Development of Phenological Models and Management Strategies for Narrowleaf Goldenrod (*Euthamia graminifolia* L.) in Wild Blueberry (*Vaccinium angustifolium* Ait.) Fields

By

Lienna Hoeg

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ABSTRACT

Narrowleaf goldenrod (*Euthamia graminifolia*) has emerged as a major perennial weed challenge in wild blueberry (*Vaccinium angustifolium*) production in Nova Scotia, impacting crop management and yield quality. This thesis investigated the phenological development of *E. graminifolia* and evaluated integrated strategies for its control. Predictive models based on growing degree days were developed to accurately describe shoot emergence and flowering timing, enabling growers to better schedule post-emergence management. Narrowleaf goldenrod ramet emergence began at 25-71 GDD, and continued to 1,047-1,665 GDD across all study sites. Narrowleaf goldenrod ramets were observed at the flowering bud stage between 710 and 871 GDD (June 21 – 28), and approximately 90% of emerged ramets reached the flowering bud stage between 1303 – 1956 GDD (July 17 – August 24). Emerged ramets began flowering between 1418 – 1626 GDD (July 30 – August 7), and approximately 90% of emerged ramets were flowering between 1992 – 2225 GDD (August 27 – September 12). Cumulative *E. graminifolia* seedling emergence ranged from 2.4 ± 0.8 to 4 ± 1 seedlings m^{-2}, respectively, and seedling density from soil core samples ranged from 0.02 ± 0.01 to 6.92 ± 1.80 seedlings per core. Seedbank and seedling recruitment studies indicated limited establishment of new plants through sexual reproduction in managed fields, highlighting the necessity of focusing on established populations. Herbicide field trials were established across eleven commercial lowbush blueberry fields in Nova Scotia between 2019 and 2021 to evaluate early-POST, late-POST, and post-harvest, pre-pruning herbicide applications. These studies identified mesotrione-based treatments and targeted fall applications as the most effective methods for long-term suppression with minimal crop injury. The research supports renewed registration efforts for key herbicide programs and provides practical recommendations for sustainable weed management, helping Nova Scotia blueberry growers address the threat of an increasingly dominant, competitive weed species.

LIST OF ABBREVIATIONS USED

% Percent

°C Degrees Celcius

CO_2 Carhon dioxide

cm Centimeter

g Gram

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

GDD Growing Degree-Days

kg Kilogram

l Liter

m Meter

m-2 Per square meter

psi Pound per square inch

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Chapter 1 – General Introduction

Introduction

Wild, or lowbush blueberry (*Vaccinium angustifolium* Ait.) is Nova Scotia's largest horticultural crop by acreage and export, with 8,400 hectares harvested annually (Anonymous, 2018). In 2017, approximately 23 million kilograms of berries were harvested from the Maritime Provinces, to locations such as the United States, China, Japan, Germany and the Netherlands. The export value of lowbush blueberries in 2017 was equal to $76.3 million (Anonymous, 2018). Lowbush blueberries are grown in a 2-year production cycle in which fields are pruned to ground level to promote vegetative growth and flower bud development in the first, or non-bearing year, and fruit are harvested in the second, or bearing year. Fruit yield is highly dependent on management practices implemented during the 2-year production cycle (Yarborough, 2004).

Weeds, are one of the largest management challenges affecting quality and yield of lowbush blueberries (Anonymous, 2017). Weeds can shade blueberry plants and increase competition for space, nutrients and water. It can be a challenge to control weeds in lowbush blueberries, since crop rotation and land cultivation are not often used in blueberry management (Anonymous, 2017). A negative correlation between broadleaf weed cover and blueberry yield has been shown across several studies (Marty et al. 2019; Drummond et al. 2012). In addition, management strategies intended to raise yield of berries, such fertility inputs, can increase the occurrence of weeds (Penney & McRae, 2000). Creeping herbaceous perennial weeds are particularly problematic in lowbush blueberry fields (Kender and Eggert, 1966; McCully et al. 1991; Yarborough and Marra, 1996) and control strategies for these species are highly sought after.

This project will focus on narrowleaf goldenrod (*Euthamia graminifolia* L.), which is a creeping herbaceous perennial found in lowbush blueberry fields (Hall, 1959; McCully et al. 1991; Lyu et al. 2020). In the mid 1980's a weed survey of lowbush blueberry fields across Nova Scotia found that goldenrod species were present in 40% of the 115 fields surveyed (McCully et al., 1991). In more recent years, another weed survey indicated occurrence of narrowleaf goldenrod in more than 80% of fields surveyed and reduced occurrence of other goldenrod species (Lyu et al. *in press*). Farooq (2018) concluded that sequential herbicide treatments of mesotrione applied post-emergence at 14, 21, and 28 days apart provided adequate control of narrowleaf goldenrod. This treatment, however, remains unregistered for use in lowbush blueberry. In addition, there is limited knowledge of the general phenology and emergence patterns exhibited by narrowleaf goldenrod in lowbush blueberry fields, and little knowledge of the seedbank dynamics or extent and occurrence of seedling recruitment of this weed species in lowbush blueberry fields. Further research is needed to identify alternative herbicide applications and investigate the phenology and seed dynamics of narrowleaf goldenrod. The overall objectives of this study are to explore alternative management strategies for narrowleaf goldenrod and to develop predictive models for narrowleaf goldenrod phenological development.

Introduction of Lowbush Blueberry

Taxonomy and Distribution of Lowbush Blueberry

Lowbush blueberry belongs to the family Ericaceae (Hall et al. 1979). Lowbush blueberry is endemic in the Atlantic provinces of Nova Scotia, New Brunswick, Prince Edward Island and Newfound and Labrador, Canada but also reaches as far west as Manitoba and extends south along the east coast of the United States (Anonymous, 2014). Lowbush blueberry is a low growing deciduous shrub that reproduces by seed and rhizomes (Vander Kloet, 1988). The majority of lowbush blueberry plant biomass resides in the 10-15 cm of soil (Vander Kloet, 1988). Rhizomes allow for vegetative reproduction. In an established population of lowbush blueberry, plants are referred to as “clones.” Clones can be very large (Jensen and Yarborough, 2004), and within a field there can be immense genetic variability (Hepler & Yarborough, 1991). The two species of lowbush blueberry most common in commercial fields are *Vaccinium angustifolium* Ait. (low sweet blueberry) and *Vaccinium myrtilloides* (velvet leaf blueberry; Aalders & Hall, 1962). Low sweet blueberry has smooth stems with glossy green leaves that turn red in the fall (McIsaac, 1997). Velvet leaf blueberry produces velvet-like hairs on its stems (Vander Kloet & Hall, 1981), and is reportedly more shade tolerant than *V. angustifolium* (Moola & Mallik, 1998). Plants of each species can grow 20-50 cm in height (Bell et al., 2009). Lowbush blueberries prefer an acidic, well-drained, low fertility soil with a pH of 4.3 - 5.5 (Prouse, 1996) Flowers of lowbush blueberry are white to pink in colour, regular, bell shaped and approximately 1 cm long (Bell et al., 2009). Fruit set of lowbush blueberries is influenced by factors such as pollen availability, pollinators, limited resources (e.g., water and nutrients) and pollinator competition with weeds (Bajcz et al., 2017; McKinney et al., 2010). Differences in annual yields can be affected by pollination, irrigation, climate, vegetation cover and other management practices (Hepler & Yarborough, 1991).

Production and Management of Lowbush Blueberries

Commercially harvested lowbush blueberry fields are derived from naturally occurring stands of lowbush blueberry and occur on cleared forest areas or retired farmland (Hall, 1959; Yarborough, 2004). Commercial fields are typically managed on a two-year production cycle

(Jordan and Eaton, 1995). In the first year (non-bearing year) pruning is conducted by burning or mowing plants to ground level (Yarborough, 2004). Shoots emerge from established rhizomes during the non-bearing year, and by fall will have formed flower buds that will harden off for winter (Prouse, 1996). In the bearing year, plants break dormancy in the spring (Hall et al., 1979). Flower buds swell with the onset of warm temperatures (White et al., 2012) and fields are in full bloom by late spring (Yarborough, 2012; White et al. 2012). Commercial honeybees and native pollinators pollinate fields (Aras et al., 1996) and fruit begins to develop after pollination occurs (Mallik & Hamilton, 2017). The use of irrigation can increase the weight of berries in the bearing year and can increase flower and leaf bud formation in the non-bearing year (Prive et al., 2012). Harvest generally begins at the beginning of August and can continue into September. Harvest is conducted by mechanical picking or hand raking (Farooque, 2013). Harvested berries are cleaned and sold as fresh or frozen and can be made into a variety of value-added products. The presence of weeds in fields can increase harvest difficulty and lower quality and yield of lowbush blueberries (McCully et al., 1991).

General Weed Flora in Lowbush Blueberry Fields

The general weed flora of lowbush blueberry fields consists of a range of herbaceous and woody perennial plants, with traditionally few species of shorter-lived (e.g., annual) plants. A weed survey conducted in 1984 and 1985 identified 119 weed species within Nova Scotia lowbush blueberry fields (McCully et al., 1991). The most ubiquitous weeds found at the time of this survey were all perennials and included bunchberry (Cornus canadensis L.), colonial bentgrass (Agrostis tenuis L.), poverty oat grass (Danthonia spicata L.) , sheep sorrel (Rumex acetosella L.), false lily-of-the-valley (Maianthemum canadense Desf.), goldenrods (Solidago spp.), hawkweeds (Hieracium spp.), and woolly panicum (Panicum lanuginosum Ell.; McCully et al., 1991). A second survey conducted in 2000-2001 identified over 200 weed species present in blueberry fields across the province of Nova Scotia (Jensen & Yarborough, 2004), a large increase from the 1984 and 1985 survey conducted by McCully et al. (1991). The majority of weed species were once again woody and herbaceous perennial weeds, with increasing prevalence of problematic weeds such as narrowleaf goldenrod (Jensen and Sampson, unpublished data).

Basic Biology of Creeping Herbaceous Perennial Weeds

Seedling Recruitment in Creeping Herbaceous Perennial Weed Populations

Creeping herbaceous perennial weeds reproduce by seeds and vegetative reproductive structures such as rhizomes, creeping roots, tubers, bulbs, corms, and stolons (Bhowmik, 1997). While production of new plants from vegetative reproductive structures in perennial plants is common, seedling recruitment by creeping perennials has been reported as infrequent unless plants are establishing in a new area (Hakansson, 1982). Sheep sorrel relies on both seedling and ramet recruitment to maintain populations, but established populations are maintained predominantly by vegetative reproduction of ramets from creeping roots (Kennedy, 2009; White et al., 2014; White et al., 2015). Hawkweed species (*Hieracium* spp.) use initial seedling recruitment if there is a break in the vegetation canopy or bare ground occurs (Reader & Buck, 1986). Approximately 80% of orange hawkweed (*Hieracium aurantiacum* L.) seeds landed within a square meter of the mother plant but seeds had low viability and germination rates (Stergios, 1976), indicating limited establishment of new seedlings. Yellow clintonia (*Clintonia borealis* Ait. (Raf.)) is a creeping herbaceous perennial that spreads almost exclusively via vegetative growth with very little seedling recruitment in established populations (Pitelka et al., 1985). Seedling recruitment is important for Canada goldenrod (*Solidago Canadensis* L.*)* when invading a new area, but once seedlings become established, reproduction is primarily achieved via vegetative growth (Hartnett & Bazzaz, 1985). Seedling recruitment within established stands of narrowleaf goldenrod in blueberry fields may be uncommon, but there is no data in the published literature on this subject**.**

Physiological Basis for Management of Creeping Herbaceous Perennial Weeds

To lower populations of problematic perennial weeds, methods to reduce seedling recruitment and vegetative reproduction are needed. Determining optimal treatment times requires an understanding of energy reserves and carbohydrate movement in perennials (Radosevich et al., 1997). When vegetative reproductive structures break winter dormancy and begin to sprout, carbohydrates are translocated acropetally from the roots to the new emerging shoots (Nkurunziza & Streibig, 2011). Concentration of stored carbohydrates in vegetative reproductive structures declines as shoot growth commences and carbohydrates are translocated upwards into the developing shoots (McAllister & Haderlie, 1985). This provides opportunity for herbicide application to newly emerged shoots as treatment can damage shoots and disrupt growth (Ross & Lembi, 2009). Upward translocation of carbohydrates continues until emerged shoots have enough leaf area to produce photosynthetic products for growth and respiration (McAllister & Haderlie, 1985). Carbohydrate reserves will begin to be replenished when basipetal movement of photosynthetic materials to vegetative structures begins (Nkurunziza & Streibig, 2011). This usually occurs as emerged shoots approach peak height or the flower bud stage and again in the autumn, at which time excess assimilates produced by the shoots will be translocated to the vegetative reproductive structures (Bradbury & Hofstra,1977). This provides another adequate timing opportunity for herbicide treatment, as the basipetal translocation of carbohydrates facilitates movement of herbicide through the plant (D'hertefeldt & Jónsdóttir, 1999).

