PHENOLOGICAL STUDY AND MANAGEMENT OF RED FESCUE *(Festuca rubra)* IN WILD BLUEBERRY

by

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DEDICATION PAGE

I dedicate this thesis to my family, teachers and friends who always suppprt and guide me on each and every steps of my life. I also dedicate this thesis to my friend Swati, whose unconiditional help and support guided me to complete my Master of Science.

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ABSTRACT

Red fescue is a perennial rhizomatous and sod forming turf grass species that is a newly emerging weed in wild blueberry fields of Nova Scotia. There is no published information on the impact, phenology and effective control management of red fescue in wild blueberry. A two year field study was conducted to study red fescue growth dynamics in wild blueberry fields, identify effective herbicides and maximize herbicide efficacy with proper application timing. Results indicate that if wild blueberry fields were maintained free of red fescue from May through October that the red fescue population reduced declined in the following year. Between 60 to 80% emergence of red fescue occurred at around 160 GDD before emergence of wild blueberry which occurred at 222-265 GDD and reached peak height between 850 to 920 GDD. Most of the spring applied herbicide increased berry yield comapared to control, but glyphosate also controlled red fescue (60-80%). Propyzamide was also effective in a fall application trial with 99% control with minimal risk of crop damage. We recommend fall applications of propyzamide followed by spring application of glyphosate, if substantial red fescue survives to the following spring.

LIST OF ABBREVIATIONS USED

%	Percent
°C	Degrees Celsius
a.i.	Active ingredient
cm	Centimeter
g	Gram
ha	Hectare
kg	Kilogram
l	Liter
m	Meter
m^2	Meter square area
ms^{-1}	Meter per second
MSL	Mean Sea Level
psi	Pound per square inch
χ^2	Chi square

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CHAPTER 1 INTRODUCTION

1.1 General Introduction

The wild blueberry (*Vaccinium angustifolium* Ait.) is a major crop in Nova Scotia. Canada produced 123,860 tonnes of blueberries in 2011, of which 12% was produced in Nova Scotia alone, which contributed over $22 million to annual farm-value in Nova Scotia (Statistics Canada 2012). It is the most important fruit crop in Atlantic Canada with respect to total acreage, export sales, and provincial wealth (Statistics Canada 2012). Commercial production occurs predominantely in Maine, Quebec and the four Atlantic Canadian provinces (Jensen and Yarborough 2004).

Weeds are a major yield limiting factor in commercial blueberry fields (McCully et al. 1991). Weed management is typically acknowledged as one of the most laborious aspects of crop production (McFadyen 1998), though there are many management options including mechanical, cultural, biological, and chemical, each with associated benefits and risks (DiTomaso 1997). Herbicides are applied annually to control weeds that compete with blueberries for moisture, light, and nutrients (McCully et al. 1991) and may also restrict blueberry expansion, reduce berry yields (Kinsman 1993) and interfere with harvests.

Red fescue (*Festuca rubra* L.) is a common, sod forming grass used in the turf industry. It is also used as a cover crop in fields of winter wheat to improve environmental performance (i.e. preserve biodiversity, increase organic matter, increase biotic interaction and natural pest regulation etc.) (Shili-Touzi et al. 2010). Localized infestations of red fescue within commercial blueberry fields have occurred since 2008 in the Collingwood area.

Growers report that red fescue inhibits blueberry growth, spread, and berry yields. Management of this weed species is especially problematic because crop rotation and cultivation are not options within this perennial crop and as a result herbicides are the primary means of weed control. However, no herbicides are registered for control of this species in blueberry fields and there are no effective management options at this time. Given that it is likely to spread throughout the province, it is prudent to establish effective management strategies before it becomes widespread.

There is no published research on the impact of red fescue on wild blueberry production. Therefore the overall objective of this research is to determine if and when competition between blueberry and red fescue occurs, to enhance our understanding of the phenology of red fescue within blueberry fields, and to identify herbicides with efficacy on this weed species.

1.2 Wild Blueberry

1.2.1 Biology of Wild Blueberry

The wild, lowbush blueberry (*Vaccinium angustifolium* Ait.) is a native, perennial berry species in Nova Scotia. It is an important successional species of cleared woodland and abandoned farmlands of northeastern North America. It is a low growing and rhizomatous shrub with underground rhizomes that can endure fires and other disturbances (Jensen and Yarborough 2004). Wild blueberry can grow to an approximate height of 10-30 cm (Vander Kloet 1978; Rowe 1983) in acidic (pH between 4.2 and 5.5) soils as well as marginal soils with low mineral content and poor water holding capacities (Percival and Garbary 2012). The leaves are broad to elliptical shaped, which are glossy blue-green in summer and turn purple to red in fall. Buds are brownish red on stem axils, and flowers are white, bell shaped and 5 mm long. The berries when mature are sweet in taste with varying acidity (Hall et al. 1979).

1.2.2 Blueberry Production and Management

Wild blueberries are a nutritious treat and a good source of ascorbic acid and dietary fiber. It is commercially cultivated in parts of Canada and the United States (Yarborough and Bhowmik 1989). In Canada the area of wild blueberry production increased by 57% between 1992 and 2003, of which Nova Scotia alone contributed 34% of the increase. Commercial fields are expected to exceed 40,000 acres across Nova Scotia by the end of 2013 (Strik and Yarborough 2005). Over the past 20 years, wild blueberry yields have increased 3.5 fold per year on average (Yarborough 2004). Productivity gains are mainly due to advances in weed control, although increased use of fertilizer, irrigation, pest management and pollination also contribute (Jensen and Yarborough 2004).

The wild blueberry is managed on a 2 year cycle. The first year of the cycle is called the vegetative or nonbearing year and during this year shoots emerge from underground rhizomes and grow (Penney and McRae 2000). Floral buds develop in the fall. The second year of the cycle is the reproductive or bearing year. In this year shoots flower, berries develop and the harvest occurs (White et al. 2012). Following harvest, fields are burned or pruned near the surface (Penney and McRae 2000). The biannual cycle maximizes productivity, increases vegetative growth and also provides pest protection by interrupting insect and disease cycles (Yarborough 2012).

Regular application of chemical fertilizers has shown long term positive effects on productivity. Moreover, application of fertilizers (especially N-P-K) in conjunction with herbicides significantly increased yields especially over the long term (Eaton et al. 2009; Kennedy et al. 2010). Selective herbicide usage has been shown to increase yields four-fold (Yarborough 2004). Velpar (hexazinone) and Kerb (propyzamide) are some of the most common herbicides applied by growers to control grasses and some broad leaf weeds in blueberry fields.

1.3 Weeds in Wild Blueberry Fields

Weeds compete with wild blueberry plants for resources necessary for adequate plant growth such as light, soil nutrients, and moisture (Sampson et al. 1990; Kennedy et al. 2011). They also serve as alternate hosts for insects and diseases, hinder harvest, contaminate blueberry packs, reduce berry quality and interfere with the proper application of pesticides (Hall et al. 1961; Yarborough et al. 1984; Jensen and Yarborough 2004). Common weeds of wild blueberry fields include woodland species, annual, perennial grasses and composites of species from abandoned farmland (Jensen and Yarborough 2004). Perennials with creeping roots or rhizomes such as sheep sorrel and bunchberry are the most difficult to control as such species thrive under the blueberry production systems and herbicides rarely provide 100% control. As a result, repeated treatments are needed to successfully manage them (Ross et al. 1999; Wu 2010). Weeds can also escape control due to late season or intermittent germination timing or poor herbicide application timing and techniques (McCully 1988). Perennial weeds are most effectively managed at the seedling and early vegetative stage before they start to form reproductive structures (Ross et al. 1999; Wu 2010).

1.3.1 Weed Competition

Weeds interact with crops either directly or indirectly by changing the environment in various ways. They can either interfere with crop growth through allelopathy or they can serve as alternate hosts for nematodes, pests and diseases, and harbor beneficial insects. Weeds primarily affect on crop growth and yield through competition for the resources needed for growth and development (Patterson 1995). Weed competition on crops has been the subject of a lot of research (Vilà et al. 2004). Competition occurs when available resources are not enough to fulfill the combined demands of neighboring organisms in a community (Patterson 1995). Weeds compete with crops for both above and below ground resources. High levels of fertilizer application may be deleterious to crop growth as weed growth may be enhanced more so than the crop (Kennedy et al. 2010). Another study on buckwheat control in wheat showed that the productivity of wheat did not increase by fertilizer application, in fact dry matter of wheat reduced by 30-37% due to severe competition by buckwheat (Patterson 1995). It is known that wild blueberry responds slowly to fertilizer application whereas weeds respond with greater vigor (Kennedy et al. 2010).

Some of the biological factors influencing competition include the weed species, weed density, crop density, and duration of growth of both the weed and the crop during competition. These factors are usually modified by the physical environment and depend on environmental stress (Patterson 1995; Gherekhloo et al. 2010). Light is one of the primary environmental resources for which both weeds and desired crops compete. Unlike nutrients, water, or carbon dioxide, no reservoir of light exists in the soil and atmosphere. Light competition reduces photosynthates to support root growth and hence influences the ability of both weeds and crops to compete for nutrients and water (Patterson 1995).

Weeds reduce the amount of available soil water required to support crop growth, which ultimately leads to reduced crop yield. Water competition is influenced by varying transpiration rates, water use efficiencies, responses to declining water availability and water stress between crops and weeds. The competition for water or other resources depends upon relative abilities of crop and weed species to obtain resources and to tolerate deficits of that resource (Patterson 1995).

The effect of weeds on crop yields depends on the duration of competition and the growth stages of both weed and crop during competition. Evidence indicates that the time of removal is equally as important as removal itself (Vilà et al. 2004). The 'critical period', defined as the minimum period of time during which the crops must be free of weeds in the total crop growth span in a season, is a major concept used to prevent crop yield reduction. The critical period can also be represented as the time period between the maximum weed infested period and minimum weed-free period. The weed infested period refers to the time period in which the weeds emerge and remain with the crops before they start to interrupt crop growth. The weed-free period refers to the length of time the crop must be free of weeds after planting or from the start of the growing season. Thus weed control can be highly effective especially when they are controlled in the critical period (Ghosheh et al. 1996). The critical period of weed control (CPWC) provides the correct time period in which the weed communities or populations can be observed and should be actively managed in the crop fields. These timely observations and this CPWC approach saves time and resources in effectively controlling weeds in crop fields (Dille 2014).

Crop yield losses also depend on the density of weed species and crops in the field (Vilà et al. 2004). Increasing densities of weeds allows weeds to compete for nutrients and water, which were available for crop growth and development. Increasing weed density stimulates competition for light and all the other resources. Alfalfa yield has been shown to decrease by 56 and 74% due to increased quack grass densities of up to 50-100 heads per m^2 respectively (Moyer and Schaalje 1993). Decreases in weed diversity and abundance have been proven to be associated with increase in wild blueberry yield (Yarborough and Bhowmik 1993); however the competitive ability of red fescue in wild blueberry fields has not been documented.

1.3.2 Red Fescue

Red fescue is a common, cool season, sod forming perennial grass that spreads via seeds and rhizomes. It has dark green wiry leaves that appear almost round, a stem that is bent and typically red at the base, and a slender, compact panicle. It is a hardy grass that prefers well drained, acidic soils and is drought and shade tolerant (Anonymous 2012). Its ability to thrive with minimal maintenance makes it an ideal turf species, as well as an effective living mulch or cover crop (Shili-Touzi et al. 2010). In grasslands, it can dominate over time, especially in abandoned areas (Jacquemyn et al. 2011). These attributes, combined with the plant's tendency to increase tillering and seed production following burning (Gossen et al. 2002) suggests that red fescue is likely to thrive in wild blueberry fields.

Red fescue is a new weed in the wild blueberry industry. It grows and spreads rapidly in blueberry fields forming dense stands. It is relatively localized in the Collingwood area but new populations appear to be spreading throughout the province in areas such as Parrsboro, Nova Scotia. It is likely to become widespread and where it occurs it results in severe yield reductions and in some cases abandonment of the field (N. Boyd personal communication).

Red fescue was first identified in wild blueberry fields in Nova Scotia by the Vegetation Management Research Program in 2008 although it was likely introduced several years previous. The initial infection source of red fescue in wild blueberry fields is still unknown, but it is thought that its seeds were likely introduced via hay bales which were used for burning.

1.3.3 Integrated Weed Management

Integrated weed management (IWM) includes different weed control methods which are applied together in an integrated system to achieve a sustainable production system. The different control methods are preventive, cultural, mechanical, chemical, and biological (McCully et al. 2005). The first step towards the adoption of IWM is to identify the problem species and implement an effective monitoring program. The most effective management options can be selected and implemented when weed pressures reach a critical threshold.

Prevention is a key component of IWM and includes all techniques that prevent weed introduction and spread into a field. One of the important preventive practices is to clean equipment before use and while switching fields. Cultural practices that encourage vigorous, dense and healthy crop cover reduce bare spots and associated weed pressure in blueberry fields. Bare spots can be covered by either mulching using wood chips, sawdust, bark mulch or planting blueberry plants, thereby increasing crop cover and reducing weed pressure.

Mechanical methods of weed control include hand-pulling, pruning, burning and clipping in blueberry fields. Hand-pulling is the oldest method but tends to provide poor perennial weed control due to the difficulty associated with removal of 100% of the roots (Vilà et al. 2004). Pruning is mainly done to promote rejuvenation of blueberry plants. This also controls some weed species but promotes the growth of other perennial weeds which have extensive underground root systems by removing apical dominance. Burning also kills many weed seeds present near the soil surface. Clipping tops off the weeds before seeds ripen reduces shading and can reduce weed seed banks. Biological weed control includes use of selective pests such as release of insects or pathogens against target weed populations causing disease epidemics for weeds in the area. However, in wild blueberry the prospect of this control is limited (McCully et al. 2005).

Chemical weed control utilizes either selective or nonselective herbicides in blueberry fields. Selective herbicides are effective on specific weeds without any effect on the blueberry crop. However, non-selective herbicides can kill both weeds and crop. All herbicides should be applied at the recommended rate and time of application (McCully et al. 2005). Another category of herbicide product includes pre-emergence and post-emergence herbicides, which provide contact, residual or systemic activity. Pre-emergence herbicides are applied before weed emergence. They are usually applied to soil and are taken up by plants through root uptake upon their emergence. Post-emergence herbicides are applied after weed emergence in crop fields. Selective post-emergence herbicides are broadcast on foliage in the crop field and non-selective post-emergence herbicides are applied only to the weed top growth (Jensen and Yarborough 2004).

1.3.4 Chemical Weed Management in Wild Blueberry Field

Weeds in wild blueberry fields can harm the crop in a number of ways. They compete with blueberry, interfere in harvest operations, reduce berry quality, and decrease yields. Growers predominately rely on herbicides for weed control since traditional cultural weed management practices such as crop rotation cannot be practiced in a perennial crop like blueberry (Kennedy et al. 2010). Physical control such as tillage is ineffective since it encourages vegetative spread of red fescue and hand-pulling of individual weeds or plant patches is often not economically viable on large farms (Jensen and Yarborough 2004). The dominant weed control tool in the past few decades has been chemical (Jensen and Yarborough 2004).

They are usually sprayed before blueberry emergence (PRE) with some applications after blueberry emergence (POST). Herbicides such as hexazinone and terbacil are commonly used in blueberry fields (Yarborough 2004) with some post-emergence herbicides such as glyphosate also used (Ismail et al. 1981). Hexazinone was introduced in the early 1980s and drastically modified the traditional weed flora. It is widely used as a broad spectrum, selective herbicide in wild blueberry fields. Hexazinone application has limited impact on grasses with no activity on red fescue. Other principal herbicides used prior to 1980s were Sinbar (terbacil) which is effective in controlling grassy weeds (Jenson et al. 2004). Ultim (nicosulfuron + rimsulfuron) provides a "clean-up program" that removes grass and some broadleaf weeds that escape the base program (McCully et al. 2005). Kerb (propyzamide) is the only known herbicide that suppresses red fescue but it is very expensive, difficult to apply, and provides inconsistent results.

The use of tank mixes of herbicides has proven to be effective in managing perennial weeds. Yarborough et al. (1986) studied weed control including grasses in wild blueberry fields using herbicides. That study showed that the grasses were significantly reduced as the hexazinone herbicide product application rate was increased. *Danthonia spicata* (L.) (Poverty oat grass), *Agrostis scabra* wild (Tickle grass), *Poa compressa* (L.)

(Canada blue grass), *Panicum capillare* (L.) (Witch grass) are some more perennial grasses which were managed by using the terbacil herbicide product in wild blueberry fields.

In this research, screening of different herbicides applied alone or in tank mixes (different modes of action) at different application rates and timing was conducted to examine which is the most effective in managing red fescue in commercial wild blueberry fields.

1.3.5 Modelling Weed Growth Patterns

Modern, environmentally-conscious weed research calls for alternative weed control systems, economic weed management systems, scouting, modeling and integrated crop production systems. Modeling can be defined as "the dynamic simulation of plant growth and development by numerical integration of constituent processes with the aid of computers" (Prostko et al. 1998).

Understanding weed biology may allow us to predict the optimum timing for weed management, either mechanical or chemical (Webster et al. 1999). The more accurate the prediction, the greater the success rate in developing an IWM system. Baldwin and Santelmann (1980) encouraged modeling to aid in prediction of the consequences of weed interaction in crop production. Models which predict seedling emergence of weeds such as Johnson grass (*Sorghum halepense* L.) helps in estimating the different stages of weed growth and interference intensities which can help in improving timing and effectiveness of herbicide treatments (Prostko et al. 1998).

