January 2008

The Effect of Sanding and Pruning on Yield and Canopy Microclimate in 'Stevens' Cranberry

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THE EFFECT OF SANDING AND PRUNING ON YIELD AND CANOPY MICROCLIMATE IN ‘STEVENS’ CRANBERRY

A Thesis Presented

by

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

MASTER OF SCIENCE

September 2008

Plant and Soil Sciences

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ACKNOWLEDGEMENTS

I would like to give special thanks to Justine Vanden Heuvel and Carolyn DeMoranville as my advisors for their guidance, wisdom, and patience throughout my project. Along with Wesley Autio, they provided me with much needed assistance with my manuscript. I am especially thankful that they gave me this opportunity to earn my advanced degree.

This research was made possible through SARE funding. I would also like to thank the people at the Cranberry Station who helped me collect and analyze my samples. I would like to extend an additional thanks to Wesley Autio and Peter Jeranyama for their wonderful help with statistical questions.

My parents, Bela and Brenda, were a constant source of support and inspiration throughout this journey and for my whole life. Lastly, I would like to thank Joanna for her unending support and love. I hope that someday I can return the favor. I love you.

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CHAPTER 1

A REVIEW OF SANDING AND PRUNING PRACTICES IN THE AMERICAN CRANBERRY

Summary

The American Cranberry (*Vaccinium macrocarpon*) is a long-lived, woody vine, native to North America (Eck, 1990). This low-growing, perennial vine reproduces vegetatively by either producing horizontal shoots (stolons), known in the cranberry industry as ‘runners’, or by producing shorter vertical shoots, known as uprights, from axillary buds (Roper and Vorsa, 1997). The uprights bear fruit in a biennial manner. As a result, the bog-wide population of vegetative uprights (U_v) and fruiting uprights (U_f) is roughly a 50:50 ratio in any given year. In general, the uprights are vegetative in their first year and fruiting in the following year. This alternation of vegetative and fruiting continues until the uprights bow under their own weight and function as runners (Eck, 1990).

Excessive vegetative growth in cranberry can be detrimental to yield (Davenport and Vorsa, 1999). The inverse relationship seen between excessive vegetative growth and yield is likely the result of several factors, including shading, diversion of carbon resources from fruit production to vegetation, and promotion of fungal diseases. Shading has been shown to have a significant negative impact on cranberry fruit set (Roper et al., 1995). With less light penetrating the canopy, uprights compete for sunlight. This competition may lead to carbohydrate resource diversion to increased growth towards the light. An overly vegetative bog with a deep and dense canopy can also create a microenvironment conducive to fruit rot and other fungal disease due to increased

relative humidity (Oudemans et al., 1998). Without canopy management, yield reductions and disease incidence in overly vegetative bogs can be substantial as seen the previously referenced studies.

In addition to yield, fruit quality has also been shown to be affected by light penetration. Anthocyanin concentration (red pigment) in the fruit vitally depends on adequate light penetration (Toledo et al., 1993, and Strik and Poole, 1991). Onayemi et al. (2006) performed defoliation experiments that showed an increase in total anthocyanin production and total flavonol concentration with an increase in light penetration. Berries with high anthocyanin content are considered to be of higher quality by buyers. In most cases, a cranberry crop must exceed a minimum anthocyanin content to be accepted for sale, and growers may receive extra compensation for fruit with high anthocyanin content. Furthermore, cranberries that are redder in color are more desirable to consumers for their appearance and potential antioxidant benefits (Vinson et al., 2002). In order to maintain an optimum level of anthocyanin production in the fruit, it is important to prevent a bog from becoming overly vegetative.

One practice used to manage the cranberry plant canopy is sanding. Sanding is used to rejuvenate an old bog or curtail overly vegetative bogs (Strik and Poole, 1995) and has a variety of potential benefits. This practice has been common in cranberry cultivation in the Northeast since the 1800s. Although a variety of application options are available, in recent years ice sanding has become the preferred method. In this method, a layer of sand is spread on the ice-covered bog during the winter and allowed to melt through and settle on the vines. Typically, sanding is done every 2-5 years with varying depth between 1.2 and 5 cm (DeMoranville and Sandler, 2000). In addition to opening the canopy to increase light penetration and lower relative humidity, sanding buries and encourages the rooting of old runners. This results in an increase of new upright growth (DeMoranville and Sandler, 2000).

Strik and Poole (1995) studied sanding on two Oregon ‘Stevens’ bogs of varied age. Treatments were light (1.3 cm) and heavy (2.5cm) sanding. Heavy sanding proved to be detrimental to yield at both sites, but light sanding improved yield in the year after treatment at the younger bog only. The authors suggested that sanding may be similar to pruning (Strik and Poole, 1992) in that moderate intensity levels of either practice may be beneficial but more vigorous application of either method may be detrimental to crop yield. Davenport and Schiffhauer (2000) performed a similar sanding experiment using the same depths on the cultivars ‘Stevens’ and “Early Black’. As in the Strik and Poole (1995) study, heavy sanding had a negative effect on yield for both cultivars. However, in this instance, light sanding showed no difference from the controls. This could be caused by the barge sanding depositing less than the target depth as seen in Hunsberger et al. (2006).

Pruning is another method that can be used to maintain a healthy, productive bog canopy. In many ways, pruning serves the same purpose as sanding by rejuvenating excessively vegetative bogs and making them more productive (Marucci, 1987). Opening the canopy is just one potential benefit. Another potential benefit stems from the pruning of terminal buds. Removal of the terminal buds breaks apical dominance allowing lateral buds to grow. This results in an increase in new uprights. However, this would be a long-term benefit since loss of the terminal would potentially reduce crop in the year of pruning while the new uprights would potentially fruit in the following year.