Introduction of Narrowleaf Goldenrod

Taxology and Biology of Narrowleaf Goldenrod

Goldenrods are some of the most common creeping perennial weeds in lowbush blueberry fields in Nova Scotia (McCully et al., 1991), with narrowleaf goldenrod now the most common species of goldenrod in this cropping system (Lyu et al, *in press*). Narrowleaf goldenrod is a creeping herbaceous perennial plant that reproduces by seeds and rhizomes. The plant is part of the family Asteraceae, and *Euthamia* spp. are generally considered a subgenus of the *Solidago* genus (Sieren, 1981). Narrowleaf goldenrod is native to North America (Werner et al.,1990) and can be found from Nova Scotia to British Columbia and south into Florida, USA (Sheahan, 2012). Narrowleaf goldenrod prefers moist bare ground and is often found in agricultural fields, roadsides, ditches, wetlands, and wooded edges (Siren, 1981). This plant can persist on poor- to well-drained soils that are coarse or sandy in texture (Sheahan, 2012). Established plants can tolerate drought and can become dominant in abandoned farmland. Narrowleaf goldenrod can produce dense patches and out compete surrounding vegetation (Butcko & Jensen, 2002). Narrowleaf goldenrod has exhibited allelopathic effects on radish (*Raphanus sativus* L.) and lettuce (*Lactuca sativa* L.) when seeds of each species were exposed to leaf extracts of narrowleaf goldenrod (Butcko & Jensen, 2002). Allelopathy may also be important in narrowleaf goldenrod-lowbush blueberry interactions.

Narrowleaf goldenrod has a corymb inflorescence that is flat or slightly convex (Price, 2003), multi-branched, with flowers produced in clusters of 20-25 (Sheahan, 2012). Flowers are pale to bright yellow after maturity in August and set seed from September to October (Siren, 1981). Seeds have a pappus and are wind dispersed (Siren, 1981), though dispersal distance is unknown. Seeds of *S. canadensis* traveled 2.4 m from the parent plant when released from a height of 1 m (Werner et al. 1990). Narrowleaf goldenrod with a similar floral height may have a similar dispersal distance. Price (2003) determined seed viability of narrowleaf goldenrod seeds to be 0.006% suggesting limited importance of sexual reproduction for dispersal. Information on narrowleaf goldenrod seedling emergence, however, is generally lacking in the literature. Seedling emergence in other goldenrod species, such as *S. canadensis*, however, often occurs in the spring and shoots begin to emerge from established rhizomes in late April (Werner et al., 1990). After the first year of growth, *Solidago* spp. have the ability to reproduce by rhizomes. Each ramet can give rise to 2 - 6 daughter rhizomes, and each individual rhizome possesses the ability to produce one shoot from its apical growth tip (Werner et al., 1990).

Potential Approaches to the Management of Narrowleaf Goldenrod

Management of weeds relies on utilization of physical and mechanical, cultural, biological, and chemical methods of weed control. Physical and mechanical weed control consists of the use of strategies such as tillage, mowing, mulches, and flame weeding for weed control. Tillage is very effective for the management of perennial rhizomatous weeds and has been used to manage Canada thistle (*Cirsium arvense* L.), in conjunction with subsequent herbicide applications, in various cropping systems (Darwent et al., 1994). Use of tillage in lowbush blueberries, however, is difficult due to potential damage to lowbush blueberry rhizomes and is not widely recommended for weed control. Mechanical management of narrowleaf goldenrod includes manually pruning stems when above the lowbush blueberry canopy (Boyd et al., 2009). Farooq (2018) found that a single cutting at the floral bud stage in the non-bearing year can lead to significant reductions in narrowleaf goldenrod density in the non-bearing year but does not maintain control in the bearing year. This approach, however, is not utilized widely by growers.

Cultural weed management involves the use of crop rotation, fertility management, cultivar selection, and other strategies that increase crop competitiveness against weeds. Cultural management practices encourage vegetative growth of lowbush blueberries while reducing weed occurrence (Morrison et al., 2000). Use of mulches, a cultural and mechanical weed control tool, can increase blueberry coverage and potentially make the crop more competitive with weeds. Sanderson and Cutcliffe (1991) found that sawdust mulches increased the rate of lowbush blueberry rhizome growth, therefore, contributing to increased competitiveness with weeds. Mulching aids soil fertility management in lowbush blueberry, and by maintaining soil fertility, vigor and spread of plants is increased (Kender & Eggert, 1966). Interplanting competitive blueberry crop cultivars could help reduce bare spots and increase genetic diversity within fields (Jones & Percival, 2003). A cultivar developed in Kentville, NS named KBF-10 resulted in traits favorable for interplanting (Jamieson, 2008). As lowbush blueberries prefer acidic soil, applications can be used to lower soil pH. A study conducted from 2004 - 2007 concluded that a pre-emergent application of sulfur at 1120 kg /ha decreased soil pH for the subsequent three years. This contributed to decreased ground cover of broadleaf and grass weeds in lowbush blueberry fields (Smagula et al., 2009).

Biological control employs the use of beneficial organisms that target and reduce pests. Currently, this approach for weed management is limited in lowbush blueberries. Ground beetle and field cricket have been observed consuming the seeds of common weeds such as sheep sorrel and hair fescue (*Festuca filiformis* Pourr.) (Cutler et al., 2016), indicating these natural enemies may contribute to weed biocontrol in lowbush blueberry fields. Ability of the dogbane beetle (*Chrysochus auratus* Fabricius) to reduce spreading dogbane (*Apocynum androsaemifolium* L.) populations has also been investigated (MacEachern-Balodis et al., 2017), though this insect did not establish large enough populations under field conditions to adequately control this weed. Natural enemies of narrowleaf goldenrod that could be utilized in a potential biocontrol program have not been assessed.

Chemical management of creeping herbaceous perennial weeds is generally very effective. These management strategies include the use of both soil-applied herbicides and foliar applied contact and symplastic herbicides. Soil applied herbicides are applied to the soil prior to crop planting or applied as a pre-emergent treatment, before the blueberries sprout. After application, the herbicide persists in the soil and the plant absorbs the chemical through its roots. Herbicide is then transported acropetally to emerging shoots (Nishimoto, 1971). Hexazinone is widely used in lowbush blueberry management and is applied as a pre-emergent treatment and provides weed control in the non-bearing and bearing years. It is typically applied in the spring of the non-bearing year and is activated in the soil by rainfall (Boyd et al., 2009). Herbicides applied pre-emergence traditionally controlled most species of goldenrods (Jensen, 1985; Yarborough et al., 1986). Recent research trials, however, have shown reduced control of narrowleaf goldenrod by hexazinone (White et al. 2016). Other currently registered PRE herbicides in lowbush blueberry in Canada are generally ineffective on goldenrods (Table 1-1;

Anonymous, 2017; Smagula and Ismail 1981). Table 1-1 outlines herbicide effectiveness on goldenrod species in lowbush blueberry fields. Herbicides applied after emergence (POST-emergence), contribute to goldenrod management in lowbush blueberries. POST mesotrione applications provide suppression in the year of application. Control is improved when mesotrione is applied after PRE hexazinone applications (Boyd and White, 2010). Also, if mesotrione is applied sequentially or as a spot application (Farooq et al. 2019), densities of goldenrod can reduce. Other POST herbicides with efficacy on goldenrods generally pose a risk of lowbush blueberry injury. Therefore, these herbicides generally need to be used as direct spot applications (Farooq et al., 2019). Alternative application timings that reduce injury risk to lowbush blueberry (e.g., early in the non-bearing year or after harvest in the bearing year) could be identified and evaluated with further research.

Table 1-1. Various herbicide products and their effect on goldenrods in lowbush blueberry production.

Application Timing	**Herbicide active ingredient**	**Registered for use in lowbush blueberry as of 2025 (yes/no)**	**Herbicide trade name registered for use in lowbush blueberry**	**Estimated response of narrowleaf goldenrod to herbicide treatments**	**Additional comments based on available literature**
Pre-Emergence	Pronamide	Yes	Kerb SC Herbicide	Tolerant	Little control achieved by label application (Dickman et al., 1977).
	Terbacil	Yes	Sinbar Herbicide WDG	Tolerant	Goldenrod spp. can withstand high concentrations of terbacil without sustaining permanent damage (Genez & Monaco, 1983).
	Hexazinone	Yes	Velpar L CU Herbicide Velpar DF CU Herbicide Water Dispersible Granule	Variable	PRE applications of hexazinone can provide control in the non-bearing year and lower densities in the subsequent bearing-year (Boyd & White, 2010), though recent research also indicates limited efficacy on narrowleaf goldenrod (White et al., 2016).
Post Emergence	Mesotrione	Yes	Callisto 480SC Herbicide	Suppressed	Carotenoid inhibiting herbicide. Supressed by one-time application of mesotrione. Multiple treatments can provide control in the non-bearing year and reduce weed density in the bearing-year (Farooq et al., 2019; Boyd & White 2010; Sandler, 2017).
	Sethoxydim	Yes	Poast Ultra Liquid Emulsifiable Herbicide	Tolerant	Provided little to no control of goldenrod spp. in trials (Kapusta & Krausz, 1993).
	Rimsulfuron & Nicrosulfuron	Yes	Ultim Herbicide	Suppressed	Ineffective on Canada goldenrod and narrowleaf goldenrod in lowbush blueberry trials (Farooq, 2018).
	Fluazifop-P-butyl & S-isomer	Yes	Venture L Herbicide	Tolerant	Typically used to treat annual and perennial grasses with little effect on blueberry plants (Jensen & Yarborough, 2004).
Spot Treatments	Dicamba	Yes	Various Trade Names	Susceptible but may require sequential treatments	Inconsistent results, spot applications resulted in 80-90% shoot injury in non-bearing year, but less than 70% of shoots died after treatment (Farooq, 2018).
	Glyphosate	Yes	Various Trade Names	Susceptible	Can lower stem densities in the non-bearing year and bearing-year when applied in the non-bearing year (Farooq et al., 2019).

Clopyralid (dimethylamine salt)	Yes	Lontrel 360 Herbicide Lontrel 72 Herbicide Lontrel XC Herbicide	Variable	Provides control when applied in the non-bearing year but plants recover in the bearing-year (Farooq, 2018).
Sulfentrazone	Yes	Authority 480 Herbicide	Variable	

Objectives

The objectives of this research are to i) determine the timing and extent of narrowleaf goldenrod ramet emergence, ramets at the flowering bud stage, and flowering ramets in lowbush blueberry fields, ii) develop growing degree-day models to predict narrowleaf goldenrod shoot emergence and phenological development in lowbush blueberries, iii) determine if narrowleaf goldenrod forms seedbanks in lowbush blueberry, and iv) evaluate a range of herbicide use patterns for management of narrowleaf goldenrod in lowbush blueberry fields.

Objectives are based on the hypothesis that i) temperature, when expressed as growing degree-days, will adequately explain emergence and phenology of narrowleaf goldenrod in lowbush blueberry, ii) narrowleaf goldenrod does not form seedbanks in lowbush blueberry fields and that new seedlings do not emerge in established populations, and iii) alternative sequential herbicide applications and herbicide application timing can improve narrowleaf goldenrod control in lowbush blueberry fields.

Chapter 2 – Growing Degree Day Models for Predicting *Euthamia graminifolia* L. Phenology in Lowbush Blueberry Fields in Nova Scotia

Abstract

Narrowleaf goldenrod (*Euthamia graminifolia* (L.) Nutt.) is the most common goldenrod species in lowbush blueberry (*Vaccinium angustifolium* Ait.) fields in Nova Scotia, Canada. Knowledge of ramet emergence and phenological development of this weed is limited, and it is unknown if seedling emergence contributes to maintenance of established populations. The objectives of this research were to 1) develop predictive growing degree day (GDD) models for *E. graminifolia* ramet emergence and phenological development, 2) determine if *E. graminifolia* forms seedbanks in lowbush blueberry fields, and 3) determine if *E. graminifolia* seedlings emerge in lowbush blueberry fields. Cumulative *E. graminifolia* ramet emergence was explained as a function of GDD using a 4-parameter Weibull equation that predicted emergence to begin at 72 GDD and 90% emergence to occur at 458 GDD. Cumulative ramets at the flower bud and flowering stages was explained as a function of GDD using a 3-parameter Gompertz equation that predicted initiation of the flower bud and flowering stages at 644 and 1369 GDD, respectively, and 90% of ramets at the flower bud and flowering stages at 1522 and 2113 GDD, respectively. Cumulative *E. graminifolia* seedling emergence ranged from 2.4 ± 0.8 to 4 ± 1 seedlings m^{-2}, respectively, and seedling density from soil core samples ranged from 0.02 ± 0.01 to 6.92 ± 1.80 seedlings per core. *Euthamia graminifolia* seedbanks and seedling recruitment may therefore be limited in lowbush blueberry fields. Growers should prioritize management of established plants using the developed GDD models to aid timing of management practices.