Most plant models are based on the relationship between temperature and rate of plant growth and development. The thermal concept was an old concept further refined to heat units also called growing degree days (GDD) (Prostko et al. 1998). Synder et al. (1999) suggested that air temperature is one of the most important factors in influencing the phenological phases of perennial weeds like red fescue. White et al. (2012) suggested that instead of calendar date, GDD can be used to measure the time of weed emergence and growth patterns. Heat units accumulated in plants are calculated by subtracting the threshold or base temperature from the daily mean temperature. A series of Johnson grass seedling emergence growth chamber experiments were conducted in which the data from seedling emergence to flowering were collected and were modelled both using a poikilotherm rate equation and a Weibull function (Prostko et al. 1998). GDD can be used to compare the emergence patterns of weeds between sites of different altitude and during different years. White et al. (2012) developed a successful model of wild blueberry and red sorrel (*Rumex acetosella* L.) emergence in wild blueberry fields.

Other models have been successfully developed for seedling emergence and growth of Johnson grass (*Sorghum halepense* L.) in various cropping systems (Arnold et al. 1990; Arnold et al. 1990). Other phenological parameters predicted via modeling of Johnson grass are dormancy release and germination rate, rhizome sprouts emergence, tiller emergence and rhizome biomass. All these models were based on accumulation of thermal heat units or a GDD approach (Holshouser et al. 1996). Wu (2010) suggested that thermal time models are best to predict emergence of a variety of weed species, and developed a growth model using GDD for spreading dogbane

(*Apocynum androsaemifolium* L.) in blueberry fields. Thus, developing a growth and development model using thermal units to understand the biology of red fescue could determine the optimal time to manage it's population using herbicides.

1.4 Objectives

The overall objective of the this research was to increase our understanding of red fescue growth dynamics in wild blueberry fields, identify effective herbicides and maximize herbicide efficacy with proper application timing. The specific research objectives are as follows:

1. Evaluate the impact of red fescue removal timing on wild blueberry growth and reproduction.
2. Develop temperature-based phenological models with respect to height development and tillering of red fescue.
3. Evaluate potential herbicides and maximize herbicide efficacy with proper application timing, for red fescue suppression in wild blueberry fields.

1.5 Hypothesis

1. Red fescue competes with blueberry and suppresses its growth and yield during the vegetative stage if they were not removed early in the growing season.
2. Development stages of red fescue in blueberry fields can vary with temperature in terms of growing degree days.
3. Among all herbicides that are being evaluated, propyzamide is expected to provide the greatest suppression of red fescue in wild blueberry fields.

CHAPTER 2 COMPETITION OF RED FESCUE WITH WILD BLUEBERRY

2.1 Introduction

Wild blueberry (*Vaccinium angustifolium* Ait. and *Vaccinium myrtilloides* Michx.) are native, perennial berry species in Nova Scotia. It is commercially cultivated in parts of Canada and the United States (Yarborough et al. 1989) and is managed commercially on a 2 year cycle. In the vegetative year, shoots emerge and grow from underground rhizomes and flowers buds develop in the fall. The following crop year, the flowers open and berries are produced and harvested during August and September. Wild blueberry is a leading source of antioxidant phytonutrients supplying the growing market for value added products such as health food supplements. Meeting the growing consumer demand for blueberry products requires an increase in blueberry production efficiency (Glass et al. 2005).

Red fescue (*Festuca rubra* L.) is a cool season, sod forming perennial grass that spreads via seeds and rhizomes. It grows and spreads rapidly in blueberry fields forming dense stands (N. Boyd personal communication). Red fescue is tolerant to shade and other stress factors, which makes it a highly competitive plant. Its presence in winter wheat fields has been shown to reduce *Elytrigia repens* (L.) rhizome biomass by 40% in late autumn and restrains the development of new shoots due to severe competition (Bergkvist et al. 2010). It is a concern to the growers, because where it occurs, it causes severe yield reductions and in some cases abandonment of the blueberry fields (N. Boyd personal communication).

Competition occurs when the available resources do not fulfill the combined demands of neighboring organisms in a community (Patterson 1995). Weeds compete with crops for resources required for adequate plant growth such as light, soil nutrients, and moisture. Some of the most common impacts of resource limitation include reduced plant size, leaf area and crop yield (Glass et al. 2005). Weeds interfere with crops either directly or indirectly by serving as alternate hosts for insects and diseases, hindering harvest operation, or interfering with the proper application of pesticides (Hall et al. 1961; Yarborough et al. 1984; Jensen and Yarborough 2004).

The overall objective of this experiment was to determine the effect of red fescue removal timing on wild blueberry (objective #1). The specific objectives were to evaluate the impact of red fescue removal timing on biomass and height of blueberry and red fescue in both the vegetative and crop year; density of blueberry in both years and red fescue in the crop year; soil moisture, soil nutrients, floral bud count, leaf area and total nitrogen content of blueberry in the vegetative year; early and late ground cover of blueberry and red fescue in the crop year and leaf stages of red fescue, flower count and yield of blueberry in the crop year.

2.2 Materials and Methods

2.2.1 Site Description and Experimental Design

In 2012, experimental sites were identified in two commercial blueberry fields in the Collingwood area. One was in Scotch Hill (45° 35′ 58.354″ N, 63° 48′ 10.336″ W, 185.97 m MSL) and the other one was in Rushton (45° 34′ 20.235″ N, 63° 43′ 20.335″ W, 247.06 m MSL), Nova Scotia. Soils at both sites were from the Rodney series and were well drained, gravelly sandy loams (Nowland and MacDougall, 1973). Particle size distribution was measured using the hydrometer method as described by the Soil Analytical Laboratory, Dalhousie Agricultural Campus, Truro, Nova Scotia (Brewster, 2001). Soil pH was obtained from the soil test report from the provincial soil test analytical lab, Truro, Nova Scotia. Soil at Scotch Hill contained 65.2% sand, 19% silt and 15.8% clay with a pH of 4.6. Similarly, soils at Rushton contained 66.4% sand, 26.1% silt, and 7.5% clay with a pH of 4.8.

Prior to experimental setup, both the sites were managed by the commercial farm operators which included biannual pruning or burning plus routine fertilizer, and herbicide application. Scotch Hill was burned, whereas, the Rushton field was pruned in the year before the experimental setup. The Scotch Hill site had healthy, dense blueberry stands whereas the Rushton field had comparatively stunted with sparse blueberry stands, which looked weedier than the Scotch Hill site.

At both sites, the experimental design was a randomized complete block design with four blocks and five treatments. The treatments were applied in the vegetative year at both sites. The treatments comprised an unweeded control, weed-free 31st May onwards, weed-free 30th June onwards, weed-free 31st July onwards and weed-free 31st August onwards. The plots were 2 m x 2 m with 1 m buffer between the blocks at both sites. Weed removal was completed by hand pulling commencing on the respective dates above in 2012. The plots were left undisturbed in the following crop year, 2013.

2.2.2 Data Collection

2.2.2.1 Soil Data

Soil cores of 15 cm (volume of 47 cm^3) depth were taken from two random locations within each plot at both sites at the end of the vegetative year. These two subsamples were combined to form a composite sample for each treatment. The soil samples were air dried at room temperature for 7 days. The dried soil samples were analysed for total N by combustion analysis (Vario MAX CN Analyzer, Elementar Germany) and for available P and K (Mehlich III) analysis by the provincial soil test analytical lab, Truro, Nova Scotia.

Soil volumetric moisture content was measured every 12 hours in each plot from June to November 2012. HOBO data loggers were used in conjunction with soil moisture smart sensors (dielectric aqua-meter probe) (On-set Computer Corp., Bourne, MA, USA). Moisture sensors were installed at 45^{o} angle in the soil profile at 10 cm soil depth in Control and Weed-free (May onwards) plots of each block at both sites.

2.2.2.2 Vegetative Year Data

In the vegetative year, 2012, a non-destructive measurement of height of red fescue and blueberry and a destructive measurement of biomass of red fescue and blueberry was taken before every treatment application. The heights of five randomly selected plants of red fescue and blueberry were measured using a ruler from soil base to the tip of the uppermost extended leaf, in each plot of all blocks at both sites. Above ground biomass of red fescue and blueberry was collected within a 25 cm x 25 cm quadrat placed at randomly selected corners of each plot. Biomass was sorted and oven dried at 70 ^{o}C for 48 hours, and then weighed.

To measure leaf area, three wild blueberry stems were randomly selected from each plot. The freshly harvested leaves from randomly selected blueberry stems were scanned and the leaf area was calculated using Win-FOLIA software (Regent Instruments Inc. Canada). Stem density of blueberry and floral bud count per stem of blueberry were measured once on October 15, 2012. Blueberry stem density was measured in a 25 cm x 25 cm quadrat randomly placed in each plot in all 4 blocks at both sites. To measure floral bud counts, 10 stems from each plot were selected and the total number of floral buds was counted per stem. These blueberry stems were selected by placing a line transect diagonally across the plot then stems were selected at particular intervals close to the line. Floral buds were counted in the vegetative year to estimate the yield potential in the crop year. Total nitrogen content of wild blueberry was also estimated using aboveground biomass collected from all plots. The aboveground biomass of blueberry was oven dried (70^{o} C for 48 hours) and ground to pass 1 mm using Wiley mills (Thomas Scientific USA). A subsample (450-550 mg) was then analysed for total N by combustion analysis (Vario MAX CN Analyzer, Elementar Germany).

2.2.2.3 Crop Year Data

In the crop year, 2013, height and biomass of red fescue and blueberry were measured as described above on July 17, 2013, which coincided with peak growth of the wild blueberry. Similarly, stem density of red fescue and blueberry was measured on June 7, 2013 as described above. The number of flowers per stem of blueberry was counted on June 5, 2013 in the same way that floral buds were counted in the vegetative year. Red fescue leaf stage was measured by counting the total number of leaves present in the same randomly selected plants which were used for height in all plots.

Ground cover was measured twice in 2013, on June 7 (Early) and August 15 (Late). The percentage cover of each plant species was determined from the number of points for each species and the total number of points sampled (Najafi and Solgi 2010). Ground cover was measured by using the point intersects method (Heady et al. 1959) where species and bare spot beneath the intersections were identified. It was taken from 50 cm x 50 cm randomly placed quadrates in all plots. Yield of wild blueberry was measured on August 11, 2013. Ripe berries were harvested using hand held rakes from the whole plot. Leaves and debris were removed by wind and the fresh weight of berries was measured.

2.2.3 Statistical Analysis

Wild blueberry and red fescue data were analyzed using the PROC MIXED procedures in SAS 9.3 (SAS Institute Inc., Cary, NC, USA). The assumptions for normality and constant variance of the error terms were checked in Minitab statistical software (verson16). For analysis data were transformed to satisfy assumptions when needed. However, data were back transformed for presentation. Significance of p-values was tested based on 5% level of significance. Fishers Least Significant Difference (LSD) multiple mean comparisons were conducted using least square (LS) means procedure in SAS 9.3.

2.3 Results and Discussion

Data for early red fescue cover, late wild blueberry and red fescue cover for 2013 were analysed and presented separately for each site as there was a significant site by treatment interaction (p-value = 0.0003, 0.0109, 0.0017 respectively). However, the remaining data collected in both years at both sites showed no significant site by treatment interaction. Therefore, these data were combined for the two sites (Scotch Hill and Rushton field) for analysis.

2.3.1 Soil Fertility and Moisture

There was no significant difference in soil available N, P and K content in the vegetative year at both sites, across all treatments (data not shown). We can conclude that treatments had no significant impact on soil nutrients. It is expected as soil acts as a natural buffer and resists change. It takes a long period of time under perennial system, where soil can change its nutritional composition (Stanford et al. 1972; Balesdent et al. 1988; Seybold et al. 1999).

From June to November in 2012, soil moisture tended to be higher in the weed-free May onwards plots versus the control plots at both sites (Figure 2.1a, 2.1b). Higher soil moisture might be due to less competition for moisture between plants as compared to the control where the weeds also compete for moisture with wild blueberry plants. More weeds present in the control plots as compared to the weed-free May onwards plots would also increase evapo-transpiration. Hence, from the above results, it is evident that red fescue tends to reduce moisture levels within a given zone and this indicates it may compete with blueberry for available water. In the Scotch hill, the negative values shown in the Figure 2.1a may be because sensor was not installed properly, which might have caused poor soil contact and also contact with foreign material adjacent to the sensor.

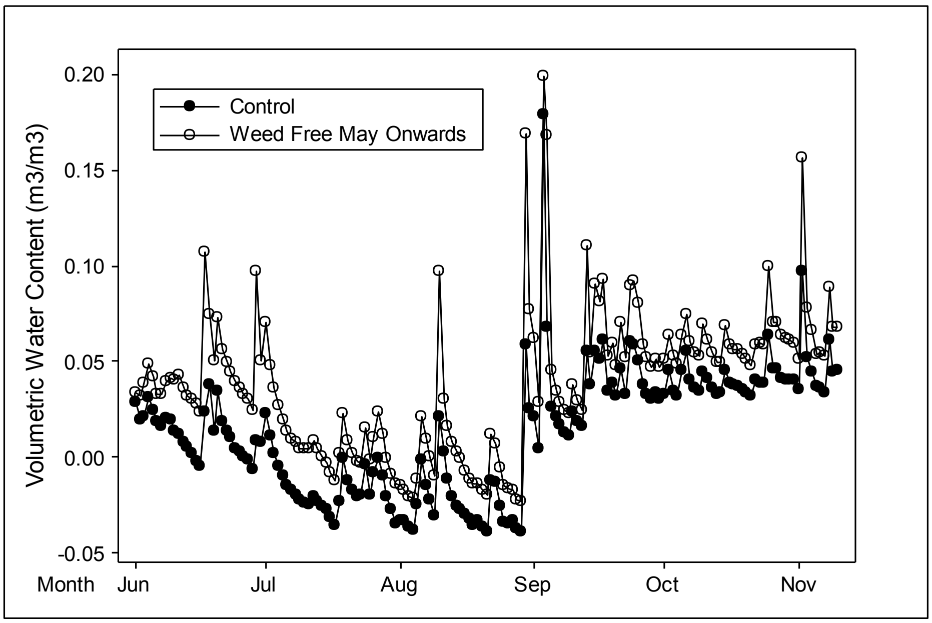

Figure 2.1a: Time series plot of soil moisture content in Scotch Hill at Collingwood, Nova Scotia

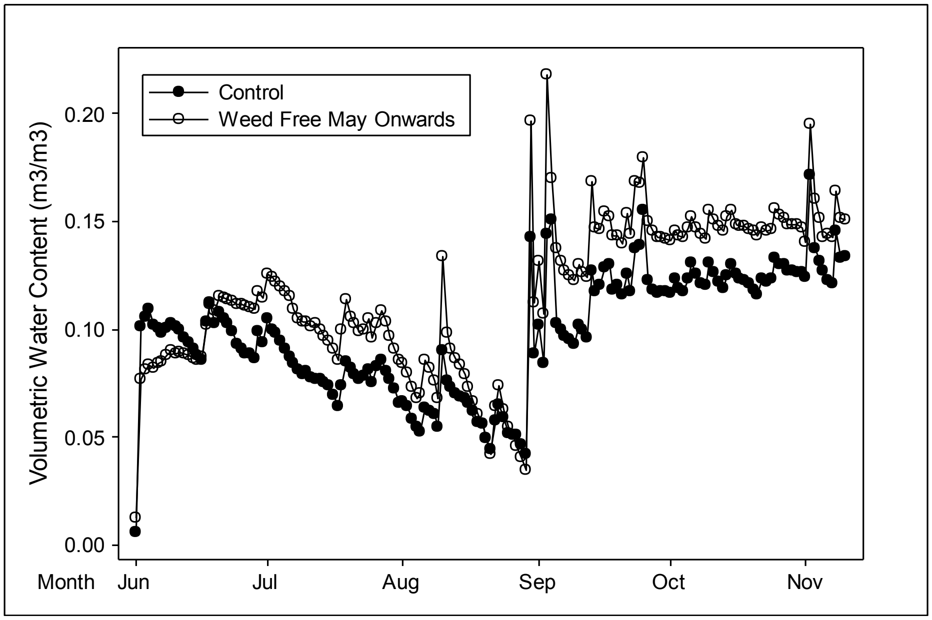

Figure 2.1b: Time series plot of soil moisture content in Rushton Field at Collingwood, Nova Scotia

2.3.2 Vegetative Year Data Analysis

All the treatments showed no significant difference in blueberry height and biomass. In general, the height of red fescue and blueberry increased continuously as the season progressed and the height of red fescue was greater than blueberry throughout the season (Figure 2.2). Biomass of red fescue and blueberry also increased as the season progressed. Biomass of blueberry was reduced in August due to loss of leaves (Figure 2.3).

