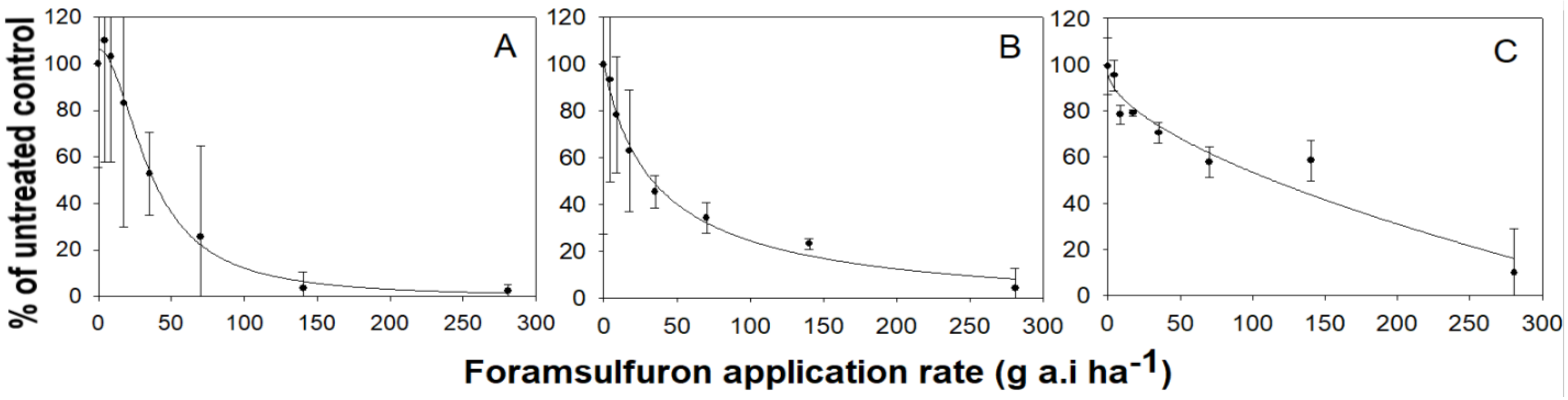

Figure 2-3. Flowering tuft density (A), inflorescence number (B), and inflorescence height (C) of poverty oat grass at Portapique as influenced by foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form f (x)= min + (max-min)/[1 + $(x/I_{50})^b$]. Parameter estimates for the four-parameter logistic dose response are provided in Table 2-5. Total tuft density was not significantly reduced at this site.

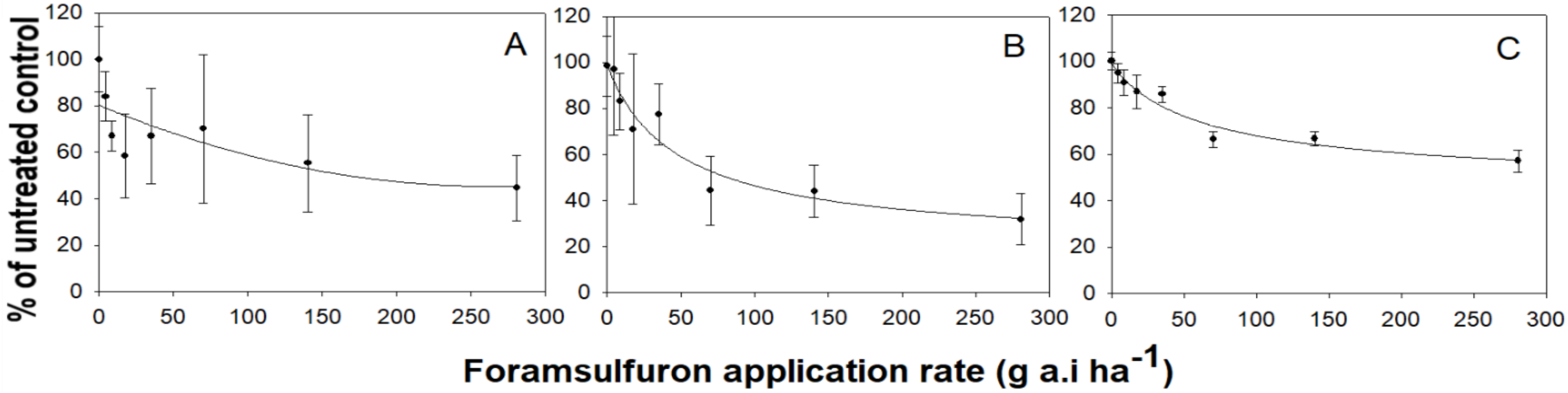

Figure 2-4. Flowering tuft density (A), inflorescence number (B), and inflorescence height (C) of poverty oat grass at Rawdon as influenced by foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form f (x)= min + (max-min)/[1 + $(x/I_{50})^b$]. Parameter estimates for the four-parameter logistic dose response are provided in Table 2-5. Total tuft density was not significantly reduced at this site.

Table 2-5. Parameter estimates (min, max, b, and I50) and I90 estimates for the four-parameter logistic dose response curve describing the relationship between foramsulfuron dose levels and the target grass response in blueberry fields in Nova Scotia, Canada.

Species	Site	Grass responses	Four parameters of logistic dose response curve[b]				I_{90}
			min	max	b	I_{50}	
Poverty Oat grass	Rawdon	Flowering tuft density	-	-	-	166.7	> 280
		Inflorescence number	19.8 ± 28.6	99.3 ± 8.2	- 1.0 ± 0.6	49.0 ± 45.0	> 280
		Inflorescence height	46.3± 19.4	99.7 ± 4.0	- 0.9 ± 0.4	66.5 ± 61.4	> 280
	Portapique	Flowering tuft density	-0.4 ± 5.5	106.4 ± 3.8	-2.0 ± 0.4	35.8 ± 3.9	111.9
		Inflorescence number	-6.3 ± 13.6	101.6 ± 4.7	-0.9 ± 0.2	36.8 ± 12.8	238.0
		Inflorescence height	-	96.2 ± 9.3	-0.6 ± 0.6	112.9 ± 3.0	> 280
	Tatamagouche	Flowering tuft density	-56.0 ± 336.2	94.9 ± 6.5	-1.9 ± 2.4	258.3 ± 599.9	> 280
		Total tuft density	-11.2 ± 282.4	96.8 ± 7.4	-1.8 ± 3.1	241.5 ± 721.2	> 280
		Inflorescence number	3.6 ± 31.7	98.1 ± 12.5	-1.0 ± 0.6	32.9 ± 30.5	> 280
		Inflorescence height	48.8 ± 5.9	99.8 ± 1.5	-0.9 ± 0.1	51.8 ± 15.9	> 280
Blue grass	Londonderry	Flowering stems	-33.7 ± 136.1	99.6 ± 16.2	-0.4 ± 0.6	14.4 ± 76.43	84.2
		Grass height	25.7 ± 6.2	100.4 ± 5.7	-1.0 ± 0.3	7.8 ± 2.3	> 280
Tickle grass	Rawdon	Flowering tuft density	-0.6 ± 2.6	93.7 ± 4.0	-4.2 ± 1.0	10.2 ± 0.7	16.4
		Total tuft density	-0.6 ± 3.3	106.4 ± 4.9	-3.5 ± 0.7	13.1 ± 1.1	24.0
		Inflorescence number	-1.5 ± 2.3	101.0 ± 4.1	-1.9 ± 0.3	5.4 ± 0.5	15.3
		Inflorescence height	-1.2 ± 3.6	92.6 ± 5.5	-3.0 ± 0.7	12.6 ± 1.3	24.0

[a] The four-parameter logistic dose response curve was of the form $y = f(x) = min + \frac{max-min}{1+(\frac{x}{I50})^{b}}$.

[b] Logistic dose response curve parameters, min = lower limit of the response, max = upper limit of the response, b = slope, I_{50} = the dose response required for 50% injury or inhibition to target weed species.

[c] Values represent the parameter estimate ± 1 SE.

Table 2-6. Comparison of effects of foramsulfuron and two industry standard postemergence products, flauzifop-p-butyl and sethoxydim, on poverty oat grass. Inflorescence number and inflorescence height at Tatamagouche site were log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Site	Treatment	Application rate (g a.i. ha^{-1})	Flowering tuft density (tufts m^{-2})	Total tuft density (tufts m^{-2})	Inflorescence number (# $stem^{-1}$)	Inflorescence height (cm)
Rawdon	Untreated control	0	7.8 ± 0.6a	7.8 ± 0.6a	21.7 ± 1.4a	65.2 ± 1.3a
	Foramsulfuron	4.4	6.6 ± 0.4ab	6.6 ± 0.4ab	21.4 ± 3.1a	61.8 ± 1.4ab
	Foramsulfuron	8.8	5.3 ± 0.3ab	5.3 ± 0.3ab	18.3 ± 1.3a	59.2 ± 1.7ab
	Foramsulfuron	17.5	4.6 ± 0.7b	4.6 ± 0.7ab	15.7 ± 3.6ab	56.6 ± 2.3b
	Foramsulfuron	35	5.3 ± 0.8ab	5.3 ± 0.8ab	17.1 ± 1.5ab	55.9 ± 1.4b
	Foramsulfuron	70	5.5 ± 1.3ab	5.8 ± 1.4ab	9.8 ± 1.6bc	43.3 ± 1.1c
	Foramsulfuron	140	4.3 ± 0.8b	4.3 ± 0.8ab	9.7 ± 1.2bc	43.4 ± 1.1c
	Foramsulfuron	280	3.5 ± 0.6bc	3.8 ± 0.6 b	7.0 ± 1.2cd	37.2 ± 1.5c
	Fluazifop-p-butyl	250	0.0 ± 0.0d	3.4 ± 0.9b	0.0 ± 0.0d	0.0 ± 0.0d
	Sethoxydim	495	0.9 ± 0.3cd	4.5 ± 0.1ab	2.8 ± 0.6cd	42.5 ± 2.9c
Tatamagouche	Untreated control	0	6.4 ± 0.6ab	9.5 ± 0.7a	2.0 ± 0.2a (7.1)	4.0 ± 0.0a (53.8)
	Foramsulfuron	4.4	5.8 ± 1.3ab	8.9 ± 1.5a	1.8 ± 0.2a (5.6)	3.9 ± 0.0a (51.6)
	Foramsulfuron	8.8	5.2 ± 0.4ab	7.7 ± 0.8a	1.6 ± 0.2ab (4.8)	3.9 ± 0.0ab (48.7)
	Foramsulfuron	17.5	7.2 ± 0.9a	10.4 ± 0.6a	1.9 ± 0.2a (6.0)	3.8 ± 0.0abc (47.1)
	Foramsulfuron	35	5.6 ± 1.2ab	10.0 ± 1.2a	1.3 ± 0.2abc (2.9)	3.7 ± 0.0bcd (41.7)
	Foramsulfuron	70	5.4 ± 0.7ab	7.2 ± 0.6ab	1.1 ± 0.2abc (2.2)	3.6 ± 0.0d (38.1)
	Foramsulfuron	140	3.9 ± 0.4bc	6.7 ± 0.7abc	1.3 ± 0.2abc (3.3)	3.5 ± 0.0de (35.3)
	Foramsulfuron	280	0.8 ± 0.3cd	3.3 ± 0.4bcd	0.8 ± 0.2bcd (1.2)	3.4 ± 0.0e (30.9)
	Fluazifop-p-butyl	250	0.0 ± 0.0d	1.9 ± 1.3cd	0.0 ± 0.2d (0.0)	3.5 ± 0.1de (8.4)
	Sethoxydim	495	0.3 ± 0.2d	2.7 ± 0.4d	0.6 ± 0.2cd (0.9)	3.6 ± 0.0cde (28.5)

[a]Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Bluegrass control increased with increasing foramsulfuron application rate (Table 2-4, Figure 2-5 and 2-6). Increasing foramsulfuron rate did not affect bluegrass total stem density, but significantly reduced bluegrass flowering stem density and height (Table 2-4). Initial bluegrass density in Londonderry was 338 ± 134 stems m^{-2}. Foramsulfuron rates required to reduce flowering stem density and height by 50% were 14.4 g a.i ha^{-1} and 7.8 g a.i ha^{-1}, respectively. Unacceptably high rates (> 280 g a.i ha^{-1}) of foramsulfuron were required to obtain 90% bluegrass control (Table 2-5). Foramsulfuron application at the registered rate (35 g ha^{-1}) did reduce flowering stem density by over 50% (Table 2-5 and Figure 2-6), however, indicating potential suppression of this grass with foramsulfuron. Canada bluegrass requires treatment with postemergence herbicides earlier in the season than poverty oat grass and ticklegrass, indicating that foramsulfuron may be effective for bluegrass control if applied in conjunction with later season application of fluazifop-p-butyl or sethoxydim.

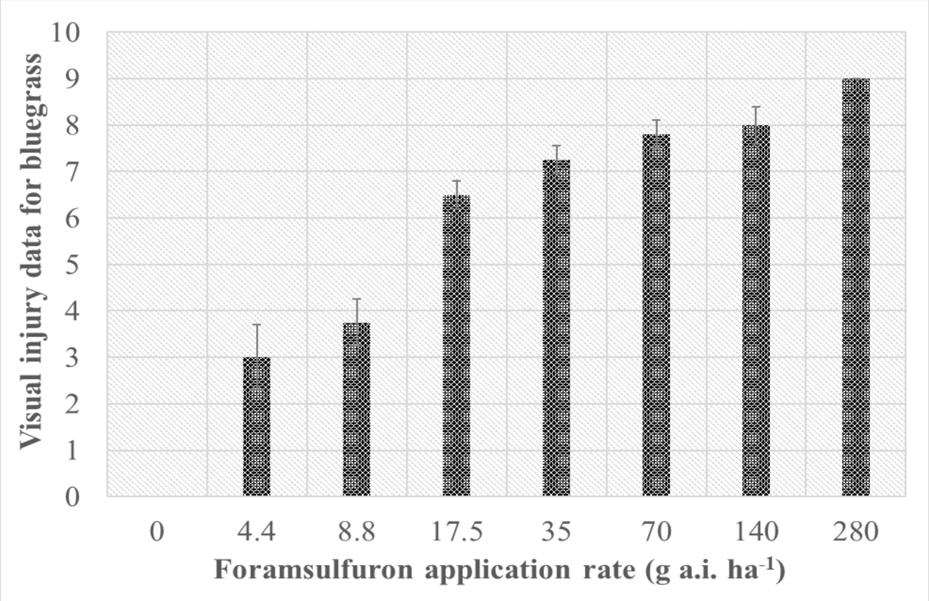

Figure 2-5. Herbicide visual injury rating of bluegrass at 45 days after application following treatment with various foramsulfuron application rates at Londonderry in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

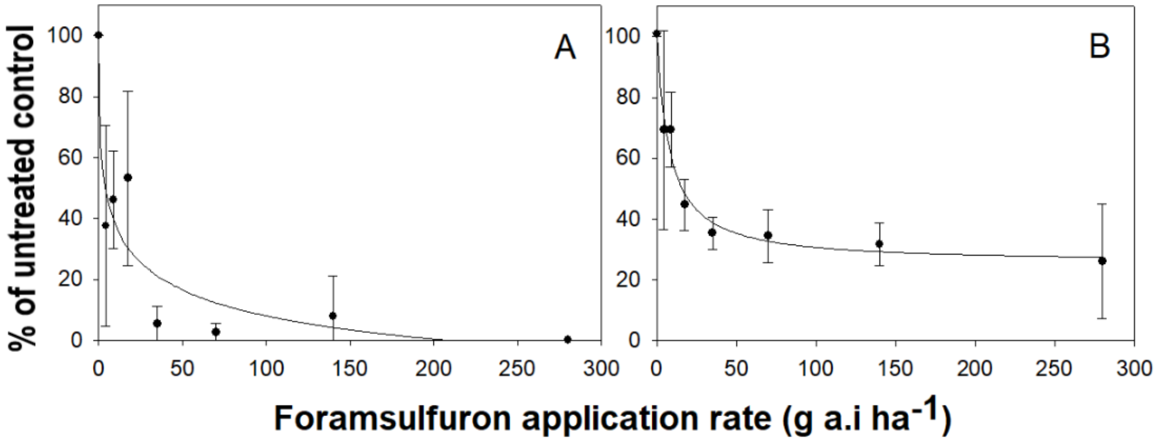

Figure 2-6. Flowering stem density (A) and stem height (B) of bluegrass at Londonderry as influenced by increasing foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form f (x)= min + (max-min)/(1 + $(x/I_{50})^b$). Parameter estimates for the four-parameter logistic dose response are provided in Table 2-5.

For tickle grass, there was a significant effect of foramsulfuron application rate on flowering tuft density, total tuft density, inflorescence number, and inflorescence height (Table 2-4). Initial tickle grass density was 4 ± 3 tufts m^{-2} in Rawdon. Ticklegrass was very susceptible to foramsulfuron, with very low doses of foramsulfuron required to reduce all measured response variables by 50% (Table 2-5). The visual injury rate was also increased with increasing foramsulfuron application rate (Figure 2-7). Application rates below the registered rate (35g a.i ha^{-1}) provided more than 90% reduction in tickle grass tuft density, inflorescence number, and inflorescence height (Table 2-5). Compared to applications of fluazifop-p-butyl at 250 g a.i ha^{-1}, it only required approximately 8.8 g a.i ha^{-1} foramsulfuron to obtain similar results, which was 1/4 of the registered foramsulfuron rate (Table 2-7). These results suggested that foramsulfuron could be used in rotation with fluazifop-p-butyl and sethoxydim to control tickle grass in wild blueberry. Since fluazifop-p-butyl and sethoxydim are Group 1 herbicides and foramsulfuron is in Group 2, the use of this herbicide should contribute to resistance management for tickle grass.

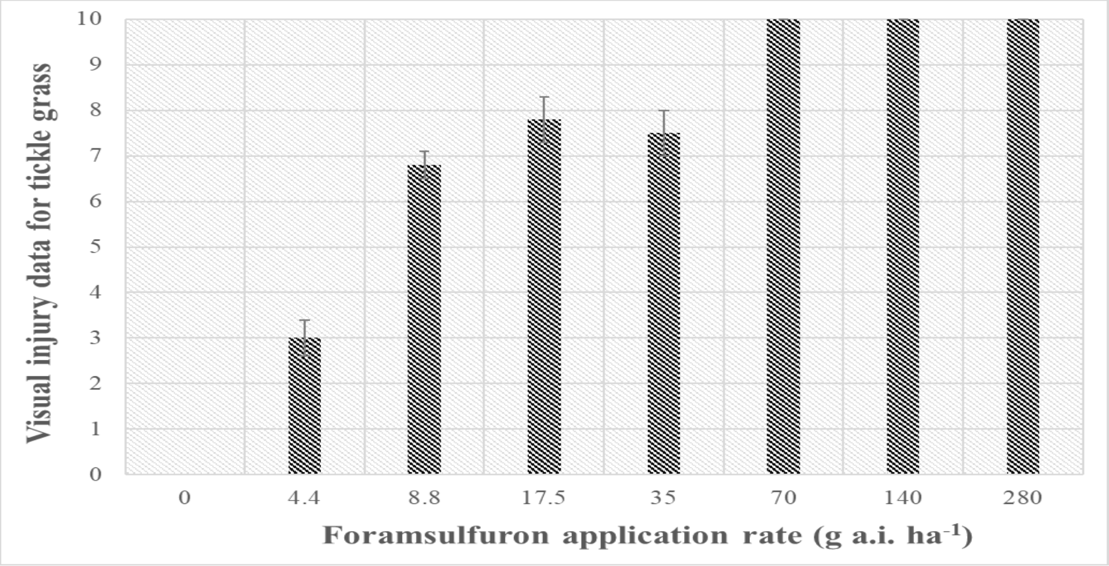

Figure 2-7 Herbicide visual injury rating of tickle grass at 45 days after application following treatment with various foramsulfuron application rates at Rawdon in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

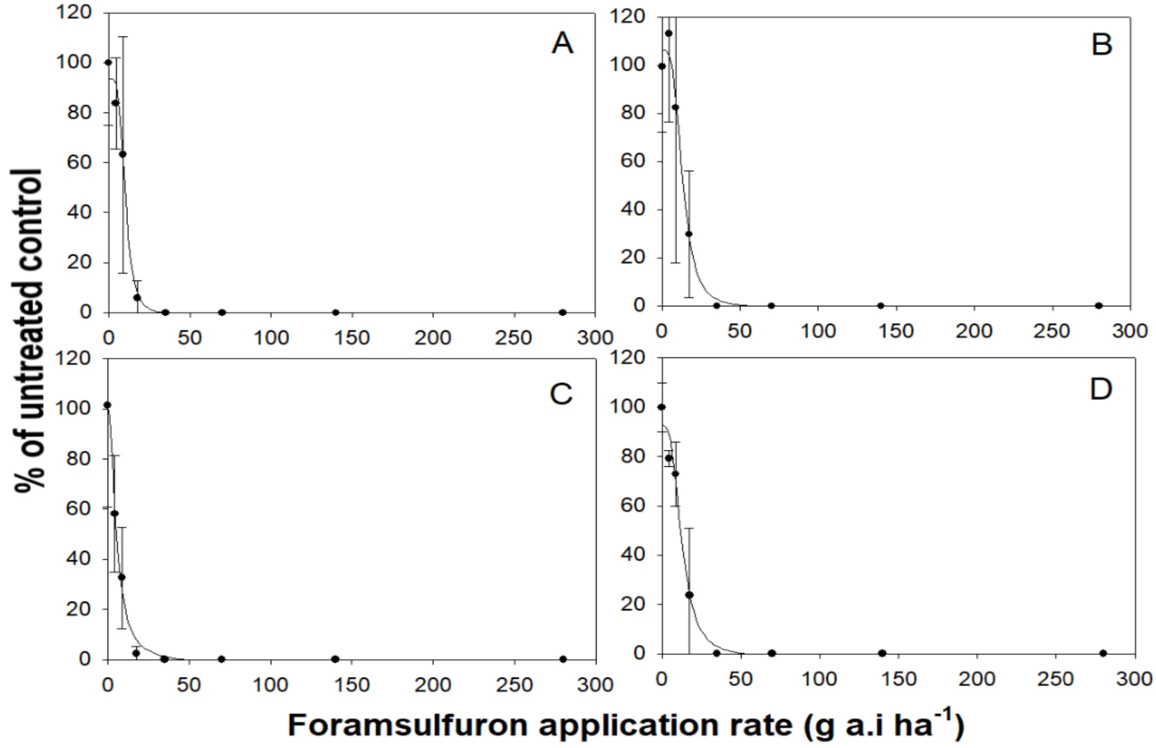

Figure 2-8. Flowering tuft density (A), total tuft density (B), inflorescence number (C) and inflorescence height (D) of tickle grass at Rawdon site as influenced by the increasing foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form f (x)= min + (max-min)/[1 + $(x/I_{50})^b$]. Parameter estimates for the four-parameter logistic dose response are provided in Table 2-5.

Table 2-7. Comparison of effects of foramsulfuron and two industry standard post-emergence products, fluazifop-p-butyl and sethoxydim, on tickle grass management.

Treatment	Application rate (g a.i. ha^{-1})	Flowering tuft density (tufts m^{-2})	Total tuft density (tufts m^{-2})	Inflorescence number (# $tuft^{-1}$)	Inflorescence height (cm)
Untreated control	0	5.7 ± 0.7a	7.3 ± 1.0a	26.4 ± 5.3a	56.9 ± 2.8a
Foramsulfuron	4.4	4.8 ± 0.5a	8.3 ± 1.3a	15.1 ± 3.1ab	45.1 ± 1.0a
Foramsulfuron	8.8	3.6 ± 1.3ab	6.0 ± 2.3a	8.5 ± 2.6bc	41.5 ± 3.7ab
Foramsulfuron	17.5	0.4 ± 0.2b	2.2 ± 1.0a	0.6 ± 0.4c	13.5 ± 7.8c
Foramsulfuron	35	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Foramsulfuron	70	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Foramsulfuron	140	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Foramsulfuron	280	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Fluazifop-p-butyl	250	0.8 ± 0.5b	2.1 ± 1.0a	2.2 ± 1.9bc	16.7 ± 9.8bc
Sethoxydim	495	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Greenhouse experiment. Average initial tiller number and leaf number of poverty oat grass in the greenhouse experiment were 2 ± 0.3 tillers tuft^{-1} and 7 ± 1 leaves tuft^{-1}. There were significant effects of experimental run ($p = 0.0033$) and foramsulfuron ($p < 0.0001$), but there was no significant experimental run X foramsulfuron interaction effect ($p = 0.8091$) on poverty oat grass final plant biomass (Table 2-8). Therefore, poverty oat grass final biomass data were combined by run for further analysis in ANOVA and Sigma Plot. There was a significant foramsulfuron effect on poverty oat grass final plant biomass by 50% ($p < 0.0001$). In greenhouse experiments, it required only 5.0 g a.i ha^{-1} foramsulfuron to reduce the poverty oat grass plant biomass by 50% at 28 days after herbicide application (Figure 2-9; Table 2-9). Poverty oat grass did appear more tolerant in the greenhouse study, but most poverty oat grass plants still survived in the pot experiment. The result indicated that foramsulfuron was effective at slowing down poverty oat grass seedlings biomass accumulation. Visual injury, however, occurred slowly (Table 2-10). The results suggested that foramsulfuron application at the registered rate (35g a.i ha^{-1}) could not control poverty oat grass seedling effectively.

Table 2-8. Test of main and interactive effects of experimental run and foramsulfuron on poverty oat grass and tickle grass final plant biomass at 28 days after herbicide application in greenhouse experiments.

Effects	Poverty oat grass	Tickle grass
Experimental run	***	***
Foramsulfuron	***	***
Experimental run * Foramsulfuron	NS	***

[a]Abbreviation: NS, no significant difference

[b]*P < 0.05, **P < 0.01, ***P < 0.001 level of significant obtained with PROC MIXED in SAS

Table 2-9. Parameter estimates (min, max, b, and I50) and I90 estimates for the four-parameter logistic dose response curvea describing the relationship between foramsulfuron dose levels and the target grass response at 28 days after application in greenhouse experiments.

Species	Four parameters of logistic dose response curve[b]				I_{90}
	min	max	b	I_{50}	
Poverty Oat grass	25.6 ± 3.4	99.6 ± 6.0	-1.8 ± 0.7	5.0 ± 0.9	> 280
Tickle grass	21.8 ± 2.3	99.8 ± 4.3	-2.1 ± 0.6	4.2 ± 0.5	> 280

[a] The four-parameter logistic dose response curve was the form $y = f(x) = min + \frac{\max - min}{1+(\frac{x}{I50})^b}$.

[b] Logistic dose response curve parameters, min = lower limit of the response, max = upper limit of the response, b = slope, I_{50} = the dose reponse required for 50% final plant biomass inhibition to target weed species.

[c] Values represent the parameter estimate ± 1 SE.

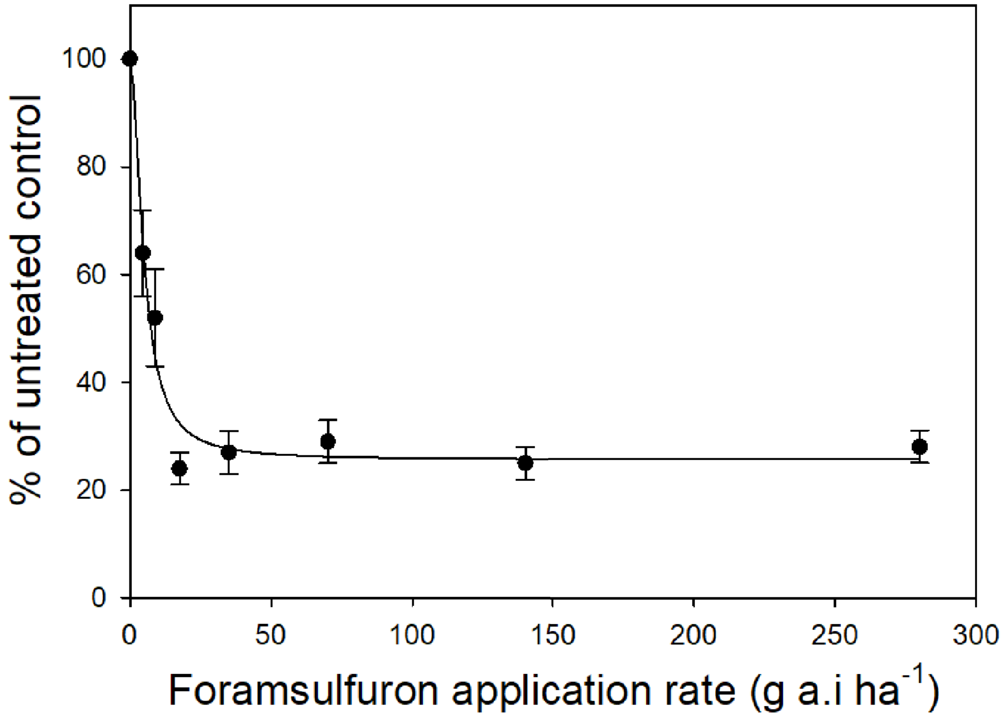

Figure 2-9. Poverty oat grass final plant biomass at 28 days after herbicide application in greenhouse experiments as influenced by the increasing foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form f (x)= min + (max-min)/[1 + $(x/I_{50})^b$]. Parameter estimates for the four-parameter logistic dose response are provided in Table 2-9

Table 2-10. Effect of foramsulfuron dose level on poverty oat grass visual injury rate in 28 days after herbicide application in the greenhouse experiment.

