Weed Management Options for Organic Wild Blueberry (*Vaccinium angustifolium* Ait.) Production

by

Goutam Kuwar

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Supervisor: ________________________________

Readers: ________________________________

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Signature of Author

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Abstract

Weeds are considered a major problem for organic wild blueberry (*Vaccinium angustifolium* Ait.) production due to their excessive growth and limited management options available. Therefore, the primary objective of this study was to investigate burning in combination with sulphur application as a weed management option for organic blueberry production. In addition, Finalsan® and Ecoclear™ as potential candidates for perennial weed control in organic production were evaluated. Burned and sulphur plots produced higher blueberry stem density, blueberry cover and yield compared to mowed and no-sulphur plots, respectively, although, the interaction was not significant. Similarly, low weed density and cover were observed in burning and sulphur application plots. Mycorrhizal colonization in blueberry roots was significantly higher in burned plots than mowed plots. A single application of Finalsan® and Ecoclear™ effectively controlled goldenrod, sweet fern and bracken fern. However, a single application of either product did not control wild raisin or moss.

List of Abbreviations and Symbols Used

CO_2	Carbon dioxide
cm	Centimetre
DAS	Days after spraying
°C	Degree Celsius
EMF	Ericoid mycorrhizal fungi
ha	Hectare
kg	Kilogram
km	Kilometre
KPa	Kilopascal
LS	Least square
L	Litre
L ha^{-1}	Litre per hectare
m	Metre
m^2	Metre square
ml	Millilitre
N	Nitrogen
OM	Organic matter
KOH	Potassium hydroxide
%	Percent
v	Volume

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Chapter 1.0 Introduction

1.1 Introduction to the Problem

Lowbush blueberry (*Vaccinium angustifolium* Ait.), commonly known as wild blueberry, is a native shrub of northeastern North America (Eaton et al. 2004). It is an important crop in Maine, Quebec and Atlantic Canada (Bell et al. 2010). In Nova Scotia alone, more than 14,000 metric tonnes of blueberries (high bush and low bush) were produced in 2010 and contributed more than $22 million to the farm gate value in the same year (Statistics Canada 2011). Total wild blueberry acreage has increased in Atlantic Canada over the past decade but the total area managed organically remains very small with the actual acreage unknown. However, there is interest in producing organic wild blueberries due to price premiums, strong demand and environmental concerns (Drummond et al. 2009).

Weeds are considered one of the major problems in wild blueberry production. They compete for nutrients, moisture and light and also act as hosts for diseases and pests. Common horticultural practices such as crop rotation and cultivation are not viable management alternatives because the blueberry is a perennial crop. Hexazinone, a pre-emergent herbicide introduced in the early 1980's, provides excellent control of most grasses, many herbaceous perennials and some important woody weeds (Jensen and Yarborough 2004). Yarborough (2004) reported that hexazinone use reduced weed pressures and contributed to a two-fold or more increase in blueberry yields. Thus, it has become the most prominent method of weed control in conventional wild blueberry production but this herbicide cannot be used on organic farms. Therefore, alternative weed management options need to be identified for organic blueberry production.

Lowering the soil pH may be a management strategy that could maximize nutrient uptake to blueberry and minimize nutrient availability to the weeds because blueberries are adapted to low pH (Townsend and Blatt 1966). Smagula et al. (2009) observed an increase in blueberry yield in areas that were pruned with fire and soil pH lowered with sulphur applications when compared to flail mowing without soil pH modification. They attributed the yield increase to less grass cover and increased blueberry stem density. Thus, the primary objective of this experiment was to further evaluate prune burning and soil pH reduction as organic management options and determine their impact on crop yield, weed dynamics and mycorrhizal colonization.

Within these objectives, my hypothesis are:

1. Burning and sulphur application plots will have higher percent mycorrhizal infection in the roots of blueberry plants.
2. If high temperatures are achieved with the burn then weed seed germination should decrease due to seed death.
3. If burning impacts weed density then soil moisture may decrease in burned plots.

1.2 Background: Wild Blueberry and its Production

Two major lowbush blueberry species in commercial blueberry fields in Maine, the Maritime Provinces of Canada, and Quebec are the sweet lowbush blueberry *Vaccinium angustifolium* Ait. and the sourtop blueberry *V. myrtilloides* Michx. (Hall et al. 1979). Up to 30% of the clones in commercial blueberry fields in Maine and New Brunswick are V *myrtilloides* (Vander Kloet 1978); the majority of fruits harvest in commercial fields are from *V. angustifolium* (Smagula et al. 2009). According to Vander

Kloet (1994) *V. myrtilloides* is less adaptable and competitive as compared to *V. angustifolium* and sensitive to widely used herbicides such as hexazinone (Jensen 1985).

The lowbush blueberry is considered to be ‘wild’ because fields are developed from naturally existing stands (Yarborough et al. 1986). Wild blueberry is a perennial calcifuge shrub native to northeastern North America (Eaton et al. 2004). It is a rhizomatous shrub averaging 20 cm in height with a deep tap root system and it reproduces by seeds and rhizomes (Hall et al. 1979). Wild blueberry is abundant in abandoned agricultural land and other disturbed areas that result from clear cutting and forest fire (Hall et al. 1979). The area of wild blueberry production in Canada increased by 57% from 1992 to 2003. The major portion of that increase occurred in Quebec and Nova Scotia which accounted for 37% and 34% of the total increased area, respectively (Strik and Yarborough 2005). Similarly, wild blueberry yield in the past 20 years has increased on average 3.5 fold (Yarborough 2004). Increased use of fertilizers, irrigation, pollinators and pest management have contributed to increased blueberry yields per acre (Strik and Yarborough 2005).

The wild blueberry is managed on a biennial production cycle by regular pruning of the above ground plant parts (Hall et al. 1979). Double cropping, harvesting from the same field two years in a row, is rarely done because the production in the subsequent years decreases steadily due to fewer resources available for fruit production (Jordan and Eaton 1995). The year when pruning is carried out is called “sprout year”. In the “crop year”, fruit is harvested. Most of the commercial farmers manage half of their fields as crop year fields and the rest as sprout year fields (Kinsman 1993).

Prior to 1984, 100% of the wild blueberries were harvested by rakes that were designed in Maine in 1883 (Kinsman 1993). Now, the majority of fields are machine harvested in all growing regions in Atlantic Canada. Approximately 40% of fields in Maine, 80% in Nova Scotia, 55% in Prince Edward Island and 25% in New Brunswick were harvested by machine in 2003 (Strik and Yarborough 2005).

1.3 Organic Production of Wild Blueberry

The area under organic wild blueberry cultivation is relatively small. Only 119.4 to 200.3 hectare (ha) of wild blueberries were produced organically in North America in 2003, though this is expected to increase in the near future (Strik and Yarborough 2005).

Organic production has great potential because of the higher economic returns (Neilsen et al. 2009) and increasing consumers demand at the grocery store (Drummond et al. 2009). According to Drummond et al. (2009), organic blueberries were sold at a wholesale price of $2.50 per pint (approx. 338 g) and retailed at $4.00 per pint, as compared to the prices for conventionally produced berries which sold to processors for $0.40 to $1.00 per pound (453 g) in Maine, US in 2007. However, the conventionally produced berries are also sold at a higher price in the fresh market. Wang et al. (2008) evaluated fruit quality and antioxidant capacity in conventional and organically produced highbush blueberries var. Bluecrop (*Vaccinium corymbosum* L.). The results showed that blueberry fruit grown organically yielded significantly higher sugars, malic acid, total phenolics, total anthocyanins, and antioxidant activity (ORAC) than fruit from the conventional culture. But, there are limited numbers of organically approved herbicides available (Drummond et al. 2009). The best strategy to manage wild blueberry organically is to manipulate the crop environment in a way that favors fruit production but not pests (Drummond et al. 2009).

There is limited research on organic wild blueberry production. Using fertilizers to improve the nutrient status in soil without herbicides decreased the blueberry yield due to stimulated weed growth (Ismail et al. 1981). Therefore, the main challenge for organic wild blueberry production is to correct nutritional deficiencies without accelerating weed growth (Smagula et al. 2009). Smagula et al. (2009) investigated the effect of mowing and burning, with or without the addition of sulphur, on blueberry yield and weed population in Maine, USA. They found that mowed treatments had significantly higher grass and broadleaf weed cover than burned treatments. Similarly, plots treated with sulphur had significantly less grass and broadleaf weed cover than the untreated plots.

1.4 Blueberry Management

1.4.1 Weed Control

Weeds are one of the major limiting factors in blueberry production (McCully et al. 1991, Jensen and Specht 2002); because they decrease berry yield, inhibit harvest operation and reduce berry quality (Kennedy et al. 2010). Yarborough and Marra (1997) showed that blueberry yields were reduced from 5000 kg ha^{-1} without weed cover to less than a 1000 kg ha^{-1} with 100% weed cover. In cranberry (*Vaccinium macrocarpon* Ait.), a linear reduction in yield with weed population was observed by Patten and Wang (1994). Yarborough and Bhowmik (1993) also observed a decrease in blueberry fruit count and yield with increasing bunchberry (*Cornus canadensis* L.) density.

Large numbers of weed species, ranging from annual herbs, grasses, perennial shrubs and woody perennials, are common in blueberry fields. In a weed survey of Nova Scotia blueberry fields by McCully et al. (1991), 119 different species of weeds were found; among them the most common were bunchberry, colonial bentgrass *(Agrostis tenuis)*, poverty oatgrass *(Danthonia spicata)*, red sorrel *(Rumex acetosella)*, and false lily-of-the-valley *(Maianthemum canadense)*.

Weed control activities before 1980 mainly involved cutting, burning and directed spot application of non-selective herbicides (Jensen and Specht 2002). After the introduction of selective herbicides during the 1980s, blueberry production increased dramatically (Jensen and Kimball 1985), mainly due to decreased weed pressure following herbicide application (Yarborough et al. 1986). The present weed management strategies in blueberry are based on the use of herbicides. Hexazinone, a broad spectrum systemic herbicide, is routinely used in wild blueberry (Vienneau et al. 2004) in the prune year of the production cycle (Keizer et al. 2001). Since these herbicides cannot be used in organic production, controlling weeds in organic blueberry production is the major challenge.

Any single method of weed control may not be effective to lower weed pressure, especially in organic production. Therefore, an integrated approach to control weeds by combining preventive, biological, cultural and mechanical practices as well as use of organic herbicides will be necessary.

Preventive Measures

Preventive measures limit the spread of weed seeds and propagules and stop them from germinating. According to Boyd and White (2009), harvesting equipment is a major vector of seed dispersal on blueberry fields. Any effort to minimize that dispersal is a key component in the integrated weed management plan (Boyd and White 2009). Weed seed dispersal may be reduced by avoiding dense weed patches and periodic cleaning of equipment between the fields (Boyd and White 2009). Cutting weeds before flowering will help to decrease weed pressure in the field. If burning is the method of pruning, then weed free straw should be used.