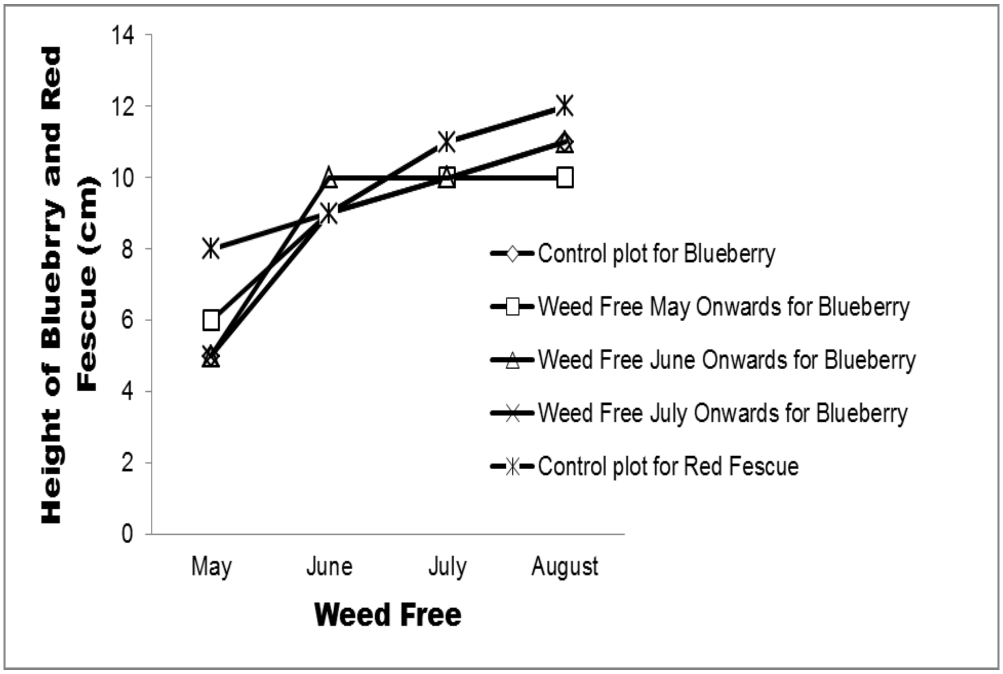

Figure 2.2: Effect of weed-free period on height of blueberry and red fescue as compared to control in both sites at Collingwood, Nova Scotia in 2012.

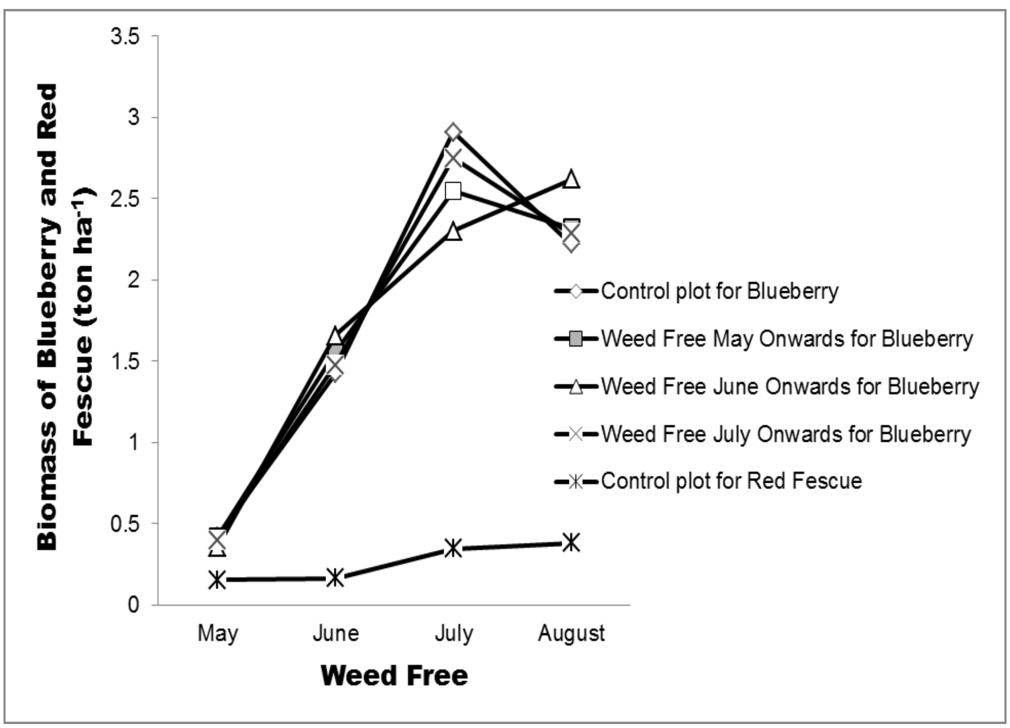

Figure 2.3: Effect of weed-free period on biomass of blueberry and red fescue as compared to control in both sites at Collingwood, Nova Scotia in 2012.

There was no significant difference between all weed-free and control treatments for wild blueberry stem height, biomass, leaf area, stem density, floral bud and total N content during the vegetative year at both sites (Table 2.1).

Table 2.1: Biomass, stem density, height, floral bud, total N-content and leaf area of wild blueberry at both sites in Collingwood, Nova Scotia during the crop vegetative year, 2012.

Treatments	[a]Biomass (ton ha^{-1})	Stem Density (m^{-2})	[a]Height (cm)	Floral bud (per stem)	[a]Total N (% mg L^{-1})	[a]Leaf Area (cm^2)
Un-weeded (control),	2.251 ± 0.183	1024 ± 72	15	4 ± 1	1.08 ± 0.05	1.38 ± 0.17
Weed-free May onwards	2.394 ± 0.301	1101 ± 59	13	5 ± 1	1.11 ± 0.04	1.36 ± 0.17
Weed-free June onwards	2.641 ± 0.189	1095 ± 62	15	5 ± 1	1.14 ± 0.05	1.54 ± 0.19
Weed-free July onwards	2.295 ± 0.127	1021 ± 58	16	4 ± 1	1.03 ± 0.04	1.80 ± 0.18
Weed-free August onwards	-	1084 ± 65	-	4 ± 1	-	-
p value	0.5142	0.8105	0.0607	0.4584	0.1554	0.2139

[a]Biomass, Height, Total N-content and leaf area of blueberry collected at the end of August were analyzed.
Dash line (-) indicated that data was not included in analysis as it served as control during data collection.

2.3.3 Crop Year Data Analysis

Weed-free periods during the vegetative year significantly reduced red fescue biomass in the following crop year when compared to the control (Table 2.2). Our results suggest that a weed-free period of any time during the growing season reduces red fescue biomass in the following year. Although red fescue biomass as a result of weed-free periods of May, June, July and August onwards were not significant, regardless, red fescue biomass tended to be lower when a weed-free period of May was maintained onwards as compared to other treatments. Weed-free periods during the vegetative year had no significant effect on red fescue height and leaf stages in the crop year (Table 2.2) at both sites.

Table 2.2: Biomass, stem density, height and leaf stages of red fescue at both sites of Collingwood area, Nova Scotia, 2013.

Treatments	Biomass (ton ha^{-1})	Stem Density (m^{-2})	Height (cm)	Leaf Stage
Un-weeded (control),	0.461 ± 0.072 a[1]	772 ± 158 a	30 ± 3	2
Weed-free May onwards	0.048 ± 0.013 b	110 ± 15 c	22 ± 2	3
Weed-free June onwards	0.158 ± 0.055 b	342 ± 115 bc	25 ± 3	3
Weed-free July onwards	0.096 ± 0.050 b	350 ± 63 bc	25 ± 2	3
Weed-free August onwards	0.174 ± 0.047 b	542 ± 150 ab	26 ± 3	2
p value	0.0001	0.0028	0.2897	0.0686

[1]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
SE = standard error

Weed-free periods during the vegetative crop phase had a significant effect on red fescue density in the crop year (Table 2.2) at both sites. Our results suggest that weed-free periods from May, June and July onwards during the vegetative crop phase reduced red fescue density in the crop year when compared to the unweeded control. Weed-free August onwards resulted in no significant difference with the control for red fescue density in the crop year. Although red fescue density for May, June and July onwards weed-free period treatments were not statistically significantly different, red fescue density for the May treatment tended to be lower when compared to other treatments. This combined result with respect to weed biomass and density suggests the earlier the red fescue is removed from the above ground surface in the crop vegetative phase, the greater the impact on the following year towards reducing weed pressure. This can be made possible with the use of a post-emergence herbicide. The results also indicate that the number of red fescue plants did not regain their original population due to a treatment effect evident in the following year.

Weed-free periods during the vegetative year had no significant effect on blueberry height, biomass, density, flower count and yield in the crop year (Table 2.3) at both sites. The yield data showed high variability, this could be due to low sample size, high natural variation in plots and environmental factors. Weed-free periods during the vegetative year had no significant effect on early and late red fescue cover at Scotch Hill (Table 2.4). Similarly, early blueberry cover (Table 2.4) at both sites and late blueberry cover at Scotch hill (Table 2.4) during the crop year were also not significantly affected. However, treatments at Rushton showed a significant reduction of early and late red fescue cover as compared to the control (Table 2.4). Moreover, late blueberry cover at Rushton was significantly increased in all treatment plots as compared to the control in the crop year (Table 2.4). This also suggests that maintaining weed-free conditions from

May onwards in the vegetative year significantly increased blueberry cover at Rushton in the following crop year.

Table 2.3: Yield, biomass, stem density, height and flower count of wild blueberry at both sites of Collingwood, Nova Scotia, 2013.

Treatments	Yield (ton ha^{-1})	Biomass (ton ha^{-1})	Stem Density (m^{-2})	Height (cm)	Flower Count (per stem)
Un-weeded (control),	2.843 ± 1.404[1]	3.916 ± 0.419	856 ± 37	19 ± 1	25
Weed-free May onwards	4.184 ± 1.393	4.044 ± 0.510	900 ± 81	18 ± 1	20
Weed-free June onwards	3.782 ± 1.467	4.343 ± 0.448	950 ± 100	18 ± 1	22
Weed-free July onwards	3.363 ± 1.308	4.256 ± 0.420	920 ± 133	20 ± 2	19
Weed-free August onwards	3.667 ± 1.362	4.350 ± 0.378	912 ± 88	18 ± 1	15
p value	0.2256	0.8624	0.9435	0.7504	0.2660

[1]Means ± SE

Table 2.4: Percent cover of Red Fescue and Wild Blueberry at both sites of Collingwood, Nova Scotia, 2013.

Treatments	Red Fescue				Wild Blueberry		
	Early[y] Ground Cover[x] (%)		Late[y] Ground Cover (%)		Early Ground Cover (%)	Late Ground Cover (%)	
	Scotch Hill	Rushton Field	Scotch Hill	Rushton Field	Scotch Hill + Rushton Field	Scotch Hill	Rushton Field
Un-weeded (control),	13 ± 4	32 ± 3 a[z]	8 ± 2	74 ± 4 a	66 ± 6	76 ± 11	25 ± 4 c
Weed-free May onwards	1 ± 1	1 ± 1 c	3 ± 3	21 ± 9 b	79 ± 5	76 ± 10	68 ± 7 ab
Weed-free June onwards	3 ± 2	13 ± 5 b	6 ± 4	37 ± 8 b	78 ± 4	66 ± 17	57 ± 8 b
Weed-free July onwards	9 ± 5	3 ± 3 c	16 ± 12	15 ± 9 b	79 ± 5	62 ± 14	79 ± 6 a
Weed- free August onwards	7 ± 1	3 ± 3 c	26 ± 7	33 ± 12 b	78 ± 3	67 ± 7	55 ± 7 b
p value	0.0568	<0.0001	0.1640	0.0024	0.1112	0.7520	0.0004

[z]Means within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
[y]Early ground cover measured on June 7, 2013 and late on August 15, 2013.
[x]Ground Cover is a percentage of plant species in particular given area.

This difference in red fescue and blueberry cover between sites may be due to the difference in the stand health of wild blueberry and may be also due to previous management practices for each site. Scotch hill was burned before the experiment was set up in 2012, whereas Rushton field was mowed instead of burning. Seeds and propagules of weed species present in the soil might have been destroyed or killed because of burning in Scotch Hill. So, the control plots had similar weed cover as that of other treatment plots in Scotch Hill unlike the Rushton field. Smagula et al. (2009) also found that burned plots had significantly lower weed cover compared to mowed plots.

The above results indicate that wild blueberry was not affected by red fescue either in the vegetative or crop year as observed from berry yield results. This suggests that red fescue does not compete with wild blueberry. However, this is contrary to grower reports of significant crop losses. This may be because the red fescue weed pressure observed in plots used for research was less than observed in other fields for unknown reasons. This could also be due to higher ability of blueberry to survive in nutrient and moisture poor soil. Regardless of the nutrient and moisture competition offered by this weed, wild blueberry was not affected.

Results also indicated that the weed-free period during the vegetative year significantly reduces red fescue biomass, stem density and ground cover in the crop year in this study. This suggests that effective control of red fescue in its early stages of growth (weed-free period May onwards) may be helpful to reduce the population increase of red fescue over subsequent years in blueberry fields.

2.4 Conclusion

Results from this study show that there was reduction by red fescue for moisture in wild blueberry during the vegetative year, but the competitive response was not reflected in yield and other biometric measurements of wild blueberry. However weed-free periods in the vegetative year reduced the biomass and density of red fescue in the crop year. We can also conclude that although red fescue at the infestation levels found at these sites was not directly affecting wild blueberry, indirectly, red fescue may interfere with wild blueberry harvesting, decrease blueberry pack quality, or increase insect infestation, although these have not been focused on in this study.

CHAPTER 3 PHENOLOGICAL MODEL OF RED FESCUE GROWTH AND DEVELOPMENT IN WILD BLUEBERRY

3.1 Introduction

Red Fescue (*Festuca rubra* L.) is a cool season, sod forming perennial grass that spreads via seeds and rhizomes. It grows and spreads rapidly in blueberry fields forming dense stands. It is a concern to growers, because where it occurs, it causes severe yield reduction and in some cases abandonment of the blueberry fields (N. Boyd personal communication). There is currently no published information on the phenology of red fescue in wild blueberry fields.

The emergence of weeds and the length of its emergence period can be used to improve weed control efficacy (Otto et al. 2007). Understanding weed biology is an important component of integrated weed management which includes emergence patterns, life cycle and seed production. Emergence and development models may allow us to predict the optimum timing for weed management, either mechanical or chemical (Webster et al. 1999). The more accurate the prediction, the greater the success rate in developing an integrated weed management system. Baldwin and Santelmann, (1980) encouraged modeling to aid in prediction of the consequences of weed interaction in crop production.

Plant emergence and development times are greatly influenced by environmental factors such as temperature, light, moisture and soil characteristics (Wu at al. 2013). Synder et al. (1999) suggested that air temperature is one of the most important factors in influencing the phenological phases of perennial weeds like red fescue. White et al.

(2012) suggested that instead of calendar date, growing degree days (GDD) can be used to measure time of weed emergence and growth patterns. GDD can be calculated by subtracting base air temperature from average daily air temperature. The base air temperature is the minimum air temperature at which it is assumed that the emergence and development of plants will not occur (Derakhshan et al. 2014). Thus, plant emergence and development can be interlinked with cumulative air temperature instead of calendar days. Therefore, the use of GDD is also helpful to compare the emergence patterns of weeds between sites of different altitude and during different years. Wu, (2010) developed a growth model using GDD for spreading dogbane (*Apocynum androsaemifolium* L.) in blueberry fields. He also suggested that thermal time models are best to predict emergence of a variety of weed species but little information is known about perennial weed species such as red fescue. Thus, developing growth and development models using thermal units to understand the biology of red fescue could determine the optimal time to manage the population using herbicides.

The overall objective of this experiment was to increase our understanding of red fescue growth dynamics in wild blueberry fields (objective # 2). The specific objective was to develop temperature-based phenological models with respect to height development and tillering. Emergence count, leaf development and seed head stages of red fescue were plotted against GDD.

3.2 Materials and Methods

3.2.1 Sites Description and Experimental Design

In 2012, experimental sites were identified in two commercial blueberry fields in the Collingwood area. The two sites were Scotch Hill and Rushton in Nova Scotia. A full description of these two sites was provided in chapter 2.

3.2.1.1 Growth Chamber study

A growth chamber study conducted in 2013 was designed to examine the dynamics of growth stages of red fescue under controlled environments. This information was then used to develop an emergence and development model of red fescue against GDD.

Red fescue rhizomes were collected from commercial blueberry fields at both sites. These rhizomes from two sites were the treatments. Rhizomes were washed and cut into consistent lengths (same number of nodes). Three pieces of rhizomes of the same length with an equal number (n=2) of nodes were planted in each pot. The potting mixture consisted of a 1:1 ratio of play sand (Shaw Resources, Shubenacadie, Nova Scotia) and planter mix (Compliments Professional Planter mix, Mississauga, Ontario). The pots were placed in a growth chamber at 20ºC for 16 hours in light and 10ºC for 8 hours in dark over a period of four months. They were watered and fertilized with 20-20-20 NPK general fertilizer as per requirement once a week and month respectively. The experimental design was a complete randomized design with 10 replications and was repeated thrice.

3.2.1.2 Field study

The experiment occurred in the untreated control plots of the herbicide screening trial in 2012 and 2013. The experiment was the observational study of red fescue from all the randomly placed eight quadrates at both sites. The emergence count, height, leaf development, tillering and seed head of the red fescue was monitored from eight permanent randomly placed quadrats (50 cm x 50 cm) at each site in Collingwood.

3.2.2 Data Collection

Height, leaf development and tillering of red fescue were collected weekly from the controlled environment study. Red fescue height was measured using a ruler from the base of the plant to the tip of the uppermost extended leaf in each pot. The number of leaves was counted from the same plants measured for height. The height of red fescue shoots was divided by the maximum height of red fescue shoot measured in the whole experiment to determine the percentage of maximum height. The percentage of maximum leaf stage and tillers were calculated as above.

