Management of goldenrods (*Solidago* spp.) in wild blueberry (*Vaccinium angustifolium* Ait.) fields

by

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DEDICATION

I dedicate this thesis to my grandparents Mr. and Mrs. Malik Aurangzeb Awan, parents Mr. and Mrs. Muhammad Farooq Malik, and the rest of my family members for their support, love and endless prayers. I love you guys and thank you for everything!

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ABSTRACT

Weeds are considered a major yield limiting factor in wild blueberry fields, and creeping herbaceous perennials have become common and problematic. Goldenrods are creeping herbaceous perennial weed that reproduces by seeds and extensive underground rhizomes. Current management plans do not provide adequate control of goldenrod in each production year. Therefore, it remains a serious problem in wild blueberry cropping systems. Multiple experiments were conducted over two years to evaluate 1) summer broadcast herbicide applications, 2) summer and fall spot herbicide applications, 3) mechanical control, 4) optimum timing of mechanical and chemical control, and 5) main and interactive effects of mechanical and chemical control on goldenrods to develop an integrated management plan to control goldenrod species in wild blueberry fields. Post-emergence broadcast applications of mesotrione followed by sequential mesotrione application at 14, 21 and 28 days after initial application (DAIA), as well as mesotrione alone or tank mixed with bicyclopyrone, effectively controlled goldenrod shoots in the non-bearing and bearing year. Summer spot applications of glyphosate and mesotrione reduced goldenrod shoot density in both the non-bearing and bearing years. In addition, fall spot applications of glyphosate significantly reduced goldenrod shoots in the following year after application. Repeated cutting at the floral bud stage significantly reduced goldenrod shoot density in the non-bearing year, but not the bearing year. Glyphosate application at all growth stages, but particularly at flowering, caused a significant reduction in goldenrod shoot density in both the non-bearing and bearing years. In another experiment, glyphosate applied alone followed by nothing at the floral bud stage significantly decreased shoot density in both years. Based on these results, cutting twice had limited effects on goldenrod, and herbicides are recommended for goldenrod management in wild blueberries.

LIST OF ABBREVIATIONS AND SYMBOLS USED

% - Percent

< - Less than

> - More than

± - Margin of error of a quantity

≤ - Less or equal

≥ - Greater or equal

® - Registered trademark

°C - Degrees Celsius

AAFC - Agriculture and Agri-Food Canada

ANOVA - Analysis of Variance

cm - Centimeter

CO_2 - Carbon dioxide

CRD - Completely randomized design

DAIA - Days after initial application

DAS - Days after spraying

fb - Followed by

g - Grams

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

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

Kg - Kilogram

Kg a.i ha^{-1} - Kilograms of active ingredient per hectare

Km h^{-1} - Kilometer per hour

kPa - Kilopascal

l - Liter

L ha^{-1} - Liters per hectare

LS Means - Least Squared Means

m - Meter

m^{-2} - Per square meter

mm - Millimeter

MT - Management technique

MT-C - Management technique cutting

MT-G - Management technique glyphosate

MTT - Management technique timing

N - North

N/A - Not applicable

NPAR - Non-parametric

NS - Non-significant

PS II - photosystem

S - Significant

SAS® - Statistical analysis system

SE - Standard error

v/v - Volume by volume

W - West

WBPANS - Wild blueberry producers association of Nova Scotia

XR - Extended range nozzles

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Chapter 1- Introduction

1.1 Introduction

Wild blueberries (*Vaccinium angustifolium* Ait.) are a native berry species of Quebec, the Atlantic provinces of Canada, and Maine in the United States of America (Strik and Yarborough 2005; Bell et al. 2010). Wild blueberry is one of the most important horticultural crops in Nova Scotia in terms of total acreage, export sales, and value to the provincial economy (Kinsman 1993; Mclsaac 1997). Wild blueberry production has increased significantly over the recent years, especially in the Northeastern North America. In 2015, Canada produced 103,131 tons of wild blueberry, with approximately 32,569 tons produced in Nova Scotia (Statistics Canada 2016).

Weeds are a major yield limiting factor in wild blueberry production (Yarborough 2011) and weed management represents one of the most significant production challenges (Jensen and Yarborough 2004). Weeds compete with wild blueberry for space (Yarborough and Bhowmik 1993), light (Hall 1958), moisture and nutrients (Penney and McRae 2000; Ismail et al. 1981), act as alternate hosts for diseases and other pests (McFadyen 1998), hinder harvest (Yarborough et al. 1986), contribute undesirable fruit to the harvested blueberry crop (McCully et al. 1991), and reduce overall yields (Yarborough and Marra 1997). The majority of weeds in wild blueberry fields are perennials (McCully et al. 1991), and creeping herbaceous perennial weeds are especially problematic in this cropping system due to lack of tillage and crop rotation.

Several species of creeping herbaceous perennial weeds cause problems in wild blueberry fields (McCully et al. 1991; Lapointe and Rochefort 2001), but goldenrods *(Solidago* spp.) are notable because they are aggressive and difficult to control (Boyd and White 2010). Lapointe and Rochefort (2001) reported that goldenrods were one of the most common weeds in blueberry fields in Quebec, occurring in 50% of fields surveyed. Goldenrods occurred in more than 40% of wild blueberry fields surveyed in the early 1980's in Nova Scotia (McCully et al. 1991) and continue to be common in wild blueberry fields in this province due to lack of effective control options, suspected resistance to hexazinone, and the ability to reproduce from seed or recover following dissipation of residual hexazinone (Jensen and Kimball 1985; Yarborough and Bhowmik 1989). Mesotrione has been used as a post emergent herbicide and when applied at the correct time can effectively suppress goldenrod (Boyd and White 2010), but does not provide complete control.

Goldenrods are perennial herbs which reproduce through seed and vegetatively from rhizomes (Werner et al. 1980). Plants mostly occur in disturbed, early successional habitats where they remain for several years (Hartnett and Bazaaz 1985). Goldenrods are considered problematic in wild blueberry fields (Boyd and White 2010) because it spreads rapidly once established (Pavek 2012) and are difficult to control due to vegetative reproduction (Guo et al. 2009). Goldenrod shoots interfere with mechanical harvest operations (McCully et al. 2005) and can result in yield loss.

Goldenrod shoots depend on carbohydrates from rhizomes during initial stages of growth (Hartnett and Bazzaz 1983), but ultimately become independent and return carbohydrates to these structures during later stages of growth (D'Hertefeldt and Jónsdóttir 1999). This results in temporal changes in rhizome carbohydrates, and in turn these structures are depleted and replenished during the growing season (Becker and Fawcett 1998). This pattern of depletion and replenishment is generally a function of shoot growth stage, and it is therefore possible to predict the timing of low carbohydrates reserves in rhizomes based on the growth stage of aboveground shoots. This predictability can be exploited through management strategies that inhibit new shoot establishment (Ross and Lembi 2009), remove emerged shoots at growth stages when the carbohydrate levels are low in rhizome (Bradley and Hagood Jr. 2002), or facilitate herbicide translocation from shoots back to rhizomes during periods of carbohydrate replenishment (Carlson and Donald 1988). Therefore, successful management of goldenrods requires strategies that reduce the vigor and growth of established plants and reduce rhizome biomass through utilization of proper management strategies at suitable plant growth stages.

Wild blueberry producers are facing significant problems controlling creeping herbaceous perennial weeds such as goldenrod. Recent evaluations of pre and post-emergence herbicides have improved suppression of these weeds (Boyd and White 2010), but integrated management plans are still lacking. Therefore, it is critical to study goldenrod management in wild blueberry fields. The general objective of this study is to determine the effect of mechanical, and chemical control strategies on goldenrod shoot regeneration, to increase our understanding of the growth stages of goldenrods within blueberry fields, and to evaluate herbicides for efficacy on goldenrod.

1.2 Taxonomy, habitat and biology of wild blueberry

The Wild blueberry is a perennial flowering plant in the Ericaceae, or heath family (Eck and Childers 1966) and sub family *Vaccinoideae* (Fernald 1950). The sub-family *Vaccinoideae* has two important genera: *Vaccinium* (ex. blueberry) and *Gaylussacia* (ex. Huckleberry). The wild blueberry plant falls under the genus *Vaccinium* and subgenus *Cyanococcus* (Galleta and Ballington 1996). Four species of lowbush blueberries have been identified and include Common lowbush blueberry (*Vaccinium angustifolium* Ait.), Black lowbush blueberry (*Vaccinium angustifolium f. nigrum*) (Vander Kloet 1978), Sour top blueberry (*Vaccinium myrtilloides* Michx.) and Ground hurts blueberry (*Vaccinium boreale*) (Hall et al. 1979; Kinsman 1993). *Vaccinium angustifolium* and *Vaccinium myrtilloides* are native clones found in commercial wild blueberry fields (Strik and Yarborough 2005). However, *Vaccinium angustifolium* Ait. (Common lowbush or Wild blueberry) is the most commercially grown species in Eastern Canada (Eck and Childers 1966).

Wild blueberries are found on a wide-range of organic soils (Jensen and Yarborough 2004) but are most common on coarse textured, well-drained, infertile, and acidic soils of alluvial origin (Percival and Garbary 2012). Wild blueberry grows best in soils with pH ranging from 4.0 to 5.5 (Kinsman 1993). These types of acidic soils are usually not suitable for horticultural and agronomic crops (McIsaac 1997; Howatt 2008). Wild blueberry is drought tolerant and survives well in dry periods (Jeliazkova and Percival 2003), but requires long day sunlight for ideal growth (Camp 1945).

The wild blueberry is a native, rhizomatous, perennial low growing deciduous shrub (McIsaac 1997; White et al. 2012). Blueberry plant populations consist of diverse and variable clones that slowly spread by rhizomes to provide complete ground cover (Jensen and Yarborough 2004). Each clone is a genetically distinctive individual, or genet, that has established naturally from seed (Burgher-MacLellan and Mackenzie 2004; Bell et al. 2009, 2010). Individual shoots, or ramets, that emerge from the rhizomes of each genet constitute the aboveground portion of each plant (Barker and Collins 1963), from which fruit is harvested. Wild blueberry can grow to an estimated height of 10 – 30 cm (Vander Kloet 1978). Stems have broad to oval shaped alternate leaves which are shiny blue-green in summer and turn purple to red in fall (Hall et al. 1979). Buds are brownish red on stem axils and flowers are white to pinkish-white, bell shaped and about 5 mm long. Flowers are not self-compatible and need to be pollinated by insects (McIssac 1997). The ripened fruit are sweet in taste with varying acidity (Hall et al. 1979).

1.3 Wild blueberry production and management

The lowbush blueberry is grown commercially in North Eastern Canada and Maine in the United States (Strik and Yarborough 2005; Yarborough 2009). Based on combining estimated acreage and crop value of Atlantic provinces of Canada and Maine in the United states in 2015, these regions had 200,000 acres of lowbush blueberry crop under management, with a combined production of nearly 180 million pounds of fruit, and contributing $600 million dollars annually to provincial and federal economies (AAFC 2016; USDA 2016). Nova Scotia is the largest producer of wild blueberries in Atlantic Canada and contributed approximately 27% of total Canadian production of wild blueberry in 2015 (AAFC 2016). The production acreage in the province increased by 31% between 1992 and 2003 (Strik and Yarborough 2005). Over forty million pounds of lowbush blueberries were produced in Nova Scotia in 2015 with an estimated farm gate value of $ 32.5 million dollars (Statistics Canada 2016). Wild blueberry is the number one fruit crop in Nova Scotia with respect to land, export sales and value (Kinsman 1993; McIssac 1997; Anonymous 2012). Nova Scotia exports 90% of the berries to Asia, Europe and other parts of North America each year.

The wild blueberry is a unique horticultural crop as commercial fields are developed from native stands rather than being planted (Kinsman 1993). Commercial wild blueberry fields are intensively managed to encourage blueberry clonal spread. They are usually managed with a 2-yr production cycle. The first year of the cycle is called the vegetative, or non-bearing year, in which fields are pruned by burning or flail mowing (Kinsman 1993) to stimulate production of new shoots, roots, and vegetative growth (Penney and McRae 2000). Wild blueberry fields are pruned by cutting stems to ground level every two years, late in the fall after harvest in the crop year or in the early spring in the vegetative year (Eaton and Nams 2006). The vegetative shoot grows until tip dieback, which usually starts in July and August (Barker and Collins 1963; Smagula and DeGomez 1987). Flower buds develop mostly in the upper axils after the end of vegetative growth (Eaton and Nams 2006). However, most of the agronomic practices, including weed management and fertilizer application, occur in the non-bearing year (Barker et al. 1964; Kinsman 1993). Crop rotation and other agricultural practices, such as tillage, cannot be accomplished in wild blueberry fields due to the perennial nature of the crop. Therefore, growers mostly managed the competing vegetation with herbicides (Boyd and White 2010). Application of herbicides has reduced overall weed populations, and increased quality and yield of the blueberry crop by four-fold (Jensen and Yarborough 2004). Lowbush blueberries are oligotrophic plants that require low amount of nutrition, therefore commercial blueberry producers conduct soil and leaf tissue samples after every two to three years to assess the proper fertilizer dose (Eaton et al. 2009). Fertilizer application without herbicides increases weed infestation in the field due to slow response of blueberry plants to fertilizer inputs (Starast et al. 2007; Kennedy et al. 2010). However, significant increases in the growth and yield have been shown in lowbush blueberry when fertilizers are applied with herbicides (Eaton 1994; Percival et al. 2002). The second year of the cycle is the crop, or bearing year, when floral buds produce flowers, fruit develops, and harvest occurs (AAFC 2005). Cross pollination by honeybees is usually required to ensure good fruit set (Mclsaac 1997; MacKenzie 2008). The crop is harvested in August by hand rake or harvester (Yarborough 1996) and the two-year cycle begins again following pruning.

1.4 Competing vegetation of wild blueberry fields

Weeds are one of the most limiting factors and an ongoing problem in wild blueberry fields (Jensen 1985; McCully et al. 1991). The weed flora of wild blueberry fields has traditionally been dominated by herbaceous or woody perennial species growing well under the two-year production cycle due to suitability of their life cycle to the wild blueberry production system (McCully et al. 1991; Yarborough 2011). Approximately 80 to 90% of the weed species identified in a weed survey in 1984-1985 were perennials (McCully et al. 1991). These weeds compete with the wild blueberry for resources essential for adequate plant growth such as space, light, temperature, moisture and soil nutrients (Jensen and Yarborough 2004; McCully et al. 1991) and also contribute distasteful fruit which reduce the quality of the processed blueberry pack (Yarborough and Ismail 1980; Yarborough 2011).

Wild blueberry fields are developed from abandoned farmland or woodland in Nova Scotia (McIsaac 1997). Fields established from abandoned hayfields or pastures generally contain a variety of grasses and herbaceous perennial weeds, whereas fields established from woodland contain weed flora associated with woodland vegetation and perennial bushes and shrubs (Anonymous 1999). The most abundant weeds occurred in fields developed from woodland were black chokeberry (*Aronia melanocarpa* Michx.), gray birch (*Betula populifolia* Marsh.), quaking aspen (*Populus tremuloides* Michx.), rhodora (*Rhododendron canadense* L.), and ferns: hay-scented fern (*Dennstaedtia punctilobula* (Michx.) T. Moore), and bracken fern (*Pteridium aquilinum*) (Hall 1959). Velvet-leaf blueberry (*Vaccinium myrtilloides* Michx.) was the most common in newly developed fields from woodland, with a lower density in older fields established from hayfields. Species observed with higher density in fields developed from hayfields were colonial bent grass (*Agrostis capillaris* L.), haircap moss (*Polytrichum commune* L.), meadowsweet (*Filipendula ulmaria* L.), yellow or meadow hawkweed (*Hieracium caespitosum* Dumort.) and rough goldenrod (*Solidago rugosa* Ait.). The species observed in both woodland and hayfields, but found more often in those established from woodland, were sheep laurel (*Kalmia angustifolia* L.), bunchberry (*Cornus canadensis* L.), and red cherry (*Prunus pensylvanica* L.)

(Hall et al. 1979). Wild blueberry fields in Nova Scotia, developed from abandoned pastures or hayfields and initially were covered with the native grasses and legumes of forage production, followed by the rhizomatous perennial grasses: poverty oat (*Danthonia spicata* L.), brown top (*Agrostis capillaris* L.) and red top grasses in open areas (Kinsman 1993). Perennial broadleaved weeds, such as spreading dogbane (*Apocynum androsaemifolium* L.), sheep sorrel (*Rumex acetosella* L.), goldenrods (*Solidago* spp.), hawkweeds (*Hieracium* spp.), bunchberry (*Cornus canadensis* L.), and ferns would then begin to occur, followed by the occurrence of heath plants including teaberry (*Gaultheria procumbens* L.), three species of labrador tea (*Rhododendron tomentosum*, *Rhododendron groenlandicum*, *Rhododendron neoglandulosum*), rhodora, sheep laurel, and wild blueberry.