Recognizing the negative effect of an overly vegetative bog, Chambers (1918) carried out pruning experiments on a heavily vined bog that had been declining steadily in production. In the year of pruning, there was a 10% loss in production; however, the following year, production increased by 45%. The initial loss in production was likely the result of removing some existing fruiting uprights as an unavoidable consequence of the pruning treatment. Factors that may have contributed to the increase in the following year include the removal of apical dominance and an increase in light penetration into the canopy. Due to the biennial nature of cranberry fruiting, the new uprights that resulted from the removal of apical dominance would have produced fruit in the second year (Roper et al., 1993). Also, the increase in light penetration into the canopy in the first year may have led to increased photosynthetic carbon fixation, providing additional resources for flower bud formation in late June and early July, thus increasing the potential yield in the second year (Patten and Wang, 1994).

Growers in the Pacific Northwest tend to use pruning as a bog management practice but seldom use sanding (Roper and Vorsa, 1997). Strik and Poole (1991 and 1992) evaluated mechanical pruning on a 30-year-old ‘McFarlin’ commercial cranberry bog in Oregon. The timing of the pruning, whether early (December) or late (March), proved to have no effect on cranberry yield, likely due to the fact that the vines were dormant in each instance. Light, moderate, and heavy pruning treatments were repeated in each of the first two years. Compared to the control, all pruning treatments caused a decline in yield and number of fruiting uprights. In the third year, the vines were not pruned and allowed to recover. The result was a dramatic increase in yield. Combining the three years, lightly pruned plots had the highest yield, followed by the control, while moderately and heavy pruned plots had poor total yields. As a result, the authors recommended light pruning every other year for maximum benefit. It was noted that fruit from the heavily-pruned plots had the highest concentration of anthocyanins, supporting the notion that sunlight is important in production of these pigments.

Sanding and pruning treatments have shown the potential to be beneficial for excessively vegetative bogs. Both treatments are capable of increasing new upright growth and providing the benefits associated with a less dense canopy; however, results have been mixed regarding potential effects on crop yield. Sanding has potential drawbacks when compared to pruning. One such drawback is the increasing price of sand. Over the past few years, sand has become increasingly expensive, leading many to search for a cheaper alternative to either supplement or replace sanding altogether. Hunsberger et al. (2006) pointed out another potential drawback to sanding, irregularity in the depth of sand deposition with both barge and ice sanding. With both methods, much of the bog received the equivalent of the heavier treatments. Yield in these areas could be decreased.

Implementation of pruning as an alternative practice could overcome the cost and uniformity problems. Based on the limited studies to date, pruning appears to accomplish the same horticultural purpose as sanding. However, these two practices have not been compared directly within the same cranberry bog. The objective of this study was to directly compare pruning and sanding treatments on ‘Stevens’ cranberry to determine effects on crop yield and canopy microclimate.

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CHAPTER 2

THE EFFECT OF SANDING AND PRUNING ON YIELD AND CANOPY MICROCLIMATE IN 'STEVENS' CRANBERRY

Abstract

Sanding and pruning are two practices used in the cranberry industry for vine management and yield stimulation. This study compared the effects of varying levels of sanding and pruning in April 2006 on vine canopy characteristics and yield over the course of two growing seasons. Each practice was applied at four levels: sanding at four depths: control (0 cm), light (1.5 cm), moderate (3.0 cm), or heavy (4.5 cm) of sand; pruning at four numbers of passes with a commercial pruner: control (0 passes), light (1 pass), moderate (2 passes), and heavy (3 passes). Pruning levels had no affect on upright density over the two seasons whereas heavy sanding treatment decreased the number of uprights per unit area significantly. A linear increase in light penetration was observed for the first season only as intensities increased for both pruning and sanding. Number of fruiting uprights relative to total uprights decreased in the first year as intensity increased for sanding and pruning. This effect continued in the second year for sanding treatments. Yield and net returns averaged over the two years were greatest in lightly pruned plots, followed by lightly sanded plots. Moderate and heavy treatments were associated with lower yields and net returns than those for the controls.

Introduction

The American Cranberry (*Vaccinium macrocarpon*) is a low-growing vine, with a perennial growth habit (Eck, 1990). This native fruit to North America reproduces vegetatively by either producing horizontal shoots (stolons), known in the cranberry industry as 'runners', or by producing shorter vertical shoots, known as uprights, from axillary buds (Roper and Vorsa, 1997). The uprights bear fruit in a biennial manner and are generally vegetative (U_v) in their first year and fruiting in the following year (U_f). The result is a 50:50 population of vegetative and fruiting uprights in any given year. Uprights will continue to grow in this manner until they bow under their own weight and function as runners (Eck 1990).

Excessive vegetative growth in cranberry can be detrimental to yield (Davenport and Vorsa, 1999). Decreased yield from excessive growth may be the result of shading and fungal disease. Shading has been shown to have a significant negative impact on cranberry fruit set (Roper et al., 1995). Flower bud formation depends on adequate light penetration (Roper et al., 1993). Therefore, yield would be reduced with a large amount of shading. In addition to shading, excessive vegetative growth may also increase the relative humidity under the canopy. The result is a microenvironment conducive to fruit rot and other fungal diseases (Oudemans et al., 1998).

Fruit quality has also been shown to be affected by light penetration. Berries with high anthocyanin concentration (red color) are considered to be of higher quality to buyers due to their appearance and potential antioxidant benefits (Vinson et al., 2002). As with flower bud formation, anthocyanin production depends on adequate light penetration (Toledo et al., 1993, and Strik and Poole, 1991). In many situations, a cranberry crop must exceed a minimum anthocyanin content to be accepted for sale. Extra compensation may also be awarded to growers for fruit with high anthocyanin content in some cases. Due to the implications of an overly vegetative bog, it is important to employ cultural practices that open the canopy and maintain a productive bog.

Sanding is a cultural practice used in the Northeast to manage the cranberry plant canopy. Typically, this practice is performed every 2-5 years by spreading a 1.2 to 5 cm deep layer of sand over an ice covered bog in the winter (DeMoranville and Sandler, 2000). The sand is allowed to melt through the ice and ultimately settles on the cranberry vines. As the sand settles, it opens the canopy and therefore increases light penetration and lowers relative humidity as a result. Sanding also buries and encourages rooting of old runners. This stimulates the growth of new uprights that may bear fruit the following year (DeMoranville and Sandler, 2000).