Introduction

Wild, or lowbush blueberry (*Vaccinium angustifolium* Ait.) is Nova Scotia's largest horticultural crop by acreage and export, with 15,901 hectares harvested annually (Anonymous 2021). Lowbush blueberries are grown in a 2-year production cycle in which fields are pruned to ground level to promote vegetative growth and flower bud development in the first, or non-bearing year, and fruit are harvested in the second, or bearing year. Commercial fields are therefore maintained as perennial no-till monocultures, making weeds an important management challenge (Jensen and Yarborough 2004). The weed flora of lowbush blueberry fields consists primarily of native and non-native woody and herbaceous perennial plants (Jensen and Yarborough 2004; McCully et al. 1991), with creeping herbaceous perennials among the most common types of weeds in this cropping system (Lyu et al. 2021).

Narrowleaf goldenrod (*Euthamia graminifolia* (L.) Nutt.) is a common creeping herbaceous perennial weed in lowbush blueberry fields (Hall 1959; McCully et al. 1991). The plant reproduces by seed and rhizomes, though the relative contribution of seedlings and ramets to established populations in lowbush blueberry fields is unknown. *Euthamia graminifolia* occurred in 86% of lowbush blueberry fields surveyed between 2017 and 2019 (Lyu et al. 2021) and the plant is now the most common species of goldenrod in lowbush blueberry fields in Nova Scotia, presumably due to reduced hexazinone efficacy on this weed (White et al. 2016). Growers currently rely on postemergence mesotrione applications to suppress *E. graminifolia*, with application timing based primarily on height of emerged shoots (Boyd and White 2010) due to limited knowledge of shoot emergence patterns in lowbush blueberry fields. *Euthamia graminifolia* shoots are also taller than lowbush blueberry stems (Farooq 2018) and the weed can therefore be controlled by weed wiper applications of non-selective herbicides such as glyphosate. Success with this approach, however, is variable, possibly due to poor application timing and lack of knowledge of when emerged ramets are most susceptible (Farooq 2018).

Ramet emergence patterns and progression of ramet phenological development has been studied for many perennial weeds and is used to help improve weed management (Miyazaki et al. 2005; Stoller and Wax 1973; Webster and Cardina 1999; Wu et al. 2013). When emergence and phenology data are related to reliable explanatory variables, such as temperature and/or moisture expressed as growing degree days or hydrothermal time, predictive models can be developed to help improve future timing of management practices (Blatt et al. 2022; Donald 2000; Ekeleme et al. 2004). Such models have been developed for the lowbush blueberry plant (White et al. 2012) and the associated weed species red sorrel (*Rumex acetosella* L.) (White et al. 2015) and spreading dogbane (*Apocynum androsaemifolium* L.) (Wu et al. 2013). These models are currently being used by growers to aid management decisions, but similar models for *E. graminifolia* are lacking.

Euthamia graminifolia can produce dense patches and out compete surrounding vegetation (Butcko & Jensen 2002), and a negative correlation between broadleaf weed cover and blueberry yield has been demonstrated across several studies (Drummond et al. 2012; Marty et al. 2019; Yarborough and Marra 1996). There is, however, limited knowledge of the general emergence and phenology patterns exhibited by *E. graminifolia* in lowbush blueberry fields, and little knowledge of the seedbank dynamics or extent and occurrence of seedling recruitment of this weed species in lowbush blueberry fields. The objectives of this research were therefore to 1) develop predictive growing degree day models for *E. graminifolia* ramet emergence and phenological development, 2) determine if *E. graminifolia* forms seedbanks in lowbush blueberry fields, and 3) determine if *E. graminifolia* seedlings emerge in lowbush blueberry fields.

Materials and Methods

Ramet Emergence and Phenological Development

The experiment was established in eight non-bearing year commercial lowbush blueberry fields with known established *E. graminifolia* populations (Table 2-1). The experiment consisted of monitoring *E. graminifolia* ramet emergence and phenological development in ten 0.5 m × 1 m quadrats placed in areas containing *E. graminifolia* within each field. Emerged ramets were counted and marked with colored elastics twice weekly from early April until late summer. Specific elastic colors or color combinations were used on each counting date to keep emergence cohorts separate. Emerged ramets at the flower bud and flowering stages were also counted and tagged on each counting date. Ramets were considered to be at the bud and flowering stage when at least one flower bud or open flower were visible, respectively. All counts were continued until two consecutive weeks of zero values occurred. The number of emerged ramets, ramets at the flower bud stage, and ramets at the flowering stage were expressed as percent cumulative data for statistical analysis and presentation.

Temperature loggers (Watchdog 1400-series data loggers, Spectrum Technologies; Aurora, IL, USA) were placed at each location to record hourly air temperature and were attached to stakes and placed 0.5 m above the soil surface. Regional air temperature data from the nearest Environment Canada weather station were used to supplement temperature logger data (Table 2-2) to determine cumulative growing degree days (GDD) at each site beginning on April 1 using the formula:

$$GDD = \sum_{i=1}^{n} (T_{mean} - T_{base}) \qquad [1]$$

where T_{mean} is the mean daily air temperature, T_{base} is the lowest air temperature at which we assume ramet emergence or development will not occur, and n is the number of days over which GDD's are calculated. In this equation, GDD = 0 if $T_{mean} \leq T_{base}$. A base temperature of 0ºC was used and was determined using the iterative process described by Izquierdo et al. (2009) in the non-linear equations described below. Rainfall data for the 2017, 2018, 2019, and 2020 growing seasons were obtained from the Environment Canada weather station located near Debert, NS (Table 2-3).

Growing Degree-Day Model Development

Cumulative ramet emergence, ramets at the flower bud stage, and flowering ramets were plotted as functions of GDD. Fitting of non-linear equations and parameter estimates for equations was conducted using the Gauss-Newton algorithm in PROC NLIN in SAS (SAS Version 9.3, SAS Institute, Cary, NC). Non-linear equations were chosen based on goodness of fit statistics (described below), visual alignment of model predictions with observed data, and presence of biologically relevant parameters. Percent cumulate ramet emergence (Y) was related to GDD using a 4-parameter Weibull equation of the form:

$$Y = a[1-exp(-k(GDD-x0)^{c})] \qquad [2]$$

where *a* = theoretical maximum percent cumulative emergence, *k* = rate of increase in percent cumulative emergence, *x0* = the lag phase until the onset of emergence, and *c* = a shape parameter (Martinson et al. 2007).

Percent cumulative ramets at the bud stage and flowering stage (Y) were related to GDD using a 3-parameter Gompertz equation of the form:

$$Y = a\ exp[-exp(-k(GDD-x0))] \qquad [3]$$

where a = theoretical maximum percent cumulative ramets at the bud stage or flowering stage, k = rate of increase in percent cumulative ramets at the bud stage or flowering stage, and $x0$ = the inflection point of the curve on the x-axis (Dorado et al. 2008). Goodness of fit for the proposed models was determined by calculating the coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), and root-mean-square-error (RMSE) as described by White et al. (2012; 2015). Models were validated with three additional emergence, ramets at the bud stage, and flowering ramet data sets not used in the original model calibration. Ramet emergence, ramets at the flower bud stage, and flowering ramet predictions were calculated with the models and were plotted against observed data at each site used for model validation. Agreement of model predicted and observed values was based on the R^2_{adj} and RMSE.

Seedling Recruitment

The experiment was established in two non-bearing year commercial lowbush blueberry fields with known *E. graminifolia* infestations located near Webb Mountain (45.58525N; -63.684667W) and Mount Pleasant (45.770806N; -63.838472W), Nova Scotia. The experiment was established on 20 April 2020 at each site and consisted of monitoring *E. graminifolia* seedling emergence in ten 0.5 m × 1 m quadrats placed in areas containing *E. graminifolia* within each field. Newly emerged seedlings were counted twice weekly throughout the season, with newly emerged seedlings marked with colored elastics on each counting date to prevent double counting. Counts were continued until two consecutive weeks of zero values occurred.

Seedbank Analysis

The objective of this experiment was to determine the presence or absence of *E. graminifolia* seedbanks in lowbush blueberry fields. Seedbank presence or absence was determined by collecting 12 soil cores per field from 7 non-bearing year lowbush blueberry fields located near Londonderry (45.481562N, -63.577846W), Camden (45.291023N, -63.130170W), Collingwood (Purdy [45.590922N, -63.811182] and Stanley [45.590680N, -63.820964W] fields), Westchester (45.640918N, -63.600899W), Farmington (45.573702N, -63.900311W), and Mount Pleasant (45.769682N, -63.841162W), Nova Scotia, in early May of 2019. All fields had known presence of *E. graminifolia* prior to sampling. Cores were collected with a 333cm^3 (7.5cm depth) soil bulk density core sampler, bagged individually in paper bags in the field, and brought back to the lab where they were dried and sieved through a 2 mm soil sieve to remove coarse debris. Each core sample was then combined with 1000 ml of Pro-Mix Potting Mix (Premier Tech Home and Garden Inc., Brantford, ON, Canada) and placed in germination trays in the greenhouse under a 16h/8h (night/day) photoperiod and maintained at approximately 21°C. Trays were watered daily throughout the experiment. Samples were checked weekly, and any emerged seedlings were identified and removed. This continued until no new seedlings emerged for two consecutive weeks.

Results and Discussion

Ramet Emergence

Euthamia graminifolia ramets emerged between 25 and 71 GDD (early to mid-April) and emergence continued until 1047 – 1665 GDD at all sites (Figure 1A). Emergence to approximately 90%, however, was rapid and this threshold was reached by 312 – 705 GDD across sites (Figure 1A). Shoot emergence beyond 90% consisted primarily of sporadic shoot emergence over several weeks until cessation of emergence in late summer, particularly at Webb Mountain (Figure 1A). The proposed Weibull model fit the field data well and accurately predicted emergence in the field as a function of growing degree days (Figure 2-1A; Table 2-4). Model prediction for the onset of emergence was 72 GDD and 10, 50, and 90% emergence were predicted to occur at 86, 179, and 458 GDD. Model predicted emergence also agreed closely with observed emergence at the sites used for model validation (Figure 2-2C), suggesting the model can accurately predict *E. graminifolia* emergence to aid weed management decisions. For example, Donald (2000) suggested his GDD model for Canada thistle could be used to estimate 80% shoot emergence and therefore guide use of mechanical and chemical weed control for this weed species. Similarly, our model could be used to revise postemergence mesotrione application timing for *E. graminifolia* management based on shoot emergence rather than shoot size (Boyd and White 2010). When considered in the context of crop-weed competition, *E. graminifolia* ramets emerge approximately 172 GDD earlier than lowbush blueberry ramets (White et al. 2012). Weeds that emerge prior to crop plants cause larger yield reductions than weeds emerging later in the season (Swanton et al. 2008), suggesting *E. graminifolia* may be competitive with lowbush blueberry. Emergence prior to lowbush blueberry, however, may provide an opportunity for early season *E. graminifolia* suppression with non-selective herbicides and this could be considered in future research.

Ramets at Flower Bud Stage

Emerged ramets were first observed at the flower bud stage between 710 and 871 GDD (June 21 – 28) and approximately 90% of emerged ramets were at the flower bud stage between 1303 – 1956 GDD (July 17 – August 24) across sites (Figure 2-1B). The proposed Gompertz model fit the field data well and accurately predicted ramet development to the flower bud stage as a function of GDD (Figure 2-1B; Table 2-4). Model prediction for the onset of the flower bud stage was 644 GDD and 10, 50, and 90% of emerged ramets at the flower bud stage was predicted to occur at 801, 1074, and 1522 GDD, respectively. Except for North River (Figure 2-2E), model predictions for emerged shoots at the flower bud stage agreed closely with the observed shoots at the flower bud stage at each site (Figure 2-2D). Model deviation from the observed values at North River is not fully understood, but we did observe what appeared to be insect feeding damage to the apical meristem region of emerged stems at this site that seemed to disrupt the onset of the flower bud and flowering stages. This site was not being actively managed by the landowner at the time of data collection, and hence there were no herbicide, fungicide, or insecticide applications made to the field, which may explain the injury and variation observed. Validation results from the other two sites, however, suggest the model can be used to predict ramets at the bud stage and thus be used to aid weed management. For example, spot applications of glyphosate and flazasulfuron to *E. graminifolia* at the flower bud stage reduce ramet density in the year after application (Farooq 2018; White 2021) and the model can be used to help growers plan weed wiper or spot applications of these herbicides for *E. graminifolia* control.

Flowering Ramets

Emerged ramets began flowering between 1418 – 1626 GDD (July 30 – August 7) and approximately 90% of emerged ramets were flowering between 1992 – 2225 GDD (August 27 – September 12) (Figure 2-1C). The proposed Gomperts model fit the field data well and accurately predicted ramet development to the flowering stage as a function of GDD (Figure 2-1C; Table 2-4). Model prediction for the onset of flowering was 1369 GDD and 10, 50, and 90% of emerged ramets at the flower stage was predicted to occur at 1521, 1777, and 2113 GDD, respectively. Validation of the model gave similar results to the flower bud model in that model predictions deviated from observed values at North River (Figure 2-2H) but aligned well with observed flowering at the other two sites (Figure 2G, I). Much like ramet development to the flower bud stage, it is likely that flowering was also disrupted by insect damage observed on the apical meristem of emerged ramets at the North River site. Validation results from the other two sites, however, suggest the model can accurately predict flowering and could thus be used to aid weed management. For example, glyphosate applications to *E. graminifolia* at the flowering stage reduce shoot density in the year after application (Farooq 2018), and the model can be used to help growers plan weed wiper or spot applications of glyphosate or other symplastic herbicides for late-season *E. graminifolia* control.