Therefore, wherever the wild blueberry occurs, be it on abandoned hayfields, farmland, woodland, or heath, it co-exists with many other plants in a complex plant community. There are hundreds of plant species in these fields growing from the initial stages to the forested climax, from which we only wish to retain the wild blueberry (Kinsman, 1993). The control of these unwanted species, such as the weed flora of wild blueberry production, is critical to the successful development and long-term management of wild blueberry fields (Jensen and Specht 2004).

1.5 Status and biology of goldenrod in wild blueberry fields

Goldenrods are the most common rhizomatous perennial species in commercially managed wild blueberry fields. A comparison of weed flora surveys in Nova Scotia wild blueberry fields have reported a 26% increase in the presence of goldenrods between the early 1980's and the early 2000's (McCully et al. 1991; Jensen and Sampson unpubl. data). Currently, goldenrods occur in approximately 60% of the blueberry acreage in Nova Scotia (Jensen and Sampson unpubl. data) due to their rapid spread and limited control options (Boyd and White 2010).

The *Euthamia genus* is comprised of 8 to 10 species, which are typically native to North America. All species were previously classed in *Solidago* genus, goldenrods. They were separated based on morphological differences, including arrangement of the flower heads in the inflorescence and the glands on the leaves (Sieren 1981). The species of genus *Euthamia* belongs to the Asteraceae family and are herbaceous perennials that reproduce by seed and creeping rhizomes (Sieren 1981). However, the establishment of goldenrods mainly occurs through rhizome growth resulting in dense cover that is most frequently found in wet areas and bare spots in wild blueberry fields. Goldenrods are aggressive weeds that can decrease yield potential and impede harvesting of blueberry. The most dominant goldenrod species that were found in wild blueberry fields are Canada goldenrod (*Solidago canadensis* L.) and narrow-leaved goldenrod (*Euthamia graminifolia* (L.) Nutt. ex. Cass.) (McCully et al. 1991; Jensen and Sampson unpubl. data).

Solidago canadensis has several common names, including Canada goldenrod, meadow goldenrod, common goldenrod, giant goldenrod, and tall goldenrod. Canada goldenrod is a native warm-season, long-lived perennial, which are most frequently observed in perennial crops, abandoned fields, open woodlands, dykes, roadsides, riverbanks, and floodplains (Werner et al. 1980; Bradbury 1974). Generally, Canada goldenrod thrives well in moist and medium textured soils, and is fairly intolerant of shade (Werner et al. 1980).

Canada goldenrod has an extensive, deep and fibrous root system with 6 to 18 cm long rhizomes (usually reddish in colour) emerging at the base of aerial stems (Werner et al. 1980). Stems are 30 to 200 cm tall, leafy, mostly smooth and unbranched, hairless at the bottom, but covered with fine hairs at the top. Leaves are alternate with a single leaf per node, slender, lanceolate, tapered at both ends, sharply serrated around the edge, hairless on the upper surface, and hairy mainly on the lower veins (Fig. 1.1). Leaves have 3 prominent mid-veins, without stalks or petioles, and are 5 to 12 cm long (Pavek 2012) (Fig. 1.1).

Fig. 1.1. Upper and lower surface of Canada Goldenrod (*Solidago canadensis* L.) leaves (Farooq MH 2016).

Inflorescences (yellowish-green in colour) form dense, elongated, pyramid-shaped clusters blooming from July through October (Fig. 1.2). Flower clusters usually consist of 8 to 16 yellow ray flowers surrounded by less than 10 yellow disk flowers which are 3 to 20 cm wide (Fig. 1.2). Seeds are small, dry and with a bunch of white thin bristles (pappus) at the tip (Jarvis 1998).

Fig. 1.2. Flower head of Canada Goldenrod (*Solidago canadensis* L.) (Farooq MH 2016).

Euthamia graminifolia also known as narrow-leaved or grass-leaved goldenrod, is an erect herbaceous perennial, up to 100 cm tall (Sieren 1981). Leaves are simple (lobed or unlobed), alternate with one leaf per node along the stem, long and narrow like grass leaves. Leaf tips are moderately tapered to a sharp point and the basal leaves are stalk-less. Leaves have smooth glandular dots on the surface with very short, cilia type hairs, especially along the edges and prominent veins on the underneath (Fig.1.3).

Yellow flower heads occur in small clusters that form a terminal, flat-topped flowering body (Fig.1.4). Flowers are compound and lack distinct petals. Narrow-leaved goldenrod blooms in August and September in Nova Scotia (Boyd and White 2009b).

Fig. 1.3. Leaves of Narrow-leaved goldenrod (*Euthamia graminifolia*) in a wild blueberry field (Farooq MH 2016).

Fig. 1.4. Flower head of Narrow-leaved goldenrod (*Euthamia graminifolia*) (Farooq MH 2016).

1.6 Integrated weed management in wild blueberry cropping system

Weed management continues to be one of the major yield-limiting factors in successful production of wild blueberries (Jensen et al. 2003). Mechanical and chemical weed control options are available to the growers. Mechanical weed control comprises of a hand pulling, mulching, mowing or tillage that can be helpful to disrupt weed life cycles or prevent the establishment of weeds. Chemical weed control can be attained by using selective pre-emergent herbicides along with selective and non-selective post-emergent herbicides.

1.6.1 Physical and mechanical control in wild blueberry fields

Mechanical weed control refers to any physical means of weed suppression (Yarborough 2011). Hand pulling can be effective and helpful for spot treatments. Weeds should be removed before flowering. Properly cleaned field machinery or harvest equipment can prevent the spread of weed seeds and vegetative structures between fields (Boyd and White 2009; Yarborough 2017). Cutting woody weeds (birch, maple, and willow) to ground level will provide assistance in the reduction of weeds, but require repeated cuttings of new stems to completely remove these weeds (Yarborough 2017). Mowing and cutting above the blueberry plants can be effective for the suppression of certain weeds (bracken fern and sweet fern), and this should be done during vegetative year or when densities are low to prevent weed spread (Yarborough 2011, 2017). The latter will result in damage to blueberry plants as multiple passes with the mower may be required during the production cycle. However, mowing or cutting alone has not effectively suppressed perennial weeds. Repeated cuttings are required for several years to completely control perennial weeds and improve harvest efficiency (Yarborough 2017). Finally, the use of mulches, sawdust, or wood chips can help to inhibit the germination of some herbaceous weeds by excluding light, while woody perennial weeds will be able to germinate through the mulch (Yarborough 2017).

These physical practices such as biannual mowing can be effective to control weeds and will strengthen weed management programs in wild blueberry cropping systems. However, the use of herbicides provides better control of woody and creeping perennial weeds (Jensen 1985). As a result, herbicides have been the major source of weed control in wild blueberry production in recent years (Jensen and Yarborough 2004).

1.6.2 Chemical control in wild blueberry fields

Early pre-emergent weed control was attained in wild blueberry with the selective herbicide terbacil (trade name of Sinbar™). Initially, this selective herbicide was found to control perennial grass species and sedges in wild blueberries (Ismail 1974; Jensen and Yarborough 2004). Application of terbacil increased blueberry yields (two-fold) in fields infested with perennial grasses and sedges (Trevett and Durgin 1972; Ismail 1974; Ismail et al. 1981). Doughty (1975, 1978) reported that terbacil successfully controlled problematic perennial weeds including quack grass (*Elytrigia repens* L.), horsetail (*Equisetum arvense* L.), and sheep sorrel (*Rumex acetosella* L.). The use of terbacil provided good weed (perennial grasses) control for two years in highbush blueberries (Talbert et al. 1975). Kerb 50-W (common name propyzamide), a soil applied herbicide, can control or suppress the large number of annual and perennial grasses in wild blueberry fields (McCully et al. 2005).

Hexazinone (trade name of Velpar™), is the most commonly used herbicide in wild blueberry (Yarborough 2004; Boyd and White 2010). Hexazinone was registered in the early 1980's and is used on most acreage (McCully et al. 2005). Yarborough (2004) reported that initial use of hexazinone provided a doubling of wild blueberry yield. Initially, hexazinone provided good control of woody weeds, such as sheep laurel (*Kalmia angustifolia* L.) (Jensen 1985; Yarborough and Bhowmik 1989). Pre-emergent applications of hexazinone, after pruning, controlled hawkweed (*Heiracium pilsella* L.) and goldenrod species including *Solidago canadensis* L., *S. graminifolia* L., *S. rugosa* Ait., *S. bicolor* L., and *S. nemoralis* Ait. (Jensen and Kimball 1985). Boyd and White (2010) have also reported that hexazinone applied at 1.92 kg a.i ha^{-1} in 200 L water ha^{-1} successfully suppressed goldenrods. Hexazinone applications have also significantly reduced achene weight, shoot and reproductive biomass, as well as the reproductive: shoot biomass ratio of sheep sorrel (Kennedy et al. 2011). Hexazinone applied at 2.0 kg product ha^{-1} provided excellent control of grasses and herbaceous broadleaved weeds (Jensen and Kimball 1985, 1987). There has been little reported crop injury associated with appropriate use of hexazinone, and this has been due to the ability of *Vaccinium* spp. to limit acropetal translocation of hexazinone (Baron and Monaco 1986).

Other commonly used pre-emergent herbicides for weed control in wild blueberry fields includes flumioxazin (trade name of Chateau®) for hair-cap moss control (*Polytrichum strictum* Hedw.) (Percival and Garbary 2012); sulfentrazone (trade name of Authority®) for the control of wild buckwheat (*Polvgonum convolvulus* L.), lamb's quarters (*Chenopodium album* L.) and pig weed (*Amaranthus palmeri* S. Wats.). Sulfentrazone application (0.22 to 0.29 L ha^{-1} in 100 L water ha^{-1}) made to dormant blueberry plants, once in a two-year production cycle effectively suppressed sheep sorrel (Anonymous 2016).

Several selective and non-selective post-emergent herbicides are also available for weed control in wild blueberries. 2, 4-D (2, 4- dichlorophenoxy acetic acid) was the main chemical which successfully controlled broadleaf weeds in wild blueberries in 1980s (Kinsman 1993; Jensen 1985). A combination of Glyphosate [*N*-(phosphonomethyl) glycine] and 2, 4-D application while using a selective roller applicator was successful in controlling barrenberry plants that exceeded the height of blueberry plants in the fruit year of the crop cycle (Yarborough and Ismail 1979).

Yarborough and Ismail (1981) have reported that selective post-emergent applications of 2, 4-D and glyphosate following blueberry leaf abscission in late fall provide excellent control of sheep laurel (*Kalmia augustifolia* L.). The herbicide dicamba (trade name of Banvel®) has also been added to the tank mix of 2, 4-D which provides effective, post-emergent control of late senescing speckled alder (*Alnus incana* (L.) Moench.) in wild blueberry fields (Jensen and North 1987).

A large number of registered post-emergent herbicides are available for weed control in wild blueberries which includes clopyralid (Lontrel®) for hawkweed control (Eriavbe 2015); nicosulfuron/rimsulfuron (Ultim®) for black bulrush control (Jensen and Specht 2004; Boyd and White 2010) ; tribenuron methyl (Spartan® or Express®) for bunchberry control (Yarborough and D'Appollonio 2009a); triclopyr (trade name of Garlon®) for control of spreading dogbane (Wu 2011) and woody weeds (mainly alder, birch, poplar, pin cherry and maples); foramsulfuron (Option®) for control of fescue (Yarborough and Cote 2014; White and Kumar 2017); and fluazifop-p-butyl and S-isomer (trade name of Venture®) for control of tickle grass (*Agrostis scabra* Willd.) and witch grass (*Panicum capillare* L.) weeds (Anonymous 2016). Despite the wide variety of herbicides available for weed control blueberry growers relied predominately on hexazinone (Jensen and Specht 2002) and mesotrione to control broadleaf weeds (Boyd and White 2010). This has resulted in repetitive use of these herbicides since registration, changing the competing vegetation by selecting for species that are tolerant to the hexazinone (Jensen and Kimball 1985; Jensen and Specht 2004). After more than 30 years of continuous use, it is time to evaluate the new herbicides for weed control in wild blueberry fields and develop sustainable weed management practices for the future.

1.7 Basic biology of creeping herbaceous perennials

Creeping herbaceous perennials reproduce by seeds and through vegetative means, including lateral roots, stolons, and rhizomes (Bhowmik 1997). These reproductive strategies favor the survival of these plants, since they can multiply and compete in most managed and natural systems, including annual crops, mowed herbaceous perennial crops, grazing lands, and nurseries (Ross and Lembi 2009). These species are the dominant weeds found in perennial crops due to their similar growth patterns (Holm et al. 1977).

Carbohydrate dynamics in creeping perennials play an important role for understanding the basic biology of these plants. Carbohydrate reserves in most perennial weed vegetative structures generally show a movement of depletion during early season vegetative growth as carbohydrates stored in the roots or rhizomes are translocated to emerging shoots in spring until a seasonal low occurs around bud to mid-flower. Subsequent basipetal movement of photosynthates first begins when the leaf area is ample for photosynthesis to compensate for growth and respiration losses (Cyr et al. 1990). Thereafter, carbohydrate levels generally start to accumulate for the next season (McAllister and Haderlie 1985a). For example, Nkurunziza and Streibig (2011) observed that fructan, a water-soluble carbohydrate, was continuously depleted in the roots of Canada thistle, reaching a minimum about one month after emergence. Basipetal movement of photo- assimilates started about 20 days after emergence when emerged stems were at the eight-leaf stage and had a total leaf area of 200 cm^2. Tworkoski (1992) also found that maximum basipetal translocation of photo-assimilate to Canada thistle roots occurred at the bolt stage in spring or during vegetative regrowth in the fall. Carbohydrate reserves in field bindweed roots declined with vegetative growth and reached seasonal lows during early bud and mid-flowering, with increases during fall (Arny 1932; Barr 1940). Similarly, late season replenishment of carbohydrates has been observed in hemp dogbane (Becker and Fawcett 1998). Carbohydrate levels of field-grown common milkweed dropped from late May to June, with a rapid decline to about 10% in July, and 25% increase in October (Bhowmik 1994).

1.8 General approaches to control creeping herbaceous perennials

1.8.1 Effect of mechanical control on creeping herbaceous perennial weeds

Mechanical weed control refers to any technique that involves the use of field equipment to control weeds. Hand hoeing, tillage and mowing are examples of mechanical control techniques (Huiting et al. 2011). Mowing and cutting is more effective on tall growing perennial weeds and can prevent seed formation, but usually has little effect on underground structures (Amor and Harris 1977). Mowing and cutting can decrease seed production and limit weed growth, when cut before they flower and set seed (Hanson 1996). Mowing may also give short-term suppression of perennial weeds, especially if several cuttings occur during a single season (Anonymous 2012). Repeated mowing may also deplete carbohydrate reserves in underground vegetative reproductive structures (Huiting et al. 2011) by destroying new shoots before they replenish root carbohydrate reserves (Hatcher and Melander 2003; Graglia et al. 2006). Lukashyk et al. (2008) suggested that six mowing events in four sequential growing seasons are required to control Canada thistle. Cutting three times per year for two consecutive year's decreased Canada thistle density up to 85% (Beck and Sebastian 2000). The best time for mowing is usually when the underground root reserves are at a low level, between full leaf development and before flowering (Miller 2016). Although mowing and cutting is effective, it can be more useful if combined with other control methods to control perennial weeds (Lowday and Marrs 1992).

1.8.1.1 Hand weeding

Hand removal by pulling or hoeing can be an effective method to control creeping perennial weeds in certain situations (MacDonald et al. 2013). Hand pulling may be a good alternative in fields where herbicides or other methods cannot be used. Hand weeding can effectively control spot infestations of creeping perennials when weeds are pulled before seed formation and the entire root system is removed (McCully et al. 2005). For example, hand pulling Johnson grass is economical and effective if done before rhizome formation (McWhorter 1989). Hand pulling has also been successful in the control of small infestations of Canada thistle (DiTomaso 2000). Hand pulling, however, is only efficient for a few isolated plants, small areas, or for a high value crop (Chicouene 2007). Hand weeding is labor intensive and may release apical dominance if the vegetative reproductive structures are not completely removed (Huiting et al. 2011). It is also essential to remove the weeds from the field, since many pulled weeds can still produce seeds when the plants remain on the soil surface (Marrs 1984).