Sanding studies results have been mixed regarding potential effects on crop yield. Strik and Poole (1995) studied sanding on two ‘Stevens’ bogs in Oregon. Heavy sanding (2.5 cm) proved to be detrimental to yield at both sites, while light sanding (1.3 cm) improved yield in the year after treatment at only one site. Davenport and Schiffhauer (2000) also showed that heavy sanding was detrimental. However, light sanding showed no difference from the controls.

Pruning is another method that can be utilized for canopy management. Much like sanding, pruning opens the canopy and encourages new productive growth (Marucci, 1987). Pruning also has the potential benefit of breaking apical dominance. The removal of apical dominance would allow lateral buds to grow (Roper et al., 1993). This results in an increase of new uprights that have to potential of fruiting the following year.

Chambers (1918) performed pruning experiments on a heavily vined bog that had been steadily declining in production. He noticed a 10% decrease in yield in the initial year followed by a 45% increase in the following year. The initial loss is likely due to the unavoidable removal of existing fruiting uprights. However, the increase in yield for the second year may be the result of the removal of apical dominance and increased light penetration in the first year, which is critical for flower bud formation (Roper et al., 1993). Strik and Poole (1991 and 1992) also evaluated the effectiveness of pruning on yield. They showed that light, medium, and heavy treatments had reduced yields in the years of treatment. Light treatments had a significantly greater yield than the control in the year following treatments while medium and heavy treatments were had lower yields than the control.

Sanding and pruning have shown the potential to be beneficial for excessively vegetative bogs. Each treatment is capable of increasing new upright growth and providing the benefits associated with a less dense canopy. However, sanding has a couple drawbacks when compared to pruning. Two of these drawbacks are the increasing price of sand and the non-uniformity of sand deposition (Hunsberger et al., 2006). Since pruning appears to accomplish the same horticultural goals as sanding without the cost and uniformity drawbacks, it may be used as a replacement or supplement to sanding. However, these two practices have not been compared directly within the same cranberry bog. The objective of this study was to directly compare pruning and sanding treatments on ‘Stevens’ cranberry to determine effects on crop yield and canopy microclimate.

Materials and Methods

Experimental design: This study was conducted at Rocky Pond Bog, a commercial ‘Stevens’ cranberry bog in Myles Standish State Forest, North Carver, MA (lat. 41° 53’ 09.74’’N, long. 70° 41’ 55.23’’W). The experimental design consisted of a randomized complete block design of sanding vs. pruning, with four levels of each practice including a control, replicated 4 times (Figure 1).

The sanding treatments were performed on 14 April 2006 using coarse sand, mined on-site. A commercial sander, a small self-propelled vehicle with a hopper and a drop spreader, was used for on-vine sanding. The sander was calibrated to deliver a depth of 1.5 cm on each pass. The levels of sanding were determined by the number of times the sander passed over the plot: control (0 passes), light (1 pass), moderate (2 passes), and heavy (3 passes). Based on the width of the sander, each sanding plot was 2.4 m wide. Plots were 7.6 m long (Figure 1).

The pruning treatments were performed on 17 April 2006 using a commercial pruner, a small, self-propelled, mechanical knife-rake pruner with revolving blades. A rake mounted on the back of the pruner collected the prunings. As with the sanding, the levels of pruning were determined by the number of times the pruner passed over the plots. The pruner passed over the light pruning plots once, moderate plots twice, heavy plots three times, and did not prune the control plots. Again, plot width was set to the width of the machine, 1.8 m. Plot length was the same as that in the sanding plots (Figure 1). Light pruning removed the equivalent of 443 $kg \bullet ha^{-1}$.

Upright Density, Leaf Area, and Dry Weight: A 15.2 cm diameter ring (182 cm^2) was placed randomly in each plot on June 2, 2006 and again on June 4, 2007. All plant material originating from within the ring was removed. This sampling was repeated twice in each plot. The excised plant material from each ring was evaluated as follows. The uprights were removed at the origin and counted to determine density. The leaves were removed, and leaf area was measured using a LI-3100 Leaf Area Meter (Li-Cor Inc., Lincoln, NE). The leaves and uprights were then dried at 70° C for 10 days and weighed along with the non-upright material.

Light Penetration: Light penetration into the cranberry canopy was measured in the second week of July and the third week of August in 2006 and 2007 using an Accupar linear PAR/LAI ceptometer (model PAR-80, Decagon Devices, Inc, Pullman, WA). An external, unobstructed sensor was also employed to determine the ratio of below-canopy light to above-canopy light (Tau). The ceptometer was placed under the canopy in a south-west direction at four randomly selected locations in each plot; hence 32 readings were taken in each block. Readings were only taken from Blocks 1 and 2 due to weather, time restrictions, availability of the ceptometer, and equipment malfunctions.

Leaf Wetness: Leaf wetness was approximated and recorded at 0.5 h intervals using HOBO® Micro Station Data Loggers and Leaf Wetness Smart Sensors (Onset Computers, Bourne, MA). Based on field observations, the dry/wet threshold was set at 20%. Data were collected for four weeks in each year. Block 1 was monitored in the first week of July 2006, and Block 2 in the second week of July 2006. Using these data, the average of number of dry hours per week in early July was determined. Sensors were redeployed similarly in the third and fourth weeks of August, and the average number of dry hours per week in late August was calculated. The procedure was repeated in 2007.

Spray Penetration: TeeJet (Wheaton, IL) water sensitive papers were used to measure spray penetration through the canopy. The papers were placed at the base of the uprights and mid-way between the base and tips of the uprights. A mock-chemigation event was then performed using timings as for an insecticide application. The papers were allowed to dry, collected and brought back to the lab for evaluation. Penetration was evaluated as the percent surface area of the paper that changed color in response to water.

Berry Yield / Marketable Yield: In 2006 and 2007, berry yield was estimated using a 929 cm^2 square randomly placed within each plot. Two subsamples were taken from each plot and the data from the subsamples were averaged. All berries were picked from within the 929 cm^2 square and all viable berries were weighed. Average berry weight was also evaluated using sub-samples from each plot. In 2007, non-marketable berries were counted (i.e. berries deemed too small, rotten, or insect-damaged) to allow a calculation of marketability percentage.