Run	Treatment	Days after planting			
		7	14	21	28
1	Untreated control	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	Foramsulfuron 4.4 g a.i ha^{-1}	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2
	Foramsulfuron 8.8 g a.i ha^{-1}	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2
	Foramsulfuron 17.5 g a.i ha^{-1}	0.0 ± 0.1	0.0 ± 0.0	0.3 ± 0.2	3.2 ± 0.7
	Foramsulfuron 35.0 g a.i ha^{-1}	0.0 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	5.5 ± 0.3
	Foramsulfuron 70.0 g a.i ha^{-1}	0.0 ± 0.3	0.2 ± 0.2	0.3 ± 0.2	5.5 ± 0.4
	Foramsulfuron 140.0 g a.i ha^{-1}	0.0 ± 0.4	0.5 ± 0.2	0.5 ± 0.2	6.3 ± 0.2
	Foramsulfuron 280.0 g a.i ha^{-1}	0.0 ± 0.5	0.2 ± 0.2	0.7 ± 0.2	6.7 ± 0.2
	p-value	0.4400	0.7746	0.0374	< 0.0001
2	Untreated control	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	Foramsulfuron 4.4 g a.i ha^{-1}	0.3 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	0.3 ± 0.2
	Foramsulfuron 8.8 g a.i ha^{-1}	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.5 ± 0.2
	Foramsulfuron 17.5 g a.i ha^{-1}	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.3
	Foramsulfuron 35.0 g a.i ha^{-1}	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	1.0 ± 0.3
	Foramsulfuron 70.0 g a.i ha^{-1}	0.2 ± 0.2	0.5 ± 0.2	0.7 ± 0.2	3.3 ± 0.6
	Foramsulfuron 140.0 g a.i ha^{-1}	0.2 ± 0.2	1.0 ± 0.0	0.7 ± 0.2	6.0 ± 0.4
	Foramsulfuron 280.0 g a.i ha^{-1}	0.2 ± 0.2	0.7 ± 0.0	1.5 ± 0.4	6.3 ± 0.7
	p-value[c]	0.9494	< 0.0001	< 0.0001	0 < 0.0001

[a] Values represent the mean ± 1 SE.

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

[c] p-values associated with the Kruskal–Wallis test for treatment significance using PROC NPAR-1-WAY in SAS.

There were significant effects of experimental run ($p < 0.0001$), foramsulfuron ($p < 0.0001$), and experimental run X foramsulfuron interaction ($p < 0.0001$) on tickle grass final grass biomass (Table 2-8). Therefore, biomass data for tickle grass were analyzed separately by run. Unfortunately, tickle grass biomass data for run 1 did not conform to the assumption of normality and constant variance, and only run 2 data was available for further analysis in ANOVA and Sigma Plot. There was a significant foramsulfuron effect on tickle grass final plant biomass ($p < 0.0001$). Approximately 4.2 g a.i ha^{-1} foramsulfuron was required for tickle grass biomass reduction by 50% in greenhouse experiments (Table 2-9; Figure 2-10). Tickle grass seedlings were very susceptible to foramsulfuron, and the significant visual injury occurred within 7 days after application (Table 2-11). Generally, foramsulfuron injury occurred slower in lower foramsulfuron dose levels, but greater than 87% injury was observed in all treated plants at 28 days after application (Table 2-11). The results indicated that foramsulfuron was effective in inhibiting the growth of tickle grass seedlings. These greenhouse data are consistent with the results found in the field as well, and suggested that growers should consider foramsulfuron use for tickle grass management.

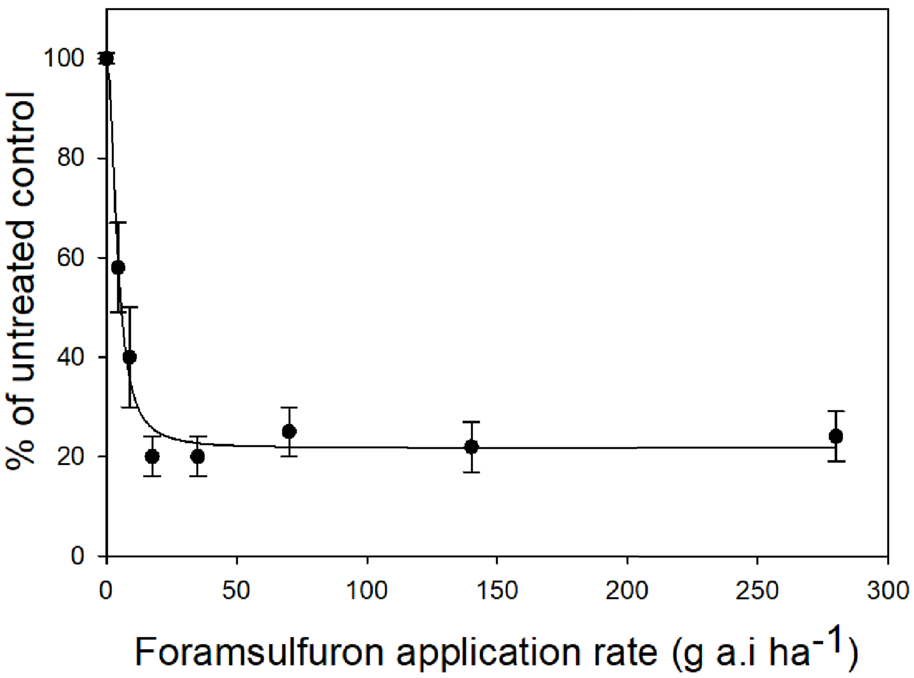

Figure 2-10. Tickle grass final plant biomass at 28 days after herbicide application in greenhouse experiments as influenced by the increasing foramsulfuron application rate. Symbols represent the mean value ± 1SE. Solid lines represent predicted response obtained from a four-parameter logistic dose response curve of the form $f(x) = \min + (\max - \min)/[1 + (x/I_{50})^b]$. Parameter estimates for the four-parameter logistic dose response are provided in Table 2-9.

Table 2-11. Effect of foramsulfuron dose level on tickle grass visual injury rate in 28 days after herbicide application in the greenhouse experiment

Run	Treatment	Days after application			
		7	14	21	28
1	Untreated control	0.0 ± 0.0	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0
	Foramsulfuron 4.4 g a.i ha^{-1}	1.2 ± 0.4	6.8 ± 0.2	8.7 ± 0.3	8.7 ± 0.2
	Foramsulfuron 8.8 g a.i ha^{-1}	1.7 ± 0.2	6.8 ± 0.4	8.7 ± 0.3	8.8 ± 0.3
	Foramsulfuron 17.5 g a.i ha^{-1}	1.5 ± 0.2	6.5 ± 0.2	9.3 ± 0.2	9.8 ± 0.2
	Foramsulfuron 35.0 g a.i ha^{-1}	3.0 ± 0.4	7.7 ± 0.2	9.7 ± 0.2	10.0 ± 0.0
	Foramsulfuron 70.0 g a.i ha^{-1}	3.3 ± 0.3	8.5 ± 0.4	9.5 ± 0.2	9.7 ± 0.2
	Foramsulfuron 140.0 g a.i ha^{-1}	5.8 ± 0.2	8.7 ± 0.3	9.8 ± 0.2	10.0 ± 0.0
	Foramsulfuron 280.0 g a.i ha^{-1}	6.7 ± 0.7	8.7 ± 0.2	9.7 ± 0.2	10.0 ± 0.0
	p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2	Untreated control	0.0 ± 0.0	0.3 ± 0.2	0.3 ± 0.2	0.0 ± 0.0
	Foramsulfuron 4.4 g a.i ha^{-1}	1.0 ± 0.5	6.7 ± 1.0	7.5 ± 0.7	8.7 ± 0.8
	Foramsulfuron 8.8 g a.i ha^{-1}	1.7 ± 0.2	6.0 ± 0.5	8.2 ± 0.7	7.8 ± 0.6
	Foramsulfuron 17.5 g a.i ha^{-1}	1.5 ± 0.2	7.0 ± 0.4	9.2 ± 0.3	9.5 ± 0.2
	Foramsulfuron 35.0 g a.i ha^{-1}	2.5 ± 0.3	7.2 ± 0.3	9.3 ± 0.2	9.3 ± 0.2
	Foramsulfuron 70.0 g a.i ha^{-1}	3.5 ± 0.4	8.2 ± 0.2	8.2 ± 0.2	9.7 ± 0.2
	Foramsulfuron 140.0 g a.i ha^{-1}	5.8 ± 0.9	8.8 ± 0.3	8.8 ± 0.3	10.0 ± 0.0
	Foramsulfuron 280.0 g a.i ha^{-1}	5.3 ± 0.2	8.0 ± 0.4	8.0 ± 0.4	9.7 ± 0.2
	p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] Values represent the mean ± 1 SE.

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

[c] p-values associated with the Kruskal–Wallis test for treatment significance using PROC NPAR-1-WAY in SAS.

Potential antagonistic effect of mesotrione on foramsulfuron. Application of tested herbicide treatments did not increase visual injury level of wild blueberry plants at 45 days after application. There was a significant experimental site X grass herbicide interaction effect on blueberry flower bud number per stem ($p = 0.0323$), but there was no significant experiment site X grass herbicide X mesotrione effect on blueberry stem density ($p = 0.3385$), stem height ($p = 0.4711$) and flower bud number per stem ($p = 0.0550$) (Table 2-12). Therefore, these blueberry response variables were pooled across sites for further analysis. There were no significant effects of mesotrione ($p = 0.7875$), grass herbicides ($p = 0.7406$), and grass herbicide X mesotrione interaction ($p = 0.8344$) on blueberry stem density, which averaged 380.7 ± 213.8 stems m^{-2} across all sites. There was a significant effect of mesotrione ($p = 0.0195$), but no significant effects of grass herbicide ($p = 0.2384$) and grass herbicide X mesotrione interaction ($p = 0.1977$) on blueberry flower bud number per stem. No treatments significantly affected blueberry flower bud number per stem relative to the untreated control, and the flower bud number per stem averaged 5 ± 2 bud $stem^{-1}$ across sites. There were no significant effects of grass herbicide ($p = 0.4922$) and mesotrione ($p = 0.8900$), but there was a significant effect of grass herbicide X mesotrione interaction ($p = 0.0008$) on blueberry height. Sethoxydim applied alone significantly increased blueberry stem height relative to untreated control for unknown reasons, and no significant effects of other treatments were found on wild blueberry stem height (Table 2-13). The results showed that tank mixture of mesotrione and grass herbicides did not affect blueberry yield potential. Further studies can be conducted to determine the effect of the tank mixture of mesotrione and foramsulfuron on blueberry yield.

Table 2-12. Test of main and interactive effects of treatment and experimental site on blueberry potential and yield in preemergence foramsulfuron antagonistic trial at Tatamagouche, Portapique and Rawdon in Nova Scotia, in 2016-2017.

Effects	Blueberry stem density (stems m^{-2})	Blueberry stem height (cm)	Blueberry flower buds (# $stem^{-1}$)
Experimental site	***	**	***
Grass herbicide	NS	NS	*
Mesotrione	NS	NS	*
Grass herbicide by Mesotrione	NS	***	NS
Experimental site by grass herbicide	NS	NS	*
Experimental site by mesotrione	NS	NS	NS
Experimental site by grass herbicides by mesotrione	NS	NS	NS

[a]Abbreviation: NS, no significant difference

[b]*P < 0.05, **P < 0.01, ***P < 0.001 level of significant obtained with PROC MIXED in SAS

Table 2-13. Effect of herbicide treatments on wild blueberry stem height and across all sites in Nova Scotia, Canada in 2016.

Grass herbicide	Callisto	Active ingredients	Application rate (g a.i ha^{-1})	Blueberry stem height (cm)
None	No	Nontreated control	-	12.2 ± 0.7b
None	Yes	Mesotrione	144	14.4 ± 0.8ab
Venture	No	Fluazifop-p-butyl	250	13.0 ± 0.8ab
Venture	Yes	Fluazifop-p-butyl + Mesotrione	250+144	13.5 ± 0.6ab
Poast	No	Sethoxydim	495	14.9 ± 1.0a
Poast	Yes	Sethoxydim + Mesotrione	495+144	12.8 ± 0.8ab
Option	No	Foramsulfuron	35	13.4 ± 0.6ab
Option	Yes	Foramsulfuron +Mesotrione	35+144	12.7 ± 0.8ab

[a]Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Site-combined data set of visual injury, flower tuft density, and inflorescence height did not conform to the assumptions for normality and constant variance when testing for the effect of experimental site. Therefore, these grass responses were analyzed separately by site. General trends at each site were similar. Visual injury was not different in plots treated with tank mixture of mesotrione and grass herbicides relative to grass herbicide applied alone (Figure 2-11). There were significant effects of grass herbicide ($p < 0.0001$) and experiment site X grass herbicide interaction ($p < 0.0001$) in the site-combined poverty oat grass inflorescence number data set (Table 2-14). However, there were no significant effects of experiment site X grass herbicides X mesotrione interaction on the site-combined poverty oat grass initial grass density ($p = 0.7764$), total tuft density ($p = 0.4875$) and inflorescence number ($p = 0.4867$). Therefore, these grass responses were combined across sites for analysis. Poverty oat grass initial grass density at application averaged 8 ± 3 tufts m^{-2} across all sites ($p = 0.6356$). The was a significant grass herbicide effect ($p < 0.0001$), but no significant effects of mesotrione ($p = 0.8715$) and grass herbicide X mesotrione interaction ($p = 0.5242$) on poverty oat grass inflorescence number. Poverty oat grasses that were treated with fluazifop-p-butyl and sethoxydim had the lowest inflorescence number, while foramsulfuron did not reduce poverty oat grass inflorescence number at the application rate used (Table 2-15). This was similar with the results from foramsulfuron dose responsible experiment, which again indicated the limited potential for poverty oat grass control with foramsulfuron. Also, addition mesotrione to grass herbicides did not affect poverty oat grass inflorescence number (Table 2-15). There was no significant mesotrione effect ($p = 0.9334$), but there were significant effects of grass herbicide ($p = 0.0004$) and grass herbicide X mesotrione interaction ($p = 0.0272$) on poverty oat grass total tuft density. Mesotrione on grass herbicides interaction did not effect on poverty oat grass total tuft density (Table 2-15). Therefore, efficacy of foramsulfuron on total tuft density was not affected when tank mixed with mesotrione related to the grass herbicides applied alone (Table 2-15).

There was a significant grass herbicide effect ($p < 0.0001$), but no significant grass herbicide X mesotrione interaction effect ($p \geqslant 0.1032$) on poverty oat grass flowering tuft density and inflorescence height at all sites. Similar with the results of poverty oat grass total tuft density and inflorescence number, tank-mixing with mesotrione did not significantly increased grass herbicide efficacies on poverty oat grass flowering tuft density and inflorescence height at all sites (Table 2-16, 2-17 and 2-18). Among three tested grass control herbicides, fluazifop-p-butyl was consistently the most effective one in reducing poverty oat grass flowering tuft density, eliminating all flowering tufts across sites. However, foramsulfuron was relatively ineffective on poverty oat grass, indicating that foramsulfuron should not be used when developing poverty oat grass control strategies.

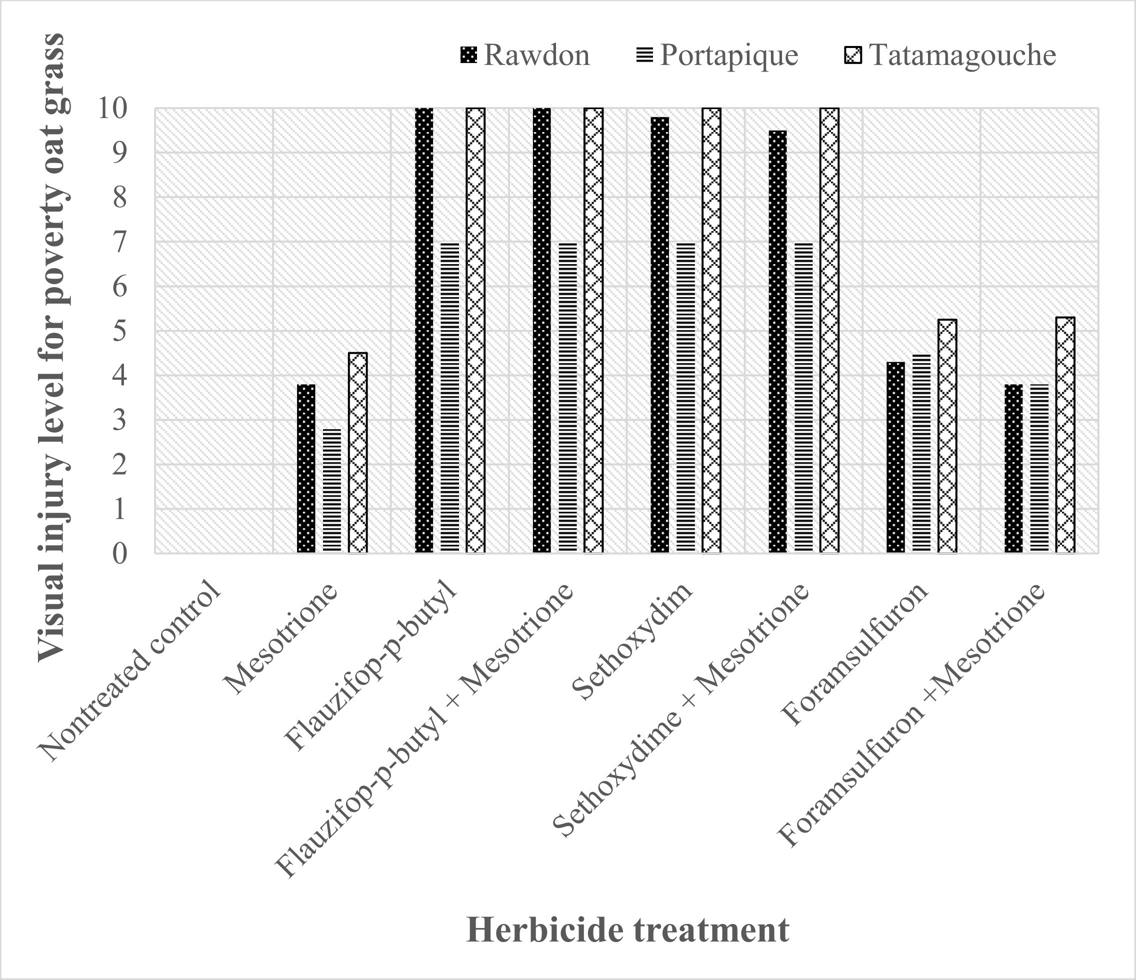

Figure 2-11. Herbicide visual injury rating of poverty oat grass treated with related herbicides at 45 days after herbicides application in foramsulfuron antagonistic experiment at Rawdon, Portapique and Tatamagouche in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

Table 2-14 Test of main and interactive effects of treatment and experimental site on poverty oat grass flowering tuft density, total tuft density, inflorescence number and inflorescence height in foramsulfuron antagonistic experiment.

Effect	Mean initial grass density at application (tufts m^{-2})	Flowering tuft density[a] (m^{-2})	Total tuft density (tuft m^{-2})	Inflorescence number (# $tuft^{-1}$)	Inflorescence height (cm)
Experimental site	NS	-	***	***	-
Grass herbicide	NS	-	*	***	-
Mesotrione	NS	-	NS	NS	-
Grass herbicide by mesotrione	NS	-	NS	NS	-
Experimental site by grass herbicide	NS	-	NS	***	-
Experimental site by mesotrione	NS	-	NS	NS	-
Experimental site by grass herbicides by mesotrione	NS	-	NS	NS	-

[a] Abbreviation: NS, no significant difference

[b] *P < 0.05, **P < 0.01, ***P < 0.001 level of significant obtained with PROC MIXED in SAS

Table 2-15. Potential antagonistic effect of mesotrione on foramsulfuron on poverty oat grass total tuft density and inflorescence number across sites in Nova Scotia in 2016-2017. Inflorescence number was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Grass herbicide	Callisto	Active ingredients	Application rate (g a.i ha^{-1})	Total tuft density (tuft m^{-2})	Inflorescence number (# tuft^{-1})
None	No	Nontreated control	-	11.1 ± 1.5 a	2.2 ± 0.2a (10.2)
None	Yes	Mesotrione	144	8.9 ± 1.4ab	2.1 ± 0.2a (8.8)
Venture	No	Fluazifop-p-butyl	250	6.7 ± 1.1b	0.2 ± 0.2b (0.2)
Venture	Yes	Fluazifop-p-butyl + Mesotrione	250+144	8.1 ± 1.4b	0.2 ± 0.2b (0.3)
Poast	No	Sethoxydim	495	7.2 ± 1.6b	0.6 ± 0.2b (1.0)
Poast	Yes	Sethoxydim + Mesotrione	495+144	8.4 ± 1.6ab	0.5 ± 0.2b (0.9)
Option	No	Foramsulfuron	35	8.9 ± 1.1ab	1.9 ± 0.2a (7.2)
Option	Yes	Foramsulfuron + Mesotrione	35+144	8.7 ± 0.9ab	2.1 ± 0.2a (8.8)

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 2-16. Potential antagonistic effect of mesotrione on foramsulfuron on poverty oat grass at Portapique in Nova Scotia, in 2016-2017. Flowering tuft density in all sites log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Grass herbicide	Callisto	Active ingredients	Application rate (g a.i ha^{-1})	Flowering tuft density (tuft m^{-2})	Inflorescence height (cm)
None	No	Nontreated control	-	1.9 ± 0.3a (7.0)	44.9 ± 3.8ab
None	Yes	Mesotrione	144	1.8 ± 0.3a (6.7)	48.5 ± 4.4a
Venture	No	Fluazifop-p-butyl	250	0.0b (0.0)	12.6 ± 7.3d
Venture	Yes	Fluazifop-p-butyl + Mesotrione	250+144	0.0b (0.0)	12.5 ± 7.2d
Poast	No	Sethoxydim	495	1.5 ± 0.3b (0.2)	30.0 ± 2.5c
Poast	Yes	Sethoxydim + Mesotrione	495+144	0.0 ± 0.4b (0.2)	26.5 ± 2.3cd
Option	No	Foramsulfuron	35	1.8 ± 0.3a (5.8)	33.3 ± 1.4bc
Option	Yes	Foramsulfuron +Mesotrione	35+144	1.5 ± 0.3a (5.7)	38.9 ± 1.9abc

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 2-17. Potential antagonistic effect of mesotrione on foramsulfuron on poverty oat grass at Rawdon in Nova Scotia, in 2016-2017. Flowering tuft density and inflorescence height was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Grass herbicide	Callisto	Active ingredients	Application rate (g a.i ha^{-1})	Flowering tuft density (tuft m^{-2})	Inflorescence height[b] (cm)
None	No	Nontreated control	-	2.0 ± 0.1a (6.7)	4.1 ± 0.0ab (60.6)
None	Yes	Mesotrione	144	1.9 ± 0.1a (5.6)	4.2 ± 0.0a (65.3)
Venture	No	Fluazifop-p-butyl	250	0.0 ± 0.1b (0.0)	0.0 ± 0.0
Venture	Yes	Fluazifop-p-butyl + Mesotrione	250+144	0.0 ± 0.1b (0.0)	0.0 ± 0.0
Poast	No	Sethoxydim	495	0.1 ± 0.1b (0.2)	3.8 ± 0.0c (22.1)
Poast	Yes	Sethoxydim + Mesotrione	495+144	0.2 ± 0.1b (0.3)	3.8 ± 0.0c (23.0)
Option	No	Foramsulfuron	35	2.0 ± 0.1a (6.3)	4.0 ± 0.0b (55.7)
Option	Yes	Foramsulfuron +Mesotrione	35+144	1.9 ± 0.1a (5.9)	4.1 ± 0.0b (59.0)

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

[b] Inflorescence height from the fluazifop-p-butyl treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

Table 2-18. Potential antagonistic effect of mesotrione on foramsulfuron on poverty oat grass at Tatamagouche in Nova Scotia, in 2016-2017. Flowering tuft density and height were log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Grass herbicide	Callisto	Active ingredients	Application rate (g a.i ha^{-1})	Flowering tuft density[b] (tuft m^{-2})	Inflorescence height[b] (cm)
None	No	Nontreated control	-	1.5 ± 0.2a (4.8)	3.8 ± 0.1a (44.0)
None	Yes	Mesotrione	144	1.5 ± 0.2a (4.8)	3.7 ± 0.1a (40.5)
Venture	No	Fluazifop-p-butyl	250	0.0 ± 0.0	0.0 ± 0.0
Venture	Yes	Fluazifop-p-butyl + Mesotrione	250+144	0.0 ± 0.0	0.0 ± 0.0
Poast	No	Sethoxydim	495	0.0 ± 0.4b (0.1)	3.5 ± 0.1a (25.7)
Poast	Yes	Sethoxydim + Mesotrione	495+144	0.0 ± 0.4b (0.1)	0.0 ± 0.0
Option	No	Foramsulfuron	35	1.3 ± 0.2a (3.9)	3.6 ± 0.0a (36.1)
Option	Yes	Foramsulfuron +Mesotrione	35+144	1.6 ± 0.2a (5.3)	3.6 ± 0.0a (36.5)

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

[b] Inflorescence height from the fluazifop-p-butyl treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

The initial tickle grass tuft density at Rawdon was 3.5 ± 1.4 tufts m^{-2}. Tickle grass visual injury level was not affected in plots treated with tank mixtures of mesotrione and grass herbicides relative to grass herbicide applied alone (Figure 2-12). There was a significant grass herbicide effect ($p < 0.0001$), but no significant grass herbicide X mesotrione interaction effect ($p \geqslant 0.0978$) on tickle grass flowering tuft density, total tuft density, inflorescence number and inflorescence height (Table 2-19). Three tested grass herbicides all effectively eliminated tickle grass flowering and total tuft density, which was similar with the results from the foramsulfuron does response experiment. Therefore, foramsulfuron could be an alternative to fluazifop-p-butyl or sethoxydim in controlling tickle grass. The results also indicated that efficacies of foramsulfuron, fluazifop-p-butyl or sethoxydim was not affected when tank mixed with mesotrione, and the tank mixture of mesotrione and foramsulfuron should be considered when both tickle grass and other susceptible broadleaf weeds are present.