1.8.2 Chemical control

Herbicides are a practical and economical method for controlling creeping perennial weeds (Miller 2016). Potential effect of herbicides on creeping perennial weeds can be summarized into four general such as preemergence, postemergence, contact and postemergence symplastic herbicides. Soil residual herbicides are usually applied on the soil to control creeping perennials during seed germination and the seedling stage. These herbicides persist in the soil for several weeks to months, killing germinating seedlings and depend on rainfall for mobilization and even distribution in the soil (Ross and Lembi 2009). The results of Shen et al. (2004) showed that Canada goldenrod (*Solidago canadensis*) were successfully managed with the soil applied herbicides sulfometuron-methyl (375-750g a.i. /ha) and imazapyr (750-1125g a.i. ha^{-1}), whose duration was 35 weeks and 16-18 weeks, respectively. Contact or non-translocated herbicides are applied to control aboveground vegetation or prevent seed production of creeping perennials. These herbicides can delay the development of creeping perennials for 3 to 4 weeks without detriment to roots and other underground structures (Marrs 1984).

Symplastically translocated herbicides can control both shoots and underground structures of creeping perennial weeds. These herbicides move from leaves to sites of metabolic activity (sinks of sugar consumption) such as underground meristems (root tips) and storage organs (Ashton and Crafts 1981). Symplastically translocated herbicides can provide good full season control of creeping perennial weeds with only one or two foliar applications. Colquhoun (2001) found that symplastically translocated herbicides, including glyphosate, when applied after crop maturation but before harvesting, provide good control against creeping perennial weeds. Glyphosate (non-selective herbicide) successfully controls quack grass (Doll 1993), Canada thistle (Hunter 1996), and common milkweed (Bhowmik 1994) when applied during active growth. Dicamba plus diflufenzopyr and clopyralid (selective herbicides) provide good control of Canada thistle shoots during the growing season and damage underground root systems (Devine and Born 1985).

Herbicide activity in creeping perennials mainly depends on foliar absorption and transport from the leaves to the roots or rhizomes. New leaves move nutrients from the root in an upward, direction, while more mature leaves transport photosynthetic products to the underground structures for storage (McWhorter 1961a; McWhorter 1961b; Ross and Lembi 2009). Thus, the most effective herbicide activity occurs as carbohydrates, the product of photosynthesis, move downward to the roots just before the floral bud and flower stage. Late summer or fall is the second-best time to apply the herbicide as during that time, carbohydrate also moves downward (Colquhoun 2001).

1.8.2.1 Glyphosate

Glyphosate (Tradename Round up WeatherMax® or Touch down®) is a non-selective, postemergence Group 9 herbicide that is effective on a wide range of annual and biennial species of grasses, sedges, as well as perennial broadleaved rhizomatous species in wild blueberry fields (Yarborough 2004). It functions by inhibiting the plant enzymes involved in the synthesis of aromatic amino acids including tyrosine, tryptophan, and phenylalanine (Steinrucken and Amrhein 1980; Duke and Powles 2008). It is a systemic herbicide which is absorbed into the foliage and moves to the plant root system, controlling both above and below ground growing points. It is mostly effective when applied during periods of fully expanded and actively growing foliage (Malik et al. 1989; Yarborough 2004). It may take 2 to 3 weeks to cause visual damage to targeted weeds. Some visible symptoms include a gradual wilting and yellowing of the plant, which leads to a complete blackening of the above ground growth and killing underground roots and rhizomes (Kim and Amrhein 1995).

Glyphosate was registered primarily in land preparation for controlling perennial weeds in wild blueberry production in Eastern North America (Yarborough 2004; Anonymous 2016). Glyphosate products can only be used in wild blueberries if applied as direct spot applications or with selective roller/wiper applicators to treat weed foliage above blueberry plants. Wild blueberries are very sensitive to glyphosate treatments and contact will result in injury to the blueberry plant. Some previous studies showed that glyphosate applied as direct spot spray suppressed the spreading dogbane shoots density, but not completely controlled this weed in wild blueberry fields in Nova Scotia (Wu 2012). Sikoriya (2014) also reported that spot applied glyphosate controlled > 80% red fescue stand density and increased the blueberry floral buds, plant height and yield. Due to the effectiveness of glyphosate products on creeping perennial weeds such as spreading dogbane and red fescue in wild blueberry fields, therefore, it is important to conduct further research on the efficacy of glyphosate on goldenrods in this cropping system.

1.8.2.2 Mesotrione

Mesotrione (Tradename Callisto®) is a selective, Group 27 herbicide that is useful on a wide range of broadleaved and grass weeds control in wild blueberries (Yarborough and D'Appollonio 2009b). It is a systemic herbicide with both preemergence and postemergence activity. It functions by inhibiting an enzyme, p-hydroxyphenylpyruvate dioxygenase (HPPD) which is involved in pigment (carotenoid) biosynthesis (James et al. 2006). Visible effects on susceptible plants include bleaching in a week on leaf foliage and growing points, followed by plant death within 2 to 3 weeks later (Mitchell et al. 2001).

Mesotrione can be applied as a broadcast or spot application in the non-bearing year of the wild blueberry crop cycle. Previous research showed that post-emergent mesotrione application in the non-bearing year following hexazinone can suppress goldenrod and black bulrush, but did not provide complete control (Boyd and White 2010). Mesotrione POST followed by acetochlor PRE-controlled > 80% smooth pigweed, giant foxtail and horse nettle species in corn (Armel et al. 2003). Because of its good performance in controlling perennial weeds in blueberries and corn crops, it is possible that this product could control narrow-leaved goldenrod in wild blueberry fields. Therefore, the effect of mesotrione on *Euthamia* spp. in wild blueberry fields should be studied.

1.9 Research Objectives

The objectives of the first research chapter were to 1) identify the optimal interval between sequential postemergence mesotrione applications; 2) evaluate postemergence bicyclopyrone applications on goldenrod, and 3) to evaluate multiple herbicides applied as postemergence spot treatments to goldenrod shoot injury and shoot regeneration. This research was based on the hypothesis that 1) sequential mesotrione application will be more effective than single mesotrione application and will cause greater reduction in goldenrod shoot growth, and 2) bicyclopyrone applications at floral bud initiation stage will have equal effect as mesotrione on goldenrod shoot reduction. It is anticipated that results of this objective will provide information to improve the goldenrod control and provide new postemergence herbicide products with efficacy on goldenrods that can be registered for use in wild blueberry fields in Nova Scotia.

The objectives of the second research chapter were to determine 1) the effect of two cuttings on goldenrod shoot regrowth, 2) the effect of combining cutting and symplastic herbicide application timing on goldenrod shoot regeneration, and 3) the main and interactive effects of cutting and symplastic herbicide applications on goldenrod shoot regeneration. This research was based on the hypothesis that 1) cutting twice at floral bud stage will reduce goldenrod shoot density and growth as compared to single cut, 2) symplastic herbicide application at floral bud stage will be better than cutting and will reduce the goldenrod shoot growth, and 3) cutting goldenrod at floral bud stage followed by glyphosate application to regrowth will cause a greater reduction in shoot density than cutting or herbicide applications alone. It is anticipated that results of this objective will provide the information needed for an integrated management plan at different growth stages of goldenrod, which will help growers in better understanding on how to control goldenrod species in wild blueberry fields.

Chapter 2 - Evaluation of summer broadcast and summer and fall spot herbicide applications for goldenrod management in wild blueberry

2.0 Abstract

Goldenrods (*Solidago* spp.) are common creeping herbaceous perennial weeds in wild blueberry fields in Atlantic Canada. Currently, there is lack of management options for this species. Field studies were conducted in commercial wild blueberry fields in 2016 and 2017 to evaluate summer broadcast, and summer and fall spot applied herbicides for the management of goldenrod. The results of this research showed that postemergence broadcast applications of mesotrione at 144 g a.i ha^{-1} followed by sequential mesotrione application at 14 and 21 days after initial application (DAIA) provided > 95% control of goldenrod shoots in both the non-bearing and bearing year. There was 85 to 90% goldenrod damage achieved with broadcast application of mesotrione tank mix with bicyclopyrone at 144 and 50 g a.i ha^{-1}, respectively, at one of two sites. Post emergence summer spot applications of bicyclopyrone, triclopyr, and dicamba caused 80 to 90% goldenrod shoot injury in non-bearing year, but < 70% of treated shoots died. Summer spot applications of glyphosate and mesotrione provided complete control of treated goldenrod shoots in both years while glufosinate and flazasulfuron provided acceptable control of goldenrod shoots in non-bearing year only. Postemergence fall spot application of glyphosate significantly reduced goldenrod shoots in the following year after application.

2.1 Introduction

Lowbush blueberry (*Vaccinium angustifolium* Ait.), also known as wild blueberry, is a native perennial, deciduous horticultural shrub of Northeastern North America (Vander Kloet 1988). It is cultivated commercially in Quebec, the Atlantic Provinces of Canada, and Maine in the United States of America (Yarborough 1996). Wild blueberry is the most important fruit crop in Nova Scotia (Strik and Yarborough 2005), contributing 32.5 million dollars to farm gate value in 2015 (Statistics Canada 2016). Commercial fields are developed where native blueberry stands already exist on cleared woodland or abandoned agricultural land (AAFC 2005). These stands are composed of multiple and variable clones that spread by underground rhizomes (Glass and Percival 2000). Mature wild blueberry stands are managed predominantly on a two-year production cycle in which fields are pruned to ground level in the first year (non-bearing year) to stimulate new shoot growth, and berries are harvested in the second year (bearing year) following bloom and fruit set (AAFC 2005, Jensen and Yarborough 2004).

Weeds are one of the major yield-limiting factors affecting berry production (Yarborough 2009). Competing vegetation interferes with blueberry rhizome growth, decreases yields, and hinders mechanical harvest operations (Yarborough and Bhowmik 1993; Hanchar et al. 1985; Jensen and Yarborough 2004). The most common weeds in wild blueberry fields are herbaceous and woody perennial species (McCully et al. 1991) due to the perennial nature of the crop. Management options for many species are limited, and these weeds present a major challenge in wild blueberry fields (McCully et al. 1991). Goldenrods are perennial broadleaf weeds that are commonly found in wild blueberry fields in Eastern North America (Boyd and White 2010). Goldenrods reproduce sexually through seeds (Werner et al. 1980) and asexually by underground stems called rhizomes (Pavek 2012). Goldenrods rapidly colonize an area once established due to vegetative reproduction (Pavek 2012) and can decrease wild blueberry yields (Boyd and White 2010). Goldenrods were reported to be some of the most common weeds in wild blueberry fields and occurred in 94% of 115 sampled fields in Nova Scotia (McCully et al. 1991). The Wild Blueberry Producers Association of Nova Scotia ranked goldenrods as the fifth most important weed to manage in 2010-2011 (Anonymous 2011).

Current goldenrod management practices include post-emergent mesotrione (2-[4-(Methylsulfonyl)-2-nitrobenzoyl] cyclohexane-1, 3-dione, trade name Callisto®) applications in the non-bearing year or wiping with glyphosate once goldenrod is taller than wild blueberry plants (Boyd and White 2010), as crop rotation and cultivation cannot be used in this perennial crop. Broadcast application of mesotrione can suppress perennial weeds such as goldenrod, but it does not provide complete control (Boyd and White 2010) and plant recovery usually occurs in the year after application. However, the management of other perennial weeds with mesotrione has been improved by using sequential applications. For example, sequential application of mesotrione provided complete control of the perennial weed horsenettle (*Solanum carolinense* L.) compared to single mesotrione applications (Armel et al. 2003). Growers are also consistently reporting incomplete control of goldenrod in wild blueberry fields after a single mesotrione application (Scott White, personal communication). Sequential applications of mesotrione could improve goldenrod control in wild blueberries.

In situations where weed infestations are smaller or patchy, spot applied herbicides can be more effective and economical than broadcast applications. Spot sprays are applied with backpack or handheld sprayers and they can improve coverage and results in reduced crop damage and enhanced weed control versus broadcast application (Wu 2011). Spot spray application can also be conducted with non-selective herbicides as damage to blueberry plants can be reduced or avoided (Wu 2011). Spot applied herbicides can effectively control herbaceous perennial weeds growing above the wild blueberries (Yarborough 2011). Dicamba (3, 6-dichloro-2-methoxybenzoic acid, trade name of Banvel®) can be applied as a spot spray to control perennial weeds including spreading dogbane (*Apocynum androsaemifolium*) (Wu and Boyd 2012). Glyphosate [N (phosphonomethyl) glycine, trade name of Roundup Weathermax®], can be safely used in blueberry fields and selectively spot applied to the weed foliage (Yarborough 2011).

Goldenrod abundance has increased in recent years in wild blueberry fields in Nova Scotia (McCully et al. 1991; Jensen and Sampson 2001, unpublished data). However, due to suspected resistance to traditional herbicides (Jensen and Yarborough 2004), and there is also a lack of control from some registered herbicides (Anonymous 2016). Research on goldenrod species with susceptibility to post emergence herbicides in wild blueberry fields is not sufficient, however, there is a need to evaluate new post emergent herbicide products with efficacy on goldenrod. The objectives of this research were to 1) identify the optimal interval between sequential postemergence mesotrione applications; 2) evaluate postemergence bicyclopyrone applications on goldenrod, and 3) to evaluate multiple herbicides applied as postemergence spot treatments to goldenrod.

2.2 Materials and Methods

2.2.1 Study sites selection

Experiments were carried out in four commercial wild blueberry fields in Nova Scotia between 2016 and 2017 (Table 2.1). All fields were mature, well-established and had been harvested and pruned at the end of the previous season. The dominant species at each site was narrow leaf goldenrod (*Euthamia graminifolia*), though some patches of Canada goldenrod (*Solidago canadensis*) were present at the Londonderry site.

Table 2.1. Description of study sites used for collection of goldenrod shoot density, plant height and visual damage injury data in wild blueberry fields in Nova Scotia, Canada.

Site-year	Production year	Latitude	Longitude	Elevation (m)
Debert-2016	Non-bearing	45°26'12.9"N	63°27'23.3"W	37
Debert-2017	Bearing			
Farmington-2016	Non-bearing	44°36'47.74"N	64°39'54.35"W	151
Farmington-2017	Bearing			
Londonderry-2016	Non-bearing	45°26'21.3"N	63°32'44.6"W	62
Londonderry-2017	Bearing			
Portapique-2016	Non-bearing	45°24'16.98"N	63°42'11.5"W	17
Portapique-2017	Bearing			

2.2.2 Weather data

Air temperature, relative humidity and wind speed at each site during spraying was monitored using a pocket size weather meter (Kestrel® 3000 Weather Meter, Nielsen-Kellerman Corporation, Boothwyn, PA, USA). Regional air temperature and rainfall data for all sites was collected from the nearest Environment Canada weather station. Mean monthly air temperature and rainfall data was attained for non-bearing and bearing year sites (Table 2.2).

Table 2.2. Monthly mean air temperature and total monthly rainfall from nearest Environment Canada weather stations.