Fruiting uprights (U_f) / total upright (U_t) Ratio: In each plot, random samples of approximately 25 uprights were collected, counted, and evaluated as fruiting (presence of fruit or persistent pedicels) or non-fruiting. The ratio of fruiting uprights (U_f) to total uprights (U_t) was then calculated.

TAcy (total anthocyanin concentration): Total anthocyanin concentration (mg per 100 g fresh mass) in cranberry fruit samples was determined with a modification of the protocol of Fuleki and Francis (1968) using an acidifed aqueous extractant (0.2N HCl).

Economic Analysis: The costs of treatments were assigned based on information provided by two commercial cranberry growers (R. Gilmore, A.D. Makepeace Company and M. Beaton, Sure-Cran services, Inc., personal communication) as well as the current cost of sand, \$16 per m^3 including delivery (Cape Cod Cranberry Growers Association). The price of cranberries that was used (\$43.40 per 45 kg barrel) was the blended return to growers (fresh and processed fruit) in Massachusetts in 2007 (NASS, 2008).

Data Analysis: Analysis of variance was conducted on all data using the Proc GLM procedure in SAS (SAS Institute, Cary, N.C.). Linear and quadratic trends were evaluated.

Results and Discussion:

Pruning appeared to have no affect on upright density in 2006, whereas sanding had a quadratic effect (Fig 2A). The lack of a pruning effect is consistent with the results of Strik and Poole (1991) and may be the result of high variability in upright number across the bog. They reported that pruning had no significant effect on the total number of uprights in the year of treatment. There was a significant difference between sanding and pruning effects on upright density. This discrepancy is likely the result of the heavy sanding treatments burying and weighing down young uprights. The year after treatment, 2007, there was a significant increase in the total number of uprights for all treatments including the control (Fig 2B). A significant interaction between treatment and intensity was seen. As was the case in previous pruning research (Strik and Poole 1992), the total number of uprights seemed unaffected by the pruning treatments. There continued to be a significant quadratic effect in the sanding treatments with the heavy sanding treatments continuing to lag behind the controls. Upright density in the lowest intensity (light sanding or pruning) plots in 2007 was significantly greater than that in the controls when the data were analyzed together (data not shown). This indicates a possible stimulation effect by a light pruning or sanding treatments.

Total upright dry weight decreased linearly for sanding in the first year as severity increased whereas pruning showed a quadratic effect (Fig 3A). Heavy sanding had the lowest dry weight, followed by moderate sanding. There were no significant trends in the second year (Fig 3B). There was a significant quadratic effect in the first year for total upright leaf area in both sanding and pruning (Fig 4A). The light treatments seemed to have a stimulating effect in total leaf area whereas heavy treatments (sanding in particular) inhibited leaf area. This trend continued in the second year for sanding only (Fig 4B). When leaf area per upright was analyzed, there was a significant negative linear trend in the first year for sanding (Fig 5A). This trend has potential negative effects on net photosynthetic activity for heavily sanded areas in the year of treatment. The following year showed no significant trends (Fig 5B).

Three months after treatment (July 2006), light penetration (Tau) into the canopy was greater in the sanding treatments than in the pruned plots (Fig 6A). Light penetration increased linearly in both sanded and pruned plots as treatment severity increased. Light penetration in July is important since this is when flower bud formation occurs for the following year's crop (Roper et al., 1993). The linear relationship between light penetration and treatment severity continued for sanding into late August 2006 but by that time, differences among pruning intensities were no longer significant (Fig 6B). The recovery of the canopy was evidenced by the decrease in light penetration as time progressed (Fig 6 A-D). The light penetration continued to decrease in the second year and normalized across treatment and severity.

In July of 2006, pruning plots showed a linear trend for increasing average number of dry hours per week with increasing pruning severity (Fig 7A). There was no such effect in the sanding plots. These trends continued in August of the same year (Fig 7B). This has possible consequences for disease management since a drier microenvironment is less favorable to fungal disease (Oudemans et al., 1998). As was the case with light penetration, canopy wetness in all treatments and intensities was similar by July 2007 (Fig 7C) and continued through August 2007 (Fig 7D).

Spray penetration into the canopy was also evaluated using water sensitive papers. In a simulated chemigation event, there was complete spray penetration of the canopy in every plot (data not shown). This has important ramifications for pest and disease control. Results might have been different on a bog with a denser vine canopy. Rocky Pond Bog was not considered to be an overly vegetative bog.

The ratio of fruiting uprights to total uprights was affected as severity increased for both sanding and pruning in the year of treatment (Fig 8A). As treatment severity increased, the relative number of U_f decreased. Strik and Poole (1991) showed this same trend in their pruned plots in the year of treatment. In the second year, the negative linear trend with pruning intensity was eliminated (Fig 8B). The negative trend did, however, continue for the sanding plots.

Pruning plots had higher yields than sanding plots in the year of treatment (Fig 9A). Light pruning had the greatest yield, followed by light sanding, while heavy sanding had the worst. Sanding had a significant negative linear trend with increasing intensity whereas the differences among pruning plots were not significant. However, heavy pruning was associated with the lowest mean yield among the pruning treatments. Yield effects of pruning and sanding in the year of treatment were similar to those in Oregon (Strik and Poole 1991 and 1995). In a study of barge sanding in New Jersey (Davenport and Schiffhauer, 2000), yield reduction was associated with the application of 2.5 cm of sand – equivalent to the moderate level in this study. The negative impact of heavy sanding is likely the result of the combined effect of a decreased upright density along with a decreased U_f/U_t ratio. Previous studies of cranberry yield components have identified percent flowering uprights as a critical determinant of yield (Eaton and Kyte, 1978). Yield decreased across all treatments and severities in the second year (Fig 9B). The significant negative linear trend for sanding treatments continued in 2007. Once again, heavier sanding had the lowest yield, and those plots remained lowest in upright density and U_f/U_t ratio. Analyzing the 2006 and 2007 data on a cumulative basis removed the significant negative trends, but moderate and heavy sanding had the second to lowest and lowest yield respectively (Fig 9C). The interaction between treatment and severity was non-significant. No treatment had any effect on average fruit weight or percent marketable yield (data not shown).