Cultural Measures

Using bark mulch and wood chips between clones may reduce weed density and enhance blueberry clonal expansion. The mulch must be thick enough so that re-sprouting weeds cannot penetrate through it (Yarborough 1996). Wild blueberries are generally adapted to soil with low fertility. Therefore, fertilizer applications need to be done carefully as weeds may respond more rapidly to applied fertilizers than blueberries. Yarborough et al. (1986) observed that nitrogen (N) application reduced blueberry yield significantly if no herbicides were applied. Similarly, Ismail et al. (1981) and Smagula and Ismail (1981) also observed a decrease in blueberry yield with higher rates of fertilizers. The decrease in yield might be due to the increased weed competition stimulated by fertilizers (Ismail et al. 1981). Therefore, excessive use of fertilizers should be avoided if weeds are not controlled.

Sulphur is used to reduce soil pH (Yarborough 2004). Generally, 112 kg ha^{-1} sulphur is required to lower 0.1 pH unit (Yarborough 2011). Lower soil pH level is found to be effective for controlling weed growth and seed germination. In a study to investigate the effect of soil pH on the growth of 3 weed species, above ground dry weights of powell amaranth *(Amaranthus powellii)* and velvetleaf *(Abutilon theophrasti)* were significantly lower at pH 4.8 than at pH 6.0 or 7.3, whereas growth of green foxtail *(Setaria viridis)* was greater at pH 4.8 than at pH 7.3 (Weaver and Hamill 1985). Similarly, growth of redroot pigweed (*Amaranthus retroflexus* L.), chickweed (*Stellaria media* L.), common dandelion (*Taraxacum officinale*) and wild mustard (*Brassica kaber*) was severely reduced in soils with soil pH of 4.8 than 5.7 (Buchanan et al. 1975). Germination of kudzu (*Pueraria lobata)* seed was greatest in pH 5.4 and lowest germination was at pH 4.0 (Susko and Mueller 1999). Similarly, highest seed germination percentage was found at pH 5 in red clover *(Trifolium pretense)*(Agic et al. 2009). In Virginia buttonweed (*Diodia virginiana*), maximum germination of seeds occurred at pH 6 (Baird and Dickens 1991). Thomson and Witt (1987) studied the effect of pH on germination of cutleaf groundcherry *(Physalis angulata),* smooth groundcheery *(Physalis subglabrata)* and eastern black nightshade *(Solanum ptycanthum).* The optimum range for germination was 5 – 8 in eastern black nightshade and smooth groundcherry and was 6 – 8 in cutleaf groundcherry. Germination decreased in all species when pH was below 5.0. Similarly, in another study, the optimum pH for germination of Canada thistle *(Cirsium arvense)* seeds was between 5.8 – 7 and at a pH below 5.8 and above a pH of 7, the rate of germination was reduced (Wilson 1979).

Mechanical Measures

Hand pulling is a traditional method of weed control. It is effective against spot infestations and prevents seed dispersal if pulled before the weed flowers and produces seeds (Yarborough 2012). This technique is labor intensive and may not be effective for perennial weeds with extensive root systems. Although hand pulling is effective to control annual and biennial weeds, pulling alone was ineffective for controlling an established population of spreading dogbane weed (Wu 2010).

Mowing and burning are the common methods of pruning blueberry fields which also reduce weed pressure. Weeds must be mowed several times to suppress their growth. Burning can be done with straw, free burn or with oil. The impact of burning varies with the species present in the field. Penney et al. (2008) investigated the long term (24 - years) effects of burning on the flora of wild blueberry fields. They found that some weed species, such as common juniper *(Juniperus communis* var. depressa*)*, crowberry *(Empetrum nigrum)* and reindeer lichen *(Cladina rangiferina),* were eliminated by initial burning and did not appear again in the plots while the occurrence of some less dominant species, such as common hair cap (*Polytrichum commune)* and Virginia strawberry (*Fragaria virginiana* ssp. Glauca), common bent (*Agrostis capillaries),* pearly everlasting *(Anaphalis margaritacea),* knapweed *(Centaurea nigra),* common yarrow *(Achillea millefolium)* and common hawkweed *(Hieracium lachenalii),* increased substantially. Similarly, other species, such as sheep-laurel *(Kalmia angustifolia)* and poverty oatgrass were reduced significantly after initial burning but there were no significant changes over longer periods. The differences in response of weed species to the burning might be due to the location of the rhizomes in the soil, plant hardiness as well as the number and type of seeds produced by the weeds.

Mid season clipping of the weed shoots before seeds ripen will help to prevent the formation and further spread of the seeds. Controlling goldenrod (*Solidago* spp.) is most effective if they are clipped before developed shoots begin to replenish rhizome food reserves (Boyd et al. 2009). This generally occurs when the shoots reach one third of the total expected height.

Biological Control

Due to the human health and environmental risks of inorganic herbicides, biological control of weeds is attracting the attention of many researchers and farmers. It is safe, environmentally sound and cost effective (McFadyen 1998). However, the effect on non-target species is the major concern of biological control (McFadyen 1998). It uses selective species that will reduce the population of target weeds. In a study by Morrison et al. (1998), it was found that the leaf-feeding beetle (*Chrysolina hyperici*) caused mid-summer de-foliation of common St. Johnswort *(Hypericum perforatum)* by 27% in 1993 and 51% in 1994. In another study, Campbell and McCaffrey (1991) concluded that St. Johnswort root borer (*Agrilus hyperici*) has contributed significantly to St. Johnswort suppression in Idaho, US.

Similarly, 53.2% and 70.5% of St. Johnswort seedlings were killed within 6 and 9 weeks after inoculation with *Colletotrichum gloeosporioides,* respectively; all remaining plants were infected and failed to survive the winter (Hildebrand and Jensen 1991). A host specific fungal pathogen, *Colletotrichum gloeosporiodies*, gave excellent control against round-leaved mallow (*Malva neglecta*) under natural conditions (Mortensen 1988).

Herbicides for Organic Production

Synthetic herbicides are the major tools for controlling weeds in blueberry field, but these cannot be used in organic production. Therefore, weed management is a great challenge in organic production. Only a limited number of organic herbicides are available and most of them are contact and burn down products. Due to this reason, organic herbicides are mostly used as a spot application to manage weed patches in the fields.

Several studies have investigated acetic acid at different concentrations, as an option for organic weed management. It is a contact herbicide and gives a range of weed control depending upon nature of the weeds and stage of application. Evans et al. (2009) observed that acetic acid and clove oil were less effective when they were applied at later stages of their development. Therefore, timing is critical to the effective use of herbicides for organic production (Evans and Bellinder 2009).

More than 80% control of lambs-quarters, corn spurry and wild radish was achieved when Ecoclear™ (30% acetic acid) was applied to emerged weeds and before potato emergence (Ivany 2010). Radhakrishnan (2002b) investigated the efficacy of vinegar (active ingredient - acetic acid) for weed control in organic farming. He treated weeds with 0.0, 5.0, 10.5, 15.3 and 20.2% acetic acid and found that the lower concentrations of 5 and 10% were more effective in killing the weeds during the early stages while at later stages they were not as effective as the 15 and 20% concentrations. Similarly, vinegar provided 95-100% kill at all growth stages of the weeds studied at 15 and 20% concentrations. In another study, Evans et al. (2009) reported 84 to 100% pigweed control when treated with 636 L ha^{-1} vinegar, regardless of growth stage.

According to Radhakrishnan (2002b), the effectiveness of the vinegar was dependent on the concentration and plant growth stage.

Scythe® is another organic based herbicide which contains pelargonic acid as the active ingredient (Federal Register 1997). It is a naturally occurring fatty acid found in plants and animals which has no risks to humans or the environment when applied according to the label directions (USEPA 2000). Pelargonic acid rapidly desiccates green tissue by removing the waxy cuticle of the plant and disrupting the cell membrane, resulting in cell leakage, causing tissue death (Federal Register 1997). Webber and Shrefler (2006) found that the pelargonic acid was effective in controlling multiple species of grass and broadleaf weeds as a burn-down herbicide.

1.4.2 Pruning in Blueberry

The wild blueberry is forced to a biennial production cycle from its natural perennial production system by regular pruning of the above ground plant parts (Hall et al. 1979). The plants are pruned to stimulate new shoots and floral bud formation in the first year and produce flowers and berries in second year (Jensen and Yarborough 2004). Pruning is mostly carried out in the late fall or early spring (Warman 1987). Plants generally respond to fertilization in the season following pruning (Warman 1987).

Pruning is carried out either by burning or flail mowing (Jensen and Yarborough 2004). Burning offers the advantages of disease, insect and weed control, but the ever increasing cost of oil is a concern (Warman 1987). Therefore, flail mowing is the most common method to prune blueberry fields (Yarborough et al. 1986). The impact of the pruning methods on berry yield was observed in several studies. Higher berry yield in the burned plots than mowed plots was found by Warman (1987). Similarly, Ismail et al. (1981) observed an almost doubling of yield in burned plots as compared to mowed plots. Penney et al. (1997) also observed greater mean annual yield of ripe fruits in burned plots than in unburned. The increase in yield might be due to the control of diseases, insects and weeds (Warman 1987). Contrary to these results, Smagula and Dunham (1995) found no effect of pruning methods on blueberry yield.

Blueberry rhizomes grow close to the soil surface, usually within the top 2 to 10 cm (Eaton and Jensen 1997). Thicker layer of organic matter (OM) may ensure better nutrients and water to the roots. In a 24-year study, Penney et al. (1997) found no significant change in surface depth of the organic layer due to burning. A similar result was also found by Hanson et al. (1982) where they observed no significant differences in soil OM or pH, when plants were pruned by flail mowing or by burning. Contrary to these results, Smith and Hilton (1971) found that continuous burning depleted the surface layer of OM with greater removal with an oil burner than with straw burns. These contradictory results might be due to the differences in the length of study, type of fuel and climatic conditions (Penney et al. 1997).

A further impact of pruning method was observed on plant architecture. Mowing significantly increased the number of branched stems when compared to burning (Ismail et al. 1981). Moreover, mowing resulted in a significant increase in total stem length (20.4 cm) as compared with burning (14.0 cm) (Ismail et al. 1981).