Location	Weather station Location	Month	Site year 2016 Temperature -----°C-----	Site year 2016 Rainfall -----mm-----	Site year 2017 Temperature -----°C-----	Site year 2017 Rainfall -----mm-----
Debert	Debert	June	14.6	61.1	14.6	62
		July	19	83.3	18.1	66.1
		Aug	18.4	116	17.6	109
		Sept	14.4	73	15.5	62.7
		Oct	8.8	159.3	10.8	47.9
Farmington	Nappan	June	N/A	N/A	15	86.5
		July	N/A	N/A	18	31.9
		Aug	N/A	N/A	17.7	58.5
		Sept	14.9	50	16	34.1
		Oct	9.2	124.3	11.5	57.6
Londonderry	Debert	June	N/A	N/A	14.6	62
		July	N/A	N/A	18.1	66.1
		Aug	N/A	N/A	17.6	109
		Sept	14.4	73	15.5	62.7
		Oct	8.8	159.3	10.8	47.9
Portapique	Debert	June	14.6	61.1	14.6	62
		July	19	83.3	18.1	66.1
		Aug	18.4	116	17.6	109
		Sept	14.4	73	15.5	62.7
		Oct	8.8	159.3	10.8	47.9

[a]Mean monthly air temperature and rainfall data for all sites were obtained from the Environment Canada weather stations located at Debert and Nappan, Nova Scotia (45°26'12.9"N, 63°27'23.3"W, elevation of 37.50 m; 45°45'34.400" N, 64°14'29.200" W, elevation of 19.80 m)

2.2.3. Broadcast herbicide evaluations

Experiments were conducted in 2016 and 2017 to evaluate broadcast herbicide applications for goldenrod management. Experiments were conducted in two commercial wild blueberry fields located in Debert (45°26'12.9"N; 63°27'23.3"W) and Portapique (45°24'16.98"N; 63°42'11.5"W), Nova Scotia. The first experiment was designed to evaluate sequential mesotrione applications for goldenrod management. The experiment was arranged as a Randomized Complete Block Design with 8 blocks at Portapique and 9 blocks at Debert. Plot size was 2 by 4 m, with a 1-meter buffer between each block. Treatments consisted of 1) nontreated control, 2) mesotrione application at 30cm shoot height, 3) mesotrione application at 30cm shoot height followed by a sequential mesotrione application at 7 days after initial application (DAIA), 4) mesotrione application at 30cm shoot height followed by a sequential mesotrione application at 14 days after initial application (DAIA), 5) mesotrione application at 30cm shoot height followed by a sequential mesotrione application at 21 days after initial application (DAIA), and 6) mesotrione application at 30cm shoot height followed by a sequential mesotrione application at 28 days after initial application (DAIA). Mesotrione was applied at a rate of 144 g a.i ha^{-1} in 200 L ha^{-1} water with 0.2% v/v nonionic surfactant using a CO_2 pressurized research plot sprayer equipped with four Teejet XR8002VS nozzles. Weather conditions and mean goldenrod height at the time of treatment applications for each site are given in Table 2.3.

The second experiment was designed to evaluate post emergence mesotrione and bicyclopyrone applications on goldenrod shoots. The experiment was arranged as a Randomized Complete Block Design with 6 blocks at Debert and 8 blocks at Portapique. Plot size was 2 by 4 m, with a 1-meter buffer strip between blocks. Treatments consisted of 1) non-treated control, 2) mesotrione, 3) bicyclopyrone, and 4) mesotrione plus bicyclopyrone. Herbicide applications were made at floral bud initiation stage of goldenrod in the beginning of non-bearing year. Mesotrione and bicyclopyrone were applied at a rate of 144 and 50 g a.i ha^{-1}, respectively, in 200 L ha^{-1} water with 0.2% v/v nonionic surfactant. Herbicide applications were made using a CO_2 pressurized research plot sprayer equipped with four XR8002VS Teejet nozzles operated at a spray pressure of 275 KPa. Weather conditions and mean goldenrod height at the time of treatment applications for each location are given in Table 2.4.

Table 2.3. Application dates, mean goldenrod shoot height, air temperature, relative humidity, and wind speed at the time of sequential mesotrione herbicide applications at Debert and Portapique, Nova Scotia, in 2016.

			Mean shoot height	Temp[a]	RH[a]	WS[a]
Site	Treatment	Application dates	---cm---	---^{o}C---	---%---	---Km h^{-1}---
Debert	Non-treated Control	N/A[a]	N/A	N/A	N/A	N/A
	Mesotrione	3-Jun-16	28 ± 2	21	46	3
	Mesotrione fb[a] mesotrione (7 days)	10-Jun-16	35 ± 1.5	18.4	62	2
	Mesotrione fb mesotrione (14 days)	17-Jun-16	34 ± 1.4	14	57	1
	Mesotrione fb mesotrione (21 days)	24-Jun-16	38 ± 1.5	19	65	3
	Mesotrione fb mesotrione (28 days)	2-Jul-16	34 ± 1.6	18	70	2
Portapique	Non-treated Control	N/A	N/A	N/A	N/A	N/A
	Mesotrione	3-Jun-16	29 ± 1.9	23	53	2
	Mesotrione fb mesotrione (7 days)	10-Jun-16	45 ± 1	20	65	2
	Mesotrione fb mesotrione (14 days)	17-Jun-16	40 ± 1.4	15	60	2
	Mesotrione fb mesotrione (21 days)	24-Jun-16	44 ± 1.2	20	83	4
	Mesotrione fb mesotrione (28 days)	2-Jul-16	42 ± 1.8	20	78	3

[a]Abbreviations: Temp, temperature; RH, relative humidity; WS, wind speed; fb, followed by; N/A, not applicable.
[b]First application of mesotrione in all plots occurred on June 10th.

Table 2.4. Application dates, mean goldenrod shoot height, air temperature, relative humidity, and wind speed at the time of herbicide applications for bicyclopyrone evaluation at Debert and Portapique, Nova Scotia, in 2016.

Locations	Application date	Mean shoot height	Temperature	Relative humidity	Wind speed
		-----cm----	------°C------	------%------	----Km h^{-1}----
Debert	11 June 2016	40 ± 0.8	18.4	62	2
Portapique	11 June 2016	52 ± 1.6	17	72	3

2.2.4 Evaluation of summer and fall herbicide spot applications

Experiments were conducted in 2016 and 2017 to evaluate various summer and fall herbicide options for goldenrod control (Table 2.5). The summer spot herbicide application experiment was conducted in commercial wild blueberry fields located in Debert (45°26'12.9"N; 63°27'23.3"W) and Portapique (45°24'16.98"N; 63°42'11.5"W), and the fall spot herbicide application experiment was conducted in Farmington (44°36'47.74"N; 64°39'54.35"W) and Londonderry (45°28'30.7"N; 63°36'08.7"W) Nova Scotia, Canada. The experimental design for each experiment was a Completely Randomized Design with 12 and 11 treatments in the summer and fall experiments, respectively (Table 2.5). There were 8 and 9 replications in Portapique and Debert, respectively, and 5 replications at each location for the fall spot spray experiment. Herbicides were applied to the 1 by 1 m plots at the goldenrod floral bud stage and at the goldenrod post-seed set stage in the summer and fall experiments, respectively. Herbicides were applied with a CO_2 pressurized research plot sprayer equipped with a single Teejet 8002VS nozzle operated at a spray pressure of 275 KPa. Goldenrod was sprayed until the herbicide solution run-off from the leaves in all applications. Weather conditions and mean goldenrod shoot height at the time of herbicide applications at all sites are given in Table 2.6.

Table 2.5. Post emergent herbicides evaluated as summer and fall spot applications to goldenrod in wild blueberry fields located at Debert, Portapique, Farmington, and Londonderry, Nova Scotia, Canada.

Trade name	Common name	Application rate (g a.i. or a.e L water^{-1})[a]
Non-treated Control	N/A[a]	N/A
Roundup Weathermax	Glyphosate	7.24
Ignite[b]	Glufosinate	0.75
Callisto[c]	Mesotrione	0.72
Syn-A16003[c]	Bicyclopyrone	0.25
Mission[c]	Flazasulfuron	0.31
Banvel	Dicamba	1
Distinct[c]	Dicamba + diflufenzopyr	0.7 + 0.3
Garlon	Triclopyr	1.68
Lontrel	Clopyralid	0.08
Express[c]	Tribenuron methyl	0.2
Option[c]	Foramsulfuron	0.2

[a]Abbreviations: a.i, active ingredient; a.e, acid equivalent; N/A, not applicable.
[b]Ignite was only applied at floral bud initiation stage of goldenrod in summer spot spray experiment, but not in fall applied herbicide trial.
[c]Option was applied with 28% UAN at a rate of 12.5mL L water^{-1}; Mission was applied with non-ionic surfactant Desikote Max at a rate of 0.2% v/v. Callisto, Distinct, Express and Syn-A 16003 were applied with non-ionic surfactant Activate plus at a rate of 0.2% v/v.

Table 2.6. Application date, mean goldenrod shoot height, air temperature, relative humidity, and wind speed at the time of herbicide applications at Debert and Portapique for summer spot herbicides and at Farmington and Londonderry, Nova Scotia for fall spot herbicides in 2016.

Locations	Application date	Mean shoot height	Temperature	Relative humidity	Wind speed
		------cm------	------°C------	------%------	---- Km h^{-1}----
Debert	29 June 2016	40 ± 1.3	19.8	83	1
Portapique	16 June 2016	52 ± 1.2	23	85	2
Farmington	06 Oct 2016	46 ± 1.5	21.7	65	3
Londonderry	19 Sept 2016	59 ± 1.6	13.8	80	3

2.3 Data collection

Data collection in all experiments included goldenrod shoot density, shoot height, and herbicide damage ratings in each treatment. Goldenrod shoot density in the broadcast and summer spot applied herbicide experiments were determined prior to treatment applications, at the end of the non-bearing year (October 20, 2016), and in early summer of the bearing year (June 21, 2017). Goldenrod shoot density in the fall herbicide spot application experiment was determined prior to herbicide application at the end of non-bearing year (September 19, 2016) and in early summer of the bearing year (June 06, 2017). Goldenrod shoot density was determined in 2 $1m^{-2}$ quadrats in all broadcast experiments and on a whole-plot basis for summer and fall spot experiments. Goldenrod shoot height was determined on 30 randomly selected shoots in each plot and was determined prior to all treatment applications. Herbicide damage was evaluated in all experiments except the fall herbicide spot application experiment at 7, 14, 21, 28, and 35 days after spraying (DAS). Visual damage ratings were conducted using a scale from 0 to 100, where 0 meant no plant kill and 100 was complete plant kill.

2.4 Statistical analysis

All statistical analyses were performed using SAS (version 9.4, Raleigh, NC). Goldenrod shoot density and height were analyzed using ANOVA in PROC MIXED in SAS. Treatments were fixed effects and blocks were random effects. All sites were analyzed separately. Means were determined using the LS MEANS statement, and mean separation, where necessary, was conducted using Tukey's multiple means comparison test at $p = 0.05$. Assumptions of normality, constant variance, and independence were tested using PROC UNIVARIATE analysis where residual*predicted values were plotted. Differing data transformations (square root, log) were used when needed to meet the normality and constant variance assumptions. Subjective data (e.g.

damage ratings) was analyzed using non-parametric analysis in PROC NPAR-1-WAY, and treatment effects were determined using the Kruskal-Wallis test. The subroutine pdmix800.sas (Saxton 1998) was used to provide letter groupings.

2.5 Results and Discussion

2.5.1 Broadcast herbicide evaluations

Initial goldenrod shoot density did not vary across treatments at any site. Mesotrione treatments had a significant effect on goldenrod shoot density ($p < 0.0001$). A single mesotrione application caused 39 to 58% injury to goldenrod and reduced shoot density relative to the nontreated control at the end of the non-bearing year at Debert (Table 2.7). Visual injury was higher at Portapique, but non-bearing year density was not reduced by single mesotrione applications at this site (Table 2.7). Goldenrod also recovered in this treatment in the bearing year and shoot density was similar to the nontreated control at each site (Table 2.7). Single mesotrione applications therefore suppress narrow leaf goldenrod at Debert, but do not completely control at each site. Sequential mesotrione applications caused > 98% injury to goldenrods by 35 DAS and significantly reduced goldenrod shoot density at the end of the non-bearing year relative to the nontreated control and the single mesotrione application at Debert, but not in Portapique (Table 2.7). Sequential mesotrione applications made 7 DAIA were less effective at Portapique, however, and the most consistent reductions in shoot density occurred when sequential applications were made at 14, 21, and 28 DAIA (Table 2.7). This suggests that two applications of mesotrione provided better weed control than a single application, and our results are generally consistent with other published research. For example, the perennial weed horsenettle was controlled more effectively with two sequential applications of mesotrione (Armel et al. 2003). Control of black bulrush (*Scirpus atrovirens*) in wild blueberry fields was also improved following two mesotrione applications (Boyd and White 2010). Jones and Christian (2007) also observed that management of creeping bentgrass (*Agrostis stolonifera*) in Kentucky bluegrass was more effective with sequential applications of mesotrione. Mesotrione was effective on these species, however, the reasons or mechanism behind the efficacy of multiple treatments was not fully discussed in these studies.

Reductions in bearing year shoot density on both sites in the sequential mesotrione treatments (Table 2.7) suggests damage to rhizomes or reduction in rhizome biomass by these treatments. Mesotrione significantly reduced the number and weight of new tubers of volunteer potato (*Solanum tuberosum*) in sweet corn (Boydston 2004; Boydston et al. 2008), indicating potential for sequential mesotrione applications to inhibit or damage underground vegetative reproductive structures such as rhizomes. In addition, Boydston and Al-Khatib (2008) reported that up to 15% of foliar applied mesotrione was translocated to developing roots and tubers of potato plants. Sequential mesotrione applications to goldenrods may therefore increase the amount of mesotrione translocated to roots and rhizomes, possibly contributing to the increased control observed in the bearing year. Wild blueberry growers in Maine are using sequential mesotrione applications on wild blueberry fields (Yarborough and D'Appollonio 2009b), and a similar registration was suggested for Canada (Boyd and White 2010). Our results suggest that growers should use sequential mesotrione applications that are spaced from 14 to 28 days apart, and pursuit of this registration to improve weed control with mesotrione in Canada is warranted.

Table 2.7. Effects of sequential mesotrione application timings on goldenrod visual injury ratings and shoot density at wild blueberry fields in Debert and Portapique, Nova Scotia, Canada.

Site	Treatment	Density before application	Visual injury[a] at 7 DAS[b]	Visual injury at 21 DAS	Visual injury at 35 DAS	Non-bearing year shoot density	Bearing year shoot density
		---shoots m^{-2}---	-----------------%-----------------			---shoots m^{-2}---	--shoots m^{-2}--
Debert	Non-treated Control	76 ± 0.2 a	0 ± 0	0 ± 0	0 ± 0	56 ± 0.3 a[c]	40 ± 0.3a
	Mesotrione	70 ± 0.2 a	39 ± 2	58 ± 3	43 ± 5.5	17 ± 0.3 b	36 ± 0.3 a
	Mesotrione fb mesotrione (7 days)	68 ± 0.2 a	41 ± 4	99 ± 1.1	100	3 ± 0.3 c	10 ± 0.3 b
	Mesotrione fb mesotrione (14 days)	66 ± 0.2 a	100	100	100	3 ± 0.3 c	4 ± 0.3 b
	Mesotrione fb mesotrione (21 days)	68 ± 0.2 a	89 ± 3	98 ± 1.5	98 ± 1.5	0 ± 0.3 c	6 ± 0.3 b
	Mesotrione fb mesotrione (28 days)	85 ± 0.2 a	87 ± 3	98 ± 1.5	99 ± 1	1 ± 0.3 c	7 ± 0.3 b
	p-value[d]	---	<.0001	<.0001	<.0001	---	---
Portapique	Non-treated Control	67 ± 0.8 a	0 ± 0	0 ± 0	0 ± 0	61 ± 0.6 a	35 ± 0.3 a
	Mesotrione	84 ± 0.8 a	46 ± 4	77 ± 2	55 ± 3	51 ± 0.6 ab	29 ± 0.3 ab
	Mesotrione fb mesotrione (7 days)	98 ± 0.8a	52 ± 2	90 ± 1.8	100	30 ± 0.6 abc	10 ± 0.3 c
	Mesotrione fb mesotrione (14 days)	62 ± 0.8 a	96 ± 2	100	100	19 ± 0.6 c	6 ± 0.3 c
	Mesotrione fb mesotrione (21 days)	83 ± 0.8 a	85 ± 4	100	95 ± 1.8	26 ± 0.6 bc	5 ± 0.3 c
	Mesotrione fb mesotrione (28 days)	79 ± 0.8 a	86 ± 4	94 ± 2.6	100	27 ± 0.6 bc	10 ± 0.3 c
	p-value[d]	---	<.0001	<.0001	<.0001	---	---

[a]Visual damage ratings were estimated using a 0 to 100 scale, where 0 means no plant kill and 100 means complete plant death. [b]Abbreviations: fb, followed by; DAS, days after spraying. [c]Means within columns with different letters are significantly different at $P < 0.05$ according to Tukey's test. Values expressed as mean ± one standard error of mean. [d] p-value associated with Kruskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Density prior to the treatment applications was not significantly different across treatments at either site in the bicyclopyrone herbicide evaluation experiment (Table 2.8). There was a significant effect of herbicide treatment on goldenrod shoot density in the non-bearing year at each site ($p < 0.0001$), but only on bearing year density at Debert ($p < 0.0073$). Mesotrione caused >85% injury to goldenrod by 35 DAS and reduced shoot density relative to the nontreated control at each site in the non-bearing year (Table 2.8). Goldenrod recovered in the bearing year, however, and density was not reduced relative to the nontreated control (Table 2.8). Bicyclopyrone caused 69 to 80% injury to goldenrod by 35 DAS and tended to reduce shoot density in the non-bearing year (Table 2.8), but goldenrod recovered in the bearing year, so density was not reduced. Bicyclopyrone therefore appears to provide similar suppression of goldenrod as that achieved with mesotrione. The tank mixture of mesotrione and bicyclopyrone caused > 90% injury to goldenrod and reduced shoot density in both the non-bearing and bearing years at Debert but only in the non-bearing year at Portapique (Table 2.8). Availability of bicyclopyrone for use as a tank mixture with mesotrione may therefore improve goldenrod control in wild blueberry, and this use could warrant additional research with this herbicide. Improved control at Debert was likely due to lower goldenrod density and shorter plants at this site (Table 2.4). This is consistent with the findings of Yu and McCullough (2016), who observed mesotrione efficacy on shorter plants of annual bluegrass and had a limited effect on taller plants. Armel et al. (2005) also reported that mesotrione effectively controlled shorter plants of Canada thistle (*Cirsium arvense* L.) better than taller plants. Mesotrione and other carotenoid-inhibiting herbicides are often evaluated in tank mixture or in sequential applications with PSII-inhibitor herbicides (Armel et al. 2003; Abendroth et al. 2006; Woodyard et al. 2009; Williams et al. 2011), but due to lack of research we are unable to find examples of different carotenoid-inhibiting herbicides evaluated as tank mixtures with each other.

