EVALUATION OF CLETHODIM FOR HAIR FESCUE (*FESTUCA FILIFORMIS* POURR) AND RED FESCUE (*FESTUCA RUBRA* L.) MANAGEMENT IN LOWBUSH BLUEBERRY (*VACCINIUM ANGUSTIFOLIUM* AITON) FIELDS IN NOVA SCOTIA

by

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Dalhousie University is located in Mi'kma'ki, the
ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

DEDICATION

This thesis is dedicated to my parents, Kimble and Darlene MacLean.

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Abstract

Lowbush blueberry is grown on a two year cycle of mowing, growing, wintering, fruiting, and harvesting. Lowbush blueberry fields cannot be tilled as the crop predominantly spreads via underground rhizomes during the vigorous growth triggered by mowing. The perennial no-till nature of this cropping system leads to challenges managing perennial weeds like hair fescue and red fescue. The tuft forming hair fescue represents a serious threat to the productivity of lowbush blueberry fields, whereas the rhizomatous red fescue is an emerging threat. Both are difficult to manage with currently available herbicides and have a history of resistance development. Clethodim is a group 1 herbicide that has shown variable efficacy on *Festuca spp.* and has preliminary research showing suppression of hair fescue in lowbush blueberry during the non-bearing year. Non-bearing and bearing year field efficacy trials were established for hair and red fescue. Greenhouse efficacy trials and field dose response trials were also conducted for hair fescue. Non-bearing and bearing year clethodim applications reduced hair flowering tuft density and tuft inflorescence count ($P \leq 0.0126$). Clethodim also reduced leaf number ($P < 0.0001$) and dry biomass ($P < 0.0001$) of fescue plants from 15 separate populations in greenhouse trials. Dose response trials indicated the anticipated label rate of 91 g a.i. ha^{-1} is adequate for suppression of hair fescue. Red fescue was not suppressed in the non-bearing year ($P \geq 0.0966$) while bearing year applications reduced flowering stem density by 93.2% ($P = 0.0006$). This thesis supports the registration of clethodim for the management of hair fescue in lowbush blueberry fields and additional research is required to determine if clethodim will contribute to red fescue management.

List of Abbreviations

Abbreviation	Definition
°C	Degrees Celsius
a.i.	Active ingredient
ACCase	Acetyl-CoA carboxylase
ANOVA	Analysis of variance
CDN	Canadian Dollars
cm	Centimeter
CO_2	Carbon dioxide
g	Gram
ha	Hectare
hr	Hour
kg	Kilogram
km	Kilometer
L	Litre
m	Meter
mm	Millimeter
N	North
SE	Standard error
SQRT	Square root
W	West

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Chapter 1: Introduction

Abstract

Lowbush blueberry is grown on a two year cycle of mowing, growing, wintering, fruiting, and harvesting. Lowbush blueberry fields cannot be tilled as the crop predominantly spreads via underground rhizomes during the vigorous growth triggered by mowing. The perennial no-till nature of this cropping system leads to challenges managing perennial weeds like hair fescue and red fescue. The tuft forming hair fescue represents a serious threat to the productivity of lowbush blueberry fields, whereas the rhizomatous red fescue is an emerging threat. Both are difficult to manage with currently available herbicides and have a history of resistance development. Clethodim is a group 1 herbicide that has shown variable efficacy on *Festuca spp.* grasses and has preliminary research showing suppression of hair fescue in lowbush blueberry during the non-bearing year.

1.1 – Introduction

Wild, or lowbush blueberry (*Vaccinium angustifolium* Aiton) is a perennial shrub which spreads by seeds and rhizomes (Pritts & Hancock, 1984). Production area in Nova Scotia exceeds 15000 ha (Anonymous, 2021). Lowbush blueberry production in Canada was worth \$121.5 million and \$112.2 million in farmgate value in 2019 and 2020, respectively (Anonymous, 2021). Lowbush blueberries account for the majority of blueberry production in Canada both in value (53.3%) and tonnage (60.6%) (Anonymous, 2020). Most lowbush blueberry fields are managed on a two year cycle where fields are mowed to the ground to stimulate new shoot growth in the first (non-bearing) year, and fruit is produced in the second (bearing) year (Eaton et al., 2004).

Weeds are highly problematic in lowbush blueberry fields, contributing to high variations in yield (Yarborough, 2011), and weed abundance has been increasing over the last several decades (Lyu et al., 2021). A common problematic weed in lowbush blueberry fields is hair fescue (*Festuca filiformis* Pourr). Hair fescue is a perennial, tuft-forming grass that is present in approximately 75% of lowbush blueberry fields in Nova Scotia (Lyu et al., 2021). Red fescue (*Festuca rubra* L.), a rhizomatous perennial grass, has also increased in occurrence (Lyu et al., 2021) and, although less common than hair fescue, reduces yields and is difficult to manage (Sikoriya, 2014).

Managing hair and red fescue is challenging in lowbush blueberry as few currently registered herbicides manage or suppress these grasses and they cannot be managed with non-chemical weed control practices such as tillage. Previously effective herbicides, such as terbacil (WSSA Group 5) and hexazinone (WSSA Group 5), exhibit variable efficacy on hair fescue (White, 2019) and hexazinone-resistant hair fescue biotypes have recently been identified in lowbush blueberry fields (Laforest et al., 2022). Both species can be suppressed with postemergence foramsulfuron (WSSA Group 2) applications (Sikoriya, 2014; White and Kumar, 2017), with the recently registered herbicide flazasulfuron (WSSA Group 2) providing additional suppression of hair fescue (Zhang et al. 2018; White 2022). Both herbicides, however, exhibit the same site of action and therefore exhibit risk of resistance evolution with repeated use. Pronamide (WSSA Group 3) provides good control of both hair and red fescue, but overreliance on this herbicide also poses risks for resistance evolution. Pronamide is also expensive ($500.00

ha^{-1} CDN), limiting use of this herbicide by growers during periods of low crop prices. Pronamide is, however, the only currently registered herbicide for bearing year hair and red fescue management, forcing many growers to overuse this herbicide or suffer significant reductions in net returns in order to harvest their bearing year fields. As such, new herbicides with unique modes of action and bearing year application timings are required to help improve hair fescue management in lowbush blueberry fields.

Clethodim (WSSA Group 1) is a postemergence herbicide used for annual and perennial grass management that was recently identified as having efficacy on hair fescue (White and Graham, 2021). Initial work with this herbicide, however, was limited to only a few field sites and it was not evaluated on red fescue. As such, additional research is required to identify the utility and efficacy of this herbicide on hair and red fescue in lowbush blueberry. The overall objective of this research is to evaluate clethodim efficacy on hair and red fescue in lowbush blueberry fields. This work will be accomplished through field and greenhouse trials and the data collected during this research will be used to support the registration of clethodim in lowbush blueberry and as the basis for grower recommendations for clethodim use following registration.

Literature review

1.2.1 – Lowbush blueberry

1.2.1.1 – Blueberry production

Lowbush blueberry is native to Nova Scotia and commercial fields are developed on deforested land or old agricultural fields (Hall, 1959). The plant is a perennial rhizomatous woody shrub and plants spread by both seed and rhizomes in commercial fields (Pritts &

Hancock, 1984). Fields are developed on former farm or woodland that already have blueberry plants present (Government of Canada, 2017; Hall, 1959). Stands are comprised of genetically identical plants, or “clones” that started from seed but now spread via rhizomes (Drummond, 2019; Hall, 1959) The crop is managed on a two year cycle in which stems are mowed to the ground to promote new vegetative growth from the rhizome during the first, or non-bearing year (Eaton et al., 2004) and plants produce flowers and fruit in the second, or bearing year (Fig. 1.1).

Figure 1.1. Lowbush blueberries ready for harvest with hair fescue growing throughout.

1.2.1.2 – Weeds in lowbush blueberry

Weeds are a major limiting factor in lowbush blueberry production (Jensen, 1985). The number of weed species, amount of each species, and total amount of weeds has increased in lowbush blueberry fields in the last three decades (Lyu et al., 2021; McCully et al., 1991). A recent weed survey identified 211 weed species in lowbush blueberry fields in Nova Scotia (Lyu et al., 2021) compared to 141 species identified in a similar survey in 1984-1985 (McCully et al., 1991). The dominant weeds are herbaceous and woody perennials, followed by annual broadleaf plants and perennial grasses (Lyu et al., 2021). The prominence of perennial weeds is likely the product of the no-till, perennial monoculture associated with lowbush blueberry production (McIsaac, 1997).

Weeds cause a variety of production issues in lowbush blueberry fields. They compete with lowbush blueberry for space (Yarborough & Bhowmik, 1993), light (Hall, 1958), and nutrients (Penney & Macrae, 2000). Infestations of weeds reduce berry quality and contribute to high variation in yield (Ismail et al., 1981; Yarborough & Bhowmik, 1989). Additionally, species such as bunchberry (*Cornus canadensis*), can lower the fruit quality by contributing undesirable berries to the harvest, reducing the product value (Yarborough & Bhowmik, 1993). Mechanical harvesters can be a vector for weeds to spread within and between fields (Boyd & White, 2009). Weeds also reduce harvester efficiency by clogging harvester heads which must then be manually removed by the operator (Peter Burgess, personal communication).

1.2.1.3 – Weed management in lowbush blueberry fields

Weed management in lowbush blueberry fields increases blueberry stem density, flower buds per stem, and fruit yield (Yarborough et al., 1986) and is essential to sustainable lowbush blueberry production. Large scale use of herbicides for weed management was associated with terbacil and hexazinone registration in the late 1970's and early 1980's. Terbacil was the first selective PRE herbicide in lowbush blueberry and doubled yields when used (Ismail et al., 1981). Hexazinone provided broader-spectrum weed management and likewise caused large yield increases when used (Yarborough et al., 1986; Yarborough & Bhowmik, 1989). Furthermore, hexazinone managed many species of grasses, sedges, and herbaceous and woody broadleaf species during the initial years of use (Jensen, 1985).

Today close to 20 herbicides are registered for weed management in lowbush blueberries in Canada and chemical weed management has become the dominant form of weed management in this cropping system due to the perennial monoculture associated with lowbush blueberry production (Anonymous, 2017). Prior to the introduction of broad spectrum herbicides in the 1980s weed management largely consisted of cutting, burning, pruning, and spot spraying broad spectrum herbicides (Jensen, 1985).