1.5 Blueberry – Ericoid Mycorrhiza Association

Mycorrhizae occurring in association with members of the Ericales family are called ericoid mycorrhizae (Goulart et al. 1993). These are ascomycetes and lack vesicles and arbuscules (Read 1983). *Hymenoscyphus ericae, Oidiodendron griseum* and *Scytalidium vaccinii* are common fungal species associated with the Ericales (Goulart et al. 1993). Most of the ericoid mycorrhizae are found in soils of low pH, high organic matter content, and low available nutrient status (Read 1983). Hyphae penetrate epidermal cells then form compact intracellular hyphal complexes confined to epidermal cells (Perotto et al. 1995). The root system of blueberry is characterized as fibrous with shallow roots (Lyrene 1997) and largely devoid of root hairs (Erb 1993, Pliszka et al. 1993). Therefore, mycorrhizal association is considered to be very important for blueberry since it enhances nutrient and water uptake by the roots from the soil (Haynes and Swift 1985). Although, the blueberry plants are colonized naturally by ericoid mycorrhizal fungi (EMF), the colonization can be increased by inoculating EMF to the roots. Scagel (2005) observed a 15 – 30% increase in root colonization after inoculating EMF in container-grown highbush blueberry plants. It was also observed that the colonization was higher in the plants that were grown in the media, rich in organic fertilizers. Similarly, Scagel (2005) observed in highbush blueberry that the plants inoculated with EMF took up more N, P, K, and Zn as compared to non-innoculated plants. It was also reported that EMF enables plants to uptake N and phosphorus from the compounds unavailable to non-mycorrhizal plants (Bajwa and Read 1985, Kerley and Read 1997). Similarly, the highbush blueberry plants (variety Jersey) treated with ericoid fungus *Oidiodendron rhodogenum* had shoots four times longer than non-inoculated plants in the third year after inoculation (Koron and Gogala 2000). Similarly, the number of shoots was approximately two times higher in comparison with non-inoculated plants (Koron and Gogala 2000).This enhancement was probably due to increased solubility of the nutrients and increased area for their absorption (Koron and Gogala 2000). Scagel (2005) reported that the inoculation of EMF not only increased nutrient uptake, but also increased the nutrient use efficiency in many cultivars of highbush blueberry. It was also noted that mycorrhizal fungi provided resistance to heavy metals (Bradley et al. 1982) and protected roots against the attack of pathogenic organisms (Koron and Gogala 2000). In a study by Bradley et al. (1982) mycorrhizal and non-mycorrhizal plants were grown in soil with heavy metal ions. The levels of metal accumulation were significantly lower in the shoots of mycorrhizal plants, whereas in the absence of the mycorrhizal fungi, the plants were unable to exclude the metal ions and they accumulated in the shoots to toxic levels.

Several factors affect mycorrhizal infection in blueberry roots. Scagel and Yang (2005) noticed that blueberry plants grown in soils with higher pH had lower levels of root colonization by EMF. In another study, the percentage of mycorrhizal infection was considerably greater at pH 4.5 than at 6.5 (Haynes and Swift 1985). While investigating the effect of pH of the nutrient medium on the production of siderophores by *Hymenoscyphu ericae*, it was found that the maximum amounts of siderophores were produced at pH 4.5 (Federspiel et al. 1991). Similarly, at pH 7.5, the amounts of siderophores were reduced to less than 5%, in comparison to pH 4.5.

Kosola and Workmaster (2007) observed a decrease in mycorrhizal colonization with increasing depth in the cranberry root zone soil. Contrasting results were found by

Jeliazkova and Percival (2003) where there was no significant difference in the mycorrhizal colonization in upper (0 – 7.5 cm) and lower soil profiles (7.5 – 15 cm) in wild blueberry. Application of fungicides may also have a negative impact on mycorrhizal infection rates in blueberry roots. Percival and Burnham (2006) observed a significant reduction in colonization following application of benomyl. Similar response of mycorrhiza to fungicides was also observed in onion (*Allium cepa* L.) (Manjunath and Bagyaraj 1984), sitka-spruce (*Picea sitchensis*) and ash (*Fraxinus excelsior*) (O'Neill and Mitchell 2000). In a work carried out by Jeliazkova and Percival (2003), mycorrhizal colonization was not affected by drought stress. Nutrient status in soil was also found to control mycorrhizal activities. Stribley and Read (1976) noticed a suppression in mycorrhizal activities in cranberry with very low and very high levels of ammonium N. Similarly, Smagula and Litten (1988) found that mycorrhizal infection rates were significantly lower in fertilized than in unfertilized cultured plantlets.

Chapter 2.0 Weed and Blueberry Responses to Burning and Sulphur Application

2.1 Introduction

The lowbush blueberry, commonly known as wild blueberry, is a native shrub of northeastern North America (Eaton et al. 2004). It is cultivated commercially in Canada and the United States (Yarborough and Bhowmik 1989). The principal commercial wild blueberry producing areas are Nova Scotia, Newfoundland, New Brunswick, Prince Edward Island, Quebec and Maine (McIssac 1997). It is mostly grown on abandoned agricultural land and other disturbed areas that result from clear cutting and forest fire (Hall et al. 1979). Commercial blueberry fields are not planted but clonal expansion is encouraged in their natural habitat.

Controlling weeds is one of the major challenges in blueberry production. In Nova Scotia, 119 different species of weeds were found in a weed survey by McCully et al. (1991). Weeds decrease berry yield and quality, and also inhibit harvest operations (Kennedy et al. 2010). The present weed management strategies for conventional wild blueberry production are based on the use of chemical herbicides. Alternative methods of weed control are needed that can be adopted by organic growers.

Pruning in blueberry is conducted biennially, either by burning or mowing, to produce new shoots in the sprout year. Although the principal reason for pruning is to rejuvenate the blueberry plants, pruning methods also partially control weeds by mechanical removal of vegetative growth. Therefore, pruning becomes a key part of integrated weed management. Weeds respond differently with burning and mowing. Burning eliminates many shallow rooted woodland species (Hall 1959) and weed seeds

(Swan 1970), but some rhizomatous perennials such as goldenrod are adapted to low intensity burning (Swan 1970). Burning also creates open space for invaders such as birch (*Betula* spp.) and aspen (*Populus tremuloides* Michx.) (Swan 1970). Many research reports showed positive effects of burning on blueberry yield. Warman (1987), Penney et al. (1997) and Ismail et al. (1981) observed greater yield in burned fields than in unburned.

Sulphur is commonly used to lower the soil pH in the field because blueberries tolerate acidic soils. According to Patten and Wang (1994), lowering the soil pH reduced weeds that were not controlled by herbicides in cranberry (*V. macrocarpon* Ait.). This is largely due to growth inhibition or seed emergence inhibition. Moreover, Smagula et al. (2009) observed almost triple blueberry yield with burning and pH reduction with sulpur application as compared to mowing and without pH reduction. Therefore, sulphur may be an optional weed management tool for blueberry.

The overall objective of this experiment was to evaluate prune burning and soil pH reduction as organic management options. The specific objectives were to determine the impacts of burning and soil pH modification on crop yield, weed dynamics, mycorrhizal colonization, soil nutrient and soil moisture status.

2.2 Materials and Methods

2.2.1 Trial Description

In 2010, experimental sites were identified in two commercial blueberry fields in Collingwood (45° 36′ 35.941″ N, 63° 47′ 09.797″ W) and Earltown (45° 34′ 39.94″ N, 63° 8′ 16.48″ W), Nova Scotia. Soils at the Collingwood site were a stony, well drained sandy loam of the Rodney soil series (Nowland and MacDougall 1973). Soil contained 28% sand, 61% silt and 11% clay. Similarly, soils at the Earltown sites were well drained sandy loams to gravelly sandy loams of the Westbrook Soil series (Nowland and MacDougall 1973). The percent sand, silt and clay were 27, 61 and 12 respectively. The common weeds at the Collingwood site were red sorrel and bunchberry. Grasses such as creeping bentgrass (*Agrostis stolonifera* L.) and quackgrass (*Elymus repens* L.) were the dominant weed species at the Earltown site. Similarly, the Collingwood site was managed without pesticides one year prior to the study and the Earltown site was managed without pesticides for several years prior to the establishment of the study. A 2 x 2 factorial design, organized as a randomized complete block design with four blocks, was established after commercial blueberry harvesting in 2009. Treatments included combinations of pruning methods (burning versus mowing) and soil pH modification (sulphur versus no-sulphur) with four treatments in total. Each plot size was 4 m x 6 m with 1m buffer on all sides.

The fields at both sites were commercially harvested in 2009 and the entire experimental areas were flail mowed in spring of 2010. After mowing in the spring of 2010, the plots that were assigned the burning treatments were burned. The 2010 year was thus the first pruning year for the experiment. The crop year of the experiment, when yield was determined, was 2011 and the second pruning year was 2012. For the second pruning year in 2012, mowing was carried out on the designated mowing plots in November of 2011, and burning was carried out in April of 2012 on the designated burning plots. A straw-burn was done at the Collingwood site in April, 2010 due to the lack of vegetative matter in the field while a free burn was done at the Earltown site in plots that were burned. Soil surface temperature during the burning was measured using K-type thermocouples. Four sensors were put in four burning plots in each site. In April 2010, pelletized elemental sulphur was applied to those treatments receiving sulphur prior to blueberry emergence to lower the soil pH. Elemental sulphur was applied at a rate of 112 kg ha^{-1} for every 0.1 soil pH unit needed to drop to achieve the target pH (4.0). The initial soil pH at the Collingwood and Earltown sites were 4.4 and 5.2, respectively. Therefore, the total amount of sulphur applied to lower the soil pH to 4.0 at Collingwood and Earltown was 450 and 1415 kg ha^{-1} respectively. No fertilizer was applied in the pruning year. In the crop year, a pelletized dehydrated poultry manure (Nutriwave 4-1-2; Envirem Technologies, Fredericton, New Brunswick, Canada) was applied to both sites at the rate of 500 kg Nutriwave ha^{-1} on May 2011.

2.2.2 Data Collection

Data were collected in the 2010 pruning year, the 2011 crop year and the 2012 pruning year.

Soil Data

Soil sub-samples were taken from three random locations in each plot on August 10, 2011 and August 07, 2012. These subsamples were combined to form a composite sample for each treatment to provide background soil fertility under each treatment. The soil was sampled from the blueberry root zone i.e. 0 – 15 cm. Soils were submitted to the Harlow Institute, Truro, Nova Scotia, for a complete soil nutrient analysis.

Soil pH was measured on May 17, 2010 and August 07, 2012 using a Fisher Scientific Accumet pH meter (AP72) in two different layers i.e. 0 – 5 cm and 5 – 15 cm.

A composite sample of three subsamples from every plot was taken for each depth increment.

HOBO Smart Temp (STMB-M002) temperature sensors and soil moisture smart sensors (dielectric aquameter probe) were connected to HOBO Micro Stations (H21-002) (On-set Computer Corp., Bourne, MA, USA). Four moisture sensors were installed in each location, two sensors placed in two different plots that were burned and other two sensors were placed in two different plots that were mowed. Volumetric soil moisture was record every 12 hours and temperature was recorded hourly. Sensors were placed at the 10 cm soil depth.