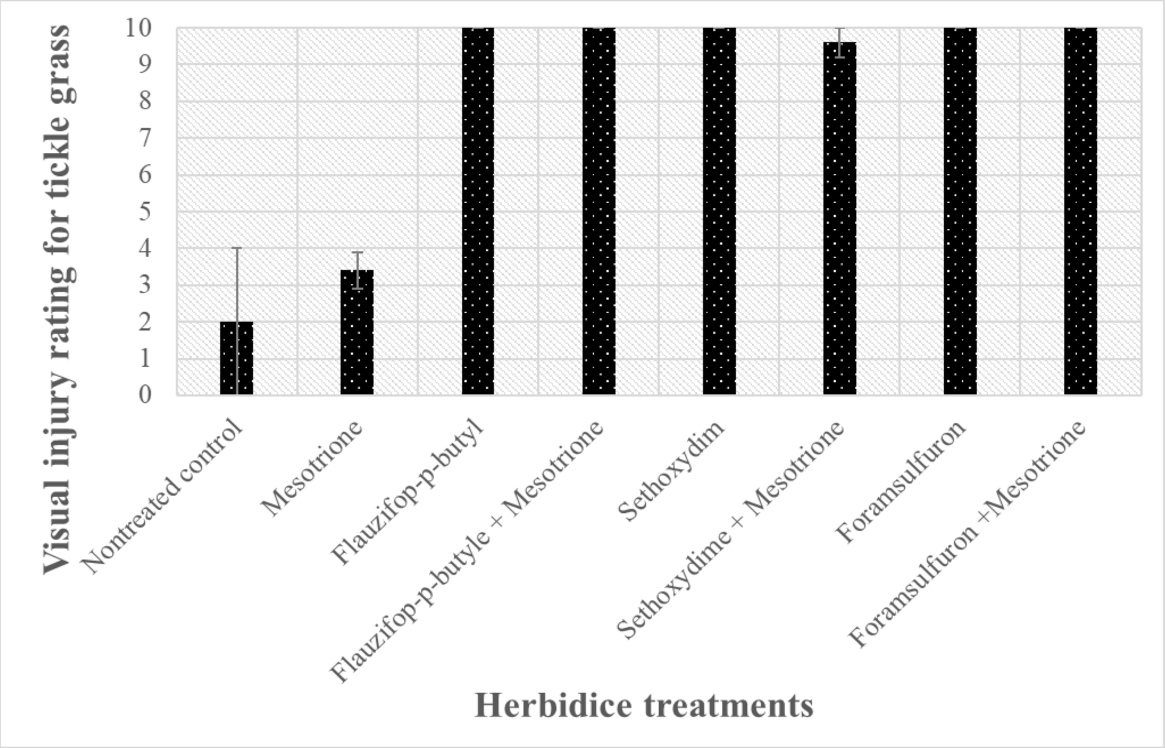

Figure 2-12 Herbicide visual injury rating of tickle grass treated with related herbicides at 45 days after application in experiment 3 at Rawdon, Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

Table 2-19. Potential antagonistic effect of mesotrione on foramsulfuron on tickle grass at Rawdon site in Nova Scotia, in 2016-2017. Flowering tuft density and inflorescence number were square root transformed, and total tuft density was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Grass herbicide	Callisto	Active ingredients	Application rate (g a.i ha^{-1})	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})	Inflorescence number (# tuft^{-1})	Inflorescence height (cm)
None	No	Nontreated control	-	2.3 ± 0.2a (5.7)	2.0 ± 0.3 a (7.9)	5.5± 0.4a (31.1)	62.9±2.3a
None	Yes	Mesotrione	144	2.3 ± 0.2a (5.4)	2.0 ± 0.3a (7.5)	4.1 ± 0.4a (17.5)	47.7±3.9a
Venture	No	Fluazifop-p-butyl	250	0.6 ± 0.2b (0.9)	0.7 ± 0.3ab (1.4)	1.1 ± 0.4b (3.6)	16.4±10.1b
Venture	Yes	Fluazifop-p-butyl + Mesotrione	250+144	0.3 ± 0.2b (0.5)	1.5 ± 0.6ab (0.9)	0.4 ± 0.4b (0.8)	6.0±6.0b
Poast	No	Sethoxydim	495	0.4 ± 0.2b (0.3)	0.0 ± 0.3b (0.3)	0.7 ± 0.4b (1.0)	19.2±7.8b
Poast	Yes	Sethoxydim + Mesotrione	495+144	0.3 ± 0.2b (0.3)	0.5 ± 0.4ab (0.9)	0.5 ± 0.4b (0.7)	12.1±7.5b
Option	No	Foramsulfuron	35	0.0 ± 0.2b (0.0)	0.0 ± 0.4b (0.4)	0.0 ± 0.4b (0.0)	0.0±0.0b
Option	Yes	Foramsulfuron + Mesotrione	35+144	0.1 ± 0.2b (0.1)	0.0 ± 0.3b (0.7)	0.2 ± 0.4b (0.2)	0.2±0.2b

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Chapter 3 - Herbicide combination for hair fescue (*Festuca filiformis*) management

Abstract

Hair fescue (*Festuca filiformis*) is becoming a serious weed problem in wild blueberries in Nova Scotia, as propyzamide is the only effective herbicide for this weed. Four field experiments were conducted to develop new use patterns for foramsulfuron and glufosinate on hair fescue to reduce the reliance on propyzamide. The objective of experiment 1 was to develop a use pattern for foramsulfuron and/or glufosinate which could provide the same fescue control levels as propyzamide. Results showed that a glufosinate and terbacil tank mixture, followed by foramsulfuron, provided similar efficacy to propyzamide, which could be used as an alternative treatment to propyzamide to suppress hair fescue in the non-bearing year. Terbacil and foramsulfuron had variable efficacy on hair fescue when applied alone, but terbacil efficacy was improved when tank mixed with glufosinate. Hexazinone herbicide combinations were consistently the least effective in the experiment, indicating this herbicide should be avoided when developing hair fescue management strategies. The objective of experiment 2 was to develop optimum combination of bearing year propyzamide and non-bearing year herbicide applications for hair fescue control. Results showed that fall bearing year propyzamide applications followed by spring non-bearing year applications of terbacil, glufosinate, or foramsulfuron did not improve hair fescue control over that achieved with propyzamide alone. The objective of experiment 3 was to determine if fall bearing year herbicide applications increased non-bearing year foramsulfuron efficacy on fescues. Non-bearing year fescue suppression with spring

foramsulfuron was generally higher when application on preceded by fall applications of dichlobenil or glufosinate relative to just fall herbicide applications alone. Fall terbacil applications, either alone or followed by foramsulfuron, did not suppress hair fescue. The objective of experiment 4 was to evaluate the effect of fall and spring glufosinate applications on foramsulfuron efficacy on hair fescue. The results showed that foramsulfuron efficacy was improved when it was applied following glufosinate applied in the Fall or Spring. Sequential applications of fall glufosinate, spring glufosinate, and spring foramsulfuron provided the most effective control of fescue grass in the non-bearing year. Among all experiments, recovery of fescues occurred in the bearing year in all treatments lacking a fall non-bearing year propyzamide application. Therefore, additional research should be conducted to determine alternative treatments for fall non-bearing year fescue grass management in wild blueberry.

Introduction

Hair fescue, *Festuca filiformis* Pourr., is one of the most common perennial grasses in wild blueberry fields in Nova Scotia. It is a cool-season grass, native to Europe, and now established in eastern and north western North America (USDA 2016c). As discussed in previous chapters, perennial grasses that spread by seeds have become serious weed problems in wild blueberry fields, and hair fescue has been found to produce almost 3000 seeds per plant (White and Kumar 2017). Increasing fescue grass pressures have been observed in Nova Scotia wild blueberry fields, and these grass tufts compete aggressively with the crop for growing space (Picture 1). Being valued for soil erosion control (Ball et al. 1991), *festuca* spp. can easily establish on bare ground, outcompeting wild blueberry plants. FThe levels of fescue infestation in previous research did not show reduced yield on wild blueberry (White and Kumar 2017; Sikoriya 2014). It can be partially explained by the wild blueberry's slow response to herbicide applications, and the higher yield generally occur between 3 and 6 years after treatments (Eaton 1994). However, growers did report significant yield loss in commercial wild blueberry fields due to hair fescue infestation (White and Kumar 2017; Sikoriya 2014). Researchers also worried that the spread of hair fescue would interfere with crop harvesting and decrease blueberry pack quality (White and Kumar 2017; Sikoriya 2014).

Figure 3-1. Hair fescue invasion in the wild blueberry field, Stewiacke, NS 2016

In wild blueberry fields, weed control options are limited to pruning and herbicide application. Burning has been used in the past to prune wild blueberry fields, and transition from burning to mowing for pruning may partially explain why the occurrence of fescue grass has increased in Nova Scotia (White and Boyd 2016; Penny et. al 2008; Jensen and Yarborough 2004). Although there were some initial effects of burning, *Festuca filiformis* has remained one of the most dominant species after burning (Penny et. al 2008). Pruning by burning has been replaced by mowing in recent years due to the rising cost of fuel and environmental pollution. However, pruning by mowing only once in a production cycle can not be a potential tool for *festuca* spp. control (Johnson 1989). Herbicide application remains the primary method of hair fescue control in wild blueberry fields.

Hair fescue was traditionally controlled in wild blueberry fields with several herbicides, including glyphosate (Anonymous 2016a; Sikoriya 2014), atrazine (Sampson et al. 1990; Jensen 1986), hexazinone (Anonymous 2016a; Jensen and Yarborough 2004), and terbacil (Anonymous 2016a). Glyphosate has variable control on hair fescue (Anonymous 2016a). Wild blueberry is very sensitive to glyphosate and contact with the product can result in long-term damage to blueberry plants, which affect berry yields in the bearing year (Anonymous 2016a; Sikoriya 2014). Due to the problems with soil persistence and underground water contamination, atrazine use was banned and a special review of the pesticide was required by law in 2013.This herbicide is no longer registered for used in wild blueberry fields. Hexazinone, as the primary preemergence herbicide in wild blueberry fields, has been used for decades and herbicide resistant fescue species were suspected to have developed in Nova Scotia (Anonymous 2016a; Jensen and Yarborough 2004; Jensen and Kimball 1985). When applied alone, terbacil is not effective and has variable control on fescue grass (Anonymous 2016a). Other common registered graminicides in wild blueberry fields, such as fluazifop-p-butyl and sethoxydim, do not supress or control fescue grass due to an insensitive form of ACCase in *festuca* spp. (Anonymous 2016a; Stoltenberg et al.1989; Catanzaro et al. 1993).

Propyzamide (Kerb$^{@}$) is a selective, preemergence herbicide in group 3 (Shaner 2014). It functions by inhibiting microtubule assembly and disrupting cell division in late prometaphase of mitosis (Shaner 2014). Propyzamide is registered in wild blueberry fields in Canada for grass control, but it was rarely used in the past due to its poor control on poverty oat grass and limited control of woody and broadleaved species (Anonymous 2016a). It is now considered the most effective herbicide for suppressing fescue grasses, which are generally tolerant to hexazinone and other common graminicides in wild blueberry fields (Anonymous 2016c; Skikoriya 2014; Yarborough and Cote 2014). Propyzamide can effectively control fescue biomass up to 99% (Sikoriya 2014). Wild blueberry is very tolerant to propyzamide (Anonymous 2016a; Sikoriya 2014). Since it is applied after the pruning of wild blueberry fields, no damage to wild blueberry was found (Sikoriya 2014). However, propyzamide is very expensive. Growers would need to spend over \$200 acre^{-1} in using propyzamide, while other common herbicides discussed above only cost \$30 - \$100 acre^{-1}. Timing of propyzamide application is important to ensure optimum results. Propyzamide should be applied when soil temperature is below 4 ^{o}C but before it freezes (Anonymous 2016a; Sikoriya 2014). Rainfall and high soil moisture are required to move propyzamide into the soil where it is active and absorbed into roots (Anonymous 2016a; Shaner 2014). Due to these strict weather condition requirements, variability in weed control has been found with this product because of conditions, such as dry soil, warm temperature, and frozen ground, reduced the herbicides effectiveness (Anonymous 2016a). Even with the ideal weather at application, recovery of hair fescue tufts following propyzamide treatment is common; thus, the effect of propyzamide, applied in conjunction with subsequent spring herbicide applications should be assessed (S. White, personal observation). The introduction of new herbicides is important for a long-term sustainable hair fescue management in wild blueberry fields.

Foramsulfuron is a newly registered Group 2 herbicide for postemergence control of fescue grass in wild blueberry fields. Previous research showed some initial suppression of hair fescue with foramsulfuron applications, but overall, control levels were generally unacceptable and regrowth of hair fescue was often observed from initially injured plants (White and Kumar 2017; Yarborough and Cote 2014). Inconsistent growth stages of hair fescue tufts in fields can partially explain it. Foramsulfuron is most effective on young seedlings at the 1-6 leaf stage, while most established hair fescue tufts of infestation in fields exceed this growth stage (White and Kumar 2017; Anonymous 2016a). Glufosinate ammonium, a non-selective burndown herbicide, might be a solution to reduce excessive growth of hair fescue (White and Kumar 2017). Application of glufosinate prior to foramsulfuron reduced hair fescue tuft leaf number and improve efficacy of postemergence foramsulfuron applications in the greenhouse (White and Kumar 2017). However, results obtained in fields were less effective than those from the greenhouse (White and Kumar 2017).

A single application of a currently registered herbicide, other than propyzamide, did not give effective controls on hair fescue and may have led to herbicide resistance. Improved herbicide efficacies were observed in herbicide combinations and so, these new herbicide use patterns should be developed. Rotating herbicides with different modes of action, or using them in combinations with each other, might provide a better level of hair fescue control and prevent the development of resistant grasses (Yarborough and Cote 2014). The successful example of increasing efficacy of sequential glufosinate and foramsulfuron applications on suppression of hair fescue in the greenhouse indicated the potential role of foramsulfuron and glufosinate on hair fescue control. However, efficacies of glufosinate and foramsulfuron, when used with other currently used herbicides that have different modes of action, have not been tested.

The overall objective of this chapter was to develop use patterns for foramsulfuron and glufosinate on hair fescue grass to reduce the reliance on propyzamide. Specific objectives were to 1) develop a use pattern for foramsulfuron and/or glufosinate which could provide similar hair fescue control levels to those currently obtained from propyzamide, 2) determine optimum combinations of bearing year propyzamide and non-bearing year herbicide application on hair fescue control, 3) determine if fall bearing year herbicide applications increase non-bearing year foramsulfuron efficacy on hair fescue, and 4) evaluate the effect of fall and spring glufosinate application on foramsulfuron efficacy on hair fescue.

Methods and Materials

Experiment 1 - Development of a use pattern for foramsulfuron and glufosinate ammonium on hair fescues. Field experiments were conducted to develop use patterns for foramsulfuron (Option® 2.25 OD Herbicide, Bayer CropScience) and/or glufosinate (Ignite@ Herbicide, Bayer CropScience) which could provide similar hair fescue control levels to those currently used. Other herbicides that were evaluated in the experiment for optimum herbicide use patterns included propyzamide (Kerb™ SC Herbicide, Dow Agro Science LLC) and terbacil (Sinbar@ Herbicide, Tessenderlo Kerley Inc.). All experiments were established in the fall after mowing or in the spring non-bearing year in wild blueberry fields located in Stewiacke (45°16'18.68"N; 63° 4'36.49"W), Parrsboro (45°25'38.01"N; 64°28'39.74"W) and Portapique (45°24'36.85"N; 63°43'28.07"W) in

Nova Scotia, Canada. The experiment was arranged as a randomized complete block design with 15 treatments (Table 3-1). Block number and plot size varied across sites based on fescue density and space available for trial establishment. There were 5 blocks in Portapique and 4 blocks in both Stewiacke and Parrsboro. Plot sizes at Parrsboro and Portapique were 2 mf X 6 m with a 1-m-wide unsprayed strip between each block, while the plot size was 2 m X 5 m at the Stewiacke site. Propyzamide, terbacil, glufosinate and hexazinone plus nicosulfuron + rimsulfuron treatments were applied preemergence to wild blueberry plants, and foramsulfuron was applied post emergence to wild blueberry plants. All herbicides tested in the experiment were applied postemergence to wild blueberry plants. The detailed herbicide application timings and weather conditions during herbicide applications of each trial are shown in Table 3-2. Herbicides were applied with a CO_2 pressurized research plot sprayer outfitted with four 11002 XR nozzles, calibrated to deliver a water volume of 200 L ha^{-1} (terbacil, foramsulfuron, and glufosinate) or 300 L ha^{-1} (propyzamide) at a pressure of 276 kPa.

Table 3-1. Treatment details for Experiment 1 to development of a use pattern for foramsulfuron and glufosinate ammonium on hair fescues

Common name	Application Rate (g a.i. ha^{-1})	Application timing[a]
Nontreated control	-	-
Propyzamide	2240	ABY
Propyzamide	2240	ABY + ANBY
Terbacil	2000	SNBY
Foramsulfuron[b]	35	SNBY
Terbacil fb Foramsulfuron	2000 + 35	SNBY + SNBY
Terbacil fb Propyzamide	2000 + 2240	SNBY + ANBY
Foramsulfuron fb Propyzamide	35 + 2240	SNBY + ANBY
Terbacil fb Foramsulfuron fb Propyzamide	2000 + 35 + 2240	SNBY + SNBY + ANBY
Terbacil + Glufosinate	2000 + 750	SNBY + SNBY
Terbacil + Glufosinate fb Propyzamide	2000 + 750 + 2240	SNBY + SNBY+ ANBY
Terbacil + Glufosinate fb Foramsulfuron	2000 + 750 + 35	SNBY + SNBY + SNBY
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	2000 + 750 + 35 + 2240	SNBY + SNBY + SNBY +ANBY
Hexazinone + Foramsulfuron	1920 + 35	SNBY + SNBY
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	1920 + 34 + 35	SNBY + SNBY + SNBY

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016

[b] Foramsulfuron was applied with a liquid nitrogen fertilizer (28 % UAN, Urea-Ammonium Nitrate) at a rate of 2.5 L ha^{-1}

[c] fb, followed by

Table 3-2. Herbicide application dates and related weather conditions in each trial in the Experiment 1 - development of a use pattern for foramsulfuron and glufosinate ammonium on hair fescues

Site	Application timing[a]	Date of spraying	Temp. (°C)	Humidity (%)	Wind speed (km*h^{-1})
Stewiacke	ABY	11-Nov-2015	8.9	64.0	4.5
	SNBY	04-May-2016	-	-	-
		24-May-2016	20.9	73.3	1.3
	ANBY	25-Nov-2016	3.3	44.0	1.9
Parrsboro	ABY	11-Nov-2015	13.9	55.0	4.0
	SNBY	12-May-2016	5.9	56.8	4.8
		29-May-2016	23.2	40.5	5.0
	ANBY	25-Nov-2016	7.0	48.5	2.1
Portapique	ABY	10-Nov-2015	-1.0	60.0	1.0
	SNBY	10-May-2016	7.2	65.0	2.6
		29-May-2016	15.9	45.7	10.8
	ANBY	25-Nov-2016	10.5	53.4	1.6

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016

Data collection included 1) damage ratings of blueberry and hair fescue, 2) grass density prior to treatment applications, in late summer of the year of herbicide applications, and in mid-summer of the bearing year, 3) grass inflorescence number and inflorescence height following treatment applications, 4) wild blueberry stem density, stem height, and flower bud number per stem at the end of the non-bearing year, and 5) wild blueberry yield in the bearing year. Damage rating was recorded for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 1.5 months after Spring Non-Bearing Year (SNBY) herbicide application. Tuft densities were determined in two 1 m X 1 m quadrats per plot. Inflorescence number and height of hair fescue were counted and measured in the field by randomly selecting 10 grasses per plot. Initial fescue grass tuft densities in the non-bearing year were determined on April 26, 2016 at Stewiacke and April 27, 2016 at Parrsboro and Portapique. Hair fescue flowering and total tuft densities were determined on June 19, 2016, June 28, 2017, and June 27, 2017 at Stewiacke, Parrsboro, and Portapique, respectively. Hair fescue inflorescence number and height in the non-bearing year were determined on July 7, 2016, July 11, 2016, and July 8, 2016 at Stewiacke, Parrsboro, and Portapique, respectively. Fescue grass flowering and total tuft densities in the bearing year were determined on July 7, 2017, July 10, 2017 and July 29, 2017 at Stewiacke, Parrsboro, and Portapique, respectively. Blueberry shoot counts were conducted in fields in two 30 cm X 30 cm quadrats per plot in late autumn in the non-bearing year. In each plot, 30 randomly selected blueberry stems were clipped at ground level, bagged in the field, and brought back to the lab in late autumn. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Wild blueberry yield was determined in two 1 m X 1 m quadrats per plot and wild blueberry fruit was harvested using hand rakes in mid-August of the crop year. Blueberry stem density counts and stem collections were completed at Stewiacke, Parrsboro, and Portapique on October 5, 2016, September 22, 2016, and October 20, 2016, respectively. Wild blueberry yields were determined on August 3, 2017, August 14, 2017, and August 2, 2017 at Stewiacke, Parrsboro, and Portapique, respectively.

Experiment 2 - Optimum combination of fall bearing year propyzamide and spring non-bearing year herbicide applications. Field experiments were conducted to determine the optimum combination of fall bearing year propyzamide application and non-bearing year herbicide applications in controlling fescue grass. Non-bearing year herbicides evaluated in this study were terbacil, foramsulfuron, and glufosinate ammonium. All experiments were conducted in wild blueberry fields located in Stewiacke and Parrsboro in Nova Scotia, Canada. Experimental trials were established on November 11, 2015 at Stewiacke and on November 4, 2015 at Parrsboro. The experiment was arranged as a randomized complete block design with 8 treatments (Table 3-3) and four blocks at each site. Foramsulfuron was applied with a liquid nitrogen fertilizer (28% UAN, Urea-Ammonium Nitrate) at a rate of 2.5 L ha^{-1}. Plot size was 2 m X 6 m with a 1-m-wide unsprayed strip in between each block at all sites. Propyzamide, terbacil, and glufosinate were applied pre-emergence to the wild blueberry, and foramsulfuron was applied post-emergence to the wild blueberry. The detailed herbicide application timings and the weather condition at application of each trial are shown in Table 3-4. Herbicides were applied using a CO_2 pressurized research plot sprayer outfitted with four 11002 XR nozzles and calibrated to deliver a water volume of 300 L ha^{-1} (propyzamide) or 200 L ha^{-1} (all spring herbicides) at a pressure of 276 kPa.

Table 3-3. Treatment details for the Experiment 2 – use of fall bearing year herbicides to improve non-bearing year hair fescue management

Common name	Application rate (g a.i. ha^{-1})	Application timing
Nontreated control	-	-
Propyzamide	2240	ABY
Propyzamide fb Terbacil	2240 + 2000	ABY + SNBY
Propyzamide fb Foramsulfuron[b]	2240+ 35	ABY + SNBY
Propyzamide fb[c] Glufosinate	2240 + 750	ABY + SNBY
Propyzamide fb Terbacil fb Foramsulfuron	2240 + 2000 + 35	ABY + SNBY + SNBY
Propyzamide fb Terbacil + Glufosinate	2240 + 2000 + 750	ABY + SNBY+ SNBY
Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	2240 + 2000 + 750 + 35	ABY + SNBY + SNBY+ SNBY

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016

[b] Foramsulfuron was applied with a liquid nitrogen fertilizer (28 % UAN, Urea-Ammonium Nitrate) at a rate of 2.5L ha^{-1}

[c] fb, followed by

Table 3-4. Herbicide application dates and related weather conditions in each trial for the Experiment 2 – use of fall bearing year herbicides to improve non-bearing year fescue management

Site	Application timing	Date of spraying	Temp. (°C)	Humidity (%)	Wind speed (km h^{-1})
Stewiacke	ABY	18-Nov-2015	8.9	64.0	4.5
	SNBY	04-May-2016	-	-	-
		19-Jun-2016	28.6	47.0	1.5
Parrsboro	ABY	10-Nov-2015	13.9	55.0	2.5
	SNBY	12-May-2016	5.9	56.8	4.8
		29-May-2016	23.2	40.5	5.0

[a]ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016

Data collection included 1) damage ratings of blueberry and hair fescue, 2) grass density prior to treatment applications, in late summer of the year of herbicide applications and in mid Summer of the bearing year, 3) grass inflorescence number and inflorescence height following treatment applications, 4) wild blueberry stem density, stem height, and flower bud number per stem at the end of the non-bearing year, and 5) wild blueberry yield in the bearing year. Damage rating was conducted for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 1.5 months after Spring Non-Bearing Year (SNBY) herbicide application. Tuft densities were determined in two 1 m X 1 m quadrats per plot. Inflorescence number and height of hair fescue were counted and measured in fields by randomly selecting 10 grasses per plot. Initial fescue grass tuft densities in the non-bearing year were determined on April 26, 2016 at Stewiacke, and April 27, 2016 at Parrsboro. Hair fescue grass flowering and total tuft densities were determined on June 19, 2016 at Stewiacke and June 28, 2016 at

Parrsboro. Hair fescue inflorescence number and height in the non-bearing year were determined on July 7, 2016 at Stewiacke, and July 11, 2016 at Parrsboro. Hair fescue flowering and total tuft densities in the bearing year were determined on July 7, 2017 at Stewiacke, and July 10, 2017 Parrsboro. Blueberry shoot counts were conducted in fields in two 30 cm X 30 cm quadrats per plot at the end of the field season in the non-bearing year. In each plot, 30 randomly selected blueberry stems were clipped at ground level, bagged in the field, and brought back to the lab in late autumn. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Wild blueberry yield was determined in two 1 m X 1 m quadrats per plot and wild blueberry fruit was harvested using hand rakes in mid-August of the bearing year. Blueberry stem density counts and blueberry stem collations were completed on October 5, 2016 at Stewiacke and on September 22, 2016 at Parrsboro. Blueberry yields were determined on August 3, 2017 at Stewiacke and August 14, 2017 at Parrsboro.

Experiment 3 - Effect of fall bearing year herbicide applications on non-bearing year foramsulfuron efficacy on hair fescue in wild blueberry fields. Experiment 3 was conducted to evaluate the effect of fall bearing year herbicide applications on spring non-bearing foramsulfuron efficacy on hair fescue in wild blueberry fields. The fall bearing year herbicides that were applied prior to non-bearing year foramsulfuron applications in the experiment were terbacil, propyzamide, glufosinate ammonium, and dechlobenil (Casoron G-4@ Herbicide, MacDermid Agricultural Solutions). All experiments were conducted in wild blueberry fields located at Stewiacke and Portapique in Nova Scotia, Canada. Experimental trials were established on November 6, 2015 at Stewiacke and on October 8, 2015 at Portapique. This experiment was a randomized complete block design with four blocks at each site. It was a 5 X 2 factorial arrangement of fall bearing year herbicide (none, terbacil, propyzamide, glufosinate, and dichlobenil) and non-bearing year foramsulfuron application (Yes, No). The application rate of terbacil, propyzamide, glufosinate, and dichlobenil were 2000, 2240, 750 and 1920g a.i. ha^{-1}, respectively. The application rate of foramsulfuron was 35g a.i. ha^{-1}. Foramsulfuron was applied with a liquid nitrogen fertilizer (28 % UAN) at a rate of 2.5 L ha^{-1}. Plot size was 2 m X 6 m with a 1-m-wide unsprayed strip between each block at all sites. Propyzamide, terbacil, glufosinate and dichlobenil were applied pre-emergence to the wild blueberry, and foramsulfuron was applied post-emergence to the wild blueberry. The detailed herbicide application timings and the weather condition at application of each trial are shown in Table 3-5. Herbicides were applied using a CO_2 pressurized research plot sprayer outfitted with four 11002 XR nozzles and calibrated to deliver a water volume of 300 L ha^{-1} (propyzamide) or 200 L ha^{-1} (terbacil, propyzamide, and glufosinate) at a pressure of 276 kPa, with the exception of dichlobenil, which was applied directly to treatment plots in dry form.

Table 3-5. Herbicide application dates and related weather conditions in each trial for the experiment - Evaluation of fall bearing year herbicide application on non-bearing year foramsulfuron efficacy on hair fescue in wild blueberry fields.

Site	Application timing	Date of spraying	Temp. (°C)	Humidity (%)	Wind speed (km*h^{-1})	
					Avg.	Max
Stewiacke	ABY	11-Nov-2015	8.9	64.0	4.5	-
	SNBY	04-May-2016	-	-	-	-
Portapique	ABY	10-Nov-2015	-1.0	60.0	1.0	-
	SNBY	10-May-2016	7.2	65.0	2.6	-

[a]ABY, Autumn Bearing Year 2015; SNBY, Spring Non-bearing Year 2016

Data collection included1) damage ratings of blueberry and hair fescue, 2) grass density prior to treatment applications, in late summer of the year of herbicide applications and in mid Summer of the bearing year, 3) grass inflorescence number and height following treatment applications, 4) hair fescue seed production in late fall in non-bearing year, 5) fescue seedling density in the early summer of the crop year, 6) wild blueberry stem density, stem height, and flower bud number per stem at the end of non-bearing year, and 7) wild blueberry yield in the bearing year. Damage rating was conducted for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 1.5 months after Spring Non-Bearing Year (SNBY) herbicide application. Tuft densities were determined in two 1 m X 1 m quadrats per plot. Inflorescence number and height of hair fescue were counted and measured in the field by randomly selecting 10 grasses per plot. Seed production was determined by collecting all inflorescence heads from 5 randomly selected plants in each plot. Hair fescue seedling densities were counted in fields in three 30 cm X 30 cm quadrats per plot. Initial hair fescue tuft densities in the non-bearing year were determined on April 26, 2016 at Stewiacke, and April 27, 2016 at Portapique. Hair fescue flowering and total tuft densities in the non-bearing year were determined on June 19, 2016 at Stewiacke and June 27, 2016 at Portapique. Hair fescue inflorescence number and height in the no-bearing year were determined on July 7, 2016 at Stewiacke, and July 8, 2016 at Portapique. Hair fescue inflorescence heads were collected for seed production counting on October 5, 2016 at Stewiacke and Portapique. Hair fescue seedling densities were determined on May 26, 2017 at Stewiacke and May 24, 2017 at Portapique. Hair fescue flowering and total tuft densities in the bearing year were determined on July 7, 2017 at Stewiacke, and June 29, 2017 Portapique. Blueberry shoot counts were conducted in fields in two 30 cm X 30 cm quadrats per plot at the end of the field season in the non-bearing year. In each plot, 30 randomly selected blueberry stems were clipped at ground level, bagged in the field, and brought back to the lab in late fall. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Wild blueberry yield was determined in two 1 m X 1 m quadrats per plot and wild blueberry fruit was harvested using hand rakes in mid-August of the bearing year. Blueberry stem density counts and blueberry stem collations were completed on October 5, 2016 at Stewiacke and on October 20, 2016 at Portapique. Blueberry yields were determined on August 3, 2017 at Stewiacke and August 02, 2017 at Portapique.