From a beneficial perspective, late-season *E. graminifolia* flowering is asynchronous with the early-season flowering of lowbush blueberry (White et al. 2012), suggesting that *E.*

graminifolia is not competitive for pollinators of lowbush blueberry. On the contrary, we observed significant bee activity on open *E. graminifolia* flowers in late summer and goldenrods are frequently visited by a range of managed and native pollinators (Dibble et al. 2020; McCallum and McLean 2017; Stubbs et al. 1992). As such, late flowering species such as *E. graminifolia* may be beneficial for pollinators by providing late summer food sources. Growers may therefore consider sparing patches of *E. graminifolia* to improve late summer forage opportunities for pollinators.

Seedling Recruitment and Seedbank Characteristics

Mean cumulative *E. graminifolia* seedling emergence at Mount Pleasant and Webb Mountain was 2.4 ± 0.8 and 4 ± 1 seedlings m^{-2}, respectively. *Euthamia graminifolia* seedlings therefore emerge in lowbush blueberry fields, but density is quite low. *Euthamia graminifolia* seedling density from soil core samples, however, ranged from 38 ± 25 to $10{,}940 \pm 1{,}456$ seedlings m^{-2} (Table 2-5). These results suggest that *E. graminifolia* forms seedbanks in lowbush blueberry fields, despite the low levels of seedling emergence observed. Leck and Leck (1998) found an increase in both *E. graminifolia* percent cover and seed density in the seedbank in a 10-year study of an abandoned hayfield. Similarly, conversion of an abandoned hayfield to agriculture reduced aboveground occurrence of *E. graminifolia*, but seeds were present in the seedbank after 5 years of crop production (Hill et al. 1989). In contrast, *E. graminifolia* was a common component of the aboveground vegetation but lacking from the seedbank in a tallgrass prairie ecosystem (Zylka et al. 2016). *Euthamia graminifolia* is therefore capable of forming seedbanks but appears to do so on some sites and not on others. Given that lowbush blueberry fields appear to be sites where *E. graminifolia* seedbanks can form, management of this weed species should likely include strategies that target both newly emerging seedlings and established plants. Seedling emergence should also be determined at additional sites and paired with local seedbank data to improve our understanding of the potential importance of seedbanks and seedling recruitment for *E. graminifolia* establishment in lowbush blueberry fields.

Conclusion

Euthamia graminifolia ramet emergence and development to the flower bud and flowering stages were accurately predicted by GDD. Predictive models have been developed to facilitate use of GDD's by growers to improve timing of management decisions for management of this weed species. Growers can now base postemergence mesotrione application timing on percentage ramet emergence rather than height of emerged shoots, and this should be evaluated in future research. It is also anticipated that timing of weed wiper and spot applications of symplastic herbicides such as glyphosate and flazasulfuron can now be based on model predictions for bud stage and flowering of emerged ramets to maximize efficacy of these herbicides on *E. graminifolia*. It is also acknowledged that *E. graminifolia* flowering is asynchronous with that of lowbush blueberry, and that *E. graminifolia* flowers may provide an important late-season flower source for wild and managed pollinators. Seedling recruitment of *E. graminifolia* in lowbush blueberry fields was minimal despite the presence of an *E. graminifolia* seedbank at several sites. Seedling emergence of this weed species should therefore be studied in greater detail in lowbush blueberry fields and management efforts should focus on control of both seedlings and established plants.

Table 2-1. Site locations and date of experiment establishment for monitoring *Euthamia graminifolia* ramet emergence and phenological development in lowbush blueberry fields in Nova Scotia, Canada from 2017 - 2020.

Site-year	Latitude	Longitude	Date Established	Elevation (m)	Soil type	Soil pH	Soil OM (%)
Baseline 2019	45.481389N	-63.578417W	26 April 2019	128	Sandy Clay Loam	4.54	9.1
Debert 2017	45.481278N	-63.465639W	10 April 2017	150	-[a]	-	-
Farmington 2017	45.574278N	-63.899806W	10 April 2017	266	Clay	4.84	8.3
Mount Pleasant 2020	45.770806N	-63.838472W	20 April 2020	76	Clay Loam	5.07	2.4
North River 2018	45.465139N	63.212917W	16 April 2018	85	Sandy Clay Loam	4.70	5.6
Portapique 2017	45.407778N	-63.72625W	10 April 2017	22	Loam	-	-
Webb Mountain 2020	45.58525N	-63.684667W	20 April 2020	278	Sandy Clay Loam	5.20	8.6
Westchester 2019	45.640611N	-63.601361W	26 April 2019	115	Clay Loam	5.12	3.8

[a]Information not available.

Table 2-2. Date of data logger establishment and duration of temperature data supplementation with air temperature data from the nearest Environment Canada weather station at lowbush blueberry fields used to monitor *Euthamia graminifolia* emergence and phenology in Nova Scotia, Canada.

Site	Date of temperature logger installation	Duration of data supplementation from Environment Canada	Source of Environment Canada air temperature data[a]	Approximate linear distance between Environment Canada weather station and study site (km)
Baseline 2019	4 April 2019	1 April – 4 April 2019	Debert, NS	14.49
Debert 2017	18 April 2017	1 April – 18 April 2017	Debert, NS	4.65
Farmington 2017	19 April 2017	1 April – 19 April 2017	Nappan, NS	33.9
Mount Pleasant 2020	8 April 2020	1 April – 8 April 2020	Nappan, NS	31.09
North River 2018	31 March 2018	-[b]	-	-
Portapique 2017	18 April 2017	1 April – 18 April 2017	Debert, NS	20.26
Webb Mountain 2020	8 April 2020	1 April – 8 April 2020	Debert, NS	22.44
Westchester 2019	4 April 2019	1 April – 4 April 2019	Debert, NS	24.54

[a]Debert weather station located at 45.416667N, -63.466667W, elevation 37.5m; Nappan weather station located at 45.7759556N, -64.241444W, elevation 20m.
[b]Use of Environment Canada weather data not required at this site.

Table 2-3. Monthly rainfall (mm) during the period of *Euthamia graminifolia* emergence and phenology data collection in 2017, 2018, 2019, and 2020. Data were obtained from records for the Environment and Climate Change Canada weather station located at Debert, Nova Scotia, Canada (45.42N, 63.47W, elevation of 37.5m).

	Month					
Year	April	May	June	July	August	September
2017	32	135	62	66	109	63
2018	104	94	176	47	65	83
2019	201	88	177	118	65	135
2020	39	81	34	100	89	82

Table 2-4. Parameter estimates for the proposed Weibull and Gompertz equations describing the relationship between growing degree days (GDD) calculated from air temperature (T_{base} = 0°C) and percent cumulative *Euthamia graminifolia* ramet emergence, ramets at the flower bud stage, and ramets at the flowering stage in non-bearing year wild blueberry fields at Debert-2017, Collingwood-2017, Baseline-2019, Westchester-2019, and Webb Mountain-2020 in Nova Scotia, Canada.

		Model parameters[b]			
Model	Equation[a]	*a*	*k*	*x0*	*c*
Percent cumulative emergence	Weibull	99.0913 ± 1.3762[c]	0.00795 ± 0.00450	70.9209 ± 8.43	0.9578 ± 0.1034
Percent cumulative ramets at bud stage	Gompertz	98.7244 ± 1.3316	0.00445 ± 0.0003	986.4 ± 10.621	-[d]
Percent cumulative flowering ramets	Gompertz	106.6 ± 3.8203	0.00446 ± 0.000490	1713.6 ± 15.6637	-

[a]The Weibull equation was of the form $Y = a[1-exp(-k(GDD-x0)^c)]$ and the Gompertz equation was of the form $Y = a \times exp[-exp(-k(GDD-x0))]$.

[b]Weibull parameters, *a* = theoretical maximum percent cumulative emergence, *k* = rate of increase in percent cumulative emergence, *x0* = the lag phase until the onset of emergence, and *c* = a shape parameter (Martinson et al. 2007). Gompertz model parameters, *a* = theoretical maximum percent cumulative ramets at the flower bud stage or flowering stage, *k* = rate of increase in percent cumulative ramets at the flower bud stage or flowering stage, and *x0* = the inflection point of the curve on the x-axis (Dorado et al. 2008).

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

[d]Parameter not a component of the equation.

Table 2-5. Total *Euthamia graminifolia* seedling emergence from soil cores[a] collected from non-bearing year lowbush blueberry fields in Nova Scotia in 2020.

Site	Seedling density seedlings m^{-2})
Baseline	4,056 ± 716[b]
Camden	1,056 ± 392
Farmington	10,940 ± 1,456
Mount Pleasant	434 ± 179
Purdy	604 ± 123
Stanley Field	38 ± 25
Westchester	5,414 ± 912

[a]A total of 12 soil cores were collected from each site using a $333cm^3$ soil bulk density core sampler. Cores were sieved to remove coarse debris, combined with 1000ml of Pro-Mix potting mix, placed in greenhouse trays, watered daily, and inspected for seedling emergence weekly.

[b]Values represent the mean ± SE of 12 replications.

Figures

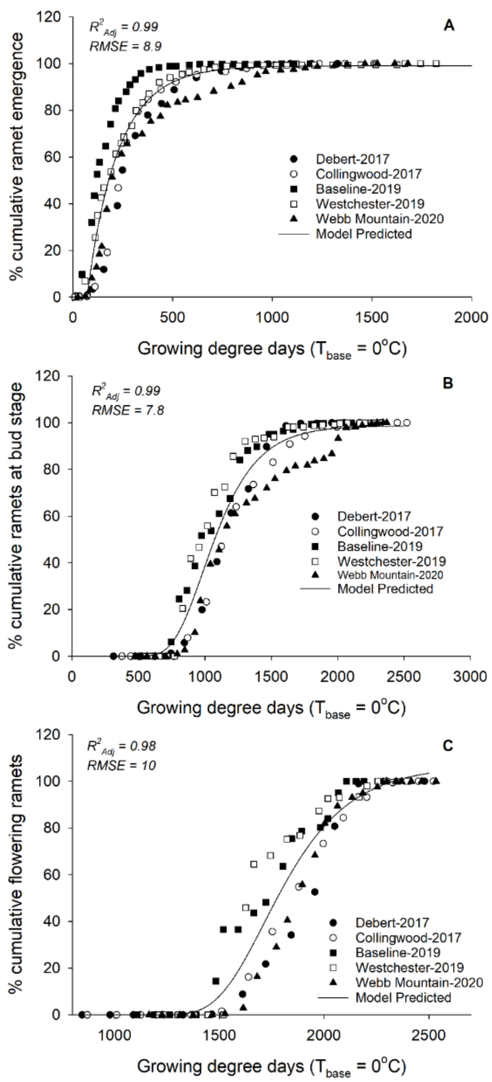

Figure 2-1. Percent cumulative *Euthamia graminifolia* ramet emergence (A), ramets at the flower bud stage (B), and ramets at the flowering stage (C) in relation to growing degree days (GDD) calculated from air temperature (T_{base} = 0°C) at sites used for model calibration in Nova Scotia, Canada. Symbols are the mean of 10 observations. Lines are fitted regression equations. A Weibull equation of the form $Y = a[1-exp(-k(GDD-x0)^c)]$ was fit to percent cumulative ramet emergence. A Gompertz equation of the form $Y = a X exp[-exp(-k(GDD-x0))]$ was fit to percent cumulative ramets at the bud stage and percent cumulative flowering ramets. Parameter estimates for each equation are provided in Table 2-3.