Weed Data

A non-destructive measurement of ground cover was carried out on July 23, 2010, July 27, 2011 and August 07, 2012 by using a point transect method where plants beneath each intersection along the surveyed transect were identified. A 50 cm x 50 cm quadrat with 25 intersections was used. 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). Two measurements were taken in each plot. The number of weeds in two 30 cm x 30 cm quadrats in each plot was counted to estimate the weed density on July 29, 2011 and August 12, 2012. Weed biomass was measured by harvesting two individuals of the most common weed species from each plot and oven dried at 70° C for 72 hours and weighed on August 17, 2010, August 09, 2011 and August 14, 2012. Red sorrel and creeping bentgrass were selected in the Collingwood and Earltown sites, respectively.

Blueberry Data

Twenty stems from each plot were randomly selected on November 10, 2010 to count the floral buds. Blueberry stem density was determined by counting the number of stems in two 50 cm x 50 cm quadrats in each plot on May 26, 2011 and August 07, 2012. The blueberry stems were counted at the ground surface. Measurement of blueberry cover was carried out on July 23, 2010, August 02, 2011 and August 07, 2012 by using a point transect method. Similarly, flowers and green berries were counted on 20 randomly selected stems in each plot. Flowers were counted on June 03, 2011 and green berries were counted on July 15, 2011. Twenty random blueberry leaves were collected from each plot at blueberry tip die back. These samples were combined to form a composite sample for each treatment and submitted for nutrient analysis. Ripe berries were harvested on August 15, 2011 from two 100 cm x 30 cm quadrats in each plot. Leaves and debris were removed by wind and the fresh weight was taken.

Mycorrhizal colonization of blueberry roots was assessed in the crop year (November 21, 2011) and pruning year (July 17, 2012). Blueberry roots with root hairs were dug out of the ground using a shovel to a depth of 0 – 10 cm. Roots were separated from the soil and washed with tap water until free of soil. Root clearing was done in 10% potassium hydroxide solution (KOH). First, roots were immersed in 10% KOH over night at room temperature. Then, the KOH solution was changed and roots were boiled for 20 minutes at 121 °C. The KOH solution was then removed and the roots were rinsed several times with tap water, then rinsed with 1% hydrochloric acid (HCL) and then placed in distilled water for two hours. Roots were removed from distilled water and stained overnight in a staining solution. The staining solution was prepared by mixing 5 ml of 0.4% trypan blue in 500 ml lactoglycerol (1,300 ml 85% lactic acid, 950 ml 99% glycerol, 930 ml distilled water). Five mycorrhiza infected root hairs from each treatment plots were observed with a compound microscope at 400 magnification and pictures were taken with a digital camera (Sony DSC -T5). Same zoom was used in the camera to take all the pictures. The percentage infection by mycorrhiza in blueberry roots was determined by placing grid lines over the picture on the computer screen. Lines were spaced 0.5 cm apart. These grid lines were designated as either colonized or non-mycorrhizal. The intersections with blue stain were identified as colonized. All intersections were scanned and percentage infection of roots by mycorrhiza was quantified by dividing numbers of intersections that were blue by total numbers of intersections observed.

2.2.3 Statistical Analysis

Blueberry and weed parameters were analyzed using the PROC MIXED procedures in SAS 9.1 (SAS Institute Inc., Cary, NC, USA). Soil pH was analyzed using the PROC MIXED procedure with repeated measures in the SAS. The assumptions for normality and constant variance of the error terms was checked in Minitab statistical software (verson13) by constructing a normal probability plot of the residuals and by plotting the residuals versus the fitted values, respectively. Significant effects were detected at a 5% level according to least square (LS) means procedure, using SAS 9.1.

2.3 Results and Discussion

No significant interaction between sites and treatments were observed. Therefore, all the data except number of green berries were combined for the two sites (Collingwood and Earltown) for 2011 and 2012. Similarly, time effect was significant; therefore data for 2011 and 2012 were analyzed separately to see the pattern over the time.

2.3.1 Soil Analysis

The effect of sulphur on soil pH changed over time at both soil depths (0 – 5 cm and 5 – 15 cm) and sites (Collingwood and Earltown). Sulphur applied on April, 2010 significantly decreased the soil pH in both sites and depths on August, 2012 but not on May, 2010 (Table 1). No effect of sulphur on May, 2010 probably due to the short time period available for sulphur to take effect. In August, 2012, sulphur application lowered the soil pH to an average of 4.10 and 4.41 in the 0 – 5 cm soil depth at Collingwood and Earltown, respectively. The decrease in soil pH was slightly greater in 0 – 5 cm than at 5 – 15 cm soil depth (Table 1).

Soil nutrient content was not studied in depth here; however several observations made could be interest for more detailed studies. Soil nutrient content data were not replicated and therefore were not analyzed statistically (Appendix 1 & 2). However, we observed that at Collingwood and Earltown, burned plots tended to have higher N, phosphorus and potassium than mowed plots in 2011 and 2012 (Appendix 1 &2). Burning releases potassium and phosphorus in the ash, resulting in higher soil phosphorus and potassium after burning (Smith and Hilton 1971). The amount of sulphur was higher in sulphur application plots than in no-sulphur plots at both sites in 2011 and 2012.

Kitchen et al., (2009) in tallgrass prairie observed higher bulk soil N in 0 – 10 cm soil depth in burned plots as compared to mowed plots, though they were not significantly different. Similarly, fire increased the mean concentrations of N and P by 18.18% and 17.65% respectively in soil of dry tropical savanna (Singh 1993). Contrary to these results, Ojima et al., (1994) noticed lower N in the surface 5 cm in annually burned plots relative to unburned plots in tallgrass prairie. However, Schacht et al. (1996) measured no effect of burning on total soil N on the top 30 cm of the soil profile in grassland. These different responses of soil nutrient concentrations to burning might be due to differences in burning frequency, duration and intensity, type of vegetation present in the plots and depth of soil sampling. In our study, the peak soil temperature during burning ranged from 630 – 1050 °C and lasted only 2 – 3 seconds. The five minutes average soil temperature after that peak was 23 °C.

2.3.2 Soil Moisture Content

Soil moisture content was measured from mid-May to mid-August in 2010, 2011 and 2012. During most of the time period, soil moisture was higher in burned plots as compared to mowed plots (Figure 1a, 1b and 1c) in Collingwood. At the Earltown site, soil moisture was higher in burned plots in 2010 and 2012 (Figure 1d and 1f). In 2011, the soil moisture was slightly higher in the burned plots until mid-June (Figure 1e) after which it was higher in mowed plots. Higher soil moisture in burned plots might be due to less competition for moisture. Weed coverage and density (Table 2) were higher in mowed plots while blueberry density and cover (Table 3) were higher in burned plots. Water loss from evapo-transpiration might be higher from weed plants than blueberry plants due to plant characteristics, although it was not measured in this study.

2.3.3 Blueberry Leaf Tissue Analysis

Like soil data, the blueberry leaf tissue data were not replicated; therefore were not analyzed statistically (Appendix 3 & 4). These values were compared with standard minimum and maximum leaf nutrient concentrations from Quebec (Lafond 2009). The minimum and maximum leaf nutrient concentrations were 1.6 – 2.0%, 0.11 – 0.16%, 0.54 – 0.71%, 0.29 – 0.38% and 0.13 – 0.18% for N, P, K, Ca and Mg, respectively. In Collingwood and Earltown, blueberry leaf N concentration in burned plots was within the range, but in mowed plots, it was slightly lower than minimum value in 2011 and 2012. Phosphorus (P) and magnesium (Mg) values were close to minimum and maximum values, respectively. Similarly, potassium (K) was lower than minimum value but calcium was higher than maximum.

2.3.4 Weed Cover, Density and Biomass

Pruning method and soil pH modification had no significant effects on weed cover and biomass in 2010 (Table 2). In 2011 and 2012, significantly lower weed cover was observed where burning or sulphur treatments were applied, but no significant differences were found in weed biomass of most common weeds (Table 2).

Pruning method had no significant effect on weed density, but soil pH modification had a marginally significant effect ($p = 0.057$) in 2011 (Table 2). Plots with sulphur application had significantly less weed density. But in 2012, both pruning method and soil pH modification had significant effect on weed density. Burned plots and sulphur application plots had significantly lower weed density.

Lower weed cover and density in burned plots might be because grass seeds and propagules near the soil surface were destroyed or killed by burning. Smagula et al. (2009) also noticed significantly lower grass and broadleaf weed cover in burned plots, as compared to mowed plots. Similarly, they also observed that plots treated with sulphur had significantly less grass and broadleaf weed cover than the untreated plots. Lowering the soil pH might have a negative effect on nutrient uptake that may decrease relative competitive ability of the weeds. A similar response to sulphur was also observed by Yarborough and Guiseppe (2006). A significant reduction in grass cover in 2004 and 2005 was seen in the plots where 1134 kg ha^{-1} of sulphur as 80% sulphur pellets was applied in 2000.

2.3.5 Mycorrhizal Colonization

Site had a significant effect on mycorrhizal colonization in blueberry roots in 2011 ($p = 0.0032$) and 2012 ($p<0.001$) but there was no significant interaction of site by pruning method ($p = 0.85$ for 2011 and $p = 0.99$ for 2012) or pH modification ($p = 0.15$ for 2011 and $p = 0.72$ for 2012). Mycorrhizal colonization was significantly higher in burned plots as compared to mowed plots in 2011 and 2012 (Table 3). However, soil pH modification had no impact on mycorrhizal colonization.

Although there are no previous studies on the response of ericoid mycorrhizae to burning and mowing of blueberry fields, there are several reports that examined the effect of fire and mowing on arbuscular mycorrhizae (AM) in tallgrass prairie. The effects of fire and mowing on mycorrhizal colonization in tallgrass prairie were not uniform. Bentivenga and Hetrick (1991) observed temporary stimulation of mycorrhizal colonization after burning in tallgrass prairie. Eight days after burning, the root colonization of burned plants was significantly greater than that of unburned plants. By 32 days after burning, the root colonization of burned plants was not different from that of unburned plants. This temporal increase in mycorrhizal colonization was possibly due to increased soil temperature (Bentivenga and Hetrick 1991). A negative effect of fire on mycorrhizal colonization was observed by Dhillion et al. (1988). They found that AM fungal colonization levels in little bluestem (*Schizachyrium scoparium*) roots were significantly lower on the burned sites than on the unburned sites during the first growing season but there were no significant differences between sites during the second year. Anderson and Menges (1997) observed that colonization by AM fungi was unaffected by burning in four herbaceous plant species (*Aristida stricta*, *Liatris tenuifolia* var. laevigata, *Pityopsis graminifolia* and *Balduina angustifolia*). Similarly, no significant effect of burning and mowing on AM fungal colonization was also noticed by Eom et al. (1999) in roots of tallgrass prairie. The reason for these contradictory results might be due to the difference in amount of time after burning that sampling was conducted.