Weed management can include non-chemical controls. Non-chemical controls may include cultural, mechanical, biological, and preventative measures. Cultural controls include methods such as burn pruning, a method which previously aided in weed management but is now rarely utilized by growers due to regulatory pressures (Penney et al., 1997). Mechanical management consists of the physical removal of weed species which is cost prohibitive (Yarborough & Marra, 1997). Biological control is typically effective in highly controlled systems where a single species is the target of the management, which is not the case a blueberry field. Preventative measures include practices such as cleaning equipment between uses and before entering a new field which aids in preventing the spread of weed seeds (Boyd & White, 2009).

1.2.2 – Hair fescue (*Festuca filiformis* Pourr)

1.2.2.1 – Species identification

Hair fescue is a fine leaved, tuft forming grass that is originally native to Europe (Aiken et al., 1997). This species was introduced to North America as a turf grass species and has since spread throughout the Eastern and Western United States and Canada (Anonymous, 2016).

Hair fescue leaves are deep green or bluish grey green and can reach up to 40 cm long (Aiken et al., 1997). Tufts form dense bases due to an abundance of tillering (White, 2018). Tillers are erect with purple bases (Aiken et al., 1997). This plant does not produce horizontal rooting stems, but rather vegetative shoots (tillers) grow out from the crown of the tuft. Inflorescences are about 4 cm long, forming at the end of flowering stalks. Individual plants can produce over 3000 seeds which shatter easily from the panicle inflorescence (Munro et al., 2014; White & Kumar, 2017). Seeds lack primary dormancy and germinate readily in the spring and fall (Piessens et al., 2005; White, 2018).

1.2.2.2 – Economic significance

Hair fescue occurs in 75% of lowbush blueberry fields in Nova Scotia (Lyu et al., 2021). Hair fescue reduces lowbush blueberry yield by up to 50% (White, 2019), however, the cause of yield loss is not clear (White, 2019) and consistent yield losses have not occurred in research trials (White & Kumar, 2017). Other perennial grasses, however, also reduce yield potential and yield (Boyd et al., 2014; Sikoriya, 2014) and growers report yield losses due to hair fescue, especially in areas where the grass forms dense sods. Hair fescue also interferes with mechanical harvesting by jamming mechanical harvest heads with leaves and flowering stems (Peter Burgess, personal communication).

1.2.2.3 – Population dynamics

Hair fescue reproduces and spreads exclusively by seed. The plant is a cool season grass with a vernalization requirement for flowering (White, 2018). Flowers are produced in early spring and mature seed is formed by late summer. Hair fescue tufts can produce over 3000 seeds (White & Kumar, 2017). The majority of hair fescue seeds remain near the soil surface in lowbush blueberry fields (White, 2018), similar to weed seed in other no-till cropping systems (Cardina et al., 2009; Yenish et al., 1992). Seeds lack primary dormancy and new seedlings therefore emerge in fall following release of seeds by parent plants, with additional seedlings emerging in the spring (White, 2018). Mean seedling density in lowbush blueberry fields ranges from 1500 to over 6000 seedlings m^{-2} (White, 2018; Wilcox & Healy, 2016). Seedbanks are likely transient due to lack dormancy as seed banks can be reduced when hair fescue is effectively managed (White, 2019). Seed longevity is limited but not well defined (Piessens et al., 2005) and no data on seed longevity in lowbush blueberry fields are available. Seeds lack natural secondary dispersal mechanisms but are likely dispersed by human-mediated secondary seed dispersal on equipment such as harvesters (Boyd and White, 2009).

1.2.2.4 – Hair fescue management

Hair fescue was previously managed with preemergence atrazine, terbacil, and hexazinone applications (Jensen 1985; Jensen 1986). The atrazine registration for lowbush blueberries in Canada, however, was discontinued in the early 2000's (Anonymous, 2003). Terbacil applications provide good non-bearing year control in some fields (White, 2019) but efficacy of this herbicide is variable in Nova Scotia due to suspected resistance development (White & Zhang, 2020; Zhang et al., 2018). Hexazinone no longer controls hair fescue in Nova

Scotia and elsewhere (White, 2019; Yarborough and Cote, 2014; Zhang, 2017) and hexazinone-resistant hair fescue biotypes have recently been identified in Nova Scotia (Laforest et al. 2022).

At present time hair fescue is most effectively managed by PRE applications of pronamide (White, 2019; Yarborough & Cote, 2014; Zhang et al., 2018). This herbicide generally provides >90% hair fescue control throughout the 2-yr production cycle (White, 2019). This herbicide is expensive (>$500.00 CDN ha^{-1}) and requires cold soil and air conditions to be effective. These conditions are becoming increasingly more difficult to predict due to climate change. As such, lowbush blueberry growers are interested in alternatives to this herbicide for hair fescue management.

Hair fescue can be suppressed during the non-bearing year with POST glufosinate, nicosulfuron + rimsulfuron, flazasulfuron, or foramsulfuron applications (White and Kumar, 2017; White, 2019; White and Zhang, 2020; Zhang et al., 2018; Zhang, 2017). Glufosinate does not reduce living tuft density but may reduce flower tuft density and inflorescence number (White, 2019). Similarly, foramsulfuron does not reduce total tuft density but reduces flower tuft density and inflorescence number (White, 2019). Hair fescue tufts recover from non-bearing year glufosinate and foramsulfuron applications by the bearing year, however, complete control is not obtained unless fall non-bearing year pronamide applications are used in conjunction with these herbicides. Flazasulfuron is generally more effective than nicosulfuron + rimsulfuron and foramsulfuron, particularly when applied in tank mixture with glufosinate (White, 2022). This herbicide shares a similar site of action with nicosulfuron + rimsulfuron and foramsulfuron, however, and there is a risk of resistance evolution to nicosulfuron +

rimsulfuron, foramsulfuron, and flazasulfuron due to ongoing use of these herbicides for hair fescue suppression.

1.2.3 – Red fescue (*Festuca rubra* L.)

1.2.3.1 – Species identification

Red fescue is another cool season perennial *Festuca* spp. in lowbush blueberry fields in Nova Scotia (Lyu et al., 2021). This species includes at least 10 subspecies (Anonymous, 2012). Most subspecies are able to spread and regrow via rhizomes as well as seed. Red fescue produces a single inflorescence per shoot and the base of stems are reddish in colour (Fig. 1.2). The culm is hollow and can be 30 – 100 cm tall (Anonymous, 2012). Most leaves are basal, 5 – 15 cm long, and only 1 – 2 mm wide. New shoots grow out of the leaf axils and leaf sheaths. Red fescue is a hardy species but does best in well drained, acidic soil (Anonymous, 2012). The plant is also shade and drought tolerant.

Figure 1.2. Red fescue specimen with a large amount of tillering.

1.2.3.2 – Economic significance

Red fescue is a relatively new weed species in lowbush blueberry fields. It forms dense stands that can spread rapidly via rhizome and presumably by seed (Sikoriya, 2014). The first instance of red fescue in lowbush blueberry production in Nova Scotia was found in 2008 by the Vegetation Management Research Program at the Nova Scotia Agricultural College (now Dalhousie Faculty of Agriculture) (Sikoriya, 2014). It is suspected to have been introduced years prior to being detected as contamination in hay bales. Red fescue populations have increased from a 0.8% occurrence in lowbush blueberry fields in 2000-2001 to about 8% in 2017-2019

(Lyu et al., 2021). In fields where the weed was present it had high field uniformity and density (Lyu et al. 2021) suggesting the weed spreads aggressively in infested fields. This weed is expected to continue to spread throughout the blueberry industry and cause severe yield reductions (Sikoriya, 2014).

1.2.3.3 – Red fescue management

Limited research has been done on the chemical management of red fescue in lowbush blueberry, with the most effective control obtained from fall pronamide applications (Sikoriya, 2014). Managing red fescue with glyphosate increased blueberry yield by 56% (Sikoriya, 2014), suggesting this grass reduces yield in lowbush blueberry fields. Spring glyphosate applications prior to lowbush blueberry emergence can be effective (Sikoriya, 2014) but have not been adopted by growers due to crop injury risk if glyphosate contacts actively growing blueberry plants. Other common herbicides user in lowbush blueberry such as terbacil, hexazinone, glufosinate, and foramsulfuron provide variable suppression of red fescue and none provide effective control.

1.2.4 – Clethodim

Clethodim is a post-emergence, group one herbicide (acetyl coA-carboxylase (ACCase) inhibitor), used to manage several grass species in a variety of crops. The herbicide is absorbed by the plant through foliage where it then moves to growing points in the roots and shoots. This herbicide inhibits the ACCase enzyme which prevents new fatty acid synthesis ultimately required for cell growth (Shaner, 2014). Clethodim should be applied after sensitive grass species begin growth in spring but prior to emergence of inflorescences (Reynolds et al., 1993).

Clethodim is unique among the group one herbicides in that it exhibits variable levels of toxicity on *Festuca* spp. For example, clethodim applied in spring or fall at 22.4 g a.i. ha^{-1} reduced inflorescence count in tall fescue (*Festuca arundinacea* Schreb) (Reynolds et al., 1993). Increasing rate of clethodim, later treatment dates, and using crop oil concentrate adjuvant also increased clethodim's activity on tall fescue (Reynolds et al., 1993). Clethodim reduced seed production of creeping red fescue (*Festuca rubra L.*), chewing fescue (*Festuca rubra* L. *subsp. commutata*), and hard fescue (*Festuca ovina* L. var. *duriuscula*) in commercial turf grass seed production systems (Cole et al., 2002). Inflorescence production was also suppressed in chewing and hard fescue. Initial research with hair fescue in lowbush blueberry indicates clethodim reduces flowering tuft density and inflorescence number (White & Graham, 2021). This suggests clethodim has potential to reduce the seedbank and seedling recruitment of hair fescue (White, 2018) and may contribute to management of both hair and red fescue.

1.2.5 – Objectives and hypotheses

The overall objective of this research was to determine clethodim efficacy on hair and red fescue in lowbush blueberry fields. Specific objectives of the research were to 1) evaluate clethodim efficacy in multiple non-bearing year lowbush blueberry fields in Nova Scotia using field and greenhouse trials, 2) evaluate clethodim for bearing year hair fescue suppression in lowbush blueberry fields, 3) determine the effect of clethodim application rate on hair fescue suppression and lowbush blueberry tolerance, and 4) evaluate clethodim for red fescue suppression in non-bearing and bearing year lowbush blueberry fields. This research was based on the hypotheses that 1) hair fescue susceptibility to clethodim is consistent across geographic locations, 2) clethodim provides bearing year hair fescue suppression, 3) hair fescue suppression is improved with higher clethodim application rates, and 4) clethodim also provides suppression of red fescue in lowbush blueberry fields.