In 2006, there was a significant positive linear effect of pruning intensity on anthocyanin concentration while sanding intensities showed no significant effect (Fig 10A). The linear increase in light penetration into the canopy (Fig 6A) is likely responsible for the linear increase in anthocyanin concentration in the pruning treatment (Strik and Poole, 1991 and 1992). Based on canopy effects, increase in anthocyanin was expected for the sanding treatment, but was not found. However, ANOVA of the combined data showed no difference between sanding and pruning. In the following year there were no significant trends in fruit anthocyanin for either sanding or pruning treatments possibly due to the recovery of the canopy.

In order to facilitate economic cost/benefit analysis for the treatments, calculated yield (Fig. 9) was converted to Mg per hectare and given a value based on the NASS (2008) mixed value of $43.40 for cranberries per 45.36 kg barrel in 2007 (Table 1). As previously stated, the highest yield in the year of treatment was associated with the light pruning treatment followed by the light sanding treatment. All other severity levels were associated with lower yield than that in control plots. This trend continued into the second year. However, in the year after treatment the lightly pruned and lightly sanded treatments had similar yield.

Massachusetts cranberry growers provided cost information for the two practices and production cost (M. Beaton, R. Gilmore and G Rogers, personal communication, Table 2). After accounting for the cost of the sanding or pruning and the production cost per hectare ($7907 in 2006 and $8154 in 2007), the light intensity of either practice provided the greatest net return for each year. Based on the greater return with light pruning in the first year, this practice gave the greatest net return for the two year period despite the equivalent return for the two practices in the second year. Light pruning resulted in a $43,973 2-year net return per hectare whereas light sanding yielded a $35,146 net return (Table 2). Based on this data, an alternate year pruning regimen could potentially increase returns, on average, as much as $4000 per year when compared to a sanding regimen of every 4 years. Heavy sanding was the only treatment and severity combination that resulted in a net loss in return, as was the case in 2006 and 2007. Sanding intensity showed a significant negative linear trend in 2006, 2007, and the 2-year cumulative return (Fig. 11). No such significant relationship existed for pruning intensities. Pruning had a significantly higher return than sanding in 2006 and cumulatively for the 2 years.

Light (a single pass with a pruner or 1.5 cm of sand) pruning or sanding can be a useful tool for canopy management. Both practices can facilitate light penetration and canopy dryness. More importantly, the light severity treatments had a positive effect on yield over controls. After factoring in the cost of each practice, the net return of light pruning or sanding was still greater than that in the controls. Sanding does have an increased risk over pruning in that the practice itself is more expensive and there is a greater negative impact on yield if the treatments are heavier. At each level of intensity, pruning had a higher yield than sanding in the first year. Heavy pruning treatments were largely able to recover after the first year, whereas heavy sanding treatments still had detrimental effects on yield in the second year. This is important to remember since the pest management benefits of sanding are only effective with the equivalent of the moderate or heavy treatments in this study (Sandler, et al., 1997). The prolonged decrease in yield may make sanding an impractical option as a pest control method. Due to the potential benefits of light pruning and the reduced risk associated with over treatment, pruning may be a viable option for growers as a replacement or, more likely, a supplement to sanding.

Table 1: Calculated yield for sanding and pruning treatments in 'Stevens' cranberry. Values calculated from fruit sample data (Figure 6). Cranberry payments are based on 100 lb (45.36 kg) barrels.

Treatment	Severity	2006 $Mg \cdot ha^{-1}$	2006 $Value \cdot ha^{-1}$	2007 $Mg \cdot ha^{-1}$	2007 $Value \cdot ha^{-1}$
Pruning	Control	26.00	$24,876	18.61	$17,806
	Light	39.16	$37,472	24.04	$23,004
	Moderate	24.24	$23,191	15.73	$15,047
	Heavy	19.80	$18,945	17.24	$16,492
Sanding	Control	23.39	$22,379	22.59	$21,617
	Light	32.74	$31,329	24.11	$23,068
	Moderate	15.38	$14,718	11.45	$10,951
	Heavy	12.19	$11,665	6.76	$6,473

[z] Values given in U.S. dollars
[y] Values based on $43.40 per 45.36 kg barrel

Table 2: Cost vs. returns for 'Stevens' cranberry in the year of pruning or sanding treatment and the year following treatment. Calculations based on yield data from Table 1 and treatment costs and production costs provided by commercial cranberry growers (M. Beaton , R. Gilmore, and G. Rogers, personal communication).

Treatment	Severity	Treatment cost•ha^{-1}	2006 net return•ha^{-1} [w]	2007 net return•ha^{-1} [v]	2 year net return•ha^{-1}
Pruning	Control	$0	$16,969	$9,652	$26,620
	Light	$442	$29,123	$14,850	$43,973
	Moderate	$885	$14,399	$6,893	$21,292
	Heavy	$1,327	$9,711	$8,338	$18,048
Sanding	Control	$0	$14,472	$13,463	$27,935
	Light	$3,190	$20,232	$14,914	$35,146
	Moderate	$5,965	$846	$2,797	$3,643
	Heavy	$8,734	-$4,977	-$1,681	-$6,658

[z] Cost and returns given in U.S. dollars
[y] Costs of treatments based on values provided by commercial cranberry growers and $16•m^{-3} sand
[x] Values based on $43.40 per 45.36 kg barrel
[w] 2006 return after treatment costs and production cost ($7907•ha^{-1} in 2006)
[v] 2007 return after production cost ($8154•ha^{-1} in 2007)