Experiment 4 - Effect of fall and spring glufosinate application on foramsulfuron efficacy on fescue grass. Experiment 4 was conducted to determine the effect of fall and spring glufosinate applications on foramsulfuron efficacy on hair fescue in lowbush blueberry fields. All experiments were conducted in wild blueberry fields located at Portapique and Parrsboro in Nova Scotia, Canada. Experimental trials were established on November 3, 2015 at Portapique and November 4, 2015 at Parrsboro. This experiment was a randomized complete block design with four blocks at each site. It was a 2 X 2 X 2 factorial arrangement of fall glufosinate application (yes, no), spring glufosinate application (yes, no), and spring foramsulfuron application (yes, no). Glufosinate and foramsulfuron were applied at a rate of 750 and 35 g a.i. ha^{-1}, respectively. Foramsulfuron was applied with a liquid nitrogen fertilizer (28 % UAN) at a rate of 2.5 L ha^{-1}. Plot size was 2 m X 6 m with a 1-m-wide unsprayed strip between each block at all sites. Glufosinate was applied pre-emergence to the wild blueberry, and foramsulfuron was applied post-emergence to the wild blueberry. The detailed herbicide application timings and the weather condition at application of each trial are shown in Table 3-6. Herbicides were applied using a CO_2 pressurized research plot sprayer outfitted with four 11002 XR nozzles and calibrated to deliver a water volume of 200 L ha^{-1} at 276 kPa.

Table 3-6. Herbicide application dates and related weather conditions in each trial for Experiment 4 - effect of fall and spring glufosinate ammonium application on foramsulfuron efficacy on hair fescue

Site	Application timing	Date of spraying	Temp. (°C)	Humidity (%)	Wind speed (km*h^{-1})
Portapique	ABY	10-Nov-2015	-1.0	60.0	1.0
	SNBY	10-May-2016	7.2	65.0	2.6
Parrsboro	ABY	11-Nov-2015	13.9	55.0	2.5
	SNBY	13-Nov-2016	9.7	37.8	6.7

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-bearing Year 2016.

Data collection included 1) damage ratings of blueberry and hair fescue, 2) grass density prior to treatment applications, in late summer of the year of herbicide applications and in mid Summer of the bearing year, 3) grass inflorescence number and height following treatment applications, 4) hair fescue seed production in late fall of non-bearing year, 5) hair fescue seedling density in the early summer of the crop year, 6) wild blueberry stem density, stem height, and flower bud number per stem at the end of non-bearing year, and 7) wild blueberry yield in the bearing year. Damage rating was conducted for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 1.5 months after Spring Non-Bearing Year (SNBY) herbicide application. Tuft densities were determined in two 1 m X 1 m quadrats per plot. Inflorescence number and height of hair fescue were counted and measured in fields by randomly selecting 10 grasses per plot. Seed production was determined by collecting all inflorescence heads from 5 randomly selected plants in each plot. Hair fescue seedling densities were counted in fields in three 30 cm X 30 cm quadrats per plot. Initial fescue tuft densities in the non-bearing year were determined on April 27, 2016 at Parrsboro, and April 27, 2016 at Portapique. Hair fescue flowering and total tuft densities in the non-bearing year were determined on June 28, 2016 at Parrsboro and June 27, 2016 at Portapique. Hair fescue grass inflorescence number and height in the no-bearing year were determined on July 11, 2016 at Parrsboro, and July 8, 2016 at Portapique. Hair fescue grass inflorescence heads were collected for seed production counting on October 8, 2016 at Parrsboro and October 20, 2016 at Portapique. Hair fescue seedling densities in bearing year were determined on May 29, 2017 at Parrsboro and May 24, 2017 at Portapique. Hair fescue grass flowering and total tuft densities in the bearing year were determined on July 10, 2017 at Parrsboro, and June 29, 2017 Portapique. Blueberry shoot counts were conducted in fields in two 30 cm X 30 cm quadrats per plot at the end of the field season in the non-bearing year. In each plot, 30 randomly selected blueberry stems were clipped at the ground level, bagged in the field, and brought back to the lab in late fall. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Wild blueberry yield was determined in two 1 m X 1 m quadrats per plot and wild blueberry fruit was harvested using hand rakes in mid-August of the bearing year. Blueberry stem density counts and blueberry stem collations were completed on October 5, 2016 at Stewiacke and on October 20, 2016 at Portapique. Blueberry yields were determined on August 14, 2017 at Parrsboro and August 02, 2017 at Portapique.

Statistical Analysis

For all data in each experiment, firstly, tests of main and interactive effects of treatments and experimental sites were conducted to determine whether data could be combined across sites. When data conformed to the assumptions for ANOVA and the interaction effect of sites by treatments were not significant after analysis, these data were pooled across experimental sites for further analysis. Otherwise, data were analyzed separately by sites. Damage rating data for wild blueberry and target species were analyzed in PROC NPAR1WAY in SAS system for Windows (Statistical Analysis System, Version 9.2, SAS Institute, Cary, NC). Objective data were analyzed using analysis of variance (ANOVA) in PROC MIXED in SAS for Windows. In the Mixed Model, treatments were used as fixed effects, while blocks within each trial were considered as random effects. The assumption of constant variance was tested to ensure that residuals had constant variance with a normal distribution. Some data were transformed to achieve normality and constant variance, and transformations are indicated as needed in tables and figures. Significant differences among treatments were determined using Tukey's multiple means comparison test at a probability level of $P < 0.05$.

Results and Discussion

Experiment 1 - Development of a use pattern for foramsulfuron and glufosinate ammonium on hair fescues. Visual injury rating, blueberry stem height, flower bud number per stem, and blueberry stem density data did not conform to the assumptions for analysis of variance in the combined data set. Therefore, these blueberry response variables were analyzed separately by sites. Compared to the untreated control, no treatments increased visual injury rating of blueberry plants by 45 days after herbicide application in non-bearing year at all sites ($p \geq 0.0598$), and the average visual injury rating was less than 1.3 ± 0.6 for the crop at all sites. There were no significant treatment effects on blueberry stem height, flower bud number per stem, and blueberry stem density at all tested sites. Blueberry stem height averaged 16.3 ± 0.3 cm at Stewiacke, 18.3 ± 0.3 cm at Parrsboro, and 14.2 ± 0.18 cm at Portapique. Blueberry flower bud number per stem averaged 4 ± 0.2 bud stem^{-1} at Stewiacke, 8 ± 0.3 bud stem^{-1} at Parrsboro, and 7 ± 0.3 bud stem^{-1} at Portapique. Blueberry stem density averaged 313 ± 14 stems m^{-2} at Stewiacke, 519 ± 11 stems m^{-2} at Parrsboro, and 233 ± 12 stems m^{-2} at Portapique. The results indicated that tested herbicide use patterns were safe for wild blueberry plants and did not affect the blueberry yield potential.

There was no significant site by treatment interaction effect on blueberry yield ($p = 0.2580$), and blueberry yield data were combined across sites. There was a significant treatment effect on blueberry yield ($p < 0.0001$) (Table 3-7). Although the fall bearing year propyzamide application increased blueberry yield by 82%, the difference was not significant relative to the untreated control (Table 3-7). Fall bearing year applications of propyzamide followed by fall non-bearing year applications of propyzamide doubled the blueberry yield when compared to the untreated control (Table 3-7). Spring non-bearing year terbacil, foramsulfuron, or terbacil fb foramsulfuron increased blueberry yield (24.2 to 66.1%), though increases were not as high as those following propyzamide applications. Plots that were treated with terbacil + glufosinate fb foramsulfuron in the spring of the non-bearing year propyzamide in fall of the non-bearing year had the highest blueberry yield, with a greater than 100% yield increase within these plots. However, plots that were treated with hexazinone, and hexazinone + foramsulfuron and hexazinone + nicosulfuron + rimsulfuron fb foramsulfuron in non-bearing year had the lowest blueberry yields, with only 10% yield increase in these treatments.

Table 3-7. Effects of herbicide combinations for foramsulfuron and glufosinate in Experiment-1 on blueberry yield at Portapique, Parrsboro and Stewiacke, Nova Scotia, in 2016-2017.

Herbicide treatment	Application timing[b]	Blueberry yield ($kg\ ha^{-1}$)
Nontreated control	-	1907.7 ± 285.7c
Propyzamide	ABY	3484.6 ± 339.0abc
Propyzamide fb[c] Propyzamide	ABY fb ANBY	3938.5 ± 398.8ab
Terbacil	SNBY	2369.2 ± 407.4bc
Foramsulfuron	SNBY	3053.9 ± 462.2abc
Terbacil fb Foramsulfuron	SNBY fb SNBY	3169.2 ± 347.4abc
Terbacil fb Propyzamide	SNBY fb ANBY	2884.6 ± 220.4abc
Foramsulfuron fb Propyzamide	SNBY fb ANBY	2415.4 ± 294.8bc
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	3553.9 ± 362.8abc
Terbacil + Glufosinate	SNBY + SNBY	2503.9 ± 371.7bc
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	2469.2 ± 351.3bc
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	2415.4 ± 269.1bc
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	4353.9 ± 548.5a
Hexazinone fb Foramsulfuron	SNBY fb SNBY	2100.0 ± 401.0c
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	2169.2 ± 274.7c

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1SE.

[b] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016

[c] fb, followed by

Effect on hair fescue in the non-bearing year. Initial grass tuft densities in Stewiacke, Parrsboro, and Portapique were 32 ± 10, 43 ± 11, and 18 ± 7 tufts m^{-2}, respectively. Hair fescue response data in the combined data set did not conform to assumptions for ANOVA, so data were analyzed separately for each site. Generally, trends of these response variables were similar across three sites. Compared to the untreated control, all treatments significantly increased hair fescue visual injury at each site ($p < 0.0001$) (Figure 3-2). Hair fescue that was treated with propyzamide and with more than one herbicide generally had a higher visual damage level, compared to hair fescues that were only treated with a single herbicide. Even though all treatments visually damaged hair fescue 45 days after herbicide application, recovery of hair fescue differed by treatments.

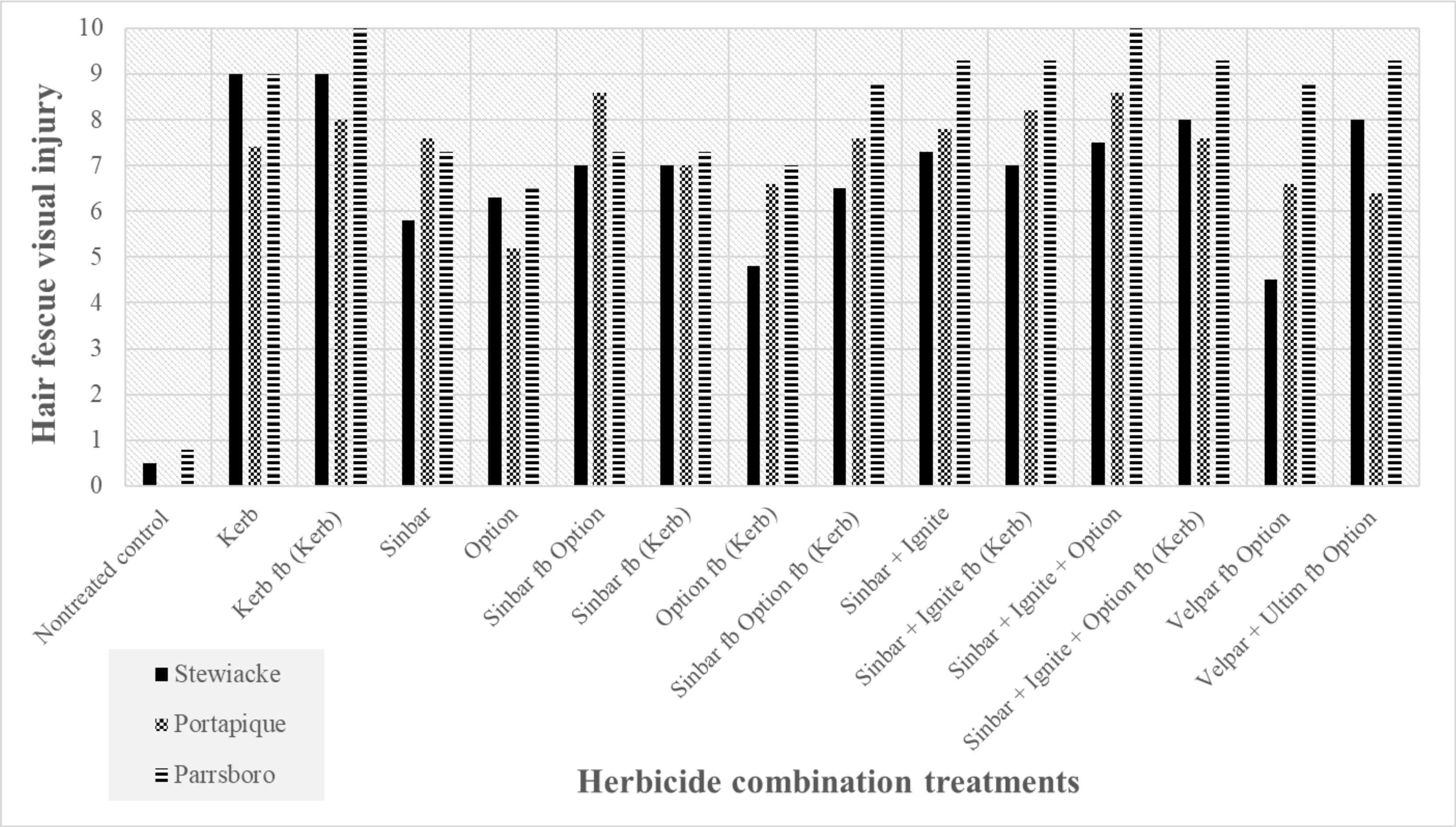

Figure 3-2. Herbicide visual injury rating of hair fescue treated with related herbicides at 45 days after application in the experiment (Evaluation of herbicide combinations for foramsulfuron and glufosinate on hair fescue control in wild blueberry) at Stewiacke, Parrsboro, and Portapique in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death. Kerb, when presented in parentheses, did not affect the visual injury rating in the figure, as treatments were not applied prior to collection of visual injury rating data provided.

There was a significant treatment effect on hair fescue total tuft density and flowering tuft density at all sites ($P \leq 0.0006$; Tables 3-8, 3-9, and 3-10). Autumn bearing year propyzamide applications most effectively reduced non-bearing year fescue total tuft density and flowering tuft density (Table 3-8, 3-9, and 3-10), reducing total tuft density by over 80% and completely eliminating flowering tufts. Terbacil and foramsulfuron, applied alone or sequentially, had variable effects on both total tuft and flowering tuft density across sites (Table 3-8, 3-9, and 3-10). Foramsulfuron did not reduce total tuft density at any sites, but did significantly reduced flowering tuft density at Stewiacke and Portapique (Table 3-8, 3-9, and 3-10). Terbacil significantly decreased flowering tuft density at Stewiacke and Portapique, but not at Parrsboro (Table 3-8, 3-9, and 3-10). Efficacy of terbacil and foramsulfuron applied sequentially was similar to when these herbicides were applied alone. Terbacil applied in tank mixture followed by foramsulfuron gave the most consistent reductions in flowering tuft density at Portapique and Parrsboro, outside of the propyzamide treatments (Table 3-8, 3-9, and 3-10). However, at Stewiacke, terbacil + glufosinate fb foramsulfuron was not consistently effective in reducing hair fescue total tuft density and flowering tuft density, indicating that hair fescue at this site was more tolerant to this herbicide use pattern. The hexazinone + foramsulfuron tank mixture was relatively ineffective on hair fescue at each site, though the mixture of hexazinone + nicosulfuron + rimsulfuron fb foramsulfuron reduced flowering tuft density at Stewiacke and Portapique (Table 3-8, 3-9, and 3-10).

Table 3-8. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, inflorescence number and inflorescence height in non-bearing year at Stewiacke, NS, Canada.

Herbicide treatment	Application timing[a]	Total tuft Density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})	Inflorescence height (cm)	Inflorescence number (# $tuft^{-1}$)
Nontreated control	-	31.3 ± 1.6a	24.9 ± 3.4a	33.2 ± 2.3a	25.9 ± 5.4a
Propyzamide	ABY	6.0 ± 4.0c	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Propyzamide fb[d] Propyzamide	ABY fb ANBY	5.5 ± 2.0c	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Terbacil	SNBY	22.4 ± 2.6abc	10.6 ± 3.0b	20.9 ± 0.4b	10.7 ± 1.0cd
Foramsulfuron	SNBY	22.9 ± 4.5abc	8.1 ± 2.2b	19.3 ± 0.7b	11.1 ± 1.8bcd
Terbacil fb Foramsulfuron	SNBY fb SNBY	16.8 ± 3.7abc	7.6 ± 3.3b	12.6 ± 0.7c	11.5 ± 2.6bcd
Terbacil fb Propyzamide	SNBY fb ANBY	14.1 ± 5.4abc	7.8 ± 4.2b	24.3 ± 3.1b	8.6 ± 0.8bcd
Foramsulfuron fb Propyzamide	SNBY fb ANBY	30.6 ± 0.5a	12.9 ± 2.0ab	23.2 ± 1.7b	12.4 ± 1.0bcd
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	17.1 ± 4.5abc	7.5 ± 3.1b	13.5 ± 1.0c	16.1 ± 2.6abc
Terbacil + Glufosinate	SNBY + SNBY	15.9 ± 3.5abc	5.6 ± 2.5b	19.1 ± 0.3b	5.2 ± 1.3d
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	15.5 ± 2.6abc	3.5 ± 0.5b	22.6 ± 1.2b	5.6 ± 0.9cd
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	18.3 ± 4.5abc	5.5 ± 4.5b	13.4 ± 0.9c	6.6 ± 0.2cd
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	12.3 ± 3.3bc	0.8 ± 0.3b	9.5 ± 3.2c	4.5 ± 1.8d
Hexazinone fb Foramsulfuron	SNBY fb SNBY	28.3 ± 3.1ab	14.1 ± 2.6ab	13.0 ± 0.2ab	17.9 ± 0.9ab
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	19.5 ± 3.1abc	4.9 ± 1.7b	11.6 ± 0.5c	12.5 ± 1.3bce

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016.

[b] Propyzamide that were presented in the parenthesis did not affect results in the table as they were applied in the late autumn of the non-bearing year, while the first-year fescue data was collected in the late summer of the non-bearing year.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE. Flowering tuft density, inflorescence height, and inflorescence number in propyzamide treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

[d] fb, followed by

Table 3-9. Effect of herbicide treatments on fescue grass total tuft density, flowering tuft density, inflorescence number and inflorescence height in non-bearing year at Parrsboro, NS, Canada. Flowering tuft density and inflorescence height was log(x) transformed. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Herbicide treatment	Application timing [a]	Total tuft density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})	Inflorescence height (cm)	Inflorescence number (# $tuft^{-1}$)
Nontreated control	-	22.4 ± 2.2a	2.5 ± 0.4 (13.1)ab	3.3 ± 0.1(26.5)a	6.3 ± 1.5ab
Propyzamide	ABY	1.0 ± 0.4c	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Propyzamide fb Propyzamide	ABY fb ANBY	1.0 ± 1.0c	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Terbacil	SNBY	22.0 ± 2.7a	2.6 ± 0.4(14.8)a	3.1 ± 0.1(22.3)ab	4.1 ± 1.2ab
Foramsulfuron	SNBY	13.4 ± 4.9abc	1.5 ± 0.4 (8.1)abc	3.0 ± 0.1(19.8)ab	5.8 ± 1.7ab
Terbacil fb Foramsulfuron	SNBY fb SNBY	15.4 ± 2.0abc	1.8 ± 0.4 (6.8)ab	2.9 ± 0.1(17.5)ab	6.3 ± 1.8ab
Terbacil fb Propyzamide	SNBY fb ANBY	20.6 ± 5.1a	2.9 ± 0.4 (13.5)a	3.2 ± 0.1(25.9)a	8.8 ± 2.8a
Foramsulfuron fb Propyzamide	SNBY fb ANBY	13.9 ± 2.5abc	0.8 ± 0.4 (3.3)bc	3.0 ± 0.1(20.7)ab	3.5 ± 1.0ab
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	15.0 ± 3.5abc	1.8 ± 0.4 (7.1)abc	2.8 ± 0.1(16.5)b	7.6 ± 0.7ab
Terbacil + Glufosinate	SNBY + SNBY	9.3 ± 2.4abc	0.3 ± 0.5 (0.4)c	3.1 ± 0.1(16.4)ab	0.8 ± 0.3b
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	10.4 ± 3.7abc	0.9 ± 0.5 (1.3)abc	3.0 ± 0.1(14.8) ab	1.2 ± 0.5b
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	3.8 ± 1.9bc	0.0 ± 0.0	2.9 ± 0.2(4.4)ab	1.0 ± 1.0b
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	4.9 ± 1.7bc	0.0 ± 0.0	2.4 ± 0.2(2.8)b	0.8 ± 0.8b
Hexazinone fb Foramsulfuron	SNBY fb SNBY	16.5 ±2.8ab	1.6 ± 0.4 (5.5)abc	2.9 ± 0.1(18.8)ab	4.3 ± 1.0ab
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	16.8 ± 1.5ab	2.4 ± 0.4 (8.3) ab	2.8 ± 0.1(16.5)b	7.1 ± 2.1ab

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016.

[b] Propyzamide that were presented in the parenthesis did not affect results in the table as they were applied in the late autumn of the non-bearing year, while the first-year fescue data was collected in the late summer of the non-bearing year.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE. Flowering tuft density, inflorescence height, and inflorescence number in propyzamide treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

[d] fb, followed by

Table 3-10. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, inflorescence number and inflorescence height in non-bearing year at Portapique, NS, Canada. Flowering tuft density in Parrsboro was log(x) transformed and flowering tuft density in Portapique was square root transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Herbicide treatment	Application timing [a]	Total tuft density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})	Inflorescence height (cm)	Inflorescence number (# tuft^{-1})
Nontreated control	-	3.7 ± 0.2 (44.8)a	4.7 ± 0.3 (23.0)a	38.5 ± 2.8a	3.4 ± 0.2 (30.7)a
Propyzamide	ABY	1.4 ± 0.2 (4.1)d	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Propyzamide fb Propyzamide	ABY fb ANBY	1.9 ± 0.2 (7.9)cd	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Terbacil	SNBY	2.6 ± 0.2 (13.7)bc	3.1 ± 0.3 (10.0)b	25.2 ± 0.7abc	2.9 ± 0.2 (18.4)a
Foramsulfuron	SNBY	2.8 ± 0.2 (18.3)abc	2.7 ± 0.3 (7.9)b	27.8 ± 0.8ab	2.7 ± 0.2 (16.4)a
Terbacil fb Foramsulfuron	SNBY fb SNBY	2.5 ± 0.2 (12.0)bcd	2.7 ± 0.3 (7.5)b	23.0 ± 0.9abc	2.9 ± 0.2 (20.2)a
Terbacil fb Propyzamide	SNBY fb ANBY	2.3 ± 0.2 (10.5)bcd	3.0 ± 0.3 (9.1)b	24.2 ± 1.6abc	2.5 ± 0.2 (12.3)a
Foramsulfuron fb Propyzamide	SNBY fb ANBY	3.2 ± 0.2 (29.4)ab	3.3 ± 0.3 (11.5)ab	27.4 ± 0.9ab	2.8 ± 0.2 (16.5)a
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	2.0 ± 0.2 (8.4)cd	2.1 ± 0.3 (5.1)bc	18.5 ± 1.0bc	2.5 ± 0.2 (12.7)a
Terbacil + Glufosinate	SNBY + SNBY	1.8 ± 0.2 (6.9)cd	0.8 ± 0.3 (1.7)c	6.8 ± 6.8c	1.3 ± 0.4 (2.0)abc
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	2.1 ± 0.2 (8.9)cd	0.8 ± 0.3 (1.2)c	9.0 ± 5.6bc	1.1 ± 0.3 (1.2)bcd
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	1.9 ± 0.2 (7.9)cd	0.7 ± 0.3 (0.9)c	7.3 ± 4.5c	1.0 ± 0.3 (1.8)cd
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	1.9 ± 0.2 (7.3)cd	0.7 ± 0.3 (0.8)c	7.6 ± 3.6c	0.0 ± 0.4 (0.2)d
Hexazinone fb Foramsulfuron	SNBY fb SNBY	3.3 ± 0.2 (28.1)ab	3.4 ± 0.3 (11.8)ab	15.4 ± 1.9abc	2.7 ± 0.2 (15.4)a
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	2.5 ± 0.2 (12.1)bcd	2.6 ± 0.3 (7.5)b	7.9 ± 3.4bc	2.6 ± 0.3 (7.9)ab

[a] ABY, Autumn Bearing year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016.

[b] Propyzamide that were presented in the parenthesis did not affect results in the table as they were applied in the late autumn of the non-bearing year, while the first-year fescue data was collected in the late summer of the non-bearing year.

[c] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE. Flowering tuft density, inflorescence height, and inflorescence number in propyzamide treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

[d] fb, followed by

There was a significant treatment effect on fescue inflorescence height and inflorescence number ($p \leq 0.0008$; Table 3-8, 3-9, and 3-10), and trends were generally similar to what were observed with total and flowering hair fescue tuft density. Flowering tuft inflorescence height and number from the propyzamide treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality. Similar to flowering tuft density, inflorescence number and height were reduced to 0 in the propyzamide treatments (Table 3-8, 3-9, and 3-10). Terbacil, foramsulfuron, or terbacil followed by foramsulfuron significantly reduced flowering tuft inflorescence height or inflorescence number in the non-bearing year at Stewiacke, but not at Parrsboro and Portapique. However, the tank mixture of terbacil + glufosinate consistently reduce flowering tuft inflorescence number relative to terbacil applied alone at all sites, with over 50% reduction in inflorescence number. The results again indicated the potential role of this burndown herbicide in increasing the efficacy of terbacil. A previous research showed a lower fescue seed production when application of glufosinate was followed by foramsulfuron (White and Kumar 2017). Therefore, application of glufosinate prior to systemic herbicides, such as foramsulfuron and terbacil, could be helpful in the management of fescue grass in wild blueberry fields. Foramsulfuron applications following terbacil + glufosinate did not significantly reduce inflorescence height and number across sites relative to terbacil + glufosinate alone, except for height at Stewiacke (Table 3-8, 3-9, and 3-10). Hexazinone, or hexazinone followed by foramsulfuron was consistently ineffective on hair fescue across sites, though the mixture of hexazinone + nicosulfuron + rimsulfuron followed by foramsulfuron reduced inflorescence height at Stewiacke and Portapique (Table 3-8, 3-9, and 3-10).

Effect on hair fescue in the bearing year. There was significant treatment effect on hair fescue total tuft density and flowering tuft density in the bearing year at all sites (Table 3-11, 3-12 and 3-13). Hair fescue recovered from non-bearing year herbicide injury in the plots where only spring non-bearing year herbicides were applied. Autumn application of propyzamide in the non-bearing year significantly reduced flowering tuft density to 0 in the bearing year, regardless of what herbicides were applied previously. Autumn application of propyzamide in the non-bearing year dramatically lowered the difficulty of harvesting fescue-infested blueberry fields, and increased blueberry yield (Table 3-7). Even though non-bearing year herbicides did not affect the efficacy of propyzamide in the bearing year at Stewiacke and Parrsboro, they did affect blueberry yield. Autumn non-bearing year propyzamide significantly increased blueberry yield when used in combination with terbacil + glufosinate fb foramsulfuron in spring of the non-bearing year, which had an over 80% yield increase relative to terbacil + glufosinate fb foramsulfuron applied alone and an over 100% yield increase relative to the untreated control (Table 3-7). However, combinations of other spring non-bearing year herbicides and autumn non-bearing year propyzamide applications did not increase blueberry yield, compared to the fall non-bearing year propyzamide applied alone (Table 3-7). It indicated that application of foramsulfuron and terbacil applied alone or in sequence in spring non-bearing year should be avoided if autumn non-bearing year propyzamide applications would be applied. The bearing year data results suggested that except for autumn propyzamide application, efficacy of herbicides evaluated in the non-bearing year could last for no more than one year, and did not provide consistent hair fescue control in the bearing year. Therefore, autumn non-bearing year herbicide applications are essential for managing bearing year hair fescue, and further studies are needed to determine the optimum fall non-bearing year hair fescue management strategies to reduce reliance on propyzamide.