Chapter 2: Evaluation of clethodim for hair fescue (*Festuca filiformis* Pourr) suppression in lowbush blueberry (*Vaccinium angustifolium* Aiton)

Abstract

Lowbush blueberry is grown on a two-year cycle in which fields are pruned to ground level in the first year and fruit are harvested in the second year. Lowbush blueberry fields cannot be tilled as the crop predominantly spreads via underground rhizomes during the vigorous growth triggered by mowing. The perennial no-till nature of the crop leads to challenges managing perennial weeds. A common perennial weed in lowbush blueberry fields is hair fescue, which is now present in 75% of fields in Nova Scotia. This weed spreads rapidly, reduces yield, and is challenging to manage due to limited efficacy of currently registered herbicides and occurrence of herbicide-resistant biotypes. The objectives of this research were to 1) evaluate clethodim efficacy on a range of hair fescue populations in Nova Scotia, 2) determine if bearing year clethodim applications suppress hair fescue, and 3) utilize dose response methodology to determine the response of hair fescue to a range of clethodim application rates. Clethodim reduced hair fescue flowering tuft density ($P \leq 0.0126$) and tuft inflorescence count ($P \leq 0.0001$) at seven of nine non-bearing year sites and reduced flower tuft density and tuft inflorescence count at six bearing year sites ($P \leq 0.0001$). Clethodim reduced leaf number ($P \leq 0.0001$) and dry biomass ($P \leq 0.0001$) of greenhouse-grown hair fescue plants grown from seeds collected from 15 different populations. The dose response trial indicated the anticipated label rate of 91 g a.i. ha^{-1} is adequate for suppression of hair fescue. Together these

results suggest clethodim can be an effective tool in managing hair fescue in lowbush blueberry.

2.1 – Introduction

Lowbush blueberry fields are the product of native stands which are developed into dense commercial fields (Government of Canada, 2017). Fields are grown on a two-year cycle in which stems are mowed to the ground in the first (non-bearing) year to promote new vegetative growth and flower bud formation. Plants flower and produce fruit in the second (bearing) year. Weeds are highly problematic in lowbush blueberry fields and contribute to high variations in yield (Yarborough, 2011). A recent weed survey identified 211 weed species in lowbush blueberry fields in Nova Scotia (Lyu et al., 2021) compared to 141 species identified in a similar survey in 1984-1985 (McCully et al., 1991). Likely due to the perennial, no-till, nature of this cropping system, the dominant weeds are perennial shrubs and grasses (McIsaac, 1997).

A common perennial grass weed in lowbush blueberry fields is hair fescue (*Festuca filiformis* Pourr). Hair fescue is a perennial, tuft-forming grass that occurs in approximately 75% of lowbush blueberry fields in Nova Scotia (Lyu et al., 2021). This grass is a concern in lowbush blueberry fields because tufts form dense sods that reduce lowbush blueberry yield by up to 50% (White, 2019). Individual tufts can produce hundreds of inflorescences (Zhang et al., 2018) that clog mechanical harvesters, reducing harvest efficiency and contributing to reductions in berry quality (Peter Burgess, personal communication). Seeds of this grass also shatter easily from the panicle inflorescence (Munro et al., 2014) and are common contaminants on harvesting equipment (Boyd and White, 2009). Seeds also lack primary dormancy, resulting in rapid increase in established populations via seedling recruitment following the seed rain in autumn (White, 2018).

Hair fescue management is challenging in lowbush blueberry as few currently registered herbicides control or suppress this grass and it cannot be managed with non-chemical weed control practices such as tillage. Previously effective herbicides, such as terbacil (WSSA Group 5) and hexazinone (WSSA Group 5), exhibit variable efficacy on hair fescue (White, 2019) and hexazinone-resistant hair fescue biotypes have recently been identified in lowbush blueberry fields (Laforest et al., 2022). Hair fescue can be suppressed with postemergence foramsulfuron applications (Sikoriya, 2014; White and Kumar, 2017), with the recently registered herbicide flazasulfuron (WSSA Group 2) providing additional suppression (Zhang et al., 2018; White, 2022). Both herbicides, however, exhibit the same site of action and therefore exhibit risk of resistance evolution with repeated use. Pronamide (WSSA Group 3) provides good control of hair fescue, but overreliance on this herbicide also poses risks for resistance evolution. Pronamide is also expensive (\$500.00 ha^{-1} CDN) and has strict weather conditions needed to achieve optimal efficacy. These factors limit use of this herbicide by growers. Pronamide is, however, the only currently registered herbicide for bearing year hair fescue management, forcing many growers to overuse this herbicide or suffer significant reductions in net returns in order to harvest their bearing year fields. As such, new herbicides with unique sites of action and bearing year application timings are required to help improve hair fescue management in lowbush blueberry fields.

Clethodim (WSSA Group 1) is a postemergence herbicide used for annual and perennial grass management that was recently identified as having efficacy on hair fescue in lowbush blueberry (White and Graham, 2021). Initial work with this herbicide, however, was limited to only a few field sites. As such, additional research is required to identify the utility and efficacy of clethodim on hair fescue in lowbush blueberry.

The objectives of this research were to 1) evaluate clethodim efficacy on a range of hair fescue populations in Nova Scotia, 2) determine if bearing year clethodim applications suppress hair fescue, and 3) utilize dose response methodology to determine the response of hair fescue to a range of clethodim application rates. These objectives are based on the hypotheses that 1) clethodim will exhibit similar efficacy across a range of hair fescue populations, 2) bearing year hair fescue applications will suppress hair fescue, and 3) clethodim application rates above 91 g a.i. ha^{-1} (anticipated label rate for lowbush blueberry) will improve hair fescue suppression.

Materials and Methods

2.2.1 – Evaluation of clethodim efficacy on hair fescue populations in Nova Scotia lowbush blueberry fields

The objective of this experiment (experiment 1) was to evaluate clethodim efficacy on hair fescue populations in lowbush blueberry fields throughout Nova Scotia using field and greenhouse trials. The field experiment was conducted in 9 non-bearing year lowbush blueberry fields throughout Colchester, Cumberland, and Pictou Counties in Nova Scotia in 2021 and 2022 (Table 2.1). The field experiment consisted of 5 treatments arranged in a Randomized Complete Block Design with 5 blocks and 2 m X 4 m plot size. Treatments consisted of 1) nontreated control, 2) foramsulfuron (WSSA Group 2) (35 g a.i. ha^{-1}) (Option OD herbicide, Bayer CropScience Inc., Calgary AB, Canada), 3) fluazifop-p-butyl (WSSA Group 1) (250 g a.i. ha^{-1}) (Venture L herbicide, Syngenta Canada Inc., Guelph, ON, Canada), 4) sethoxydim (WSSA

Group 1) (495 g a.i. ha^{-1}) (Poast Ultra herbicide, BASF Canada, Mississauga, ON, Canada), and 5) clethodim (91 g a.i. ha^{-1}) (Select herbicide, Arysta LifeScience North America, LLC, Cary, NC, USA). Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer, sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant (Merge, BASF Canada, Mississauga, ON, Canada) and clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant (Amigo adjuvant, UPL AgroSolutions Inc., King of Prussia, PA, USA). Herbicide treatments were applied during daylight hours using a CO_2-pressurized research plot sprayer (Pentair, Ireland, UK) equipped with four Hypro ULD120-02 (ultra-low drift with 120° spray angle) nozzles (BellSpray Inc., LA, USA) and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa. Herbicide application dates and related weather conditions are provided in Table 2.1. Weather conditions were measured with a Kestrel 3000 pocket weather meter. Drift was managed by using ultra-low drift spray nozzles and waiting to spray until periods of low wind.

The greenhouse experiment was arranged in a completely randomized design with five replications and four treatments. Treatments were as described for the field experiment, though sethoxydim was not included in the greenhouse experiment due to space constraints. Hair fescue plants were established from seed collected from 15 lowbush blueberry fields throughout Nova Scotia (Table 2.2) and each population (e.g., seed from a specific field) was evaluated as a separate experiment. Hair fescue seeds were germinated and planted into 13cm X 10.5cm X 6cm (L X W X H) (820 cm^{-3}) pots as outlined by White and Kumar (2017) and White (2018). Four plants were established in each pot, with each pot representing a single experimental unit. Plants were grown for 6 weeks prior to treatment with herbicides and were at the 7 ± 0 leaf stage at the time of herbicide applications (Fig. 2.1). Herbicides were applied during daylight hours using a CO_2-pressurized single nozzle research sprayer equipped with a TeeJet 8002 nozzle and calibrated to deliver 200 L water ha^{-1} at 276 kPa.

Figure 2.1. Setup for the hair fescue greenhouse efficacy trials. Each site has two trays with two treatments each replicated five times.

Data collection in the field experiment included hair fescue tuft density at the time of herbicide applications, hair fescue vegetative and flowering tuft density in July of the non-bearing and bearing years, and hair fescue tuft inflorescence number in July of the non-bearing year. Hair fescue tuft density was determined in two 1 m X 1 m quadrats $plot^{-1}$. Hair fescue tuft inflorescence number per tuft was determined on 10 tufts $plot^{-1}$ using a line transect method described by White and Kumar (2017). Data collection for lowbush blueberry included lowbush blueberry stem density in August of the non-bearing year, stem height and flower bud number in October of the non-bearing year, and yield in August of the bearing year. Lowbush blueberry stem density was determined in three 0.3 m x 0.3 m quadrats per plot. Lowbush blueberry stem height and flower bud number were determined on 30 stems per plot selected using the line transect method described above. Lowbush blueberry yield was determined by hand raking all berries in two 1 m X 1 m quadrats per plot.

Data collection in the greenhouse experiment included leaf number at the time of herbicide applications and leaf number and aboveground biomass at 6 weeks after application. Hair fescue aboveground biomass was determined by clipping each plant at soil level, drying in paper bags for 48 hours at 50 °C, and then weighing.

Table 2.1. Site location, year of trial establishment, herbicide application date, and weather conditions at application for field sites used to evaluate non-bearing year clethodim efficacy on hair fescue populations in Nova Scotia.