Data from the field study were collected in both years (vegetative and crop) of commercial wild blueberry production at both sites in 2012 and 2013. Red fescue emergence was counted from quadrats (50 cm x 50 cm) weekly. The height, leaves and tillers of red fescue were measured from already tagged plants (n=5) of red fescue in each quadrat. Red fescue seed heads were also counted within each 50 cm x 50 cm quadrat. The percentage of maximum emergence count, height, leaves, tillers and seed head production were also calculated as above.

3.2.3 Air and Soil Temperature

Air and soil temperature was recorded hourly using HOBO temperature data loggers (HOBO U23 pro v2; Onset Computer Corporation, Bourne, MA). A HOBO logger was placed 75 cm above the ground to record air temperature and soil probes placed at 2.5 cm depth to record soil temperature at both sites. Data loggers were installed on May 7, 2012 and April 17, 2013 at both sites. To calculate the cumulative GDD from April 1, regional air temperature data were used from nearest Environment Canada weather station (Wu et al. 2013). April 1 was used as the biofix date as plant emergence rarely occurs before this date in Atlantic Canada. The Environment Canada (EC) weather station nearest to Collingwood is Nappan, NS (45° 46′ N, 64° 14′ W; elevation, 19.8 m).

3.2.4 Data Analysis

From both controlled environment and field, data for growth and development stages of red fescue were plotted against GDD. Fitting of non-linear equations and parameter estimates for % of maximum height and tillers were assessed through use of Sigma Plot version 12 (Systat Software, Inc., San Jose California USA). All other data collected (emergence count, leaves and seed head) were plotted against GDD in scatter plot by using sigma plot version 12.

For the growth chamber study, all the collected data was analyzed using the PROC MIXED procedure in SAS 9.3 (SAS Institute Inc., Cary, NC, USA). The assumptions for normality and constant variance of the error terms were checked in Minitab statistical software (verson16).

Growing Degree Days (GDD, ^{o}C) was calculated as follows (White et al. 2012):

$$GDD = \sum_{i=1}^{n} (\text{Tmean} - \text{Tbase})$$

Where T_{mean} refer to the mean daily air temperature, T_{base} is the base temperature and n refers to the number of days on which GDD were calculated. If $T_{mean} \leq T_{base}$ then GDD = 0 was used. The base temperature for red fescue was estimated to be 2^{o}C (Larsen, 2004; Lonati et al. 2009). This was achieved by iterating a range of base temperature (0-3^{o}C) in the above equation to achieve a maximum fit between cumulative GDD and % developmental stage of red fescue (White et al. 2012).

Red fescue height in the controlled environment study was modelled with a sigmoidal, three-parameter model:

$$y = a / [1+\exp(-(x-x_0)/b)]$$

Where y is the dependent variable (% of maximum height at any given GDD), a is the asymptote (estimated value of % of maximum height), x is the cumulative GDD, x_0 is the growing degree days at 50% of the maximum height and b is the curve shaped parameter (Wu et al. 2013).

Red fescue tillering under controlled conditions is presented as % of maximum tillers with respect to the cumulative GDD. A sigmoidal, Gompertz, three-parameter model was fitted to the data

$$y = a*\exp[-\exp(-(x-x_0)/b)]$$

Where y is the % of maximum tillering at any given GDD, a is the maximum estimated value of % of maximum tillers, x is the cumulative GDD, x_0 is the inflection point of the curve for GDD and b is the rate of increase in the % of maximum tillers (White et al. 2012).

3.3 Results and Discussion

3.3.1 Growth Chamber Study

All the above models were assessed for goodness of fit by calculating the adjusted coefficient of determination (R^2_{Adj}) and root mean square error (RMSE) in sigma plot version 12. R^2Adj values close to 1 and lower values of RMSE were used for Goodness of model fit.

Data of percentage of maximum height and tillers in the growth chamber study were analysed and presented separately for each repeat as there was a significant treatment by repeat interaction (p-value = 0.0456 and 0.0096). Model parameters of percentage of maximum height and tillers were compared, to find if any significant difference exists between both sites, by using 90% confidence interval. If the confidence intervals of model parameters overlapped, then there is no significant difference between parameters and models. Combined models were developed, when confidence intervals of all parameters of individual models for each site overlapped. Even if one parameter of the model is different, then the models were made separately. The percentage of maximum leaves showed no significant treatment by repeat interaction (p-value = 0.2669). Therefore, all three repeats were combined for the two sites (Scotch Hill and Rushton field) for analysis.

3.3.1.1 Red Fescue Height Development under Controlled Conditions

Red fescue height was accurately described by a sigmoid, three parameter model for rhizome samples from both sites for all three repeats. The coefficient of determination (R^2_{Adj}) and root mean square error (RMSE) for all three repeats are given in Table 3.1.

Table 3.1 Parameter estimates for non-linear models describing percent of maximum red fescue height in growth chamber.

Repeats	Sites	Equation[x]	Model parameters[y]	CI[z] - L	CI - U	R^2_{Adj}	RMSE[w]
1	Combined	Sigmoid	a = 105.3	100.4	110.1	0.99	2.06
			b = 153.0	132.8	173.2		
			x_0 = 520.0	494.7	545.4		
2	Combined	Sigmoid	a = 100.3	97.5	102.9	0.99	1.97
			b = 185.5	167.2	203.7		
			x_0 = 553.4	532.4	574.3		
3	Scotch Hill	Sigmoid	a = 103.5	99.7	107.3	0.99	2.14
			b = 225.5	200.4	250.6		
			x_0 = 679.8	650.9	708.7		
	Rushton Field	Sigmoid	a = 104.2	100.9	107.4	100	1.74
			b = 193.7	176.8	210.6		
			x_0 = 802.9	781.4	824.5		

[w]RMSE = root mean square error.
[x]The Sigmoid equation is $y = a/[1+\exp(-(x-x_0)/b)]$.
[y]Sigmoid model parameters, a = asymptote (estimated value of % of maximum height), x_0 = growing degree days at 50% of the maximum height and b = curve shaped parameter (Wu et al. 2013).
[z]CI = confidence Interval of lower and upper limit.

From Figure 3.1, it is evident that model predictions for red fescue height were very close to the observed values from rhizomes from both sites in all the three repeats. This indicates good performance of this model for predicting height of red fescue in controlled conditions in response to GDD. The models of three repeats are presented separately since treatment x repeat was significant. This could be due to the difference in the time of rhizome collection from the fields, and difference in the age of stored rhizomes used in the experiment. We can also conclude that the red fescue increase in height with the increase in GDD and peak % of maximum height was achieved between 1000 to 1400 GDD from rhizomes of both sites for all the three repeats (Figure 3.1).

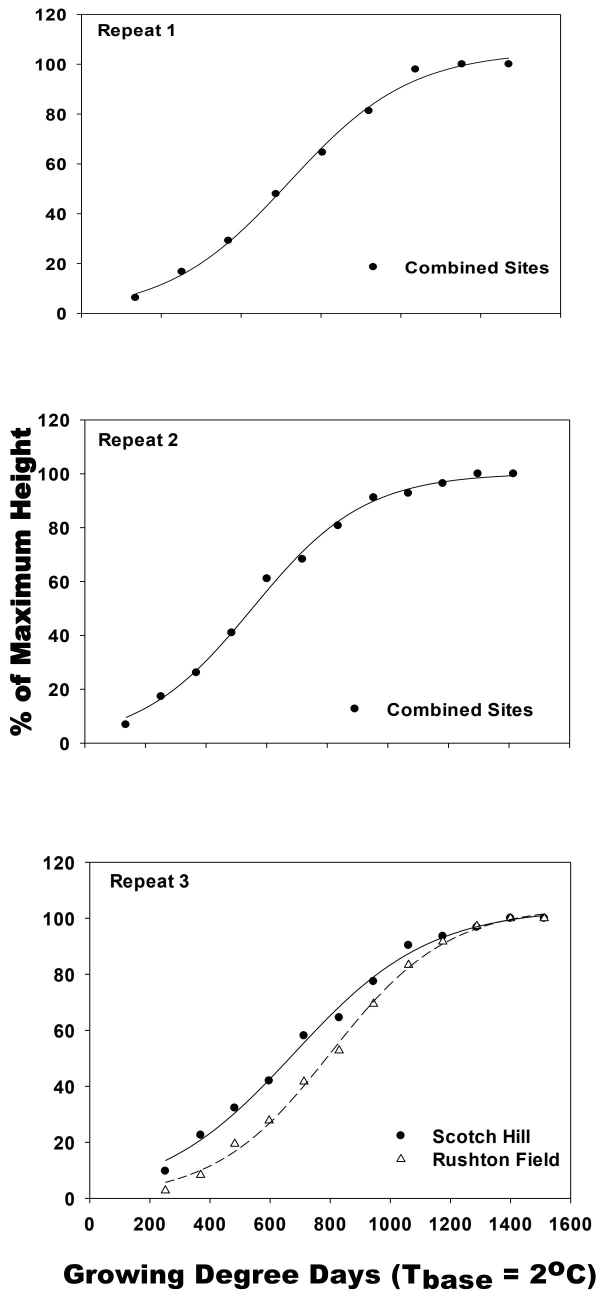

Figure 3.1: Growing degree days (GDD) models for predicting percent of maximum height of red fescue for all three repeats. Symbol represents observations and a line is fitted regression equations. A sigmoid equation of the form $y = a / [1+\exp(-(x-x_0) / b)]$ was fit to the observed data. Parameter estimates and goodness of fit statistics for regression equation is given in Table 3.1.

3.3.1.2 Red Fescue Leaf Development under Controlled Conditions

In the growth chamber, 15-20% of the maximum number of leaves developed occurred at 136 GDD with rhizomes from both sites. The peak % of maximum leaves developed was attained between 2000 to 2100 GDD from rhizomes of both sites for all the three combined repeats (Figure 3.2). The repeats were combined because treatment x repeat were not significant. Since, more than 80% of maximum leaves occurred around 600 GDD, so we can conclude that red fescue rapidly increases its development of leaves then remains approximately constant with only a slight further increase in leaf number throughout the growing season.

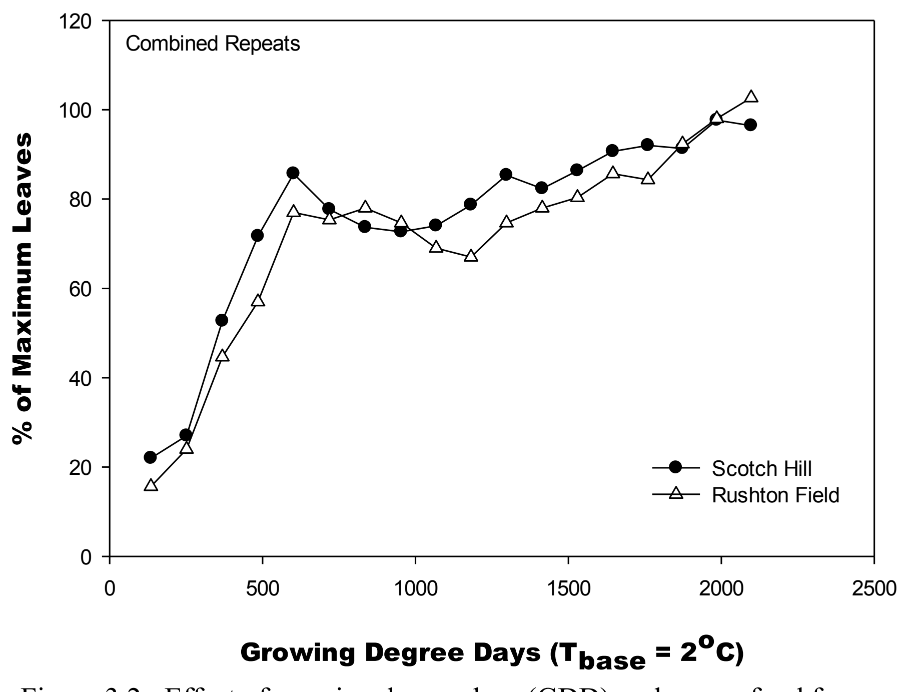

Figure 3.2: Effect of growing degree days (GDD) on leaves of red fescue.

3.3.1.3 Red Fescue Tillering under Controlled Conditions

Red fescue tillering was accurately described by a sigmoidal, Gompertz, three parameter model at both sites in the growth chamber for all three repeats. The coefficient of determination (R^2_{Adj}) and root mean square error (RMSE) for all three repeats are given in Table 3.2.

From Figures 3.3, it is evident that model predictions for red fescue tillers were very close to the observed values for rhizomes from both sites in all three repeats. This indicates good performance of these models for predicting tillers of red fescue in the growth chamber. The reason for presenting three repeats separately is given in 3.3.1.1. We can also conclude that the red fescue increases its tillers with the increase in GDD. Red fescue started to produce its tiller between 650 to 750 GDD and reached a peak % of tillers between 1900 to 2000 GDD from rhizomes from both sites for all the three repeats (Figure 3.3).

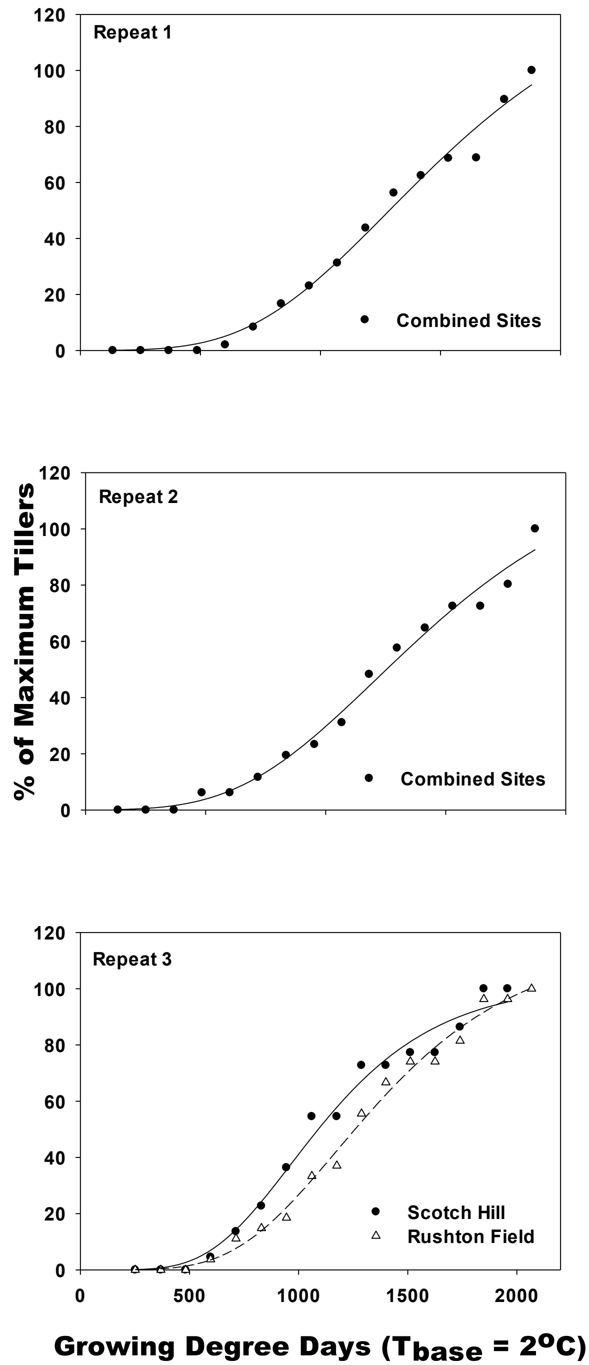

Figure 3.3: Growing degree days (GDD) models for predicting percent of maximum tillers of red fescue for all three repeats. Symbols represent observations and line is fitted regression equations. A Gompertz equation of the form $y = a*\exp[-\exp(-(x-x_0) / b)]$ was fit to the observed data. Parameter estimates and goodness of fit statistics for regression equation is given in Table 3.2.

Table 3.2 Parameter estimates for non-linear models describing percent of maximum red fescue tillers in growth chamber.

Repeats	Sites	Equation[x]	Model parameters[y]	CI[z] - L	CI - U	R^2_{Adj}	RMSE[w]
1	Combined	Gompertz	a = 135.0	101.2	168.8	0.99	3.53
			b = 573.3	402.7	743.9		
			x_0 = 1283.2	1113.0	1453.5		
2	Combined	Gompertz	a = 126.7	96.9	156.6	0.98	3.65
			b = 570.6	400.2	740.9		
			x_0 = 1212.3	1049.9	1374.7		
3	Scotch Hill	Gompertz	a = 102.1	92.2	112.1	0.98	4.32
			b = 372.7	283.3	462.2		
			x_0 = 964.8	906.6	1023.1		
	Rushton Field	Gompertz	a = 116.3	104.6	128.1	0.99	3.09
			b = 466.6	380.8	552.3		
			x_0 = 1180.3	1116.5	1244.1		

[w]RMSE = root mean square error.
[x]The Gompertz equation is $y = a*\exp[-\exp(-(x-x_0)/b)]$.
[y]Gompertz model parameters, a = maximum estimated value of % of maximum tillers, x_0 = inflection point of the curve for GDD and b = rate of increase in the % of maximum tillers (White et al. 2012).
[z]CI = confidence Interval of lower and upper limit.

