Use of Flame Cultivation as a Nonchemical Weed Control In Cranberry Cultivation

Katherine M. Ghantous

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USE OF FLAME CULTIVATION AS A NONCHEMICAL WEED CONTROL IN CRANBERRY CULTIVATION

A Dissertation Presented

by

KATHERINE M. GHANTOUS

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 2013

Department of Plant and Soil Sciences
USE OF FLAME CULTIVATION AS A NONCHEMICAL WEED CONTROL IN CRANBERRY CULTIVATION

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DEDICATION

To my family, for always nurturing my inquisitive mind.
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ABSTRACT

USE OF FLAME CULTIVATION AS A NONCHEMICAL WEED CONTROL IN CRANBERRY CULTIVATION

SEPTEMBER 2013

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Cranberry (Vaccinium macrocarpon Ait.) is a woody perennial crop that can remain productive for decades. Competition for resources between cranberries and weeds can depress cranberry farm yields, resulting in large annual crop losses. Renewed interest in reducing chemical inputs into cranberry systems has provided the motivation to evaluate methods, such as flame cultivation (FC), as potential nonchemical options for weed control. Also known as thermal weeding, FC exposes plants to brief periods of high temperature that causes the water in the plant tissue to expand rapidly, rupturing plant cells and leading to necrosis. Various FC methods have been used successfully in annual crops as both a preemergence and postemergence weed control, but few scientific reports have been published on the use of FC on perennial weeds in a woody perennial crop system.

Dewberry (Rubus spp.), sawbrier (Smilax glauca), and common rush (Juncus effusus) are cranberry weeds that are difficult to control, spread quickly and can cause significant crop loss. Flame cultivation may be an effective non-chemical means for controlling these weeds in cranberry systems. FC would ideally be used as a spot
treatment for weeds growing in the cranberry canopy, as well as on larger non-production areas where cranberry vines are not as abundant, such as bog edges, ditches, and dikes. Using FC to treat weeds within the cranberry canopy will likely cause localized damage to cranberry plants immediately surrounding the weeds, thus cranberry response to FC is also of interest.

The following experiments were designed to examine the response of weeds and cranberry plants to FC. Perennial plants rely on reserves of nonstructural carbohydrates (NSC) for growth and survival, thus the efficacy of FC treatments to weeds will likely be impacted by the timing and frequency of treatments as they relate to the specific carbohydrate cycles of targeted weeds, such as dewberry. An additional experiment studied the seasonal fluctuations of NSC in dewberry roots. Cranberry growers were also surveyed on their past experiences with FC, as well as their willingness to adopt FC if proven an effective method for controlling weeds.
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CHAPTER 1

INTRODUCTION

Cranberry (*Vaccinium macrocarpon* Ait.) is a long-lived woody perennial with slender trailing stems that grows in acidic sandy soils (Eck 1990). It is one of the few commercially grown fruit species native to North America. Cranberries in the United States are produced primarily in Massachusetts, Wisconsin, New Jersey, Washington, and Oregon and are important agricultural commodities for these states. In 2012 it was estimated that a total of 40,300 acres of cranberries were harvested in the United States, generating over $386 million dollars from 8 million barrels of fruit (USDA 2013).

Cranberries can remain productive for decades, and will form dense continuous mats of vegetation. Competition for resources between cranberries and weeds can depress cranberry bog yields, resulting in large annual crop losses (Patten and Wang 1994; Swanton et al. 1993). In some cases, severe weed infestations make it necessary for entire bogs to be renovated, at an average cost of $24,600 per acre (Cape Cod Cranberry Growers’ Association 2008). Due to the perennial nature of cranberry vines, weed control methods used in other crops such as soil tillage are not utilizable, and the majority of problematic weeds are also long lived perennials. Current weed management strategies include cultural controls such as flooding and sanding of bogs, mechanical controls such as hand weeding, and chemical controls with pre- and postemergence herbicides (Sandler 2013).

The cranberry industry is committed to identifying sustainable production and pest management practices that reduce chemical inputs into cranberry systems (DeMoranville 2009; Sandler 2008). Renewed interest in reducing chemical inputs into
cranberry systems has provided the motivation to evaluate methods, such as flame cultivation (FC), as potential nonchemical options for weed control. FC exposes plants to brief periods of high temperature that causes the water in the plant tissue to expand rapidly, rupturing plant cells. Interference with cellular processes such as photosynthesis occurs even with very brief (e.g., 125 ms) exposures to high temperatures (Ellwanger et al. 1973). Heat disrupts and destroys cellular membranes and leads to necrosis (Daniell et al. 1969). Many different methods of FC are available ranging from open flames to infrared (radiant heat), hot foam and boiling water.

Prescribed burning has been used in perennial woody lowbush blueberry (*Vaccinium myrtilloides* and *V. angustifolium*) cultivation for decades as a method of pruning to increase yield, and aid in the control of weeds, pests, and pathogens (Ismail and Yarborough 1981; Vander Kloet and Pither 2000). Historically, low intensity burns were sometimes used on dormant cranberry vines as a way to remove old growth and stimulate new growth (Darrow et al. 1924). Although modern day practices such as mowing have replaced this method, cranberry plants are able to tolerate localized heat treatments primarily intended to control weeds (Ghantous et al. 2013).

Various FC methods have been used successfully in annual crops such as carrots, corn, onions and potatoes as both a preemergence and postemergence weed control (Diver 2002), but few scientific reports have been published on the use of FC on perennial weeds in a woody perennial crop system. Continuous mats of cranberry vegetation present a logistical challenge for FC since weeds grow within the cranberry canopy structure. Although not the target, treating weeds on cranberry farms with FC may cause localized damage to cranberry plants immediately surrounding the weeds. FC
would ideally be used as a spot treatment for weeds growing in the cranberry canopy, as well as on larger non-production areas where cranberry vines are not as abundant, such as bog edges, ditches, and dikes.

Dewberry (*Rubus* spp.) and sawbrier (*Smilax glauca*) are woody cranberry weeds identified as “Priority 1”, meaning that they are difficult to control, spread quickly and can cause significant loss of crop (Else et al. 1995). Dewberry is a prostrate woody perennial vine covered in hairs, with trifoliate leaves and white flowers (Jensen and Hall 1979). Sawbrier is also a woody perennial vine with greenish, rounded stems having stout prickles and alternate, simple, leaves that have a glaucous underside and shiny top (Gleason and Cronquist 1991). Current practices for controlling dewberry and sawbrier include hand pulling young weeds, wiping weeds with glyphosate, or spot renovation of heavily infested areas. Glyphosate use on bogs provides only minimal success for controlling dewberry and sawbrier. Glyphosate wipes work best when there is a significant height differential between the target weeds and the cranberry vines because cranberries are very sensitive to glyphosate, and these weeds are typically intermingled with the cranberry canopy.

Woody perennial plants such as these weed species use stored root reserves for initial growth during the growing season. These root reserves typically decrease rapidly after vegetative and reproductive development, and rise later in the season (Loescher et al. 1990). The ability of woody plants to resprout after cutting is affected by the time of the cutting, and is thought to be linked to the carbohydrate reserves (Kays and Canham 1991). Flame cultivation may provide an effective control for dewberry and sawbrier as an alternative to current methods. The efficacy of FC treatments to woody weeds will
likely be impacted by the timing and frequency of treatments as they relate to the specific carbohydrate cycles of targeted woody weeds.

In addition to woody weeds, herbaceous perennials are also problematic weeds. Common rush (\textit{Juncus effusus}) is a common weed in irrigation ditches that readily spreads into cranberry production areas. Typical controls include digging out the weeds, using a string trimmer to cut them back, or using a glyphosate wipe. Flame cultivation may be an effective non-chemical means for controlling large areas of rushes in irrigation ditches as well as spot treating isolated weeds in production areas.

Cranberry growers were surveyed to garner information on their past experiences with FC, as well as their willingness to adopt FC if proven an effective method for controlling weeds (Chapter 2). The following experiments were designed to examine the response of weeds and cranberry plants to FC. The effect of a single FC exposure on two perennial woody weeds (dewberry and sawbrier) (Appendix A), four cranberry cultivars (Appendix B), and an herbaceous perennial weed (common rush) (Chapter 5) using different FC torches and exposure durations. After identifying the most effective tool and exposure time for woody weeds, the effects of treatment timing and treatment frequency on dewberry plants were studied (Chapter 3). We also collected root samples of untreated dewberry plants and used HPLC (High-performance liquid chromatography) to study the seasonal fluctuations of the ratio of structural to nonstructural carbohydrates to identify the most effective window of time for FC treatments (Chapter 4). After identifying the most effective tool and exposure time for FC treatments of rushes, we compared the effect of a single FC treatment, clipping the weed to the ground, clipping before FC, and clipping after FC (Chapter 5).


CHAPTER 2
MASSACHUSETTS CRANBERRY WEED MANAGEMENT: A GROWER SURVEY OF PROBLEMATIC WEEDS AND THEIR USE OF FLAME CULTIVATION

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Weeds present a significant threat to cranberry yields, and management of weeds is a major priority for cranberry growers. Dewberry (Rubus spp.), sawbrier (Smilax spp.), and dodder (Cuscuta spp.) are three problematic weeds found in Massachusetts cranberry production. They are rated as “Priority 1” weeds, meaning they substantially reduce yields, spread quickly, and kill cranberry vines (Else, et al. 1995). Current weed management strategies for these weeds include cultural controls such as flooding, mechanical controls such as hand weeding, and chemical control with the use of herbicides. However, none of these options are particularly effective on these Priority 1 weeds.

Along with the need to find more effective ways to manage weeds, there is an increasing interest to find ways to reduce chemical inputs into agriculture. The search for non-herbicidal alternatives to manage weeds in cranberry production is motivated by safety concerns relating to food residues and environmental issues, chemical costs, and a short list of approved chemicals for use on cranberries.

Flame cultivation (FC) is a method of weed control where target plants are exposed to brief periods of high temperature to damage or kill plant tissue. Various
flame cultivation methods have been successfully used in annual crops such as carrots, corn, onions and potatoes as both pre-emergence and post-emergence (Diver 2002). FC is being investigated as a possible method of controlling weeds on cranberry bogs (Ghantous et al. 2010).

A survey was developed and distributed to the Massachusetts cranberry grower community with the goal of gaining information about current weed problems, experience with traditional control methods, past experience using open burning or torches to control weeds, and willingness to incorporate flame cultivation into management practices if research indicates it is an effective technique. The survey had 7 questions with multiple parts, and was handed out to 219 cranberry growers on January 22, 2009 at the Annual UMass Extension Research Update Meeting, and to an additional 18 growers at a makeup meeting held on March 16, 2009. A total of 118 surveys were used to compile the following results (54% response rate).

**General demographic information**

The survey data indicated that 69% (N=115) of MA cranberry growers were 50 years or older. Only 3.5% reported being under 30 years of age, and less than 9% reported being between the ages of 30-39. Eighteen percent were between 40-49 years.

Those growers (N=103) who indicated that they were the primary decision maker for bog acreage represented approximately 6,493 acres of cranberry production in Massachusetts (14,000 acres are estimated to be in production in the state). Half of the decision maker respondents owned/managed 15 acres or less; 28% owned/managed between 15 and 50 acres and 13% owned/managed properties that were between 50 and
100 acres. One-tenth of primary decision maker respondents reported they managed more than 100 acres (with a maximum of 1800 acres).

**Weed presence and prevalence**

Growers were asked about the presence of dewberry, sawbrier, and dodder on their bogs (117 responded). Dewberry was present on 80% of bogs, sawbrier on 72%, and dodder on 97%.

Growers (N=107) were asked to estimate the percentage of acreage affected by these weeds (category = 0%, <5%, 5-25%, 25-75%, or >75%). The largest group of growers reported having 5-25% of bog acreage affected by dewberry (corresponding responses to categories: 22%, 20%, 41%, 16%, 2%). The responses for sawbrier were similar (N=107), showing the largest group of growers had 5-25% of acres affected by sawbrier. Very few had more than 25% of acres affected; no growers reported having more than 75% affected by sawbrier (responses corresponding to categories: 31%, 27%, 36%, 6%, 0%). Only 3% of growers (N=103) reported having no acreage affected by dodder, and 30% had more than 25% of acreage affected by dodder (responses corresponding to categories: 3%, 14%, 53%, 21%, 9%).

**Difficulty of control and efficacy rating of current weed control options**

Growers were asked for their opinion on the level of difficulty for controlling dewberry, sawbrier, and dodder (N=116). For all three weeds, at least 50% of growers with that weed type present rated it “very difficult to control” (dewberry, sawbrier,
dodder; 62%, 59%, 50%), while only 10% or less found these weeds “not difficult to control” (dewberry, sawbrier, dodder; 11%, 10%, 7%).

Growers were asked about their use of current industry standard methods to control each weed species, and then to rate the level of effectiveness of that control against the target weed. Results will be presented as: (treatment) (% very effective, % somewhat effective, % not effective). Overall, the majority felt current controls for these three weeds were not effective or only somewhat effective.

Dewberry control methods evaluated were mesotrione (Callisto) (N=73; 8%, 84%, 8%), glyphosate (Roundup) (N=76; 15%, 65%, 21%), digging out (N=56; 20%, 48%, 32%), clipping (N=52; 4%, 37%, 60%), and floods (N=40; 3%, 33%, 65%). Callisto and Roundup were the most popular choices for dewberry control, although most growers rated them as somewhat effective. Most respondents felt that clipping and flooding were not effective controls.

Sawbrier control methods evaluated were Callisto (N=63; 19%, 67%, 14%), Roundup (N=78; 18%, 64%, 18%), digging out (N=45; 24%, 44%, 31%), and clipping (N=47; 0%, 40%, 60%). Callisto and Roundup were also the most popular choices for sawbrier control, however the majority of growers using these controls rated them as only somewhat effective. No growers reported clipping to be a very effective method for controlling sawbrier.