Site	Latitude and Longitude Coordinates	Herbicide application date	Weather conditions at time of application[a]		
			Mean wind velocity (km hr^{-1})	Relative humidity (%)	Temperature (°C)
Westchester	45°35’35.4”N 63°40’50.0”W	05/29/2021	1.8	35	14.4
Collingwood	45°36’04.0”N 63°46’45.3”W	05/13/2021	3.4	45	22.2
Blue Mountain	45°28’53.7”N 62°26’12.7”W	05/03/2021	2.8	45	6.0
Sherbrooke	45°23’56.9”N 62°17’22.6”W	05/14/2021	6.1	38	17.2
Parrsboro	45°25’46.0”N 64°23’03.6”W	05/04/2021	1.8	18	23.3
Caanan	45°31’59.2”N 64°15’09.5”W	05/04/2021	2.5	45	6.0
Debert	45°27’12.7”N 63°25’05.9”W	05/10/2021	2.2	30	22.1
Dean	45°12’36.0”N 62°54’28.5”W	05/05/2021	5.6	30	16.1
Antigonish	45°39’11.6”N 61°59’21.0”W	05/09/2022	8.0	25	12.8

[a]Weather conditions were measured with a Kestrel 3000 pocket weather meter (Kestrel Instruments, Nielsen-Kellerman Company, New York, USA).

Table 2.1. Field locations and date of seed collection for hair fescue populations tested for clethodim susceptibility in a greenhouse experiment.

Site	Latitude and Longitude Coordinates	Seed collection date
Camden	45°18’18”N 63°10’24”W	08/13/2021
Southampton	45°35’59”N 64°14’45”W	08/13/2021
MacLennen Dr	45°29’16”N 62°24’29”W	08/11/2021
Clydesdale Rd	45°36’13”N 63°06’17”W	08/11/2021
Webb Rd	45°31’20”N 63°42’09”W	08/13/2021
Collingwood	45°36’18”N 63°45’50”W	08/13/2021
North River	45°26’36”N 63°13’51”W	08/11/2021
Blue Mountain	45°28’53”N 62°26’14”W	08/11/2021
Canaan	45°32’35”N 64°16’36”W	08/13/2021
Earltown	45°35’43”N 63°13’44”W	08/11/2021
Parrsboro	45°25’52”N 64°29’52”W	08/13/2021
George Ross Rd	45°26’35”N 62°19’17”W	08/11/2021
Lynn Mountain	45°36’12”N 64°06’08”W	08/13/2021
Sherbrooke	45°15’48”N 62°03’23”W	08/11/2021
Campbell Lake	45°29’09”N 62°25’15”W	08/11/2021

2.2.2 – Evaluation of clethodim for bearing year hair fescue suppression in lowbush blueberry fields

The objective of this experiment was to evaluate clethodim for bearing year hair fescue suppression in lowbush blueberry fields in Nova Scotia. The experiment was conducted in five bearing year lowbush blueberry fields throughout Colchester, Cumberland, and Pictou Counties, Nova Scotia in 2021 and 2022 (Table 2.3). The experiment consisted of four treatments arranged in a randomized complete block design with four blocks and 2 m x 4 m plot size. Treatments consisted of 1) nontreated control, 2) fluazifop-p-butyl (250 g a.i. ha^{-1}), 3) sethoxydim (495 g a.i. ha^{-1}), and 4) clethodim (91 g a.i. ha^{-1}). Foramsulfuron was not included as it is not currently registered for bearing year applications in lowbush blueberries in Canada. Sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant and clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using the research plot sprayer and sprayer settings outlined in experiment 1.

Data collection at all sites included hair fescue tuft density at the time of herbicide applications, hair fescue vegetative and flowering tuft density in July of the bearing year, hair fescue tuft inflorescence number in July of the bearing year, and lowbush blueberry yield in August of the bearing year. Data were collected using methods outlined for experiment 1.

Table 2.2. Site location, year of trial establishment, herbicide application date, and weather conditions at application for field sites used to evaluate bearing year clethodim efficacy on hair fescue populations in Nova Scotia.

Site	Longitude and Latitude Coordinates	Herbicide application date	Weather conditions at time of application[a]		
			Mean wind velocity (km hr^{-1})	Relative humidity (%)	Temperature (°C)
North River 1	45°27’54”N 63°12’43”W	05/03/2021	2.7	39	7.8
North River 2	45°27’48”N 63°12’41”W	05/03/2021	2.7	39	7.8
Camden	45°17’49”N 63°09’56”W	05/04/2022	1.3	38	20.6
Collingwood 1	45°36’12”N 63°49’27”W	05/04/2022	8.7	44	15
Collingwood 2	45°36’21”N 63°49’37”W	05/04/2022	6.3	48	15
Greenfield	45°23’22”N 63°07’51”W	05/04/2022	4.0	42	16.1

[a]Weather conditions were measured with a Kestrel 3000 pocket weather meter (Kestrel Instruments, Nielsen-Kellerman Company, New York, USA).

2.2.3 – Effect of clethodim application rate on hair fescue and lowbush blueberry

The objective of this experiment was to determine the effect of clethodim application rate on hair fescue suppression and lowbush blueberry crop tolerance. The experiment was conducted in three non-bearing year lowbush blueberry fields in 2021 (Table 2.4). The experiment consisted of eight treatments arranged in a randomized complete block design with five blocks and 2 m x 4 m plot size. The experiment was conducted as a dose response with treatments consisting of 0, 5.8, 11.5, 22.8, 45.6, 91.2, 182.4, and 364.8 g clethodim ha^{-1} based on a 0X, 0.25X, 0.5X, 1X, 2X, 4X, 8X, and 16X treatment arrangement where X = 22.8 g clethodim ha^{-1}. A 1X clethodim rate of 22.8 g ha^{-1} was chosen due to lack of *a priori* knowledge of the general clethodim rate response on hair fescue and to ensure that representative low and high clethodim application rates were used. Clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant and was applied using the research plot sprayer and sprayer settings outlined in experiment one.

Data collection at all sites included hair fescue tuft density at the time of herbicide applications, hair fescue vegetative and flowering tuft density in July of the bearing year, hair fescue tuft inflorescence number in July of the bearing year, and lowbush blueberry stem height and flower bud number at Camden and Debert. Unfortunately, yield data were unable to be collected for this experiment due to labor shortages preventing plot harvest prior to commercial harvest. Data were collected using methods outlined for experiment 1.

Table 2.3. Site location, herbicide application date, and weather conditions at application for field sites used to conduct a clethodim dose response on hair fescue populations in Nova Scotia.

Site	Latitude and Longitude Coordinates	Herbicide application date	Weather conditions at application[a]		
			Mean wind velocity (km hr^{-1})	Relative humidity (%)	Temperature (^oC)
Camden	45°17’59”N 63°11’00”W	05/3/2021	1.8	33	15.6
Collingwood	45°36’04”N 63°46’45”W	05/13/2021	3.4	45	22.2
Debert	45°27’12”N 63°25’05”W	05/10/2021	2.4	55	15.0

[a]Weather conditions were measured with a Kestrel 3000 pocket weather meter (Kestrel Instruments, Nielsen-Kellerman Company, New York, USA).

2.2.4 – Statistical methods

The effect of herbicide on hair fescue and lowbush blueberry response variables in the non-bearing and bearing year evaluation trials was determined using ANOVA in PROC MIXED in SAS (SAS Version 9.3, SAS Institute, Cary, North Carolina, USA). Blocks were modeled as random effects while site, treatment, and site by treatment interactions were modeled as fixed effects in the analysis.

The effect of clethodim application rate on hair fescue and lowbush blueberry response variables was determined using ANOVA in PROC MIXED in SAS. Pending suitability of the data, the effect of clethodim application rate on these response variables was determined using nonlinear regression dose response analysis in SigmaPlot version 15. The model obtained from a log-logistic dose response equation of the form:

$$Y = \text{min} + (\text{max-min})/1 + \exp\{b[(\log(X) - \log(EC_{50})]\}$$

where Y is a given hair fescue or lowbush blueberry response variable, min is the lower limit of the response, max is the upper limit of the response, b is the slope at EC_{50}, X is the clethodim application rate, and EC_{50} is the clethodim application rate required for a 50% reduction in the response variable. Significance was considered at $P<0.05$ for all analyses. Means were determined using the LS MEANS statement in SAS, and means separation, where necessary, was conducted using a Tukey's multiple means comparison test. Data were square root or log transformed as required to meet the assumptions of the variance analysis, and data transformations are indicated as required in the results tables.

Results

2.3.1 – Evaluation of clethodim efficacy on hair fescue populations in Nova Scotia lowbush blueberry fields

All hair fescue response variables were impacted by herbicide treatment, yet this effect differed by site. There was a significant site by treatment interaction effect on all hair fescue response variables ($P \leq 0.0001$). Sites were therefore analyzed separately. There was a significant herbicide treatment effect on total hair fescue tuft density at Collingwood and Dean ($P \leq 0.0235$), a significant herbicide treatment effect on flower tuft density at all sites except Debert and Earltown ($P \leq 0.0126$), and a significant herbicide treatment effect on tuft inflorescence number at all sites except Blue Mountain and Earltown ($P \leq 0.0001$). Total tuft density was somewhat reduced by foramsulfuron at Canaan and Collingwood and by fluazifop-p-butyl and sethoxydim at Dean (Table 2.5). No other treatments reduced total tuft density. Foramsulfuron reduced flower tuft density and tuft inflorescence number at Canaan, Collingwood, Dean, and Sherbrooke (Table 2.5). This herbicide also reduced flower tuft density at Blue Mountain and tuft inflorescence number at Debert and Parrsboro. Clethodim reduced flower tuft density and tuft inflorescence number at Canaan, Collingwood, Dean, Parrsboro, Sherbrooke, and Antigonish and reduced tuft inflorescence number at Debert (Table 2.5). Flower tuft density was also reduced by fluazifop-p-butyl at Dean (Table 2.5).

There was no site by treatment interaction effect on hair fescue response variables in the greenhouse experiment ($P \geq 0.0543$) and data were therefore combined across sites for analysis. There was a significant herbicide treatment effect on hair fescue final leaf number ($P < 0.0001$) and final aboveground biomass ($P < 0.0001$). Foramsulfuron and clethodim reduced final hair fescue leaf number and aboveground biomass (Table 2.6) while fluazifop-p-butyl was ineffective on hair fescue in this experiment.

Table 2.4. Effect of spring non-bearing year foramsulfuron, fluazifop-P-butyl, sethoxydim, and clethodim applications on hair fescue flowering tuft density, total tuft density, and inflorescence number in 9 lowbush blueberry fields in Nova Scotia, Canada, in 2021 (Blue Mountain, Canaan, Collingwood, Dean, Debert, Earltown, Parrsboro, Sherbrooke) and 2022 (Antigonish).