3.3.2 Field Study

3.3.2.1 Red Fescue Emergence Count

In the vegetative year (2012), a zero emergence count was not recorded due to late quadrat establishment at both sites. More than 60-80% of red fescue emergence in wild blueberry fields was obtained at 160 GDD (April 25 to May 7) at both sites (Figure 3.4). Emergence to 90% of maximum was rapid and was obtained between 630 to 680 GDD (June 21 to June 27) at both sites (Figure 3.4). This was followed by a slow emergence period which delayed peak emergence, especially at Scotch Hill. Peak red fescue emergence was obtained between 800 to 1150 GDD (July 6 to July 20) at both sites (Figure 3.4).

In the crop year (2013), 15-30% of red fescue emergence was obtained between 20 to 26 GDD (April 8 to April 17) at both sites (Figure 3.5). Similar to the vegetative year, more than 80% of emergence was obtained after less than 160 GDD (April 25 to May 9) at both sites (Figure 3.5). This rapid emergence was followed by a slow emergence period which delayed peak emergence. Peak red fescue emergence was obtained between 816 to 1046 GDD (July 4 to July 17) (Figure 3.5).

In summary, red fescue in wild blueberry field shows an initial rapid emergence up to 80% and then it slowed down before it achieved peak emergence in both years at both sites. This rapid emergence may be due to the fact that red fescue is a cool season grass with a base temperature less than 2.5 ^{o}C, so it needs less cumulative temperature for its emergence (Larsen, 2004; Lonati et al. 2009). A similar emergence trend was found in wild blueberry (White et al. 2012). This similarity in emergence pattern between the two species suggests red fescue may compete with wild blueberry. Moreover, red fescue attains its peak emergence earlier than wild blueberry requiring only 800 to 1100 GDD compared to 2132 to 2768 GDD, thus allowing it to more completely establish itself in the field and compete with the crop (White et al, 2012). The predictions obtained from both figures can be used as an indicator to estimate the time of herbicide application such as glyphosate (Chapter 4). Glyphosate can be applied between last week of April and first week of May.

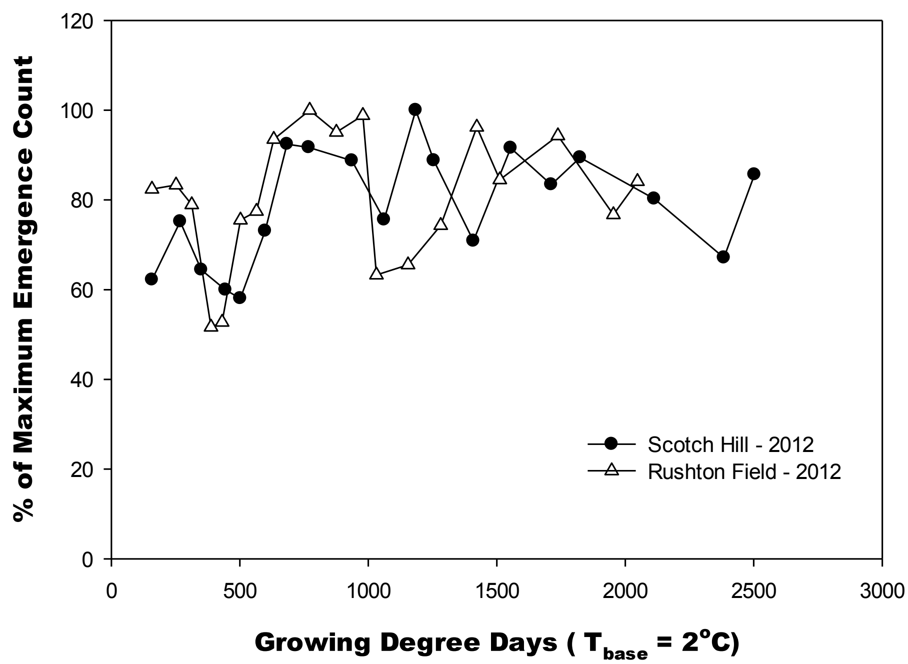

Figure 3.4: Effect of growing degree days (GDD) on emergence count of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2012.

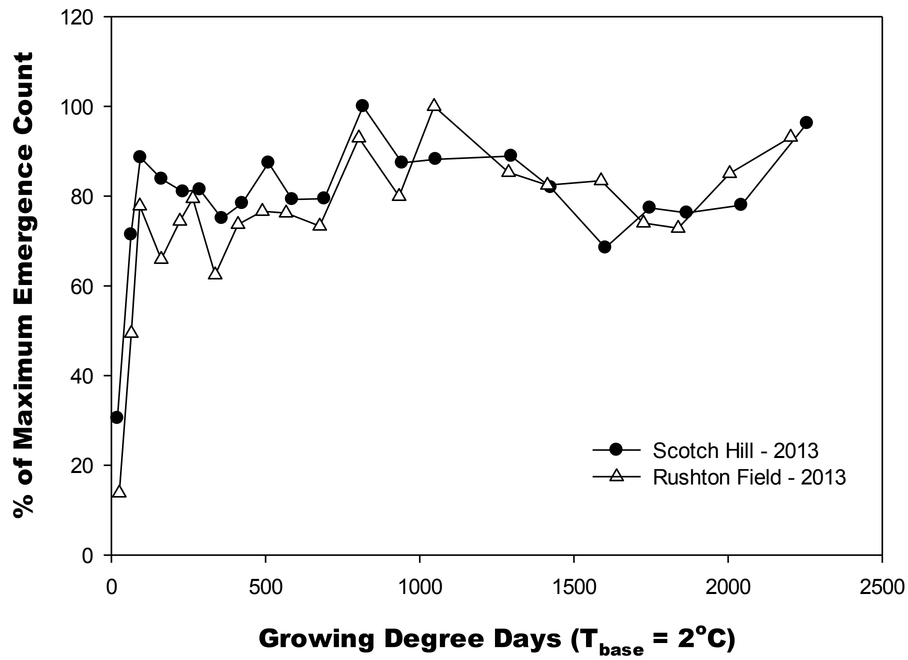

Figure 3.5: Effect of growing degree days (GDD) on emergence count of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2013.

3.3.2.2 Red Fescue Height

Red fescue height in the field study was accurately described by a sigmoid, three parameter model similar to the model developed in the growth chamber study at both sites in both years. These models can not be validated with the models obtained from controlled study because one single model can not be developed. This is due to the significant difference in interaction of repeat x treatment in controlled study.

The coefficient of determination (R^2_{Adj}) and root mean square error (RMSE) for both sites in both years are given in Table 3.3. The individual models of both sites in 2012 were combined to make a single model due to overlapping of model parameters. From Figures 3.6 and 3.7, it is evident that model prediction for red fescue height was quite close to the observed values for both sites in both years. This indicates good performance of these models for predicting height of red fescue in wild blueberry fields of Nova Scotia. We can also conclude that the red fescue increases in height with the increase in GDD and 95% of maximum height was achieved between 850 to 920 GDD (July 4 to July 20) at both sites in both years (Figure 3.6 and 3.7).

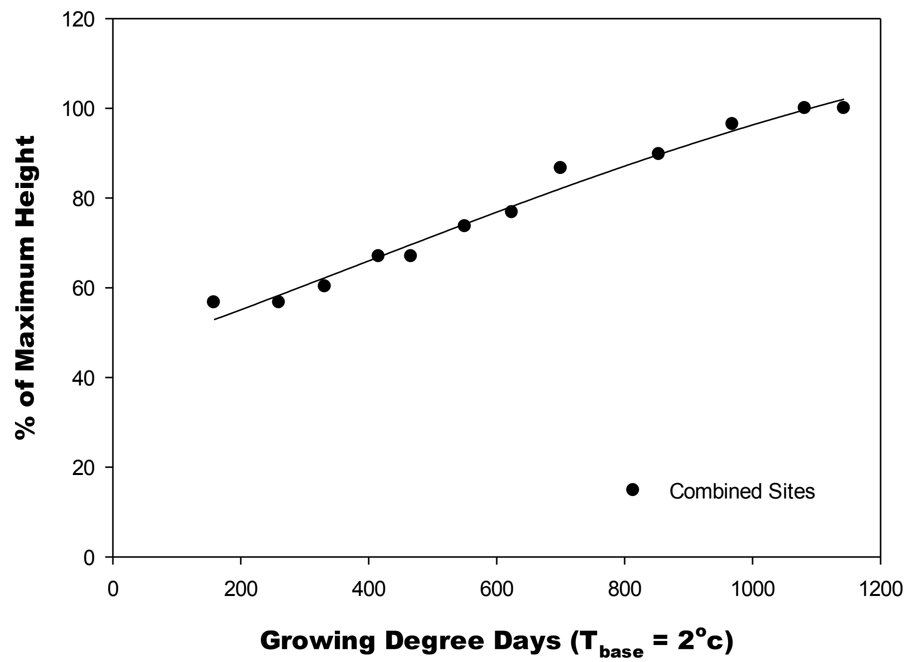

Figure 3.6: Growing degree days (GDD) models for predicting percent of maximum height of red fescue in blueberry field at both sites in Collingwood, Nova Scotia, 2012. Symbol represents observation and line is fitted regression equations. A sigmoid equation of the form $y = a / [1+\exp(-(x-x_0) / b)]$ was fit to the observe data. Parameter estimates and goodness of fit statistics for regression equation is given in Table 3.3.

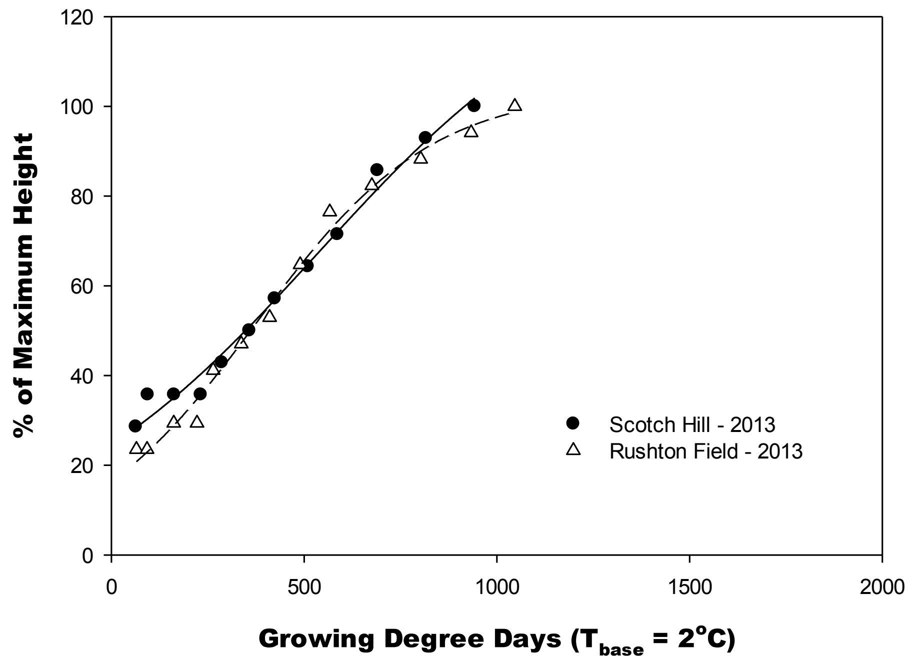

Figure 3.7: Growing degree days (GDD) models for predicting percent of maximum height of red fescue in blueberry field at both sites in Collingwood, Nova Scotia, 2013. Symbols represent observations and lines are fitted regression equations. A sigmoid equation of the form y = a / [1+exp (-(x-x_0) / b)] was fit to the observe data. Parameter estimates and goodness of fit statistics for regression equation is given in Table 3.3.

Table 3.3 Parameter estimates for non-linear models of percent of maximum red fescue height in field study 2012 and 2013.

Sites - year	Equation[x]	Model Parameters[y]	CI[z] - L	CI - U	R^2_{Adj}	RMSE[w]
Combined - 2012	Sigmoid	a = 130.8	99.2	162.3	0.98	2.18
		b = 595.4	353.5	837.4		
		x_0 = 389.5	95.9	683.0		
Scotch Hill - 2013	Sigmoid	a = 134.5	106.9	162.1	0.99	2.52
		b = 357.9	277.1	438.6		
		x_0 = 535.5	369.2	701.9		
Rushton Field - 2013	Sigmoid	a = 103.8	98.1	109.6	0.99	2.35
		b = 226.3	196.8	255.7		
		x_0 = 378.2	342.1	414.3		

[w]RMSE = root mean square error.
[x]The Sigmoid equation is y = a / [1+exp (-(x-x_0) / b)].
[y]Sigmoid model parameters, a = asymptote (estimated value of % of maximum height), x_0 = growing degree days at 50% of the maximum height and b = curve shaped parameter.
[z]CI = confidence Interval of lower and upper limit.

3.3.2.3 Red Fescue leaf development

In 2012, 70% of maximum leaves occurred at 158 GDD at both sites (Figure 3.8). However, in 2013, 90% of maximum leaves occurred at 65 GDD (April 17 to April 25) at both sites (Figure 3.9). This difference may be because the initial leaf development was not recorded due to the late collection of data commenced in 2012 at both sites. All the GDD were calculated from a biofix of 1 April. We conclude that, the red fescue rapidly increases its leaves and then remained approximately the same with a slight increase throughout the growing season. The peak percentage of maximum leaves was attained between 950 to 1280 GDD at both sites in both the years.

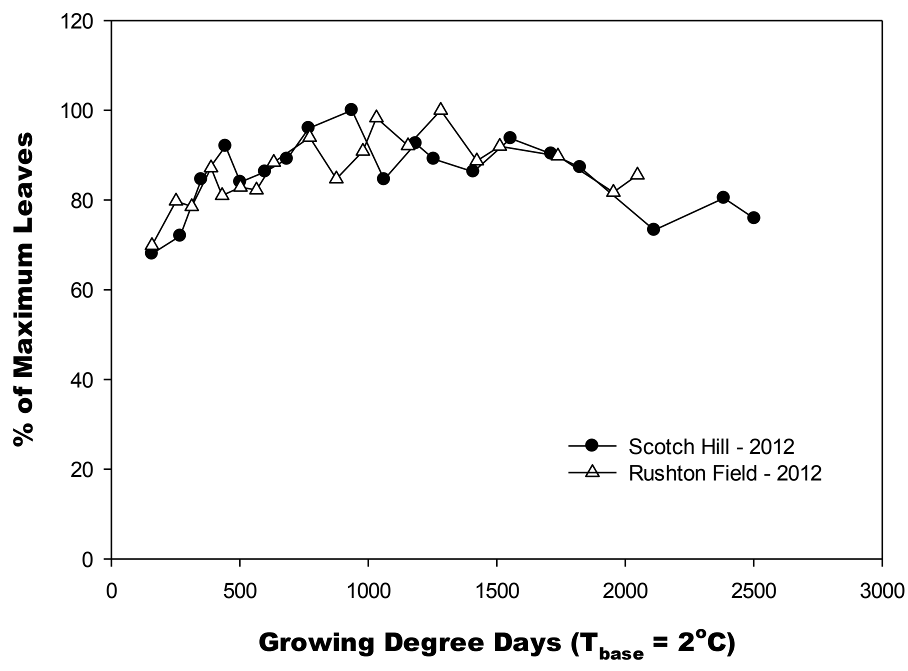

Figure 3.8: Effect of growing degree days (GDD) on leaves of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2012.

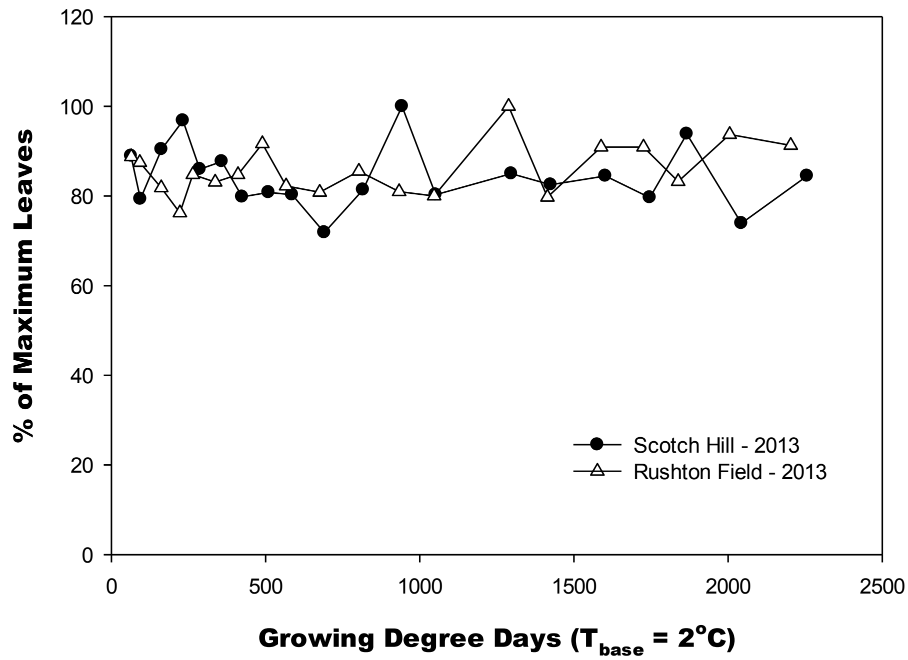

Figure 3.9: Effect of growing degree days (GDD) on leaves of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2013.