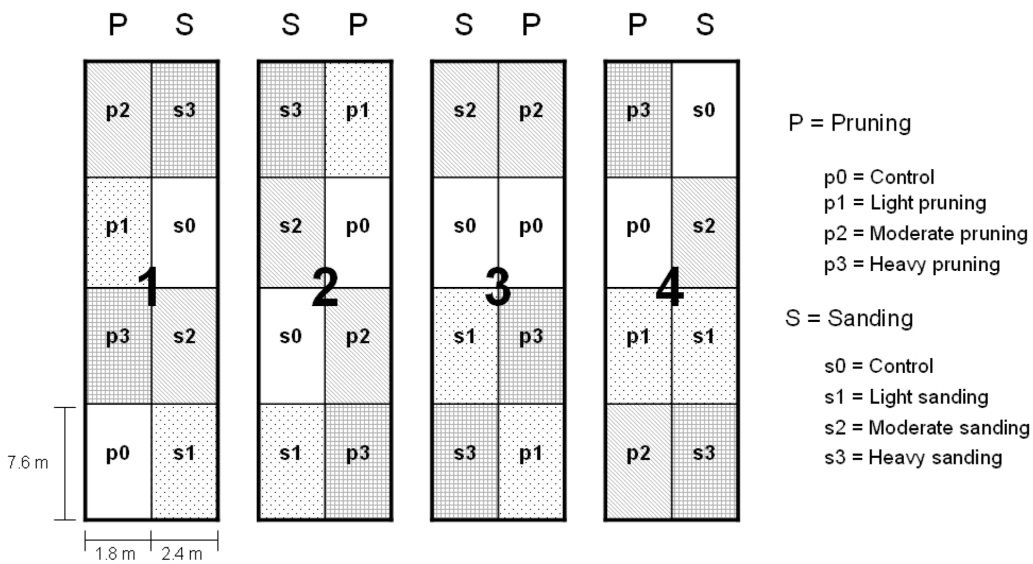

Figure 1: Randomized complete block design of sanding vs. pruning

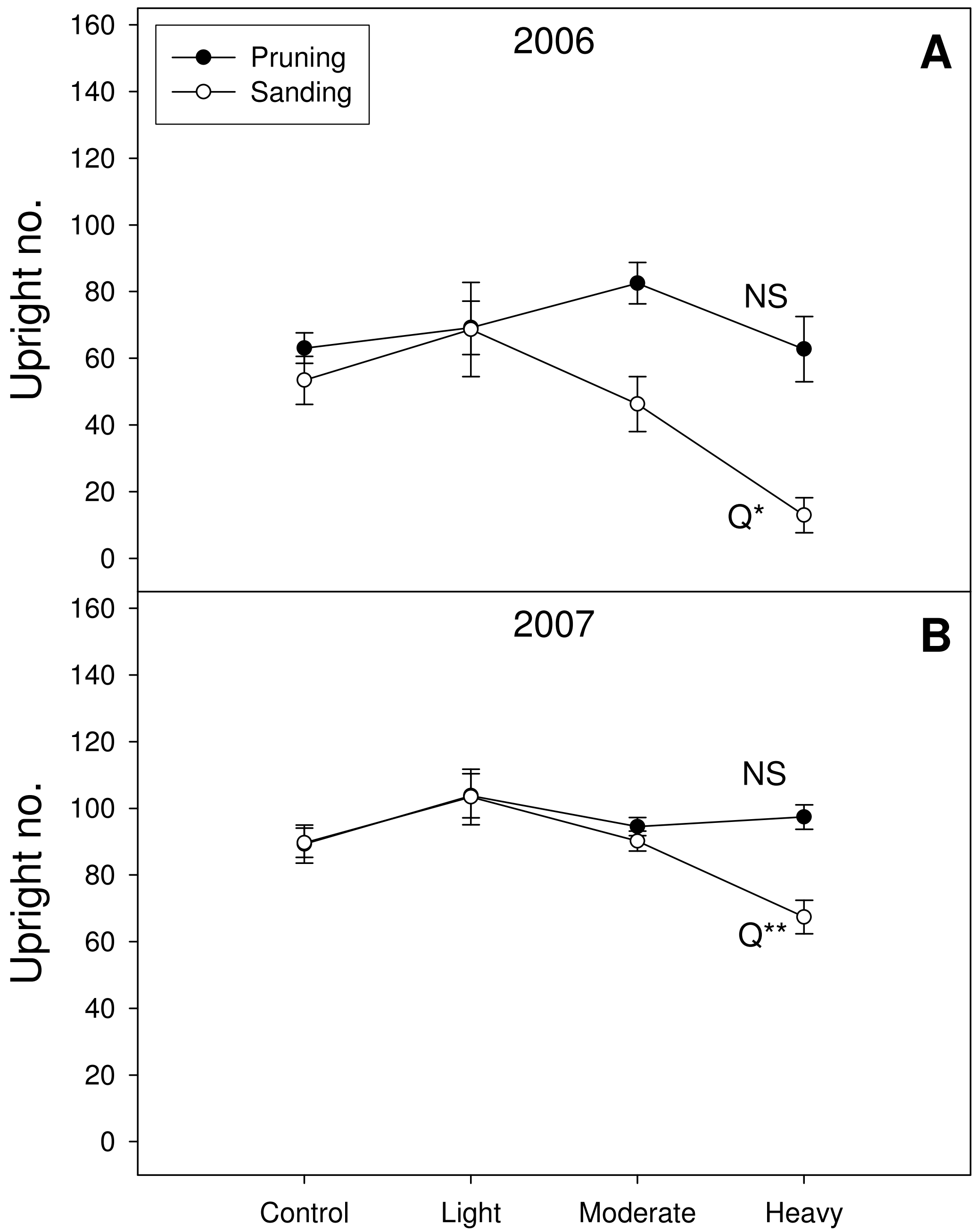

Figure 2: The effect of sanding and pruning intensities in April 2006 on canopy density in 'Stevens' cranberry in (**A**) June 2006, (**B**) June 2007. SE is represented by vertical bars. Number of uprights per 182 cm^2 area. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for quadratic (Q) effects.