Site	Treatment[a]	Total tuft density (tufts m^{-2})[b]	Flower tuft density (tufts m^{-2})[c]	Tuft inflorescence number (# $tuft^{-1}$)[d]
Blue Mountain	Untreated control	2.42 ± 0.32 (11.2) a	2.04 ± 0.35 (8.8) a	1.05 ± 0.49 (2.7) a
	Foramsulfuron	1.46 ± 0.32 (4.2) a	0.30 ± 0.35 (0.7) b	1.60 ± 0.49 (6.84) a
	Fluazifop-P-butyl	1.90 ± 0.32 (7.9) a	1.58 ± 0.35 (5.2) ab	1.27 ± 0.49 (4.36) a
	Sethoxydim	2.33 ± 0.32 (11.3) a	1.99 ± 0.35 (7.6) a	1.96 ± 0.49 (10.68) a
	Clethodim	2.02 ± 0.32 (7.7) a	0.72 ± 0.35 (1.5) ab	1.76 ± 0.49 (7.96) a
Canaan	Untreated control	29.9 ± 7.85 ab	2.17 ± 0.26 (9.7) a	2.24 ± 0.34 (12.92) a
	Foramsulfuron	15.6 ± 7.85 b	0.55 ± 0.26 (1.2) b	0.55 ± 0.34 (0.96) b
	Fluazifop-P-butyl	48.8 ± 7.85 a	2.07 ± 0.26 (7.3) a	2.03 ± 0.34 (9.12) a
	Sethoxydim	31.2 ± 7.85 ab	2.24 ± 0.26 (9.4) a	3.05 ± 0.34 (26.68) a
	Clethodim	35.4 ± 7.85 ab	0.68 ± 0.26 (1.1) b	0.22 ± 0.34 (0.28) b
Collingwood	Untreated control	38.9 ± 3.93 ab	3.23 ± 0.24 (25.7) a	2.03 ± 0.26 (7.88) a
	Foramsulfuron	35.1 ± 3.93 b	0.26 ± 0.24 (0.4) b	0.02 ± 0.26 (0.02) b
	Fluazifop-P-butyl	44.8 ± 3.93 ab	3.14 ± 0.24 (25.5) a	1.89 ± 0.26 (7.52) a
	Sethoxydim	43.2 ± 3.93 ab	3.41 ± 0.24 (31.2) a	2.20 ± 0.26 (10.1) a
	Clethodim	53.8 ± 3.93 a	0.52 ± 0.24 (7.52) b	0.12 ± 0.26 (0.14) b
Dean	Untreated control	6.77 ± 0.23 (45.0) ab	5.89 ± 0.26 (33.9) a	2.38 ± 0.16 10.26) a
	Foramsulfuron	6.87 ± 0.23 (46.6) ab	3.00 ± 0.26 (8.6) b	0.49 ± 0.16 (0.72) b
	Fluazifop-P-butyl	3.80 ± 0.23 (13.7) c	2.13 ± 0.26 (3.7) b	1.89 ± 0.16 (6.4) a

Site	Treatment[a]	Total tuft density (tufts m^{-2})[b]	Flower tuft density (tufts m^{-2})[c]	Tuft inflorescence number (# $tuft^{-1}$)[d]
	Sethoxydim	6.20 ± 0.23 (37.6) b	5.41 ± 0.26 (28.5) a	2.14 ± 0.16 (7.92) a
	Clethodim	7.18 ± 0.23 (50.6) a	2.13 ± 0.26 (3.7) b	0.19 ± 0.16 (0.22) b
Debert	Untreated control	27.2 ± 4.24 a	1.43 ± 0.53 (6.8) a	1.73 ± 0.21 (5.98) a
	Foramsulfuron	26.7 ± 4.24 a	1.85 ± 0.53 (7.8) a	0.16 ± 0.21 (0.22) b
	Fluazifop-P-butyl	21.8 ± 4.24 a	1.61 ± 0.53 (5.7) a	1.47 ± 0.21 (3.8) a
	Sethoxydim	25.5 ± 4.24 a	1.67 ± 0.53 (8.8) a	1.50 ± 0.21 (3.9) a
	Clethodim	25.3 ± 4.24 a	1.07 ± 0.53 (3.4) a	0.075 ± 0.21 (0.08) b
Earltown	Untreated control	32.4 ± 6.00 a	10.8 ± 5.86 a	2.67 ± 0.50 (7.9) a
	Foramsulfuron	31.8 ± 6.00 a	24.8 ± 5.86 a	3.76 ± 0.50 (13.46) a
	Fluazifop-P-butyl	24.3 ± 6.00 a	9.8 ± 5.86 a	3.39 ± 0.50 (11.52) a
	Sethoxydim	23.7 ± 6.00 a	17.4 ± 5.86 a	2.56 ± 0.50 (5.92) a
	Clethodim	30.4 ± 6.00 a	10.4 ± 5.86 a	2.04 ± 0.50 (4.62) a
Parrsboro	Untreated control	23.6 ± 3.40 a	3.70 ± 0.41 (12.9) a	2.99 ± 0.20 (21.02) a
	Foramsulfuron	15.5 ± 3.40 a	2.58 ± 0.41 (5.9) ab	1.72 ± 0.20 (5.9) b
	Fluazifop-P-butyl	25.3 ± 3.40 a	3.61 ± 0.41 (13.5) a	2.81 ± 0.20 (13.5) a
	Sethoxydim	23.3 ± 3.40 a	3.45 ± 0.41 (12.0) ab	2.60 ± 0.20 (13.9) a
	Clethodim	26.3 ± 3.40 a	1.99 ± 0.41 (3.3) b	0.85 ± 0.20 (1.58) c
Sherbrooke	Untreated control	35.3 ± 4.77 a	5.80 ± 0.43 (33.2) a	2.88 ± 0.20 (17.9) a
	Foramsulfuron	27.0 ± 4.77 a	2.74 ± 0.43 (6.9) b	0.89 ± 0.20 (2.12) b
Site	Treatment[a]	Total tuft density	Flower tuft density (tufts m^{-2})[c]	Tuft inflorescence

		(tufts m^{-2})[b]		number (# $tuft^{-1}$)[d]
	Fluazifop-P-butyl	26.9 ± 4.77 a	4.56 ± 0.43 (22.3) a	2.57 ± 0.20 (13.2) a
	Sethoxydim	33.3 ± 4.77 a	5.62 ± 0.43 (30.8) a	2.69 ± 0.20 (13.8) a
	Clethodim	35.2 ± 4.77 a	1.55 ± 0.43 (1.5) b	0.40 ± 0.20 (0.52) b
Antigonish	Untreated control	46.9 ± 3.27 a	3.71 ± 0.15 (40.4) a	2.85 ± 0.20 (16.74) a
	Foramsulfuron	37.4 ± 3.27 a	3.16 ± 0.15 (24.3) a	1.99 ± 0.20 (8.04) a
	Fluazifop-P-butyl	45.5 ± 3.27 a	3.45 ± 0.15 (32.2) a	2.47 ± 0.20 (11.8) a
	Sethoxydim	46.1 ± 3.27 a	3.67 ± 0.15 (38.8) a	2.63 ± 0.20 (13.4) a
	Clethodim	42.1 ± 3.27 a	1.77 ± 0.15 (5.2) b	0.44 ± 0.20 (0.6) b

Notes: Values represent means ± 1 SE. Means within columns with different letters are significantly different at P<0.05 according to Tukey's test.
[a] Foramsulfuron, fluazifop-p-butyl, sethoxydim, and clethodim were applied at 35 g a.i. ha^{-1}, 250 g a.i. ha^{-1}, 495 g a.i. ha^{-1}, and 91 g a.i. ha^{-1}, respectively. Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer. Sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant. Clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using a CO_2-pressurized research plot sprayer equipped with four HYPRO ULD120-02 (ultra-low drift with 120° spray angle) nozzles and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa.
[b] Data from Blue Mountain were LOG(Y) transformed and data from Dean were SQRT(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.
[c] Data from Blue Mountain, Canaan, Collingwood, Debert, and Antigonish, were LOG(Y) transformed and data from Dean, Parrsboro, and Sherbrooke were SQRT(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.
[d] Data from all sites except Earltown were LOG(Y) transformed and data from Earltown were SQRT(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

Table 2.5. Effect of foramsulfuron, fluazifop-p-butyl, and clethodim applications on greenhouse-grown hair fescue leaf number and aboveground biomass.

Treatment[a]	Final leaf # (leaves plant^{-1})[b,d]	Final aboveground biomass (mg pot^{-1})[c,d]
Nontreated control	2.59 ± 0.035 (12.90) a	6.46 ± 0.065 (723.13) a
Foramsulfuron	2.00 ± 0.035 (6.76) b	5.47 ± 0.065 (287.56) b
Fluazifop-p-butyl	2.58 ± 0.035 (12.97) a	6.28 ± 0.065 (621.27) a
Clethodim	2.04 ± 0.035 (6.96) b	5.65 ± 0.065 (324.69) b

Notes: Values represent means ± 1 SE. Means within columns with different letters are significantly different at $P < 0.05$ according to Tukey's test.

[a] Foramsulfuron, fluazifop-p-butyl, sethoxydim, and clethodim were applied at 35 g a.i. ha^{-1}, 250 g a.i. ha^{-1}, 495 g a.i. ha^{-1} 91 g a.i. ha^{-1}, respectively. Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer. Sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant. Clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using a CO_2-pressurized research plot sprayer equipped with four HYPRO ULD120-02 (ultra-low drift with 120° spray angle) nozzles and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa.

[b] Initial leaf counts were approximately 7.2 ± 0.3 for all treatments. Final leaf counts were collected 6 weeks after treatment application.

[c] Hair fescue aboveground biomass was determined by clipping each plant at soil level 6 weeks after treatment application, drying in paper bags for 48 hours at 50 °C, and then weighing.

[d] Final leaf number and final aboveground biomass data were LOG(Y) transformed in order to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

There was no significant site by treatment interaction effect on lowbush blueberry response variables in the non-bearing year experiment ($P \leq 0.9187$). Data were therefore pooled across sites for analysis. There was no herbicide treatment effect on lowbush blueberry stem density ($P=0.754$), stem height ($P=0.6628$), flower buds per stem ($P=0.4525$), and yield ($P=0.4116$). Mean lowbush blueberry stem density, stem height, flower buds per stem, and yield were 455.92 ± 23.98 stems m^{-2}, 16.46 ± 0.43 cm, 2.62 ± 0.143 buds $stem^{-1}$ and 2025.68 ± 1433.52 kg ha^{-2}, respectively.