3.3.2.4 Red Fescue Tillering

From the trend obtained in the Figure 3.10, tillering of red fescue reached a peak between 1148 to 1250 GDD (July 24 to August 2) at both sites. However, trend obtained in Figure 3.15, tillers initiated between 490 to 510 GDD (June 7 to June 13) and reached a peak between 1050 to 1290 GDD (July 17 to July 31) at both sites (Figure 3.11). From this response we can conclude that red fescue commences producing tillers rapidly which then remains relatively unchanged with fluctuations throughout the growing season. The nonlinear regression of red fescue tillering in the field study cannot be developed from the observed data, hence cannot be validated from the model developed under controlled environments.

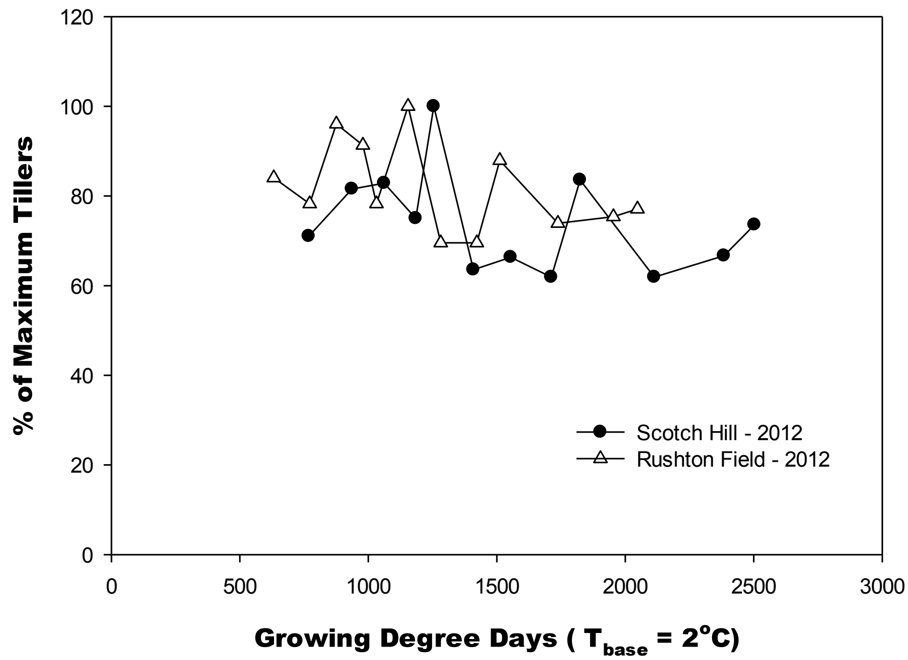

Figure 3.10: Effect of growing degree days (GDD) on tillers of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2012.

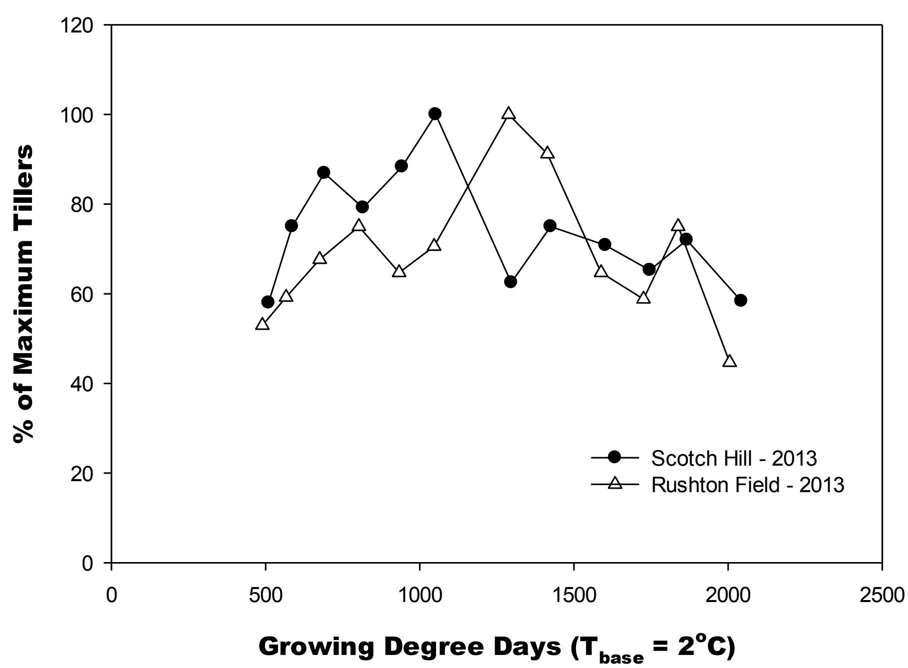

Figure 3.11: Effect of growing degree days (GDD) on tillers of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2013.

3.3.2.5 Red Fescue Seed Head Development

Red fescue seed head development trends from Figure 3.12 showed a peak around 770 GDD (June 27 to July 6) at both site in 2012, whereas in 2013 it started at 350 GDD (May 24 to May 31) and reached a peak around 500 GDD (June 13 to June 20) (Figure 3.13). From Figure 3.12 and 3.13, we can conclude that red fescue starts to produce seed heads rapidly, attains a peak seed head development stage and then starts to decrease in the rest of growing season.

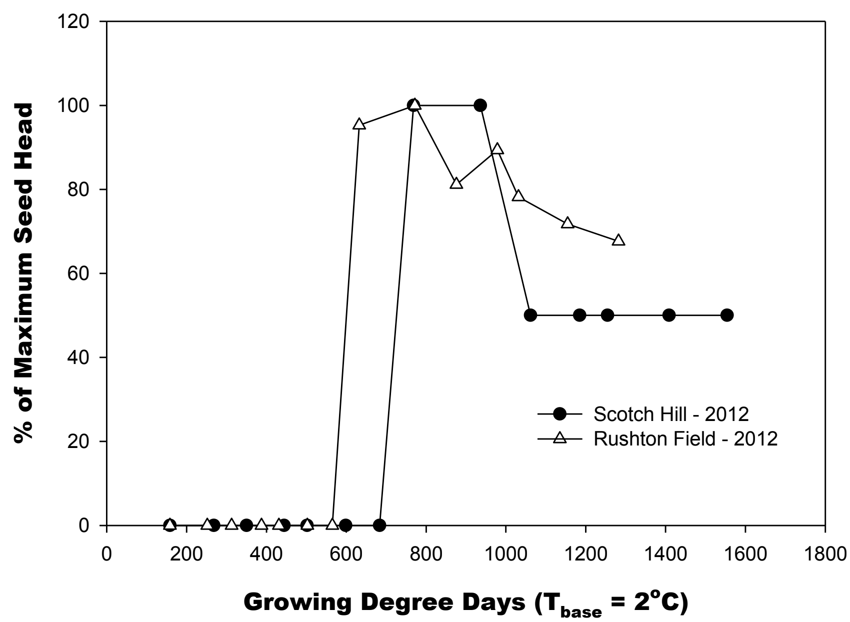

Figure 3.12: Effect of growing degree days (GDD) on seed head of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2012.

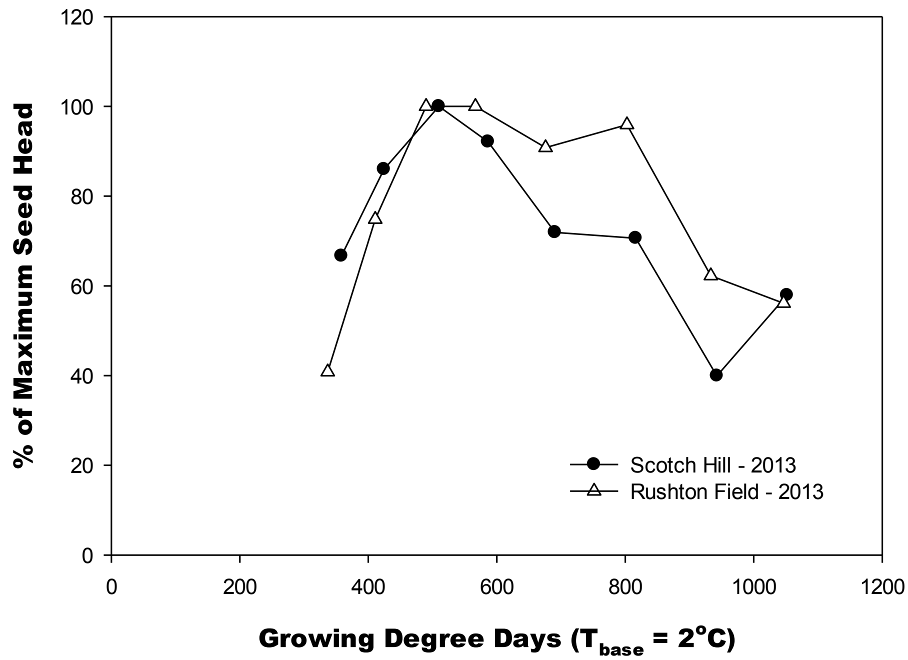

Figure 3.13: Effect of growing degree days (GDD) on seed head of red fescue in blueberry fields at both sites in Collingwood, Nova Scotia, 2013.

3.4 Conclusion

Red fescue is a weed in wild blueberry fields of Nova Scotia and effective weed management can be achieved by understanding its phenological stages. There is no published information available on modelling the phenological stages of red fescue. In this study, GDD models of red fescue were developed under controlled conditions for management and future study of this species in wild blueberry fields and to predict height and tillering of red fescue as a function of cumulative temperature regime. In the growth chamber study, red fescue was predicted to reach peak height and tillers between 1000 to 1400 GDD and 1900 to 2000 GDD respectively from rhizomes of both sites for all the three repeats. All the predicted models satisfied high R^2_{Adj} and low RMSE for good fits of the observed data. In the field study, red fescue was predicted to reach 95% of maximum height between 850 to 920 GDD at both sites in both years.

CHAPTER 4 HERBICIDES FOR CONTROL OF RED FESCUE IN WILD BLUEBERRY FIELDS

4.1 Introduction

Wild blueberry (*Vaccinium angustifolium* Ait.) is a native, perennial berry species in Nova Scotia. It is commercially cultivated in parts of Canada and the United States (Yarborough and Bhowmik, 1989). It is managed commercially on a 2 year cycle. In the vegetative year shoots emerge and grow from underground rhizomes and flower buds develop in the fall. In the following crop year, the flowers open and berries are produced. Fruits are typically harvested during August and September. Weeds are the major yield limiting factor in commercial wild blueberry fields (McCully et al. 1991). Weed management is typically acknowledged as one of the most laborious aspects of crop production (McFadyen 1998), though there are many management options including mechanical, cultural, biological, and chemical, each with associated benefits and risks (DiTomaso 1997).

Herbicides are the predominant management option for weed control in wild blueberry production because they grow as a perennial crop and crop rotation and cultivation cannot be utilized (Boyd and White, 2010). Herbicides are considered the most effective and economic option to manage weeds in these production systems (DiTomaso 1997). Herbicides control a broad spectrum of weed populations in blueberry fields. They are selective and generally dependable. Herbicides and herbicide application equipment are readily available as compared to other management options (Prostko et al. 1998).

Herbicides can be used as pre-emergent or post-emergent, and provide contact, residual or systemic activity. Pre-emergence herbicides are applied before weeds emerge. They are usually applied to soil and are taken up by plants via root uptake or through developing cotyledons. Post-emergence herbicides are applied after weed emergence in the crop fields. Selective post-emergence herbicides are broadcast on foliage in the crop field and non-selective post-emergence herbicides are applied only to the weed top growth (Jensen and Yarborough, 2004).

Red fescue (*Festuca rubra* L.) is a common, cool season, sod forming perennial grass that spreads via seeds and rhizomes. It is a hardy grass that prefers well drained, acidic soils and is drought and shade tolerant (Anonymous 2012). It is a relatively new weed in the wild blueberry industry. It grows and spreads rapidly in blueberry fields forming dense stands. It is relatively localized in the Collingwood area but new populations appear to be spreading throughout the province in areas such as Parrsboro, Nova Scotia. It is likely to become widespread and where it occurs may result in severe yield reduction and in some cases abandonment of the field (N. Boyd personal communication).

There is no published research on red fescue susceptibility to herbicides in blueberry fields. However there are some herbicides such as terbacil, glyphosate and hexazinone which show variable results for management of fescue (*Festuca* species) (McCully et al. 2005)

The overall objective of this experiment was to identify an effective herbicide or combination of herbicides, and application timing, for red fescue control in wild blueberry. The specific objectives were to evaluate spring pre-emergent (PRE), and post-emergent (POST) and fall broadcast herbicides applied in the vegetative year of wild blueberry to control red fescue and their effects on wild blueberry.

4.2 Materials and Methods

4.2.1 Site Description and Experimental Design

In 2012, experimental sites for the spring herbicide trial were set up in two commercial blueberry fields in the Collingwood, Nova Scotia. The two sites were Scotch Hill and Rushton in Nova Scotia. A full description of these two sites was provided in chapter 2. At both sites, the experimental design for the spring application trial was comprised of a randomized complete block design (RCBD) with four blocks and eleven treatments all applied between May and June, 2012. All herbicides tested have the potential to control one or more perennial weeds like grasses, and among these, glyphosate, terbacil, propyzamide and rimsulfuron + nicosulfuron were registered while the remaining herbicides have potential to be registered for use in blueberry production systems. The treatments were applied at both sites, are described in Table 4.1. The plots were 6 m x 2 m with 1m buffer between the blocks at both sites.

In 2012, a fall application herbicide trial was conducted at three different commercial blueberry fields and comprised, at each site, a completely randomize design with three replications and two treatments (Table 4.1). Quadrat size for fall trials was 50 cm x 50 cm. At all three locations selected, propyzamide had already been sprayed by the farmer in the fall of 2012. These alternate locations were chosen, because the two sites we had previously selected in fall 2012 did not have any red fescue grass present.

Table 4.1: Herbicide treatments applied during spring and fall, 2012.

Application Timing		Trade Name	Active Ingredient (a.i)	Application Rate (g a.i ha^{-1})	Application Date
Spring Trial	PRE	Control			
		Ignite + Option + UAN[2]	Glufosinate ammonium +Foramsulfuron	375 + 35.1 + 2000	May 2, 2012
		Weathermax	Glyphosate	901.8	May 2, 2012
		Ignite	Glufosinate ammonium	375	May 2, 2012
		Sinbar	Terbacil	2000	May 8, 2012
		Casaron	Dichlobenil	3.2	May 8, 2012
		Sinbar + Option + UAN	Terbacil + Foramsulfuron	2000 + 35.1 + 2000	May 8, 2012
		[m]Option + UAN	Foramsulfuron	35.1 + 2000	May 8, 2012
	POST	[n]Option + UAN	Foramsulfuron	35.1 + 2000	June 8, 2012
		Peak[1]	Prosulfuron	10	June 8, 2012
		Ultim[1]	Rimsulfuron + Nicosulfuron	25.3	June 8, 2012
Fall Trial	POST	Control			
		Kerb	Propyzamide	2250	November, 2012

1- Agral 90 was added at 0.2% v/v for these treatments as surfactant.
2- UAN- Urea Ammonium Nitrate.
m- Early Application of this treatment.
n- Late Application of this treatment.
PRE- Pre-emergence of Blueberry.
POST- After Emergence of Blueberry.

For both spring and fall herbicide trials, all herbicides were sprayed at their recommended application rate. Among all the herbicides tested, five (glufosinate ammonium, foramsulfuron + UAN, glyphosate, terbacil and dichlobenil) were pre-emergent and four (late application of foramsulfuron + UAN, prosulfuron, rimsulfuron + nicosulfuron and propyzamide) were post-emergent. All these herbicides except propyzamide were applied by using a carbon dioxide pressurized backpack sprayer equipped with XR 8002VS TeeJet nozzles, and before use it was calibrated to deliver the appropriate water volume at a pressure of 40 psi. All the herbicides were sprayed on calm days with walking speed of 1 ms^{-1}. The control plot did not receive any spray.

4.2.2 Data Collection

In the spring application trial, all data (damage rating, density, ground cover, floral bud, flower count, height, biomass and yield) were collected during both the vegetative and crop year. For the fall application trial, all data were collected during the vegetative year only and included the same measurements as for the spring trial except damage rating, flower count and yield.

Herbicide damage ratings were recorded 14, 36, 72, and 365 days after spraying, using a standard damage rating scale of 0 to 10 (0 means no visible injury and 10 means complete death of above ground shoots) used by Hartzler and Foy (1983). Red fescue and blueberry density was measured in the vegetative and crop year of blueberry production. In the vegetative year, density was measured on June 21, 2012 (early) and August 23, 2012 (late), and in the crop year, it was measured on June 7, 2013. The numbers of red fescue and blueberry plants were counted in two randomly placed 25 cm x 25 cm quadrats in each plot at both sites. Ground cover was also measured on June 21, 2012 (early) and August 23, 2012 (late) by using the point intersects method where species and bare spots beneath the intersections were identified (Heady et al. 1959). The percent cover of each plant species was determined from the number of points for each species and the total number of points sampled (Najafi and Solgi 2010). It was recorded within two quadrats (each 50 cm x 50 cm) randomly placed within each plot.

In the spring application trial, blueberry floral buds and flowers were counted on 15 randomly selected blueberry stems in each plot. Blueberry stems were selected by using a diagonally placed line transect method across the plot and blueberry stems were selected randomly close to the line. Floral buds were counted in the vegetative year and flowers in the crop year to estimate the yield potential.