2.3.6 Blueberry Stem Density and Cover

Site had a significant effect on blueberry stem density in 2011 ($p = 0.0001$) but not in 2012 ($p = 0.247$). The blueberry stem density was significantly higher in plots that were pruned by burning than in those pruned by mowing in 2011 and 2012 (Table 3). The blueberry stem density was not significantly different between sulphur and no-sulphur plots. These results support the findings of Smagula et al. (2009) that stem density was higher in burned plots as compared to mowed plots. Higher stem density in burned plots might be because it facilitated emerging of new shoots from underground rhizome while mowing mostly caused branching of the shoots above the ground surface. Therefore, when considering number of stems in ground surface, burning gave higher number than mowing.

Blueberry cover was not significantly different between sites ($p = 0.91$) in 2010. Similarly, pruning method and soil pH modification had no significant impact on blueberry cover (Table 3). In 2011, site had a significant impact on blueberry cover ($p = 0.0006$) but there was no interaction of site with pruning ($p = 0.25$) or soil pH modification ($p = 0.37$). Similarly, pruning method and soil pH modification also had a significant impact on blueberry cover (Table 3) but there was no significant interaction of pruning method by soil pH modification ($p = 0.205$). Burned plots and plots where sulphur was applied had significantly higher blueberry cover than mowed plots. In 2012, the site effect was marginally significant ($p = 0.051$). Burning and sulphur treatments significantly increased blueberry cover in 2012 compared with their treatment counterparts (Table 3). Higher blueberry cover in burned plots was probably due to higher stem density (Table 3). Moreover, higher nutrient contents (Appendix 1 & 2), and soil moisture (Figure 1) might also have contributed to higher blueberry cover in burned plots. Similarly, higher cover in sulphur applied plots might be because sulphur lowered the soil pH (Table 1) that might offer blueberry a comparative advantage over weeds for nutrient availability and uptake, which resulted in higher cover.

2.3.7 Number of Flowers, Green Berries and Berry Yield

Site ($p<.0001$) and pruning method had a significant impact on the number of flowers per stem and it was significantly higher on burned plots than in mowed plots (Table 4). Since there was a significant interaction between site and soil pH modification, the green berry data from the two sites were analyzed separately. In Collingwood, number of green berries was significantly higher in burned plots than mowed plots (Table 5). However in Earltown, both pruning method and soil pH modification had significant effects on the number of green berries. Burning plots and sulphur application plots had a higher number of green berries as compared to mowed plots and no-sulphur plots, respectively.

Pruning by burning, as well as sulphur application, significantly increased mature blueberry yield as compared to pruning by mowing and no-sulphur application, respectively (Table 4).

Higher yields in burned plots might be associated with higher blueberry stem density and cover. Similarly, less weed density and cover (Table 2), higher mycorrhizal colonization (Table 3), NPK (Appendix 1 & 2) and soil moisture (Figure 1) might also have contributed to higher yield in burned plots. Benoit et al. (1984) observed a significant increase in number and total weight of berries with increased water availability during the pruning year. Glass et al. (2005) also observed significantly lower berry number in drought treatments as compared to irrigation in both the pruning and cropping years. There are several studies concerning the response of pruning method on blueberry yield, the results are not consistent. Smagula et al. (2009), Ismail et al. (1981), Penney et al. (1997) and Warman (1987) all observed higher berry yield in burned plots than in mowed plots. Contrary to these findings, Smagula and Dunham (1995) and Ismail and Hanson (1982) observed no significant effect of pruning method on blueberry yield. These different responses of burning and mowing on blueberry yield might be due to different burning techniques, frequency and intensity. Similarly, burning in fall or spring may not achieve the same results. Vander Kloet and Pither (2000) observed fewer lateral shoots per stem when the *Vaccinium myrtilloides* was burned in fall than in spring.

There was a marginally significant difference in blueberry yield ($p = 0.0546$) due to sulphur application in 2011 which might be due to insufficient time for a measurable response in the soil. This result supports the findings of Smagula et al. (2009), where they observed greater effects of sulphur on blueberry yield in 2007 compared to 2005, when sulphur was applied in 2004. Blueberry yield in sulphur application plots can be expected to increase in subsequent crop years because of lower soil pH due to sulphur (Table 1), less weed cover and weed density in 2012 (Table 2). Lower soil pH may offer comparative advantage to blueberry by making the soil environment more conducive for nutrient uptake. Significantly higher yield was also noticed by Haynes and Swift (1986) in sulphur treated plots, as compared to no-sulphur plots, in highbush blueberry. Higher yield might be due to decreased in soil pH by sulphur application (Table 1); giving blueberry the comparative advantage for nutrient uptake over the weeds.

2.4 Conclusions

Wild blueberry is a perennial crop, making weed control practices such as tillage or mulching not possible. This imposes a significant challenge for managing weeds in organic production. Results from this study indicate that burning as well as sulphur application reduced weed density and cover as compared to mowing and no-sulphur application, respectively. Similarly, higher blueberry stem density and cover were observed in burned and sulphur application plots which contributed to increased blueberry yield. Other parameters like mycorrhizal colonization, soil moisture and soil NPK contents were also observed to be higher in burned plots. Therefore, pruning by burning and soil acidification may be a viable weed management practice for organic wild blueberry production. Investigating further non-chemical (synthetic) options for controlling weeds to combine with burning and sulphur application may help to develop an integrated weed management strategy.

Table 2.1 Effect of sulphur on soil pH in 2010 and 2012 at Collingwood and Earltown, Nova Scotia.

Year	Treatments	Soil pH			
		Collingwood		Earltown	
		0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm
2010	Sulphur	4.42 a[a]	4.43 a	5.24 a	5.30 a
	No-sulphur	4.50 a	4.42 a	5.32 a	5.46 a
2012	Sulphur	4.10 b	4.20 b	4.41 b	4.65 b
	No-sulphur	4.43 a	4.50 a	5.33 a	5.31 a

[a] Means followed by the same letter within the same column are not significantly different (LSD, $P<0.05$).

Table 2.2 Percent cover, density (per m^2) and biomass (g dry wt. $plant^{-1}$) of weeds in two Nova Scotia fields in 2011 and 2012. Values in parentheses are standard error.

Year	Treatments	Weed cover (%)	Weed density per m^2	Common weed plant biomass (g dry wt. $plant^{-1}$)
	Burning	43 (6.3)	-	0.39 (0.017)
2010	Mowing	49 (6.3)	-	0.39 (0.017)
Prune year	*P- value*	*0.480*	-	*0.820*
	Sulphur	45 (6.3)	-	0.39 (0.017)
	No-sulphur	47 (6.3)	-	0.40 (0.017)
	P- value	*0.760*	-	*0.210*
2011	Burning	36 (2.7)	519 (29.5)	0.38 (0.017)
Crop year	Mowing	46 (2.7)	559 (29.5)	0.39 (0.017)
	P- value	*0.014*	*0.342*	*0.825*
	Sulphur	35 (2.7)	498 (29.5)	0.37 (0.017)
	No-sulphur	47 (2.7)	581 (29.5)	0.40 (0.017)
	P- value	*0.005*	*0.057*	*0.218*
2012	Burning	18 (3.9)	279 (34.5)	0.41 (0.028)
Prune year	Mowing	29 (3.9)	390 (34.5)	0.40 (0.028)
	P- value	0.002	0.025	0.701
	Sulphur	18 (3.9)	285 (34.5)	0.39 (0.028)
	No-sulphur	29 (3.9)	384 (34.5)	0.41 (0.028)
	P- value	*0.001*	*0.046*	*0.483*

Table 2.3 Mycorrhizal infection in blueberry roots, percent blueberry cover and stem density (per m^2) in 2011 and 2012. Values in parentheses are standard error.

Year	Treatments	Mycorrhizal colonization (%)	Blueberry cover (%)	Blueberry stem density per m^2
2010	Burning	-	56 (6.2)	-
Prune year	Mowing	-	52 (6.2)	-
	P- value	-	*0.58*	-
	Sulphur	-	55 (6.2)	-
	No-sulphur	-	53 (6.2)	-
	P- value	-	*0.75*	-
2011	Burning	69 (1.6)	63 (2.7)	611 (26.8)
Crop year	Mowing	62 (1.6)	52 (2.7)	512 (26.8)
	P- value	*0.005*	*0.009*	*0.016*
	Sulphur	65 (1.6)	64 (2.7)	559 (26.8)
	No-sulphur	66 (1.6)	51 (2.7)	563 (26.8)
	P- value	*0.877*	*0.002*	*0.920*
2012	Burning	66 (1.6)	80 (3.8)	876 (47.3)
Prune year	Mowing	58 (1.6)	70 (3.8)	661 (47.3)
	P- value	*0.001*	*0.007*	*0.004*
	Sulphur	62 (1.6)	80 (3.8)	829 (47.3)
	No-sulphur	62 (1.6)	70 (3.8)	708 (47.3)
	P- value	*0.917*	*0.004*	*0.084*

Table 2.4 Number of blueberry flowers per stem and yield in two Nova Scotia fields in 2011. Values in parentheses are standard error.

Treatments	No. of flowers (per stem)	Blueberry yield (kg ha^{-1})
Burning	23 (1.47)	1,528 (66.94)
Mowing	20 (1.47)	1,267 (66.94)
P- value	*0.0005*	*0.0025*
Sulphur	22 (1.47)	1,474 (66.94)
No-sulphur	21 (1.47)	1,320 (66.94)
P- value	*0.52*	*0.0546*

Table 2.5 Number of green blueberries in two Nova Scotia fields in 2011. Values in parentheses are standard error.