Our data indicates that tank mixtures of these products may improve weed control, and should therefore be evaluated where possible.

2.5.2 Evaluation of summer herbicide spot applications

Initial goldenrod shoot density did not vary across treatments at either site in the summer spot application experiment (Tables 2.9 and 2.10). There was a significant effect of herbicide treatment on visual injury ratings ($p < 0.0001$) at all rating dates and on goldenrod shoot density ($p < 0.0001$) at each site (Tables 2.9 and 2.10). Glyphosate, glufosinate, mesotrione, and bicyclopyrone caused > 85% damage to goldenrod by 35 DAS and reduced shoot density relative to the nontreated control at the end of non-bearing year at Debert. These treatments also reduced shoot density at the end of the non-bearing year at Portapique (Table 2.10), though visual injury from bicyclopyrone was lower at this site relative to Debert. Glyphosate and mesotrione reduced shoot density in the bearing year at each site (Tables 2.9 and 2.10), indicating a reduction in rhizome biomass following spot application of these herbicides, though this was not measured. Biomass of vegetative reproductive structures in perennial weeds such as Canada thistle (Sprankle et al. 1975), quack grass (Claus and Behrens 1976), and yellow nutsedge (Nelson et al. 2002), however, were reduced by this herbicide, and this may explain reductions in bearing year shoot density observed. Similar reductions in bearing year shoot density in the mesotrione treatment were unexpected, though reports of root translocation of this herbicide (Boydston and Al-Khatib 2008) suggest that this herbicide may have also caused damage to rhizomes. Reductions in bearing year shoot density following spot applications also indicates that spot applications of mesotrione are more effective than broadcast applications, as bearing year shoot density was not reduced by single broadcast mesotrione applications (Tables 2.7 and 2.8). Improved plant coverage with mesotrione with spot applications relative to broadcast applications may have resulted in increased translocation and therefore higher efficacy of spot applications. In addition, a spot application may also increase mesotrione efficacy due to a higher concentration of the active ingredients applied to the targeted plants. Additional research should be conducted to determine the extent, and implications, of mesotrione rhizome translocation in goldenrod species in wild blueberry fields. Although glyphosate is effective, the use of this herbicide would require careful application due to high risk of injury to exposed blueberry leaves. Growers should therefore consider using mesotrione instead of glyphosate to control goldenrod, which results in less injury to wild blueberries. Bicyclopyrone did not reduce bearing year density at Portapique (Table 2.10), indicating that spot applications of this herbicide are less effective on goldenrods than mesotrione. Similarly, glufosinate reduced bearing year shoot density at Portapique (Table 2.10) but not at Debert (Table 2.9). Glufosinate tends to exhibit limited root translocation in treated plants, which can reduce efficacy of this herbicide on perennial weeds. For example, Bradley and Hagood (2002) reported that less than 50% of mugwort (*Artemisia vulgaris*) was controlled with glufosinate after one year of application as a result of insufficient movement of glufosinate into the rhizomes.

Flazasulfuron caused > 82% injury by 35 DAS and significantly reduced non-bearing and bearing year goldenrod shoot density at Debert (Table 2.9). This herbicide, however, caused less injury at Portapique and only reduced shoot density in the non-bearing year (Table 2.10). Goldenrod damage following dicamba and dicamba + diflufenzopyr applications ranged from 57 to 68% by 35 DAS and non-bearing year shoot density was reduced by these treatments at each site. Shoot density remained low in these treatments in the bearing year at Debert (Table 2.9), though recovery occurred in the dicamba treatment at Portapique (Table 2.10). Dicamba controlled tall goldenrod (*Solidago altissima* L.) in fescue hayfields (Payne and Bradley 2010) and spreading dogbane in wild blueberry fields (Wu and Boyd 2012), though efficacy of this herbicide on narrow leaf goldenrod seems less consistent. Triclopyr and clopyralid caused 56 to 69% injury to goldenrod by 35 DAS at each site and reduced shoot density relative to the nontreated control at the end of non-bearing year (Tables 2.9 and 2.10). Goldenrods recovered in the clopyralid treatment at each site in the bearing year, though shoot density remained low in the triclopyr treatment at Debert but not Portapique (Tables 2.9 and 2.10). Triclopyr spot applications control spreading dogbane (Wu and Boyd 2012), and this herbicide is generally effective on wide range of broadleaf weeds (Olson and Mackasey 1989; Cox 2000; Nelson et al. 2006). However, this herbicide seems variable on goldenrod and likely should not be used as a spot treatment for this weed species in wild blueberry. Similarly, clopyralid controls perennial weeds such as Canada thistle (Miller et al. 2012) and perennial sow thistle (Zollinger et al. 1992), and controls other broadleaf weeds in wild blueberry (White and Webb 2017). Goldenrod recovery in the bearing year in this treatment at each site, however, indicates that clopyralid does not damage goldenrod rhizomes and so this herbicide should not be used as spot treatment for this weed.

Tribenuron methyl and foramsulfuron caused 42 to 58% damage to goldenrod by 35 DAS and tended to reduce shoot density in the non-bearing year (Table 2.9). Goldenrod recovered in the bearing year in each treatment at Portapique, but remained reduced in the tribenuron methyl treatment at Debert. These herbicides therefore appear to be ineffective on goldenrods in wild blueberry fields. Tribenuron methyl spot treatment has been found to be effective on several other herbaceous perennial weeds such as eastern bracken (*Pteridium aquilinum* L.), yellow loosestrife (*Lysimachia terrestris* L.), speckled alder (*Alnus incana* L.), common wild rose (*Rosa virginiana* Mill.) and bunchberry (*Cornus canadensis* L.) in wild blueberry fields (Yarborough and Hess 1995; Jensen and Specht 2004). However, our results indicate that foramsulfuron has low efficacy on goldenrod. Li (2013) also reported that sulfonylurea herbicides such as

Table 2.8. Effect of post emergence bicyclopyrone and mesotrione applications on goldenrod visual injury ratings and shoot density at wild blueberry fields in Debert and Portapique, Nova Scotia, Canada.

Site	Treatment	Density before application	Visual injury[a] at 7 DAS[b]	Visual injury at 21 DAS	Visual injury at 35 DAS	Non-bearing year shoot density	Bearing year shoot density
		---shoots m^{-2}---	---------------%---------------			---shoots m^{-2}---	---shoots m^{-2}---
Debert	Non-treated Control	44 ± 0.2 a	0 ± 0	0 ± 0	0 ± 0	37 ± 0.4 a[c]	24 ± 0.5 a
	Mesotrione	48 ± 0.2 a	20 ± 2.6	83 ± 2	85 ± 2.2	15 ± 0.4 b	15 ± 0.5 ab
	Bicyclopyrone	44 ± 0.2 a	17 ± 2	70 ± 2.5	80 ± 2.5	23 ± 0.4 ab	24 ± 0.5 a
	Mesotrione plus Bicyclopyrone	46 ± 0.2 a	20 ± 2.5	82 ± 5	90 ± 3	14 ± 0.4 b	12 ± 0.5 b
	p-value[d]	---	0.0013	0.0005	0.0006	---	---
Portapique	Non-treated Control	69 ± 0.8 a	0 ± 0	0 ± 0	0 ± 0	56 ± 0.3 a	43 ± 0.2 a
	Mesotrione	58 ± 0.8 a	20 ± 3	75 ± 4.2	89 ± 1.2	18 ± 0.3 b	33 ± 0.2 a
	Bicyclopyrone	76 ± 0.8 a	17 ± 2.5	58 ± 4	69 ± 4	22 ± 0.3 b	39 ± 0.2 a
	Mesotrione plus Bicyclopyrone	56 ± 0.8 a	20 ± 2	70 ± 4	86 ± 2.6	19 ± 0.3 b	23 ± 0.2 a
	p-value[d]	---	0.0002	<.0001	<.0001	---	---

[a] Visual damage ratings were calculated using a 0 to 100 scale, where 0 means no plant damage and 100 means complete plant death.
[b] Abbreviation: DAS, days after spraying.
[c] Means within columns with different letters are significantly different at $P < 0.05$ according to Tukey's multiple mean comparison test. Values given as ± one represents standard error of means.
[d] p-value associated with Kruskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

nicosulfuron/rimsulfuron and chlorimuron methyl were ineffective on Canada and narrow-leaved goldenrod species and red sorrel, which further indicated the limited efficacy of these sulfonylurea herbicides on goldenrod in wild blueberry fields.

2.5.3 Evaluation of fall herbicide spot applications

Goldenrod shoot density at the time of treatment applications did not vary across sites (Table 2.11). There was a significant effect of herbicide treatment on goldenrod shoot density in the year after application at Farmington ($p < 0.0015$) and Londonderry ($p < 0.0035$). Glyphosate was the only herbicide to reduce shoot density in the following year relative to the nontreated control at each site (Table 2.11). This suggests that fall glyphosate applications were translocated into the root system and caused a reduction in the rhizome biomass, though this was not measured. These results are consistent with the findings of Carlson and Donald (1988), who observed that fall glyphosate applications significantly decreased Canada thistle shoot density in the year after application due to reduced root biomass. Whaley and VanGessel (2002) also reported that fall glyphosate application at the senescing stages controls horsenettle shoots due to the depletion of the rhizome biomass in the late spring of the next year. All other herbicides evaluated in the fall experiment were ineffective. Leaves on plants treated in the fall had begun to senesce, as evidenced by yellowing of leaves at the time of treatment applications. This may have affected herbicide uptake and translocation, limiting efficacy of some of the treatments. For example, fall applications of mesotrione were found to have limited efficacy to control annual bluegrass in Kentucky bluegrass at multitiller stage (yellowish in colour) due to decreased translocation of this herbicide in the roots, as compared to pretiller and one tiller (green in colour) plants (Reicher et al. 2011; Yu and McCullough 2016). Mesotrione, a carotenoid inhibiting herbicide is not effective to apply in the fall on goldenrod because the leaves are getting ready to senesce during this time. It is likely

Table 2.9. Effect of various summer spot herbicide treatments on shoot density and visual damage ratings of goldenrod at Debert, Nova Scotia, Canada.

Treatment	Density before application	Visual injury[a] at 7 DAS[a]	Visual injury at 21 DAS	Visual injury at 35 DAS	Non-bearing year shoot density	Bearing year shoot density
	---shoots m^{-2}---	---------------------%---------------------			---shoots m^{-2}---	---shoots m^{-2}---
Non-treated Control	45 ± 0.6 a	0 ± 0	0 ± 0	0 ± 0	44 ± 0.3 a[b]	35 ± 0.4 a
Glyphosate	32 ± 0.6 a	5 ± 1	82 ± 10	88 ± 11	1 ± 0.3 cd	13 ± 0.4 bcde
Glufosinate	30 ± 0.6 a	72 ± 2.2	100	100	3 ± 0.3 cd	17 ± 0.4 abcd
Mesotrione	27 ± 0.6 a	20 ± 4	84 ± 3.3	100	1 ± 0.3 cd	6 ± 0.4 def
Bicyclopyrone	31 ± 0.6 a	19 ± 2	83 ± 3	90 ± 2.35	0 ± 0.3 d	3 ± 0.4 f
Flazasulfuron	27 ± 0.6 a	14 ± 3	73 ± 10	82 ± 10.5	1 ± 0.3 cd	5 ± 0.4 def
Dicamba	30 ± 0.6 a	12 ± 5	45 ± 6.2	59 ± 8	1 ± 0.3 cd	8 ± 0.4 cdef
Dicamba and diflufenzopyr	39 ± 0.6 a	20 ± 2.3	55 ± 3.3	68 ± 2.2	2 ± 0.3 cd	4 ± 0.4 ef
Triclopyr	36 ± 0.6 a	13 ± 4	53 ± 3.3	66 ± 2.3	1 ± 0.3 d	6 ± 0.4 def
Clopyralid	40 ± 0.6 a	22 ± 3	45 ± 3	69 ± 3.5	14 ± 0.3 b	28 ± 0.4 ab
Tribenuron methyl	25 ± 0.6 a	15 ± 3	36 ± 7.8	58 ± 9	8 ± 0.3 bc	15 ± 0.4 bcde
Foramsulfuron	25 ± 0.6 a	11 ± 2.6	38 ± 7	42 ± 6.4	13 ± 0.3 b	19 ± 0.4 abc
p-value[c]	---	<.0001	<.0001	<.0001	---	---

[a]Visual damage ratings were done using a 0 to 100 scale, where 0 means no plant kill and 100 means complete plant death. DAS, days after spraying.
[b]Means within columns with different letters are significantly different at $P < 0.05$ based on Tukey's test. Numbers ± one represents standard error of means.
[c]p-value associated with Kruskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

Table 2.10. Stem density and visual damage ratings of goldenrod summer spot applications of herbicides at Portapique, Nova Scotia, Canada.

Treatment	Density before application	Visual injury[a] at 7 DAS[a]	Visual injury at 21 DAS	Visual injury at 35 DAS	Non-bearing year shoot density	Bearing year shoot density
	---shoots m^{-2}---	--------------------	--------%--------	--------------------	---shoots m^{-2}---	---shoots m^{-2}---
Non-treated Control	82 ± 0.9 a	0 ± 0	0 ± 0	0 ± 0	71 ± 0.5 a[b]	69 ± 0.7 a
Glyphosate	59 ± 0.9 a	5 ± 0	68 ± 14	86 ± 12	3 ± 0.5 d	19 ± 0.7 c
Glufosinate	46 ± 0.9 a	89 ± 4	100	100	8 ± 0.5 cd	24 ± 0.7 bc
Mesotrione	61 ± 0.9 a	30 ± 4	95 ± 2	99 ± 1.2	6 ± 0.5 cd	20 ± 0.7 c
Bicyclopyrone	53 ± 0.9 a	19 ± 3	42 ± 5.2	57 ± 3.6	12 ± 0.5 bcd	42 ± 0.7 abc
Flazasulfuron	47 ± 0.9 a	12 ± 1.6	36 ± 8	56 ± 8	24 ± 0.5 bc	42 ± 0.7 abc
Dicamba	59 ± 0.9 a	17 ± 2.5	42 ± 5.3	57 ± 4	16 ± 0.5 bcd	26 ± 0.7 abc
Dicamba and diflufenzopyr	55 ± 0.9 a	26 ± 5	55 ± 5	62 ± 4	16 ± 0.5 bcd	24 ± 0.7 c
Triclopyr	55 ± 0.9 a	21 ± 3	59 ± 6.6	67 ± 4	24 ± 0.5 bc	33 ± 0.7 abc
Clopyralid	51 ± 0.9 a	21 ± 1.2	46 ± 4.6	56 ± 3.7	12 ± 0.5 bcd	50 ± 0.7 abc
Tribenuron methyl	38 ± 0.9 a	11 ± 2.2	35 ± 6	49 ± 6.3	11 ± 0.5 bcd	50 ± 0.7 abc
Foramsulfuron	55 ± 0.9 a	18 ± 6	41 ± 4.4	50 ± 5	30 ± 0.5 b	66 ± 0.7 ab
p-value[c]	---	<.0001	<.0001	<.0001	---	---

[a]Visual damage ratings were done using a 0 to 100 scale, where 0 means no plant kill and 100 means complete plant death. DAS, days after spraying.
[b]Means within columns with different letters are significantly different at $P < 0.05$ based on Tukey's test. Numbers ± one represents standard error of means.
[c]p-value associated with Kruskal-Wallis test conducted in PROC NPAR 1WAY in SAS.

too late in the year for this herbicide treatment to be effective on perennial weeds such as goldenrod.