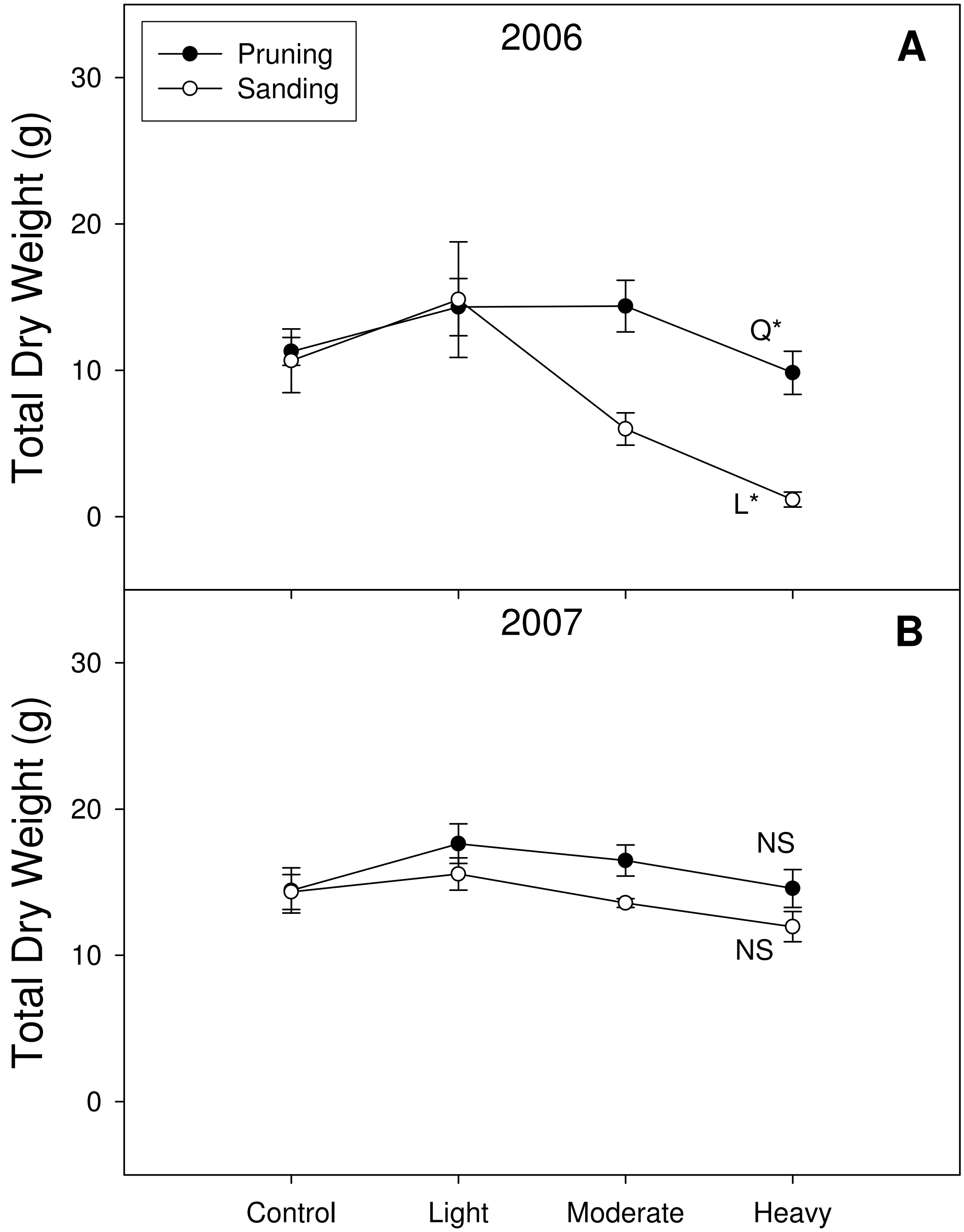

Figure 3: The effect of sanding and pruning intensities in April 2006 on total dry weight in 'Stevens' cranberry in (**A**) June 2006, (**B**) June 2007. SE is represented by vertical bars. Total dry weight per 182 cm^2 area. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) and quadratic (Q) effects.