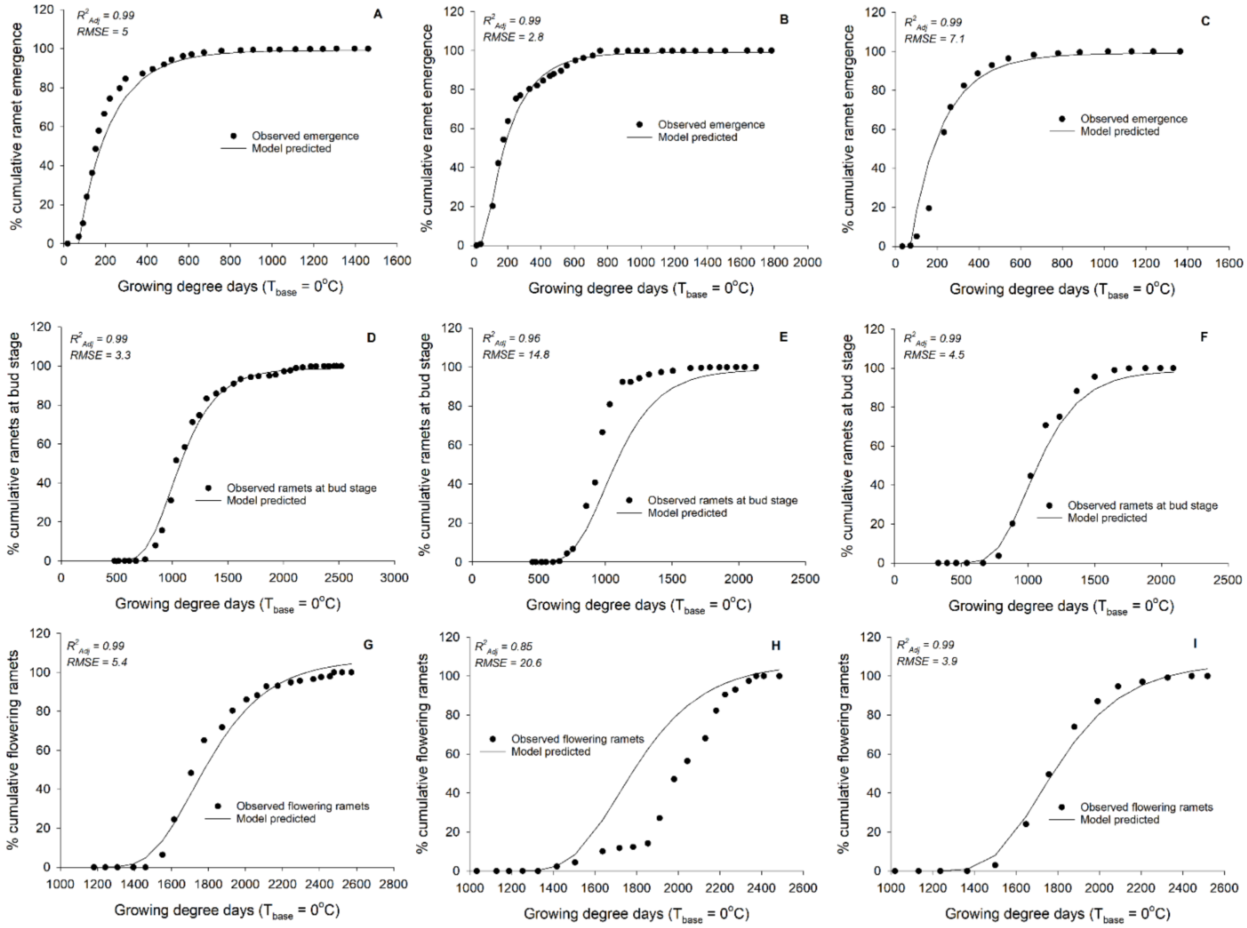

Figure 2-2. Observed and model predicted cumulative *Euthamia graminifolia* ramet emergence (A, B, C), ramets at the flower bud stage (D, E, F), and ramets at the flowering stage (G, H, I) in relation to growing degree days (GDD's) calculated from air temperature (T_{base} = 0°C) at sites used for model validation in Nova Scotia, Canada. Symbols are the mean of 10 observations. Lines are calibrated model predictions. The calibrated model for predicting percent cumulative ramet emergence was a Weibull equation of the form $Y = a[1\text{-}exp(\text{-}k(GDD\text{-}x0)^c)]$. The calibrated model for predicting percent cumulative ramets at the flower bud stage and flowering stages was a Gompertz equation of the form $Y = a\ X\ exp[\text{-}exp(\text{-}k(GDD\text{-}x0))]$.

Chapter 3 – Evaluation of Post-Emergence Herbicide Programs for Narrowleaf Goldenrod Management in Lowbush Blueberry Fields

Abstract

Narrowleaf goldenrod (*Euthamia graminifolia*) has become increasingly prevalent in lowbush blueberry production systems throughout Nova Scotia and the Atlantic provinces. Based on sites surveyed between 2000 and 2019, the occurrence of narrowleaf goldenrod in lowbush blueberry fields has increased from 45% to 86%, creating challenges for growers as it reduces crop vigor and harvest efficiency. Control options have been reduced due to deregistration of products, and reduced efficiency of currently registered products, therefore creating a need to identify effective post-emergence treatment alternatives. Three field experiments were evaluated across eleven commercial lowbush blueberry fields (2019-2021) to evaluate 1) early POST sequential herbicide applications, 2) late POST sequential herbicide applications, and 3) post-harvest, pre-pruning treatments. Results showed sequential mesotrione applications, particularly early POST or in combination with hexazinone, provided the most consistent and long-term control of narrowleaf goldenrod across sites and years. Early spring glufosinate and clopyralid improved suppression when paired with mesotrione, but these alone only reduced non-bearing year density. Late POST applications of foramsulfuron, clopyralid, or nicosulfuron/rimsulfuron were less effective. Post-harvest treatments using weed wiper glyphosate, and to a lesser extent dicamba or flazasulfuron, significantly reduced fall and subsequent summer goldenrod density with limited crop injury risk. Overall, the research identifies sequential mesotrione-based programs and targeted fall herbicide applications as the most promising tools for integrated goldenrod management in lowbush blueberry systems, supporting renewed registration efforts for

sequential mesotrione use in Canada and helping growers manage an increasingly dominant perennial weed threat.

Introduction

Wild, or lowbush blueberry (*Vaccinium angustifolium* Ait.) is Nova Scotia's largest horticultural crop by acreage and export, with 8,400 hectares harvested annually (Anonymous, 2018). Lowbush blueberries are grown in a 2-year production cycle in which fields are pruned to ground level to promote vegetative growth and flower bud development in the first, or non-bearing year, and fruit are harvested in the second, or bearing year. Fields are managed to encourage the vegetative spread of the blueberry plants, but this also promotes growth of perennial weeds.

Goldenrods are some of the most common perennial weeds in lowbush blueberry fields in Nova Scotia (McCully et al., 1991), with narrowleaf goldenrod now the most common species of goldenrod in this cropping system (Lyu et al, 2021). Narrowleaf goldenrod is a creeping herbaceous perennial plant that reproduces by seeds and rhizomes. Occurrence of this plant in lowbush blueberry fields in Nova Scotia increased from 45% of surveyed fields in 2000-2001 (Jensen and Sampson, unpubl. Data) to 86% of surveyed lowbush blueberry fields in 2017-2019 (Lyu et al. 2021). The increased occurrence of this weed is a concern in lowbush blueberry fields because narrowleaf goldenrod produces dense patches that outcompete surrounding vegetation (Butcko & Jensen, 2002) and can interfere with mechanical lowbush blueberry harvesters (Jensen and Specht 2002).

Narrow-leaved goldenrod was traditionally managed in lowbush blueberry fields with PRE hexazinone and atrazine applications (Jensen 1985; 1986; Yarborough et al., 1986). Atrazine registration in lowbush blueberries, however, was cancelled in the early 2000's (Anonymous 2003) and recent research trials have shown reduced control of narrowleaf goldenrod by hexazinone (White et al. 2016). Many growers therefore rely on POST herbicides to manage narrow-leaved goldenrod.

POST mesotrione applications suppress narrow-leaved goldenrod in the year of application (Farooq et al. 2019), though control is generally improved when mesotrione is applied after PRE hexazinone applications (Boyd and White, 2010). Sequential mesotrione applications provide better control than single applications (Farooq et al. 2019), but this use pattern remains unregistered in lowbush blueberry in Canada. Sequential mesotrione applications with other currently registered herbicides in lowbush blueberry, however, have not been evaluated. Registered POST herbicides with efficacy on broadleaf weeds at the time of this research included nicosulfuron + rimsulfuron, foramsulfuron, clopyralid, glufosinate, and tribenuron methyl. Although some of these (e.g., glufosinate and tribenuron methyl) pose crop injury risks, narrow-leaved goldenrod emerges about 170 GDD (T_{base} = 0C) before lowbush blueberry (see Chapter 2), allowing for early POST applications to narrow-leaved goldenrod before blueberry emergence. Furthermore, goldenrod stems often remain green following harvest, providing opportunities for use of herbicides to control this weed prior to pruning to reduce crop injury risks.

The objectives of this research were to determine (1) the effect of early-POST sequential herbicide applications on narrowleaf goldenrod, (2) the effect of late-POST sequential herbicide applications on narrowleaf goldenrod, and (3) the effect of post-harvest, pre-pruning herbicide applications on narrowleaf goldenrod.

Materials and Methods

Study Sites

Field trials were established and conducted in eleven commercial lowbush blueberry fields in Nova Scotia between 2019 and 2021. Site characteristics for each site such as coordinates, elevation, soil texture, soil pH, and percent organic matter are outlined in Table 3-1.

Table 3-1. Study sites used for evaluation of herbicide programs on narrowleaf goldenrod in lowbush blueberry fields in Nova Scotia, Canada.

Site,year	Production year	Latitude	Longitude	Elevation	Soil Texture	Soil pH	OM
				m			%
Camden, 2020	Nonbearing	45°17'56.6"N	63°09'19.4"W	137	Sandy Loam	4.57	5.0
Camden, 2021	Bearing						
Collingwood 1, 2019	Nonbearing	45°35'28.5"N	63°49'17.1"W	111	Sandy Loam Clay	4.43	3.9
Collingwood 1, 2020	Bearing						
Collingwood 2, 2019	Nonbearing	45°35'27.4"N	63°48'43.0"W	116	Sandy Loam Clay	4.92	3.7
Collingwood 2, 2020	Bearing						
Farmington, 2019	Nonbearing	45°34'27.4"N	63°53'59.3"W	266	Clay	4.84	8.3

Farmington, 2020	Bearing						
Mount Pleasant, 2019	Nonbearing	45°46'14.9"N	63°50'18.5"W	76	Clay Loam	5.07	2.4
Mount Pleasant, 2020	Bearing						
North River, 2020	Nonbearing	45°27'54.5"N	63°12'46.5"W	85	Sandy Clay Loam	4.70	5.6
North River, 2021	Bearing						
Union Road, 2020	Bearing	45°23’25.7” N	63°07’59.3” W	149	Sandy Loam	4.49	4.7
Union Road, 2021	Nonbearing						
Webb Mountain 2019	Nonbearing	45°35'06.9"N	63°41'04.8"W	278	Sandy Clay Loam	5.20	8.6
Webb Mountain, 2020	Bearing						
Westchester 1, 2019	Nonbearing	45°38'25.2"N	63°35'58.7"W	123	Clay Loam	5.12	3.8
Westchester 1, 2019	Bearing						
Westchester 2, 2020	Nonbearing	45°38'17.2"N	63°36'31.0"W	118	Sandy Clay Loam	4.61	5.1
Westchester 2, 2021	Bearing						
Westchester 3, 2019	Nonbearing	45°38'00.2"N	63°36'19.3"W	133	Sandy Clay Loam	4.69	6.9
Westchester 3, 2020	Bearing						

Experiment 1: Narrowleaf Goldenrod Management with Early POST Sequential Herbicide Applications

A series of experiments were established in six non-bearing year lowbush blueberry fields located near Camden (2020-2021), Farmington (2019-2020), Mt. Pleasant (2019-2020), North River (2020-2021), Westchester 2 (2020-2021) and Westchester 3 (2019-2020), Nova Scotia, Canada (Table 3-1). Due to the large treatment list and often patchy occurrence of goldenrod, this component of the research was investigated using a series of smaller experiments focused on evaluation of specific early POST herbicides. The general experimental design was a 3 × 2 factorial arrangement of early POST herbicide (none, test herbicide, hexazinone [Velpar herbicide, Tessenderlo Kerly, Inc., Phoenix, AZ) and sequential mesotrione application (no, yes) arranged in randomized complete block design with 4 or 5 blocks (depending on space available at a site), a plot size of 2 m × 4 m, and a 1 m buffer between each block. Test herbicides evaluated were clopyralid (Pyralid herbicide; Sharda, Etobicoke, ON, Canada), glufosinate (Ignite herbicide; BASF, Mississauga, ON, Canada), mesotrione (Callisto herbicide; Syngenta, Guelph, ON, Canada), nicosulfuron + rimsulfuron (Ultim herbicide; Corteva, Calgary, AB, Canada) and tribenuron methyl (Spartan herbicide; FMC, Mississauga, ON, Canada) (Table 3-2). Herbicides were applied using a CO_2-pressurized research plot sprayer equipped with four Hypro ULD 120-02 nozzles and calibrated to deliver 200L ha^{-1} at 276 kpa. Mean narrowleaf goldenrod shoot height at the first application was 4 ± 1 cm, 4 ± 1 cm, 7 ± 2 cm, 6 ± 2 cm, 4 ± 1 cm, and 7 ± 2 cm at Camden, Farmington, Mt. Pleasant, North River, Westchester 2 and Westchester 3, respectively. Weather conditions at time of herbicide applications for each test herbicide are reported in Tables 3-3 to 7.

Table 3-2. Herbicides evaluated for early POST narrowleaf goldenrod management in lowbush blueberry fields.