Dodder control methods evaluated were dichlobenil (Casoron) (N=90; 27%, 67%, 7%), Callisto (N=61; 12%, 72%, 16%), hand removal (N=72; 17%, 56%, 28%), raking (N=59; 3%, 59%, 37%), and floods (N=41; 12%, 27%, 61%). Casoron and hand removal were used by the largest number of growers for dodder control. Of the 90 respondents
using Casoron, 27% found it very effective and 67% found it somewhat effective.

Seventy two respondents rated the effectiveness of hand removal, with 17% finding it very effective and 56% finding it somewhat effective. Most growers felt that floods were not effective for dodder control.

**Past experience using fire/heat to control weeds**

Growers were asked if they ever used fire or heat to control weeds in the past, what portion of the farm was treated (e.g., bog, dike, ditch), and what specific application technique was used (open burning, torch designed for weed control, or other). Only 18% (N=20) reported having had experience with flame cultivation. Eleven growers had past experience using torches, while 6 respondents had used open burning.

Growers were asked to write in what weeds they were targeting with FC, and to rate the control as very effective, somewhat effective, or not effective.

**Bog Use**

FC was used on bogs with torches by 4 growers who identified their targets as narrow leaf goldenrod (*Euthamia tenuifolia*), asters (*Aster spp.*), sawbrier, and all weeds in general. Three growers found the control to be somewhat effective on all weeds and narrow leaf goldenrod, and one grower reported it to be very effective on all weeds.

**Dike Use**

FC was used to control weeds on bog dikes by 15 growers; 6 used torches and 7 used open burning, and 2 did not report which method they used. FC methods on dikes were used to control sawbrier, narrow leaf goldenrod, all weeds in general, and to remove mowing debris. Four growers found FC techniques to be very effective (all weeds in general). Six people found it somewhat effective against all weeds in general and
sawbrier. Three people reported it to be not effective in controlling weeds (but they did not specify which weeds they were targeting).

**Ditch Use**

Six growers had experience using FC in ditches against all weeds in general, rushes (*Juncus* spp.) grasses, and pitchforks (*Bidens frondosa*). Five of these growers evaluated the control as being very effective, and one did not rate the control.

**Future incorporation of FC into weed management practices**

Growers were asked how likely they would be to use hand-held flame cultivators for weed control if it was shown to be effective against dewberry, sawbrier, and dodder (categories: very likely, somewhat likely, not likely). Growers were more likely to employ FC for dewberry (N=82; 29%, 31%, 40%) and sawbrier (N=80; 34%, 20%, 46%) than for dodder (N=83; 25%, 24%, 51%). This is likely due to the lack of any suitable control for the woody perennial weeds compared to the ability to use preemergence and postemergence herbicides for dodder control.

The vast majority of growers had no experience with FC, and many were hesitant to use it in general on any weed. Results from ongoing research by the authors using FC on cranberry, dewberry, sawbrier, and dodder were presented at the 2010 Annual UMass Extension Research Update meeting, one year after the survey was completed. Data indicated that cranberry vines recovered from initial injury with FC as well as giving some measure of dewberry control. Although a second survey was not done at this time, there was verbal interest expressed by cranberry growers that showed increased willingness to try FC on their farms in the upcoming season. The use of hand-held flame
cultivators holds promise for the control of certain weeds in cranberry and may be especially important for organic cranberry farmers.
Literature Cited


CHAPTER 3  
EFFECTS OF TIMING AND FREQUENCY OF FLAME CULTIVATION FOR  
DEWBERRY WEED CONTROL  

Introduction  

Dewberry (*Rubus* spp.) is a perennial weed commonly found on cranberry farms. It is a prostate woody vine that arises from existing plant crowns or new buds along rhizomes. It can spread both vegetatively by tip-layering or by seeds produced on biennial canes (Jensen and Hall 1979). In cranberry production, it is a problematic weed that is difficult to control, spreads quickly and can cause significant crop loss (Else et al. 1995). In a recent survey of Massachusetts cranberry growers, approximately 80% reported having dewberry present on their farms. The majority reported the weed as “difficult to control”, and rated currently available control methods as only “somewhat effective” (Ghantous and Sandler 2010).

Current control methods (e.g., hand pulling, herbicide wipes and sprays, clipping, pruning, and spot renovation of heavily infested areas) fail to provide satisfactory management (Sandler 2010). Glyphosate will injure or kill dewberry plants, however the use of glyphosate on cranberry farms provides only minimal success because the weed stems are intertwined with cranberry stems and are approximately the same height as cranberry vines. Cranberry vines are very sensitive to glyphosate, and it is difficult for growers to treat dewberry without causing damage to proximal cranberry vines. New tools for managing dewberry are needed.
Flame cultivation (FC) is a method of weed control where target plants are exposed to brief periods of high temperature. Heat interferes with cellular processes, disrupts and destroys cellular membranes, and leads to necrosis (Daniell et al. 1969). Various flame cultivation methods have been used successfully in annual crops such as carrots, corn, onions and potatoes as both preemergence and postemergence weed controls (Diver 2002). Perennial plants rely on stored sugars and starch, known as nonstructural carbohydrates (NSC), for survival during periods when respiration exceeds carbohydrate assimilation such as during dormancy and when resuming growth after dormancy (Kozlowski 1992; Loescher et al. 1990). Damaging aboveground plant structures when plants are actively growing also causes plants to expend NSC on new growth, reducing size and vigor, and this depletion renders them more vulnerable to mortality (Kays and Canham 1991; Loescher et al. 1990).

It has been demonstrated that cutting tree saplings to the ground depletes NSC (Kays and Canham 1991). There is also evidence that fire can be used as a tool to deplete NSC and control woody species in forest management (Richberg 2005). Previous work on the use of FC to control dewberry demonstrated that a single mid-July FC exposure with a handheld torch significantly reduced both dewberry shoot and root biomass by the end of the growing season (Ghantous et al. 2012). This reduction in overall biomass is likely accompanied by a reduction in root NSC.

Spot treatments with small handheld propane torches may offer an effective approach for dewberry control on cranberry farms. A recent study showed that although cranberry plants are damaged by FC from hand-held torches, they are not killed and recover to a size similar to that prior to treatment within one year of treatment (Ghantous
Advantages to using small handheld torches include localized treatment, which minimizes damage to surrounding crop areas, and cost-effectiveness compared to the use of glyphosate wipes (Sandler and Ghantous 2011).

Work with several hardwood tree species such as *Acer rubrum* showed that cutting saplings in a specific window of time significantly decreased root carbohydrate reserves and decreased sprout growth the following year, and that this window was species dependent (Kays and Canham 1991). Dewberry roots are woody structures and a sink for NSC, thus it follows that there might be a window of time in which dewberry plants will be more impacted by FC exposure.

The objectives for the current study were to determine if seasonal timing and frequency of exposure with a portable, handheld, propane-fueled flame cultivator would differentially reduce dewberry stem length and biomass, both in the year of and the year following treatment and to evaluate whether FC treatments were altering the ratio of NSC in dewberry roots. Sugars and starch are measured as grams per gram of dry weight, and thus measure the relative amounts of these compounds rather than a total amount. Differences in this ratio between treatments will indicate that plants are allocating NSC differently.

**Methods and materials**

Study sites were located in Wareham, MA and included an organically managed commercial cranberry farm treated in 2010 (Farm Site 1) (41°44′50″N 70°44′13″W), a conventionally managed commercial cranberry farm treated in 2011 (Farm Site 2) (41°45′54″N 70°40′5″W), and a managed garden area also located at Farm Site 2 where dewberry was planted in 2010 and treated in 2011 (Garden Area).
created to provide a site for the collection of root biomass, which was not feasible on the commercial farms due to the fact it would be destructive to large areas of the cranberry farm, and also to provide data on the effects of FC on dewberry alone and permitted destructive sampling. Farm sites were chosen based on presence of dewberry infestations and grower willingness to allow experimental plots on the farm. Experimental plots were treated in the initial study year, and then followed until one year after treatment when plants were harvested. The study sites differed by treatment year as well as management style, and each site was analyzed separately.

The Garden Area was a 14 by 20 m upland area proximal to cranberry production areas at Farm Site 2. It was cleared of all vegetation, and the soil was tilled with a gas-powered rotary tiller (Barreto Hydraulic Tiller 920, La Grande, OR) prior to dewberry plants being transplanted to that area. In mid-May 2010, dewberry plants were collected from a commercial cranberry farm in Carver, MA (41°50'22"N 70°42'43"W) and transplanted into the Garden Area. Each dewberry plot contained three plant crowns. Plants were allowed to establish in the garden area for a year prior to treatment. Preparation, transplanting, and establishment of the dewberry plants followed previously published protocols (Ghantous et al. 2012).

The experiment was arranged as a randomized-complete-block design with seven treatments blocked by replicate to account for differences in growing conditions across the production area and were randomized within each replicate. Treatments were replicated five times at both Farm Sites, and four times in the Garden Area. Plots (0.5 x 0.5 m) at both Farm Sites were located in cranberry productions areas where dewberry was visibly present and plots were placed over areas that were visually assessed to have
uniform weed coverage at each site. Treatments were applied over the center of each dewberry plot in the Garden Area. Plots received either a single exposure (June, July or August) or two exposures (June/July, June/August, or July/August) or no treatment (Table 1). A FC exposure was a 9 s / 0.25 m² exposure from a handheld, propane-fueled flame cultivator (Weed Dragon vapor torch; Flame Engineering, LaCrosse, KS 67548). Exposures were timed using a digital stop watch and distributed evenly over the plot area (Ghantous et al. 2012). Water was applied to all plant foliage and soil with a hand-held watering can for 10 s before and after FC treatments to minimize risk of fire.

Quantitative measurements of dewberry stem number and length were taken periodically using a ruler to measure the length of each main stem from its origin at the ground (the crown) to the tip, but did not take into account branching of the stems. The total numbers of crowns present and the total number of stems in each plot from all crowns were counted. Baseline measurements were made prior to June treatments, at the end of the growing season prior to the onset of dewberry dormancy (as denoted by initiation of leaf color change), and again the following June. The lengths of all individual stems for each plot were added to together to calculate cumulative stem length (CSL). One year after study initiation all aboveground dewberry biomass was harvested using hand-held pruners and placed into paper bags (Table 3-1). Carbohydrate concentrations can be dependent on the root diameter, so a 1 cm diameter size criteria was selected for this study (Wargo 1976). Samples of roots 10 cm long were collected from each plot at Farm Site 1, but were not collected at Farm Site 2 because roots did not meet the minimum diameter.
Entire roots were collected from dewberry plants in the Garden Area only (Table 1). Root collection is a destructive process, and was not possible on the commercial farm sites due to concerns for crop injury. Shovels and small handheld rakes were used to extract the plants from the ground, keeping the roots intact. After extraction, aboveground shoots were separated from roots using pruners. Shoots were placed into paper bags. Roots were rinsed in water to remove soil and then placed into separate paper bags.

All biomass samples bags were placed into an oven at 60 °C for a minimum of 3 d. Dry biomass was determined by weighing each sample. Samples of dried root approximately 10 cm long and minimum diameter of 1 cm were then taken from each sample collected from the Garden Area and Farm Site 1. These samples were then ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through a 2 mm screen and used for HPLC analysis to determine concentrations of sucrose, glucose, fructose, and starch (Botelho and Vanden Heuvel 2005).

**Data Analysis**

Data were analyzed using SAS (SAS version 9.2, SAS Institute Inc., Cary, NC). To assess homogeneity of variances, data normality was tested using the Univariate Procedure. Analysis of variance was performed on CSL and biomass data using the Mixed Procedure. Means were separated using Duncan’s Multiple Range Test. Orthogonal linear contrasts were used to compare the effects of one exposure to two exposures.
Results and discussion

Fall Cumulative Stem Length

Dewberry is a perennial weed, and in temperate climates, ceases vegetative growth and enters dormancy in the fall. Cumulative stem length measured prior to dewberry dormancy in the fall was used as an alternative to a qualitative measure of weed cover. These measurements describe the short term effects of FC treatments because they give a measure of regrowth within the same season as the treatments.

The effect of treatment on fall CSL was highly significant for all three sites (P ≤ 0.001). At Farm Site 1 and Farm Site 2, all treatments had lower fall CSL than the untreated plots, but treatments did not differ from each other. At Farm Site 1, the untreated plots had an average CSL of 298.0 cm (N = 5, SE ± 68.1), while the average of the all treated plots across all treatments was 20.9 cm (N = 30, SE ± 5.0). The treated plots ranged from 58.8 cm (N = 5, SE ± 20.3) for a single June exposure down to 5.7 cm (N = 5, SE ± 4.0) for a double exposure June/August. At Farm Site 2, untreated plots averaged 373.7 cm of stem length (N = 5, SE ± 43.5) while treated plots had an average of 45.1 cm (N = 30, SE ± 10.4), with a range of 96.3 cm for a single June treatment (N = 5, SE ± 24.0) to a double June/August treatment of 3.58 cm (N = 5, SE ± 2.2). At the Garden Area all treatments had lower fall CSL than the untreated plots (x̄ = 194.9 cm ± SE 43.0, N = 4). A single June treatment (x̄ = 114.1 ± SE 11.7, N = 4) had a higher fall CSL compared to all other treatments, which did not differ from each other (x̄ = 12.0 cm ± SE 3.2, N = 20).

Any FC exposure at any time reduced the fall CSL in the year of treatment. Treatments with two exposures had significantly less CSL than treatments with a single
exposure at Farm Site 2 and the Garden Area, but not at Farm Site 1 (P ≤ 0.05). A single June treatment was the least effective at reducing fall CSL at all sites, although only statistically significant at the Garden Area.

**Biomass 1 Year after Study Initiation**

Biomass collected 1 yr after the study was initiated was the final measure of treatment effects on dewberry. The effect of treatment on shoot biomass differed between the Farm Sites and the Garden Area. For both Farm Site 1 and Farm Site 2, the effect of treatment was significant (P ≤ 0.001 and P = 0.02, respectively) with all treatments reducing biomass more than the untreated. FC treatments did not differ from one another. The average biomass of untreated dewberry at Farm Site 1 was 1.9 g plot$^{-1}$ ± SE 0.7 (N = 5) while the average biomass of treated plots was 0.19 g plot$^{-1}$ ± SE 0.05 (N = 30) and for Farm Site 2 untreated dewberry average biomass was 11.45 g plot$^{-1}$ ± SE 5.74 (N = 5) while the average of treated plots 4.73 g plot$^{-1}$ ± SE 0.67 (N = 30). Biomass was similarly reduced by one and two FC exposures.