Table 3-11. Effect of herbicide applications on hair fescue total tuft density and flowering tuft density in bearing year at Stewiacke, NS, Canada.

Herbicide treatment	Application timing [a]	Total tuft density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})
Nontreated control	-	20.3 ± 0.5a	13.6 ± 0.3a
Propyzamide	ABY	4.0 ± 2.9d	2.3 ± 2.1b
Propyzamide fb Propyzamide	ABY fb ANBY	3.6 ± 1.3d	0.0 ± 0.0
Terbacil	SNBY	19.0 ± 2.3a	13.8 ± 1.9a
Foramsulfuron	SNBY	17.5 ± 2.7a	12.3 ± 2.7a
Terbacil fb Foramsulfuron	SNBY fb SNBY	15.4 ± 1.9abc	9.8 ± 1.5ab
Terbacil fb Propyzamide	SNBY fb ANBY	4.4 ± 0.4d	0.0 ± 0.0
Foramsulfuron fb Propyzamide	SNBY fb ANBY	6.1 ± 2.0bcd	0.0 ± 0.0
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	5.4 ± 1.1cd	0.0 ± 0.0
Terbacil + Glufosinate	SNBY + SNBY	15.6 ± 2.2ab	9.5 ± 1.5ab
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	5.4 ± 1.5cd	0.0 ± 0.0
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	17.6 ± 0.6a	12.4 ± 1.1a
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	3.3 ± 2.0d	0.0 ± 0.0
Hexazinone fb Foramsulfuron	SNBY fb SNBY	19.5 ± 0.8a	13.0 ± 0.2a
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	19.0 ± 3.9a	11.5 ± 3.0a

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016.

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE. Flowering tuft density in some treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

[c] fb, followed by

Table 3-12. Effect of herbicide applications on hair fescue total tuft density and flowering tuft density in bearing year at Parrsboro, NS, Canada.

Herbicide treatment	Application timing [a]	Total tuft density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})
Nontreated control	-	24.8 ± 1.4a	18.9 ± 1.3a
Propyzamide	ABY	11.3 ± 1.4bc	4.3 ± 1.3ab
Propyzamide fb Propyzamide	ABY fb ANBY	0.5 ± 0.4c	0.0 ± 0.0
Terbacil	SNBY	24.5 ± 2.8a	18.9 ± 2.5a
Foramsulfuron	SNBY	24.5 ± 3.9a	17.0 ± 3.1a
Terbacil fb Foramsulfuron	SNBY fb SNBY	25.0 ± 1.5a	18.8 ± 1.3a
Terbacil fb Propyzamide	SNBY fb ANBY	7.0 ± 2.5bc	0.0 ± 0.0
Foramsulfuron fb Propyzamide	SNBY fb ANBY	5.0 ± 1.2bc	0.0 ± 0.0
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	6.1 ± 2.2bc	0.0 ± 0.0
Terbacil + Glufosinate	SNBY + SNBY	22.8 ± 3.0a	15.3 ± 1.8ab
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	4.5 ± 1.8bc	0.0 ± 0.0
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	14.6 ± 2.7ab	8.8 ± 3.4ab
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	2.5 ± 1.1c	0.0 ± 0.0
Hexazinone fb Foramsulfuron	SNBY fb SNBY	22.5 ± 3.1a	14.9 ± 3.1ab
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	24.8 ± 1.1a	18.5 ± 2.6a

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016.

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE. Flowering tuft density in some treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

[c] fb, followed by

Table 3-13. Effect of treatment applications on hair fescue total tuft density and flowering tuft density in bearing year at Portapique, NS, Canada. Total tuft density was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Herbicide treatment	Application timing [a]	Total tuft density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})
Nontreated control	-	3.4 ± 0.3(31.9)a	22.7 ± 1.8 a
Propyzamide	ABY	0.9 ± 0.3(3.2)cde	1.8 ± 0.9c
Propyzamide fb Propyzamide	ABY fb ANBY	0.7 ± 0.7(0.1)e	0.0 ± 0.0
Terbacil	SNBY	2.9 ± 0.3(19.1)a	15.4 ± 2.7ab
Foramsulfuron	SNBY	2.9 ± 0.3(20.6)a	14.5 ± 1.8ab
Terbacil fb Foramsulfuron	SNBY fb SNBY	2.6 ± 0.3(15.1)ab	11.4 ± 2.6bc
Terbacil fb Propyzamide	SNBY fb ANBY	0.0 ± 0.3(1.3)e	0.0 ± 0.0
Foramsulfuron fb Propyzamide	SNBY fb ANBY	2.1 ± 0.3(9.4)abcd	0.0 ± 0.0
Terbacil fb Foramsulfuron fb Propyzamide	SNBY fb SNBY fb ANBY	0.4 ± 0.3(1.8)e	0.0 ± 0.0
Terbacil + Glufosinate	SNBY + SNBY	2.9 ± 0.3 (11.0)abcd	9.0 ± 2.7bc
Terbacil + Glufosinate fb Propyzamide	SNBY + SNBY fb ANBY	1.0 ± 0.3 (3.6)bcde	0.0 ± 0.0
Terbacil + Glufosinate fb Foramsulfuron	SNBY + SNBY fb SNBY	2.5 ± 0.3 (13.4)abc	9.7 ± 2.3bc
Terbacil + Glufosinate fb Foramsulfuron fb Propyzamide	SNBY + SNBY fb SNBY fb ANBY	0.5 ± 0.4 (1.5)de	0.0 ± 0.0
Hexazinone fb Foramsulfuron	SNBY fb SNBY	3.2 ± 0.3 (26.7)a	18.5 ± 2.8ab
Hexazinone + Nicosulfuron + Rimsulfuron fb Foramsulfuron	SNBY + SNBY + SNBY fb SNBY	3.0 ± 0.3 (20.6)a	15.5 ± 1.5ab

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016; ANBY, Autumn Non-Bearing Year 2016.

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± SE. Flowering tuft density in some treatments were not included in the ANOVA analysis due to the influence of the zero values on assumptions of constant variance and normality.

[c] fb, followed by

In conclusion, fall application of propyzamide was the most effective in controlling hair fescue in wild blueberry fields, while hexazinone-related herbicide combinations were consistently the least effective. Terbacil and foramsulfuron efficacy in the sprout year varied, though efficacy of terbacil was improved when tank mixed with glufosinate. Application of the glufosinate and terbacil tank mixture, followed by foramsulfuron, had similar efficacy to propyzamide in the non-bearing year, and it could be an alternative treatment to propyzamide to suppress hair fescue in the non-bearing year. Significant recovery of hair fescue occurred in the bearing year in all treatments lacking a fall non-bearing year propyzamide application, and additional research should be conducted to identify additional treatments for fall sprout year perennial grass management in wild blueberry.

Experiment 2 - Use of fall bearing year propyzamide to improve non-bearing year hair fescue management. Site-combined visual injury rating data did not conform to the assumptions for analysis of variance, so the visual injury rating data were analyzed separately by sites. No treatments increased visual injury rating of blueberry plants by 45 days after spring sprout year herbicide application at both Stewiacke ($p = 0.3172$) and Parrsboro ($p = 0.5909$). In the tests of main and interactive effects of treatments and experimental site on blueberry potential yield, there were no significant experimental site by treatment interaction effects on blueberry flower bud number per stem ($p = 0.2825$), blueberry stem height ($p = 0.3419$), and blueberry stem density ($p = 0.5144$) (Table 3-14). These data were therefore combined across sites for further analysis. There was no significant effect of treatment on blueberry flower bud per stem ($p = 0.4724$) and blueberry stem height ($p = 0.6222$), which averaged 7.0 ± 2.4 buds stem^{-1} and 17.4 ± 2.4 cm, respectively. There was a significant effect of treatments on blueberry stem density ($p = 0.0109$) (Table 3-15). Compared to the untreated control plots, plots that were treated with fall propyzamide followed by spring herbicides all had higher blueberry stem density, with the increasing stem density ranging from 29.8% to 55.4%. Plots that were treated with autumn propyzamide application followed by spring foramsulfuron had the highest blueberry stem density (Table 3-15). The results indicated that combinations of autumn propyzamide application and non-bearing year herbicide application were safe for the wild blueberry plants, and it increased blueberry stem density in the following year. Compared to untreated control, no treatments significantly increased yield at Stewiacke (Table 3-16). However, at Parrsboro, the treatment of autumn propyzamide followed by the terbacil and glufosinate tank mixture significantly increased blueberry yield by over 178% (Table 3-16). However, there was no clear trend in the optimum combination of fall propyzamide application and sprout year herbicide applications in increasing blueberry final yield (Table 3-16).

Table 3-14. Tests of main and interactive effects of treatment and experimental site on blueberry potential and yield at Stewiacke and Parrsboro in Nova Scotia, in 2016-2017. Log(x) transformation was applied to blueberry flower buds to ensure that residuals have constant variance, with a normal distribution.

Effects	Blueberry stem density (stems m^{-2})	Blueberry stem height (cm)	Blueberry flower buds (# $stem^{-1}$)	Blueberry yield (kg ha^{-1})
Experimental site	NS	***	***	***
Treatment	NS	NS	NS	**
Experimental site by treatment	NS	NS	NS	*

[a] *P < 0.05, **P < 0.01, ***P < 0.001 level of significant obtained with PROC MIXED in SAS
[b] NS, no significant difference

Table 3-15. Wild blueberry stem density in early fall in the non-bearing year at Stewiacke and Parrsboro, Nova Scotia, in 2016-2017.

Herbicide treatment	Application timing [a]	Blueberry stem density (stems m^{-2})
Nontreated control	-	262.5 ± 36.2b
Propyzamide	ABY	340.7 ± 35.9ab
Propyzamide fb Terbacil	ABY fb SNBY	389.8 ± 28.9a
Propyzamide fb Foramsulfuron	ABY fb SNBY	407.9 ± 31.0a
Propyzamide fb Glufosinate	ABY fb SNBY	352.8 ± 39.1ab
Propyzamide fb Terbacil fb Foramsulfuron	ABY fb SNBY fb SNBY	356.9 ± 17.5ab
Propyzamide fb Terbacil + Glufosinate	ABY fb SNBY + SNBY	379.2 ± 29.5a
Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	ABY fb SNBY + SNBY fb SNBY	381.5 ± 28.6a

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

[c] fb, followed by

Table 3-16. Wild blueberry yield for Experiment 2 at Stewiacke and Portapique, Nova Scotia, in 2016-2017.

Site	Herbicide treatment	Application timing [a]	Blueberry yield (kg ha^{-1})
Stewiacke	Nontreated control	-	4325.0 ± 1103.3a
	Propyzamide	ABY	5125.0 ± 872.1a
	Propyzamide fb Terbacil	ABY fb SNBY	3850.0 ± 366.3a
	Propyzamide fb Foramsulfuron	ABY fb SNBY	5525.0 ± 883.5a
	Propyzamide fb Glufosinate	ABY fb SNBY	4525.0 ± 539.1a
	Propyzamide fb Terbacil fb Foramsulfuron	ABY fb SNBY fb SNBY	6750.0 ± 1482.4a
	Propyzamide fb Terbacil + Glufosinate	ABY fb SNBY + SNBY	4750 ± 800.5a
	Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	ABY fb SNBY + SNBY fb SNBY	4850.0 ± 1697.3a
Parrsboro	Nontreated control	-	1675.0 ± 404.9b
	Propyzamide	ABY	2800.0 ± 422.3ab
	Propyzamide fb Terbacil	ABY fb SNBY	2675.0 ± 915.0ab
	Propyzamide fb Foramsulfuron	ABY fb SNBY	3125.0 ± 552.8ab
	Propyzamide fb Glufosinate	ABY fb SNBY	3075.0 ± 576.4ab
	Propyzamide fb Terbacil fb Foramsulfuron	ABY fb SNBY fb SNBY	2125.0 ± 467.9ab
	Propyzamide fb Terbacil + Glufosinate	ABY fb SNBY + SNBY	4662.5 ± 807.6a
	Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	ABY fb SNBY + SNBY fb SNBY	2825.0 ± 471.5ab

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

[c] fb, followed by

Effect on hair fescue in the non-bearing year. Site-combined visual injury rating data and non-bearing year hair fescue grass data did not conform to the assumptions for analysis of variance, so these fescue response variables were analyzed separately by sites. Initial grass tuft densities in Parrsboro and Stewiacke were 53 ± 15 and 42 ± 10 tufts m^{-2}, respectively. Compared to the untreated control, all treatments significantly increased hair fescue visual injury ratings at both sites ($p < 0.0001$). Propyzamide effectively suppressed hair fescue, and there were no visual injury differences observed among grasses treated with different spring non-bearing year herbicides (Figure 3-3). All treatments reduced flowering tuft density to 0, regardless of whether fall bearing year propyzamide was followed by spring non-bearing year herbicide (Table 3-17). Since all treatments effectively suppressed flowering tufts density, total tuft density remained significantly lower in the plots that were treated with herbicides at both sites ($p = 0.0005$ and 0.0009 for Parrsboro and Stewiacke, respectively). These data indicated no additional benefits of spring non-bearing herbicide applications following fall bearing year propyzamide applications.

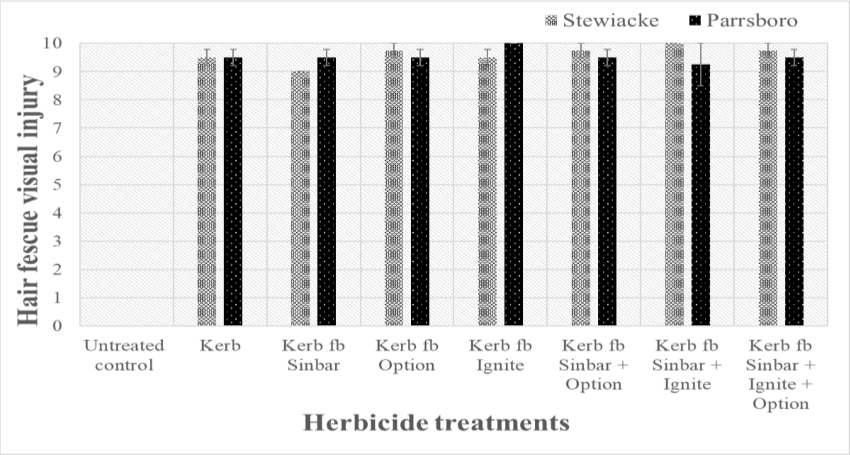

Figure 3-3. Herbicide visual injury rating of hair fescue treated with herbicides at 45 days after application in the experiment (use of fall bearing year propyzamide to improve non-bearing year fescue management) at Stewiacke and Parrsboro in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

Table 3-17. Effect of treatment applications on hair fescue total tuft density and flowering tuft density for Experiment 2 in non-bearing year at Stewiacke and Portapique, NS, Canada. Total tuft density in Parrsboro was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Site	Treatment	Application timing [a]	Total tuft density (tufts m^{-2})	Flowering tuft density (tufts m^{-2})
Parrsboro	Nontreated control		3.2 ± 0.3a (26.9)	19.1 ± 4.6
	Propyzamide	ABY	1.3 ± 0.3b (3.6)	0.0 ± 0.0
	Propyzamide fb Terbacil	ABY fb SNBY	0.7 ± 0.5b (1.2)	0.0 ± 0.0
	Propyzamide fb Foramsulfuron	ABY fb SNBY	0.1±0.4b (1.7)	0.0 ± 0.0
	Propyzamide fb Glufosinate	ABY fb SNBY	0.0±0.5b (0.5)	0.0 ± 0.0
	Propyzamide fb Terbacil fb Foramsulfuron	ABY fb SNBY fb SNBY	0.1± 0.6b (0.4)	0.0 ± 0.0
	Propyzamide fb Terbacil + Glufosinate	ABY fb SNBY + SNBY	0.0±0.4b (0.9)	0.0 ± 0.0
	Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	ABY fb SNBY + SNBY fb SNBY	0.8±0.5b (1.1)	0.0 ± 0.0
Stewiacke	Nontreated control	-	38.5 ± 1.8a	29.6 ± 1.6
	Propyzamide	ABY	12.6 ± 0.9b	0.0 ± 0.0
	Propyzamide fb Terbacil	ABY fb SNBY	12.0 ± 1.5b	0.0 ± 0.0
	Propyzamide fb Foramsulfuron	ABY fb SNBY	12.5 ± 1.5b	0.0 ± 0.0
	Propyzamide fb Glufosinate	ABY fb SNBY	9.0 ± 0.7b	0.0 ± 0.0
	Propyzamide fb Terbacil fb Foramsulfuron	ABY fb SNBY fb SNBY	9.8 ± 2.2b	0.0 ± 0.0
	Propyzamide fb Terbacil + Glufosinate	ABY fb SNBY + SNBY	10.0 ± 1.5b	0.0 ± 0.0
	Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	ABY fb SNBY + SNBY fb SNBY	10.6 ± 1.6b	0.0 ± 0.0

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

[c] fb, followed by

Effect of hair fescue in the bearing year. There was no significant experimental site by treatment effect on fescue grass flowering tuft density ($p = 0.0729$) and total tuft density ($p = 0.2411$) in the bearing year (Table 3-18). Data were therefore combined across sites for further analysis. There was a significant treatment effect on bearing year flowering tuft density ($p < 0.0001$). Flowering tuft densities in the plots that were treated with propyzamide, with or without non-bearing year herbicides, were significantly lower than the untreated control (Table 3-19). Since all treatments significantly reduced hair fescue flowering tuft density, total tuft density remained significantly lower in herbicide-treated plots in the bearing year ($p < 0.0001$) (Table 3-19). The bearing year results indicated that fall bearing year propyzamide applications reduce flowering tuft density in both the non-bearing and bearing years. However, hair fescue started to recover and grew inflorescence heads in the second year, which interfered with the harvesting process and potentially contribute to seed return to the seed bank. Fall propyzamide application followed by additional herbicide applications in the spring non-bearing year did not significantly improve the propyzamide efficacy on controlling fescue vegetative tuft density in the bearing year.

Table 3-18. Tests of main and interactive effects of treatment and experimental site for Experiment 2 on bearing year hair fescue response variables at Stewiacke and Parrsboro in Nova Scotia, in 2016-2017. Bearing year hair fescue flowering tuft density was Log(x) transformation for the analysis of variance.

Effects	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})
Experimental site	***	***
Treatment	***	***
Experimental site by treatment	NS	NS

[a] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ level of significant obtained with PROC MIXED in SAS

[b] NS, no significant difference

Table 3-19. Effect of Experiment 2 treatment applications on hair fescue total tuft density and flowering tuft density in the bearing year at Stewiacke and Portapique, NS, Canada. Flowering tuft density was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Treatment	Application Rate (g a.i. ha^{-1})	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})
Nontreated control	-	19.9 ± 1.3a	2.7 ± 0.3a (16.8)
Propyzamide	ABY	6.9 ± 1.3b	1.1 ± 0.4b (3.7)
Propyzamide fb Terbacil	ABY fb SNBY	5.5 ± 1.3b	0.7 ± 0.4b (3.1)
Propyzamide fb Foramsulfuron	ABY fb SNBY	2.6 ± 1.3b	0.0 ± 0.4b (0.8)
Propyzamide fb Glufosinate	ABY fb SNBY	5.6 ± 1.3b	0.4 ± 0.4b (1.6)
Propyzamide fb Terbacil fb Foramsulfuron	ABY fb SNBY fb SNBY	1.9 ± 1.3b	0.6 ± 0.6b (0.4)
Propyzamide fb Terbacil + Glufosinate	ABY fb SNBY + SNBY	3.1 ± 1.3b	0.0 ± 0.4b (0.6)
Propyzamide fb Terbacil + Glufosinate fb Foramsulfuron	ABY fb SNBY + SNBY fb SNBY	3.2 ± 1.3b	0.2 ± 0.4b (1.3)

[a] ABY, Autumn Bearing Year 2015; SNBY, Spring Non-Bearing Year 2016

[b] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

[c] fb, followed by

In conclusion, propyzamide was effective at controlling fescue grass and the efficacy could last for two years. However, it only suppressed fescue grass flowering tuft densities but did not continue to suppress the vegetative tufts. Fall bearing year propyzamide applications followed by spring non-bearing year applications of terbacil, glufosinate, or foramsulfuron, did not improve fescue control over that achieved with propyzamide alone, suggesting that growers applying propyzamide avoid use of other herbicides for additional fescue suppression.

Experiment 3 - Evaluation of fall bearing year herbicide application on non-bearing year foramsulfuron efficacy on hair fescue in wild blueberry fields. Site-combined visual injury rating data did not conform to the assumption for analysis of variance, and the data were analyzed separately by sites. Compared to the untreated control, no treatment significantly increased visual injury rating of blueberry plants by 45 days after herbicide application at both Stewiacke ($p = 0.7962$) and Portapique ($p = 0.6916$). There was no significant experimental site X fall bearing year herbicide X foramsulfuron interaction effect on blueberry stem density ($p = 0.9199$), stem height ($p = 0.9377$), and flower bud number per stem ($p = 0.6727$) (Table 2-20). Therefore, these blueberry response variables were combined across sites for further analysis. There were no significant effects of fall bearing year herbicide ($p = 0.3042$), foramsulfuron ($p = 0.0735$) and fall bearing year herbicide by foramsulfuron interaction ($p = 0.2914$) on blueberry stem height, flower bud number per stem, and stem density, which averaged 14.1 ± 6.1 cm, 5 ± 3 buds stem^{-1} and 346 ± 173 stems m^{-2}, respectively. Blueberry yield data were not collected at Portapique due to a large number of bare spots and uneven distribution of wild blueberry plants. Therefore, the wild blueberry yield data was only limited to Stewiacke. There were no significant effects of fall bearing year herbicide ($p = 0.3275$), foramsulfuron ($p = 0.7826$) and fall bearing year herbicide by foramsulfuron interaction ($p = 0.8795$) on blueberry yield at Stewiacke, with yield averaging 3230.0 ± 2062.3 Kg ha^{-1}. The results indicated that use of autumn bearing year herbicides with spring non-bearing year foramsulfuron applications did not increase wild blueberry yield potential and actual yield.

Table 3-20. Tests of main and interactive effects of fall bearing year herbicide, foramsulfuron, and experimental site on blueberry stem density, stem height, and flower bud number per stem for Experiment 3 at Stewiacke and Portapique in Nova Scotia, in 2016-2017.

Effects	Blueberry stem density (stems m^{-2})	Blueberry stem height (cm)	Blueberry flower buds (# $stem^{-1}$)
Experimental site	NS	***	NS
FBYH[a]	NS	NS	NS
Experimental site by FBYH	NS	NS	NS
Foramsulfuron	NS	NS	NS
Experimental site X foramsulfuron	NS	NS	NS
FBYH X foramsulfuron	NS	NS	NS
Experimental site X FBYH X foramsulfuron	NS	NS	NS

[a] FBYH, Fall Bearing Year Herbicides

[b] *P < 0.05, **P < 0.01, ***P < 0.001 level of significant obtained with PROC MIXED in SAS

[c] NS, no significant difference

Effect of hair fescue in the non-bearing year. After the testing for normality and constant variance, most of the site-combined fescue data did not conform to the assumption for analysis of variance. Therefore, all hair fescue response variables were analyzed separately by sites. The initial mean fescue tuft densities were 36 ± 12 and 37 ± 13 tufts m^{-2} at Stewiacke and Portapique, respectively. Compared to the untreated control, all treatments significantly increased fescue grass visual injury rate at both Stewiacke ($p < 0.0001$) and Portapique ($p < 0.0001$) (Figure 2-3). Generally, fescue grass that were treated with autumn bearing year herbicides followed by non-bearing year foramsulfuron had slightly higher visual injury ratings when compared to fescue grasses that were only treated with fall bearing year herbicides alone.

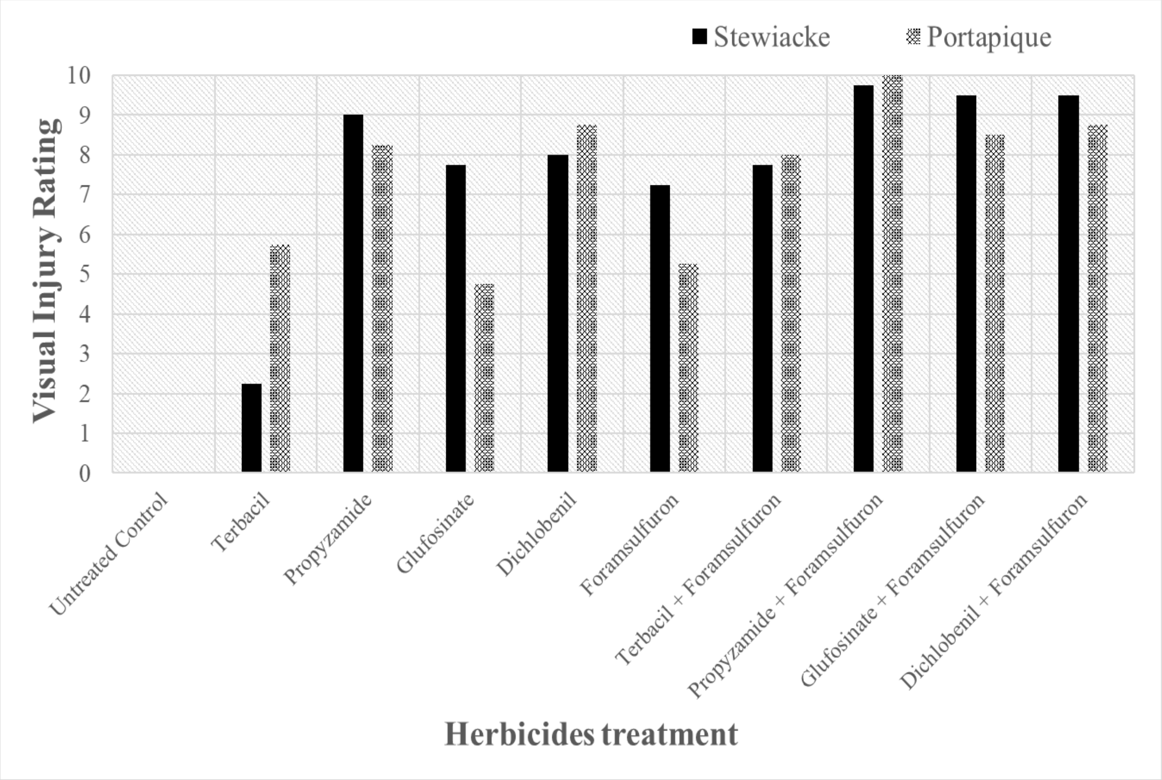

Figure 3-4. Herbicide visual injury rating of hair fescue treated with related herbicides at 45 days after option application at Stewiacke and Portapique in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death.

Effects of fall bearing year herbicides on the efficacy of spring non-bearing year foramsulfuron in controlling hair fescues density in the non-bearing year varied at two sites. In Stewiacke, there were significant effects of fall bearing year herbicide ($p < 0.0001$), foramsulfuron ($p < 0.0001$) and fall bearing year herbicide by foramsulfuron interaction ($p \leq 0.0143$) on hair fescue flowering tuft density and total tuft density in the non-bearing year. Terbacil applied alone in Stewiacke did not reduce fescue flowering tuft and total tuft density in the non-bearing year. However, sequential application of terbacil and foramsulfuron significantly reduced non-bearing year hair fescue flowering tuft density by 73.5% , compared to fall terbacil. Fall propyzamide treatments most effectively reduced hair fescue flowering tuft density in the non-bearing year (Table 3-21). Glufosinate or dichlobenil applied alone in fall of the bearing year both significantly reduced fescue flowering tuft density in non-bearing year at Stewiacke (Table 3-21). Also, hair fescue tuft density suppression was higher when glufosinate or dichlobenil were followed by spring foramsulfuron application, which both reduced hair fescue flowering tuft density by over 85% relative to untreated control (Table 3-21). In Portapique, there was a significant fall bearing year herbicide effect ($p < 0.0001$), but no significant fall bearing year herbicide by foramsulfuron interaction effect ($p \geq 0.9455$) on non-bearing year hair fescue flowering tuft and total tuft density. There was significant foramsulfuron effect on non-bearing year fescue flowering tuft density ($p = 0.0415$), but not on non-bearing year fescue grass total tuft density at Portapique ($p = 0.5301$). When fall bearing year herbicides were applied alone, propyzamide and dichlobenil were the only two treatments that significantly reduced non-bearing year fescue flowering tuft and total tuft density at Portapique (Table 3-22). Non-bearing year fescue tuft density suppression with foramsulfuron was consistently higher when applications were preceded by fall applications of terbacil (Table 3-22).