2.3.2 – Evaluation of clethodim for bearing year hair fescue suppression in lowbush blueberry fields

There was no significant site by treatment interaction effect on hair fescue response variables or lowbush blueberry yield ($P \geq 0.0708$). Data were therefore pooled across sites for analysis. There was no significant herbicide treatment effect on hair fescue total tuft density and lowbush blueberry yield ($P \geq 0.8806$) but there was a significant herbicide treatment effect on hair fescue flower tuft density ($P<0.0001$) and tuft inflorescence number ($P<0.0001$). Total tuft density and lowbush blueberry yield averaged 23.425 ± 1.06 tuft m^{-2} and 4453.92 ± 602.66 kg ha^{-1}, respectively, across sites. Clethodim reduced flower tuft density and tuft inflorescence number while flower tuft density and tuft inflorescence number in the fluazifop-p-butyl and sethoxydim treatments were similar to the nontreated control (Table 2.7).

Table 2.6. Effect of spring bearing year fluazifop-p-butyl, sethoxydim, and clethodim applications on hair fescue flower tuft density and tuft inflorescence number at 2 bearing year lowbush blueberry fields in 2021 and four bearing year lowbush blueberry fields in 2022 in Nova Scotia, Canada.

Treatment[a]	Flower tuft density (tufts m^{-2})[b]	Tuft inflorescence number (# $tuft^{-1}$)[c,d]
Nontreated control	16.83 ± 2.02 a	3.54 ± 0.15 (42.65) a
Fluazifop-p-butyl	17.33 ± 2.02 a	3.40 ± 0.15 (33.35) a
Sethoxydim	16.13 ± 2.02 a	3.27 ± 0.15 (35.11) a
Clethodim	7.20 ± 2.02 b	0.65 ± 0.15 (1.55) b

Notes: Values represent the mean ± 1 SE. Means within columns with different letters are significantly different at P<0.05 according to Tukey's test.

[a] Foramsulfuron, fluazifop-p-butyl, sethoxydim, and clethodim were applied at 35 g a.i. ha^{-1}, 250 g a.i. ha^{-1}, 495 g a.i. ha^{-1}, and 91 g a.i. ha^{-1}, respectively. Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer. Sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant. Clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using a CO_2-pressurized research plot sprayer equipped with four HYPRO ULD120-02 (ultra-low drift with 120° spray angle) nozzles and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa.

[b] Hair fescue tuft density was determined in two 1 m X 1 m quadrats per plot.

[c] Hair fescue tuft inflorescence number per tuft was determined on 10 tufts $plot^{-1}$ using a line transect method.

[d] Flower tuft density and tuft inflorescence number data were LOG(Y) transformed in order to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

2.3.3 – Effect of clethodim application rate on hair fescue and lowbush blueberry

There was a significant site by treatment effect on flowering tuft density and tuft inflorescence number (P<0.0001). Data from each site were therefore analyzed separately. There was a significant treatment effect on flowering tuft density (P<0.0001) and tuft inflorescence number (P≤0.0018) at each site. There was no significant treatment effect on total tuft density (P≥0.2247) at any site.

Hair fescue flower tuft density declined rapidly with increasing clethodim dose (Figure 2.2) with estimated EC_{50} values for flower tuft density reduction of 8.6 ± 0.92, 36.64 ± 4.84, and 15.9 ± 1.56 g clethodim ha^{-1} at Collingwood, Camden, and Debert, respectively (Table 2.8). EC_{90} values for flower tuft reduction ranged from 14.3 – 152 g clethodim ha^{-1}. Similarly, hair fescue tuft inflorescence number declined rapidly with increasing clethodim dose (Figure 2.2) with estimated EC_{50} values for tuft inflorescence reduction of 9.57 ± 1.75 and 10.07 ± 1.74 g a.i. ha^{-1} at Collingwood and Camden, respectively (Table 2.8). EC_{90} values for tuft inflorescence number reduction ranged from 22.8 – 32.7 g clethodim ha^{-1}. A similar decline in tuft inflorescence number also occurred at Debert (Figure 2.2), though the dose response equation could not be fit to these data.

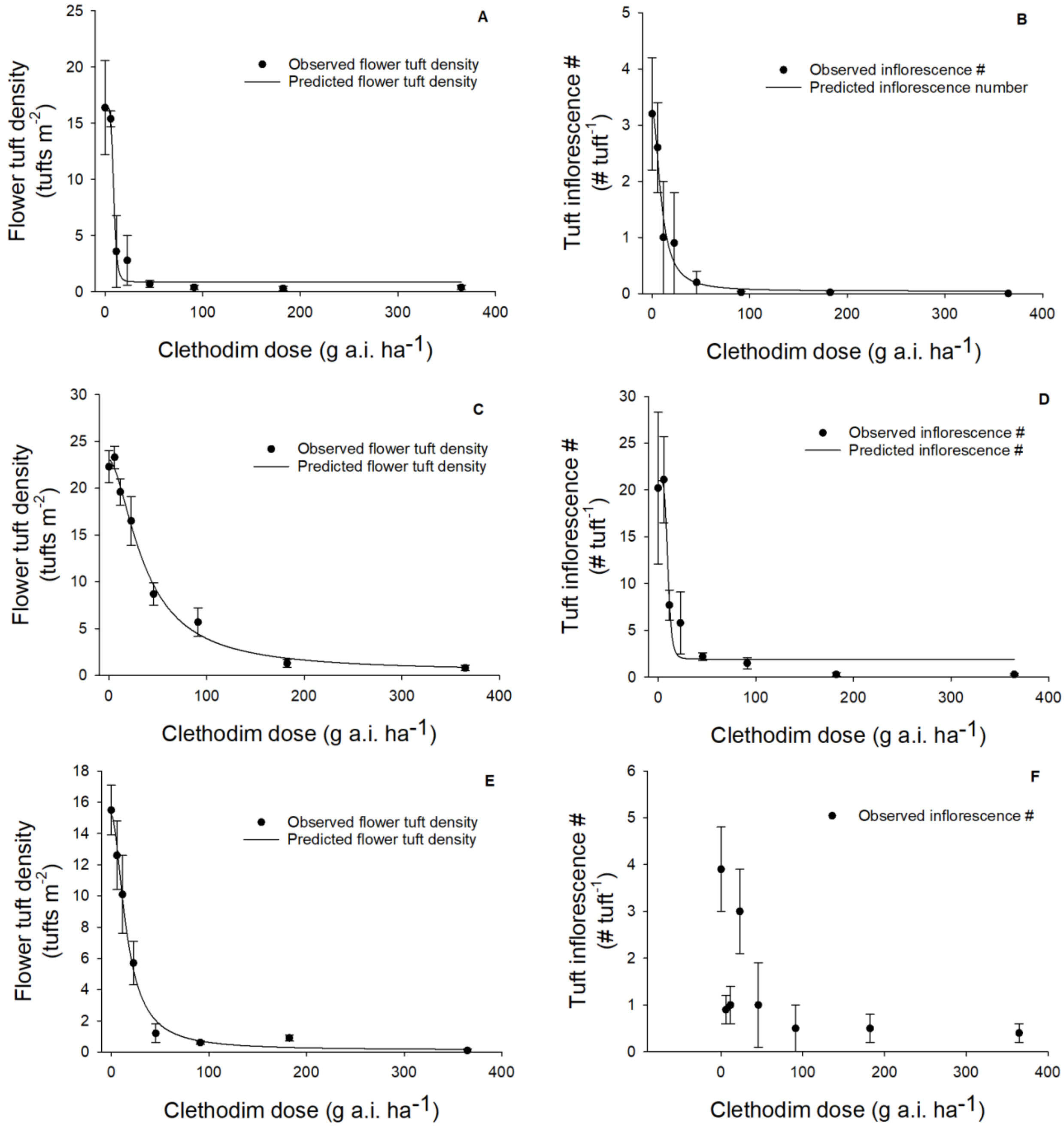

Figure 2.2. Effect of clethodim application rate on hair fescue flowering tuft density at (A) Collingwood, (C) Camden, and (E) Debert and hair fescue inflorescence number at (B) Collingwood, (D) Camden, and (F) Debert, NS, Canada in 2021. Clethodim was applied in conjunction with Amigo surfactant at 2 L ha^{-1} and was applied on May 3, May 13, and May 10 2021 at Camden, Collingwood, and Debert, respectively. Application rates evaluated were 0, 5.8, 11.5, 22.8, 45.6, 91, 182.4, and 364.8g clethodim ha^{-1}. Flower tuft density and inflorescence data were collected in July 2021. Symbols represent the mean + SE of 5 observations at each site. Lines represent the predicted flower tuft density and inflorescence number obtained from a log-logistic dose response equation of the form y = (max-min)/1+$(x/EC_{50})^{-b}$ where y = flower

tuft density, max = the maximum flower tuft density, min = the minimum flower tuft density, x = clethodim application rate, EC_{50} = the clethodim application rate to reduce flower tuft density by 50%, and b = the slope of the response at EC_{50}. Parameter estimates for each site and response are provided in Table 2.8.

Table 2.7. Parameter estimates for the log-logistic dose response evaluating the effect of clethodim application rate on hair fescue flower tuft density and tuft inflorescence number.

		Parameters[a]					
Site	Response variable	Max	Min	EC_{50}	b	R^2_{Adj}	EC_{90}
Collingwood	Flower tuft density	16.5 ± 1.03	0.89 ± 0.47	8.86 ± 0.92	-5.78 ± 1.89	0.98	14.3
	Tuft inflorescence number	3.3 ± 0.28	0.04 ± 0.17	9.57 ± 1.75	-1.93 ± 0.61	0.95	32.7
Camden	Flower tuft density	23.04 ± 0.98	0.42 ± 1.25	36.64 ± 4.84	-1.68 ± 0.34	0.98	152
	Tuft inflorescence number	21 ± 2.23	1.93 ± 1.04	10.07 ± 1.74	-5.57 ± 5.46	0.93	22.8
Debert	Flower tuft density	15.19 ± 0.63	0.13 ± 0.46	15.9 ± 1.56	-1.85 ± 0.28	0.99	54

[a]Parameter estimates are the mean ± 1 SE. Max = the maximum flower tuft density or tuft inflorescence number, min = the minimum flower tuft density or tuft inflorescence number, EC_{50} = the clethodim application rate required to reduce flower tuft density or tuft inflorescence number by 50%, and b = the slope of the response at EC_{50}.

2.4 – Discussion

Non-bearing year clethodim applications reduced hair fescue flower tuft density and tuft inflorescence number at seven of nine sites (Table 2.5) and reduced hair fescue leaf number and biomass in all 15 hair fescue populations tested in the greenhouse (Table 2.6). These results suggest that hair fescue susceptibility to clethodim is common in hair fescue populations in lowbush blueberry fields in Nova Scotia, and that growers should be able to expect suppression of this grass with clethodim.