At the Garden Area, all treatments reduced dewberry shoot biomass compared to the untreated (P ≤ 0.001). A single June treatment was least effective at reducing shoot biomass, while the July, June/July and July/August treatments were the most effective (Figure 3-1). Overall, two treatments with a hand-held FC were significantly more effective at reducing dewberry shoot biomass than a single treatment (P ≤ 0.001).

Dewberry root biomass measured from treated plots at the Garden Area showed that the effect of treatment on root biomass was significant (P ≤ 0.001). Plots receiving a June, July, or a June/August FC treatment had similar root biomass as the untreated plots.
The greatest reduction in root biomass was with June/July and the June/August treatments (Figure 3-1).

The reduction of dewberry root biomass at the Garden Area provides evidence of indirect damage from FC compared to the direct physical damage to aboveground parts as a result of FC exposure. A reduction in root biomass is indicative of damage to the entire plant. The decrease in roots could be due to root necrosis resulting from a lack of energy resources after FC treatments damaged photosynthetic shoots or because roots translocate NSC to support aboveground re-growth after damage (Loescher et al. 1990). In dewberry plants NSC can constitute as much as 8-10% of the root dryweight (Chapter 4).

All FC treated plants at the Garden Area had more root biomass than shoot biomass, while the untreated plants had more shoot biomass than root biomass (FIG garden biomass). This indicates that FC exposure impacted the root to shoot ratio of dewberry plants, even when the absolute amount of root biomass was not significantly less than the untreated control.

Overall, the most effective treatments for reducing overall dewberry biomass (shoot and root) at the Garden Area were the June/July and July/August treatments. Three out of the four plots that received a June/July treatments, and two out of the four plots that received the July/August treatments had no actively growing dewberry present at the time of the final evaluation (0 g shoot biomass, 0 g root biomass).
Dewberry root carbohydrates

The sampling of roots occurred at the conclusion of the study 1 yr after the initiation of the study. Roots were not sampled at other times because it is a destructive process, would have affected the plants, and likely confounded treatment effects. Carbohydrates were measured as mg per mg of dried sample, which give a relative amount of NSC for root biomass. There were no significant differences among treatments in the ratio of nonstructural carbohydrates in dewberry roots at either Farm Site 1 or Garden Area (Table 3-3). The biomass of the roots varied by treatment at the Garden Area, and thus it can be inferred that the total amount of NSC also varied. Although total amounts varied, the ratios of sugars and starch to dry weight was constant across all treatments, indicating that the way the plants allocate resources a year after FC damage did not differ.

Shoot cutting of hardwood trees showed that root carbohydrates varied significantly in the fall after spring and summer cuttings (Kays and Canham 1991). Canopy removal in citrus resulted in significant differences in root growth and carbohydrate levels within the month after pruning, but that these differences disappeared 9 to 11 months later (Eissenstat and Duncan 1992). It is possible that significant differences in dewberry root carbohydrate ratio existed among treatments closer to the time of treatments, but that these differences disappeared within the year between treatments and root sampling. A future study would benefit from a larger sample population that would allow for non-repetitive sampling throughout time to better study the carbohydrate dynamics after FC injury.
A comparison of stem lengths from the untreated plots at the three sites suggests that horticultural management may influence dewberry plant growth. Stems length in the untreated plots at all sites increased from baseline measurements in June to the fall measurement (same growing season), showing that in general, dewberry stems increased within a growing season without any treatment. The fall and the final measurement made in the spring 1 yr after study initiation showed that dewberry CSL decreased in this time at the two Farm Sites, but that dewberry CSL increased during this same period at the Garden Area (Figure 3-2). This suggests that common cranberry horticultural practices such as flooding and harvesting that occurred at the Farm Sites and were not performed at the Garden Area may reduce dewberry stem length (Sandler and DeMoranville 2008).

Dewberry CSL of untreated plants at Farm 1 declined between the baseline and final measurement. Even plants that received no FC exposure were smaller at the end of the study than at the initial measurement, while untreated plants at both Farm 2 and the Garden Area increased in CSL. The manager at Farm Site 1 used two atypical practices in tandem during the winter following the FC treatments. A thick layer of sand (approximately 5 cm) was applied to the production area. Sanding is used periodically in cranberry production for pest control and stimulation of new growth (DeMoranville and Sandler 2008). In addition to sanding, the grower also used a technique called “late water”, which consists of holding a flood for several weeks in the spring for pest management before cranberry plants lose dormancy (Averill et al. 1997). Dewberry emergence and growth decreases as sand depth increases (Table 3-2). Flooding is known to negatively impact NSC reserves of perennial plants (Vanden Heuvel and Goffinet 2008) and has been shown to negatively impact dewberry growth (DeMoranville et al.
2005). Although seasonal variation may have contributed to differences (Farm Site 1 treated 2010 with final measurement in 2011, while Farm Site 2 and Garden Area treated 2011 with final measurement in 2012), it is likely that the management decisions made by the grower at Farm Site 1 confounded the effect of the FC treatments compared to Farm Site 2 and the Garden Area.

Differences between the Farm Sites and the Garden Site may also be due to the presence of cranberry canopy that could potentially absorb or dissipate heat from the FC treatments intended for the dewberry target and affect the efficacy of treatments. The lack of cranberry canopy may explain the significant differences between treatments seen at the Garden Area, but not at the two Farm Sites.

In this study, entire 0.25 m² plot areas were treated with FC. In practical applications, targeting only the crowns of the dewberry plants would minimize collateral cranberry damage. Future projects could look at the efficacy of treating only dewberry crowns in a farm production area, cranberry plant response, and the effects of two successive years of treatment. Herbicide use on the experiment areas was prohibited. It is possible that herbicides may weaken dewberry plants and make them more susceptible to FC, or conversely that FC may weaken dewberry plants and make them more susceptible to herbicides. This synergistic effect is also an area of potential future work.

Conclusions

Although not significant at the Farm Sites, data from the Garden Area indicated that two treatments may be more effective than a single treatment at reducing overall dewberry biomass. For all sites, all FC treatments were able to reduce the dewberry
shoot biomass. A single June treatment was the least effective at reducing cumulative stem length at all sites and shoot biomass at the Garden Site. A study looking at the seasonal variation of NSC in dewberry roots found that they did not differ significantly between flowering/June and fruit maturity/August (Chapter 4). Although NSC stored in roots were similar during the June, July, and August treatments, the fact that a single June treatment was the least effective indicates that the damage occurred early enough in the season so that plants could replenish reserves used to recover from damage before the dormancy, while plants treated in July or August have less time to recover. These findings are consistent with studies that document cutting trees in early spring or late autumn did not reduce root reserves, while midsummer treatments did (Kays and Canham 1991).

An economic analysis showed that the time and cost of using an OF torch for spot control of weeds was similar to that of the common weed control practice of using a wick applicator to apply glyphosate to weeds (Sandler and Ghantous 2011), a common practice for controlling dewberry on cranberry farms. In addition to being as cost effective as glyphosate wipes, the non-fatal cranberry response to FC indicates that it will cause less damage to cranberry plants that are incidentally exposed during spot treatment of weeds than glyphosate (Ghantous et al. 2013).

Dewberry plants can spread vegetatively by tip-layering, as well as by seeds (Jensen and Hall 1979). Reducing the aboveground biomass will likely reduce the amount of vegetative spread. Stems, also known as canes, are usually biennially bearing, so damage to stems will also likely also reduce seed production in the following year. Dewberry plants within cranberry beds are known to spread rapidly, and can easily
spread from non production areas such as dikes into production areas. Although a single year of FC treatment may not eradicate dewberry, it can reduce the biomass and slow the spread and competition with cranberry plants.

Flame cultivation could be integrated into a sustainable and economical approach for weed control in certain situations, and would ideally be used as a spot treatment for weeds growing in the cranberry canopy, as well as on larger non-production areas where cranberry vines are not as abundant, such as bed edges, ditches, and dikes.
Table 3-1: Collection and treatment dates for all dewberry flame cultivation sites.

<table>
<thead>
<tr>
<th></th>
<th>Baseline stem measurement</th>
<th>Fall stem measurement</th>
<th>1 y after study initiation measurement</th>
<th>Biomass collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Site 1</td>
<td>6/17/10</td>
<td>9/27/10</td>
<td>6/27/11</td>
<td>6/27/11</td>
</tr>
<tr>
<td>Farm Site 2</td>
<td>6/23/11</td>
<td>9/28/11</td>
<td>6/19/12</td>
<td>6/19/12</td>
</tr>
<tr>
<td>Garden Area</td>
<td>6/20/11</td>
<td>10/21/11</td>
<td>6/25/12</td>
<td>6/25/12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Farm Site 1</th>
<th>Farm Site 2</th>
<th>Garden Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>6/17/10</td>
<td>6/23/11</td>
<td>6/20/11</td>
</tr>
<tr>
<td>July</td>
<td>7/20/10</td>
<td>7/21/11</td>
<td>7/21/11</td>
</tr>
<tr>
<td>August</td>
<td>8/18/10</td>
<td>8/23/11</td>
<td>8/23/11</td>
</tr>
</tbody>
</table>

Table 3-2: Dewberry plants with stems pruned to a 7 cm height to mimic mowing, and then covered with varying depths of sand in May 2011. Plants were harvested 5 months after treatment. Means with similar letters within a biomass category are not significantly different according to DMRT ($P \leq 0.05$).

<table>
<thead>
<tr>
<th>Sand Depth</th>
<th>Root dry weight (g)</th>
<th>Shoot dry weight (g)</th>
<th>Plant dry weight (g)</th>
<th>Plants surviving (out of 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&quot;</td>
<td>18.31 abc</td>
<td>3.41</td>
<td>21.72 ab</td>
<td>4</td>
</tr>
<tr>
<td>2&quot;</td>
<td>23.99 ab</td>
<td>8.05</td>
<td>32.04 a</td>
<td>4</td>
</tr>
<tr>
<td>4&quot;</td>
<td>28.31 a</td>
<td>9.24</td>
<td>37.54 a</td>
<td>4</td>
</tr>
<tr>
<td>6&quot;</td>
<td>5.35 c</td>
<td>2.18</td>
<td>7.53 b</td>
<td>2</td>
</tr>
<tr>
<td>8&quot;</td>
<td>11.95 bc</td>
<td>4.72</td>
<td>16.66 ab</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 3-3: Average (mean ±SE) nonstructural carbohydrates in roots of dewberry plants treated with an open flame cultivator either once or twice at varying times. Root samples were collected from Farm Site 1 and the Garden Area one year after treatment. Sucrose, glucose, fructose, starch, sugars (the sum of sucrose, glucose, and fructose), and total nonstructural carbohydrates (TNC) (the sum of starch and sugars) were measured using high performance liquid chromatography, and are reported as mg/100 mg of root biomass. The interaction of treatment and site was not significant and table means are from both sites (n = 9). Treatments did not significantly affect any variable measured (P ≥ 0.22).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sucrose (±SE)</th>
<th>Glucose (±SE)</th>
<th>Fructose (±SE)</th>
<th>Starch (±SE)</th>
<th>Sugars (±SE)</th>
<th>TNC (±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>1.2 (±0.1)</td>
<td>1.1 (±0.3)</td>
<td>1.9 (±0.5)</td>
<td>1.3 (±0.3)</td>
<td>4.2 (±0.8)</td>
<td>5.4 (±0.9)</td>
</tr>
<tr>
<td>July</td>
<td>1.5 (±0.2)</td>
<td>1.4 (±0.4)</td>
<td>2.2 (±0.5)</td>
<td>1.3 (±0.2)</td>
<td>5.1 (±0.8)</td>
<td>6.4 (±0.9)</td>
</tr>
<tr>
<td>August</td>
<td>1.0 (±0.1)</td>
<td>1.5 (±0.3)</td>
<td>2.0 (±0.3)</td>
<td>1.0 (±0.2)</td>
<td>4.6 (±0.7)</td>
<td>5.6 (±0.9)</td>
</tr>
<tr>
<td>June/July</td>
<td>1.3 (±0.2)</td>
<td>1.1 (±0.3)</td>
<td>1.8 (±0.4)</td>
<td>1.3 (±0.4)</td>
<td>4.1 (±0.8)</td>
<td>5.5 (±0.1)</td>
</tr>
<tr>
<td>June/August</td>
<td>1.2 (±0.1)</td>
<td>1.4 (±0.3)</td>
<td>2.1 (±0.4)</td>
<td>1.2 (±0.5)</td>
<td>4.7 (±0.7)</td>
<td>5.9 (±0.8)</td>
</tr>
<tr>
<td>July/August</td>
<td>1.0 (±0.1)</td>
<td>0.8 (±0.2)</td>
<td>1.3 (±0.2)</td>
<td>0.7 (±0.1)</td>
<td>3.0 (±0.5)</td>
<td>3.8 (±0.4)</td>
</tr>
<tr>
<td>None</td>
<td>1.1(±0.1)</td>
<td>0.9 (±0.2)</td>
<td>1.4 (±0.3)</td>
<td>1.1 (±0.3)</td>
<td>3.4 (±0.5)</td>
<td>4.5 (±0.6)</td>
</tr>
</tbody>
</table>
Figure 3-1: Average dewberry shoot and root biomass per (mean ± SE, n=4) 1 year after the study initiation at the Garden Area. Treatments were a 9 s/0.25m² exposure with a hand-held open flame torch. Means with similar letters within a biomass category are not significantly different according to DNMRT ($P \leq 0.05$). Bolded lowercase letters indicate comparisons among shoot biomasses and italic letters indicate comparisons among root biomass.
Figure 3-2: Average cumulative dewberry stem length per plot (mean ± SE, n=5 at Farm Sites and n=4 at Garden Area) from untreated plots at three sites measured at baseline (the initiation of the study), fall in the year of treatment (approx 3 months after baseline), and the final measurement one year after the study initiation.