Trade Name	Active Ingredient(s)	Application Rate (g a.i or a.e ha^{-1})[a]	Surfactant	Application Rate for Surfactant
Callisto	Mesotrione	144	NIS[b]	0.2% v/v
Ignite	Glufosinate ammonium	750	N/A	N/A
Pyralid	Clopyralid	151	N/A	N/A
Spartan	Tribenuron methyl	30	NIS	0.2% v/v
Ultim	Nicosulfuron+rimsulfuron	13 + 13	NIS	0.2% v/v
Velpar	Hexazinone	2560	N/A	N/A

[a]a.i active ingredient, a.e acid equivalent, N/A not applicable.

[b]NIS, non-ionic surfactant

Table 3-3. Application dates and weather conditions at the time of Mesotrione applications at Mount Pleasant, Westchester 2, and Westchester 3, Nova Scotia, Canada.

Site	Test Early-POST Herbicide		Herbicide Application Dates	Temperature	Relative Humidity	Mean Wind Speed
				°C	%	Km h^{-1}
Mount Pleasant	Mesotrione	Mesotrione	May 23, 2019	20	52.6	1.1
		Mesotrione	June 10, 2019	22	45	2
Westchester 2	Mesotrione	Mesotrione	May 20, 2020	22	28	2.4
		Mesotrione	June 5, 2020	23	69	2.1
Westchester 3	Mesotrione	Mesotrione	May 23, 2019	11	61	2.6
		Mesotrione	June 10, 2019	24	45	3.0

Table 3-4. Application dates and weather conditions at the time of Glufosinate applications at Camden, Mount Pleasant, and Westchester 3, Nova Scotia, Canada.

Site	Test Early-POST Herbicide		Herbicide Application Dates	Temperature	Relative Humidity	Mean Wind Speed
				°C	%	Km h-[1]
Camden	Glufosinate	Glufosinate	May 20, 2020	17	36.3	4.5
		Mesotrione	June 5, 2020	8	76.2	5.3
Mount Pleasant	Glufosinate	Glufosinate	May 23, 2019	17	41.3	1.4
		Mesotrione	June 10, 2019	21	42.9	2.6
Westchester 3	Glufosinate	Glufosinate	May 23, 2019	11	61	1.5
		Mesotrione	June 10, 2019	24	45	3.3

Table 3-5. Application dates and weather conditions at the time of Clopyralid applications at Camden, Farmington, and Westchester 3, Nova Scotia, Canada.

Site	Test Early-POST Herbicide		Herbicide Application Dates	Temperature	Relative Humidity	Mean Wind Speed
				°C	%	Km h-[1]
Camden	Clopyralid	Clopyralid	May 20, 2020	19	29	4.0
		Mesotrione	June 5, 2020	9	72.4	6.4
Farmington	Clopyralid	Clopyralid	May 23, 2019	12	75.8	0.7
		Mesotrione	June 10, 2019	14	69.6	0.7
Westchester 3	Clopyralid	Clopyralid	May 23, 2019	11	61	3
		Mesotrione	June 10, 2019	24	45	3

Table 3-6. Application dates and weather conditions at the time of Tribenuron methyl applications at Farmington, Westchester 2, and Westchester 3, Nova Scotia, Canada.

Site	Test Early-POST Herbicide		Herbicide Application Dates	Temperature	Relative Humidity	Mean Wind Speed
				°C	%	Km h^{-1}
Farmington	Tribenuron methyl	Tribenuron methyl	May 23, 2019	12	75	0.7
		Mesotrione	June 10, 2019	14	69.6	0.7
Westchester 2	Tribenuron methyl	Tribenuron methyl	May 20, 2020	23	26	1.8
		Mesotrione	June 5, 2020	24	69	3.6
Westchester 3	Tribenuron methyl	Tribenuron methyl	May 23, 2019	11	61	3
		Mesotrione	June 10, 2019	24	45	3

Table 3-7. Application dates and weather conditions at the time of Nicosulfuron + Rimsulfuron applications at Farmington, North River, and Westchester 3, Nova Scotia, Canada.

Site	Test Early-POST Herbicide		Herbicide Application Dates	Temperature	Relative Humidity	Mean Wind Speed
				°C	%	Km h^{-1}
Farmington	Nicosulfuron + rimsulfuron	Nicosulfuron + rimsulfuron	May 23, 2019	12	70.5	0.6
		Mesotrione	June 10, 2019	23	50.1	3.7
North River	Nicosulfuron + rimsulfuron	Nicosulfuron + rimsulfuron	May 20, 2020	20	39	3.3
		Mesotrione	June 5, 2020	15	70.1	4.2
Westchester 3	Nicosulfuron + rimsulfuron	Nicosulfuron + rimsulfuron	May 23, 2019	11	61	3

	Mesotrione	June 10, 2019	24	45	3

Experiment 2: Narrowleaf Goldenrod Management with Late POST Sequential Herbicide Applications

This experiment was established in three non-bearing year lowbush blueberry fields located near Collingwood 1 (2019-2020), Webb Mountain (2019-2020) and Westchester 1 (2019-2020), Nova Scotia, Canada (Table 3-1). The experiment was a 5 × 2 factorial arrangement of late POST herbicide (none, mesotrione, foramsulfuron, nicosulfuron+rimsulfuron, clopyralid) and sequential mesotrione application (no, yes) arranged in a randomized complete block design with 4 to 5 blocks (depending on space available), plot size of 2 m × 4 m, with a 1 m buffer between each block. Application rates for each herbicide and surfactant are reported in Table 3-8. Herbicide applications were applied using the same research plot sprayer described in the early POST experiment. Mean narrowleaf goldenrod shoot height at the first application was 13 ± 3 cm, 12 ± 3 cm, and 14 ± 5 cm at Collingwood, Webb Mt. and Westchester 1 respectively. Weather conditions at time of treatments for each experiment are reported Table 3-9.

Table 3-8. Late POST herbicides evaluated to develop sequential herbicide treatments for narrowleaf goldenrod management in lowbush blueberry fields.

Trade Name	Active Ingredient(s)	Application Rate (g a.i or a.e ha^{-1})[a]	Surfactant	Application Rate for Surfactant
Callisto	Mesotrione	144	NIS[b]	0.2% v/v
Option	Foramsulfuron	35	28-0-0 UAN	2.5L ha^{-1}
Pyralid	Clopyralid	151	N/A	N/A
Ultim	Nicosulfuron+rimsulfuron	13 + 13	NIS	0.2% v/v

[a]a.i active ingredient, a.e acid equivalent, N/A not applicable.

[b]NIS, non-ionic surfactant

Table 3-9. Application dates and weather conditions at the time of herbicide applications at Collingwood 1, Webb Mt., and Westchester 1, Nova Scotia, Canada.

Site	Treatment	Application Date	Temperature	Relative Humidity	Mean Wind Speed
			°C	%	Km h^{-1}
Collingwood 1	Late POST	June 04, 2019	14	73	3.4
	Mesotrione	June 18, 2019	22	59	4.6
Webb Mountain	Late POST	June 04, 2019	13	75	4.5
	Mesotrione	June 18, 2019	20	60	2.1
Westchester 1	Late POST	June 07, 2019	22	44	1.7
	Mesotrione	June 19, 2019	23	60	4.0

Experiment 3: Evaluation of Post-Harvest, Pre-Pruning Herbicide Applications for Narrowleaf Goldenrod Management in Lowbush Blueberry

This experiment was established in four recently harvested lowbush blueberry fields located in Collingwood 1 and 2 (2019-2020; 2020-2021), Union Road (2020-2021), and Webb Mountain (2019-2020), Nova Scotia, Canada (Table 3-1). The experiment was arranged in a randomized complete block design with 4 to 5 blocks (depending on space) and a plot size of 2 m × 4 m, with a 1 m buffer between each block. Treatments consisted of (1) nontreated control, (2) glyphosate (RoundUp WeatherMax herbicide; Bayer, Calgary, AB, Canada) (3) mesotrione (4) flazasulfuron (Chikara herbicide, ISK Biosciences; Concord, Ohio, USA) (5) dicamba (Banvel herbicide; BASF, Mississauga, ON, Canada) (6) clopyralid, (7) nicosulfuron + rimsulfuron, and (8) tribenuron methyl. Application rates for each herbicide and surfactant are reported in Table 3-10. All herbicides except glyphosate were applied using the research plot sprayer described in the Early-POST experiment. Glyphosate was applied as a 22% solution using a handheld weed wiper (Red Weeder (Hockeystick) herbicide applicator, Smucker Manufacturing Inc., Harrisburg, OR). Treatments were applied POST to goldenrod and lowbush blueberry plants following harvest but prior to field pruning, and all plots were pruned with a rotary mower 1 month after herbicide applications. Weather conditions at the time of herbicide applications at each site are reported in Table 3-11.

Table 3-10: Herbicides evaluated for post-harvest, pre-pruning narrow-leaved goldenrod management in lowbush blueberry fields.

Trade Name	Active Ingredient(s)	Application Rate (g a.i or a.e ha^{-1})[a]	Surfactant	Application Rate for Surfactant
Banvel	Dicamba	2208	N/A	N/A
Callisto	Mesotrione	144	NIS[b]	0.2% v/v
Flazasulfuron	Flazasulfuron	50	NIS	0.2% v/v
Pyralid	Clopyralid	151	N/A	N/A
RoundUp WeatherMax	Glyphosate	22%	N/A	N/A
Spartan	Tribenuron methyl	30	NIS	0.2% v/v
Ultim	Nicosulfuron + rimsulfuron	13 + 13	NIS	0.2% v/v

[a]a.i active ingredient, a.e acid equivalent, N/A not applicable.

[b]NIS, non-ionic surfactant

Table 3-11. Application dates and weather conditions at the time of herbicide applications at Collingwood 1, Collingwood 2, Union Road, and Webb Mountain, Nova Scotia, Canada.

Site	Application Date	Temperature	Relative Humidity	Mean Wind Speed
		°C	%	Km h^{-1}
Collingwood 1	October 03, 2019	7	69	2.0
Collingwood 2	October 01, 2020	12	79	4.1
Union Road	October 01, 2020	5	90	6.0
Webb Mountain	October 03, 2019	8	67	5.4

Data Collection

Data collection for each experiment included narrowleaf goldenrod shoot density and height at the time of herbicide applications, narrowleaf goldenrod shoot density at various time points after herbicide applications, and visual damage ratings for narrowleaf goldenrod and lowbush blueberry when possible. Narrowleaf goldenrod shoot density in the early and late POST experiments was recorded at the time of herbicide applications and again in July and August of the non-bearing year and early summer of the bearing year. Narrowleaf goldenrod shoot density in the post-harvest, pre-pruning trial was collected at the time of fall herbicide applications and in early summer of the following year. Shoot density was measured in two $1m^2$ quadrats in all herbicide experiments. Height of narrowleaf goldenrod in early and late POST experiments was determined on 30 randomly selected narrowleaf goldenrod shoots across the entire experimental area. Visual damage ratings for early- and late-POST trials were collected at 7, 21 and 35 d after treatment (DAT). Visual estimates of herbicide injury were recorded on a scale of 0 to 100 where 0 is no plant injury and 100 is complete plant necrosis and death. Lowbush blueberry density was determined in three $0.25m^2$ quadrats in all late POST experiments where blueberry cover was sufficient. There was not sufficient blueberry cover in early POST trials to collect blueberry density. In the fall crop trials, blueberry cover was determined by percent cover of each plot. Lowbush blueberry density was measured at the end of the non-bearing year.

Statistical Analysis

All objective data (density, height, etc.) was analyzed using linear mixed effects models in PROC MIXED in SAS (version 9.4, SAS Institute, Raleigh, NS). Main and interactive effects were modeled as fixed effects, and blocks were modeled as random effects in all analyses. Effects were considered significant at P = 0.05, and mean separation (where necessary) was conducted using a Tukey's multiple means comparison test. Subjective data (e.g., visual injury ratings) are expressed and presented as the mean visual injury rating on each date.

Results and Discussion

Experiment 1: Narrowleaf Goldenrod Management with Early POST Emergence Sequential Herbicide Applications

Significance of main and interactive effects for each early and late POST experiment are provided in Table 3-12.

Table 3-12. Significance of main and interactive effects of early and late POST herbicide applications on narrowleaf goldenrod.