Lack of clethodim efficacy at Earltown is believed to be due to late spring mowing at that site by the grower. Some hair fescue tufts had bolted at the time of mowing, and many tufts were incompletely mowed. It is, however, unclear why clethodim was ineffective at Blue Mountain. Clethodim is sensitive to photodegradation (Bridges et al., 1991; McMullan, 1996) and application during daylight hours can reduce efficacy (Bridges et al., 1991). All herbicides were applied during daylight for field trials, which may have reduced efficacy at sites such as Blue Mountain. It is, however, unclear why a similar effect would not have occurred at additional sites. Herbicides were applied earlier at Blue Mountain than at most other sites (Table 2.1), which may have affected efficacy. Plants grown from seed collected from this site were susceptible to clethodim in the greenhouse trial, however, indicating that extraneous factors, rather than inherent tolerance, affected clethodim efficacy at this site. Future research should focus on identification of the optimum application timing and possibly effects of application time of day on clethodim efficacy on hair fescue.

Bearing year clethodim applications reduced hair fescue flower tuft density and tuft inflorescence number (Table 2.7), suggesting an important role for clethodim for bearing year management of this weed species. Bearing year hair fescue management is currently limited to fall non-bearing year pronamide applications (White, 2019), exerting high selection pressure for pronamide resistant hair fescue biotypes. Pronamide cost also exceeds \$500 CDN ha^{-1}, limiting profitability of wild blueberry production when use of this herbicide is required. Clethodim efficacy in the bearing year now provides an important, economically sound alternative to pronamide that can help growers manage bearing year hair fescue populations and limit secondary seed dispersal on equipment such as harvesters (Boyd and White, 2009).

Furthermore, bearing year clethodim application timing for hair fescue coincides with fungicide application timing for *Monilinia* blight (*Monilinia vaccinii-corymbosi* Reade) (Percival and Beaton, 2012), providing opportunities for clethodim tank mixtures with commonly used fungicides in lowbush blueberry.

Dose response analysis indicated that hair fescue is susceptible to clethodim. With the exception of flower tuft density reduction at Camden, EC_{50} and EC_{90} values for flower tuft density and tuft inflorescence number reduction were < 91 g a.i. ha^{-1} (anticipated label rate for clethodim in lowbush blueberry). Application rates > 91 g a.i. ha^{-1} are therefore likely not required to improve suppression (Figure 2.2; Table 2.8). Similar to our results, Bermuda grass (*Cynodon* spp. Rich.) health was reduced by 50% by 40 – 190 g clethodim ha^{-1} (Webster et al., 2004) and *Eleusine tristachya* Lam. biomass was reduced by 90% at clethodim application rates of 112 – 120 g clethodim ha^{-1}. In contrast, up to 262 g clethodim ha^{-1} was required to reduce newly established elephant grass (*Pennisetum purpureum* Schumach) biomass by 90% (Odero and Gilbert, 2012). As such, while suppression of some perennial grasses is improved by higher clethodim application rates, there is limited support from our data for registration of clethodim application rates above 91 g a.i. ha^{-1}. It is also important to note that rates above 91 g a.i. ha^{-1} did not reduce total tuft density, further suggesting that maximum suppression is likely achieved at the anticipated label rate of 91 g a.i. ha^{-1}.

2.5 – Conclusion

Hair fescue represents a significant threat to lowbush blueberry production due to the capacity of this weed for reproduction and spread, and the lack of effective alternatives to pronamide for management. Clethodim provides an effective, novel site of action for hair fescue management that will provide growers with an economical tool for both non-bearing and bearing year suppression of this grass species. Greenhouse and field trials demonstrated widespread susceptibility of hair fescue to clethodim, and dose response trials indicated that the anticipated label rate of 91 g a.i. ha^{-1} is adequate for maximum suppression. Collectively, these data provide support for the registration of clethodim at 91 g a.i. ha^{-1} for non-bearing and bearing year suppression of hair fescue in lowbush blueberry fields. Future research should now focus on identification of the optimum clethodim application timing on hair fescue and evaluation of clethodim tank mixtures with common bearing year fungicides in lowbush blueberry production.

CHAPTER 3: EVALUATION OF CLETHODIM FOR RED FESCUE (*FESTUCA RUBRA* L.) SUPPRESSION IN LOWBUSH BLUEBERRY (*VACCINIUM ANGUSTIFOLIUM* AITON)

Abstract

Lowbush blueberry is grown on a two year cycle in which fields are pruned to ground level in the first year and fruit are harvested in the second year. Lowbush blueberry fields cannot be tilled as the crop predominantly spreads via underground rhizomes during the vigorous growth triggered by mowing. The perennial no-till nature of the crop leads to challenges managing perennial weeds such as red fescue. Red fescue is a perennial grass which spreads via seed and rhizomes and is tolerant to many herbicides used in lowbush blueberry production. Clethodim is a group 1 herbicide, which has shown variable efficacy against *Festuca spp.* The objective of this research was to evaluate clethodim efficacy on red fescue in non-bearing and bearing year lowbush blueberry fields in Nova Scotia. Non-bearing year clethodim applications did not reduce red fescue flowering stem density or total stem density ($P \geq 0.0966$) while bearing year applications reduced flowering stem density by 93.2% ($P = 0.0006$). These results suggest further research should be conducted to determine effective options for consistent red fescue suppression.

3.1 – INTRODUCTION

Lowbush blueberry fields are grown on a two-year cycle in which stems are mowed to the ground in the first (non-bearing) year to promote vegetative growth and flower bud development, and plants flower and produce fruit in the second (bearing) year. Weeds are problematic in lowbush blueberry fields as traditional weed management practices such as tillage and crop rotation are not available to lowbush blueberry growers. A recent weed survey identified 211 weed species in lowbush blueberry fields in Nova Scotia (Lyu et al., 2021), which represents a substantial increase from the 141 weed species identified in a similar survey in 1984-1985 (McCully et al., 1991). As might be expected, the dominant weeds are woody and herbaceous perennial plants (Lyu et al, 2021) due to the lack of tillage, with perennial grasses becoming an increasingly important weed problem (Anonymous, 2021).

Red fescue is a relatively new perennial grass weed in lowbush blueberry fields. This grass was first identified as a significant weed problem in lowbush blueberry production in Nova Scotia in 2008 (Sikoriya, 2014). It is suspected that it was introduced years prior to being detected as contamination in hay bales. Red fescue occurrence increased from 0.8% in lowbush blueberry fields surveyed in 2000-2001 to about 8% in fields surveyed in 2017-2019 (Lyu et al., 2021). In fields where the weed was present it had high field uniformity and density, suggesting it is a dominant weed in infested fields. This weed is expected to continue to spread throughout the blueberry industry and cause severe yield reductions (Sikoriya, 2014). Recent weed surveys cited red fescue as an emerging problem weed for lowbush blueberries and encouraged further research on the weed before it becomes a larger issue (Lyu et al., 2021).

Limited research has been done on the chemical management of red fescue in lowbush blueberry. Like hair fescue, red fescue exhibits general tolerance to group 1 herbicides such as sethoxydim and fluazifop-p-butyl (Butler and Appleby, 1986; Darwent and Lefkovitch, 1995). Growers are therefore unable to utilize these herbicides to manage this weed species. The most effective control of red fescue is obtained from fall pronamide applications (Sikoriya, 2014). Spring glyphosate applications prior to lowbush blueberry emergence were also effective

(Sikoriya, 2014) but have not been adopted by growers due to crop injury risk. Managing red fescue with glyphosate did, however, increase blueberry yield by 56% (Sikoriya, 2014), suggesting this grass reduces yield in lowbush blueberry fields. Other treatments evaluated included terbacil, hexazinone, glufosinate, and foramsulfuron, all of which provided variable suppression of red fescue without providing complete control. Although red fescue has also been reported as tolerant to clethodim (Brewster and Spinney 1989), this herbicide has not been evaluated for red fescue management in lowbush blueberry.

The objective of this research was to determine clethodim efficacy on red fescue in non-bearing and bearing year lowbush blueberry fields in Nova Scotia.

Materials and Methods

3.2 – Evaluation of clethodim for red fescue suppression in non-bearing and bearing year lowbush blueberry fields in Nova Scotia

The experiment was conducted in four non-bearing year and two bearing year lowbush blueberry fields in Colchester County in Nova Scotia in 2021 and 2022 (Table 3.1). The non-bearing year experiment consisted of five treatments arranged in a Randomized Complete Block Design with five blocks and 2 m X 4 m plot size. Treatments consisted of 1) nontreated control, 2) foramsulfuron (WSSA Group 2) (35 g a.i. ha^{-1}) (Option OD herbicide, Bayer CropScience Inc., Calgary AB, Canada), 3) fluazifop-p-butyl (WSSA Group 1) (250 g a.i. ha^{-1}) (Venture L herbicide, Syngenta Canada Inc., Guelph, ON, Canada), 4) sethoxydim (WSSA Group 1) (495 g a.i. ha^{-1}) (Poast Ultra herbicide, BASF Canada, Mississauga, ON, Canada), and 5) clethodim (91 g a.i. ha^{-1}) (Select herbicide, Arysta LifeScience North America, LLC, Cary, NC, USA). The bearing year experiment was similar in all respects except that foramsulfuron was excluded due to lack of a bearing year registration for this herbicide in lowbush blueberry. Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer, sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant, and clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using a CO_2-pressurized research plot sprayer equipped with four HYPRO ULD120-02 (ultra-low drift with 120° spray angle) nozzles and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa.

Data collection for red fescue included red fescue stem density and height at the time of herbicide applications, red fescue vegetative and flowering stem density in July of the non-bearing year, red fescue aboveground biomass in July of the non-bearing year, and red fescue vegetative and flowering stem density in July of the bearing year. Red fescue density was determined in three 0.3 m X 0.3 m quadrats per plot. Red fescue biomass was determined by clipping all red fescue stems at ground level in three 0.3 m X 0.3 m quadrats per plot. Biomass was placed in paper bags in the field, brought back to the lab, dried for 48 hours at 50 °C, and weighed.

Data collection for lowbush blueberry included lowbush blueberry stem density in August of the non-bearing year, stem height and flower bud number in October of the non-bearing year, and yield in August of the bearing year. Lowbush blueberry stem density was determined in three 0.3 m X 0.3 m quadrats per plot. Lowbush blueberry stem height and flower bud number were determined on 30 stems per plot selected using the line transect method. Lowbush blueberry yield was determined by hand raking all berries in two 1 m X 1 m quadrats per plot.