CHAPTER 4

SEASONAL NONSTRUCTURAL CARBOHYDRATE PATTERNS IN
DEWBERRY ROOTS

Introduction

Perennial plants in temperate climates follow predictable carbohydrate cycles, and these seasonal changes follow similar patterns for most plants. Reserves decrease as they support new leaf and shoot growth in the spring before photosynthetic apparatus can produce energy, and continue to decrease or remain low while plants flower, after which there is typically a net gain in carbohydrates and reserve levels increase until the plant becomes dormant in the fall (Kozlowski 1992). These reserves support respiration and metabolism through dormancy until the spring when photosynthesis can again create new carbohydrates. The specific patterns of these cycles are species dependent.

Considerable work has been done on carbohydrate movement and storage in cultivated plants. Tree species studied include fruit trees, such as apple and citrus (Kandiah 1979; Monerri et al. 2011), as well as hardwood trees such as maples, birch, and oaks (Gaucher et al. 2005; Wargo 1971; Wargo 1976). Seasonal changes in nonstructural carbohydrates (NSC) have also been studied in other woody perennial crops such as cranberry, blueberry, and raspberry (Fernandez and Pritts 1994; Hagidimitriou and Roper 1994; Jatinder et al. 2012; Palonen 1999; Roper and Klueh 1996).

There is an increasing demand for further understanding these carbohydrate cycles in non-cultivated plants from a weed science perspective, to better understand weed biology and improve weed management (Bhowmik 1997). Although seasonal NSC
changes have been studied in some weed species such as Japanese knotweed (*Fallopia japonica* (Houtt.) Ronse Decr.), milkweed (*Asclepias syriaca* L.), and purple loosestrife (*Lythrum salicaria* L. LYTSA.) (Bhowmik 1994; Katovich et al. 1998; Price et al. 2001), little is known about the NSC cycles in *Rubus* spp. which are found as weeds on cranberry farms in Massachusetts, in pastures used for animal grazing, and some annual crops with reduced or absent tillage (Glenn et al. 1997; Sather and Bradley 2012).

Three *Rubus* spp. are commonly found as weeds on Massachusetts cranberry farms (*R. allegheniensis* Porter, *R. flagellaris* Willd, and *R. hispidus* L.), however *Rubus* spp. are highly variable, readily hybridize with each other, and are difficult to identify (Jensen and Hall 1979; Rydberg 1915; Sandler 2001; Steele and Hodgdon 1963). Dewberry plants (*Rubus* spp.) are challenging to control, can cause serious crop losses in cranberry, and are lacking satisfactory controls for most growers (Sandler 2010).

Damaging aboveground plant structures when plants are actively growing also causes plants to expend NSC on new growth, reducing size and vigor, and this depletion renders them more vulnerable to mortality (Kays and Canham 1991; Loescher et al. 1990). Work in tree species demonstrated that individual species have different seasonal “windows” of time when cutting treatments will result in lower levels of autumn root NSC reserves (Kays and Canham 1991).

Dewberry is a woody plant and its roots are a sink for NSC, thus it follows that there might be a window of time in which dewberry plants will be more impacted by control measures. The specifics of dewberry seasonal carbohydrate cycles are unknown, and may improve efficacy of weed control efforts by enabling weed managers to implement controls during the window of times when resources for regrowth will be
lowest. Our objective was to follow the seasonal changes in levels of NSC within the roots of dewberry plants at different phenological growth stages to determine if changes occur in predictable patterns.

**Methods and Materials**

Sites with groups of dewberry plants were identified on cranberry farms in areas located adjacent to production areas in East Wareham, MA. Site 1 (41°45′54″N, 70°40′5″W) and Site 2 (41°49′19″N, 70°37′6″W) were sampled in 2011. Site 1 did not have sufficient amounts of dewberry plants for a second year of sampling so 2012 samples came from Site 2 and Site 3, also in East Wareham, MA (41° 49′ 45″N, 70°37′39″W). At each collection date for each location, four entire individual plants were collected to prevent resampling plants.

Dewberry root samples were collected at five distinct phenological stages in the dewberry life cycle: initial bud break, full leaf expansion, flowering, fruit maturity, and after the onset of dormancy as indicated by leaf color change and senescence. The use of phenology to select sampling time has been used in other weed studies that measured NSC (Bhowmik 1994; Tworkoski 1992). Dates of dewberry phenology varied slightly by year, and variation was likely due to normal variability in environmental conditions (Table 1). Two years is a common period for data collection in seasonal carbohydrate studies (Horak and Wax 1991; Katovich et al. 1998; Nkurunziza and Streibig 2011).

At each collection, four plants per site were excavated using shovels and rakes to remove entire plants with intact roots from the soil. Each plant was considered a replicate (Cyr et al. 1990; Katovich et al. 1998). Plants were transported with their roots
in a container of water to the lab, where they were immediately processed. A root section approximately 10 cm long was clipped from each plant. Carbohydrate concentrations can be dependent on root diameters, so roots of approximately 1-cm diameter were selected (Wargo 1976). Samples were washed, cut into small pieces using a razor blade, placed into paper bags, and dried in an oven at 60 C for 1 wk until a constant weight was maintained for dry matter determination. These samples were then ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through a 2-mm screen and used for high performance liquid chromatography (HPLC) analysis to determine concentrations of sucrose, glucose, fructose, and starch that collectively represent NSC (Botelho and Vanden Heuvel 2005).

Data Analysis

Each year was analyzed independently due to unmeasured environmental variations such as rainfall, temperature, and soil temperature between years that are known to impact plant carbohydrates (Kozlowski 1992). Data were analyzed using SAS (SAS version 9.2, SAS Institute Inc., Cary, NC). Analysis of variance was performed on total nonstructural carbohydrates (TNC, the sum of sucrose, glucose, fructose, and starch), total sugars (the sum of sucrose, glucose, and fructose), sucrose, glucose, fructose, and starch using Proc GLM. Means were separated using Duncan’s Multiple Range Test, P=0.05.

Results and Discussion

In 2011, the effect of plant phenology stage varied by site for TNC, starch, and sucrose (P ≤0.05), and was marginally significant for soluble sugars (P = 0.064).
Although the site*stage interaction was not significant for fructose or glucose, all 2011 data are presented by site for the purpose of comparison between the sugars.

For 2011, Site 1 TNC levels declined significantly between bud break and leaf expansion, then rose to levels similar to that measured at bud break and remained somewhat constant until dormancy (Figure 4-1). Starches and soluble sugars had opposite trends. Starches were lower than soluble sugars at bud break, and remained at a low level until after leaf expansion when it rose significantly until the onset of dormancy when levels were higher than that of soluble sugars. Soluble sugars were higher than starches at bud break, but then declined significantly between bud break and leaf expansion, remaining low until the onset of dormancy (Figure 4-1).

Site 2 had similar changes in 2011. The TNC level dropped between bud break and full leaf expansion, but unlike Site 1 the TNC level rose significantly between fruit maturity and dormancy, ending at a higher level than measured at bud break (Figure 4-2). Starches began the season lower than soluble sugars, but rose significantly after fruit maturity to a level higher than that measured at bud break. Soluble sugars declined between bud break and leaf expansion. Unlike Site 1, the soluble sugars at Site 2 then rose to levels similar to those seen at bud break before dormancy, but were still lower than starches as seen an at Site 1 (Figure 4-2).

At Site 1 in 2011, fructose, glucose, and sucrose decreased between bud break and leaf expansion, and ended the growing season significantly lower than at bud break (Figure 4-1). Site 2 had more variability between the sugars. Fructose and glucose declined between bud break and leaf expansion, while sucrose decreased until flowering. Sucrose increased significantly between fruit maturity and the onset of dormancy to a
level similar to that seen at bud break (Figure 4-2). The higher level of sucrose at this site could reflect that photosynthates were translocated to the roots for long term storage, and that the “dormancy” sample collection occurred prior to the conversion of sucrose to starch for winter storage.

Unlike 2011, none of the carbohydrate categories varied by site in 2012. The levels of TNC declined significantly between bud break and leaf expansion, then rose slowly until the onset of dormancy when the level was similar to that measured at bud break (Figure 4-3). Soluble sugars were higher than starches at bud break, declined significantly between bud break and leaf expansion, and remained low until the onset of dormancy. Starch levels declined between bud break and flowering, but then rose after flowering until the onset of dormancy. Sucrose declined between bud break and fruit maturity, and then rose slightly between fruit maturity and the onset of dormancy. Fructose and glucose did not vary significantly throughout 2012 (Figure 4-3).

In both years, the TNC and soluble sugars dropped significantly between when buds began to break and full leaf expansion, while starch did not decrease in this period. This indicates that plants were primarily using sugars to support growth until leaves were fully expanded to produce new carbohydrates through photosynthesis. After full leaf expansion, soluble sugar levels remained statistically similar until dormancy and always ended the season at lower levels than those measured at bud break. In contrast, starch always began the season lower than soluble sugars and, and increased significantly between the time of fruit maturity and onset of dormancy in 2011, ending the season significantly higher than at bud break (Figures 4-1, 4-2 and 4-3). This indicates that plants accumulated starch for long-term storage to support energy needs through the
winter. Plants are likely hydrolyzing starch stores into sugars before using them for energy during winter periods of low temperatures and low levels of sugars (Kozlowski 1992). This would explain why starch levels are the lowest after dormancy, while sugars are highest.

Although soluble sugars behaved similarly at all sites and all years, the components (fructose, glucose, and sucrose) behaved differently. In 2011, fructose, glucose, and sucrose behaved similarly at Site 1 while they varied from one another at Site 2, ending with a significant rise in sucrose at the end of the season (Figure 4-1 and Figure 4-2). In 2012, fructose and glucose did not vary at all while the amount of sucrose was reduced by nearly half (Figure 4-3).

It is unclear what caused these differences in the individual sugars between sites and years. Unlike starches that are built for storage, sugars are readily used for metabolism, stress responses, and growth demands. Sugars are likely more sensitive to environmental differences between the sites which likely affected the immediate energy demands of the plants. A study on sugars in dandelion roots attributed sugar fluctuations to differences in rainfall and soil temperature (Wilson et al. 2001), which were not measured in this study. Sucrose is the major form in which energy is transported in higher plants such as dewberry, and it is further broken down to the more reactive forms of glucose and fructose before use (Burley 1961) (Ward et al. 1998). The sucrose levels in dewberry roots tended to be more dynamic that those of the other sugars, and may indicate changes in source-sink relationships more than levels of fructose and glucose, which likely reflect metabolic demands of the roots.
Conclusions

Dewberry root reserves varied by site and year but followed similar trends despite these differences. Overall, TNC are depleted between bud break and full leaf expansion as plants grow new photosynthetic apparatus, and then prior to dormancy they return to levels greater than or equal to those measured at bud break prior. Soluble sugars decline between bud break and leaf expansions, and are likely the type of carbohydrate being used for this energy-intensive process. Starch (long-term storage) reserves are lowest after winter because they have been converted to sugar for use during the dormancy period, but increased throughout the growing season to levels greater than or equal to those measured at bud break before the dewberry plant goes dormant as the plant prepares for winter.

Recommendations for timing dewberry control cannot be based on NSC cycles alone. Previous work on controlling dewberry with flame cultivation showed that a single treatment in mid-June was less effective at reducing dewberry shoot biomass 1 yr after treatment compared to a single July or August treatment. Although dewberry root TNC did not differ significantly between mid-June (flowering) and mid-August (fruit maturity) (and likely also did not differ in July), damage incurred in July or August left plants with less time to replenish reserves used to recover from damage before the dormancy and resulted in smaller dewberry plants the following year, whereas plants treated in June had more time between injury and dormancy to recover and replenish TNC.

Based on these results, our recommendation would be to employ control methods which damage above ground dewberry plant parts (mowing pastures, flame cultivation of
individual plants, etc.) during the time when TNC are low, yet when plants have will not have time to fully replenish depleted root reserves prior to the onset of dormancy. This window of time would roughly coincide with fruit maturity.
Table 4-1: Sampling dates and associated phenology stage of dewberry plants when roots were collected for HPLC analysis to study seasonal fluctuations of root nonstructural carbohydrates.

<table>
<thead>
<tr>
<th>Dewberry phenology stage</th>
<th>Sampling dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
</tr>
<tr>
<td>Bud break</td>
<td>4/20</td>
</tr>
<tr>
<td>Full leaf expansion</td>
<td>5/24</td>
</tr>
<tr>
<td>Flowering</td>
<td>6/13</td>
</tr>
<tr>
<td>Fruit maturity</td>
<td>8/1</td>
</tr>
<tr>
<td>Dormancy</td>
<td>11/14</td>
</tr>
</tbody>
</table>
Figure 4-1: A. Average TNC, soluble sugars, and starch for dewberry roots samples collected in 2011 from cranberry farm Site 1 by dewberry phenology stage. Reported as mg/100 mg of root (mean ± SE, n=4). B. Average fructose, glucose, and sucrose for dewberry roots samples collected in 2012 from cranberry farms by dewberry phenology stage. Reported as mg/100 mg of root (mean ± SE, n=4). Means with similar letters within a sugar category are not significantly different according to DNMRT ($P \leq 0.05$).
Figure 4-2: A. Average TNC, soluble sugars, and starch for dewberry roots samples collected in 2011 from cranberry farm Site 2 by dewberry phenology stage. Reported as mg/100 mg of root (mean ± SE, n=4). B. Average fructose, glucose, and sucrose for dewberry roots samples collected in 2012 from cranberry farms by dewberry phenology stage. Reported as mg/100 mg of root (mean ± SE, n=4). Means with similar letters within a sugar category are not significantly different according to DNMRT ($P \leq 0.05$).
Figure 4-3: A. Average TNC, soluble sugars, and starch for dewberry roots samples collected in 2012 from cranberry farms by dewberry phenology stage. Reported as mg/100 mg of root (mean ± SE, n=8). B. Average fructose, glucose, and sucrose for dewberry roots samples collected in 2012 from cranberry farms by dewberry phenology stage. Reported as mg/100 mg of root (mean ± SE, n=8). Means with similar letters within a sugar category are not significantly different according to DNMRT ($P \leq 0.05$).
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CHAPTER 5
USE OF HANDHELD FLAME CULTIVATORS FOR CONTROL OF COMMON RUSH

Introduction

Common rush (*Juncus effusus*), also known as soft rush, is considered a weed in Massachusetts cranberry production. Common rush is a perennial plant approximately 0.6 to 1.2 m tall that prefers wet and acidic growing conditions, making it well suited to cranberry production areas, where soil pH is usually between 4 and 5 (DeMoranville 2013). Rush plants grow as circular tussocks, forming dense clumps with up to several hundred slender unbranched stems per tussock (Richards and Clapham 1941). It can spread both vegetatively by rhizomes and by seed. Soft rush produces copious amounts of seeds (as high as 4,000,000 per seeds m$^2$), which are prominent and persistent in the soil seed bank (Ervin and Wetzel 2001; Thompson and Grime 1979). Cranberry beds are surrounded by and often bisected by a system of ditches that aid in drainage and horticultural flooding practices. Rushes are commonly found growing in and along ditches where their presence can hinder drainage and water movement. They can easily spread from the ditches into production areas where they will directly compete with cranberry.