Table 3-21. Effect of fall bearing year herbicide applications on non-bearing year foramsulfuron efficacy on hair fescue flowering and total tuft density in both non-bearing year and bearing year in 2016-2017 at Stewiacke, NS, Canada.

			Non-bearing year		Bearing year	
Fall bearing year herbicides	Foramsulfuron	Application rate (g a.i ha^{-1})	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})
No	No	-	25.1 ± 2.4a	36.4 ± 1.9a	17.1 ± 1.2ab	22.0 ± 1.6a
No	Yes	35	9.6 ± 1.4b	24.6 ± 2.2ab	18.8 ± 1.6a	22.5 ± 1.3a
Terbacil	No	2000	26.8 ± 2.0a	35.1 ± 3.9a	19.5 ± 0.7a	25.5 ± 1.4a
Terbacil	Yes	2000 + 35	7.1 ± 2.1bc	22.6 ± 2.8bc	16.1 ± 1.2abc	22.6 ± 2.8a
Propyzamide	No	2240	0.0 ± 0.0c	6.4 ± 1.9d	3.8 ± 0.9de	10.1 ± 0.7bc
Propyzamide	Yes	2240 + 35	0.5 ± 0.5c	10.1 ± 2.5cd	0.6 ± 0.3e	2.5 ± 0.8c
Glufosinate	No	750	9.1 ± 1.4b	21.4 ± 1.6bc	15.8 ± 1.3abc	21.5 ± 1.3a
Glufosinate	Yes	750 + 35	3.5 ± 2.2bc	15.0 ± 2.1bcd	12.9 ± 0.7abc	19.8 ± 1.3a
Dichlobenil	No	1920	4.8 ± 2.4bc	15.6 ± 4.3bcd	9.6 ± 2.4cd	19.6 ± 2.4a
Dichlobenil	Yes	1920 + 35	2.8 ± 1.5bc	14.9 ± 2.4bcd	11.1 ± 2.1bc	18.8 ± 2.7ab

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1SE.

Table 3-22. Effect of fall bearing year herbicide applications on non-bearing year foramsulfuron efficacy on hair fescue flowering and total tuft density in both non-bearing year and bearing year in 2016-2017 at Portapique, NS, Canada.

			Non-bearing year		Bearing year	
Fall bearing year herbicides	Foramsulfuron	Application rate (g a.i ha^{-1})	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})
No	No	-	15.6 ± 2.5a	40.1 ± 9.3a	20.3 ± 2.5a	32.1 ± 3.5a
No	Yes	35	14.0 ± 1.8a	33.3 ± 4.3a	20.8 ± 1.8a	31.6 ± 3.0a
Terbacil	No	2000	16.5 ± 2.7a	27.0 ± 6.5abc	17.8 ± 3.9a	24.8 ± 5.4a
Terbacil	Yes	2000 + 35	9.9 ± 1.1ab	27.8 ± 5.4ab	19.3 ± 2.6a	29.0 ± 3.6a
Propyzamide	No	2240	0.8 ± 0.8bc	4.4 ± 2.9bcd	2.5 ± 2.3bc	3.3 ± 2.6c
Propyzamide	Yes	2240 + 35	0.0 ± 0.0c	1.5 ± 0.7d	0.0 ± 0.0c	0.5 ± 0.3c
Glufosinate	No	750	12.0 ± 2.4a	22.3 ± 5.3abcd	17.9 ± 2.9a	25.6 ± 3.4a
Glufosinate	Yes	750 + 35	8.9 ± 4.2abc	18.5 ± 7.0abcd	13.6 ± 4.9ab	22.6 ± 5.4ab
Dichlobenil	No	1920	1.8 ± 1.6bc	3.4 ± 2.2cd	4.1 ± 2.0bc	5.8 ± 2.8bc
Dichlobenil	Yes	1920 + 35	0.1± 2.1c	1.1± 0.7d	2.1 ± 2.0bc	5.1 ± 3.5c

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1SE.

Similar to flowering tuft density, fescue inflorescence height, inflorescence number, and fescue seed production were reduced to 0 in propyzamide related treatments (Table 3-23 and 3-24). These fescue data were not included in the ANOVA analysis due to the influence of zero values on assumptions of constant variance and normality. Fescue inflorescence height data at Portapique did not conform to assumptions of ANOVA, and the seedhead height data was only limited to the Stewiacke site (Table 3-23). There were significant effects of fall bearing year herbicide ($p < 0.0001$), foramsulfuron ($p < 0.0001$), and fall bearing year herbicide by foramsulfuron interaction ($p = 0.0007$) on fescue inflorescence height at Stewiacke. Besides propyzamide, dichlobenil was the most effective fall bearing year herbicide for reducing fescue inflorescence height. Terbacil and glufosinate did not significantly reduced inflorescence height relative to the untreated control (Table 3-23). Spring foramsulfuron application significantly decreased fescue inflorescence height, regardless of fall bearing year herbicide (Table 3-23).

Table 3-23. Effect of fall bearing year herbicide applications, with or without spring non-bearing year foramsulfuron applications, on hair fescue inflorescence height, inflorescence number, seed production per tuft in non-bearing year, and seedling number in bearing year in 2016-2017 at Stewiacke, NS, Canada. Fescue grass inflorescence number, seed production per tuft, and seedlings in the bearing year were log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Fall bearing year herbicides	Foramsulfuron	Application rate (g a.i ha^{-1})	Inflorescence height (cm)	Inflorescence number (# plant^{-1})	Seed production (seeds tuft^{-1})	Seedlings in the crop year (# m^{-2})
No	No	-	39.5 ± 2.0a	3.2 ± 0.2 (24.7)a	7.9 ± 0.3 (2803.3)a	4.5 ± 0.2 (100.0)a
No	Yes	35	24.9 ± 2.3d	2.7 ± 0.2 (15.0)a	6.2 ± 0.3 (642.5)bcd	7.3 ± 0.6 (54.6)abc
Terbacil	No	2000	38.0 ± 0.7ab	3.2 ± 0.2 (25.1)a	7.6 ± 0.3 (2164.3)ab	3.9 ± 0.2 (61.1)ab
Terbacil	Yes	2000 + 35	23.9 ± 3.1d	2.3 ± 0.2 (9.6)ab	5.7 ± 0.3 (407.2)cd	7.6 ± 0.6 (57.4)ab
Propyzamide	No	2240	-	-	-	3.6 ± 0.6 (12.0)de
Propyzamide	Yes	2240 + 35	-	-	-	1.7 ± 0.6 (2.8)e
Glufosinate	No	750	34.9 ± 1.4abc	2.5 ± 0.2 (12.5)ab	6.8 ± 0.3 (956.1)abc	9.3 ± 0.6 (86.0)a
Glufosinate	Yes	750 + 35	22.7 ± 1.6d	1.5 ± 0.2 (5.5)b	5.1 ± 0.3 (263.3)d	6.2 ± 0.6 (39.8)bcd
Dichlobenil	No	1920	29.6 ± 1.9bcd	2.5 ± 0.2 (12.4)ab	6.2 ± 0.3 (724.0)bcd	6.1 ± 0.6 (37.0)bcd
Dichlobenil	Yes	1920 + 35	27.3 ± 2.8cd	2.3 ± 0.2 (9.1)ab	5.7 ± 0.3 (351.4)cd	4.5 ± 0.6 (20.4)cde

[a]Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple means separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 3-24. Effect of fall bearing year herbicide application on bearing year foramsulfuron efficacy on hair fescue inflorescence number, seed production per tuft, and seedling number in non-bearing year and bearing year in 2016-2017 at Portapique, NS, Canada. Hair fescue inflorescence number and was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Fall bearing year herbicides	Foramsulfuron	Application rate (g a.i ha^{-1})	Inflorescence number (# plant^{-1})	Seed production (seeds tuft^{-1})	Seedlings in the crop year (# m^{-2})
No	No	-	3.7 ± 0.3a (49.8)	1057. 9 ± 237.9ab	120.3 ± 2.5a
No	Yes	35	3.0 ± 0.3ab (22.4)	884.1 ± 111.4ab	72.2 ± 32.8abc
Terbacil	No	495	3.3 ± 0.3ab (22.3)	1092.6 ± 197.1a	95.4 ± 25.5ab
Terbacil	Yes	250 + 35	3.1 ± 0.3ab (31.1)	840.0 ± 233.0ab	61.1 ± 23.4abc
Propyzamide	No	495 + 35	-	-	5.6 ± 3.2c
Propyzamide	Yes	250	-	-	2.8 ± 1.8c
Glufosinate	No	9	2.7 ± 0.3ab (15.3)	1240.5 ± 441.5a	104.6 ± 25.4a
Glufosinate	Yes	9 + 35	2.1 ± 0.3b (10.1)	568.6 ± 190.1ab	43.5 ± 10.2abc
Dichlobenil	No	1920	2.4 ± 0.4ab (8.7)	166.2 ± 166.1ab	38.9 ± 6.5abc
Dichlobenil	Yes	1920 + 35	2.1 ± 0.4ab (8.6)	0.0 ± 0.0b	10.2 ± 6.3 bc

[a]Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

There was a significant fall bearing year herbicide effect ($p \leq 0.0098$), but no fall bearing year herbicide by foramsulfuron interaction effect ($p \geqslant 0.3612$) on fescue inflorescence number at both sites. There was a significant spring foramsulfuron effect on fescue inflorescence number at Stewiacke ($p = 0.0004$), but there was no significant spring foramsulfuron effect on fescue inflorescence number at Portapique ($p = 0.1934$). Fall glufosinate or fall dichlobenil application was relatively more effective at reducing inflorescence number, compared to fall terbacil application. Spring foramsulfuron application alone did not reduce fescue inflorescence number at either site. Besides propyzamide, sequential application of fall glufosinate and spring foramsulfuron most effectively reduced fescue inflorescence number at both sites by over 77%, compared to the untreated control.

There was significant fall bearing year herbicide effect ($p \leqslant 0.0072$), but there was no fall bearing year herbicide by foramsulfuron interaction effect ($p \geqslant 0.1852$) on hair fescue seed production at both sites. There was significant foramsulfuron effect on fescue grass seed production at Stewiacke ($p < 0.0001$) but not at Portapique ($p = 0.1639$). Fall terbacil applied alone did not reduce fescue seed production at either site (Table 3-23 and 3-24). Fall glufosinate application reduced fescue seed production at Stewiacke (Table 3-23), but not at Portapique (Table 3-24). Besides propyzamide, fall dichlobenil application most effectively reduced fescue seeds by 75% at Stewiacke. Generally, hair fescue that were treated with fall bearing year herbicides followed by foramsulfuron had lower seed production at both sites. When fall glufosinate or fall dichlobenil was followed by spring foramsulfuron, fescue seed production was reduced by over 50% at each site (Table 3-23 and 3-24). The non-bearing year results showed the sequential fall glufosinate and spring foramsulfuron applications suppressed fescue grass in terms of lower flowering tuft density, and seed production at Stewiacke. Recent research showed that sequential glufosinate and foramsulfuron applications in the spring non-bearing year reduced hair fescue seed production and tuft height (White and Kumar 2017). Our results further improved the potential role of this herbicide combination, glufosinate with sequential foramsulfuron application can be further studied for evaluating alternative glufosinate application timing.

Effect of hair fescue in the bearing year. The trend of seedling density in the bearing year was similar with non-bearing year seed production (Table 2-23 and 2-24). There were significant effects of fall bearing year herbicides ($p < 0.0001$) and foramsulfuron ($p \leq 0.0168$), but there was no significant fall bearing year herbicide by foramsulfuron interaction effect ($p \geqslant 0.2315$) on seedling density at both sites. Plots where hair fescue produced less seeds in the non-bearing year had lower seedling density in the bearing year. The lowest seedling densities were found in plots that were treated with propyzamide and dichlobenil treatments. They were followed by glufosinate related treatments. Sequential application of glufosinate and foramsulfuron reduced seedling density by over 50% in the bearing year relative to fall glufosinate applied alone. Terbacil treatments did not reduce hair fescue seedling density. Plots that were treated with fall bearing year herbicides followed by foramsulfuron had lower seedling densities at both sites, although differences were not significant.

General trends of hair fescue flowering tuft density and total tuft density suppression in the bearing year at both sites were similar. There were no significant effects of foramsulfuron ($p \geq 0.1665$) and fall bearing year herbicide by foramsulfuron interaction ($p = 0.1759$) on hair fescue flowering and total tuft density in the bearing year at both sites

(Table 2-21 and 2-22). Spring non-bearing year foramsulfuron did not reduce hair fescue flowering tuft density and total tuft density in the bearing year. Also, there were no additional benefits of bearing year hair fescue flowering and total tuft density control from spring foramsulfuron applications following fall propyzamide applications. There was a significant fall bearing year herbicide effect on hair fescue flowering tuft density and total tuft density control in the bearing year ($p < 0.0001$) (Table 2-21 and 2-22). Hair fescue in plots that were treated with terbacil and glufosinate in fall recovered in the bearing year at both sites (Table 2-21 and 2-22). However, hair fescue flowering tuft density in plots that were treated with propyzamide and dichlobenil consistently remained low in the bearing year at both sites (Table 2-21 and 2-22). The results indicated that hair fescue suppression by propyzamide and dichlobenil could last for two years. However, efficacy of terbacil and glufosinate is likely limited to one year, and did not provide hair fescue control in the bearing year.

In conclusion, propyzamide related herbicide treatments were still the most effective hair fescue control options in both non-bearing year and bearing year. Besides propyzamide, sprout year hair fescue suppression with spring foramsulfuron was generally higher when applications were preceded by fall applications of dichlobenil or glufosinate relative to the fall herbicide applications alone, in terms of lower flowering tuft density in the non-bearing year, inflorescence number, seed production, and seedling density. Dichlobenil treatments reduced fescue flowering tuft density in the bearing year while efficacies of glufosinate related treatment only last for one year. Fall terbacil applications were not effective at either site, and this application timing likely should be avoided for fescue management in wild blueberry.

Experiment 4 -Effect of fall and spring glufosinate application on foramsulfuron efficacy on hair fescue. Site-combined visual injury rating data did not conform to the assumption for analysis of variance, and the data were analyzed separately by sites. Compared to the untreated control, no treatment significantly increased visual injury rating of blueberry plants by 45 days after herbicide application Portapique ($p = 0.0568$) and Parrsboro ($p = 0.1869$). There was no significant experimental site X fall glufosinate X spring glufosinate X foramsulfuron interaction effect on blueberry stem height ($p = 0.3336$), flower bud number per stem ($p = 0.6282$), blueberry stem density ($p = 0.1714$), and blueberry yield ($p = 0.9337$) (Table 3-25). Therefore, these blueberry response data were combined across sites for further analysis. There was no significant fall glufosinate effect ($p \geq 0.1790$), spring glufosinate effect ($p \geq 0.4106$), foramsulfuron effect ($p \geq 0.4682$), and related interactive effects ($p \geq 0.1032$) on blueberry stem height and stem density, which averaged 16.7 ± 2.0 cm and 349 ± 82 stems m^{-2}, respectively. There was a significant spring glufosinate effect ($p = 0.0015$), but no significant fall glufosinate effect ($p = 0.5947$), foramsulfuron effect ($p = 0.9994$), and related interactive effects ($p \geq 0.3531$) on blueberry flower bud number per stem. There were no significant blueberry flower bud number among treatments, and blueberry flower bud number averaged 6 ± 2 bud $stem^{-1}$. There were significant effects of fall glufosinate ($P = 0.0061$) and spring glufosinate ($p = 0.0056$), but no significant foramsulfuron effect ($p = 0.6495$), and interactive effects ($p \geq 0.5857$) on blueberry yield. Highest blueberry yields were observed in plots that were treated with fall glufosinate and spring glufosinate applications (Table 3-26).

Table 3-25. Tests of main and interactive effects of fall glufosinate, spring glufosinate, foramsulfuron, and experimental site on blueberry stem height, flower bud number per stem, stem density, and blueberry yield at Portapique and Parrsboro in Nova Scotia, in 2016-2017.

Effects	Blueberry stem height (cm)	Blueberry flower buds (# stem^{-1})	Blueberry stem density (stems m^{-2})	Blueberry yield (kg ha^{-1})
Experimental site	**	***	***	***
Fall glufosinate	NS	NS	NS	*
Experimental site X fall glufosinate	NS	NS	NS	NS
Spring glufosinate	NS	**	NS	*
Experimental site X spring glufosinate	NS	NS	NS	NS
Fall ignite X spring glufosinate	NS	NS	NS	NS
Experimental site X fall glufosinate X spring glufosinate	NS	NS	NS	NS
Foramsulfuron	NS	NS	NS	NS
Experimental site X foramsulfuron	NS	*	NS	NS
Fall glufosinate X foramsulfuron	NS	NS	NS	NS
Spring glufosinate X foramsulfuron	NS	NS	NS	NS
Fall glufosinate X spring glufosinate X foramsulfuron	NS	NS	NS	NS
Experimental site X fall glufosinate X foramsulfuron	NS	NS	NS	NS
Experimental site X spring glufosinate X foramsulfuron	NS	NS	NS	NS
Experimental site X fall glufosinate X spring glufosinate X foramsulfuron	NS	NS	NS	NS

[a] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ level of significant obtained with PROC MIXED in SAS

[b] NS, not significant

Table 3-26. Effect of fall glufosinate, spring glufosinate, and foramsulfuron applications on wild blueberry flower buds and yield at Portapique and Parrsboro in Nova Scotia, in 2016 – 2017. Blueberry flower bud number per stem was log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Fall glufosinate	Spring glufosinate	Spring foramsulfuron	Blueberry yield (kg ha-1)
no	no	no	1862.5 ± 247.1b
no	no	yes	2250.0 ± 405.8ab
no	yes	no	2662.5 ± 277.1ab
no	yes	yes	2850.0 ± 416.2ab
yes	no	no	2637.5 ± 400.0ab
yes	no	yes	2862.5 ± 481.0ab
yes	yes	no	3450.0 ± 536.2a
yes	yes	yes	3025.0 ± 531.4ab

[a]Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Effect on hair fescue in the non-bearing year. Fescue grass response in site-combined data set did not conform to the assumption for analysis of variance, and the data were analyzed separately by sites. Compared to the untreated control, all treatments significantly increased fescue grass visual injury ratings at both sites ($p < 0.0001$). Fescue grass that were treated with glufosinate and foramsulfuron combinations generally had higher visual injury rating, compared to fescues in the plots where foramsulfuron and glufosinate were applied alone (Figure 3-5). Foramsulfuron or spring glufosinate applied alone provided higher fescue visual injury rating than fall glufosinate application in summer of the non-bearing year (Figure 3-5). The initial mean fescue tuft densities were 15 ± 7 tufts m^{-2} and 48 ± 11 tufts m^{-2} at Portapique and Parrsboro, respectively. There were significant effects of fall glufosinate ($p \leq 0.0130$), spring glufosinate ($p \leq 0.0010$), and spring foramsulfuron

($p \leq 0.0005$) on non-bearing year fescue flowering tuft density at both sites. Foramsulfuron or spring glufosinate applied alone more effectively reduced flowering tuft density compared to fall glufosinate application, although it was not significant (Table 2-27). There were no effects of fall glufosinate X foramsulfuron interaction ($p = 0.4690$), spring glufosinate X foramsulfuron interaction ($p = 0.6263$), and fall glufosinate X spring glufosinate X foramsulfuron interaction ($p = 0.1583$) on fescue flowering tuft density in the non-bearing year at Portapique. There were no significant effects of fall glufosinate X foramsulfuron interaction ($p = 0.6850$) and fall glufosinate X spring glufosinate X foramsulfuron interaction ($p = 0.7553$), but there was a significant spring glufosinate X foramsulfuron interaction effect ($p = 0.0006$) on non-bearing year fescue flowering tuft density at Parrsboro. Sequential applications of fall glufosinate/spring glufosinate and foramsulfuron both did not significantly reduced fescue flowering tuft density in the non-bearing year, compared to glufosinate or foramsulfuron applied alone (Table 2-27). Among all treatments, the sequential application of fall glufosinate, spring glufosinate, and spring foramsulfuron was consistently the most effective treatment for reducing non-bearing year flowering tuft density, which controlled over 80 % hair fescue flowering tufts in the non-bearing year at both sites (Table 2-27).

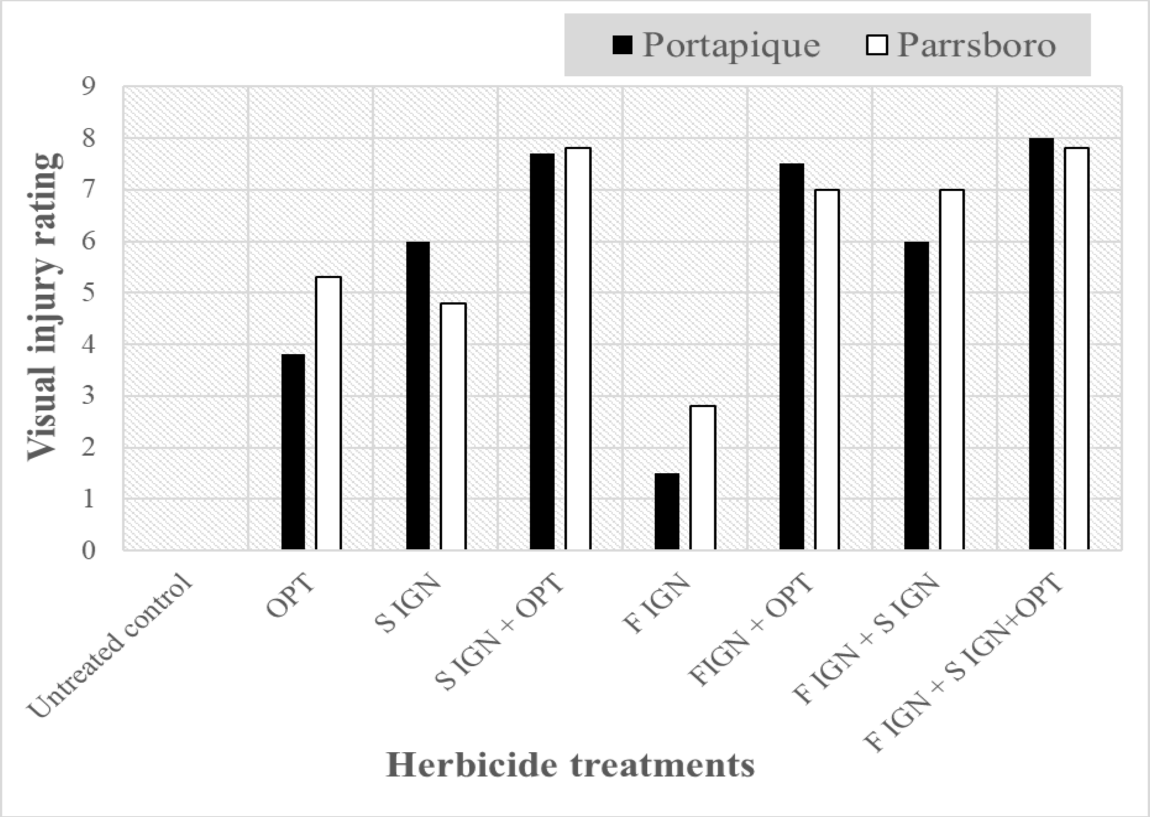

Figure 3-5. Herbicide visual injury rating of hair fescue treated with related herbicides at 45 days after option application at Parrsboro and Portapique in Nova Scotia in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death. OPT, foramsulfuron; S IGN, spring glufosinate; F IGN, fall glufosinate.

There were significant effects of fall glufosinate ($p \leq 0.0036$) and foramsulfuron ($p \leq 0.0012$), but there was no significant spring glufosinate effect ($p \geqslant 0.0844$) and related interactive effects ($p \geqslant 0.2594$) on non-bearing year hair fescue total tuft density at both sites. Sequential application of fall glufosinate and foramsulfuron and sequential application of fall glufosinate, spring glufosinate, and foramsulfuron were most effective at reducing non-bearing year fescue total tuft density at both sites (Table 3-27). They significantly reduced non-bearing year total tuft density by over 40% and 75% at Portapique and Parrsboro, respectively.

Table 3-27. Effect of fall glufosinate, spring glufosinate, and foramsulfuron applications on hair fescue flowering and total tuft density in both non-bearing year and bearing year in 2016-2017 at Portapique and Parrsboro, NS, Canada. Fescue flowering tuft density in the non-bearing year, total tuft density in the non-bearing year, and flowering tuft density in the bearing year at Portapique were log(x) transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

				Non-bearing year		Bearing year	
Site	Fall glufosinate	Spring glufosinate	Spring foramsulfuron	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})
Portapique	no	no	no	3.0 ± 0.4 (24.1)a	2.7 ± 0.3 (15.9)a	17.8 ± 3.4a	2.8 ± 0.3 (17.1)a
	no	no	yes	2.0 ± 0.4 (9.3)ab	1.9 ± 0.3 (6.0)ab	10.5 ± 1.4ab	2.2 ± 0.3 (9.5)ab
	no	yes	no	3.0 ± 0.4 (30.6)a	1.9 ± 0.3 (8.0)ab	12.4 ± 2.6ab	2.4 ± 0.3 (11.8)ab
	no	yes	yes	2.4 ± 0.4 (13.0)ab	1.6 ± 0.3 (4.4)b	13.1 ± 2.9ab	2.4 ± 0.3 (12.6)ab
	yes	no	no	2.4 ± 0.4 (14.9)ab	2.0 ± 0.3 (8.5)ab	12.8 ± 3.5ab	2.3 ± 0.3 (10.9)ab
	yes	no	yes	1.8 ± 0.4 (8.8)b	1.4 ± 0.3 (3.8)bc	9.3 ± 2.6ab	2.0 ± 0.3 (8.5)ab
	yes	yes	no	2.2 ± 0.4 (9.0)ab	1.5 ± 0.3 (4.0)bc	9.6 ± 1.6ab	2.2 ± 0.3 (9.5)ab
	yes	yes	yes	1.7 ± 0.4 (4.8)b	0.5 ± 0.3 (1.0)c	5.9 ± 2.0b	1.5 ± 2.0 (5.9)b
Parrsboro	no	no	no	21.8 ± 2.1a	14.3 ± 2.6a	22.3 ± 1.2a	17.3 ± 1.3a
	no	no	yes	15.5 ± 2.8ab	3.9 ± 1.4b	24.3 ± 0.9a	16.8 ± 1.7a
	no	yes	no	16.6 ± 3.5ab	4.8 ± 1.4b	23.1 ± 1.3a	17.5 ± 2.8a
	no	yes	yes	11.9 ± 1.0ab	1.0 ± 0.2b	23.0 ± 2.0a	15.6 ± 2.1a
	yes	no	no	16.8 ± 3.4ab	10.4 ± 1.5a	25.3 ± 1.4a	17.6 ± 1.0a
	yes	no	yes	5.4 ± 2.3b	1.1 ± 0.7b	18.5 ± 1.2a	11.5 ± 1.8a
	yes	yes	no	13.0 ± 2.5ab	3.9 ± 1.0b	23.8 ± 2.2a	17.0 ± 2.0a
	yes	yes	yes	5.4 ± 2.3b	0.3 ± 0.3b	23.6 ± 2.2a	14.8 ± 1.5a

[a]Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

There were significant effects of spring glufosinate ($p < 0.0001$) and foramsulfuron ($p < 0.0001$), but no significant interactive effects ($p \geq 0.1848$) on hair fescue height at both sites. Fall glufosinate significantly affected hair fescue height at Portapique ($p = 0.0165$), but not at Parrsboro ($p = 0.6899$). Foramsulfuron significantly reduced inflorescence height at Parrsboro when applied alone, but it did not work as good at Portapique. Single applications of fall glufosinate or spring glufosinate reduced inflorescence height at both sites, but not to the extent observed in the single foramsulfuron application (Table 3-28). Similar with non-bearing year total tuft density, sequential application of spring glufosinate fb foramsulfuron and sequential application of fall glufosinate fb spring glufosinate fb foramsulfuron were the most effective treatment in reducing fescue inflorescence height at both sites (Table 3-28). Sequential applications of fall glufosinate and foramsulfuron also reduced fescue inflorescence height at both site, but the efficacy was not as good as the sequential application of spring glufosinate and foramsulfuron (Table 3-28).