Treatments	No of green berries (per stem)	
	Collingwood	Earltown
Burning	19 (0.89)	18 (0.692)
Mowing	16 (0.89)	16 (0.692)
P- value	*0.0108*	*0.0003*
Sulphur	18 (0.89)	18 (0.692)
No-sulphur	17 (0.89)	16 (0.692)
P- value	*0.395*	*0.036*

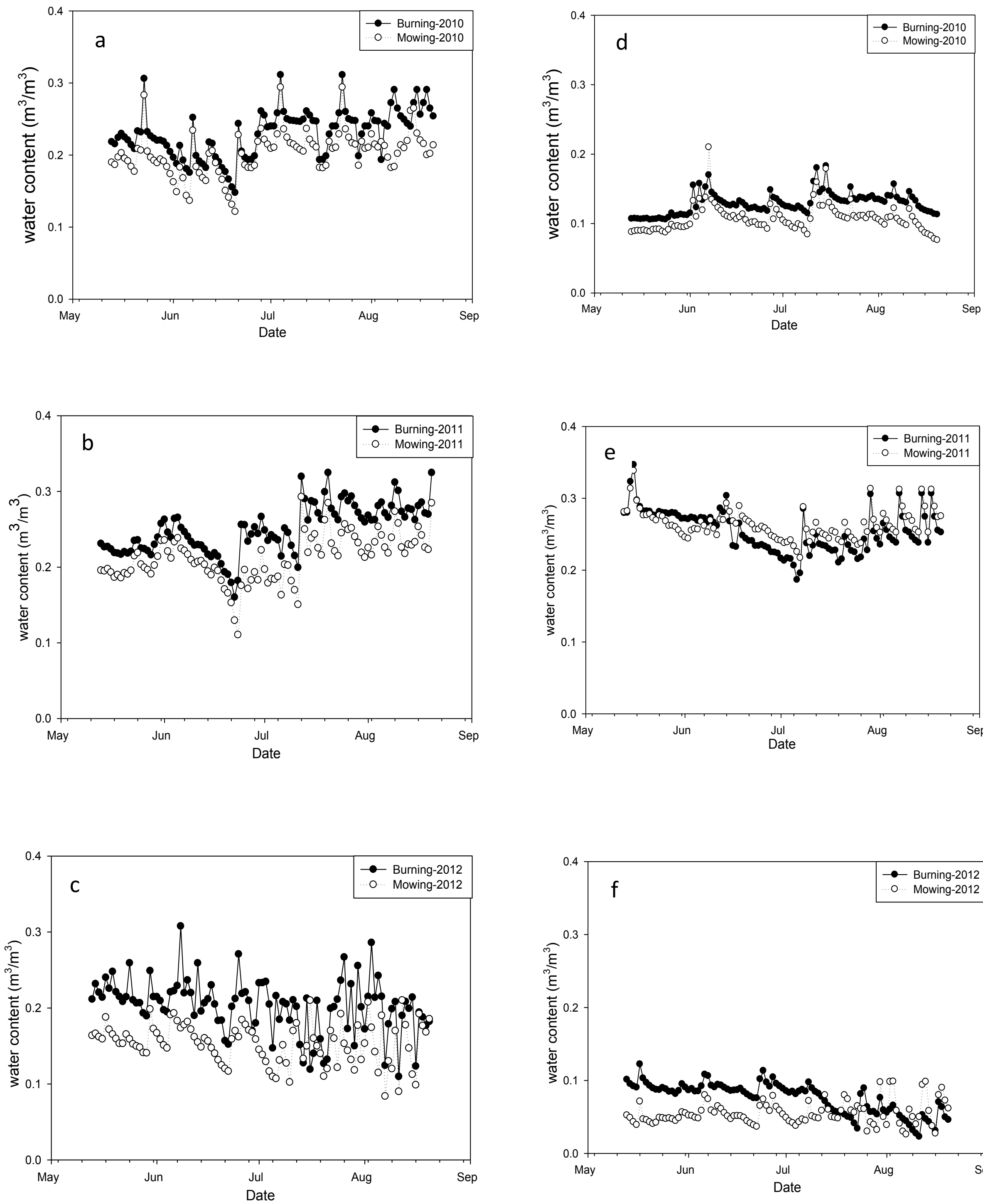

Figure 2.1 Soil moisture content in Collingwood (a, b and c) and Earltown (d, e and f), Nova Scotia from 2010 – 2012.

Chapter 3.0 Spot Application of Organic Herbicides to Control Common Weeds in Wild Blueberry

3.1 Introduction

Mechanical cultivation is the most widely used non-chemical technique of weed control for organic production but it cannot be implemented in wild blueberry because of its perennial nature. Similarly, hexazinone and other synthetic herbicides also cannot be used in organic production. Therefore, excessive weed growth with limited options for management is one of the major factors hindering the growth of organic production of wild blueberry. Spot application of organic based herbicides such as Ecoclear™ and Finalsan® could play an integral role for managing weeds in organic blueberry production.

According to a weed survey of 115 Nova Scotia blueberry fields, a total of 119 different weed species were observed (McCully et al. 1991). The most common weed species were bunchberry, colonial bentgrass, poverty oatgrass, sheep sorrel, and false lily-of-the-valley. Goldenrod was the most frequently occurring weed outside the quadrats sampled and it occurred in over 94% of the fields surveyed. Goldenrod is a herbaceous perennial that reproduces by seed and underground rhizomes. It grows rapidly, competes for light, nutrients and moisture with blueberry, reduces yield potential and hinders harvest operation (McCully et al. 2005). Ferns such as sweet fern (*Comptonia peregrina*) and bracken fern (*Pteridium aquilinum* L.) are common in the fields that are developed from woodland. Ferns spread by underground rhizomes and are difficult to control and may interfere with blueberry rhizomes. Ferns grow in clumps that may compete for space and also hinder blueberry harvest. Similarly, wild raisin

(*Viburnum cassinoides* L.) is a woodland shrub; growing mostly on the edges of blueberry fields. It may also inhibit harvesting of the blueberry.

Moss is a growing problem in wild blueberry fields. Moss pressure in blueberry fields is increasing due to the shift in management practices towards less burning as a pruning method (Graham and Melanson 2010). In a research study conducted by Percival and Garbary (2012) from 2006 to 2009, it was found that mosses were present in every sampled field (n = 40) in Nova Scotia, and hair cap moss (*Polytrichum commune)* was the most prevalent moss species observed. It is generally dark green in colour, robust, 4 - 20 cm tall and commonly found in moist areas, wet moorlands, bogs, swampy woodlands, coniferous forests, and boreal forests (Giallombardo 2001). Hair cap mosses are very competitive because these mosses form dense turfs of erect, leafy vegetative shoots interconnected by a network of underground rhizomes (Sarafis 1971). Moss colonies can be very large because it reproduces vegetative branches and propagates from plant fragments (Derda and Wyatt 1990). Similarly, mosses have long growing period, remain actively growing late into the autumn and winter (Percival and Garbary 2012). Moss physically competes for space and resources and thus reduces blueberry yield (Percival and Garbary 2012). Mosses are tolerant to most herbicides but are suppressed by burning (McCully et al. 2005). Autumn application of Chateau® suppressed hair-cap moss (Percival and Garbary 2012) but this cannot be used in organic production.

Wild blueberry fields are patchy. There are significant areas of bare ground between blueberry clones and many weed species appear in distinct patches or grow taller than the blueberries within a patch. This patchy distribution and height differential lends itself to wiping or spot application of herbicides. Spot application of herbicides is carried out with the objective of applying herbicides to the weeds but not to blueberry foliage. Most of the herbicides that organic growers can use are non-selective, burn-down products and contact with crops results in crop injury or death. Acetic acid has been used as a weed control agent for several centuries (Dayan et al. 2009). Ecoclear^{TM}, trade name for the product that consists of 25% acetic acid, is marketed to control weeds in home gardens and lawns. Several studies with varying levels of acetic acid concentrations showed acetic acid as a potential weed control agent. Ivany (2010) achieved 95% or greater control of lambs-quarters (*Chenopodium album* L.), corn spurry (*Spergula arvensis* L.) and wild buckwheat (*Polygonum convolvulus* L.) three weeks after treatment when acetic acid was applied at concentrations of 20% and 30% in potato field. Vinegar (9% acetic acid) killed more than 80% of 30 day-old or younger cotton (*Gossypium hirsutum*) and sunflower (*Helianthus annuus)* (Moran and Greenberg 2008). The United States department of agriculture, agricultural research service (USDA-ARS) has been conducting several research studies on weed control using vinegar, with the objective of developing inexpensive and environment-friendly solutions (Radhakrishnan et al. 2002b). It was found that vinegar (10 - 20% acetic acid) effectively controlled some annual and perennial weeds (Radhakrishnan et al. 2002b). Spot spraying of corn fields with vinegar (20% acetic acid) killed 80 to 100% of weeds without harming the corn (Radhakrishnan et al. 2002a). Similarly, 100% kill of top growth of Canada thistle was achieved with vinegar (5% acetic acid).

Acetic acid and other organic based contact herbicides should be applied at early stage of weed growth. Weed damage will be reduced if such herbicides applied at a mature stage (Young 2004). Moran and Greenberg (2006) achieved 100% kill of Palmer amaranth (*Amaranthus palmeri*) when vinegar (4.5% or 9% acetic acid) was applied at the age of 1.5 weeks, while vinegar (9% acetic acid) killed only 12% of Palmer amaranth when applied at the age of 3.5 weeks. According to Radhakrishnan (2002b) lower concentrations of 5 and 10% acetic acid is effective in killing weeds during early growth stages while at later stages 15 and 20% concentrations will be needed.

Fatty acids that have herbicidal activity are known as herbicidal soaps. Ammonium soap of fatty acid is a non-selective contact herbicide that does not translocate through the plant. It causes a sudden drop in intracellular pH that will result in a loss of membrane integrity and rapid cell death (Health Canada 2009). Similarly, Finalsan® is another herbicidal soap that contains pelargonic acid (186.7 g L^{-1}) as an active ingredient (Neudorff 2012). Pelargonic acid has low toxicity and environmental impact with no residual activity (Dayan et al. 2009). It is naturally occurring in many plants and animals and present in many foods.

Besides acetic acid and fatty acid, other organic based products such as corn gluten and clove oil also have the potential for use as weed control agents. Corn gluten is a natural pre-emergence weed control agent which has several growth regulating effects on certain monocotyledonous and dicotyledonous weed species (Liu and Christians 1994). It inhibits weed germination by preventing the formation of root systems in plants (Christians 1991) and also decreases seedling survival in several crops (McDade and Christians 2000). Similarly, clove oil is phyto-toxic and caused electrolyte leakage resulting in cell death (Tworkoski 2002).

Incorporating organic herbicides with other non-chemical measures of weed control, such as burning and sulphur application, might be a viable option for organic blueberry production. The objective of this experiment was to investigate the effectiveness of organic based herbicides i.e. Finalsan® and Ecoclear™ as a potential candidate for weed control in organic farming situations. Ecoclear™ and Finalsan® are registered with the Canada's pest management regulatory agency (PMRA) as non-selective contact herbicides but these are not registered for use in wild blueberry. Although Ecoclear® is registered for use in some food crops, Finalsan®, a relatively new product in market, is registered only for non-food crops.

3.2 Materials and Methods

3.2.1 Spot Application of Organic Herbicides to Control Goldenrod, Sweet Fern, Bracken Fern and Wild Raisin

In June 2012, an experiment was set up in a commercial blueberry field at Portapique (45° 25' 32'' N, 63° 43' 15'' W), Nova Scotia in a pruning year. The four weed species selected for spot application were narrow-leaved goldenrod (*Solidago graminifolia* L.), sweet fern (*Comptonia peregrina*), bracken fern (*Pteridium aquilinum* L.) and wild raisin (*Viburnum cassinoides* L.). The two herbicides used in this experiment were Finalsan® and Ecoclear™. Finalsan® contains pelargonic acid 186.7 g L^{-1} as an active ingredient while Ecoclear™ contains 25% acetic acid. The spray solution of Finalsan® was prepared mixing one part of Finalsan® with five parts of water and the Ecoclear™ solution was prepared with one part of Ecoclear™ mixed with 2.25 parts of water. Treatments included spot application of Finalsan®, Ecoclear™ and a control (water). The experiment was set up as a completely randomized design with seven replications. One ramet from each replication was selected and flagged. The date of spraying of the herbicides was July 29, 2012. Sweet fern height and bracken fern height were around 20 - 30 cm and 40 - 60 cm, respectively at the time of herbicides application. Similarly, goldenrod was in floral bud stage and wild raisin was in pre-flowering stage. The air temperature and wind speed at the time of spraying were 21 °C and 2.0 km h^{-1}, respectively. Herbicides were thoroughly sprayed with hand spray bottles to the stems and leaves until completely wet.