Experiment	Factor	July non-bearing year density	August non-bearing year density	June bearing year density
Early POST mesotrione	Early POST	<0.0001	<0.0001	0.0265
	Late POST	<0.0001	<0.0001	0.0067
	Early POST X Late POST	0.2778	0.1365	0.4870
Early POST glufosinate	Early POST	<0.0001	0.1287	0.2682

	Late POST	<0.0001	0.0006	0.0020
	Early POST X Late POST	0.0120	0.6275	0.3380
Early POST clopyralid	Early POST	<0.0001	0.0063	0.5982
	Late POST	<0.0001	<0.0001	0.0002
	Early POST X Late POST	0.1080	0.1139	0.3415
Early POST tribenuron-methyl	Early POST	0.5238	0.1666	0.5249
	Late POST	<0.0001	<0.0001	<0.0001
	Early POST X Late POST	0.5533	0.6411	0.5792
Early POST nicosulfuron + rimsulfuron	Early POST	0.0451	0.2693	0.4196
	Late POST	<0.0001	<0.0001	<0.0001
	Early POST X Late POST	0.4785	0.6713	0.7118

Early POST Mesotrione X Late POST Mesotrione

There was no significant difference in narrowleaf goldenrod shoot density across treatments at the early POST and late POST application timings in the early POST mesotrione experiment ($P \geq 0.7821$; Table 3-13). There was a significant early POST and late POST effect on summer non-bearing year and bearing year narrowleaf goldenrod shoot density (Table 3-12). Early POST hexazinone applications did not reduce non-bearing or bearing year narrowleaf goldenrod shoot density (Table 3-13). Although hexazinone has traditionally suppressed or controlled a range of goldenrod species in lowbush blueberry (Jensen 1985; Lapointe and Rochefort 2001; Yarborough and Bhowmik 1989), Boyd and White (2010) reported only partial control of goldenrods by hexazinone. Hexazinone also failed to control narrowleaf goldenrod in more recent research (White et al. 2016). Our results support the findings of White et al. (2016) and provide further evidence that hexazinone no longer controls narrowleaf goldenrod in lowbush blueberry fields. Early POST mesotrione applications reduced non-bearing year narrowleaf goldenrod shoot density (Table 3-13) and were more effective than late POST mesotrione applications. Mesotrione efficacy on broadleaf weeds is reduced by large weed size (White and Webb 2018) and it is likely that the smaller narrowleaf goldenrod stems present at the time of early POST applications were more susceptible to mesotrione than the larger stems present at the late POST application timing. Sequential early POST hexazinone and late POST mesotrione applications tended to be more effective than mesotrione applications alone, though only sequential early POST and late POST mesotrione applications reduced both non-bearing and bearing year narrowleaf goldenrod shoot density (Table 3-13). Boyd and White (2010) also found that mesotrione efficacy on goldenrod was improved by sequential hexazinone and mesotrione applications and that this treatment combination gave more consistent control across sites. Growers should therefore continue to consider this herbicide combination for narrowleaf goldenrod management. The success of sequential early POST and late POST mesotrione applications are consistent with findings of Farooq et al. (2019) and White (2024) and further support the need for a sequential mesotrione use pattern in lowbush blueberry.

Table 3-13. Effect of early and late POST sequential mesotrione applications on narrowleaf goldenrod shoot density at three lowbush blueberry fields located near Westchester and Camden, NS, Canada in 2019 and 2020.

		Narrowleaf goldenrod shoot density				
Early POST[a]	Late POST mesotrione (g a.i. ha^{-1})	At early POST application	At late POST application	July non-bearing year[c]	August non-bearing year[c]	June bearing year[d]
None	0	43 ± 12 a[b]	52 ± 14 a	58 a	41 a	41 a
Hexazinone	0	50 ± 12 a	41 ± 14 a	34 ab	28 ab	29 ab
Mesotrione	0	54 ± 12 a	32 ± 14 a	17 bc	14 bc	22 ab
None	144	59 ± 12 a	56 ± 14 a	32 ab	21 ab	21 ab
Hexazinone	144	55 ± 12 a	50 ± 14 a	10 cd	7 cd	24 ab
Mesotrione	144	44 ± 12 a	24 ± 14 a	1 d	2 d	10 b

[a]Early POST hexazinone and mesotrione application rates were 1920 and 144 g a.i. ha^{-1}, respectively.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey's multiple means comparison test at the 0.05 level of significance.

[c]Data were LOG(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

[d]Data were SQRT(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

Early POST Glufosinate X Late POST Mesotrione

There was no significant difference in narrowleaf goldenrod shoot density across treatments at the early POST timing, though shoot density was reduced by early POST glufosinate applications by the late POST application timing. There was a significant early POST and late POST effect on July non-bearing year goldenrod shoot density (Table 3-12). However, significance was limited to late POST mesotrione applications for shoot densities collected in August of the non-bearing year and June of the bearing year (Table 3-14). Early POST hexazinone applications once again did not reduce non-bearing or bearing year narrowleaf goldenrod shoot density. Early POST glufosinate applications reduced July non-bearing year narrowleaf goldenrod shoot density, though shoot density was not reduced in August of the non-bearing year or in the bearing year. The perennial weeds common milkweed (*Asclepias syriaca* L.) and horsenettle (*Solanum carolinense* L.) also exhibited shoot regrowth following treatment with glufosinate (Pline et al. 200), suggesting this herbicide alone only provides short term suppression of perennial weeds.

Early POST hexazinone in conjunction with late POST mesotrione applications reduced non-bearing and bearing year shoot density and were generally more effective than hexazinone or mesotrione applications alone. Sequential early POST glufosinate and late POST mesotrione applications also reduced non-bearing year shoot density and tended to reduce bearing year shoot density. Tank mixtures of mesotrione and glufosinate improve control of some weeds relative to either herbicide applied alone (Armel et al. 2008). Although we did not evaluate these herbicide as tank mixtures, our results suggest this herbicide combination could be useful for narrowleaf goldenrod management in lowbush blueberry. Further investigation into the timing and application of glufosinate as an early POST in conjunction with late POST mesotrione applications should be further investigated to study the potential of long-term control.

Table 3-14. Effect of early and late POST sequential glufosinate and mesotrione applications on narrowleaf goldenrod shoot density at three lowbush blueberry fields located near Westchester and Camden, NS, Canada in 2019 and 2020.

		Narrowleaf goldenrod shoot density				
Early POST[a]	Late POST mesotrione (g a.i. ha^{-1})	At early POST application	At late POST application	July non-bearing year[c]	August non-bearing year	June bearing year[c]
None	0	47 ± 10 a[b]	59 ± 15 a	61 a	36 ± 7 a	46 a
Hexazinone	0	39 ± 10 a	50 ± 15 a	40 a	28 ± 7 ab	39 ab
Glufosinate	0	47 ± 10 a	18 ± 15 b	17 b	23 ± 7 ab	34 ab
None	144	41 ± 10 a	46 ± 15 a	20 b	19 ± 7 ab	27 ab
Hexazinone	144	53 ± 10 a	63 ± 15 a	23 b	17 ± 7 b	21 b
Glufosinate	144	47 ± 10 a	19 ± 15 b	12 b	14 ± 7 b	24 ab

[a]Early POST hexazinone and glufosinate application rates were 1920 and 750 g a.i. ha^{-1}, respectively.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey's multiple means comparison test at the 0.05 level of significance.

[c]Data were LOG(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

Early POST Clopyralid X Late POST Mesotrione

There was no significant difference in narrowleaf goldenrod shoot density across treatments at the early and late POST application timings ($P \geq 0.9446$; Table 3-15). There was a significant early POST and late POST effect on July and August non-bearing year goldenrod shoot density (Table 3-11), but significance was limited to the late POST mesotrione application for shoot density collected in June of the bearing year (Table 3-12). Early POST hexazinone applications did not reduce non-bearing or bearing year narrowleaf goldenrod shoot density. Early POST clopyralid applications reduced July non-bearing year shoot density (Table 3-15) but not August non-bearing year or bearing year shoot density. White (2021) also reported that clopyralid reduced non-bearing year narrowleaf goldenrod shoot density. Clopyralid is currently registered for tufted vetch (*Vicia cracca* L.) control in lowbush blueberry and spring non-bearing year applications are also used for hawkweed (*Hieracium* spp.) management (Eriavbe 2014). Growers may therefore experience additional weed control benefits from these routine clopyralid uses. Although clopyralid is more effective on perennial weeds when applied in summer or fall rather than spring (Donald 1993), Farooq et al. (2019) found that clopyralid spot applications to narrowleaf goldenrod at the flower bud stage in summer reduced non-bearing year density but not bearing year density. Clopyralid efficacy on narrowleaf goldenrod is therefore similar across different application timings and, much like glufosinate, growers should only expect non-bearing year suppression of narrowleaf goldenrod with this herbicide.

Sequential early POST hexazinone and late POST mesotrione applications once again reduced non-bearing and bearing year shoot density, further confirming the effectiveness of this herbicide combination on narrowleaf goldenrod. Sequential early POST clopyralid and late POST mesotrione applications provided better narrowleaf goldenrod control than mesotrione or clopyralid applications alone (Table 3-15) and growers should therefore use these sequential applications if considering clopyralid as part of a narrowleaf goldenrod management program.

Table 3-15. Effect of early and late POST sequential clopyralid mesotrione applications on narrowleaf goldenrod shoot density at three lowbush blueberry fields located near Westchester and Camden, NS, Canada in 2019 and 2020.

		Narrowleaf goldenrod shoot density				
Early POST[a]	Late POST mesotrione (g a.i. ha^{-1})	At early POST application	At late POST application	July non-bearing year[c]	August non-bearing year	June bearing year
None	0	45 ± 13 a[b]	62 ± 19 a	53 a	41 ± 6 a	36 ± 5 a
Hexazinone	0	46 ± 13 a	51 ± 19 a	47 a	40 ± 6 a	38 ± 5 a
Clopyralid	0	46 ± 13 a	43 ± 19 a	29 bc	27 ± 6 ab	27 ± 5 ab
None	144	51 ± 13 a	63 ± 19 a	33 ab	23 ± 6 bc	19 ± 5 ab
Hexazinone	144	41 ± 13 a	52 ± 19 a	15 c	10 ± 6 c	16 ± 5 b
Clopyralid	144	47 ± 13 a	45 ± 19 a	16 c	12 ± 6 c	19 ± 5 ab

[a]Early POST hexazinone and clopyralid application rates were 1920 and 151 g a.i. ha^{-1}, respectively.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey's multiple means comparison test at the 0.05 level of significance.

[c]Data were LOG(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

Early POST Tribenuron-methyl X Late POST Mesotrione

There was no significant difference in narrowleaf goldenrod shoot density across treatments at the early and late POST application timings ($P \geq 0.4862$; Table 3-16). Narrowleaf goldenrod shoot density was only affected by late POST mesotrione applications in July and August of the non-bearing year and June of the bearing year (Table 3-12). Early POST hexazinone and tribenuron-methyl applications did not reduce non-bearing or bearing year narrowleaf goldenrod shoot density (Table 3-16). Jensen and Specht (2004) indicated that summer spot applications of tribenuron methyl caused visual injury to narrowleaf goldenrod but did not provide complete control. In contrast, Farooq et al. (2019) found that summer tribenuron spot applications reduced non-bearing but not bearing year narrowleaf goldenrod shoot density. Tribenuron methyl efficacy on narrowleaf goldenrod therefore appears variable and may depend on application timing. Sequential early POST hexazinone and late POST mesotrione applications reduced summer non-bearing year and bearing year shoot density. Sequential early POST tribenuron-methyl and late POST mesotrione applications reduced shoot density in July of the non-bearing year and June of the bearing year (Table 3-16). Spring non-bearing year tribenuron methyl applications are currently registered for bunchberry (*Cornus canadensis* L.) control (Jensen and Specht 2004) and can also be used to suppress red sorrel (*Rumex acetosella* L.) (White 2023). If combined with sequential mesotrione applications, these spring non-bearing year tribenuron methyl applications may also contribute to narrowleaf goldenrod management.

Table 3-16. Effect of early and late POST sequential tribenuron-methyl and mesotrione applications on narrowleaf goldenrod shoot density at three lowbush blueberry fields located near Westchester and Farmington, NS, Canada in 2019 and 2020.

		Narrowleaf goldenrod shoot density				
Early POST[a]	Late POST mesotrione ($g\ a.i.\ ha^{-1}$)	At early POST application	At late POST application	July non-bearing year[c]	August non-bearing year	June bearing year
None	0	50 ± 17 a[b]	50 ± 10 a	55 a	42 ± 6 ab	49 ± 9 ab
Hexazinone	0	55 ± 17 a	54 ± 10 a	54 a	43 ± 6 ab	60 ± 9 a
Tribenuron-methyl	0	57 ± 17 a	42 ± 10 a	55 ab	52 ± 6 a	51 ± 9 ab
None	144	49 ± 17 a	48 ± 10 a	29 abc	23 ± 6 bc	34 ± 9 b
Hexazinone	144	51 ± 17 a	44 ± 10 a	17 c	13 ± 6 c	34 ± 9 b

Tribenuron-methyl	144	42 ± 17 a	30 ± 10 a	28 bc	28 ± 6 abc	32 ± 9 b

[a]Early POST hexazinone and tribenuron-methyl application rates were 1920 and 30 g a.i. ha^{-1}, respectively.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey's multiple means comparison test at the 0.05 level of significance.

[c]Data were LOG(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

Early POST Nicosulfuron + Rimsulfuron X Late POST Mesotrione

There was no significant difference in narrowleaf goldenrod shoot density across treatments at the early and late POST application timings ($P \geq 0.5958$; Table 3-17). Narrowleaf goldenrod shoot density was only affected by late POST mesotrione applications in July and August of the non-bearing year and June of the bearing year (Table 3-12). Early POST applications of hexazinone and nicosulfuron + rimsulfuron did not reduce non-bearing or bearing year narrowleaf goldenrod shoot density (Table 3-17). Sequential early POST hexazinone and late POST mesotrione application reduced shoot density in the summer of the non-bearing year and June of the bearing year. This herbicide combination was therefore more effective than hexazinone or mesotrione applications alone in 4 of 5 trials across 5 sites. Sequential early POST nicosulfuron + rimsulfuron and late POST mesotrione applications reduced non-bearing and bearing year shoot density (Table 3-17). Nicosulfuron + rimsulfuron is often applied in early spring of the non-bearing year for management of black bulrush (*Scirpus atrovirens* L.) (Jensen and Specht 2004) and these results suggest that subsequent mesotrione applications may improve weed control. Furthermore, nicosulfuron + rimsulfuron is commonly applied in tank mixture with non-bearing year hexazinone applications to broaden the spectrum of weed control, and it would be interesting to determine the effect of sequential applications of this tank mixture with mesotrione on weed control in lowbush blueberry.