Table 3-28. Effect of fall glufosinate, spring glufosinate, and foramsulfuron applications on hair fescue inflorescence height, inflorescence number, seed production per tuft in non-bearing year, and seedling number in bearing year in 2016-2017 at Portapique and Parrsboro, NS, Canada. Fescue grass inflorescence height at Parrsboro, seed production at both sites, and seedling density at Portapique were log(x) transformed for the analysis of variance. Fescue inflorescence number at Parrsboro was square root transformed for the analysis of variance. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Site	Fall glufosinate	Spring glufosinate	Spring foramsulfuron	Inflorescence height (cm)	Inflorescence number (# plant^{-1})	Seed production (seeds tuft^{-1})	Seedling density in the bearing year (# m^{-2})
Portapique	no	no	no	36.6 ± 2.9a	27.0 ± 4.1a	7.2 ± 0.3 (1452.5)a	5.2 ± 0.2 (200.9)a
	no	no	yes	29.2 ± 3.6ab	22.3 ± 4.0abc	7.1 ± 0.3 (1463.1)ab	5.2 ± 0.2 (200.9)a
	no	yes	no	31.0 ± 18.1ab	11.8 ± 2.3bcd	6.6 ± 0.4 (870.9)abc	5.0 ± 0.2 (153.7)ab
	no	yes	yes	18.6 ± 0.7cd	8.8 ± 1.8cd	4.8 ± 0.3 (148.5)d	4.3 ± 0.2 (82.4)abc
	yes	no	no	33.9 ± 2.6ab	25.1 ± 7.6ab	7.4 ± 0.3 (1634.0)a	5.2 ± 0.2 (201.0)a
	yes	no	yes	24.2 ± 1.6bcd	7.9 ± 1.9cd	5.9 ± 0.3 (356.3)bcd	3.9 ± 0.2 (51.9)cd
	yes	yes	no	27.2 ± 2.4abc	8.6 ± 3.2cd	5.6 ± 0.3 (343.9)cd	3.9 ± 0.2 (66.7)bcd
	yes	yes	yes	13.9 ± 4.7d	5.0 ± 1.7d	5.7 ± 0.3 (349.0)cd	3.2 ± 0.2 (25.9)d
Parrsboro	no	no	no	3.4 ± 0.1 (31.2)a	3.6 ± 0.2 (12.1)a	4.1 ± 0.5 (89.5)bc	162.0 ± 17.3a
	no	no	yes	3.1 ± 0.1 (23.1)cd	2.5 ± 0.2 (5.7)b	3.8 ± 0.6 (53.7)c	92.6 ± 27.9abc
	no	yes	no	3.3 ± 0.1(27.9)abc	2.2 ± 0.2 (3.7)bc	5.4 ± 0.5 (410.1)a	123.2 ± 21.4abc
	no	yes	yes	3.0 ± 0.1 (16.0)d	1.6 ± 0.2 (1.9)bc	3.9 ± 0.5 (83.7)bc	55.6 ± 11.2c
	yes	no	no	3.4 ± 0.1 (31.0)ab	2.4 ± 0.2 (4.9)b	5.3 ± 0.6 (314.9)ab	153.7 ± 19.0ab
	yes	no	yes	3.2 ± 0.1 (18.5)abcd	1.4 ± 0.2 (1.2)bc	5.0 ± 0.6 (179.7)abc	61.1 ± 13.3c
	yes	yes	no	3.3 ± 0.1 (28.5)abc	1.9 ± 0.2 (2.7)bc	5.3 ± 0.6 (318.0)ab	80.6 ± 23.3bc
	yes	yes	yes	2.9 ± 0.1 (5.4)bcd	1.3 ± 0.2 (0.8)c	4.4 ± 0.6 (90.3)abc	56.5 ± 3.5c

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

There were significant effects of fall glufosinate ($p \leq 0.0176$), spring glufosinate ($p < 0.0001$), and spring foramsulfuron ($p \leq 0.0048$) on fescue inflorescence number. There was a significant fall glufosinate X spring glufosinate interaction effect at Parrsboro ($p = 0.0181$), but no other interactive effects at both sites ($p \geq 0.1083$). Sequential application of fall/spring glufosinate and foramsulfuron had similar effectiveness on reducing inflorescence number. Sequential application of fall glufosinate, spring glufosinate, and foramsulfuron were the most effective treatment in reducing fescue inflorescence number at both site, with 81% and 93% inflorescence reduction at Portapique and Parrsboro, respectively (Table 3-28).

Trends of seed production varied across sites. There were significant effects of fall glufosinate ($p = 0.0040$), foramsulfuron ($p = 0.0014$), fall glufosinate X spring glufosinate interaction ($p = 0.0138$), and spring glufosinate X foramsulfuron interaction ($p = 0.0408$), but there was no significant spring glufosinate effect ($p = 0.2713$) and other interactive effects ($p \geq 0.4285$) on fescue seed production at Parrsboro. There was no clear trend of seed production at Parrsboro for unknown reasons (Table 3-28). There were significant effects of spring glufosinate ($p < 0.0001$), foramsulfuron ($p = 0.0002$) and fall glufosinate X spring glufosinate X foramsulfuron interaction ($p = 0.0002$), but there were no significant effects of fall glufosinate ($p = 0.1631$) and other interactive effects ($p \geq 0.2065$). Single application of fall glufosinate, spring glufosinate, or foramsulfuron did not reduce fescue seed production at Portapique (Table 3-28).

Effect of hair fescue in the bearing year. There were significant effects of fall glufosinate ($p < 0.0001$), spring glufosinate ($p < 0.0001$), foramsulfuron ($p = 0.0002$), and fall glufosinate X foramsulfuron interaction ($p = 0.0275$), but there were no other interactive effects ($p \geq 0.0525$) on fescue seedling density at Portapique. There were significant effects of spring glufosinate ($p = 0.0044$) and foramsulfuron ($p < 0.0001$), but no significant effects of fall glufosinate ($p = 0.1056$) and other interactive effects ($p \geq 0.1587$) on fescue seedling density at Parrsboro. However, general trends of seedling density were similar across sites. Similar with seed production at Portapique, single application of either fall glufosinate, spring glufosinate or foramsulfuron did not reduce fescue seedlings at either site (Table 2-28). Significantly lower seedling densities were observed in plots at Portapique that were sequentially treated with fall glufosinate fb foramsulfuron, spring glufosinate fb foramsulfuron, and fall glufosinate fb spring glufosinate fb foramsulfuron.

Trends of bearing year fescue flowering tuft density and total tuft density varied across sites (Table 3-27). Fescue grass at Parrsboro recovered in the bearing year (Table 3-27). There were no significant main and interactive effects of fall glufosinate, spring glufosinate, and/or foramsulfuron on bearing year fescue flowering tuft density and total tuft density at Parrsboro ($p \geq 0.0520$). However, at Portapique, there were significant effects of fall glufosinate ($p \leq 0.0044$) and foramsulfuron ($p \leq 0.0188$), but there was no significant spring glufosinate effect ($p \geq 0.1067$) and interactive effects ($p \geq 0.1269$) on bearing year fescue flowering and total tuft density. Sequential application of fall glufosinate, spring glufosinate, and foramsulfuron most effectively reduced fescue flowering and total tuft density in the bearing year at Portapique. However, remaining fescue flowering tufts still interfered with the harvesting process. Results indicated that fescue grass recovered in the bearing year and additional herbicide applications should be determined for bearing year fescue grass management.

In conclusion, single application of spring foramsulfuron effectively controlled non-bearing year fescue flowering tuft density, while its efficacy on controlling inflorescence height, inflorescence number and seed production varied across sites. Foramsulfuron efficacy was not improved when it was sequentially followed glufosinate. Sequential application of fall glufosinate, spring glufosinate, and foramsulfuron most effectively controlled fescue grass in the non-bearing year. Generally, efficacies of fall/spring glufosinate and foramsulfuron sequential applications were similar, in terms of controlling fescue inflorescence height, inflorescence number and seed production. Efficacies of tested herbicide treatment on bearing year fescue control varied across sites. Recovery of fescues was observed at both sites in the bearing year. Therefore, additional treatments for bearing year fescue grass control should be further studied.

Chapter 4 - Evaluation of flazasulfuron for hair fescue (*Festuca filiformis*) suppression and crop tolerance in wild blueberry (*Vaccinium augustifolium* Ait.)

Abstract

A field experiment was conducted to evaluate the effect of flazasulfuron on blueberry crop safety and to determine the most suitable flazasulfuron application timing and rate to control hair fescue (*Festuca filiformis*) in wild blueberry. Treatments consisted of flazasulfuron applied at 38 and 50g a.i ha^{-1} in fall of the bearing year and spring, summer, and fall of the non-bearing year. Propyzamide, terbacil, and foramsulfuron were also included to evaluate flazasulfuron against currently available herbicides. Flazasulfuron can be safely used in wild blueberry fields at the rates evaluated at all indicated application timings. Spring non-bearing year flazasulfuron applications were more effective at reducing hair fescue in the non-bearing year when compared to fall bearing year flazasulfuron applications. Summer non-bearing year flazasulfuron application did not control hair fescue. Fall non-bearing year flazasulfuron applications reduced hair fescue density in the bearing year and did not cause blueberry injury, indicating potential use of this application timing to provide bearing year fescue suppression. Application rates of 38 and 50 g a.i. ha^{-1} did not increase flazasulfuron efficacy, indicating that the lower rate is adequate for fescue management. Further studies are needed to determine the most optimum herbicide use patterns of flazasulfuron with other registered herbicides that could improve fescue grass management in wild blueberry.

Introduction

Hair fescue (*Festuca filiformis* Pourr.) in wild blueberry field has quickly become a serious problem in Nova Scotia, while available herbicide options are few for managing this species. Introducing new herbicides is therefore necessary to limit the yield limiting effects of hair fescue in wild blueberry.

Flazasulfuron is a selective, Group 2 herbicide which controls grasses, broadleaf weeds, and sedges (Shaner 2014; Anonymous 2017b). It functions by inhibiting acetolactate synthase (ALS), which is a key enzyme involved in branched-chain amino acid biosynthesis (Shaner 2014). Susceptible plants are unable to synthesize proteins due to lack of branch-chained amino acids, and growth of susceptible plants is inhibited rapidly. Flazasulfuron has been registered in various countries in Asia, Europe, and South America for weed control in turf grass as well as in several agricultural crops, including grapes, citrus, and olives (Anonymous 2017b; Anonymous 2017c; Ferrell et al 2004). This herbicide is particularly effective for controlling cool-season grasses, such as festuca *spp*., in warm-season turf grasses. For example, flazasulfuron gave complete control of tall fescue in turf grass at an application rate of 50 g a.i ha^{-1} (Ferrell et al 2004). It is therefore possible that this herbicide could control hair fescue in wild blueberry fields. However, the role of this herbicide in managing hair fescue in wild blueberry has not been studied. Flazasulfuron has both preemergence and postemergence efficacy on *festuca* spp., and it can be applied at rates between 38 and 50 g a.i. ha^{-1} in spring, summer or fall (Anonymous 2017b). A range of application rates and timings should therefore be evaluated for weed control and crop safety in wild blueberry. The objective of this experiment was to determine the effect of flazasulfuron application timing and rate on hair fescue control and wild blueberry crop tolerance.

Methods and Materials

Effect of flazasulfuron on hair fescue and blueberry crop safety. The experiment was focused on the evaluation of flazasulfuron (Mission@ herbicide, Summit Agro USA LLC., Durham, NC) for crop safety and efficacy on hair fescue and was conducted in wild blueberry fields located in Stewiacke, Londonderry and Parrsboro in Nova Scotia, Canada. Field sites in Stewiacke, Parrsboro, and Portapique were established on November 6, 2015, November 4, 2015, and October 8, 2015, respectively. The experiment was a randomized complete block design with 12 treatments and four blocks at each site (Table 4-1). Treatments consisted of flazasulfuron applied at 38 and 50 g a.i ha^{-1} in fall of the bearing year and spring, summer, and fall of the non-bearing year (Table 4-1). Fall applications of propyzamide (Kerb@ SC herbicide, Dow AgroSciences Canada Inc., Indianapolis, IN) in the bearing year and spring applications of terbacil (Tessenderlo Kerley Inc., Phoenix, AZ) and foramsulfuron (Option® 2.25 OD herbicide, Bayer CropScience Inc., Calgary, Alberta) in the non-bearing year were included to evaluate flazasulfuron against currently available herbicides for fescue grass control in wild blueberry fields (Table 4-1). Propyzamide, terbacil and foramsulfuron were applied at rates of 2240 g a.i. ha^{-1}, 2000 g a.i ha^{-1}, and 35 g a.i ha^{-1}, respectively. Foramsulfuron was applied with a liquid nitrogen fertilizer (28 % UAN, Urea-Ammonium Nitrate; BASF Canada Inc., Mississauga, Ontario) at a rate of 2.5 L ha^{-1}. Plot size was 2 m X 6 m with a 1-m-wide unsprayed strip between each block. Herbicide applications were made with a CO_2 pressurized research plot sprayer outfitted with four 11002 XR nozzles calibrated to deliver a water volume of 300 L ha^{-1}

(propyzamide) and 200 L ha^{-1} (flazasulfuron, foramsulfuron, and terbacil) at a pressure of 276 kPa. Weather conditions during herbicide applications are shown in Table 4-2.

Table 4-1. Treatments used to evaluate the effect of flazasulfuron on hair fescue and blueberry crop safety

Trade name	Common name	Application rate (g a.i. ha^{-1})	Application timing
Untreated control	-	-	-
Kerb	Propyzamide	2240	Fall, 2015
Sinbar	Terbacil	2000	Spring, 2016
Option	Foramsulfuron	35	Spring, 2016
Mission	Flazasulfuron	38	Fall, 2015
Mission	Flazasulfuron	50	Fall, 2015
Mission	Flazasulfuron	38	Spring, 2016
Mission	Flazasulfuron	50	Spring, 2016
Mission	Flazasulfuron	38	Summer, 2016
Mission	Flazasulfuron	50	Summer, 2016
Mission	Flazasulfuron	38	Fall, 2016
Mission	Flazasulfuron	50	Fall, 2016

Table 4-2. Herbicide application dates and related weather conditions at each trial site for flazasulfuron evaluation experiment

Site	Application timing	Date of spraying	Temp. (°C)	Humidity (%)	Wind speed (km h^{-1})
Stewiacke	Fall, 2015	18-Nov-2015	1.7	63.0	1.1
	Spring, 2016	04-May-2016	11.7	65.0	2.8
	Summer, 2016	29-Jul-2016	28.7	76.9	2.4
	Fall, 2016	10-Nov-2016	3.3	41.0	1.9
Londonderry	Fall, 2015	10-Nov-2015	16.1	41.0	1.0
	Spring, 2016	04-May-2016	5.6	74.3	8.0
	Summer, 2016	01-Aug-2016	13.6	48.8	3.0
	Fall, 2016	08-Nov-2018	17.8	40	1.3
Parrsboro	Fall, 2015	10-Nov-2015	13.9	55.0	4.0
	Spring, 2016	12-May-2016	5.9	56.8	4.8
	Summer, 2016	01-Aug-2016	24.5	62.8	3.7
	Fall, 2016	25-Nov-2016	7.0	48.5	2.1

Data collection included 1) damage ratings of blueberry and hair fescue, 2) hair fescue density prior to treatment applications, in late summer of the non-bearing year, and in mid summer of the bearing year, 3) grass inflorescence number in late summer of the non-bearing year and in mid-summer of the bearing year, 4) inflorescence height following treatment applications, 5) wild blueberry stem density, stem height, and flower bud number per stem at the end of the non-bearing year, and 6) wild blueberry yield in the bearing year. Damage rating was assessed for both blueberry and target species by using a standard 0 – 10 visual system (0 = no damage, 10 = complete plant death) at 1.5 months after early spring herbicide applications in the non-bearing year and in mid summer of the bearing year. Tuft densities were determined in two 1 m X 1 m quadrats per plot. Inflorescence number and height of fescue grass were counted and measured in the field by randomly selecting 10 tufts per plot. Blueberry shoot counts were conducted in fields in two 30 cm X 30 cm quadrats per plot at the end of the field season in the non-bearing year. In each plot, 30 randomly selected blueberry stems were clipped at ground level, bagged in the field, and brought back to the laboratory in late autumn. Blueberry flower bud number was counted and shoot height was measured in the laboratory. Wild blueberry yield was determined in two 1 m X 1 m quadrats per plot and wild blueberry fruit was harvested using hand rakes in mid-August of the bearing year. Initial grass tuft densities were collected on November 14, 2015, April 26, 2015, and April 27, 2016 at Stewiacke, Londonderry, and Parrsboro, respectively. Flowering tuft density and total tuft density were determined in late June 2016 and in early July 2017 across all sites. Inflorescence number was determined in early July 2016 and July 2017 across all sites. Inflorescence height was determined in early July 2016 across all sites. Blueberry stem density counting and blueberry stem collection were completed in fields in early October 2016 at Stewiacke, Londonderry, and

Parrsboro. Blueberry yields were determined on August 3, 2017, August 2, 2017, and August 14, 2017 at Stewiacke, Londonderry, and Parrsboro, respectively.

Statistical analysis. For all data, firstly, tests of main and interactive effects of treatments and experimental sites were conducted to determine whether data could be combined across sites. When data conformed to the assumptions for ANOVA and the interaction effect of sites by treatments were not significant after analysis, these data were pooled across experimental sites for further analysis. Otherwise, data were analyzed separately by sites. Damage rating data for wild blueberry and fescue were analyzed in PROC NPAR1WAY in SAS system for Windows (Statistical Analysis System, Version 9.2, SAS Institute, Cary, NC). Other data were analyzed using analysis of variance (ANOVA) in PROC MIXED in SAS for Windows. In the Mixed Model, treatments were used as fixed effects, while blocks within each trial were considered as random effects. The assumption of constant variance was tested to ensure that residuals had constant variance with a normal distribution. Some data were transformed to achieve normality and constant variance, and transformations are indicated as needed in tables and figures. Significant differences among treatments were determined using Tukey's multiple means comparison test at a probability level of $P < 0.05$.

Results and Discussion

Effect of flazasulfuron on wild blueberry crop safety. Visual injury ratings of blueberry plants were not affected by flazasulfuron treatments in both non-bearing and bearing year at all sites ($p \geq 0.0598$), with visual injury rarely exceeding 13% and 5% in the non-bearing year and bearing year, respectively. There were no significant effects of experimental site X flazasulfuron interaction on blueberry stem height ($p = 0.8340$) and flower bud number per stem ($p = 0.0562$). Therefore, these two blueberry response variables were pooled across sites for analysis. There were no significant effects of flazasulfuron application timing and rate on blueberry stem height ($p = 0.2159$) and flower bud number per stem ($p = 0.7131$), which averaged 15.3 ± 0.2 cm and 6 ± 2 buds stem^{-1}, respectively. Site-combined blueberry stem density and blueberry yield data did not conform to the assumptions for ANOVA, and they were analyzed separately by sites. There were no significant flazasulfuron effects on blueberry stem density ($p \geqslant 0.2318$) and yield ($p \geqslant 0.2237$) at all tested sites. Blueberry stem density averaged 279 ± 97 stems m^{-2}, 209 ± 54 stems m^{-2}, and 305 ± 170 stems m^{-2} at Londonderry, Parrsboro, and Stewiacke, respectively. Blueberry yield averaged 2151.1 ± 1362.0 kg ha^{-1}, 2564.9 ± 1194.8 kg ha^{-1}, and 3984.0 ± 1724.8 kg ha^{-1} at Londonderry, Parrsboro, and Stewiacke, respectively. Crop injury from flazasulfuron on grapefruit and grapevine were observed at application rates of 20 and 50 g a.i ha^{-1}, respectively (Singh et. al 2012; Magne et. al 2005). However, the toxicity to the grapevine was overcome in the following year (Magne et. al 2005). Flazasulfuron also caused initial light phytotoxicity to sugarcane plants, but the symptoms disappeared after three months after application (Dario et. al 1997). However, our results indicated that wild blueberry is tolerant to flazasulfuron and that this herbicide can be safely applied in spring, summer, or fall for fescue grass control at a rate up to 50 g a.i ha^{-1} in wild blueberry fields. The results also indicated that single application of propyzamide, foramsulfuron, terbacil, and flazasulfuron did not significantly increase blueberry yield potential and yield. However, in the previous experiments, increased blueberry stem density and yield were observed in plots that were treated with herbicide combinations of fall propyzamide and other non-bearing year herbicides (Chapter 3: Experiment – 1 Evaluation of herbicide combinations for hair fescue control in wild blueberry; Chapter 3: Experiment – 2:

Optimum combination of fall bearing year propyzamide and spring non-bearing year herbicide applications). Therefore, further studies are needed to evaluate combinations of flazasulfuron and other herbicides in controlling hair fescue and improving the growth of wild blueberry plants.

Effect of flazasulfuron on hair fescue control. Initial grass tuft densities in Stewiacke, Londonderry, and Parrsboro were 37 ± 10 tufts m^{-2}, 27 ± 8 tufts m^{-2}, and 49 ± 13 tufts m^{-2}, respectively. Hair fescue response data in the combined data set did not conform to assumptions for ANOVA, so data were analyzed separately for each site. There was a significant effect of herbicide treatment on hair fescue visual injury in both the non-bearing and bearing year ($p < 0.0001$). Plots that were treated with fall bearing year propyzamide or spring non-bearing year flazasulfuron consistently had the highest visual injury ratings on fescue in the non-bearing year across sites (Figure 4-1), followed by fall bearing year application of flazasulfuron and spring foramsulfuron and terbacil applications (Figure 4-2). Visual injury ratings of hair fescue in the bearing year were highest in plots that were treated with fall bearing year propyzamide or fall non-bearing year flazasulfuron (Figure 4-3), whereas fescue tufts in most other treatments had begun to recover in the bearing year (Figure 4-3). Significant fescue grass recovery in the bearing year was often observed in the plots that lacked a fall non-bearing year or a fall bearing year propyzamide application (Chapter 3), indicating that additional research should be conducted to determine fall non-bearing year treatments for bearing year hair fescue management. The results implied that fall non-bearing year flazasulfuron could be an alternative treatment to propyzamide to suppress hair fescue in the bearing year.

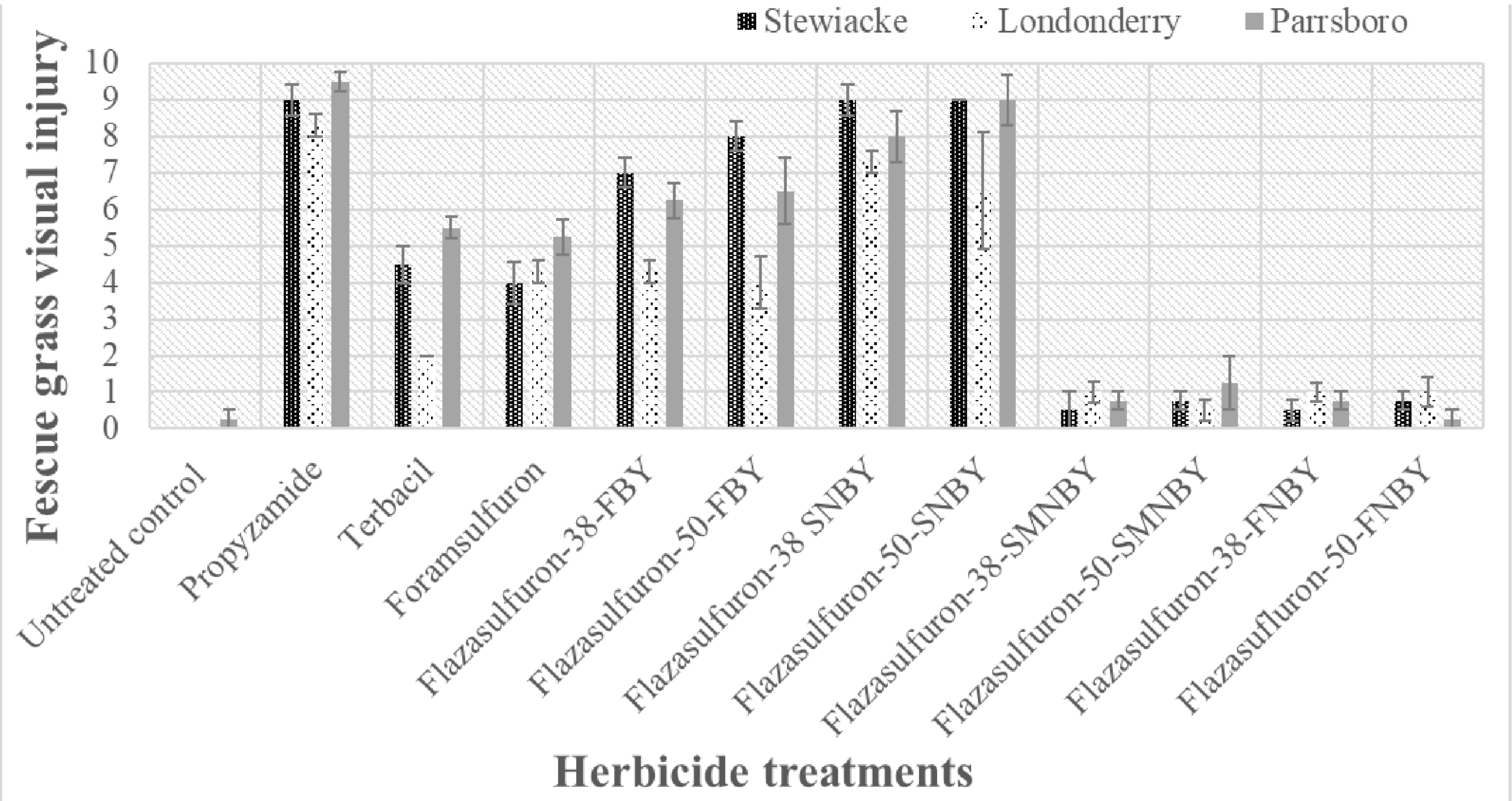

Figure 4-1. Visual injury rating of hair fescue in mid-June of the non-bearing year following treatment with fall bearing year propyzamide, fall bearing year flazasulfuron, and spring non-bearing year terbacil, foramsulfuron, and flazasulfuron applications at Stewiacke, Londonderry and Parrsboro, Nova Scotia, in 2016. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death. Treatments applied in summer and fall of the non-bearing year have low visual injury ratings as treatments were not applied prior to collection of visual injury rating data provided. FBY, Fall Bearing Year; SNBY, Spring Non-Bearing Year; SMNBY, Summer Non-Bearing Year; FNBY, Fall Non-Bearing Year.

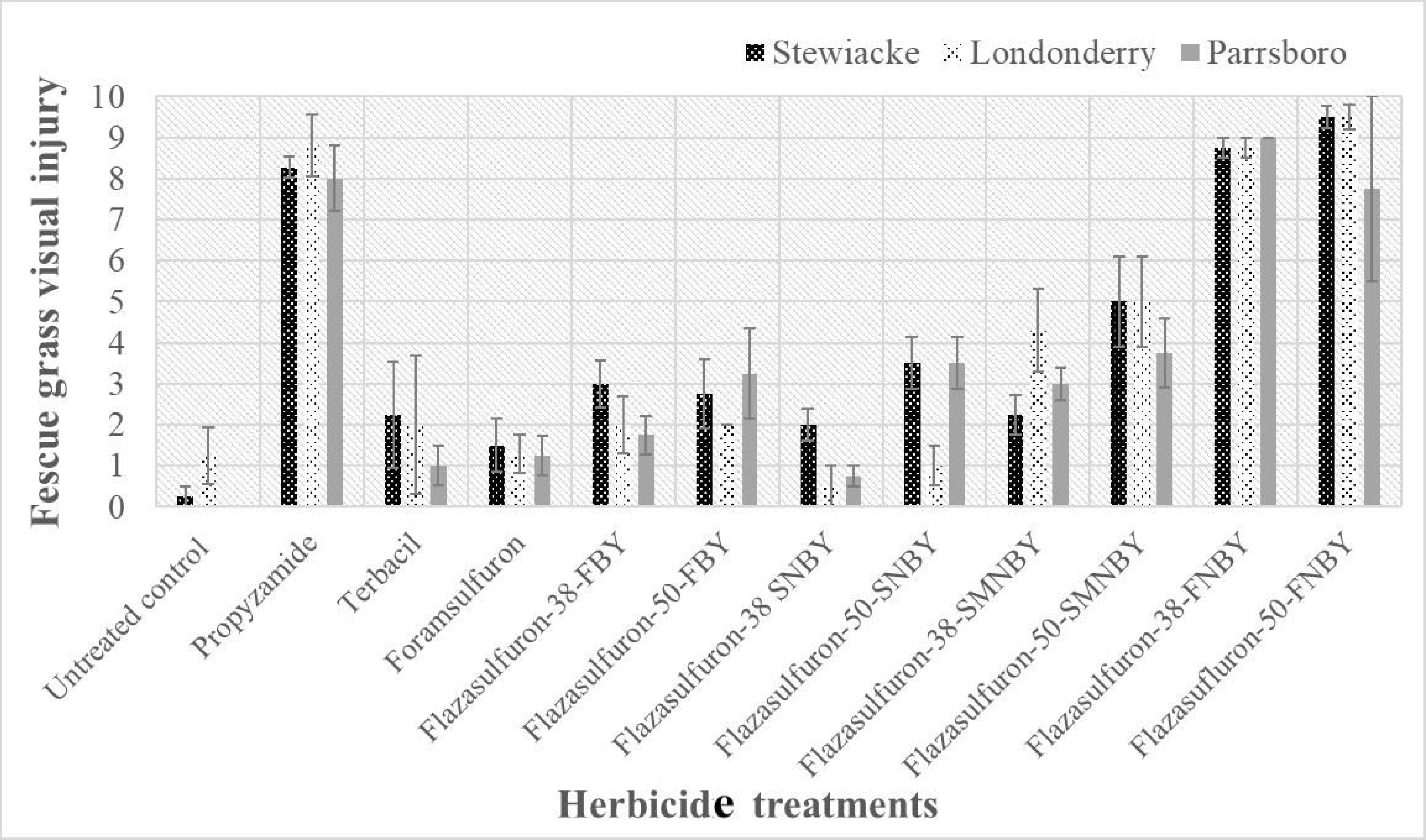

Figure 4-2. Herbicide visual injury rating of hair fescue in mid-summer of the bearing year following treatments with summer non-bearing flazasulfuron and fall non-bearing year flazasulfuron at Stewiacke, Londonderry and Parrsboro, Nova Scotia, in 2017. Visual injury was conducted using a standard 0 – 10 visual system, where 0 = no damage and 10 = complete plant death. FBY, Fall Bearing Year; SNBY, Spring Non-Bearing Year; SMNBY, Summer Non-Bearing Year; FNBY, Fall Non-Bearing year.