Current control options for rushes in cranberry production include manual removal of tussocks or cutting them down with a string trimmer. Water quality concerns limit herbicide options. Preemergence herbicides may provide some control in production areas to prevent new plants from establishing, but can not be used in ditches
and do not control existing tussocks. Postemergence herbicide control consists of glyphosate wipes or sprays that can be used in ditches, but they must be dry at the time of application and remain dry for 2 d after application (Sandler 2013). All of these options provided limited success, and must be frequently repeated.

New tools for managing rushes are needed and would be beneficial to the cranberry industry. Flame cultivation (FC) is a weed control method that uses exposure to high temperatures to damage plants. Plants are not burned or incinerated, but are wilted by the exposure which ruptures cell membranes and disrupts cellular processes (Daniell et al. 1969; Ellwanger et al. 1973). Past studies suggest that FC may be effective for controlling other types of weeds found on cranberry farms (Ghantous et al. 2012) (Table 5-1). Handheld propane torches may offer a useful approach for controlling rushes in cranberry culture.

Cranberry plants form a continuous mat of vegetation in production areas. Evidence suggests that cranberry plants are damaged but not killed by FC, and eventually recover from the effects (Ghantous et al. 2013). If effective against rushes, these types of torches could be used as isolated spot treatments within cranberry production areas and also for more extensive areas where damage to cranberry is not a concern, such as in and along ditches. FC is nonchemical, and has no water quality concerns or pre-harvest intervals that limit site and time of herbicide use. Two separate studies were conducted to evaluate the utility of FC for rush control.

**Study 1: Torch type and exposure length evaluation**

Our objectives were to determine if a single localized treatment with a handheld
flame cultivator would reduce the biomass and seed production of rushes, and if the reduction would increase with increasing exposure length and vary by flame cultivator type. Our tests evaluated three portable, handheld, propane-fueled flame cultivators that targeted rushes for various exposure times.

**Study 2: Comparison of flame cultivation to clipping**

Based on the preliminary outcome of Study 1, a single torch and single exposure duration was selected for Study 2. The objective of this study was to compare the efficacy of four different rush control treatments: FC, clipping rushes to the ground, clipping and then treating stumps with FC, or treating with FC and then clipping the remaining rushes. The clipping treatment mimics the cutting of rushes with a string trimmer, a weed control practice commonly used by cranberry growers.

**Methods and Materials**

Both studies were located at the UMass Cranberry Station, East Wareham, MA (41°45′54″N 70°40′5″W). Rushes growing along drainage ditches within cranberry beds were utilized. Prior to treatments, individual tussocks of rushes were identified. A tussock represented the experimental unit. Tussock size was variable (35 to 268 stems per tussock), and previous work showed that the size of the tussock influenced plant response to FC treatments (K. Ghantous, unpublished data). The number of stems in each tussock was quantified, and rushes were blocked by tussock size.

**Study 1: Torch type and exposure length evaluation**
This study was conducted twice (2010 and 2011) using previously untreated rushes in both years. Three handheld, propane-fueled cultivators were evaluated: open flame (OF, Weed Dragon vapor torch; Flame Engineering, LaCrosse, KS 67548), infrared and infrared with a 4.5 cm metal spike (IR, Infra-weed Eliminator and IRS, Dandy Destroyer, respectively; made by Puzzy Boy, Switzerland, distributed in the USA by Forevergreen, Blaine, WA 98230) (Figure 5-1).

The experiment was designed as a two-way factorial arranged as a randomized complete block design with five replicates. Three levels of FC torch type (OF, IR, and IRS) and four levels of exposure were tested. Exposure levels were 0, low, medium, and high durations (which were 0, 4, 8, and 12 s, respectively, for OF and 0, 20, 40, and 60 s, respectively, for IR and IRS), and were based on previous testing (K. Ghantous, unpublished data).

Tussocks of rushes were identified and evaluated for stem number and then treated (see Table 5-1 for dates). Rushes were flowering at the time of treatment. A digital stopwatch timer was used to time the exposure durations. The OF and IR treatments were applied to the base of the tussock for the duration of the exposure. The spike of the IRS was inserted into center of the tussock being treated for the length of the exposure duration.

Aboveground rush biomass was harvested in September prior to cranberry harvest (Table 1). Biomass was collected using hand held pruners to clip the stems at the ground. Rushes were placed into large paper bags and sorted in the lab. Stems were quantified as either vegetative or reproductive. Stems and floral structures were placed into separate paper bags. Plants were dried at 60 C for a minimum of 3 d and biomass
was determined.

**Study 2: Comparison of flame cultivation to clipping**

This study was conducted twice (2011 and 2012) using previously untreated rushes in both years. Tussocks of rushes were identified and evaluated for stem number and then treated (see Table 2 for dates). The experiment was designed as a randomized complete block design with five replicates blocked by plant size. Treatments were FC, clipping to the ground, clipping to the ground followed by FC, FC followed by clipping to the ground, and an untreated control. Based on data from Study 1, a medium exposure duration (8 s) with OF torch was selected as the FC treatment for this study. Clipping was done using hand held pruners to remove all stems to the ground level (0 – 5 cm stubble). Prior to cranberry harvest, all aboveground biomass was collected, sorted, and biomass was determined as described above.

**Data Analysis**

Data were analyzed using SAS (SAS version 9.2, SAS Institute Inc., Cary, NC). Percent of flowering stems was calculated by dividing the number of flowering stems per plant by the total number of stems per plant and multiplying by 100.

For Study 1, analyses of variance were performed using Proc Mixed with year, FC tool type, exposure duration, and their interactions in the model statement for biomass, number of stems, and number of flowering stems. Significant interaction between FC tool type and exposure duration were sliced by FC tool type and regression
trends were assessed for exposure duration within FC tool type. Exposure ranges are presented as categorical labels (none, low, medium, and high).

For Study 2, analysis of variance was performed using the Mixed Procedure using year, treatment, and the interaction in the model statement. Means were separated using Duncan’s Multiple Range Test, P=0.05.

Results and Discussion

Study 1: Torch type and exposure length evaluation

The effect of exposure duration varied by FC tool type for average number of stems per tussock, average biomass per tussock, and percentage of flowering stems per tussock ($P \leq 0.05$). The overall effect of year nor any of the interactions with year were significant for any parameters measured, thus data were combined across years.

Plants treated with the OF and IR torch had fewer stems and lower biomass as exposure duration increased. The IRS torch was not effective at reducing the number of stems or biomass at any exposure duration. Overall, the OF was more effective at causing a decrease in stem number and biomass than the IR torch, and showed a greater decrease at shorter exposure durations. The IRS torch was not effective at reducing the number of stems at any exposure duration (Figure 5-2 and Figure 5-3). All three torches reduced the percentage of flowering stems, including the IRS which did not affect stem number or biomass. Increasing exposure duration resulting in less flowering stems, with the OF tool causing greater decreases at lower exposure durations (Figure 5-4).

The IRS tool was not an effective choice for controlling rushes. Overall the OF tool was the most effective at decreasing the stem number, biomass, and percent of
flowering stems for rush tussocks. Although the IR tool was also effective, the OF requires much shorter exposure durations for similar results (8 s versus 60 s for a high exposure) making this tool a more attractive option due to the convenience and cost-benefit of use to growers (Sandler and Ghantous 2011).

Study 2: Comparison of flame cultivation to clipping

The overall effect of year and the interaction of year and treatment were not significant factors for any parameters measured. All treatments significantly reduced the average biomass and percentage of flowering stems per tussock as compared to the untreated plants, and treatments did not differ from each other ($P \leq 0.05$) (Table 5-2). All treatments reduced the average number of stems per tussock, but treatments did differ from one another. Clipping plants followed by a FC treatment reduced the number of stems significantly more than clipping alone, while other treatments did not differ (Figure 5). A medium exposure duration with OF was selected for this study based on the preliminary results of Study 1, offering a similar level of control as the high duration. It is possible that clipping plants before FC allowed some of the heat to penetrate the ground and affect the rhizome, and that a longer FC exposure may have provided greater control.

Conclusions

Treating rushes with a single FC exposure with an open flame or infrared handheld torch was able to reduce the biomass, stem number, and the reproductive potential of tussocks. Similar to the effects of mechanical defoliation, FC damages aboveground plant structures, and forces plants to expend stored resources on growing
new structures, and leaves them smaller, less vigorous, less stress tolerant, and more vulnerable to mortality (Kays and Canham 1991; Loescher et al. 1990). Plants were treated in June while flowering and evaluated at the end of August, a timing that would fit well within the horticultural chores performed by a cranberry grower. The studies evaluated control and regrowth within one single season. However, perennial weeds typically require multiple controls, usually over multiple years (Sandler 2013).

Previous work on rushes in pastures found that a single cutting of tussocks to the ground reduced the vigor of plants 1 year after the treatment. The efficacy increased when plants were treated twice within a growing season, and also increased when treatments were repeated a second year (Merchant 1995). Further experiments on FC use for rush control in cranberry production should explore the effects of multiple treatments and multiple years of treatments.

These studies have demonstrated that FC has potential to become a weed management option for rushes. Overall, the OF tool was the most effective at decreasing the stem number, percent of flowering stems, and biomass of rushes treated and when compared to clipping rushed to the ground, a single exposure with OF was able to reduce rushes at least as effectively as clipping. Although the IR tool was also effective, the OF requires much shorter exposure durations for similar results (8 s vs 60 s for a high exposure) making this tool a more attractive option due to the convenience of use to growers.
Table 5-1: Average seed production (mean ± SE, n=16) of dodder plants parasitizing cranberry vines which were treated with an open flame propane torch at different dodder phenological stages (preflowering, flowering, seeds developing, and when seeds were fully mature). Exposure durations were none, 3s, 6s, or 9s per 0.25 m² plot which were located on commercial cranberry farms in 2009. Seeds were collected from the center 0.062 m² area of each plot. The effect phenological stage was highly significant for total number of seeds produced (P = 0.03), but exposure duration was not significant. Means followed similar letters are not statistically different (DMRT P ≤ 0.05)

<table>
<thead>
<tr>
<th>Dodder Phenological Stage</th>
<th>Seeds produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preflowering</td>
<td>61.5 (±29.4) a</td>
</tr>
<tr>
<td>Flowering</td>
<td>77.9 (±43.5) a</td>
</tr>
<tr>
<td>Seeds developing</td>
<td>232.1 (±71.0) ab</td>
</tr>
<tr>
<td>Seeds mature</td>
<td>532.0 (±101.8) b</td>
</tr>
</tbody>
</table>

Table 5-2: Study 1 treatment and biomass collection dates for rushes treated with FC torches at varying exposure duration.