Dicamba and clopyralid have also been found to be ineffective in controlling perennial weeds such as Canada thistle, horsenettle, and spreading dogbane when applied in the fall (Donald 1990; Whaley and VanGessel 2002, Wu and Boyd 2012). Whaley and VanGessel (2002) reported similar results, with fall dicamba application at different stages of horsenettle senesce. Control in the following summer was greater when dicamba was applied in the fall to horsenettle with at least 50 to 60% of green foliage remaining. At later stages of senescence, decreased control was recorded. Similarly, in the previous summer spot spray experiment, goldenrod control was greater when these herbicides were applied before leaf senescence (Table 2.9 and 2.10), and control was decreased with late fall application timing (Table 2.11). Goldenrod control with a fall application of these herbicides should be made as early in the fall as possible or in late summer, while the goldenrod is still actively growing with green leaves. However, additional research will be needed with higher rates of each product to evaluate herbicide efficacy to control goldenrod at differe nt growth stages.

Table 2.11. Effect of fall herbicide spot treatments on goldenrod shoot density at Farmington and Londonderry, Nova Scotia, Canada.

Treatments	Farmington		Londonderry	
	Density at application	Density in year after application[a]	Density at application	Density in year after application[a]
	---Shoots m^{-2}---	---Shoots m^{-2}---	---Shoots m^{-2}---	---Shoots m^{-2} ---
Non-treated Control	48 ± 7.7 a	60 ± 8.6 a[b]	80 ± 15 a	100 ± 13 a[b]
Glyphosate	52 ± 7.7 a	9 ± 8.6 b	95 ± 15 a	25 ± 13[c] b
Mesotrione	44 ± 7.7 a	56 ± 8.6 a	100 ± 15 a	95 ± 13a
Bicyclopyrone	38 ± 7.7 a	47 ± 8.6 ab	83 ± 15 a	80 ± 13 ab
Flazasulfuron	40 ± 7.7 a	45 ± 8.6 ab	93 ± 15 a	94 ± 13 a
Dicamba	51 ± 7.7 a	37 ± 8.6 ab	93 ± 15 a	77 ± 13 ab
Dicamba and diflufenzopyr	65 ± 7.7 a	57 ± 8.6 a	102 ± 15 a	59 ± 13 ab
Triclopyr	38 ± 7.7 a	39 ± 8.6 ab	88 ± 15 a	84 ± 13 ab
Clopyralid	55 ± 7.7 a	66 ± 8.6 a	91 ± 15 a	102 ± 13 a
Tribenuron methyl	50 ± 7.7 a	56 ± 8.6 a	93 ± 15 a	104 ± 13 a
Foramsulfuron	56 ± 7.7 a	63 ± 8.6 a	104 ± 15 a	81 ± 13 ab

[a]Goldenrod shoot density was measured after 270 days of treatment application.
[b]Means within columns with different letters are significantly different at $p < 0.05$ based on Tukey's test.
[c]Numbers ± one represents standard error of means.

2.6 Conclusion

Herbicides are an effective control option for goldenrod. This weed was susceptible to spot-sprayed and broadcast applications of various herbicide products currently registered for use in wild blueberries. Postemergence sequential broadcast applications of mesotrione at 144 g a.i. ha^{-1} in 200 L ha^{-1} water in the non-bearing year with applications occurring 14, 21 and 28 days apart effectively controlled goldenrod. Broadcast application of mesotrione tank mixed with bicyclopyrone at 144 and 50 g a.i. ha^{-1} in 200 L ha^{-1} water in the non-bearing year provided acceptable management of this weed. Summer spot sprays of glyphosate or mesotrione at 7.24 or 0.72 g a.i. or a.e L $water^{-1}$, respectively in the non-bearing year effectively reduced goldenrod shoot density in the bearing and non-bearing years. In addition, summer spot sprays of bicyclopyrone and flazasulfuron at 0.25 and 0.31 g a.i L $water^{-1}$, respectively in the non-bearing year effectively controlled goldenrod shoots in the bearing and non-bearing years at one of two sites. Summer spot applied dicamba + diflufenzopyr, triclopyr and tribenuron methyl at 0.7 + 0.3, 1.68 and 0.3 g a.i L $water^{-1}$, respectively in the non-bearing year injured goldenrod and tended to lower shoot density in both years at one of two sites. However, summer spot applied dicamba and clopyralid at 1 and 0.08 g a.i L $water^{-1}$, respectively in the non-bearing year reduced shoot density only in the end of non-bearing year. Fall applications of glyphosate at 7.24 g a.e L $water^{-1}$in the end of non-bearing year at post seed stage provided good control of goldenrod shoots in the year after application. Glyphosate is effective though; the use of this herbicide would require careful application due to high risk of injury to exposed blueberry foliage. All other herbicides can be applied only causing minimal crop injury (Boyd and White 2010) and environmental damage (Carles et al. 2017) and they should be considered for goldenrod management in Nova Scotia wild blueberry fields.

Chapter 3 - Evaluation of mechanical and chemical control strategies for goldenrod (*Solidago* spp.) management in wild blueberry fields

3.0 Abstract

Goldenrods (*Solidago* spp.) are common creeping perennial weeds in wild blueberry fields in Nova Scotia that reproduce through seeds and extensive underground rhizomes. Currently, the availability of integrated management options for controlling goldenrods in wild blueberry fields is limited. Two-year field studies were therefore conducted in two commercial wild blueberry fields at Debert and Portapique, NS in 2016 and 2017 to evaluate mechanical and chemical control strategies for goldenrods. The physical or mechanical research trial consisted of:1) repeated effect of cutting on goldenrod shoots and shoot regrowth, and mechanical and chemical trials consisted of: 1) the optimum cutting and herbicide application timings on different growth stages of goldenrod and 2) to identify the combined effect of herbicide and cutting on goldenrod shoots and shoot regrowth. Results indicated that repeated cutting at the floral bud stage of goldenrod significantly reduced the shoot density in the non-bearing year, but it was ineffective in providing residual control of shoots in the bearing year. Glyphosate application at all growth stages caused a significant reduction in goldenrod shoot density relative to the cutting treatments. Glyphosate application followed by cutting at floral bud stage also significantly decreased the shoot density in both years. Based on these findings, cutting had limited effects on goldenrod shoot density, and symplastic glyphosate herbicide is recommended for goldenrod management in wild blueberry.

3.1 Introduction

Wild, or lowbush, blueberry (*Vaccinium angustifolium* Ait.) is a perennial, deciduous berry native to the Atlantic provinces of Canada and Maine in the United States of America (Vander Kloet 1988; AAFC 2016). It is the most important cash crop in Nova Scotia (Strik and Yarborough 2005; Anonymous 2016), contributing 32.5 million dollars to farm gate value in Nova Scotia for 2015 (Statistics Canada 2016). Wild blueberry grows best in wooded or open land with well-drained and acidic soils with pH between 4 and 5.5 (Kinsman 1993). Commercial fields are developed where native blueberry stands already exist on cleared woodland or abandoned agricultural land (AAFC 2005, 2016). These stands are composed of multiple clones that spread by underground rhizomes (Glass and Percival 2000). Wild blueberry fields are not planted commercially, but they are managed to encourage clonal spread, usually under a two-year production cycle. The fields are pruned by burning or mowing to stimulate vegetative growth in the first year (non-bearing year) and flowering, fruit development, and berries are harvested in the second year (bearing year) (AAFC 2016).

Growers have limited weed management options due to the perennial and wild nature of the blueberry crop. Weeds are therefore a major yield-limiting factor affecting berry production (Jensen 1985; McCully et al. 1991). The weed flora of wild blueberry fields is diverse, but several species of perennial weeds have become increasingly common in fields since the introduction of hexazinone in the early 1980s (Jensen and Yarborough 2004). Goldenrods were one of the most common weeds in wild blueberry fields in Atlantic Canada in 1990's (McCully et al. 1991). Goldenrods are creeping perennials in the Asteraceae family that reproduce mostly in fields by rhizomes or alternatively by seed (Werner et al. 1980; Pavek 2012). Established plants spread rapidly once established (Pavek 2012) and they are challenging to control due to vegetative reproduction (Guo et al. 2009). Goldenrod shoots also hinder harvest operations (McCully et al. 2005; Boyd and White 2010) and reduce wild blueberry yields.

Currently goldenrods are managed with postemergence mesotrione applications in the non-bearing year or wiping with glyphosate once goldenrod is significantly taller than the wild blueberry plants (Boyd and White 2010). There is, however, interest from the wild blueberry industry in evaluating non-chemical control strategies for weeds and other pests (Anonymous 2016), though research on effectiveness of these strategies on goldenrods is lacking. Cutting above blueberry plants is recommended to reduce seed production in tall weeds like goldenrods (Yarborough 2017), but the potential effects of this approach on weed suppression in wild blueberry have not been determined in research trials. Western ironweed (*Vernonia baldwinii*) shoot density was significantly reduced when cutting this weed at the floral bud stage due to low carbohydrate reserves in rhizomes (Linscott and McCarthy 1962). Multiple cuttings of rigid goldenrod (*Solidago rigida* L.) at the flowering stage were more effective than a single cutting in reducing shoot density of this weed (McCarthy and Linscott 1962). Repeated cuttings of spotted knapweed at the flowering stage or before seed production significantly reduced plant density (Rinella et al. 2001). Canada thistle has low carbohydrate reserves in the roots during the floral bud stage, and repeated cuttings reduced shoot density and height more effectively than a single cutting at this stage (Beck and Sebastian 2000).

In situations where weed infestations are denser or patchy, integrated weed management can be more effective than mechanical control (Miller 2016). Mechanical plus chemical control strategies involve combining weed removal through hand pulling, burning, tillage, mowing, or clipping, with herbicide application. Cutting followed by symplastic herbicide glyphosate application to regrowing shoots improved control of perennial pepperweed (*Lepidium latifolium*

L.), while either cutting or glyphosate herbicide alone were ineffective (Renz and DiTomaso 2006). Cutting followed by clopyralid tank mixed with 2, 4-D provided 98% control of spotted knapweed (*Centaurea stoebe* L.) (Brown et al. 1999). In another study, Miller and Lucero (2014) found that combinations of cutting and herbicide applications at early flowering stage effectively controlled plant density of meadow knapweed (*Centaurea debeauxii* Gren. & Godr.). Therefore, these integrated management practices can be more effective to control creeping perennial weeds.

Research on integrated management strategies of goldenrods in wild blueberry fields is limited and there is a need to develop integrated management plans for goldenrod. The objectives of this study were to 1) determine the effect of repeated cutting on goldenrod shoot regrowth; (2) determine the effect of cutting and symplastic herbicide application timings on goldenrod shoot regeneration, and (3) to determine the main and interactive effects of cutting and symplastic herbicide applications on goldenrod shoot regeneration.

3.2 Materials and Methods

3.2.1 Effect of repeated cutting on goldenrod shoot regrowth

A trial to evaluate the effect of repeated cutting on goldenrod shoot regrowth was conducted at two commercial wild blueberry fields located in Debert (45°26'12.9"N; 63°27'23.3"W) and Portapique (45°24'16.98"N; 63°42'11.5"W), Nova Scotia. Trials were established in May 2016, with the dominant goldenrod species at each site being narrow leaved goldenrod (*Euthamia graminifolia*). The experiment was arranged in a Completely Randomized Design (CRD) with 8 replications in Debert and 10 replications in Portapique. Plot size was 1 by 1 m. Treatments consisted of 1) nontreated control, 2) cutting of aboveground stems at the floral bud stage of goldenrod, and 3) cutting of aboveground stems at the floral bud stage of goldenrod followed by cutting of regenerated shoots at the end of the season. Mean goldenrod heights on cutting dates across sites for all treatments are given in Table 3.1. Cutting was conducted with manual clippers, and all aboveground shoot material was removed at each cutting.

Table 3.1. Cutting dates and mean goldenrod shoot height at the time of cutting at Debert and Portapique, Nova Scotia, in 2016.

Site	Treatment	Cutting dates	Mean shoot height at cutting -------cm-------	
			Cut once	Cut twice
Debert	Non-treated Control	N/A[a]	N/A	N/A
	Cut once at floral bud	23-Jun-16	44 ± 2	N/A
	Cut twice at floral bud	23-Jun-16 and 30-Aug-16	42 ± 2	37 ± 1.9
Portapique	Non-treated Control	N/A	N/A	N/A
	Cut once at floral bud	13-Jun-16	50 ± 1.5	N/A
	Cut twice at floral bud	13-Jun-16 and 20-Aug-16	55 ± 2	30 ± 0.9

[a]Abbreviation: N/A, not applicable.

3.2.2 Mechanical and chemical control trials

3.2.2.1 Effect of mechanical and chemical control application timing on goldenrod

An experiment was conducted in 2016 to evaluate mechanical and chemical control timings for goldenrod management. The experiment was conducted in two commercial wild blueberry fields located in Debert (45°26'12.9"N; 63°27'23.3"W) and Portapique (45°24'16.98"N; 63°42'11.5"W), Nova Scotia. The experiment was established in May 2016. The experiment was arranged as a 2 × 4 factorial arrangement of management technique (cutting or glyphosate) and management technique timing (30 cm, floral bud stage, flowering stage, and post seed stage) arranged in a Completely Randomized Design (CRD) with 8 replications in Debert and 7 replications in Portapique. Plot size was 1 by 1 m, with a half meter buffer between each plot. Weather conditions and mean goldenrod heights on application dates at each site for all treatments are given in Table 3.2 and 3.3. Glyphosate was applied at 7.24 g a.e L water^{-1} with a hand-held, CO_2 pressurized research plot sprayer equipped with a single 8002VS nozzle operated at a spray pressure of 275 KPa. The cutting treatments consisted of cutting emerged goldenrod shoots above the height of emerged blueberry stems with clippers.

3.2.2.2 Main and interactive effects of mechanical and chemical control

The experiment was designed to determine the main and interactive effect of cutting and symplastic herbicide application on goldenrod shoot regeneration. The experiment was arranged as a 2 × 3 factorial arrangement of initial control measures (cutting or glyphosate) and subsequent control measures at the floral bud stage of goldenrod (nothing, cutting, glyphosate) arranged in a Completely Randomized Design (CRD) with 8 replications in Debert and 7 replications in Portapique. Plot size was 1 by 1 m. Mean goldenrod heights on application dates across sites for initial and subsequent treatments are given in Table 3.4. Glyphosate was applied at 7.24 g a.e L water^{-1} at floral bud stage of goldenrod with hand-held, CO_2 pressurized research plot sprayer equipped with single 8002VS nozzle operated at a spray pressure of 275 KPa. The cutting treatments consisted of cutting emerged goldenrod shoots as close to the soil surface as possible with clippers.

Table 3.2. Application dates, mean goldenrod shoot height, air temperature, relative humidity, and wind speed at the time of glyphosate herbicide applications at Debert, Nova Scotia, in 2016.

Treatment	Application dates	Mean shoot height	Temperature	Relative humidity	Wind speed
		----cm----	----°C----	----%----	----km h^{-1}----
Non-treated control	N/A[a]	N/A	N/A	N/A	N/A
MT-C[a]; MTT - 30cm	03-Jun-16	28 ± 2	N/A	N/A	N/A
MT-C; MTT-floral bud	13-Jun-16	40 ± 1.7	N/A	N/A	N/A
MT-C; MTT-flowering	11-Aug-16	46 ± 1.9	N/A	N/A	N/A
MT-C; MTT-post seed	04-Oct-16	51 ± 2	N/A	N/A	N/A
MT-G; MTT-30 cm	03-Jun-16	32 ± 1.4	12	50	2
MT-G[a]; MTT-floral bud	13-Jun-16	29 ± 2	16	56	2
MT-G; MTT-flowering	11-Aug-16	35 ± 2	23	80	4
MT-G; MTT-post seed	04-Oct-16	33 ± 2	13	48	3

[a]Abbreviations: N/A, not applicable; MT-C, Management technique cutting; MTT, Management technique timing; MT-G, Management technique glyphosate.

Table 3.3. Application dates, mean goldenrod shoot height, air temperature, relative humidity, and wind speed at the time of glyphosate herbicide applications at Portapique, Nova Scotia, in 2016.