Table 3-17. Effect of early and late POST sequential nicosulfuron + rimsulfuron and mesotrione applications on narrowleaf goldenrod shoot density at three lowbush blueberry fields located near Westchester, North River, and Farmington, NS, Canada in 2019 and 2020.

		Narrowleaf goldenrod shoot density				
Early POST[a]	Late POST mesotrione (g a.i. ha^{-1})	At early POST application	At late POST application	July non-bearing year[c]	August non-bearing year	June bearing year
None	0	50 ± 21 a[b]	52 ± 14 a	51 a	51 ± 5 a	42 ± 9 abc
Hexazinone	0	43 ± 21 a	42 ± 14 a	37 ab	40 ± 5 ab	49 ± 9 a
Nicosulfuron + rimsulfuron	0	57 ± 21 a	45 ± 14 a	55 a	48 ± 5 a	43 ± 9 ab
None	144	42 ± 21 a	44 ± 14 a	28 abc	25 ± 5 bc	19 ± 9 d
Hexazinone	144	51 ± 21 a	50 ± 14 a	17 c	21 ± 5 c	24 ± 9 cd
Nicosulfuron + rimsulfuron	144	41 ± 21 a	37 ± 14 a	21 bc	21 ± 5 c	25 ± 9 bcd

[a]Early POST hexazinone and nicosulfuron + rimsulfuron application rates were 1920 and 12.75 + 12.75 g a.i. ha^{-1}, respectively.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey's multiple means comparison test at the 0.05 level of significance.

[c]Data were LOG(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

Experiment 2: Narrowleaf Goldenrod Management with Late POST Sequential Herbicide Applications

There was no significant difference in narrowleaf goldenrod shoot density across treatments at the late POST application timing ($P = 0.08742$; Table 3-18). Late POST mesotrione applications did, however, reduced narrowleaf goldenrod shoot density by the time of sequential mesotrione applications ($P = 0.0320$; Table 3-18). There was a significant late POST ($P < 0.0001$), sequential mesotrione ($P \leq 0.0005$), and late POST X sequential mesotrione interaction ($P \leq 0.0451$) effect on July and August non-bearing year narrowleaf goldenrod shoot density, though there was only a significant late POST ($P = 0.0003$) and sequential mesotrione ($P = 0.0116$) effect on June bearing year narrowleaf goldenrod shoot density. Single mesotrione applications reduced non-bearing year but not bearing year narrowleaf goldenrod shoot density (Table 3-18) and further confirm that efficacy of single mesotrione applications on narrowleaf goldenrod is limited to the year of application. Late POST foramsulfuron and nicosulfuron + rimsulfuron applications did not reduce non-bearing or bearing year shoot density. Sequential late POST foramsulfuron and mesotrione applications reduced non-bearing year narrowleaf goldenrod shoot density (Table 3-18), though reductions in shoot density were similar to that obtained with single mesotrione applications. Results suggest that late POST foramsulfuron and nicosulfuron + rimsulfuron are therefore ineffective on narrowleaf goldenrod. Late POST clopyralid applications only reduced narrowleaf goldenrod shoot density in July of the non-bearing year (Table 3-18) and sequential late POST clopyralid and mesotrione applications were generally less effective than mesotrione applications alone. Clopyralid should therefore not be used for late POST narrowleaf goldenrod management. White (2021) also found that late POST foramsulfuron, nicosulfuron+rimsulfuron, and clopyralid applications had limited efficacy on narrowleaf goldenrod and our results provide further confirmation of the limited utility of these herbicides for management of this weed species. Sequential late POST mesotrione applications reduced both non-bearing and bearing year narrowleaf goldenrod shoot density. This is similar to results reported by Farooq et al. (2019) and White (2024) and further confirm the superior efficacy of sequential mesotrione applications on narrowleaf goldenrod.

Table 3-18. Effect of late POST sequential herbicide applications on narrowleaf goldenrod shoot density at three lowbush blueberry fields located near Westchester, Webb Mountain, and Collingwood, NS, Canada in 2019 and 2020.

		Narrowleaf goldenrod shoot density				
Late POST[a]	Sequential mesotrione (g a.i. ha^{-1})	At late POST application	At sequential mesotrione application	July non-bearing year[c]	August non-bearing year	June bearing year
None	0	81 ± 23 a[b]	64 ± 14 a	80 a	57 ± 11 a	35 ± 8 a
Mesotrione	0	56 ± 23 a	31 ± 14 b	18 c	20 ± 11 cd	26 ± 8 ab
Foramsulfuron	0	67 ± 23 a	47 ± 14 ab	51 ab	48 ± 11 ab	36 ± 8 a
Nicosulfuron+ rimsulfuron	0	63 ± 23 a	45 ± 14 ab	52 ab	46 ± 11 ab	40 ± 8 a
Clopyralid	0	70 ± 23 a	38 ± 14 ab	38 bc	41 ± 11 abc	36 ± 8 a
None	144	69 ± 23 a	48 ± 14 ab	32 bc	30 ± 11 bc	29 ± 8 ab
Mesotrione	144	56 ± 23 a	33 ± 14 b	1 d	5 ± 11 d	9 ± 8 b
Foramsulfuron	144	68 ± 23 a	44 ± 14 ab	35 bc	30 ± 11 bc	30 ± 8 a
Nicosulfuron+ Rimsulfuron	144	70 ± 23 a	43 ± 14 ab	47 ab	48 ± 11 ab	34 ± 8 a

Clopyralid	144	73 ± 23 a	41 ± 14 ab	26 bc	38 ± 11 abc	31 ± 8 a

[a]Late POST mesotrione, foramsulfuron, nicosulfuron + rimsulfuron, and clopyralid application rates were 144, 35, 12.5 + 12.5, and 151 g a.i. ha^{-1}, respectively.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey's multiple means comparison test at the 0.05 level of significance.

[c]Data were SQRT(Y) transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

Experiment 3: Evaluation of Post-Harvest, Pre-Pruning Herbicide Applications for Narrowleaf Goldenrod Management in Lowbush Blueberry

Narrowleaf goldenrod shoot density did not vary across treatments at the time of fall herbicide applications (P = 0.2336; Table 3-19). There was a significant treatment effect on narrowleaf goldenrod shoot density at the end of the fall in the year of application (P <0.0001) and in summer of the following year (P <0.0001). A weed wiper application of glyphosate and broadcast dicamba and flazasulfuron applications were the most effective treatments evaluated and each reduced both fall bearing and summer non-bearing year goldenrod shoot density (Table 3-19). Weed wiping is a relatively simple, economical weed management tool in low stature crops like lowbush blueberries, and growers should therefore consider this treatment for goldenrod management. Although also effective, dicamba applications directly to lowbush blueberry plants can cause up to 53% visual injury (Wu and Boyd 2012). Fall bearing year applications of dicamba after pruning, however, did not damage lowbush blueberry (White et al. 2021). Lowbush blueberry coverage was sporadic in the portions of the study sites where we established the plots, but we did not observe significant visual injury to lowbush blueberry plants regrowing in the non-bearing year. POST dicamba applications to lowbush blueberry plants prior to pruning may therefore be safe, but additional evaluations of crop tolerance to this dicamba application timing should likely be conducted before recommending this use to growers. Flazasulfuron, although not as effective as glyphosate and dicamba, reduced shoot density in the fall of the bearing year and the summer of the non-bearing year. This herbicide is an effective spot treatment for narrowleaf goldenrod with limited risk of crop injury (White 2021) and this fall application timing for narrowleaf goldenrod management should be evaluated further. Post-harvest, pre-pruning applications of mesotrione, clopyralid, nicosulfuron + rimsulfuron and tribenuron-methyl did not reduce narrowleaf goldenrod shoot density and are not recommended for management of this weed at this application timing.

Table 3-19. Effect of post-harvest, pre-pruning herbicide applications on narrowleaf goldenrod shoot density at four lowbush blueberry fields located near Webb Mountain, Purdy Roadside, Purdy Collingwood and Union Road, NS, Canada in 2019 and 2020.

	Narrowleaf goldenrod shoot density		
Treatment	Fall application timing	October bearing year[a]	June/July non-bearing year[a]
Control	42 ± 5 a[b]	38 a	32 a
Glyphosate (weed wiper)	42 ± 5 a	14 d	12 cd
Dicamba	41 ± 5 a	16 cd	6 d
Flazasulfuron	34 ± 5 a	23 bcd	15 bcd
Mesotrione	34 ± 5 a	31 ab	24 ab
Clopyralid	36 ± 5 a	26 abc	22 abc
Nicosulfuron + rimsulfuron	30 ± 5 a	27 abc	26 ab
Tribenuron-methyl	38 ± 5 a	34 ab	28 ab

[a]Data were SQRT transformed to meet the assumptions of the variance analysis. Geometric means computed using PROC MEANS in SAS are presented.

[b]Values are the mean ± SE. Means with the same letter are not significantly difference according to a Tukey’s multiple means comparison test at the 0.05 level of significance.

The sequence of experiments in this chapter highlights several opportunities for narrowleaf goldenrod management in lowbush blueberries. Spring non-bearing year hexazinone, glufosinate, and clopyralid, when applied in conjunction with sequential mesotrione applications, generally improved narrowleaf goldenrod control relative to mesotrione applications alone. Growers should therefore consider spring non-bearing year applications of these herbicides as part of a narrowleaf goldenrod control program. Late POST foramsulfuron, nicosulfuron+rimsulfuron, and clopyralid applications alone or followed by mesotrione do not improve narrowleaf goldenrod control relative to mesotrione applications alone and are therefore not recommended for management of this weed species. Sequential mesotrione applications, regardless of application timing, give superior narrowleaf goldenrod control and this use pattern should be pursued for use in lowbush blueberry. Post-harvest, pre-pruning weed wiper glyphosate or broadcast dicamba and flazasulfuron applications reduced non-bearing year narrowleaf goldenrod shoot density and should be considered for further evaluation or use by growers to manage narrowleaf goldenrod.

Chapter 4 – Theis Conclusions

Integration of Phenological Models

Lowbush blueberry fields across Nova Scotia face persistent pressure from narrowleaf goldenrod, a herbaceous perennial weed. Narrowleaf goldenrods presence has increased as traditional herbicide options have become limited due to herbicide resistance and de-registration of products. Results from experiments outlined in this thesis highlight how predictive phenology (GDD models) and strategic herbicide application timing can be used to develop alternative management options for growers.

Herbicide Recommendations

Efficient management of narrowleaf goldenrod must be implemented strategically with the unique biennial production cycle of lowbush blueberry. This requires targeting narrowleaf goldenrod during vulnerable phenological stages, and leveraging herbicide efficacy throughout the season. GDD models show that narrowleaf goldenrod ramet emergence begins earlier in the season than lowbush blueberry ramet emergence, starting at 25-71 GDD, and continued to 1,047-1,665 GDD across all study sites. This offset of phenological development between narrowleaf goldenrod ramet emergence and lowbush blueberry emergence provides a window for early season management. It is recommended to apply mesotrione, glufosinate or clopyralid when narrowleaf goldenrod ramets reach a height of 10-15 cm, before lowbush blueberry emergence. Narrowleaf goldenrod ramets were observed at the flowering bud stage between 710 and 871 GDD (June 21 – 28), and approximately 90% of emerged ramets reached the flowering bud stage between 1303 – 1956 GDD (July 17 – August 24). Sequential mesotrione treatments resulted in the most consistent long-term control of narrowleaf goldenrod, and should therefore be prioritized for future research, registration and routine use.

Emerged ramets began flowering between 1418 – 1626 GDD (July 30 – August 7), and approximately 90% of emerged ramets were flowering between 1992 – 2225 GDD (August 27 – September 12). It is recommended to implement sequential late POST mesotrione applications to reduce non-bearing and bearing year narrowleaf goldenrod shoot density. However, late POST herbicide applications should not be considered a primary strategy for the management of narrowleaf goldenrod. This method is recommended for use as a contingency herbicide treatment when early season treatments are missed. Late season treatments in the bearing year include a weed wiper application of glyphosate, broadcast dicamba, or spot treatment of flazasulfuron and can reduce both fall bearing and summer non-bearing year goldenrod shoot density.

Adoption of predictive and integrated management systems has long-term benefits such as reducing production costs and improved crop competitiveness. Future research should expand efforts to include soil moisture, and further investigate alternative herbicide application timings in cohesion with various phenological milestones of narrowleaf goldenrod.

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