<table>
<thead>
<tr>
<th>Study 1</th>
<th>Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>Year 2</td>
</tr>
<tr>
<td>Treatment</td>
<td>6/1/10</td>
</tr>
<tr>
<td>Biomass collected</td>
<td>9/1/10</td>
</tr>
</tbody>
</table>

Table 5-3: Study 2 Biomass and Flowering stems of rushes after treatments. Mean ± SE, N=10. Means with similar letters are not significantly different according to Duncan’s Multiple Range Test (P ≤ 0.05).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ave. Biomass (g)</th>
<th>Flowering stems (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>174.7 (±30.1) a</td>
<td>22.1 (±4.7) a</td>
</tr>
<tr>
<td>Burn</td>
<td>58.0 (±19.4) b</td>
<td>2 (±1.3) b</td>
</tr>
<tr>
<td>Clip</td>
<td>86.3 (±14.8) b</td>
<td>0.6 (±0.4) b</td>
</tr>
<tr>
<td>Clip then burn</td>
<td>30.6 (±9.4) b</td>
<td>0.1 (±0.1) b</td>
</tr>
<tr>
<td>Burn then clip</td>
<td>40.2 (±16.9) b</td>
<td>0.3 (±0.3) b</td>
</tr>
</tbody>
</table>
Figure 5-1: Types of handheld propane torches evaluated. The OF is a torch with a 5.1 cm bell that operates at a maximum capacity of 100,000 BTU and approximate working flame temperature of 1121°C. The IR has an enclosed propane flame that is projected onto a rectangular ceramic plate 8.3 cm by 17.1 cm that provides radiant heat output up to 2500 BTU. The IRS has an enclosed flame that is projected onto a 4.5 cm round ceramic plate, with a 4.5 cm metal spike protruding. Both the plate and the spike provide radiant heat output up to 6000 BTU.
Figure 5-2: The average number of stems per rush tussock (mean ± SE, n=10) 3 months after treatment with a single exposure with a hand-held torch. Exposure of none, low, medium and high correspond to 0, 20, 40, and 60 s for the infrared torch (IR) and the infrared torch with spike (IRS), and to 0, 4, 8, and 12 s for the open flame torch (OF). IR $y = -36.02x + 168.48$ ($r^2 = 0.91$). OF $y = -39.58x + 125.42$ ($r^2 = 0.84$). IRS = n.s.
Figure 5-3: The average biomass (g) per rush tussock (mean ± SE, n=10) 3 months after treatment with a single exposure with a hand-held torch. Exposure of none, low, medium and high correspond to 0, 20, 40, and 60 s for the infrared torch (IR) and the infrared torch with spike (IRS), and to 0, 4, 8, and 12 s for the open flame torch (OF). IR \( y = -23.81x + 91.17 \) \( (r^2 = 0.84) \). OF \( y = -70.58x + 14.60x^2 +87.41 \) \( (r^2 = 0.99) \). IRS \( y = \text{n.s.} \).
Figure 5-4: The average percent of flowering stems per rush tussock (mean ± SE, n=10) 3 months after treatment with a single exposure with a hand-held torch. Exposure of none, low, medium and high correspond to 0, 20, 40, and 60 s for the infrared torch (IR) and the infrared torch with spike (IRS), and to 0, 4, 8, and 12 s for the open flame torch (OF). IR $y = -19.01x + 57.67$ ($r^2 = 0.85$). OF $y = -58.10x + 12.68x^2 + 61.76$ ($r^2 = 0.98$). IRS $y = -16.35x + 73.77$ ($r^2 = 0.91$).
Figure 5-5: Average number of stems per rush tussock (mean ± SE, n=10) 3 months after treatment. Means with similar letters are not significantly different according to Duncan’s Multiple Range Test ($P \leq 0.05$).
Literature cited


APPENDIX A

HANDHELD FLAME CULTIVATORS AS A MANAGEMENT OPTION FOR

WOODY WEEDS

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Handheld Flame Cultivators as a Management Option for Woody Weeds

Katherine M. Ghantous, Hilary A. Sandler, Wesley R. Autio, and Peter Jeranyama*
Handheld Flame Cultivators as a Management Option for Woody Weeds

Katherine M. Ghantous, Hilary A. Sandler, Wesley R. Autio, and Peter Jeramyan

Dewberry is a weed found on cranberry bogs that spreads quickly, causes high yield loss, and has no effective management strategy. Finding options to manage damaging perennial weeds in a perennial crop system, such as cranberry, is key to long-term industry sustainability. This study presents preliminary data on the use of flame cultivation (FC) in cranberry weed management. Utilizing weeds transplanted from commercial cranberry farms to a prepared area at the UMass Cranberry Station, we evaluated three handheld propane-fueled FC instruments: infrared torch, open flame torch, and an infrared torch with a spike. A single, midsummer exposure (zero, low, medium, or high duration) with each FC was tested. The industry standard of using a single wipe application of an herbicide solution (111 g L⁻¹ of glyphosate, isopropylamine salt) was also included in the evaluation. Dewberry shoot, root, and total biomass did not reduce as exposure increased; the effect of FC treatment was not significant. Data indicated that, regardless of the specific torch utilized, spot treatment with FC reduced dewberry biomass. The results of this exploratory study suggest that FC may offer an alternative technique for managing woody weeds and that further research is warranted.

Nomenclature: Glyphosate; dewberry, Rubus spp.; cranberry, Vaccinium macrocarpon Ait.

Key words: Perennial woody weeds, flame weeding, thermal weeding, integrated weed management, nonchemical options.

Rubus sp. es una maleza que se encuentra en el cultivo de arándano y que se dispersa rápidamente, causa altas pérdidas en rendimiento y no tiene una estrategia eficaz de manejo. Encuentran opciones para el manejo de malezas perennes en sistemas de cultivos perennes, tal como el arándano, es clave para la sostenibilidad de la industria a largo plazo. Este estudio presenta información preliminar sobre el uso de un quemador de llama (FC) en el manejo de malezas en este cultivo. Utilizando malezas transplantadas de granjas comerciales de arándano hacia un área preparada en la estación de arándano en la Universidad de Massachusetts, evaluamos tres instrumentos manuales de gas propano FC: antorcha infrarroja (IR), antorcha de llama abierta (OF) y antorcha infrarroja con una espuela (IRS). Se evaluó una sola exposición a la mitad del verano (duración cero, baja, media o alta) con cada FC. También se incluyó en la evaluación el tratamiento estándar de la industria haciendo una sola aplicación de herbicida con una solución de 111 g/L de glifosato, sal isopropilamínica. La prueba acuática, la raíz y el total de la biomasa de Rubus disminuyeron linealmente conforme la exposición se incrementó y el efecto del tipo de herramienta FC no fue significativo. Los datos indicaron que sin importar la antorcha específica utilizada, el tratamiento localizado con FC redujo la biomasa de Rubus. Los resultados de este estudio exploratorio sugieren que FC puede ofrecer una técnica alternativa para el manejo de malezas leñosas y que se justifica investigación adicional.

Weeds present a significant threat to cranberry yields. Dewberry is a perennial woody weed found on cranberry bogs. It is identified as Priority 1, meaning that it is difficult to control, spreads quickly, and can cause significant loss of crop (Else et al. 1995). A recent grower survey showed that 80% of respondents indicated dewberry was present on their bogs, and 62% reported it as being “very difficult to control” (Ghantous and Sandler 2010).

Dewberry is a prostrate woody vine covered in hairs or thorns, with trifoliate leaves and white flowers (Jensen and Hall 1979). Vines arise from existing plant crowns or new buds along rhizomes and spread vegetatively. In addition, vines that touch the ground can form roots and stems and spread in this manner. The biennial canes reproduce and senesce in the second year. Rubus spp. are highly variable, readily hybridize with each other, and are difficult to identify to species (Jensen and Hall 1979; Sandler 2001).

Current control methods (e.g., hand pulling, herbicide wipes and sprays, clipping, pruning, and spot renovation of heavily infested areas) fail to provide satisfactory management (Sandler 2010b). Glyphosate use on cranberry farms provides...
only minimal success for controlling dewberry since the weed stems are intertwined with and approximately the same height as cranberry uprights. Glyphosate wipes work best when there is a significant height differential between the target weeds and the cranberry vines, because cranberry are very sensitive to glyphosate. A recent grower survey indicated that the majority of growers found herbicides to be only somewhat effective, and clipping was not effective in controlling dewberry on bogs (Ghanous and Sandler 2010). Spot renovation involves the removal of existing surface vegetation coupled with replanting of cranberry vines, can cost as high as $74,000 ha⁻¹ (Cape Cod Cranberry Growers’ Association 2008), and is a not a viable option in many circumstances.

Perennial plants rely on stored carbohydrates for the resumption of growth following dormant periods. Past research has shown that damaging aboveground structures forces perennial plants to expend stored resources on growing new structures, leaving them smaller, less vigorous, less stress tolerant, and more vulnerable to mortality by leaving the plant with fewer resources (Kays and Canham 1991; Loescher et al. 1990). In annual crops, carbohydrate depletion of perennial weeds can be accomplished with mechanical controls such as repeat tillage or with other mechanical controls such as mowing in pastures and turf (Zimdahl 1999). Evidence shows that fire can be used as a tool to deplete stored carbohydrates and control woody species in forest management (Richburg 2005), but fire has not been investigated as a potential tool in cranberry.

Few scientific reports have been published on the use of FC on perennial weeds in a woody perennial crop system. Prescribed burning has been used in lowbush (Vaccinium myrtillus L. Michx. and V. angustifolium Ait.) cultivation for decades as a method of pruning to increase yield and aid in the control of weeds, pests, and pathogens (Ismael and Yarborough 1981; Vander Kloet and Pither 2000). Cranberry is a close relative of blueberry (V. myrtillus and V. angustifolium), and preliminary evidence strengthened the premise that cranberry will also tolerate FC well (Ghanous et al. 2009). Historically, low-intensity burns were sometimes used on dormant cranberry vines as a way to remove old growth and stimulate new growth (Darrow et al. 1924). Although other cultural practices such as mowing or pruning have replaced this method, past evidence that cranberry plants recover after being exposed to fire indicates that cranberry plants should be able to tolerate FC spot treatment of weeds.

The majority of past research involving fire, burning, or other forms of thermal control of woody weeds has been in nonagricultural settings such as roadsides and right of ways or the use of prescribed burns in forests. The focus of agricultural work has been mainly on herbaceous plants in annual crops. The effects of spot treatments are likely to differ from prescribed burns because these latter treatments burn all vegetation, affect soil temperatures, and may alter soil chemistry. Spot treatment with handheld torches use brief exposures of heat to damage plants without incineration.

New tools for managing dewberry are needed and would be very beneficial to the cranberry industry. Flame cultivation may offer a practical approach, particularly since it can be used as a spot treatment on cranberry bogs. The small size of the handheld torches allows for localized impact, minimizing damage to surrounding crop areas. The cost of weed control treatments with a short exposure with a FC is comparable to glyphosate wipes (Sandler and Ghanous 2011). Spot treating perennial weeds with flame cultivators could be an additional management option that allows cranberry growers to target the treatment to aboveground plant structures such as weed leaves and stems.

Our objectives were to determine if a single localized treatment with a handheld flame cultivator would reduce the biomass of dewberry and if biomass reduction would increase with increasing exposure times and vary by flame cultivator. Our tests evaluated three portable, handheld, propane-fueled flame cultivators that targeted dewberry for various exposure times.

**Methods and Materials**

Three handheld, propane-fueled cultivators were evaluated (Figure 1). The Weed Dragon vapor torch (Flame Engineering, LaCrosse, KS) is an open flame (OF), 86.4-cm-long torch with a 5.1-cm bell that operates with propane gas with a rated maximum capacity of 100,000 BTU and approximate working flame temperature of 1121 °C. The infrared Eliminator (Puzzy Boy, R. Mueller Agriculture Forestry and Garden Equipment, Rastatt, Germany) is an infrared (IR) cultivator with an enclosed propane flame that is projected onto a rectangular ceramic plate 8.5 cm by 17.1 cm and provides radiant heat output up to 2500 BTU. The Dandy Destroyer (Puzzy Boy) is an infrared with spike (IRS) cultivator that has an enclosed propane flame that is projected onto a 4.5-cm round ceramic plate, with a 4.5-cm protruding metal spike; both the plate and the spike provide radiant heat output up to 6000 BTU). The study site was located at the UMass Cranberry Station, East Wareham, MA (41°45’54”N 70°40’5”W). A 14 by 20 m upland area proximal to the cranberry farm was cleared of all vegetation, and the soil was tilled with a gas-powered rotary tiller (Barreto Hydraulic Tiller 920, La Grande, OR). Soil pH was determined and found to be within the normal range for cranberry soils (pH 4 to 5) (DeMarsalis 2010).
The experiment was arranged as a two-way factorial with three levels of FC (OF, IR, and IRS) as the main plot and five levels of exposure as the subplot. The experimental design included four replications. Exposure levels were 0, low, medium, and high durations which were 0, 3, 6, and 9 s, respectively, for OF and 0, 15, 30, and 45 s, respectively, for IR and IRS) or a glyphosate wipe application. The glyphosate wipe was included in each block as a treated control to represent the current practice for managing these weeds (Sandler 2010a). Plots were 0.25 m², and plot centers were 1.3 m apart. The experiment was part of a Master’s graduate research project and not repeated due to the time constraints of a typical 2-year Master’s graduate program.

Dewberry plants were collected between May 28 and June 9, 2008, from a commercial cranberry bog system in Wareham, MA. Plants were taken from bog banks, waterhole edges, and sand piles where corresponding weed populations were found on the adjacent bogs. Plants were visually assessed to be of similar size, and extracted with shovels, preserving as much of the root system as possible. Plants were transported bare rooted in buckets of water and transplanted into the plots immediately after collection. Plants were allowed to acclimate for 1 yr prior to treatment with flame cultivators to allow recovery from transplant shock. Pine bark mulch was placed around each plot to minimize moisture loss and growth of unwanted weeds. Areas between plots were sprayed on July 30, 2008, with a 44 g L⁻¹ ae glyphosate solution made by diluting a glyphosate (isopropylamine salt) concentrate (445 g L⁻¹ ae) 1 : 9 parts herbicide: water. These areas were also hand-weeded on July 14, 2009, and September 30, 2009.

Each dewberry plot contained three plant crowns (i.e., the point where stems emerge from the woody roots) per plot. Transplants were watered three times daily by oscillating sprinklers, which were run for 1-hr intervals. Watering began at transplanting (May 28, 2008) and continued throughout the year. Since no literature was found specifically on the seasonal carbohydrate cycles of dewberry, the treatment timing was targeted to when the plants reached full leaf expansion and entered the reproductive phase, based on the assumption that these plants follow a typical pattern of seasonal variations of root reserves for woody plants in temperate zones (Kozlowski 1992; Looscher et al. 1990).

Aboveground and belowground dewberry biomass was harvested between September 28 and October 6, 2009, terminating the study. Biomass harvesting was labor intensive and required several days to complete. Care was taken to ensure that entire blocks were harvested within a single day. Shovels and small hand-held tines were used to extract the plants from the ground, keeping the roots intact. After extraction, aboveground shoots were separated from roots using clippers. Shoots were placed into paper bags. Roots were rinsed in water to remove soil, and then placed into a separate paper bag. Plants were dried at 60°C for a minimum of 3 d and dry weight was determined.

Data Analysis. Data were analyzed using SAS (SAS version 9.2, SAS Institute Inc., Cary, NC). To assess homogeneity of variances, data normality was tested using the Univariate Procedure. Weights of dewberry shoots were log-transformed to meet the assumptions for variance analysis. Means were back-transformed for presentation. Analysis of variance was performed using the Mixed Procedure using FC tool type and exposure and its interaction in the model statement. Exposure data were assessed for significant regression trends at the linear and quadratic levels using orthogonal contrasts. Coefficients of determination ($r^2$) values were calculated for linear trends by dividing the sums of squares associated with the linear contrast by the sums of squares associated with exposure. $r^2$ values were calculated for quadratic trends by dividing the sums of squares associated with both the linear and quadratic contrasts by the sums of squares associated with exposure. Means for each exposure were compared to glyphosate means using Dunnett’s test.
Results and Discussion

Dewberry shoot, root, and total biomass decreased linearly as FC exposure increased (P ≤ 0.001) (Figure 2); the effect of FC tool type was not significant. Regardless of the FC tool used, increasing exposure resulted in an increasing reduction in dewberry biomass, indicating increasing damage to the woody FC caused visually apparent physical damage to aboveground plant structures. Reduction in shoot biomass was likely the result of direct physical damage.