		Average shoot height	Temperature	Relative humidity	Wind speed
Treatment	Application dates	----cm----	----°C----	----%----	---- km h^{-1}---
Non-treated control	N/A[a]	N/A	N/A	N/A	N/A
MT-C [a]; MTT-30 cm	03-Jun-16	29 ± 2	N/A	N/A	N/A
MT-C; MTT-floral bud	13-Jun-16	52 ± 1.8	N/A	N/A	N/A
MT-C; MTT-flowering	11-Aug-16	69 ± 2.5	N/A	N/A	N/A
MT-C; MTT-post seed	04-Oct-16	67 ± 2.4	N/A	N/A	N/A
MT-G; MTT-30 cm	03-Jun-16	28 ± 1.5	19	60	3
MT-G [a]; MTT-floral bud	13-Jun-16	35 ± 2.4	13	57	1
MT-G; MTT-flowering	11-Aug-16	42 ± 2.5	22	83	2
MT-G; MTT-post seed	04-Oct-16	42 ± 2.5	13	57	3

[a]Abbreviations: MT-C, Management technique cutting; MTT, Management technique timing; MT-G, Management technique glyphosate.

Table 3.4. Application dates and mean goldenrod shoot height at initial control measures and subsequent control measures at floral bud initiation stage at Debert and Portapique, Nova Scotia, in 2016.

Site	Treatments	Application dates	Mean shoot height ------cm------
Debert	Non-treated Control	N/A[a]	N/A
	Initial Control Measures[b]	23-Jun-16	42 ± 2
	Subsequent Control Measures[b]	20-Aug-16	50 ± 2.6
Portapique	Non-treated Control	N/A	N/A
	Initial Control Measures	23-Jun-16	59 ± 2
	Subsequent Control Measures	20-Aug-16	49 ± 2.3

[a]Abbreviation: N/A, not applicable.
[b]Initial control measures (cutting, glyphosate) and subsequent control measures (nothing, cutting, glyphosate).

3.3 Data collection

Data collection included goldenrod shoot density and height in each treatment. Goldenrod shoot density was determined prior to treatment applications (Tables 3.1, 3.2, 3.3, and 3.4), at the end of the non-bearing year (October 20, 2016), and in the following bearing year (June 21, 2017) in all treatments. Goldenrod shoot density was determined on a whole-plot basis. Goldenrod height was determined using a meter stick on 30 randomly selected shoots in each plot prior to all treatment applications.

3.4 Statistical analysis

Goldenrod shoot density and height were analyzed using ANOVA in PROC MIXED in SAS for all experiments (version 9.4, Raleigh, NC). For the repeated cutting experiment, treatments were fixed effects and shoot density was the response variable. All sites were analyzed separately in this experiment. For factorial experiments, initially a test of main and interactive effects of treatment and experimental site was conducted to determine if the data could be combined across sites. Otherwise, data were analyzed separately by site. All effects, as well as subsequent interactions, in the factorial experiments were considered as fixed effects in the analysis. Assumptions of normality and constant variance were tested before analysis using PROC UNIVARIATE where residual*predicted values were plotted. Data were transformed where required to ensure validity of the analysis of variance and shown in the data table with transformations. Means were determined using the LS MEANS statement, and mean separation, where necessary, was conducted using Tukey's multiple means comparison test at $p < 0.05$. The subroutine pdmix800.sas (Saxton 1998) was used to provide letter groupings.

3.5 Results and Discussion

3.5.1 Effect of repeated cutting on goldenrod shoot regrowth

Initial goldenrod shoot density did not vary across treatments at each site ($p \geq 0.6631$) with shoot density averaging 48 ± 4 and 54 ± 9 shoots m^{-2} at Debert and Portapique, respectively. There was a significant effect of cutting treatment on goldenrod shoot density at the end of the non-bearing year at Debert ($p < 0.0001$) and Portapique ($p < 0.0007$), but no significant effect on bearing year density at Debert ($p = 0.0817$) and Portapique ($p = 0.6908$). Single cutting at the floral bud stage reduced goldenrod shoot density relative to the nontreated control at each site in the non-bearing year (Table 3.5). Goldenrod recovered in this treatment in the bearing year and the density was not reduced relative to the nontreated control (Table 3.5). A single cutting therefore suppress goldenrod in the non-bearing year, but it does not provide control in the bearing year.

Table 3.5. Effect of repeated cutting on goldenrod shoot density in commercial wild blueberry fields in Debert and Portapique, Nova Scotia, Canada.

Site	Treatments	Density before cutting	Non-bearing year shoot density[b]	Bearing year shoot density[b]
		---shoots m^{-2}---	---shoots m^{-2}---	---shoots m^{-2}---
Debert	Non-treated Control	48 ± 4 a[a]	41± 2 a	38 ± 10 a
	Cut once at floral bud	47 ± 4 a	22 ± 2 b	54 ± 10 a
	Cut twice at floral bud	49 ± 4 a	0 ± 2 c	74 ± 10 a
Portapique	Non-treated Control	54 ± 8.8 a	5 ± 0.4 a (28)	6 ± 0.6 a (34)
	Cut once at floral bud	46 ± 8.8 a	4 ± 0.4 b (15)	7 ± 0.6 a (42)
	Cut twice at floral bud	61 ± 8.8 a	3 ± 0.4 bc (9)	6 ± 0.6 a (34)

[a]Means within a column followed by the same letter are not significantly different at $P < 0.05$ based on Tukey's test. Numbers ± one represents standard error of means.
[b]Non-bearing and bearing year shoot density at Portapique were square-root transformed for the analysis of variance. Transformed data are presented for means comparisons and back transformed means are provided in parentheses.

Goldenrod shoot density was significantly reduced with two cuttings compared to a single cutting. Repeated cutting significantly reduced goldenrod shoot density at the end of non-bearing year relative to the nontreated control and the single cutting at Debert (Table 3.5), but not in Portapique, indicating that cutting twice provided better goldenrod control at one site in the non-bearing year than a single cutting. Repeated cutting reduced the perennial weed tropical soda apple (*Solanum viarum*) as compared to a single cutting (Mislevy et al. 1999), indicating potential for repeated cuttings to deplete food reserves in underground vegetative reproductive structures such as rhizomes (Yarborough 2017). Repeated cutting reduced the rhizome length of two perennial weeds, bermudagrass (*Cynodon dactylon* (L.) Pers.) and johnsongrass (*Sorghum halepense* (L.) Pers.) than a single cutting (Horowitz 1972). Regrowth of annual weeds such as large crabgrass

(*Digitaria sanguinalis* L.), barnyardgrass (*Echinochloa crus-galli* L.), common lambsquarters (*Chenopodium album* L.) and giant ragweed (*Ambrosia trifida* L.) were also reduced with repeated cutting as compared to single cutting and nontreated control (Butler et al. 2013). Control of Cogon grass (*Imperata cylindrica*) was also improved following multiple cuttings (Willard et al. 1996). Goldenrod shoot density was, however, high in the repeated cutting treatment in the bearing year as compared to the non-bearing year, again indicating single-season suppression of goldenrods with cutting treatments. Growers looking to adopt this strategy would therefore have to be prepared to conduct repeated cuttings in both the non-bearing and bearing years of the production cycle to maintain adequate control.

In general, repeated cutting had no significant effect on goldenrod regrowth in the bearing year at each site (Table 3.5). This is consistent with the result of Peters and Lowance (1978), who reported repeated mowing or cutting at the floral bud stage caused greater reduction of gray goldenrod shoots in one season relative to a single cutting, but not in the next season. Beaton (2014) also noted repeated mowing provides control of wild chervil (*Anthriscus sylvestris* (L.) Hoffm.) in the year of treatment application, but does not control wild chervil regrowth in the following year. Repeated mowing consistently reduced common reed by the end of the growing season, but had no effect on regrowth of this weed in the following year (Derr 2007). Averill et al. (2008) had similar findings as well, where repeated mowing controlled pale swallow-wort (*Vincetoxicum rossicum*) in one year but not in the next year. Our results therefore suggest that repeated cutting may suppress goldenrod in the non-bearing year, but it seems likely that effects of repeated cutting on goldenrod are limited in the bearing year in wild blueberry fields.

3.5.2 Effect of cutting and herbicide application timings at various shoot growth stages on goldenrod shoot regeneration

The significant model effects are given in Table 3.6. There was no significant effect of experimental site × management technique × management technique timing interactions on goldenrod shoot density at the time of treatment application ($p = 0.5615$) and in the bearing year ($p = 0.3791$). However, there was a significant effect of higher order interactions on non-bearing shoot density ($p < 0.0001$) (Table 3.6). Goldenrod shoot density at Portapique was almost double that of the shoot density at Debert at the time of treatment application, as well as in the bearing year (Table 3.6). Sites were therefore analyzed separately due to the differences in magnitude of the shoot density prior to treatment applications (Table 3.6).

There were no significant effects of management technique ($p \geq 0.1237$) and management technique timing ($p \geq 0.0636$) on shoot density at the end of the non-bearing year at Debert and Portapique, respectively. There was, however, a significant effect of the management technique × management technique timing interaction on goldenrod shoot density at the end of the non-bearing year ($p < 0.0001$) at each site (Table 3.6). There was a significant effect of management technique ($p < 0.0001$), but no significant effect of management technique timing ($p \geq 0.3496$) and management technique × management technique timing interactions ($p \geq 0.0781$) on goldenrod shoot density in the bearing year at Debert and Portapique, respectively (Table 3.6).

Table 3.6. Test of main and interactive effects of experimental site, management technique, and management technique timing on goldenrod shoot density in commercial wild blueberry fields in Debert and Portapique, Nova Scotia, Canada.

Effect	Initial density at application	Non-bearing shoot density	Bearing year shoot density
	---shoots m^{-2}---	---shoots m^{-2}---	---shoots m^{-2}---
Experimental site	**	**	**
MT	NS	NS	**
MTT	*	NS	NS
MT by MTT	NS	**	NS
Experimental site by MT	NS	NS	*
Experimental site by MTT	*	NS	NS
Experimental site by MT by MTT	NS	**	NS

Abbreviations: NS, non-significant; MT, management technique; MTT, management technique timing.
[a]Level of significance were obtained using PROC MIXED in SAS®: * $P < 0.05$, and ** $P < 0.0001$.

Goldenrod shoot density was the same in all the treatments prior to treatment applications at each site (Table 3.7). Cutting at 30 cm shoot height and floral bud stage did not reduce goldenrod shoot density relative to the nontreated control in either the non-bearing or bearing years at each site (Table 3.7). Cutting at flowering and post seed stage significantly reduced shoot density at each site at the end of the non-bearing year relative to the nontreated control, cutting at 30 cm shoot height and floral bud stage (Table 3.7). Goldenrod regrowth was observed in these treatments in the bearing year, however, and shoot density was not different than the nontreated control (Table 3.7). Cutting at these growth stages therefore suppresses goldenrod at the end of the non-bearing year, but they do not control goldenrod in the bearing year. Mowing or cutting can control perennial weeds like gray goldenrod (Peters and Lowance 1978) and Canada thistle (Bicksler and Masiunas 2009) but it requires repeated mowing (Butler et al. 2013) to deplete carbohydrate reserves in the rhizomes and maximize effectiveness. Repeated cutting improved control of perennial weeds such as rigid goldenrod (McCarthy and Linscott 1962), gray goldenrod (Peters and Lowance 1978), Canada thistle (Beck and Sebastian 2000), tropical soda apple (Mislevy et al. 1999), bermudagrass and johnsongrass (Horowitz 1972) as compared to a single cutting, and this further supports the increased effectiveness of repeated cuttings or mowing on perennial weeds. We did, however, find that even repeated cutting of goldenrod did not reduce density in the bearing year (Table 3.5), indicating that cutting, regardless of timing and frequency, likely has limited efficacy on goldenrods when used as a sole means of control.

Glyphosate application at 30 cm shoot height, floral bud, and flowering stages reduced goldenrod shoot density relative to the nontreated control at the end of the non-bearing year at each site (Table 3.7). Applications at the flowering stage, however, gave the greatest reduction in goldenrod regrowth in the bearing year versus applications at 30cm and at the bud stage at Debert

(Table 3.7). Glyphosate applications at the post-seed stage did not reduce non-bearing year density, as expected, but also did not consistently reduce bearing year density across sites (Table 3.7). Differences in efficacy of this treatment across sites are confusing, as post-seed application timing is generally very effective on perennial weeds such as Canada thistle (McAllister and Haderlie 1985a; Hunter 1996). Better control at Debert with this treatment was likely due to more glyphosate translocation on the shorter and less dense plants as compared to taller and denser plants at Portapique. It may also due to the use of higher rate of active ingredients and better coverage to the goldenrod shoots. Ahmadi et al. (1980) reported that translocation of glyphosate and effectiveness was reduced in taller and denser plants of barnyard grass (*Echinochloa crus-galli* L.) relative to the smaller plants. Based on this, further studies should be conducted to determine goldenrod susceptibility to post-seed stage herbicide applications in wild blueberry.

Overall, reductions in bearing year shoot density in glyphosate treatments suggests damage to the rhizomes (Table 3.7). This observation is supported by other studies that reported the carbohydrates translocate to the rhizomes of perennial weeds such as Canada goldenrod during their flowering stage (Bradbury and Hofstra 1976), and glyphosate should therefore effectively control these weeds at this stage. Findings of Yonce and Skroch (1989) that glyphosate consistently controlled sericea lespedeza (*Lespedeza cuneata*) when applied at the flowering stage is in agreement with our findings. Our results strongly suggest that goldenrod can be efficiently controlled by glyphosate treatment at flowering stage in wild blueberry fields.

Table 3.7. Effect of management technique and management technique timings on goldenrod shoot density at commercial wild blueberry fields at Debert and Portapique, Nova Scotia, Canada.

Site	Management technique	Management technique timing	Density prior to application	Non-bearing year shoot density	Bearing year shoot density
			---shoots m^{-2}---	---shoots m^{-2}---	---shoots m^{-2}---
Debert	Non-treated Control	Non-treated Control	62 ± 9 a[a]	40 ± 3 a	62 ± 8 a
	Cutting	30 cm	41 ± 9 a	22 ± 3 a	52 ± 8 ab
	Cutting	Floral Bud	45 ± 9 a	24 ± 3 a	78 ± 8 a
	Cutting	Flowering	64 ± 9 a	9 ± 3 b	68 ± 8 a
	Cutting	Post Seed	44 ± 9 a	2 ± 3 b	67± 8 a
	Glyphosate	30 cm	49 ± 9 a	3 ± 3 b	24 ± 8 bc
	Glyphosate	Floral Bud	36 ± 9 a	4 ± 3 b	18 ± 8 c
	Glyphosate	Flowering	70 ± 9 a	7 ± 3 b	1 ± 8 d
	Glyphosate	Post Seed	61 ± 9 a	30 ± 3 a	2 ± 8 d
Portapique	Non-treated Control	Non-treated Control	123 ± 16 a	91± 5 a	132 ± 15 a
	Cutting	30 cm	124 ± 16 a	50 ± 5 a	102 ± 15 a
	Cutting	Floral Bud	132 ± 16 a	40 ± 5 a	112 ± 15 a
	Cutting	Flowering	146 ± 16 a	5 ± 5 b	98 ± 15 ab
	Cutting	Post Seed	95 ± 16 a	3 ± 5 b	99 ± 15 ab
	Glyphosate	30 cm	142 ± 16 a	7 ± 5 b	30 ± 15 cd
	Glyphosate	Floral Bud	118 ± 16 a	8 ± 5 b	20 ± 15 cd
	Glyphosate	Flowering	113 ± 16 a	14 ± 5 b	5 ± 15 d
	Glyphosate	Post Seed	88 ± 16 a	56 ± 5 a	45 ± 15 bc

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

3.5.3 Main and interactive effects of cutting and herbicide application timings on goldenrod shoot regeneration.

Site-combined data did not conform to the assumptions of normality and constant variance when testing for the effect of experimental site. Therefore, sites were analyzed separately to validate normality and constant variance assumptions. Goldenrod shoot density did not vary across treatments prior to application of the initial control measures at either site ($p \geq 0.5284$). There was a significant effect of initial control measure ($p < 0.0001$) on goldenrod shoot density prior to application of subsequent control measures. Goldenrod shoot density prior to application of subsequent control measure was lower in the glyphosate treatments relative to the cutting treatments (Table 3.8). There was a significant effect of initial control measures ($p < 0.0001$), subsequent control measures ($p \leq 0.0005$) and initial control measures by subsequent control measures interaction ($p \leq 0.0158$) on goldenrod shoot density at the end of non-bearing year. There were significant effects of initial control measures ($p \leq 0.0068$), but no significant effect of subsequent control measures ($p \geq 0.3365$) and initial control measures by subsequent control measures interaction ($p \geq 0.3351$) on the goldenrod shoot density in the bearing year.