The height of 15 randomly selected blueberry stems were recorded in the vegetative and crop year of blueberry production. In the vegetative year, height was measured on October 16, 2012 and in crop year on June 5, 2013. As for flower buds above, stems were selected by using diagonally placed lines transect method across the plot and blueberry stems were selected at particular intervals close to the line.

The biomass of aboveground red fescue and blueberry in the vegetative year of blueberry production were measured on August 23, 2012 using two randomly placed quadrats, each 25 cm x 25 cm. They were sorted for red fescue, blueberry and other weeds (data not shown) in the laboratory and oven dried for 48 hours at 70°C to determine dry weight of each.

Blueberry yield was determined in August 13, 2013 at both sites of the spring application trial by harvesting berries from two quadrats (each 30 cm x 100 cm) per treatment using hand held rakes. Leaves and debris were removed by wind and the fresh weight of berries was measured. If a quadrat fell in a bare spot where no blueberry stems were present, it was moved to where blueberries were present.

Data collected for the fall application trial included density and ground cover of red fescue and blueberry measured on June 26 (early) and August 19, 2013 (late); biomass of red fescue and blueberry; floral bud and height of blueberry in the vegetative year 2013. All data were collected as described above for the spring application trial.

4.2.3 Statistical Analysis

All the wild blueberry and red fescue data for spring application trial except damage rating were analyzed using the PROC MIXED and for damage rating PROC NPAR1WAY procedures in SAS 9.3 (SAS Institute Inc., Cary, NC, USA). For the parametric method all the assumptions for normality and constant variance of the error terms were checked in Minitab statistical software (verson16). Normality of error terms were satisfied by pen test by constructing normal probability plot of the residuals. Constant variance was satisfied by observing an impression of horizontal band in the graph plotted against the residuals versus the fitted values. For analysis data were transformed to satisfy assumptions when needed. However, data were back transformed before representing the results. Significance of p-values was tested based on 5% level of significance. Fishers Least Significant Difference (LSD) multiple mean comparisons were conducted using least square (LS) means procedure in SAS 9.3.

The wild blueberry and red fescue data for the fall application trial were analyzed using PROC TTEST and PROC NPAR1WAY procedures in SAS 9.3 respectively. For the parametric method all the assumption were satisfied as stated above and for red fescue Kruskal-Wallis test was used in nonparametric method. Significance of p-values was tested based on a 5% level of significance.

4.3 Results and Discussion

Early ground cover, and blueberry density in 2012 and flower count and blueberry height in 2013 were analyzed and presented separately for each site as there was a significant site by treatment interaction. However, all other data (damage rating of red fescue and blueberry, early and late density of red fescue, late density of blueberry, early and late ground cover of red fescue, late ground cover of blueberry, density of blueberry and red fescue in crop year, biomass of red fescue and blueberry, height of blueberry in vegetative year and yield of blueberry) collected in both years at both sites showed no significant site by treatment interaction. Therefore, these data were combined for the two sites (Scotch Hill and Rushton) for analysis.

4.3.1 Spring Herbicides Trials

Blueberry and red fescue damage rating differed significantly with herbicide treatment at 14, 36, 72 and 365 days after spraying (DAS) at both sites (Table 4.2). None of the herbicide treatments had greater damage to blueberries except dichlobenil, glyphosate and prosulfuron at both sites (Figure 4a). Damage ratings for blueberry plants due to dichlobenil and glyphosate at 36 DAS was 50% and 20% respectively in vegetative year, but the effect of both herbicides gradually decreased so that by 365 DAS there was no apparent visible damage to blueberries. However, prosulfuron consistently damaged blueberry from 36 to 365 DAS and the damage rating ranged from 30 to 40%.

Table 4.2: The Pr>χ^2 values of damage ratings of species on 14, 36, 72 and 365 Day After Spraying as affected by different herbicide treatments at both sites in Collingwood, Nova Scotia, 2012.

Species \ DAS[1]	14 DAS	36 DAS	72 DAS	365 DAS
Red Fescue	<0.0001	<0.0001	<0.0001	<0.0001
Blueberry	<0.0001	<0.0001	<0.0001	<0.0001

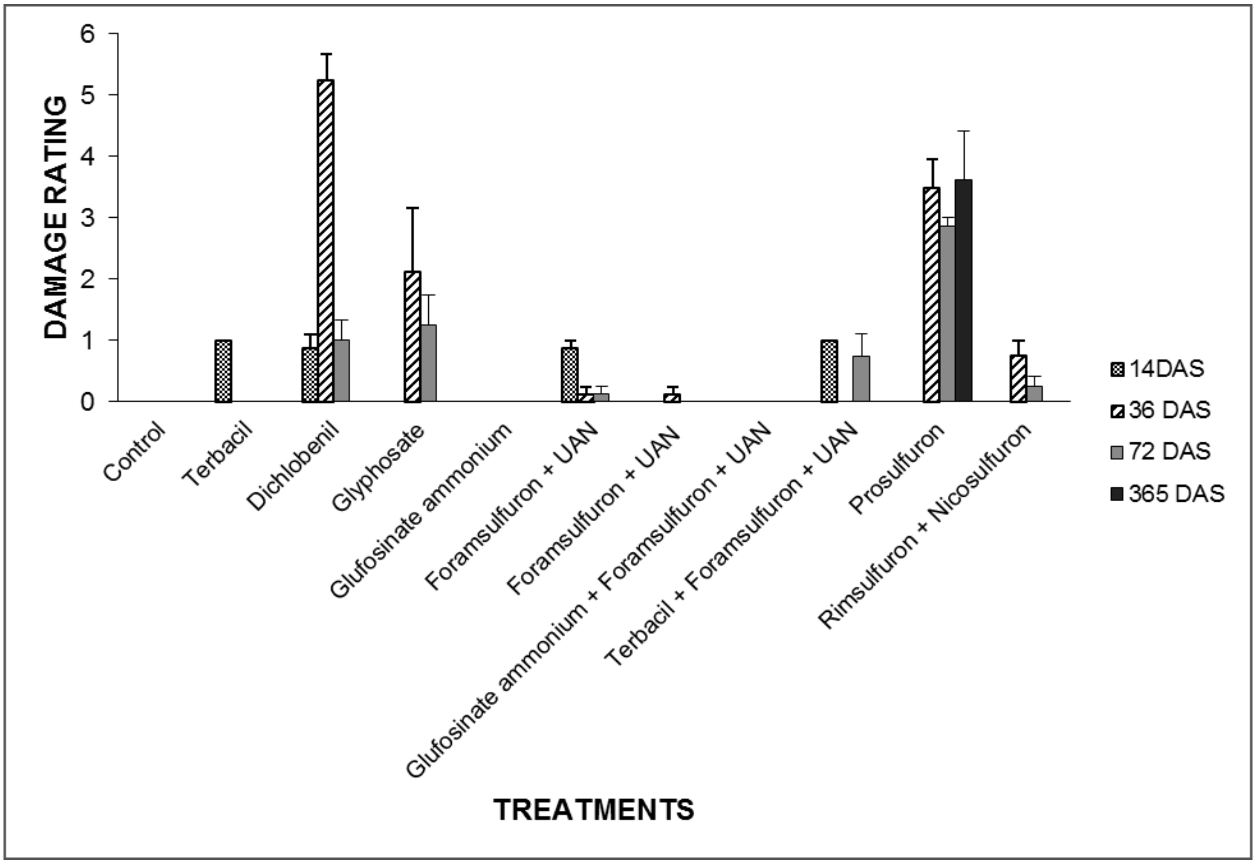

Figure 4a: Blueberry damage ratings at both sites, Collingwood, Nova Scotia as affected by spring applied pre- and post-emergence herbicides. Error bars state the standard error of means. Blueberry damage ratings were recorded on a 0 to 10 scale.

Glyphosate showed the highest damage to red fescue on day 36 before dropping but remaining consistently the highest for all treatments from 72 to 365 DAS (Figure 4b). The reduction in visible damage of red fescue on 36, 72 and 365 DAS were 80%, 60% and 60% respectively. From these results recorded during the vegetative year, we can conclude that glyphosate appears to provide significant control of red fescue at both sites. Jensen and Yarborough (2004) mentioned that glyphosate can control broad spectrum of herbaceous species including sedges, grasses and ferns. None of the other herbicide treatments resulted in adequate control of red fescue at both sites.

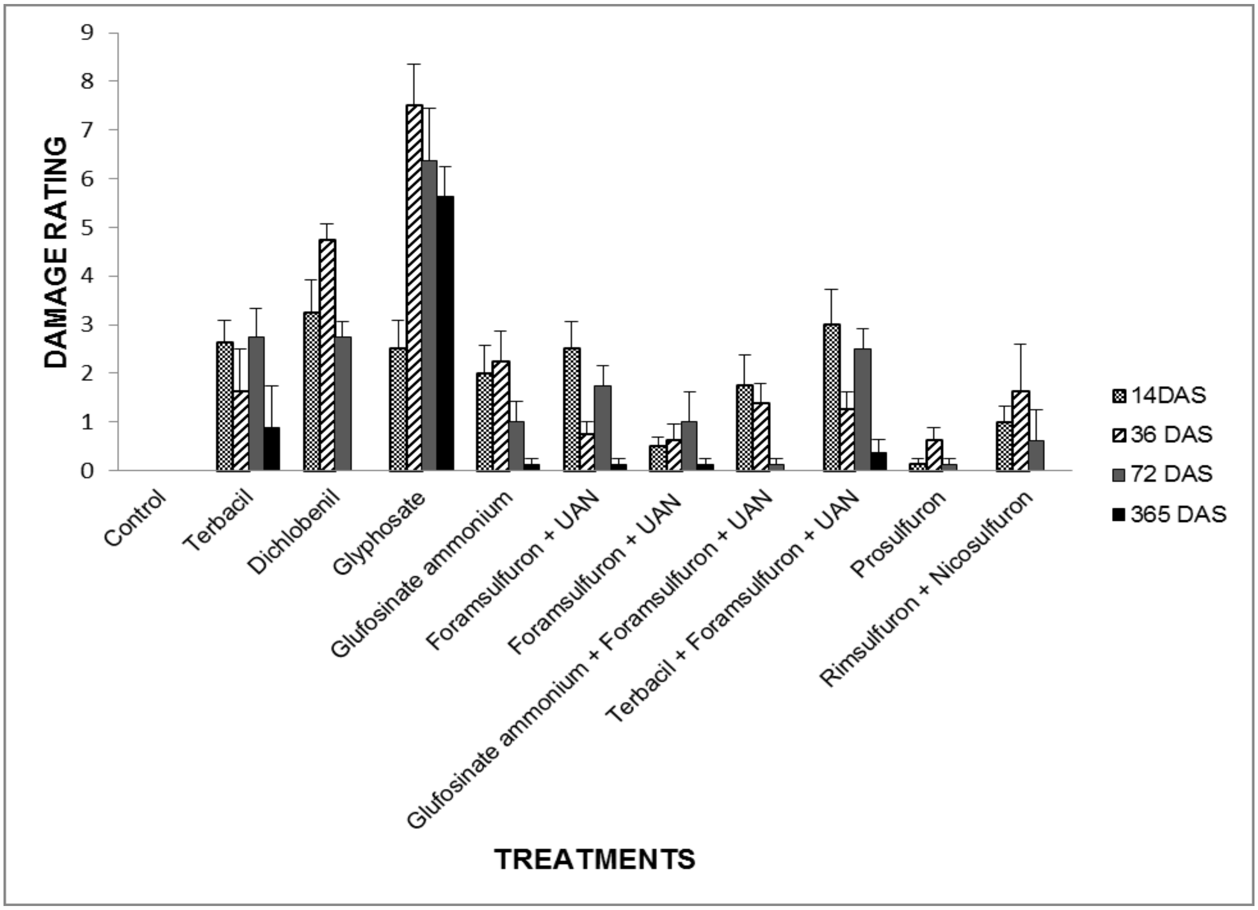

Figure 4b: Red Fescue damage ratings at both sites in Collingwood, Nova Scotia as affected by spring applied pre- and post-emergence herbicides. Error bars state the standard error of means. Red Fescue damage ratings were done on a 0 to 10 scale.

Herbicides had no effect on the early measured density of blueberry at Scotch hill and late density of blueberry at both sites (Table 4.3) during the vegetative year. Among all the herbicides tested, prosulfuron, rimsulfuron + nicosulfuron, dichlobenil, glyphosate and glufosinate ammonium + foramsulfuron + UAN showed significant reduction of early ground cover of blueberry as compared to the control at the Rushton site (Table 4.3). Glyphosate, however, significantly reduced the early density and ground cover of blueberry at the Rushton site in the vegetative year when compared to the control (Table

4.3). Even though the pre-emergence herbicides were sprayed before blueberry emergence, the crop damage caused by them may be due to the fact that the blueberry ramets might have begun to emerge but were beneath the thatch layer. The Rushton site had a high soil organic matter (9.6%) or thatch layer, as compare to Scotch hill (6.9%) (Harlow Institute, Truro, Nova Scotia) which might retain the herbicide for longer period.

With respect to herbicide effects on red fescue during the vegetative year, at both sites the stand density (m^{-2}) of this weed, was significantly reduced by all the herbicide treatments, but only when measured in late August but not June (early) (Table 4.4), and with the exception of herbicides foramsulfuron + UAN, and rimsulfuron + nicosulfuron. Glyphosate reduce red fescue density by 73% and biomass by 64% in August as compared to the control at both sites. In the following crop year (2013), however, all herbicide treatments failed to influence the density of red fescue and blueberry at both sites (Table 4.4 and 4.6).

Table 4.3: Effects of herbicide treatments on wild blueberry density and ground cover at both sites in Collingwood, Nova Scotia, 2012.

Treatments	Density (m^{-2})			[x]Ground Cover (%)		
	Early		Late	[y]Early		Late
	Scotch Hill	Rushton Field	Combined Sites	Scotch Hill	Rushton Field	Combined Sites
Control	738 ± 161[z]	724 ± 59 cd	1135 ± 136	65 ± 3	62 ± 6 a	70 ± 3
Terbacil	978 ± 19	1062 ± 130 ab	969 ± 45	66 ± 8	57 ± 3 abc	73 ± 4
Dichlobenil	668 ± 89	592 ± 30 d	922 ± 116	61 ± 9	44 ± 1 d	73 ± 3
Glyphosate	1000 ± 39	336 ± 60 e	841 ± 80	70 ± 8	19 ± 2 e	71 ± 5
Glufosinate ammonium	790 ± 180	976 ± 63 ab	1078 ± 124	63 ± 9	63 ± 2 a	71 ± 5
[m]Foramsulfuron + UAN[1]	964 ± 244	1116 ± 147 a	1068 ± 111	71 ± 7	61 ± 3 a	70 ± 4
[n]Foramsulfuron + UAN	718 ± 207	1030 ± 137 ab	1094 ± 125	66 ± 8	58 ± 5 ab	69 ± 6
Glufosinate ammonium + Foramsulfuron + UAN	930 ± 247	1118 ± 85 a	972 ± 91	76 ± 8	51 ± 2 bcd	74 ± 5
Terbacil + Foramsulfuron + UAN	1230 ± 90	982 ± 56 ab	1151 ± 117	80 ± 2	63 ± 3 a	71 ± 5
Prosulfuron	1048 ± 93	842 ± 84 bc	1113 ± 70	62 ± 6	49 ± 1 cd	66 ± 2
Rimsulfuron + Nicosulfuron	1035 ± 60	912 ± 143 abc	961 ± 84	66 ± 7	52 ± 4 bcd	68 ± 5
p value	0.2949	<0.0001	0.1100	0.6929	<0.0001	0.9477

[z]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
SE- standard error, m- Early application, n- Late application and 1- Urea Ammonium Nitrate.
[y]Early ground cover and density measured on June 21, 2012 and late on August 23, 2012.
[x]Ground Cover is a percentage of plant species in particular given area.

Table 4.4: Effects of herbicide treatments on red fescue density during the vegetative and crop year, and ground cover and biomass of red fescue at both sites during the vegetative year in Collingwood, Nova Scotia.

Treatments	Density (m^{-2})			[x]Ground Cover (%)		Biomass (ton ha^{-1})
	2012		2013	[y]Early	Late	
	Early	Late				
Control	646 ± 4	699 ± 5 ab[z]	574 ± 10	20 ± 3	22 ± 3	0.241 ± 0.004
Terbacil	298 ± 18	394 ± 10 bc	290 ± 7	22 ± 6	15 ± 4	0.107 ± 0.006
Dichlobenil	481 ± 20	405 ± 11 bc	497 ± 5	15 ± 4	15 ± 2	0.139 ± 0.003
Glyphosate	164 ± 6	189 ± 7 c	241 ± 1	9 ± 2	6 ± 2	0.087 ± 0.007
Glufosinate ammonium	426 ± 7	441 ± 10 bc	509 ± 11	18 ± 3	12 ± 3	0.152 ± 0.006
[m]Foramsulfuron + UAN[1]	740 ± 11	839 ± 5 a	582 ± 4	19 ± 3	15 ± 4	0.260 ± 0.002
[n]Foramsulfuron + UAN	631 ± 13	844 ± 11 a	495 ± 4	16 ± 3	16 ± 4	0.273 ± 0.005
Glufosinate ammonium + Foramsulfuron + UAN	400 ± 15	463 ± 14 abc	554 ± 4	17 ± 5	16 ± 4	0.177 ± 0.007
Terbacil + Foramsulfuron + UAN	638 ± 7	412 ± 10 bc	431 ± 1	17 ± 4	20 ± 5	0.168 ± 0.005
Prosulfuron	409 ± 5	376 ± 3 bc	467 ± 9	22 ± 5	13 ± 3	0.156 ± 0.002
Rimsulfuron + Nicosulfuron	405 ± 8	505 ± 3 ab	482 ± 24	21 ± 6	16 ± 5	0.170 ± 0.001
p value	0.0801	0.0081	0.2500	0.1671	0.1710	0.2286

[z]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
SE- standard error, m- Early application, n- Late application and 1- Urea Ammonium Nitrate.
[y]Early ground cover and density measured on June 21, 2012 and late on August 23, 2012.
[x]Ground Cover is a percentage of plant species in particular given area.