Glyphosate is the industry standard for controlling woody weeds in Massachussetts cranberry production and served as a treated control in this study. For dewberry plants, untreated and low exposure had greater root biomass and greater total biomass when compared to the glyphosate treatment; untreated, low, and medium exposure treatments had greater shoot biomass compared to glyphosate (P ≤ 0.05) (Figure 2). High exposure reduced dewberry biomass to levels similar to the glyphosate treatment, indicating that FC is at least as effective as the industry standard control with potential to cause much less damage to the surrounding crop (Ghantous et al. 2009).

Dewberry plants had their biomass evenly distributed between aboveground and belowground plant structures (untreated plants, mean root: shoot biomass = 0.56, n = 15). FC may affect other weeds with different distributions of biomass differently. Less aboveground biomass available for exposure to FC could result in the treatments having less impact on the total plant, and conversely greater ratios of aboveground biomass could result in treatments being more effective because more of the total plant would be affected. This ratio can vary significantly between species (Ghantous, unpublished data), and more research is needed to establish the relationship of root: shoot biomass to treatment efficacy, and the potential to predict treatment efficacy of a species based on this parameter.

Although stored carbohydrates were not measured, other studies have shown a relationship between biomass reductions in the roots of woody plants and a reduction in carbohydrates (Alvarado-Rays et al. 2007; Lindhauser and Lieffers 2003). The significant decreases in dewberry root biomass as a result of FC treatments could indicate that plants were expending underground reserves on regrowth of aboveground structures following damage from FC. This result supports the hypothesis that FC could be an effective way to use carbohydrate starvation to control dewberry. Perennial plants rely on stored carbohydrates for the resumption of growth following dormant periods. Carbohydrates stored in roots and other underground storage organs are particularly important for early season growth (Loescher et al. 1990). Physiology and carbohydrate cycles differ by species, but most woody plants tend to have sharp decreases in stored carbohydrates beginning at bud break through reproduction, after which plants begin to accumulate reserves (Kays and Canham 1991; Kozlowski 1992).

Although all carbohydrates can never be completely depleted by the removal of aboveground biomass, past research has shown that if plants are depleted of enough carbohydrates during their growing season, plants exhaust their stored reserves on regrowth of shoots. This depletion can severely impair regrowth the following season or even cause mortality by leaving the plant with fewer resources for dormant season respiration and making it less tolerant to stress (Kays and Canham 1991; Loescher et al. 1990).

Although this work shows the FC has potential for weed management of perennial weeds in cranberry production, several points should be considered. Cranberry plants in a managed field situation have a continual year of vegetation. Treating weeds on cranberry farms with FC will cause localized damage to cranberry plants immediately surrounding the weed, but recent research indicates that cranberry plants recover well from FC exposure (Ghantous et al. 2009). This method of weed control would be ideally used as spot treatment to control small populations of weeds before serious infestation occurs.

Secondly, FC could be used in larger nonproduction areas to control weeds. Weeds growing in ditches negatively affect drainage and water movement around bogs. Weeds growing in areas where cranberry vines are not as abundant, such as bog edges, ditches, and dikes are also problematic. These weeds can spread into production areas by seeds, roots, and stolons. In these areas, damage to the crop from weed control with FC is not a consideration.

Lastly, we selected a treatment timing of mid-July based on an estimate of when stored reserves would be low in the plants. It is possible that this was not the optimum time for treatments. Past research on carbohydrate depletion in woody perennials indicates that careful timing of treatments is integral to the success of these practices (Kays and Canham 1991; Loescher et al. 1990). For maximum efficiency, treatments should ideally be administered when stored carbohydrates in belowground structures are at their seasonal low point. Future research into carbohydrate cycles for woody weed species would be of particular interest for effective timing of FC treatments and predicting which species would be good candidates for this type of weed control. Further experiments that explore the effects of treatment timing, as
well as species-specific carbohydrate analysis of the plants would likely increase efficacy of FC treatment for weed control.

This experiment also included the treatment of sawbrier plants (Smiraxis glauca Wall.) with handheld flame cultivators; however, these results are not reported herein. The sawbrier plants did not recover well from the effects of transplanting (i.e., minimal new growth). No significant treatment effects were seen with sawbrier plants; however, it could not be determined if this was an artifact of stunted growth after transplanting or actual lack of response to FC, an effect related to aboveground: belowground biomass ratios, or some combination of these. Exploring the efficacy of FC on various species of perennial weeds should provide a good foundation for practical weed management recommendations for growers wishing to utilize this technology.

Our objectives were to gain preliminary data and explore the hypotheses that dewberry would be damaged by a single localized treatment with a handheld flame cultivator and that the damage would increase with increasing exposure and vary by FC tool type. FC significantly damaged dewberry. The three FC tools were equally effective in reducing weed biomass. The results of this exploratory study suggest that FC may offer an alternative technique for managing woody weeds in commercial cranberry systems. Further research is warranted to validate these results and to determine the applicability of FC to other agricultural systems.

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Literature Cited


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APPENDIX B

EFFECTS OF VARYING FLAME CULTIVATOR EXPOSURE DURATIONS ON

SAWBRIER PLANTS

Sawbrier plants (*Smilax glauca*) were tested as part of a study on the efficacy of hand-held flame cultivators as a management tool for woody weeds on cranberry farms (Ghantous et al. 2012) (Appendix A). The effects of torch type, exposure duration, and their interaction were not significant ($P \geq 0.16$). Means from this species were not presented in the publication.

Table B-1. Mean sawbrier biomass (± SE, n = 12) from plants treated with three types of handheld, propane-fueled torches (open flame torch (OF), infrared (IR); and infrared with spike (IRS). Exposure of none, low, medium and high correspond to 0 s, 15 s, 30 s, and 45 s for the IR and the IRS, and to 0 s, 3 s, 6 s, and 9 s for the OF. Effect of torch type, exposure duration, and their interaction were not significant ($P \geq 0.16$).

<table>
<thead>
<tr>
<th>Flame cultivation exposure duration</th>
<th>Total sawbrier biomass (g)</th>
<th>Sawbrier shoot biomass (g)</th>
<th>Sawbrier root biomass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>28.6 (±4.9)</td>
<td>3.4 (±0.7)</td>
<td>25.3 (±4.3)</td>
</tr>
<tr>
<td>Low</td>
<td>17.7 (±2.9)</td>
<td>2.1 (±0.5)</td>
<td>15.6 (±2.4)</td>
</tr>
<tr>
<td>Medium</td>
<td>19.6 (±6.2)</td>
<td>2.0 (±0.4)</td>
<td>17.5 (±1.5)</td>
</tr>
<tr>
<td>High</td>
<td>24.6 (±3.5)</td>
<td>2.3 (±0.4)</td>
<td>22.3 (±3.2)</td>
</tr>
</tbody>
</table>

**Literature Cited**

APPENDIX C

DAMAGE AND RECOVERY OF CRANBERRY VINES FROM EXPOSURE TO HANDHELD FLAME CULTIVATORS

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Damage and Recovery of Cranberry Vines from Exposure to Handheld Flame Cultivators

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Abstract. Damage and recovery responses of four cranberry varieties ('Mullica Queen', 'Crimson Queen', 'Stevens', and 'Howes') to handheld propane flame cultivation (FC) were evaluated. All combinations of four levels of exposure duration of three FC torches (open flame 0, 3, 6, and 9 seconds), infrared (IR) and IR with a 4.5-cm metal spike (0, 15, 30, and 45 seconds), were tested on rooted cranberry uprights (vertical stems) planted in clay pots. Pots were subjected to a single treatment from one FC torch at one exposure duration; a glyphosate wipe was also included as a treated control (industry standard). Treatments were replicated five times. All cranberry plants were damaged by all levels of exposure duration as evident by visual damage ratings, reduced net cumulative stem lengths, reduced number of uprights, and reduced proportion of reproductive uprights when compared with untreated plants. All cranberry plants treated with glyphosate had total mortality; all cranberry plants from all varieties treated with FC survived, and all had net positive stem growth in the year after treatment except for 'Stevens' treated with open flame and IR with spike. The non-fatality of response to cranberry to FC indicates that FC will cause less damage than glyphosate to cranberry plants that are incidentally exposed during spot treatment of weeds and thus could be integrated into weed control in certain situations, including organic farming.

Cranberry (Vaccinium macrocarpon Ait.) is a long-lived woody perennial with slender trailing stems that grows in acid sandy soils. Cranberries in the United States are produced primarily in Massachusetts, Wisconsin, New Jersey, Washington, and Oregon and are important agricultural commodities for these states. Competition for resources between cranberry plants and weeds can depress cranberry yields, resulting in large annual crop losses (Patton and Wang, 1944; Swanton et al., 1993). Current weed management strategies may include cultural controls such as flooding and shading of beds, mechanical controls such as hand weeding, and chemical controls with pre- and postemergence herbicides (Sandler, 2011b).

Interest in replacing chemical inputs into cranberry systems has provided the motivation to evaluate methods such as FC as potential nonchemical options for weed control. Flame cultivation exposes plants to brief periods of high temperature causing the water in the plant tissue to expand rapidly, rupturing plant cells. Heat is thought to disrupt and destroy cellular membranes and lead to necrosis (Daniell et al., 1969; Flitman et al., 1973). Many different methods of FC are available ranging from open flames to IR (radiant heat), hot foam, and boiling water. Various FC methods have been used successfully in annual crops such as carrot, corn, onion, and potato as both a pre-emergence and postemergence weed control (Diver, 2002), but little work has been done on the use of FC in cranberry.

For decades, prescribed burning has been used in perennial woody lowbush blueberry (Vaccinium myrtilloides and V. angustifolium) cultivation as a method of pruning to increase yield and aid in the control of weeds, pests, and pathogens (Fick and Childers, 1966). Historically, low-intensity burns were sometimes used on dormant cranberry vines as a way to remove old growth and stimulate new growth (Darrow et al., 1924). Although modern-day practices such as mowing have replaced this method, cranberry plants may be types to tolerate localized heat treatments primarily intended to control weeds.

Cranberry plants in a farm situation form a continuous mat of vegetation and thus present a logistical challenge for FC because weeds grow within the cranberry canopy structure. Although cranberry plants are not the target during FC treatments, treating weeds with FC may cause localized damage to cranberry plants immediately surrounding the weeds. Flame cultivation would ideally be used as a spot treatment for weeds growing in the cranberry canopy as well as on larger non-production areas where cranberry vines are not as abundant such as bed edges, ditches, and dikes.

The effect of FC on cranberry plants is not known and is an important determinant for developing recommendations for the use of FC on cranberry farms. A greenhouse study was conducted to measure cranberry response to FC in the absence of naturally occurring variations found on cranberry farms. This study was performed in conjunction with a series of experiments testing specific types of handheld propane torches (one open flame and two styles of IR) and varying exposure times on several species of perennial weeds (Ghantous et al., 2011, 2012). We hypothesized that 1) FC will cause damage to cranberry plants and that damage will increase with increasing exposure duration and vary by flame cultivator tool used; 2) cranberry plants will recover from FC treatment effect and recovery will vary with exposure duration and flame cultivator tool used; and 3) that there would be no difference in varietal response.

Materials and Methods

Vine source and propagation. Four cranberry varieties were tested. 'Mullica Queen' and 'Crimson Queen' were rooted in 2007 and tested in 2008, and 'Howes' and 'Stevens' were rooted in 2008 and tested in 2009. The study was conducted over a 2-year period as a result of plant material availability. Greenhouse conditions, propagation methods, and plant handling were uniform during the study period. Cuttings for 'Mullica Queen' and 'Crimson Queen' were made from stolons (Integrity Propagation, Chateauguay, NJ). Cuttings for 'Stevens' and 'Howes' were taken from established cranberry farms located in Wareham, MA. Cranberry plants were cut and rooted according to previously published protocols (O'Connell et al., 2011). During establishment (May through September), plants were fertilized once per week with 15N-7.0P-14.1K (833 mg L−1) by drenching the soil with the fertilizer solution.

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In December, cuttings were moved to cold storage (5°C) to acclimate to required chilling hours (Eady and Eaton, 1972). Rooted cuttings were returned to the greenhouse the next April. As the cuttings developed roots, the aboveground portion supported additional stem and leaf growth and will henceforth be termed as a plant. Approximately 1 month before treatment, four cranberry plants were transplanted into a single clay pot (15 cm diameter, 15 cm length), which was the experimental unit. Pots were fertilized four times on a 3- to 4-week interval using the same fertilizer described previously. Although each cutting grows into a plant with multiple stems, four individual plants per pot were still identifiable.

Treatments application and data collection. Three hand-held, propane-fueled cultivators were evaluated: open flame (OF, Weed Dragon vapor torch; Flame Engineering, LaCroese, KS), IR (infrared) torch (IR, Infrænd Eliminator and IRS, Dandy Destroyer, respectively; made by Puzzy Boy, Switzerland, distributed in the United States by Evergreen, Blaine, WA) (Fig. 1).