3.2.2 Spot Application of Organic Herbicides to Control Moss

The experiment was conducted in a commercial blueberry field at Great Village (45° 28' 48'' N, 63° 34' 26'' W), Nova Scotia in November, 2011 and April, 2012. The experiment was set up in November in the blueberry harvest year after mowing the field. The plots were established where at least 50% of the area was covered by moss. Finalsan® and Ecoclear™ were used in this experiment. The spray solution of Finalsan® was prepared mixing one part of Finalsan® with five parts of water and the Ecoclear™ solution was prepared with one part of Ecoclear™ mixed with 2.25 parts of water. Finalsan® and Ecoclear™ were applied at the rate of 61 kg and 56 L a.i. ha^{-1} in a water volume of 1660 and 525 L ha^{-1} respectively. A completely randomized design with four replications was established. There were five treatments: (1) Ecoclear™- fall application (2) Ecoclear™- spring application (3) Finalsan®- fall application (4) Finalsan®- spring application and (5) the control. Plot size was 4 x 2 m with one metre buffer between the blocks. Fall application and spring application were carried out on November 10, 2011 and April 30, 2012, respectively. Air temperature and wind speed were 12 °C and 2.2 km h^{-1} respectively during fall application. During spring application, air temperature and wind speed were 6.4 °C and 3.1 km h^{-1} respectively. All herbicides were applied with a CO_2 pressurized hand-held sprayer equipped with Teejet 8002VS nozzles spaced 50 cm on a 1.5 m boom at a pressure of 275 KPa.

3.2.3 Data Collection

Herbicide damage on the selected weed species was evaluated 14, 35 and 56 days after spraying (DAS). Herbicide damage to moss was evaluated as percent above ground biomass after the spring application. A final damage rating 90 DAS was also carried out for moss. A 0 to 100 scale was used for the ratings based on the visual observation, where 0 meant no visible injury and 100 indicated all above ground tissue was brown and appeared dead (Hartzler and Foy 1983).

3.2.4 Statistical Analysis

Damage ratings were analyzed using the PROC MIXED procedure with repeated measures in SAS 9.1 (SAS Institute Inc., Cary, NC, USA). Significant effects were detected at a 5% level according to least square (LS) means procedure.

3.3 Results and Discussion

3.3.1 Herbicide Effects on Goldenrod, Sweet Fern, Bracken Fern and Wild Raisin

Significant treatment by time interactions with damage ratings on sweet fern ($p = 0.0006$), bracken fern ($p = 0.0006$) and wild raisin ($p = 0.0044$) were observed. The damage done by Finalsan® and Ecoclear™ to sweet fern, bracken fern and wild raisin were significantly higher than the control at 14, 35 and 56 DAS (Table 6). Sweet fern damage at 14 and 35 DAS was significantly higher where Finalsan® was applied, compared to Ecoclear™. However, there was no significant difference in damage after 56

DAS. Applications of Ecoclear^{TM} and Finalsan® resulted in 80% bracken fern damage 14 DAS and more than 95% damage 35 and 56 DAS. Bracken fern and sweet fern damage rating tended to increase with time (Table 6). More than 95% of the each ramet was damaged after 56 DAS. Higher damage rating after 56 DAS was because the ramet did not produce new growth after first application and died almost completely 56 DAS. Webber et al. (2011) also observed more than 95% control of cutleaf groundcherry (*Physalis angulata* L.) and spiny amaranth (*Amaranthus spinosus* L.) when Scythe® (57% pelargonic acid) was applied at 9% v/v in squash.

For wild raisin, Finalsan® caused significantly higher damage than Ecoclear^{TM} 14 DAS, 35 DAS and 56 DAS (Table 6). Wild raisin damage rating tended to decrease over time and the damage rating 56 DAS was significantly lower than 14 DAS. The reduced damage over time may be because the burn down herbicide kills aerial portions of plants, but does not control the underground parts, and plants re-emerge from the root system after a few days or weeks (Dayan et al. 2009). It was also seen that basal portion of the ramet was not killed and kept growing, producing side shoots. Webber and Shrefler (2009) also noticed more than 95% broadleaf weed control three days after treatment in onion when vinegar (20% acetic acid) applied at the rate of 945 L ha^{-1}, but weed control decreased over time.

For goldenrod damage ratings, there was no time by treatment interaction ($P = 0.28$) but the treatment effect was significant ($p < 0.0001$). Damage done by Finalsan® and Ecoclear^{TM} were significantly higher than the control but not different from one another. More than 95% of goldenrod were damaged within 14 DAS of herbicides and did not exhibit re-growth. Evans et al. (2011) also observed 100% and 96% weed control in pepper and broccoli respectively one day after vinegar (20% acetic acid) application at six leaves or less. Similarly, Scythe® (57% pelargonic acid) applied at 3% v/v provided excellent control of carpetweed (*Mollugo verticillata*), spiny amaranth and yellow nutsedge (*Cyperus esculentus* L.) (Webber and Shrefler 2007). But, delaying applications by one week resulted in significantly decreased weed control.

3.3.2 Herbicide Effects on Moss

The treatment by time interaction was marginally significant ($p = 0.085$) for moss damage ratings. Fourteen DAS in spring, all four herbicide treatments damage was significantly higher on moss compared to the control (Figure 2). Moreover, Ecoclear™ and Finalsan® applied in the spring tended to achieve higher damage than Ecoclear™ and Finalsan® applied in the fall but the difference was not significant (Figure 2). Herbicide damage 35 DAS, 56 DAS and 90 DAS reduced gradually. Less than 30% damage of moss was achieved at 90 DAS. Moreover, there was no significant difference in damage done by Ecoclear™ and Finalsan® applied in the fall compared to the control. This might be because moss recovered from herbicide damage after a certain time period.

Higher damage 14 DAS in spring might be due to the reason that spring application killed new growth whereas the fall gave more time for recovery. Similarly, higher damage by Ecoclear™ and Finalsan® applied in spring 2012 as compared to Ecoclear™ and Finalsan® applied in fall 2011 was very apparent. The herbicidal effects of Ecoclear™ and Finalsan® applied in fall might have faded through the winter. The damaging effects of Finalsan® and Ecoclear™ decreased over time. Less than 30% of the moss damage at 90 DAS might be because of the recovery of the moss against herbicide damage. This result supports the findings of Fausey (2003) who suggested that neither pelargonic acid (195.3 kg·ha^{-1}) nor acetic acid (195.3 kg·ha^{-1}) completely prevented from occurring, nor did they eliminate the silver thread moss once present.

3.4 Conclusions

Weed control is a major challenge for organic blueberry production. Results from this research indicate that some common weeds can be effectively suppressed by spot application of herbicides that may be of use in organic management. Finalsan® was found to be more effective than Ecoclear™ for the species evaluated. A single application of these herbicides on goldenrod, sweet fern and bracken fern achieved more than 95% control 56 days after spraying. However, for wild raisin, a second application after 35 days after spraying might be required for better control on blueberry fields.

For moss, a single application of Finalsan® or Ecoclear™ was not effective. Although the amount of living above ground biomass of the moss was reduced after application in the spring, it increased steadily over time. Therefore, frequent application of herbicides might be necessary to suppress moss. Ecoclear™ and Finalsan® applied in spring achieved better results than fall application.

Table 3.1 Herbicides damage rating on sweet fern, bracken fern and wild raisin following spot sprays at Portapique, Nova Scotia in 2012[1].

Treatments	Time (DAS)	Weed damage rating		
		Sweet fern	Bracken fern	Wild Raisin
Finalsan®[2]	14	95 a	80 b	94 a
Ecoclear™[3]	14	80 b	80 b	69 bc
Control (Water)	14	3 c	2 c	1 f
Finalsan®	35	100 a	97 a	77 ab
Ecoclear™	35	86 b	100 a	53 cd
Control (Water)	35	0 c	1 c	1 f
Finalsan®	56	100 a	96 a	50 d
Ecoclear™	56	98 a	100 a	24 e
Control (Water)	56	0 c	0 c	1 f

[1]Means within a column cross all time period, followed by the same letter are not significantly different (LSD, P<0.05). [2]One part of stock solution mixed with five parts of water. [3]One part of stock solution mixed with 2.25 parts of water.

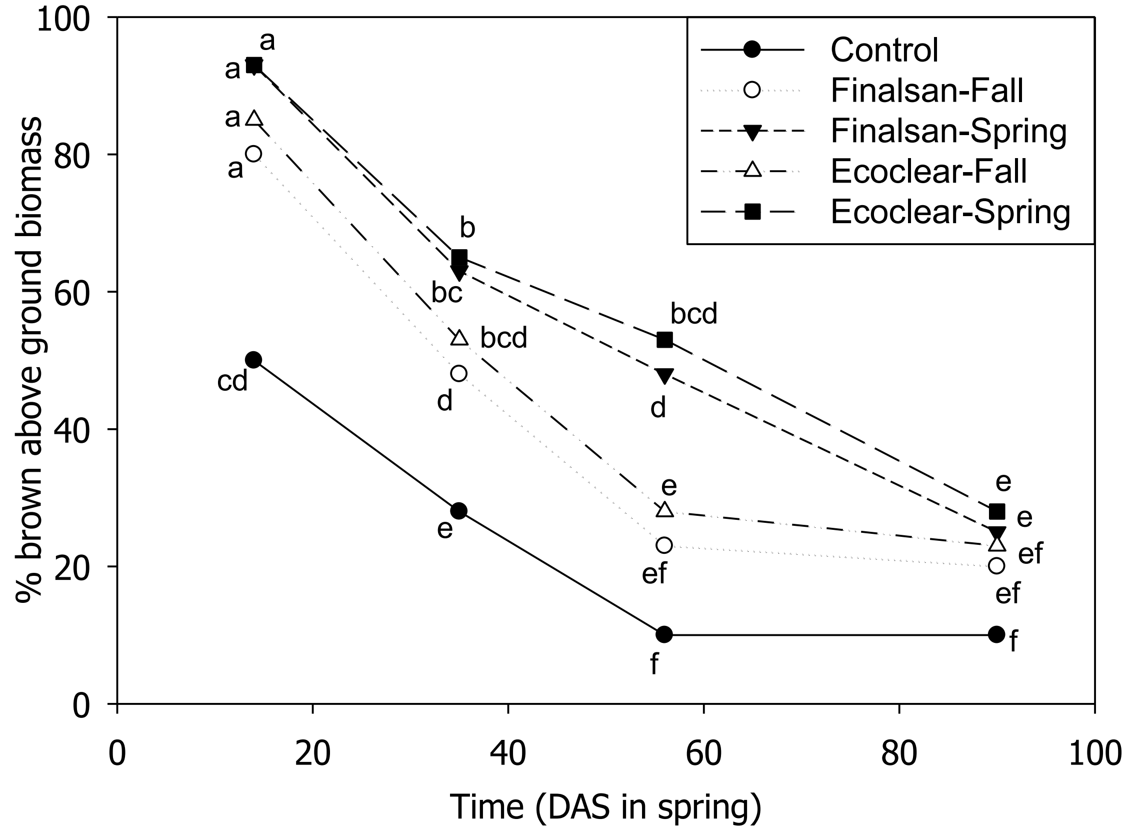

Figure 3.1 Percent brown above ground biomass of moss after applying herbicides or a just water in the control treatment in spring at Pigeon Hill, Nova Scotia in 2012. Means within a same day measurement followed by same letter are not significantly different (LSD, $P<0.05$).