The spring herbicide treatments had no significant effect on early and late red fescue ground cover (Table 4.4) at both sites in 2012. Similarly, early blueberry cover (Table 4.3) at Scotch Hill and late blueberry cover at both sites (Table 4.3) during the vegetative year were also not significantly affected. However, at Rushton a significant reduction of early blueberry cover in response to herbicides as compared to all other treatments was recorded (Table 4.3).

Table 4.5: Effects of spring herbicide treatments on biomass, height and floral bud of wild blueberry at both sites in Collingwood, Nova Scotia, 2012.

Treatments	Floral Bud ($Stem^{-1}$)	Height (cm)	Biomass (ton ha^{-1})
Control	[z]3 ± 0	12 ± 1 a	2.408 ± 0.312
Terbacil	3 ± 0	13 ± 1 a	2.285 ± 0.192
Dichlobenil	3 ± 1	13 ± 1 a	2.379 ± 0.323
Glyphosate	3 ± 0	13 ± 1 a	2.230 ± 0.454
Glufosinate ammonium	4 ± 1	14 ± 1 a	2.586 ± 0.193
[m]Foramsulfuron + UAN[1]	3 ± 1	13 ± 1 a	2.410 ± 0.180
[n]Foramsulfuron + UAN	3 ± 0	13 ± 1 a	2.188 ± 0.247
Glufosinate ammonium + Foramsulfuron + UAN	3 ± 0	13 ± 1 a	2.275 ± 0.228
Terbacil + Foramsulfuron + UAN	3 ± 0	13 ± 1 a	2.474 ± 0.263
Prosulfuron	3 ± 0	11 ± 1 b	1.803 ± 0.148
Rimsulfuron + Nicosulfuron	3 ± 0	13 ± 1 a	2.128 ± 0.271
p value	0.5183	0.0121	0.1013

[z]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
SE- standard error.
m- Early application.
n- Late application.
1- Urea Ammonium Nitrate.

Table 4.6: Effects of spring herbicide treatments on height, density, flower count and yield of wild blueberry at both sites in Collingwood, Nova Scotia, 2013.

Treatments	Height (cm)		Density (m^{-2})	Flower Count ($stem^{-1}$)		Yield (ton ha^{-1})
	Scotch Hill	Rushton Field	Combined Sites	Scotch Hill	Rushton Field	Combined Sites
Control	[z]19 ± 2 ab	13 ± 1	823 ± 60	33 ± 6	13 ± 2 bc	2.654 ± 1.431 cd
Terbacil	19 ± 0 ab	13 ± 1	804 ± 42	38 ± 1	10 ± 1 c	4.549 ± 1.575 a
Dichlobenil	18 ± 1 abc	13 ± 0	857 ± 65	34 ± 3	12 ± 3 bc	4.730 ± 1.352 a
Glyphosate	20 ± 1 a	14 ± 1	781 ± 77	31 ± 3	18 ± 1 a	4.137 ± 1.322 ab
Glufosinate ammonium	18 ± 0 abc	15 ± 0	785 ± 54	31 ± 4	16 ± 2 ab	4.380 ± 1.369 ab
[m]Foramsulfuron+UAN[1]	19 ± 1 ab	13 ± 1	1000 ± 86	36 ± 1	10 ± 1 c	4.618 ± 1.404 a
[n]Foramsulfuron+UAN	16 ± 1 cd	15 ± 0	832 ± 72	32 ± 3	12 ± 1 bc	3.071 ±1.465 bcd
Glufosinate ammonium+ Foramsulfuron+UAN	20 ± 1 a	14 ± 1	898 ± 86	31 ± 4	11 ± 1 c	4.522 ± 1.455 ab
Terbacil+Foramsulfuron+ UAN	19 ± 1 ab	14 ± 0	899 ± 51	25 ± 4	13 ± 1 bc	3.494 ± 1.465 abc
Prosulfuron	13 ± 0 d	12 ± 0	961 ± 64	30 ± 3	11 ± 2 c	2.199 ± 1.473 d
Rimsulfuron+Nicosulfuron	17 ± 1 bc	13 ± 1	893 ± 81	37 ± 2	10 ± 1 c	4.145 ± 1.502 ab
p value	0.0002	0.1851	0.2185	0.1713	0.0196	0.0012

[z]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD $P<0.05$).
SE- standard error, m- Early application, n- Late application and 1- Urea Ammonium Nitrate.

The herbicides treatments had no significant effect on blueberry height in the crop year (Table 4.6) at Rushton. However, prosulfuron treatments at both sites in the vegetative year and Scotch Hill in the crop year showed a significant reduction of blueberry height as compared to all other treatments (Table 4.5 and 4.6 respectively). Blueberry (Table 4.5) and red fescue biomass (Table 4.4) at both sites were not significantly affected by herbicide treatments in the vegetative year. Since both biomass samples were collected in the later stages of the vegetative year, no significant difference found in the biomass of both blueberry and red fescue indicates that both the plants recovered in the later stages of the vegetative year. It was reported that injured red fescue can completely recover by regenerating roots and shoots (Wyse et al. 1986) and by developing reproductive tillers (Gossen et al. 2002). Previous studies have found that either fertilizer application or herbicide at weed control in the vegetative year increased vegetative growth of blueberry. Penney and McRae (2000), found increased biomass and height of blueberry in plots where weeds were controlled by herbicides. The increase in biomass and height of blueberry was in accordance to the weed control. But in this study, there was no increase in either the blueberry biomass or the blueberry height; this could be due to recovery of red fescue also at the same time, which might have caused competition between the plants in the field as also discussed in Chapter 2. This is strongly supported by no decrease in the red fescue biomass found in this study.

There was no significant difference among herbicide treatments on blueberry floral buds in the vegetative year (Table 4.5) at both sites and flower count in the crop year (Table 4.6) at Scotch Hill. However, glyphosate and glufosinate ammonium herbicide treatments at Rushton resulted in significantly higher numbers of blueberry flowers as compared to all other treatments (Table 4.6) in the crop year. All the herbicide treatments except late application of foramsulfuron + UAN, terbacil + foramsulfuron + UAN and prosulfuron, significantly increased blueberry yields at both sites as compared to the control (Table 4.6). This may be due to the removal of plant species that compete with the blueberry and allow blueberry to use available space and nutrients (Eaton 1994).

The above results indicate that glyphosate can control red fescue and can also significantly enhance blueberry yield, flower count, height. However, it also slightly damaged blueberry in terms of visible damage ratings, immediately after application in the vegetative year although the crop recovered from the damage later the same season. Research suggested that blueberry growth should be improved during vegetative year, especially the period of later stages of vegetative year, when the fruit buds develop, since it is this period which actually determines the potential yield in the following crop year (Penney and McRae 2000). No decrease in the floral bud count in this study clearly symbolizes that the blueberry recovered from the damage caused in the early stages of the vegetative year. This recovery was strongly supported by the significant increase in the blueberry flower and yield in the following crop year. A similar result was found where Hexazinone spray did not significantly increase floral buds in vegetative year, but increased yield in the crop year. This could be attributed to the difference in the blueberry size, reduced number of weed stands and hence reduced interference of the weed during harvesting operations (Kennedy et al. 2010). From chapter 2, we found that the sooner red fescue is managed in blueberry fields, the lower the weed pressure in the following year. Glyphosate provided the greatest control of red fescue with 60 to 80% reduction in stand density respect to stand density in the year of application.

4.3.2 Fall Herbicide Trials

The fall herbicide treatment had significantly higher blueberry cover for both early and late measurement at all three sites (Table 4.7). Similarly, early and late red fescue cover (Table 4.8) at all three sites had significantly lower red fescue (98 and 96% respectively) cover as compared to control. The application of propyzamide in fall for control of grasses and fescue species was suggested by Jensen and Yarborough (2004) and McCully et al (2005). McCully et al (2005) suggested that propyzamide suppressed fescue species.

Propyzamide sprayed as a fall application proved significantly higher density of blueberry (Table 4.7) and lower density (99% and 98% respectively) of red fescue (Table 4.8) when measured on June 26 and August 19, 2013 compared to the control at all the three sites.

Fall herbicide treatments had no significant effect on floral bud and blueberry height in vegetative year (Table 4.7) at all the three sites. There was also no significant difference among treatments on blueberry biomass in the vegetative year (Table 4.7) at all three sites. However, Propyzamide treatments at all three sites produced a significant reduction of red fescue biomass (99%) as compared to the control (Table 4.8). Therefore, it can be concluded that propyzamide was the most effective fall herbicide to control red fescue.

Table 4.7: Effects of fall applied herbicide treatments on biomass, density, height, floral bud and ground cover of wild blueberry at all the three sites in Collingwood, Nova Scotia, 2013.

Treatments	Density (m^{-2})		[x]Ground Cover (%)		Height (cm)	Floral Bud (stem^{-1})	Biomass (ton ha^{-1})
	Early	Late	[y]Early	Late			
Control	720 ± 77 b[z]	764 ± 83 b	35 ± 2 b	44 ± 3 b	21 ± 1	5 ± 1	3.441 ± 0.312
Propyzamide	1076 ± 68 a	1068 ± 55 a	78 ± 5 a	92 ± 3 a	21 ± 1	6 ± 1	4.207 ± 0.339
p value	0.0031	0.0073	<0.0001	<0.0001	0.9246	0.206	0.116

[z]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
SE = standard error.
[y]Early ground cover and density measured on June 26, 2013 and late on August 19, 2013.
[x]Ground Cover is a percentage of plant species in particular given area.

Table 4.8: Effects of fall applied herbicide treatments on biomass, stem density and ground cover of red fescue at all the three sites in Collingwood, Nova Scotia, 2013.

Treatments	Density (m^{-2})		Ground Cover (%)		Biomass (ton ha^{-1})
	Early	Late	Early	Late	
Control	1886 ± 176 a[z]	2094 ± 125 a	47 ± 5 a	52 ± 2 a	1.090 ± 0.108 a
Propyzamide	9 ± 9 b	39 ± 28 b	1 ± 1 b	2 ± 2 b	0.007 ± 0.004 b
$Pr>\chi^2$	0.0002	0.0003	0.0002	0.0002	0.0003

[z]Means ± SE within columns followed by the same letter are not significantly different at 5% level of significance (LSD P<0.05).
SE = standard error.
[y]Early ground cover and density measured on June 26, 2013 and late on August 19, 2013.
[x]Ground Cover is a percentage of plant species in particular given area.

From the phenology study (chapter 3), we know that 60 to 80% red fescue emergence occurred at 160 GDD (April 25 to May 7), whereas blueberry ramet emergence occurred between 222 to 265 GDD (May 6 to May 14) (White at al. 2012). This indicates that the best time to control red fescue effectively is two weeks before emergence of blueberry i.e. the last two weeks of April to avoid damage to blueberry. It is this time when the red fescue is actively growing and it has highest probability to translocate herbicide to the roots and rhizomes (Yarborough 1999). Glyphosate was found to be the most effective herbicide among all the screened herbicide in spring application trial. However, propyzamide was also effective in the fall application trial. Glyphosate is a non-selective, broad spectrum and inexpensive herbicide which increases its adoption by the farmers. This herbicide can not only control red fescue but can also control other weeds in the field. However, the time of application is crucial to its use in blueberry fields. So, it should be sprayed two weeks before emergence of blueberry. If it is sprayed too late in blueberry fields, then there is a high chance of significant, long term damage to blueberry as well as weeds, which can cause harmful effect on yields in the crop years. Kerb is an expensive herbicide as compared to Glyphosate. However, it has shown to significantly control red fescue without causing any damage to blueberry, because it was applied after pruning of blueberry. The time of application was before frost and below 4^{o}C. It can be recommended that both the herbicides can be used in alternate production years with proper timing, for an economically viable and effective management strategy for red fescue.

4.4 Conclusions

From this study it can be concluded that, glyphosate, the pre-emergence herbicide (before blueberry emergence) was the most effective for control of red fescue in blueberry fields, among all the herbicides screened in the spring application trial. The plots sprayed with this herbicide were found to increase blueberry yields by 56% with control of 60 to 80% of red fescue during 36 to 365 DAS as compared to a control, even though it damaged blueberry in the early growth stages. Glyphosate application may affect the mycorrhizae association of blueberry, soil ecology and fertility. From the fall trial, propyzamide was found to be an efficient herbicide to control red fescue biomass up to 99% without damaging blueberry as compared to a control. Propyzamide can only be applied in fall, when temperature is below 4ºC and also it is expensive.

CHAPTER 5 CONCLUSION

5.1 Overview

The main focus of this study was to increase the understanding of red fescue growth dynamics in wild blueberry fields, identify effective herbicides and maximize herbicide efficacy with proper application timing. The specific research objectives were to 1) evaluate the impact of weed red fescue removal timing on wild blueberry growth and reproduction; 2) develop temperature-based phenological models with respect to height and tillering of red fescue and 3) evaluate potential herbicides and maximize herbicide efficacy with proper application timing, for red fescue suppression in wild blueberry fields.

5.2 Overall Conclusion

Red fescue is a perennial rhizomatous and sods forming grass and a successful turf species that is a newly emerging weed in wild blueberry fields of Nova Scotia. In this study we have shown that red fescue competes for moisture in the vegetative year of wild blueberry but this competition for resources was not reflected in yield reductions and other biometric measurements (i.e. biomass, stem density, height and leaf area) of wild blueberry at both sites. The data from this study also indicates that the effective control of red fescue in its early stages (specifically to provide a weed-free period from May onwards), may be helpful to reduce a population increase of red fescue over subsequent years in blueberry fields. Red fescue may affect wild blueberry because of moisture competition, but any significant effect was not shown at the level of weed infestation found at both sites in this study. Red fescue is not directly affecting wild blueberry in this study but these levels of infestation would still interfere with wild blueberry management operations such as harvesting, decrease blueberry pack quality, and potentially increase insect infestation, although documenting these weed impacts were beyond the scope of this study.

Red fescue emerged before emergence of wild blueberry and reached 60 to 80% emergence around 160 GDD which corresponds to the last week of April to first week of May whereas blueberry ramet emergence occurred between 222 to 265 GDD which corresponds to the first week of May to mid of May. This indicates that the best time to effectively suppress red fescue growth is two weeks before wild blueberry emergence i.e. the last two weeks of April in order to avoid damage to wild blueberry. During this period red fescue is actively growing and it has highest probability to absorb through its foliage and translocate a systemic herbicide to the above and below ground growing points. Red fescue emergence peaked earlier than wild blueberry, requiring only 800 to 1100 GDD compared to 2132 to 2768 GDD. This allows red fescue to establish itself in wild blueberry fields and compete with the crop. Red fescue height was well described by a three-parameter sigmoid nonlinear regression model and reached peak height around 850 to 920 GDD, which corresponds to the first two weeks of July.

Herbicide use is one of the common weed management practices in wild blueberry production. Among all the screened herbicides in the spring application trial, glyphosate was found to be the most effective herbicide. Glyphosate controlled 60 to 80% of red fescue during 36 to 365 DAS compared to a non-treated plot (control) with a

56% increase in berry yield shown in this study. However, in the fall application trial propyzamide was also effective and controlled 99% of red fescue as compared to non-treated plot. Glyphosate is a non-selective, broad spectrum and cheap herbicide which increases its adoption by the farmers. This herbicide can not only control red fescue but can also control other weeds in the field. However, to avoid damage to the crop the time of application is crucial to its use in blueberry fields and it should be sprayed two weeks before emergence of blueberry. If it is sprayed too late in a blueberry field, then there is a high chance of significant, long term damage to blueberry as well as weeds, resulting in yield losses in subsequent crop years. Propyzamide is an expensive herbicide as compared to glyphosate; however, we have shown here it significantly controlled red fescue without damaging the blueberry crop, because it was applied after crop pruning. The time of application was before frost and below 4ºC. It can be recommended that both these herbicides be used in alternate production years, for an economically viable and effective management strategy for red fescue. Propyzamide can be applied in the fall. If it is applied at the right time, it is a good herbicide otherwise it can give inconsistent results. This can be followed by spring application of glyphosate, if substantial red fescue emergence is noted. Also, missing spots can be sprayed by the use of glyphosate as spot spray.

5.3 Future Directions

To assess the direct effect of red fescue removal on wild blueberry, a competition study should be conducted for more than two years. In future studies the competition for light can also be studied along with nutrient and moisture levels to get a more comprehensive understanding of competition. In a future phenology study of red fescue, validated emergence, height, tillering and seed-head production models can also be developed to use over a wide geographic region. In future herbicide screening trials, testing of different concentrations of glyphosate application rates and also the effect of propyzamide and glyphosate applied one after another on red fescue control should be assessed. We should also screen many other potential herbicides for fall application for control of red fescue.

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