The experiment was a randomized complete-block split-plot design with four levels of variety as the main plot, three levels of PC tool type (OF, IR, and IR with spike (IRS)) as the subplot, and four levels of exposure duration as the sub-subplot; treatment combinations were replicated five times. Exposure duration levels were none, low, medium, and high durations (0, 3, 6, and 9 s, respectively, for OF and 0, 15, 30, and 45 s, respectively, for IR and IRS). Timings were selected based on those used in a previous study (Ghanousi et al., 2012) and are of equal intervals to allow comparisons between torches. A glyphosate wipe was included as a treated control to represent the current practice for managing woody perennial weeds in cranberry (Sandler, 2011b). Immediately before treatment, baseline counts of the number of cranberry stems in each pot were determined. In addition, the length of each stem was measured to the nearest millimeter. Water was applied to all plant foliage and soil with a handheld watering can for 10 s before and after FC treatments to minimize risk of fire. Pots intended for glyphosate treatments were also watered before treatment. Treatments were applied in mid-July when plants were actively growing. Each pot was placed into the center of a 0.25-m² plot area for the duration of the exposure. Uniformity was achieved by using a digital stopwatch timer (Traceable Stopwatch 1645; Control Company, Friendswood, TX) and applying the treatment as a number of passes over the 0.25-m² area.

The low, medium, and high treatments were one, two, and three passes, respectively. The OF was held 30 cm above the vines and the IR was physically in contact with the vines during application. The spike of the IRS was inserted into the center of the pot for the duration of the exposure.

Glyphosate treatments were applied using a small sponge. Cranberry plants were wiped until leaves appeared wet. In 2008, ‘Mullica Queen’ and ‘Crimson Queen’ plants were treated with a 12.5% a.i. (high end of the recommended range) glyphosate solution that resulted in 100% mortality. In 2009, a medium rate (6.25% a.i.) was selected for treatment of ‘Skeena’ and ‘Hosvoid’ plants (Sandler, 2011b).

Visual evaluations of damage were made 1 d after treatment, 1 week after treatment (WAT), and 4 WAT. At 4 WAT, the amount of damage was progressing, and new growth was apparent. Visual evaluations after this point focused on cranberry plant recovery. Visual recovery evaluations were made to assess subsequent regrowth at 3 WAT, 7 WAT, and 18 WAT. The scale for damage evaluation for plants in each pot was: 0 = all plants healthy; 1 = plants show minor damage (less than 30%); 2 = plants show moderate damage (30% to 60%); 3 = plants show severe damage (60% to 90%); and 4 = plants show very severe damage or dead (greater than 90%). The scale for recovery evaluations of each pot (four plants per pot) was: 0 = all plants grown with no visible regrowth; 1 = one or two plants have at least one to two new stem sprouts; 2 = three or four plants have at least one to two new stem sprouts; 3 = all plants showing two or more new stem sprouts; 4 = vigorous regrowth; and 5 = no apparent damage/normal growth.

All data were analyzed using SAS (Version 9.2; SAS Institute Inc., Cary, NC). Normality was tested using Proc Univariate. Net cumulative stem length was calculated for each pot by subtracting the cumulative total length of all stems per pot before treatment from the cumulative total length of all stems per pot at the final evaluation. Proc Correlation was used to compute Pearson correlation coefficients for net cumulative stem length and final stem dry weight per pot. The proportion of flowering sprouts was calculated by dividing the number of flowering sprouts by the total number of sprouts (per pot basis). Proportion data were arcsine-transformed before analysis of variance and converted to percentages for presentation. All cranberry plants treated with glyphosate died. Data from these treatments were not included in the statistical analysis.

Although two varieties were tested per year, this experiment was designed as a greenhouse study to test environmental and growing conditions were uniform. All plants were propagated and handled in a consistent manner, and year variability was not considered, which is an accepted practice for greenhouse studies (Fernandez, 2007). Analyses of variance were performed using Proc Mixed with variety, FC tool type, exposure duration, and their interactions in the model statement for visual damage and recovery ratings, net.
cumulative stem length, number of upright stems, and proportion of upright stems that were reproductive. For data sets in which the main effect of exposure duration was significant, data were assessed for significant regression trends at the linear and quadratic levels using orthogonal contrasts in Proc GLM. For data sets in which the main effect of variety or FC tool type was significant, means were compared using Tukey's honestly significant difference (HSD) multiple comparisons test (P = 0.05). Significant interactions between variety and FC tool type were sliced by variety and assessed with Tukey's HSD for FC tool type within variety. Significant interactions between FC tool type and exposure duration were sliced by FC tool type and regression trends were assessed for exposure duration within FC tool type. Exposure ranges are presented as categorical labels (none, low, medium, and high) to allow for combining data into a single figure.

Results and Discussion

Visual damage ratings. All cranberry plants treated with glyphosate died. Presented ratings are from the last damage evaluation made 4 WAT. The effect of exposure duration on damage rating varied by FC tool type (P = 0.001), but the interaction of variety and exposure duration was not significant. Overall, plants treated with the OF tool showed more damage than those treated with the IR or IRS tools. As exposure duration increased, the amount of damage increased for all FC tools (data not shown). As evident by the quadratic nature of the regression trends for all tools, the largest increase in the damage rating was seen between the control (no exposure) and low exposure, whereas the assessment of damage for the low, medium, and high exposures differed less from one another [IR: y = -0.731x^2 + 3.286x + 0.111 (R^2 = 0.97), OF: y = -0.993x^2 + 4.184x - 0.196 (R^2 = 0.94), IRS: y = -0.65x^2 + 3.015x + 0.135 (R^2 = 0.95)]. Any small differences between the FC exposures (excluding the untreated) are likely not important from a practical weed management perspective. The advantage of using a longer exposure to improve weed control would likely outweigh any minor increase in crop damage incurred from the longer exposure.

The effect of variety on damage rating varied by FC tool type (P = 0.031). The interaction was the result of 'Howes' plants showing more damage than 'Crimson Queen' plants when treated with the IRS tool (P = 0.021, data not shown). Damage to the other varieties was similar across tool types.

Visual recovery ratings. Presented ratings are from evaluations conducted 18 WAT (before plants being moved into cold storage to induce chilling hours) and are used to assess cranberry recovery within the same growing season as the FC treatments. Like with damage ratings, the effect of exposure duration on recovery ratings varied by FC tool type for all varieties (P = 0.001), but the interaction of variety and exposure duration was not significant (data not shown). Cranberry plants treated with IR had greater recovery compared with those treated with OF and IRS. The largest decrease in recovery rating was seen between the untreated (no exposure) and plants treated with low exposure, whereas differences in the amount of recovery rating among the low, medium, and high exposures were smaller in magnitude [IR: y = 0.255x^2 - 0.965x + 4.948 (R^2 = 0.92), OF: y = 0.5123x^2 - 2.483x + 4.855 (R^2 = 0.97), IRS: y = 0.563x^2 - 2.663x + 4.885 (R^2 = 0.96)].

The effect of variety on recovery rating varied by FC tool type (P = 0.04). The interaction was the result of 'Howes' plants showing greater recovery than 'Crimson Queen' or 'Stevens' plants when treated with the IRS tool (P = 0.001 and P = 0.047, respectively, data not shown). No other varieties showed significant differences for the interaction.

Cranberry stem recovery: The effect of variety on the final net cumulative stem length of cranberry plants 11 MAT varied by FC tool type (P = 0.032) (Fig. 2). 'Crimson Queen', 'Mullica Queen', and 'Stevens' plants treated with the IR tool had significantly greater net cumulative stem length than plants treated with OF or IRS tools, which did not differ from each other. For 'Howes' plants, the IR and the IRS tools did not differ from one another and both had significantly greater net cumulative stem length than plants treated with the OF tool. The effect of exposure duration on net cumulative stem length of cranberry plants varied by FC tool type (P = 0.008) (Fig. 3), but not by variety. The effect of exposure duration was not significant for plants treated with the IR tool. Net cumulative stem length decreased quadratically as exposure duration increased for plants treated with the OF tool and decreased linearly for plants treated with the IRS tool. However, all net values were positive, indicating that even plants with the least amount of stems present had at least recovered to a level similar to that of their pre-treated state the previous year; the OF high exposure duration treatment mean was just above zero at 0.69 cm. Even at the longest exposure, no cranberry plants died. All plants began to regrow within 3 WAT and all plants demonstrated normal seasonal response (i.e., evidence of endodormancy by foliar color change) and resumed typical growth after accruing sufficient chilling hours.

![Fig. 2. Change in cumulative stem length per pot (mean ± se, n = 20) between pre-treatment and final measurements 6-11 months after flame cultivation treatments with infrared torch (IR), open flame torch (OF), or IR torch with splice (IRS). Means with similar letters within a variety are not significantly different according to Tukey's honestly significant difference (P ≤ 0.05).](image-url)
In contrast to FC treatments, all plants that were treated with the glyphosate wipe died (data not shown). Although cranberry plants are not intentionally exposed to glyphosate as part of routine cranberry growing practices, this herbicide is wiper-applied as a spot treatment for weeds and a portion of cranberry vines proximal to the weeds is typically injured during treatment. Although cranberry plants treated with FC were damaged, the non-fatal response indicates that cranberry plants that are incidentally exposed during spot treatment with FC will recover.

In addition to reducing net cumulative cranberry stem length, FC also reduced the number of total uprights per pot. Similar to the trends seen for the change in stem length, the effect of exposure duration on the number of total upright stems per pot varied by FC tool type ($P < 0.001$) (Fig. 4). The number of uprights decreased quadratically as exposure duration increased for plants treated with the OF and the IRS tool. Use of the IR tool at any exposure duration did not affect the number of uprights per pot. The main effect of variety was also significant ($P < 0.001$). ‘Crimson Queen’ and ‘Hovest’ did not differ from one another, and both had significantly more uprights than ‘Mullica Queen’ or ‘Stevens’, which did not differ from one another (data not shown).

The reason for the differences in the cumulative net stem length or number of uprights as a response to FC tool type is unclear but may be the result of the design of the tools. The OF tool generates the highest working temperature, and the IRS tool has a spike that is inserted into the soil, which is intended to impact on root structures. The IR tool has a lower working temperature than the OF tool and lacks a soil spike.

Reproductive potential. The percentage of reproductive uprights the year after treatment decreased quadratically as exposure duration increased ($P < 0.001$) (Fig. 5). The percentage of uprights that are reproductive is an important contributor to yield in cranberry (Eaton and Kyte, 1978). The main effect of FC was also significant ($P = 0.036$). Plants treated with the OF tool had a lower percentage of uprights that were reproductive ($x = 4.3\%$) than plants treated with the IR tool ($x = 7.7\%$). IR did not differ from IRS, and IRS ($x = 6.4\%$) did not differ from OF. In addition, variety significantly affected the percentage of reproductive uprights ($P < 0.001$). ‘Crimson Queen,’ ‘Mullica Queen,’ and ‘Stevens’ did not differ from one another; however, all had a higher percentage of reproductive uprights than ‘Hovest’ (data not shown). ‘Hovest’ is a native variety, whereas the other three are hybrids. Differences in reproductive potential are likely the result of innate differences between the variety rather than any treatment effects (Curran, 2008).

In this study, FC treatments caused damage to the cranberry stems present in the pot at the time of treatment. Most of the treated plants became defoliated and exhibited damage and/or death of exposed stems. The plants began to regrow 3 WAT, and this regrowth was typically in the form of new shoots emerging from the soil or the lowest parts of the plants and not seen as recovery of the existing older material (e.g., growing new leaves on stems existing before FC, recovery of the existing terminal bud). New uprights produced as a result of terminal bud fuses were generated from lateral buds that are primarily vegetative in the first year of growth (Sandler, 2011a).

Previous pruning and mowing studies of cranberry beds showed that pruned or mowed vines had a reduction in fruit yield the year after treatment, and the reduction increased as the severity of pruning increased (Sandler, 2011a; Sandler and DeMeraval, 2009; Strick and Poole, 1991). The second year after pruning, vines typically produce greater yields than before pruning (Chambers, 1918). Flame cultivation treatments reduce vine stem length...
and are likely affecting vines in a similar manner to a heavy pruning or mowing.

Current data indicate that plants treated with FC will have reduced reproductive potential the year after treatment. Cranberry vines would be expected to recover to typical reproductive output in subsequent years provided no other limitations are imposed (Sandler and DeMoranville, 2009; Vanden Heuvel and Davenport, 2005). We speculate that if the plants had been followed for an additional year (second year after treatment), the percentage of reproductive uprights would have returned to levels comparable to the untreated controls.

Cranberry vine damage by exposure to FC was verified by reduced root stem length, lower number of uprights, and lower percentages of reproductive uprights when compared with untreated plants in the year after treatment. Flame cultivation did not kill treated cranberry plants, which began making new growth within 3 weeks of being treated. Damage and subsequent recovery were comparable to the response of cranberry vines after mowing or heavy pruning (Sandler, 2011a; Sandler and DeMoranville, 2009). Subsequent research should follow FC-treated vines into a second year after treatment to verify long-term response. In addition, future work should evaluate the response of cranberry vines in a farm setting where cranberry plants grow densely and create a continuous mat of vegetation to evaluate if a thick canopy could diffuse FC heat and mitigate a portion of the damage noted in this greenhouse study.

Flame cultivation has been demonstrated to be effective at controlling some weed species found in cranberry such as dewberry (Rubus spp.) and musk (Anemone euforbus). All torches were equally effective at controlling dewberry, whereas the IRS was less effective than the IR and OF at controlling musk (Ghanotis, et al., 2011, 2012). Although there were minor response differences between the cranberry varieties tested, all showed recovery from FC damage irrespective of which torch was used or duration of exposure. Although the IR and IRS torches caused slightly less cranberry damage than the OF torch, the long exposure times of the IR and IRS (45 s compared with 9 s, respectively) and possible lower efficacy of weed control form the IRS made them a less attractive option for weed control. An economic analysis showed that the time and cost of using an OF torch for spot control of weeds was similar to that of the common weed control practice of using a wide applicator to apply glyphosate to weeds (Sandler and Ghanotis, 2011). In addition to being an cost-effective as glyphosate wipes, the non-fatal cranberry response to FC indicates that it will cause less damage to cranberry plants that are incidentally exposed during spot treatment of weeds than glyphosate.

Flame cultivation could be integrated into a sustainable and economical approach for weed control in certain situations. This technology would be applicable for conventional production as well as organic production and would ideally be used as a spot treatment for weeds growing in the cranberry canopy as well as on larger non-production areas where cranberry vines are not as abundant such as bed edges, ditches, and dikes.

**Literature Cited**


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