Chapter 4.0 Conclusions

4.1 Overall Conclusions

Weed management is one of the major challenges for the organic blueberry industry. For this reason we decided to investigate pruning methods and soil pH modification as well as two organic based herbicides that may be eligible for use in organic production. Burning, in combination with sulphur applications, helped to decrease weed density and cover and increased the blueberry stem density and cover, number of flowers, and ultimately increased blueberry yield in both sites. Similarly, mycorrhizal infection was also higher in burning plots. Similarly, there was a trend of higher soil moisture and soil nutrients, such as NPK in burned plots. Therefore, higher yield in burned plots might be due to multiple factors. There were no significant pruning methods by soil pH modification interactions, though there was a greater decrease in weed cover, density and higher blueberry cover, stem density and yield, when pruning was carried out by burning and sulphur was applied to lower soil pH. Pruning by burning and soil acidification using sulphur, therefore, may be a viable weed management practice for organic wild blueberry production.

Organic herbicides can be incorporated with other physical and mechanical measures in organic production to control persistent problems. Single application of Finalsan® or Ecoclear™ effectively controlled goldenrod, sweet fern and bracken fern but not wild raisin. Finalsan® was found slightly better than Ecoclear™. Neither product effectively controlled moss.

4.2 Recommendations

The best weed management strategies for organic blueberry production should incorporate all possible non-chemical methods of weed control, including preventive, cultural, mechanical and biological measures. Cleaning equipment, after use in each field, is the first step that limits the spread of weed seeds. Similarly, mulching, using bark and wood chips, may reduce weed density and cover. Then, pruning by burning and sulphur application facilitates blueberry growth and improves the soil physical and nutritional status. The change in soil pH by sulphur application is not permanent, so it is necessary to monitor soil pH every 3 - 4 years.

Finalsan® and Ecoclear™ showed promising results against goldenrod, sweet fern and bracken fern. Although Finalsan® and Ecoclear™ are not yet registered for weed control in organic blueberry production; they have potential to become organically approved herbicides. It may be necessary to reformulate the products to ensure they are acceptable for organic production. Therefore, integrating mechanical and cultural measures of weed control with spot applications of Finalsan® and Ecoclear™, will help to control weed patches of goldenrod, sweet fern and bracken fern in blueberry fields. To control wild raisin effectively, a second application after 35 DAS may be needed. Repeated applications may diminish the underground resources and achieve sustained weed control. For moss, spot application of Finalsan® should be carried out when majority of mosses are green. Repeated applications may be needed to suppress moss in long term. These are non-selective burn-down products which may also damage the crops. Therefore, extra precautions should be taken during application to avoid crop damage.

4.3 Future Direction

Pruning in blueberry is carried out every two years either by burning or mowing. Continue burning or mowing will bring changes in soil and plant characteristics, thus in blueberry yields. Therefore, this study should be continued to study the long term effect of burning and mowing. Leaf nutrient content is a good indicator of plant nutrient status. Similarly, soil OM and soil nutrients should be evaluated under mowing and burning. Therefore, these should be measured in future studies. Additional research should be conducted to investigate the potentiality of other organic based herbicides such as corn gluten, clove oils and soap-based products to identify the best candidate, so that they can be combined with other physical, mechanical or cultural measures of weed control.

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Appendix 1: Soil nutrient content in 2011 and 2012 at Collingwood, Nova Scotia[1].

Treatments	2011				2012			
	Burning		Mowing		Burning		Mowing	
	NS	S	NS	S	NS	S	NS	S
N^2 (%)	0.66	0.60	0.39	0.57	0.68	0.58	0.42	0.61
P_2O_5 (kg ha^{-1})	59	81	50	70	118	58	56	65
K_2O (kg ha^{-1})	141	142	104	126	207	182	80	97
Ca (kg ha^{-1})	381	548	252	206	664	320	283	311
Mg (kg ha^{-1})	69	70	35	37	95	40	36	47
Na (kg ha^{-1})	27	19	19	21	44	27	20	26
S (kg ha^{-1})	63	249	102	249	65	167	92	155
Al (ppm)	2,258	1,903	2,340	2,068	2,033	2,292	2,499	2,214
Fe (ppm)	250	346	183	310	302	258	217	312
Mn (ppm)	17	30	12	12	22	17	11	14
Cu (ppm)	1.23	0.83	1.30	0.94	0.99	0.83	1.16	1.08
Zn (ppm)	3.4	4.1	2.6	2.4	3.9	2.2	2.0	2.4
CEC (meq100g^{-1})	11	11	8.5	9.2	15	13.9	11.5	15.3
Base Saturation								
K (%)	1.4	1.4	1.3	1.4	1.5	1.4	0.7	0.7
Ca (%)	8.6	12.5	7.4	5.6	11.1	5.7	6.2	5.1
Mg (%)	2.6	2.7	1.7	1.7	2.6	1.2	1.3	1.3
Na (%)	0.5	0.4	0.5	0.5	0.6	0.4	0.4	0.4
H (%)	86.9	83.1	89.1	90.8	84.2	91.3	91.4	92.6

Data were not replicated and therefore were not analyzed statistically. NS - no-sulphur, S - Sulphur

1 Soil nutrient availability by Mehlich III unless otherwise mentioned

2. Total nitrogen by combustions

Appendix 2: Soil nutrient content in 2011 and 2012 at Earltown, Nova Scotia[1].

Treatments	2011				2012			
	Burning		Mowing		Burning		Mowing	
	NS	S	NS	S	NS	S	NS	S
N^2 ($kg\ ha^{-1}$)	0.59	0.68	0.55	0.54	0.61	0.65	0.57	0.58
P_2O_5 ($kg\ ha^{-1}$)	21	21	19	19	23	25	20	20
K_2O ($kg\ ha^{-1}$)	155	129	133	123	162	139	113	125
Ca ($kg\ ha^{-1}$)	443	582	647	471	1191	540	911	321
Mg ($kg\ ha^{-1}$)	72	81	95	63	176	69	123	52
Na ($kg\ ha^{-1}$)	77	25	31	26	50	26	37	19
S ($kg\ ha^{-1}$)	39	216	56	374	39	407	52	458
Al (ppm)	2,190	2,201	2,225	2,233	2,384	2,509	2,466	2,624
Fe (ppm)	94	95	87	79	85	126	93	113
Mn (ppm)	6	9	7	10	11	12	9	11
Cu (ppm)	0.61	0.71	0.70	0.64	0.65	0.60	0.58	0.56
Zn (ppm)	1.6	2.0	4.6	1.8	2.5	2.0	1.8	1.8
CEC ($meq100g^{-1}$)	9.8	10.1	10.3	9.7	15.3	14.9	13.8	14.6
Base Saturation								
K (%)	1.7	1.4	1.4	1.3	1.1	1.0	0.9	0.9
Ca (%)	11.3	14.5	15.7	12.1	19.5	9.1	16.5	5.5
Mg (%)	3.1	3.4	3.8	2.7	4.8	1.9	3.7	1.5
Na (%)	1.7	0.5	0.7	0.6	0.7	0.4	0.6	0.3
H (%)	82.3	80.3	78.4	83.2	73.9	87.6	78.3	91.8

Data were not replicated and therefore were not analyzed statistically. NS - no-sulphur, S - Sulphur

1 Soil nutrient availability by Mehlich III unless otherwise mentioned

2. Total nitrogen by combustions

Appendix 3: Leaf nutrient content of wild blueberry plants at Collingwood, Nova Scotia.

Treatments	2011				2012			
	Burning		Mowing		Burning		Mowing	
	NS	S	NS	S	NS	S	NS	S
N (%)	1.81[1]	1.79	1.69	1.77	1.59	1.55	1.49	1.52
P (%)	0.13	0.13	0.13	0.12	0.11	0.11	0.11	0.11
K (%)	0.36	0.42	0.34	0.38	0.34	0.41	0.40	0.38
Ca (%)	0.69	0.55	0.56	0.66	0.52	0.45	0.58	0.57
Mg (%)	0.21	0.18	0.18	0.20	0.19	0.16	0.20	0.19
Fe (ppm)	40.92	33.13	31.65	33.32	52.89	41.09	37.30	36.08
Mn (ppm)	1,201	1,774	1,595	2,102	935	1,543	1,404	1,728
Cu (ppm)	5.4	5.2	4.98	4.03	3.51	4.22	3.8	3.16
B (ppm)	26.47	21.50	22.30	28.33	16.08	15.18	20.59	20.61
Zn (ppm)	21.89	16.14	17.19	15.33	14.29	15.11	14.04	14.16

[1]Data were not replicated and therefore were not analyzed statistically. NS - no-sulphur, S - Sulphur

Appendix 4: Leaf nutrient content of wild blueberry plants at Earltown, Nova Scotia.

Treatments	2011				2012			
	Burning		Mowing		Burning		Mowing	
	NS	S	NS	S	NS	S	NS	S
N (%)	1.67[1]	1.64	1.65	1.69	1.47	1.46	1.44	1.45
P (%)	0.10	0.11	0.10	0.11	0.09	0.09	0.08	0.09
K (%)	0.29	0.32	0.27	0.32	0.27	0.29	0.24	0.36
Ca (%)	0.65	0.75	0.66	0.64	0.61	0.55	0.57	0.54
Mg (%)	0.26	0.27	0.29	0.23	0.28	0.25	0.25	0.23
Fe (ppm)	29.72	29.19	28.16	29.19	34.22	31.77	32.01	30.39
Mn (ppm)	203	827	234	913	200	994	223	1423
Cu (ppm)	6.59	6.53	5.35	6.24	5.04	3.88	4.25	4.61
B (ppm)	30.96	29.86	34.81	30.09	27.89	25.55	28.02	26.02
Zn (ppm)	10.34	12.57	11.49	12.52	10.24	11.46	10.89	10.81

[1]Data were not replicated and therefore were not analyzed statistically. NS - no-sulphur, S - Sulphur