There was a significant treatment effect on hair fescue flowering and total tuft density in the non-bearing year at all sites ($p \leq 0.0172$; Table 4-3, 4-4, and 4-5). Fall bearing year propyzamide applications most effectively reduced non-bearing year total and flowering fescue tuft density (Figure 4-3; Table 4-3, 4-4, and 4-5), completely eliminating flowering tufts at all sites. Terbacil or foramsulfuron applied alone reduced flowering and total tuft density at all sites, but efficacy varied (Table 4-3, 4-4, and 4-5). Terbacil significantly decreased fescue flowering and total tuft densities at Stewiacke, and foramsulfuron did not work (Table 4-3). However, neither terbacil nor foramsulfuron affected hair fescue density in the non-bearing year at Londonderry and Parrsboro (Table 4-4 and 4-5). Efficacies of fall bearing year flazasulfuron applications at 38 and 50 g a.i ha^{-1} were similar and were generally more effective than foramsulfuron or terbacil (Table 4-3, 4-4 and 4-5). Fall bearing year flazasulfuron application reduced fescue flowering and total tuft density in the non-bearing year by over 41 and 34%, respectively, across all sites (Table 4-3, 4-4 and 4-5). Spring non-bearing year flazasulfuron applications at both application rates were also effective, with this application timing providing the most consistent reduction in fescue flowering tuft density in the non-bearing year, outside of the propyzamide treatments (Table 4-3, 4-4 and 4-5). These treatments reduced fescue flowering tuft density by 85 and 61% at Stewiacke and Londonderry, respectively (Table 4-3 and 4-4). However, compared to Stewiacke and Londonderry, spring non-bearing year application of flazasulfuron at Parrsboro was not as effective in reducing flowering tuft density (Table 4-5). The efficacy of spring non-bearing year flazasulfuron application on controlling total tuft density was similar with foramsulfuron or terbacil that were applied at the same application timing across all sites (Table 4-3, 4-4 and 4-5).

Figure 4-3. Hair fescue (within red lines) suppressed by fall bearing year propyzamide application in Londonderry, NS 2016.

Table 4-3. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, inflorescence number, and inflorescence height in the non-bearing year 2016 at Stewiacke, NS, Canada. Inflorescence number was log(x) transformed. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Active ingredient	Application rate (g a.i ha^{-1})	Application timing	Total tuft density (tufts m^2)	Flowering tuft density (tufts m^2)	Inflorescence number (# tuft^{-1})	Inflorescence height (cm)
-	-	-	28.4 ± 2.6a[a]	19.5 ± 1.6abc	3.3 ± 0.1a (27.1)	40.2 ± 0.9a
Propyzamide	2240	Fall	8.4 ± 1.3d	0.0 ± 0.0e	0.0 ± 0.1e (0.0)	0.0 ± 0.0d
Terbacil	2000	Spring	18.5 ± 0.5bc	12.8 ± 0.6bcd	2.9 ± 0.1abcd (18.6)	32.0 ± 1.0b
Foramsulfuron	35	Spring	22.1 ± 2.1abc	12.1 ± 2.2cd	2.6 ± 0.1bcd (13.2)	32.0 ± 1.0b
Flazasulfuron	38	Fall	18.4 ± 3.0bc	11.5 ± 2.7cd	2.5 ± 0.1cd (11.6)	32.1 ± 2.2b
Flazasulfuron	50	Fall	15.3 ± 1.9cd	8.4 ± 1.5de	2.6 ± 0.1cd (13.2)	32.0 ± 0.8b
Flazasulfuron	38	Spring	14.5 ± 1.1cd	2.9 ± 1.2e	2.6 ± 0.1bcd (13.4)	20.8 ± 2.1c
Flazasulfuron	50	Spring	17.4 ± 0.7cd	2.8 ± 0.7e	2.5 ± 0.1cd (11.4)	15.1 ± 1.4c
Flazasulfuron	38	Summer	30.4 ± 3.6a	23.5 ± 0.6a	3.2 ± 0.1abc (22.7)	41.0 ± 0.8a
Flazasulfuron	50	Summer	26.8 ± 1.3ab	16.1 ± 2.7abcd	3.3 ± 0.1ab (25.2)	40.5 ± 2.2a
Flazasulfuron	38	Autumn	29.5 ± 2.4a	20.9 ± 1.2ab	3.6 ± 0.1 a (38.4)	41.8 ± 1.0a
Flazasulfuron	50	Autumn	29.3 ± 1.7a	22.4 ± 1.7a	3.4 ± 0.1 a (28.9)	43.4 ± 0.9a

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple means separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 4-4. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, inflorescence number, and inflorescence height in the non-bearing year 2016 at Londonderry, NS, Canada.

Active ingredient	Application rate (g a.i ha^{-1})	Application timing	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Inflorescence number ($stem^{-1}$)	Inflorescence height (cm)
-	-	-	47.3 ± 5.4a[a]	20.3 ± 2.1a	123.9 ± 19.7a	49.8 ± 1.8a
Propyzamide	2240	Fall	32.3 ± 5.4a	0.0 ± 2.1d	0.0 ± 19.7c	0.0 ± 1.8e
Terbacil	2000	Spring	30.2 ± 5.4a	14.0 ± 2.1abc	82.1 ± 19.7abc	36.2 ± 1.8c
Foramsulfuron	35	Spring	43.3 ± 5.4a	20.1 ± 2.1a	139.0 ± 19.7a	46.5 ± 1.8ab
Flazasulfuron	38	Fall	23.7 ± 5.4a	10.4 ± 2.1abcd	121.1 ± 19.7ab	42.1 ± 1.8bc
Flazasulfuron	50	Fall	31.0 ± 5.4a	11.0 ± 2.1abc	69.3 ± 19.7abc	37.6 ± 1.8c
Flazasulfuron	38	Spring	28.3 ± 5.4a	4.6 ± 2.1cd	25.4 ± 19.7bc	18.7 ± 1.8d
Flazasulfuron	50	Spring	37.0 ± 5.4a	7.9 ± 2.1bcd	68.5 ± 19.7abc	23.1 ± 1.8d
Flazasulfuron	38	Summer	45.8 ± 5.4a	20.0 ± 2.1a	158.9 ± 19.7a	52.3 ± 1.8a
Flazasulfuron	50	Summer	44.0 ± 5.4a	16.1 ± 2.2ab	164.6 ± 19.7a	51.1 ± 1.8a
Flazasulfuron	38	Fall	50.3 ± 5.4a	18.5 ± 2.1a	160.6 ± 19.7a	50.0 ± 1.8a
Flazasulfuron	50	Fall	44.5 ± 5.4a	18.1 ± 2.1ab	142.9 ± 19.7a	49.7 ± 1.8ab

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[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 4-5. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, inflorescence number, and inflorescence height in the non-bearing year 2016 at Parrsboro, NS, Canada. Inflorescence number and height were log(x) transformed. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Active ingredient	Application rate (g a.i ha^{-1})	Application timing	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Inflorescence number ($stem^{-1}$)	Inflorescence height (cm)
-	-	-	25.4 ± 2.4abcd[a]	18.5 ± 3.3ab	2.4 ± 0.2ab (10.7)	3.4 ± 0.1ab (29.6)
Propyzamide	2240	Fall	1.0 ± 0.6e	0.0 ± 0.0d	0.0 ± 0.2c (0.0)	0.0 ± 0.0d (0.0)
Terbacil	2000	Spring	16.4 ± 5.2bcd	10.5 ± 4.0abcd	2.0 ± 0.2ab (6.6)	3.2 ± 0.0bc (24.6)
Foramsulfuron	35	Spring	19.0 ± 2.1bcd	4.6 ± 1.5cd	1.5 ± 0.2b (3.8)	3.1 ± 0.0c (20.6)
Flazasulfuron	38	Fall	11.9 ± 3.5de	9.0 ± 3.2bcd	2.1 ± 0.1ab (7.7)	3.4 ± 0.0ab (28.1)
Flazasulfuron	50	Fall	13.1 ± 3.3cde	8.4 ± 2.9bcd	2.0 ± 0.2ab (6.6)	3.4 ± 0.0ab (29.0)
Flazasulfuron	38	Spring	17.1 ± 1.0bcd	8.8 ± 1.4bcd	2.0 ± 0.2ab (6.4)	3.1 ± 0.0c (21.9)
Flazasulfuron	50	Spring	24.4 ± 5.8bcd	10.6 ± 2.4abcd	2.0 ± 0.2ab (7.0)	3.1 ± 0.0c (20.8)
Flazasulfuron	38	Summer	33.9 ± 3.4a	23.6 ± 3.3a	2.3 ± 0.2ab (9.3)	3.5 ± 0.0a (32.0)
Flazasulfuron	50	Summer	27.7 ± 3.5abc	16.0 ± 4.3abc	1.9 ± 0.2ab (5.7)	3.5 ± 0.0a (31.3)
Flazasulfuron	38	Fall	18.3 ± 3.1ab	17.3 ± 2.4abc	2.4 ± 0.2a (11.9)	3.4 ± 0.1ab (30.1)
Flazasulfuron	50	Fall	15.8 ± 2.2abc	19.6 ± 2.7ab	2.6 ± 0.1a (13.2)	3.5 ± 0.0a (31.2)

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

There was a significant treatment effect on hair fescue inflorescence number in the non-bearing year at all sites ($p< 0.0001$). Inflorescence number was reduced to 0 in the fall bearing year propyzamide treatments as no tufts flowered in these plots (Table 4-3, 4-4 and 4-5). In Stewiacke, efficacies of fall bearing year flazasulfuron, spring non-bearing year flazasulfuron and foramsulfuron were similar and they all gave significant reductions in non-bearing fescue inflorescence number relative to the untreated control (Table 4-3). In Londonderry, spring non-bearing year flazasulfuron was most effective at reducing hair fescue inflorescence number in the non-bearing year outside of fall bearing year propyzamide treatment, with up to 79.5% inflorescence number reduction when applied at 38g a.i ha^{-1} (Table 4-3). It was followed by fall bearing year flazasulfuron and terbacil applications, while foramsulfuron was ineffective on reducing non-bearing year fescue inflorescence number in Londonderry (Table 4-4). There was a significant treatment effect on hair fescue inflorescence height in the non-bearing year at all sites ($p < 0.0001$). Inflorescence height was reduced to 0 in plots treated with fall bearing year propyzamide as no flowering tufts were found in these plots. The effect of other treatments varied across sites (Table 4-3, 4-4 and 4-5). Terbacil and foramsulfuron significantly reduced hair fescue inflorescence height at Stewiacke and Parrsboro, providing similar reductions in height at both sites (Table 4-3 and 4-5). Similar to the inflorescence number, foramsulfuron did not reduce inflorescence height in Londonderry, indicating that the hair fescue in Londonderry were more tolerant to foramsulfuron (Table 4-4). Fall bearing year flazasulfuron application provided similar height reduction of hair fescue with terbacil at Stewiacke and Londonderry (Table 4-3 and 4-4), while the efficacy was not as good at Parrsboro (Table 4-5). With the exception of fall bearing year propyzamide applications, spring non-bearing year flazasulfuron application was consistently most effective at suppressing hair fescue height (> 26%) in the non-bearing year across all sites (Table 4-3, 4-4 and 4-5).

There were significant treatment effects on fescue flowering tuft density, total tuft density, and inflorescence number in the bearing year at all sites ($p \leq 0.0004$). General trends were similar across sites. Hair fescues were completely recovered in the bearing year in plots treated with terbacil, foramsulfuron, fall bearing year flazasulfuron, and spring non-bearing year flazasulfuron across all sites (Table 4-6, 4-7 and 4-8). Fescue density and inflorescence number in these treatments did not differ from the untreated control in the bearing year (Table 4-6, 4-7 and 4-8). Summer non-bearing year flazasulfuron were also generally ineffective in the bearing year (Table 4-6, 4-7 and 4-8). Plots that were treated with fall bearing year propyzamide and fall non-bearing year flazasulfuron consistently had the lowest flowering tuft density (< 20%), total tuft density (< 40%), and inflorescence number (< 40%) across sites (Table 4-6, 4-7 and 4-8). Hair fescue flowering tuft density and inflorescence number were not reduced when fall non-bearing year flazasulfuron was applied at 50 g a.i ha^{-1} relative to 38 g a.i ha^{-1} (Table 4-6, 4-7 and 4-8). Even though propyzamide and fall non-bearing year flazasulfuron treatments effectively reduced hair fescue in bearing year, the remaining fescue inflorescences still interfered with the blueberry harvesting process. However, the harvesting process was a lot easier in these two treatments than that in the untreated control plots and other treatment plots. Fall bearing year propyzamide and fall non-bearing flazasulfuron also exhibited excellent crop tolerance, without blueberry plant damage and yield decreases observed in these plots. However, berry yield was not increased in these two treatments. Herbicide combinations of additional non-bearing year herbicides with fall non-bearing year propyzamide effectively eliminated hair fescue in both non-bearing year and bearing year, leading to significant yield increases (Chapter 3). Therefore, further research should be conducted to determine optimum additional herbicide treatments with fall non-bearing year flazasulfuron for improving hair fescue control and increasing blueberry yield as this flazasulfuron application timing, when used in combination with other sprout year herbicides, may provide effective control of hair fescue across both the non-bearing and bearing years of the wild blueberry production cycle. Terbacil, foramsulfuron, and flazasulfuron applications in the early spring of the non-bearing year did not reduce fescue grass flowering tuft density, total tuft density, and inflorescence number per tuft in the bearing year (Table 4-6, 4-7 and 4-8), indicating single-season hair fescue control from these treatments. Summer non-bearing year flazasulfuron application did not work on controlling fescue density and inflorescence number in neither non-bearing year or bearing year, indicating that summer non-bearing year flazasulfuron application should be avoided as this is after hair fescue flowering in the non-bearing year and the treatment provides little fescue suppression in the bearing year.

In conclusion, flazasulfuron can be safely used in wild blueberry fields at rates up to 50 g a.i g ha^{-1} in fall of the bearing year and spring, summer, and fall of the non-bearing year without injuring the crop. Application rates of 38 and 50 g a.i. ha^{-1} did not significantly affect flazasulfuron efficacy on hair fescue at all indicated application timings. Based on this, growers should use flazasulfuron at the lower rate for hair fescue control in wild blueberry. Application timing significantly affected the flazasulfuron efficacy on hair fescue. Flazasulfuron applied in fall bearing year or spring non-bearing year decreased hair fescue in non-bearing year, but hair fescue recovered in each treatment in the bearing year.

Spring non-bearing year application of flazasulfuron provided better hair fescue control in the non-bearing year than the fall bearing year flazasulfuron application. Summer non-bearing year application of flazasulfuron did not work in non-bearing year and bearing year, indicating the summer non-bearing year flazasulfuron application should be avoided. Fall non-bearing year flazasulfuron application most effectively reduced hair fescue tuft density and inflorescence number in the bearing year. As well, herbicide application alone at the end of sprout year did not improve the blueberry growth and increase yield. Therefore, further research is needed to determine the optimum herbicide use patterns of flazasulfuron with other sprout year herbicides to increase blueberry yield.

Table 4-6. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, and inflorescence number in the bearing year 2017 at Stewiacke, NS, Canada. Inflorescence number was log(x) transformed. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Active ingredient	Application rate (g a.i ha^{-1})	Application timing	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Inflorescence number ($stem^{-1}$)
-	-	-	25.2 ± 1.5a[a]	18.5 ± 1.5a	3.1 ± 0.2a (24.0)
Propyzamide	2240	Fall	8.2 ± 2.0c	3.0 ± 1.1b	1.1 ± 0.2b (3.3)
Terbacil	2000	Spring	20.9 ± 2.9a	13.4 ± 1.2a	3.3 ± 0.2a (30.6)
Foramsulfuron	35	Spring	22.2 ± 1.4a	16.5 ± 0.7a	3.3 ± 0.2a (31.0)
Flazasulfuron	38	Fall	16.4 ± 3.2abc	13.4 ± 2.4a	3.3 ± 0.2a (30.4)
Flazasulfuron	50	Fall	18.8 ± 1.8ab	13.5 ± 1.9a	3.3 ± 0.2a (30.0)
Flazasulfuron	38	Spring	23.3 ± 0.5a	15.5 ± 1.2a	3.3 ± 0.2a (22.0)
Flazasulfuron	50	Spring	16.1 ± 1.2abc	12.0 ± 0.8a	3.0 ± 0.2a (22.6)
Flazasulfuron	38	Summer	22.0 ± 1.7a	16.8 ± 2.0a	2.5 ± 0.2a (12.9)
Flazasulfuron	50	Summer	25.2 ± 1.9ab	14.8 ± 1.2a	2.7 ± 0.2a (14.3)
Flazasulfuron	38	Fall	9.4 ± 0.8c	2.6 ± 0.5b	1.2 ± 0.2b (3.6)
Flazasulfuron	50	Fall	10.1 ± 1.6bc	2.0 ± 0.4b	1.0 ± 0.2b (2.8)

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's multiple mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 4-7. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, and inflorescence number in the crop year 2017 at Londonderry, NS, Canada.

Active ingredient	Application rate (g a.i ha^{-1})	Application timing	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Inflorescence number (stem^{-1})
-	-	-	36.4 ± 4.2 a	22.1 ± 2.6 a	19 ± 3.5abcd
Propyzamide	2240	Fall	12.3 ± 4.2b	6.6 ± 2.6bc	8.1 ± 3.5d
Terbacil	2000	Spring	21.3 ± 4.2 ab	13.3 ± 2.6abc	26.6 ± 3.5abc
Foramsulfuron	35	Spring	40.3 ± 4.2a	22.8 ± 2.6a	22.8 ± 3.5abc
Flazasulfuron	38	Fall	20.5 ± 4.2ab	11.6 ± 2.6abc	31.3 ± 3.5ab
Flazasulfuron	50	Fall	22.6 ± 4.2ab	14.4 ± 2.6abc	29.0 ± 3.5abc
Flazasulfuron	38	Spring	26.3 ± 4.2ab	16.6 ± 2.6ab	27.1 ± 3.5a
Flazasulfuron	50	Spring	26.1 ± 4.2ab	17.6 ± 2.6ab	32.8 ± 3.5a
Flazasulfuron	38	Summer	34.5 ± 4.2a	19.3 ± 2.6ab	16.3 ± 3.5cd
Flazasulfuron	50	Summer	26.4 ± 4.2ab	11.5 ± 2.6ab	17.2 ± 3.5bcd
Flazasulfuron	38	Fall	10.8 ± 4.2b	3.5 ± 2.6c	7.3 ± 3.5d
Flazasulfuron	50	Fall	10.4 ± 4.2b	2.0 ± 2.6c	5.9 ± 3.5d

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Table 4-8. Effect of herbicide treatments on hair fescue total tuft density, flowering tuft density, and inflorescence number in the crop year 2017 at Parrsboro, NS, Canada. Inflorescence number was log(x) transformed. Transformed data are presented for means comparisons, and back-transformed data are presented in parentheses.

Active ingredient	Application rate (g a.i ha^{-1})	Application timing	Total tuft density (tuft m^{-2})	Flowering tuft density (tuft m^{-2})	Inflorescence number (stem^{-1})
-	-	-	25.5 ± 3.6a	17.0 ± 1.9ab	3.4 ± 0.2a (33.7)
Propyzamide	2240	Fall	8.8 ± 2.3b	4.0 ± 1.9d	2.3 ± 0.2bc (7.7)
Terbacil	2000	Spring	20.3 ± 2.1ab	14.4 ± 2.6abc	3.3 ± 0.2ab (33.1)
Foramsulfuron	35	Spring	22.5 ± 1.1a	14.8 ± 1.2abc	3.2 ± 0.2ab (24.6)
Flazasulfuron	38	Fall	17.1 ± 3.2ab	10.4 ± 2.3abcd	2.9 ± 0.2ab (19.7)
Flazasulfuron	50	Fall	20.0 ± 0.9ab	14.3 ± 1.6abc	3.3 ± 0.2ab (29.9)
Flazasulfuron	38	Spring	27.4 ± 2.9a	18.3 ± 1.0a	3.3 ± 0.2ab (29.4)
Flazasulfuron	50	Spring	24.4 ± 5.8a	15.8 ± 1.2abc	3.4 ± 0.2a (31.1)
Flazasulfuron	38	Summer	25.5 ± 4.9a	16.8 ± 1.4ab	3.3 ± 0.2ab (27.1)
Flazasulfuron	50	Summer	25.7 ± 3.2a	16.5 ± 0.3bcd	3.1 ± 0.2ab (25.2)
Flazasulfuron	38	Fall	18.3 ± 3.1a	9.0 ± 1.5cd	1.8 ± 0.2c (6.0)
Flazasulfuron	50	Fall	15.8 ± 2.2ab	7.5 ± 1.5cd	1.5 ± 0.2c (4.7)

[a] Means within columns followed by the same letter do not differ significantly according to a Tukey's mean separation test at the 0.05 level of significance. Values represent the mean ± 1 SE.

Chapter 5 - Conclusions

Overview

Perennial grasses are a serious weed problem in wild blueberry fields in Nova Scotia, and management of these weeds is difficult due to limited herbicide options. Therefore, it is important to explore and introduce new herbicides to wild blueberry fields for limiting spread of perennial grasses, as well as ensuring a long-term sustainable weed management. This project was focus on 1) determining the potential role of foramsulfuron in managing poverty oat grass, tickle grass and bluegrass in wild blueberry fields; 2) developing use patterns for foramsulfuron and glufosinate on hair fescue to try to reduce the reliance on propyzamide; and 3) evaluating flazasulfuron for hair fescue management in wild blueberry fields.

Potential role of foramsulfuron in managing poverty oat grass, tickle grass, and bluegrass

In chapter 2, we concluded that foramsulfuron had variable efficacy on perennial grasses in wild blueberry fields. Results indicated that foramsulfuron supressed bluegrass and provided complete control to tickle grass when applied at the currently registered rate of 35 g a.i ha^{-1}, while poverty oat grass was not adequately controlled or suppressed by this application rate. Poverty oat grass and tickle grass seedlings were, however, both susceptible to foramsulfuron in a greenhouse dose response study, requiring no more than 5 g a.i ha^{-1} foramsulfuron to reduce final plant biomass by half. Poverty oat grass did appear to be more tolerant in the greenhouse study as well as most poverty oat grass plants survived in the pot experiment while most of the tickle grass seedlings were killed.

Foramsulfuron was effective at slowing down poverty oat grass seedling biomass accumulation, but visual injury of poverty oat grass occurred slowly. Therefore, foramsulfuron should be considered in a herbicide rotation for managing tickle grass, but not poverty oat grass. Foramsulfuron suppressed bluegrass, but it did not provide a complete control when applied alone. Therefore, further research can be conducted to explore potential roles of foramsulfuron when it is applied in conjunction with other herbicides, such as later season application of fluazifop-p-butyl or sethoxydim.

Chapter 2 also concludes that there was no effect of mesotrione on foramsulfuron efficacy when they are applied as tank mixture. Based on this, growers should consider use of tank mixture of foramsulfuron with mesotrione when both susceptible broadleaf and perennial grass weeds are present as this tank mix did not have antagonistic effects on controlling target grass species.

Herbicide use pattern for hair fescue management

In Chapter 3, we explored various herbicide combinations for managing hair fescue in wild blueberry fields. Specifically, experiments in this chapter were designed to determine 1) if hair fescue control from fall bearing year propyzamide applications is improved by spring herbicide applications, 2) if hair fescue suppression from spring non-bearing year foramsulfuron applications is improved by fall bearing year herbicide applications, and 3) if spring non-bearing year combinations of terbacil, foramsulfuron, and glufosinate control hair fescue. Fall bearing year propyzamide was still the most effective method for non-bearing year hair fescue control. Additional spring non-bearing year herbicide application of foramsulfuron, terbacil, or glufosinate did not improve non-bearing year hair fescue control, compared to that achieved with fall bearing year propyzamide application alone. Additional spring non-bearing year herbicide applications should not be used when propyzamide has been applied in the previous fall season to control hair fescue in the non-bearing year, both to save money on herbicides and to prevent herbicide resistance. Even though fall bearing year propyzamide application alone provided a good control of hair fescue in the non-bearing year, fescue began to recover in the bearing year, and all tested additional spring non-bearing herbicides application did not reduce it. Therefore, further research should be focus on determining if bearing year hair fescue suppression from fall bearing year propyzamide can be improved by fall non-bearing year or spring bearing year herbicide applications.

Besides propyzamide, the glufosinate and terbacil tank mixture, followed by foramsulfuron in spring non-bearing year suppressed non-bearing year hair fescue, and it can be an alternative treatment to propyzamide to manage hair fescue in the non-bearing year. These two herbicide use patterns both provided nearly complete control of hair fescue in the non-bearing year. Besides these two herbicide use patterns, non-bearing year hair fescue suppression can also be achieved with spring foramsulfuron applications, preceded by fall applications of dichlobenil, or preceded by fall and spring applications of glufosinate. Even though these herbicide use patterns were effective at non-bearing year hair fescue management, significant recovery of hair fescue occurred in the bearing year occurred most treatments evaluated across experiments. Regrowth of hair fescue in the bearing year effected wild blueberry yield and interfered with the harvesting process. Our results indicated that weed control in fall non-bearing year or spring of the bearing year is therefore essential when developing hair fescue management strategies in commercial wild blueberry fields. However, propyzamide is currently the only herbicide available for bearing year hair fescue control, and bearing year suppression or control of hair fescue was only achieved in treatments containing propyzamide. Therefore, further research should be conducted to develop alternative treatments to propyzamide in fall of the non-bearing year, or to find bearing year herbicides, to improve hair fescue management throughout the whole two-year wild blueberry crop cycle. In particular, reducing reliance on propyzamide over the long term will require new herbicides that can be used in conjunction with foramsulfuron and other less effective treatments.

The objective of Chapter 4 was to evaluate flazasulfuron for hair fescue suppression and crop tolerance in wild blueberry. Flazasulfuron supressed non-bearing year hair fescue when the application was made in fall of the bearing year or in spring of the non-bearing year, though summer non-bearing year applications were ineffective and should be avoided. Similar to other suppressive treatments, however, hair fescue recovered in these treatments in the bearing year and additional treatments would be required to provide control over the 2-yr production cycle. Fall non-bearing year flazasulfuron applications, however, gave good suppression of hair fescue in the bearing year. This herbicide may therefore have a role as an alternative to propyzamide as a fall non-bearing year treatment and could contribute to reduced propyzamide use if a registration in wild blueberry can be obtained. Our results also showed that flazasulfuron exhibited excellent crop tolerance on wild blueberry, with no reduction to wild blueberry plant growth and the blueberry yield at any tested application timings and rates. With the flexible application timing and the good performance on hair fescue control, flazasulfuron should be explored in further studies to determine the optimum herbicide use patterns with other registered herbicides for improving hair fescue management in wild blueberry.

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