All data were analyzed using ANOVA in PROC MIXED in SAS (SAS Version 9.3, SAS Institute, Cary, North Carolina, USA). Blocks were modeled as a random effect while site, treatment, and the site by treatment interaction were modeled as fixed effects in the analysis. Significance was considered at P=0.05 for all analyses. Means were determined using the LS MEANS statement in SAS, and means separation, where necessary, was conducted using a Tukey's multiple means comparison test. Data were square root or log transformed as required to meet the assumptions of the variance analysis, and data transformations are indicated as required in the results tables.

Table 3.1 Site location, trial production year, herbicide application date, and weather conditions at application for field sites used to determine non-bearing and bearing year clethodim efficacy on red fescue in Nova Scotia.

Site	Latitude or Longitude Coordinates	Trial production year	Herbicide application date	Weather conditions at time of application[a]		
				Mean wind velocity (km hr^{-1})	Relative humidity (%)	Temperature (°C)
Collingwood 1	45°36’06.3”N 63°48’08.6”W	Non-bearing	05/10/2022	6.6	18	16.7
Collingwood 2	45°35’31.1”N 63°51’21.8”W	Non-bearing	05/10/2022	6.6	18	16.7
Collingwood 3	45°36’23.2”N 63°49’39.1”W	Non-bearing	05/10/2022	6.6	18	16.7
Westchester	45°35’35.4”N 63°40’50.0”W	Non-bearing	05/29/2021	1.8	35	14.4
Purdy Road	45°35’28.2”N 63°50’28.5”W	Bearing	05/13/2021	3.9	38	17.2
Silica Road	45°35’59.2”N 63°49’13.0”W	Bearing	05/13/2021	3.9	38	17.2

[a]Weather conditions were measured with a Kestrel 3000 pocket weather meter (Kestrel Instruments, Nielsen-Kellerman Company, New York, USA).

Results

3.3.1 Non-bearing year clethodim applications

There was no significant site by treatment interaction effect on red fescue response variables in the non-bearing year trial ($P \geq 0.3503$). All data were therefore pooled across sites for analysis. There was a significant treatment effect on initial red fescue density ($P=0.0170$) and initial density was lower in the clethodim treatment (Table 3.2). There was, however, no significant herbicide treatment effect on red fescue flowering stem density or total stem density ($P \geq 0.0966$) (Table 3.2).

Table 3.2. Effect of spring non-bearing year foramsulfuron, fluazifop-P-butyl, sethoxydim, and clethodim applications on red fescue flowering stem density, total stem density, and biomass in four non-bearing year wild blueberry fields near Collingwood, NS, Canada, in 2021 and 2022.

Treatment[a]	Initial plant density (plants 30cm2(-1))[b,c]	Flowering plant density (Flowering plants m^{-2})[c]	Total stem density (stems m^{-2})[c]	Dry biomass (g m^{-2})[d]
Untreated control	12.81 ± 2.64 (164.11) ab	11.17 ± 1.46 (124.67) a	13.51 ± 1.27 (182.56) a	9.25 ± 1.592 a
Foramsulfuron	14.52 ± 2.64 (210.88) ab	10.76 ± 1.46 (115.78) a	13.35 ± 1.27 (178.33) a	8.28 ± 1.592 a
Fluazifop-P-butyl	14.11 ± 2.64 (199.11) ab	12.24 ± 1.46 (149.78) a	15.79 ± 1.27 (249.22) a	13.24 ± 1.592 a
Sethoxydim	15.52 ± 2.64 (240.88) a	12.42 ± 1.46 (154.22) a	16.10 ± 1.27 (259.22) a	13.41 ± 1.592 a
Clethodim	12.56 ± 2.64 (157.77) b	13.78 ± 1.46 (190.00) a	15.32 ± 1.27 (234.78) a	9.25 ± 1.592 a

Notes: Values represent means ± 1 SE. Untransformed means are contained in brackets. Means within columns with different letters are significantly different at $P < 0.05$ according to Tukey's test.

[a] Foramsulfuron, fluazifop-p-butyl, sethoxydim, and clethodim were applied at 35 g a.i. ha^{-1}, 250 g a.i. ha^{-1}, 495 g a.i. ha^{-1} 91 g a.i. ha^{-1}, respectively. Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer. Sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant. Clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using a CO_2-pressurized research plot sprayer equipped with four HYPRO ULD120-02 nozzles and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa.

[b] Red fescue plant density was determined in three 30 cm X 30 cm quadrats per plot.

[c] Initial plant density, flowering plant density, and total plant density data were SQRT(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

[d] Biomass data were LOG(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

3.3.2 Bearing year clethodim applications

There was no significant site by treatment interaction effect on red fescue response variables ($P \geq 0.1452$). Data were therefore pooled across sites for analysis. There was no significant herbicide treatment effect on red fescue total stem density and dry biomass ($P \geq 0.2315$). There was a significant herbicide treatment effect on red fescue flowering stem density ($P = 0.0006$). Clethodim reduced flowering stem density by 93.2% (Table 3.3).

Table 3.2. Effect of spring bearing year fluazifop-P-butyl, sethoxydim, and clethodim applications on red fescue flowering stem density, total stem density, and dry biomass in two bearing year wild blueberry fields near Collingwood Nova Scotia in 2021.

Treatment[a]	Flowering stem density (plants m^{-2})[b,c]	Total stem density (plant m^{-2})	Dry biomass (g m^{-2})
Untreated control	7.87 ± 2.66 (62.00) a	234.78 ± 33.76 a	26.33 ± 2.72 a
Fluazifop-P-Butyl	10.04 ± 2.66 (100.89) a	310.44 ± 33.76 a	29.78 ± 2.72 a
Sethoxydim	7.94 ± 2.66 (63.00) a	230.55 ± 33.76 a	28.00 ± 2.72 a
Clethodim	2.05 ± 2.66 (4.22) b	178.44 ± 33.76 a	23.00 ± 2.72 a

Notes: Values represent means ± 1 SE. Untransformed standard errors are contained in brackets. Means within columns with different letters are significantly different at P<0.05 according to Tukey's test.

[a] Foramsulfuron, fluazifop-p-butyl, sethoxydim, and clethodim were applied at 35 g a.i. ha^{-1}, 250 g a.i. ha^{-1}, 495 g a.i. ha^{-1} 91 g a.i. ha^{-1}, respectively. Foramsulfuron was applied in conjunction with 2.5 L ha^{-1} of 28% UAN liquid nitrogen fertilizer. Sethoxydim was applied in conjunction with 2 L ha^{-1} of Merge petroleum hydrocarbon surfactant. Clethodim was applied in conjunction with 2 L ha^{-1} of Amigo phosphate ester adjuvant. Herbicide treatments were applied using a CO_2-pressurized research plot sprayer equipped with four HYPRO ULD120-02 (ultra-low drift with 120° spray angle) nozzles and calibrated to deliver 200 L water ha^{-1} for each herbicide at a pressure of 276 kPa.

[b] Red fescue stem density was determined in two 30 cm X 30 cm quadrats per plot.

[c] Flowering stem density data were LOG(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

[d] Dry biomass data were SQRT(Y) transformed prior to analysis to meet the assumptions for the analysis of variance. Transformed data are provided to indicate variance, and geometric means are presented in brackets.

3.4 Discussion

Non-bearing year clethodim applications did not reduce red fescue flowering stem density or total stem density. Bearing year clethodim applications, however, reduced flowering stem density by 93.2%. These results suggest that clethodim exhibits variable efficacy on red fescue. Red fescue is generally not killed by clethodim (Brewster and Spinney, 1989) but Cole et al. (2002) indicated that clethodim consistently reduced inflorescence number and seed yield of red fescue. Susceptibility of some *Festuca* spp. to clethodim, however, declines with increasing plant age (Herrera, 2020) and it may be that red fescue populations were of variable ages at the time of herbicide applications.

Commercial red fescue cultivars also exhibit variability in response to the group 1 herbicide sethoxydim (Butler and Appleby, 1986). We noted variation in red fescue morphology across sites that may suggest a range of red fescue biotypes in lowbush blueberry fields that may exhibit similar variability in response to group 1 herbicides. Specifically, many individuals were observed with excessive tillering, and some were seen with more numerous and shorter leaves. These observations were made in the Collingwood region within and outside of the trial locations.

Although red fescue is thought to have been introduced into lowbush blueberry fields as a contaminant in straw used for burning, no knowledge of the geographic origin of the straw is available and we have no way of discerning if additional introductions have occurred. Future work should be conducted to document red fescue morphological variability in lowbush blueberry fields and collaboration with turfgrass specialists could aid in assessing potential variation of red fescue in this cropping system.

3.5 – CONCLUSION

Red fescue represents a weed of increasing significance in lowbush blueberry in Nova Scotia. This study demonstrated inconsistent clethodim efficacy on red fescue, suggesting this herbicide may not contribute to management of this weed species. Further research should, however, consider dose response studies, a range of clethodim application timings, and potential clethodim tank mixtures with other herbicides currently registered in lowbush blueberry to determine if these provide opportunities to improve red fescue suppression with clethodim.

Chapter 4: Conclusion

Lowbush blueberry is grown on a two year cycle of mowing, growing, wintering, fruiting, and harvesting. Lowbush blueberry fields cannot be tilled as the crop predominantly spreads via underground rhizomes during the vigorous growth triggered by mowing. The perennial no-till nature of this cropping system leads to challenges managing perennial weeds like hair fescue and red fescue. The tuft forming hair fescue represents a serious threat to the productivity of lowbush blueberry fields, whereas the rhizomatous red fescue is an emerging threat. Both are difficult to manage with currently available herbicides and have a history of resistance development. Clethodim is a group 1 herbicide that has shown variable efficacy on *Festuca spp.* and has preliminary research showing suppression of hair fescue in lowbush blueberry during the non-bearing year. Non-bearing and bearing year field efficacy trials were established for hair and red fescue. Greenhouse efficacy trials and field dose response trials were also conducted for hair fescue. Non-bearing and bearing year clethodim applications reduced hair flowering tuft density and tuft inflorescence count ($P \leq 0.0126$). Clethodim also reduced leaf number ($P < 0.0001$) and dry biomass ($P < 0.0001$) of fescue plants from 15 separate populations in greenhouse trials. Dose response trials indicated the anticipated label rate of 91 g a.i. ha^{-1} is adequate for suppression of hair fescue. Red fescue was not suppressed in the non-bearing year ($P \geq 0.0966$) while bearing year applications reduced flowering stem density by 93.2% ($P = 0.0006$). This thesis supports the registration of clethodim for the management of hair fescue in lowbush blueberry fields and additional research is required to determine if clethodim will contribute to red fescue management.

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