A single cutting followed by no subsequent control measure did not reduce shoot density in the non-bearing or bearing years at either site (Table 3.8). Previous experiments also showed that a single cutting had no effect on goldenrod shoot density in the non-bearing and bearing year (Table 3.5 and 3.7), further confirming lack of efficacy of this control measure on goldenrods. Cutting followed by cutting significantly reduced shoot density in the non-bearing year when compared to the non-treated control and single cutting at each site, though goldenrod again recovered from cutting in the bearing year and shoot density was not reduced (Table 3.8). This was similar to results from the repeated cutting experiment (Table 3.5) and again indicate the limited control of goldenrod shoots with one cutting. However, cutting followed by cutting had similar goldenrod suppression in the end of non-bearing year as the single glyphosate application (Table 3.8).

Cutting followed by glyphosate did not reduce shoot density in either year at each site (Table 3.8). The result was unexpected and reasons for this are unclear. However, in another study cutting followed by herbicide application did not consistently improve Canada thistle control (Beck and Sebastian 2000). A single cutting followed by glyphosate did not provide control of spotted knapweed (MacDonald et al. 2013), which further support the result of our study.

Glyphosate followed by nothing, cutting, or glyphosate significantly decreased goldenrod shoot density in the non-bearing and bearing year at each site (Table 3.8). Shoot density reductions in the non-bearing and bearing years were, however, equivalent in each treatment containing glyphosate as the initial control measure (Table 3.8). These results indicate that goldenrod is most effectively controlled by herbicides or cutting twice, and that strategies aimed at integrating mechanical and chemical control may increase treatment costs and labor without improving weed control. These results are in contrast to results reported for pepperweed (*Lepidium latifolium*) and bracken fern (*Pteridium aquilinum*), where cutting in the year after glyphosate applications improved control (Petrov and Marrs 2000; Renz and DiTomasso 2006; Roos et al. 2011).

Table 3.8. Effect of initial control measures and subsequent control measures on goldenrod shoot density at commercial wild blueberry fields at Debert and Portapique, Nova Scotia, Canada.

Site	Initial control measure[a]	Subsequent control measure	Density prior to initial control measure	Density prior to subsequent control measure	Non-bearing year shoot density	Bearing year shoot density
			---shoots m^{-2}---	---shoots m^{-2}---	--shoots m^{-2}--	--shoots m^{-2}--
Debert	Non- treated Control	Non- treated Control	8 ± 0.8 a [b] (61)	7 ± 0.6 a (54)	6 ± 0.7 a (46)	8 ± 1 a (68)
	Cutting	Nothing	6 ± 0.8 a (38)	5 ± 0.6 a (26)	5 ± 0.7 a (31)	9 ± 1 a (77)
	Cutting	Cutting	5 ± 0.8 a (27)	5 ± 0.6 a (25)	2 ± 0.7 b (5)	7 ± 1 a (48)
	Cutting	Herbicide	6 ± 0.8 a (40)	6 ± 0.6 a (39)	6 ± 0.7 a (40)	6 ± 1 a (40)
	Glyphosate	Nothing	6 ± 0.8 a (39)	3 ± 0.6 b (8)	3 ± 0.7 b (7)	4 ± 1 b (20)
	Glyphosate	Cutting	5 ± 0.8 a (24)	1 ± 0.6 b (1)	0 ± 0.7 b (0)	3 ± 1 b (8)
	Glyphosate	Herbicide	7 ± 0.8 a (43)	1 ± 0.6 b (2)	1 ± 0.7 b (2)	4 ± 1 b (17)
Portapique	Non- treated Control	Non- treated Control	10 ± 0.9 a (106)	9 ± 0.3 a (76)	8 ± 0.5 a (68)	10 ± 0.9 a (108)
	Cutting	Nothing	9 ± 0.9 a (88)	6 ± 0.3 a (41)	6 ± 0.5 a (35)	9 ± 0.9 a (78)
	Cutting	Cutting	8 ± 0.9 a (66)	6 ± 0.3 a (35)	1 ± 0.5 b (2)	10 ± 0.9 a (91)
	Cutting	Herbicide	10 ± 0.9 a (93)	7 ± 0.3 a (47)	6 ± 0.5 a (32)	10 ± 0.9 a (92)
	Glyphosate	Nothing	9 ± 0.9 a (84)	1 ± 0.3 b (2)	1 ± 0.5 b (1)	5 ± 0.9 b (23)
	Glyphosate	Cutting	8 ± 0.9 a (66)	1 ± 0.3 b (2)	1 ± 0.5 b (2)	3 ± 0.9 b (9)
	Glyphosate	Herbicide	8 ± 0.9 a (68)	1 ± 0.3 b (2)	2 ± 0.5 b (3)	4 ± 0.9 b (1)

[a]Data were square-root transformed for the analysis of variance. Transformed data are presented for means comparisons and back transformed means are provided in parentheses.

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

3.6 Conclusion

In conclusion, cutting twice did not provide adequate goldenrod shoot control in the bearing year. Goldenrod shoots continued to regrow in the bearing year regardless of the number of cuttings at each site. However, further research is needed to determine the effect of repeated cutting for both years (non-bearing and bearing) at the floral bud stage for the long-term management of goldenrod. Glyphosate effectively controlled goldenrod at all growth stages, but particularly when applied at the flowering stage. In another experiment, glyphosate followed by cutting did not improve control of goldenrod shoots. However, glyphosate used alone is the best option to reduce goldenrods in wild blueberries.

Chapter 4 - Conclusions

4.0 Overview

Goldenrods (*Solidago* spp.) are creeping herbaceous perennial weeds that are a serious problem in wild blueberry fields in Nova Scotia. Management of these weeds is difficult due to limited control options. It is therefore important to develop an integrated management plan for goldenrods and introduce new herbicides to ensure sustainable weed management in wild blueberry fields for limiting spread of *Solidago* species. The main focus of this research was to 1) evaluate summer broadcast and summer and fall spot herbicide applications for goldenrod, 2) evaluate efficacy of mechanical control of goldenrods, 3) determine the optimum application timing of chemical and mechanical controls on goldenrods, and 4) evaluate integrated management strategies for goldenrods in wild blueberry.

4.1 Evaluation of summer broadcast and summer and fall spot herbicide applications for goldenrod

The specific objectives of this chapter were to 1) identify the optimal interval between sequential postemergence mesotrione applications, 2) evaluate postemergence bicyclopyrone applications on goldenrod, and 3) to evaluate multiple herbicides applied as postemergence spot treatments to goldenrod. All these research trials examined the potential of new and alternative herbicides and application methods to control goldenrod. In conclusion, objective 1 indicated that broadcast sequential application of mesotrione in the non-bearing year in summer had efficacy in reducing goldenrod shoots. Results showed that a single mesotrione application suppresses narrow leaf goldenrod at the end of non-bearing year, but did not provide control in the bearing year. Sequential mesotrione applications made 14, 21, or 28 days after initial application (DAIA) resulted in > 90% injury to goldenrod by 35 days after spraying (DAS) and consistently reduced goldenrod shoot density in both the non-bearing year and bearing year (Table 2.7). Goldenrod shoot density was less dense and plant height was lower at Debert relative to Portapique, however, mesotrione efficacy was consistent at both sites. Results from this study indicate that two applications of mesotrione provided better weed control than a single application, irrespective of shoot density and plant height. Two applications of mesotrione is not a common practice for blueberry growers in Canada, however, as this use is not permitted under the current mesotrione registration in Canada. Up to three sequential mesotrione applications are allowed under the United States registration (Yarborough and D'Appollonio 2009b), giving growers in Maine the ability to have better control. Our research results provide justification to support a similar registration in Canada. Should sequential applications be approved for use in Canada, producers should use sequential mesotrione applications that are spaced 14 to 28 days apart to manage large infestations of goldenrods in wild blueberry fields. Additional research conducted to evaluate sequential mesotrione applications at lower application rates could satisfy the current registration. Research should also be conducted to identify potential role of sequential mesotrione applications on other herbaceous perennial weeds in wild blueberry fields. Finally, reasons for the increased efficacy of sequential mesotrione applications on goldenrods should be explored further. However, our study strongly suggests that sequential applications of mesotrione provided better weed control than a single application in the bearing year might be due to inhibition and damage caused to rhizomes by these treatments. Sequential mesotrione applications to goldenrods may increase the amount of mesotrione translocated to roots and rhizomes, possibly contributing to the increased control observed in the bearing year.

Objective 2 concludes that broadcast applied mesotrione and bicyclopyrone had similar suppression of goldenrod in the non-bearing and bearing years at Debert, but only in the non-bearing year at Portapique (Table 2.8). The tank mixture of these herbicides provided better control than bicyclopyrone alone in both years at Debert, but not in the bearing year at Portapique. However, results were inconsistent across sites, which was likely due to lower goldenrod density and shorter plants at Debert. Based on this, a tank mixture of mesotrione and bicyclopyrone could improve goldenrod suppression in wild blueberry, warranting additional research with bicyclopyrone. In addition, further research could be conducted to evaluate the tank mixture of mesotrione and bicyclopyrone with other carotenoid-inhibiting herbicides to control goldenrod and other weeds in wild blueberry fields. We also found a distinct lack of evaluations of carotenoid-inhibiting herbicide tank mixtures in the literature, and our work indicates that tank mixtures of these herbicides can improve weed control. Mesotrione efficacy is also improved when applied following preemergence hexazinone applications (Boyd and White 2010), and additional research could evaluate a similar use of bicyclopyrone or the bicyclopyrone and mesotrione tank mixture following preemergence hexazinone applications.

All herbicides applied in the summer spot spray experiment suppressed goldenrod in the non-bearing year (Table 2.9 and 2.10). Bicyclopyrone and flazasulfuron in the non-bearing year effectively controlled goldenrod shoots in the bearing and non-bearing years at one of two sites. Summer spot applied dicamba + diflufenzopyr, triclopyr and tribenuron methyl injured goldenrod and tended to lower shoot density in both years at one of two sites (Table 2.9 and 2.10). Summer spot applied dicamba, clopyralid and foramsulfuron in the non-bearing year reduced shoot density only in the end of non-bearing year. However, glyphosate and mesotrione were the most effective herbicides evaluated as summer spot applications on goldenrod. These herbicides reduced shoot density in both years at each site (Table 2.9 and 2.10). Reductions in bearing year shoot density following spot applications indicated that spot applications of mesotrione are more effective than broadcast applications, as bearing year shoot density was not reduced by single broadcast mesotrione applications (Tables 2.7 and 2.8). Although glyphosate is effective, the use of this herbicide as a spot treatment requires careful application due to high risk of contact and damage to blueberry plants. Growers should therefore consider using mesotrione instead of glyphosate to control goldenrod, which results in less injury to wild blueberries. Reasons for increased mesotrione efficacy as a spot application might be due to better coverage and more active ingredients applied to the targeted goldenrod. However, further research should be conducted to determine the extent, and implications, of mesotrione rhizome translocation in goldenrod species in wild blueberry fields. Bicyclopyrone, glufosinate, flazasulfuron, and the group 4 herbicides evaluated provided acceptable goldenrod damage and reduced shoot density at the end of non-bearing year, but goldenrod treated with glufosinate recovered in the bearing year at one of the two sites (Table 2.9 and 2.10). Future research could focus on higher application rates of these herbicides, or perhaps tank mixtures of these products with other herbicides, to determine potential roles of these products for spot treatment of goldenrods in wild blueberry.

In the fall spot experiment, glyphosate was the most effective herbicide. Glyphosate is already registered as a non-selective post-emergent herbicide in wild blueberry fields, and is generally used to control broad leaf weeds. Therefore, extreme care is needed when applied. Late application at leaf senescence may decrease herbicide uptake and efficacy, while early application before leaves turn yellow may cause blueberry damage if following contact with glyphosate. All other herbicides evaluated in this experiment were generally ineffective. Further research should be conducted with higher rates of each product to evaluate herbicide efficacy to control goldenrod in the fall before leaf senescence and at post seed stage.

4.2 Evaluation of mechanical and chemical control strategies for goldenrod management

The objectives of this chapter were to determine 1) the effect of two cuttings on goldenrod shoot regrowth, 2) the effect of combining cutting and symplastic herbicide application timing on goldenrod shoot regeneration, and 3) the main and interactive effects of cutting and symplastic herbicide applications on goldenrod shoot regeneration. The repeated cutting experiment indicated that cutting twice in the non-bearing year had efficacy on goldenrod shoots relative to a single cutting. Results showed that two cuttings suppress narrow leaf goldenrod at the end of non-bearing year, but had no effect on goldenrod in the bearing year as shoot density recovered in the repeated cutting treatment in the bearing year at each site (Table 3.5). Therefore, the results of this study suggest that repeated cutting may suppress goldenrod in the non-bearing year, but it seems likely that effects of repeated cutting on goldenrod are limited in the bearing year in wild blueberry fields. Growers looking to adopt this strategy would therefore have to be prepared to conduct repeated cuttings in both the non-bearing and bearing years of the production cycle to maintain adequate control. Therefore, additional research should be conducted to evaluate the effect of three or more cuttings in a single season and following years to control goldenrod shoots.

Objective 2 concludes that cutting at pre-bud and floral bud stages were not effective in controlling goldenrod in both bearing and non-bearing years, while cutting at flowering and post seed stage suppressed goldenrod shoots in the end of non-bearing year. However, these treatments did not persist to bearing year control. This indicates that cutting, irrespective of timing and frequency, likely has limited efficacy on goldenrod when used as a primary means of control. In contrast, glyphosate effectively controlled goldenrod at all growth stages, but particularly when applied at the flowering stage (Table 3.7). Based on these results, it is recommended that herbicides are still the most effective management strategy for goldenrod species in wild blueberry fields.

Growers should therefore control goldenrod with spot application of glyphosate instead of cuttings to reduce labor costs and save on time. However, further studies should be conducted in future to evaluate spot application of other symplastic herbicides at these growth stages particularly at flowering stage, which may improve control of goldenrod or other creeping perennial weeds in wild blueberry fields.

The results of main and interactive effects of glyphosate and cutting indicated that cutting followed by cutting and glyphosate did not provide control of goldenrod shoots in either the non-bearing or bearing year. Glyphosate alone or followed by cutting provided good control of goldenrod. Our results suggest that goldenrod is most effectively controlled by herbicides, and that strategies aimed at integrating mechanical and chemical control may increase treatment costs and labor without improving weed control.

In summary, this two-year study provides understanding about how goldenrod can be managed in wild blueberry fields in Nova Scotia using mechanical and chemical control strategies. Herbicides will remain the foundation of goldenrod management plans in wild blueberry production. Herbicides provided good control of goldenrod for up to one year after application in a short time period. In contrast, single cutting or two cuttings alone or in combination with glyphosate provided only control at the end of non-bearing year. Growers should therefore use herbicides rather than single or multiple cuttings for long-term management of perennial weeds in wild blueberry fields.

4.3 Management Recommendations

Goldenrods are most effectively managed with sequential broadcast mesotrione applications or spot applications of mesotrione or glyphosate. Sequential mesotrione applications should be made to emerged goldenrod stems that are approximately 30cm tall, with the subsequent application between 7 and 28 days after the initial application. For ease of implementation pending label approval, we would recommend sequential mesotrione applications be spaced at least 14 days apart as we observed slightly less reduction in stem density when using 7 day intervals between applications, and this would allow growers to potentially tank mix other herbicides (e.g. graminicides) with either the first or second application. Efforts to expand the Canadian mesotrione label to allow sequential applications should continue.

Spot applications of both glyphosate and mesotrione at the early bud stage reduced goldenrod shoot density in both the non-bearing and bearing years, indicating that mesotrione could be used as a spot treatment for goldenrods in an effort to reduce crop injury risk from these applications. Additional experiments with glyphosate indicated that symplastic herbicide efficacy generally increases as the season progresses, with applications at the flowering stage providing the most consistent reductions in non-bearing and bearing year stem density across sites. As such, growers looking to utilize glyphosate as a spot treatment for goldenrods should make applications at the flowering stage.

Cutting was generally ineffective on goldenrod, though short term suppression from this technique was obtained. Growers can therefore utilize cutting to remove goldenrod stems to reduce shading or harvest interference, but should not expect long term control from this approach. In addition, there is no benefit associated with combining cutting and herbicides, so growers should avoid use of cutting if they are planning to manage goldenrods with herbicides.

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