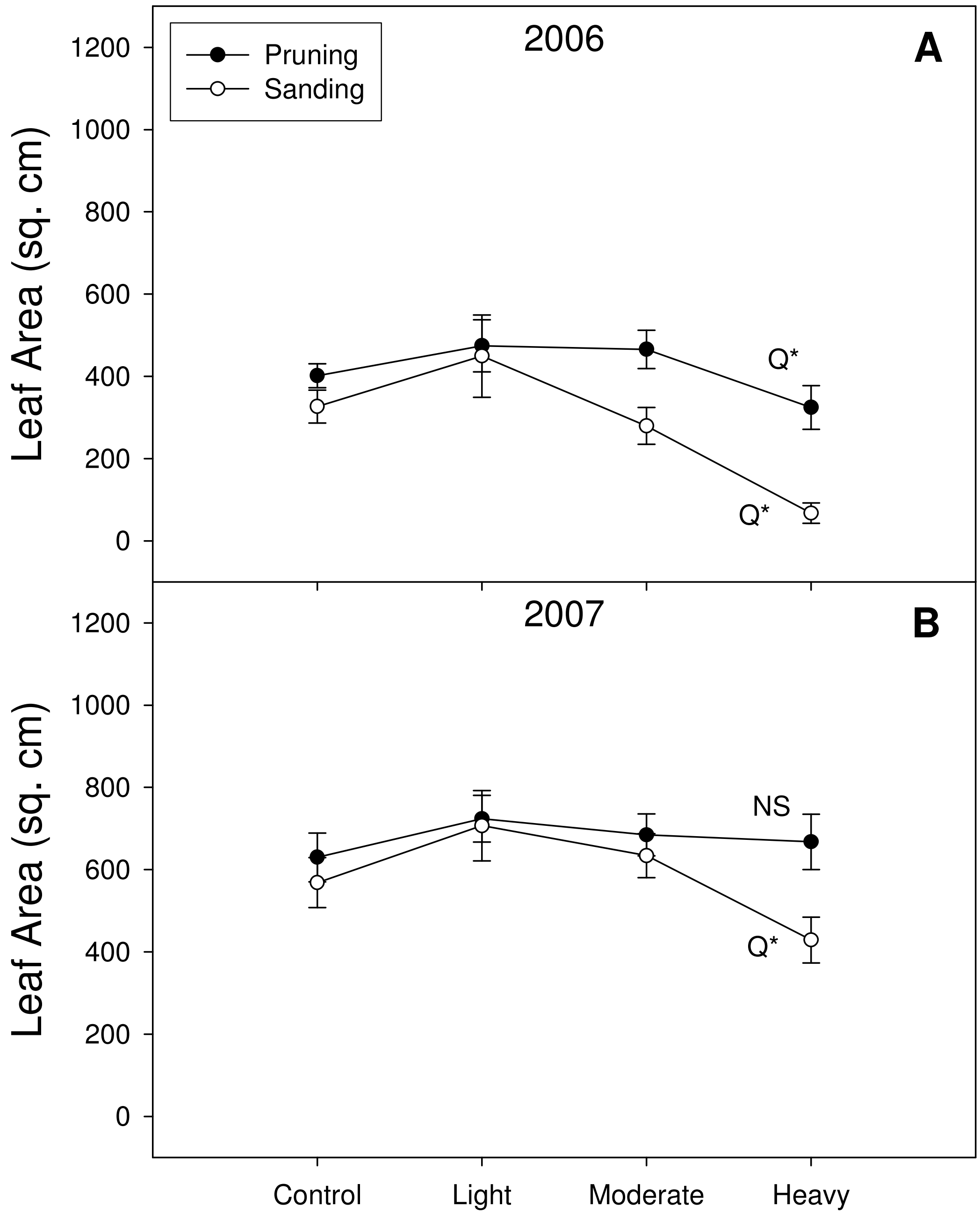

Figure 4: The effect of sanding and pruning intensities in April 2006 on total leaf area in 'Stevens' cranberry in (**A**) June 2006, (**B**) June 2007. SE is represented by vertical bars. Total leaf area per 182 cm^2 area. $^{NS, *, **}$Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for quadratic (Q) effects.

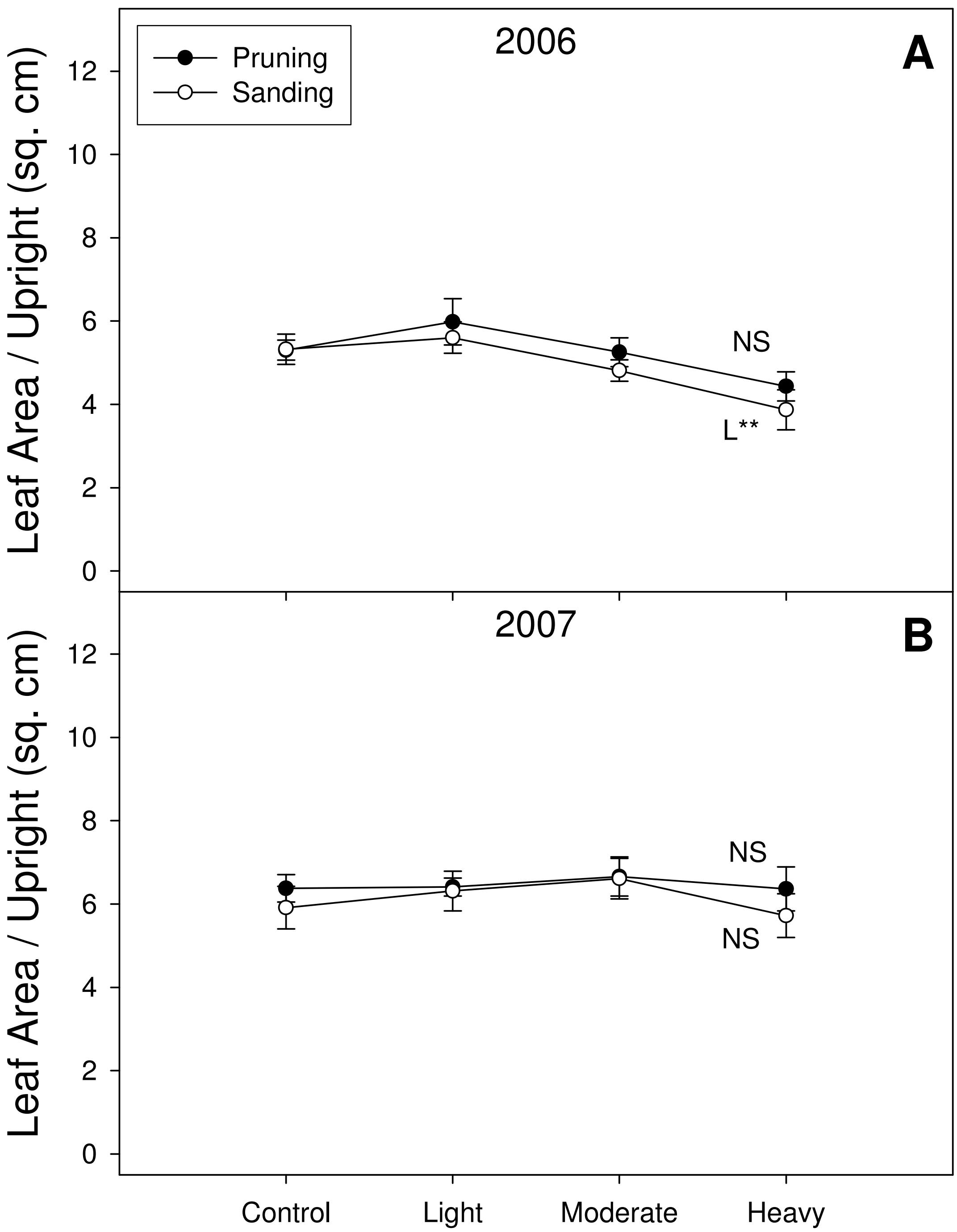

Figure 5: The effect of sanding and pruning intensities in April 2006 on leaf area per upright in 'Stevens' cranberry in (**A**) June 2006, (**B**) June 2007. SE is represented by vertical bars. Number of uprights per 182 cm^2 area. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects

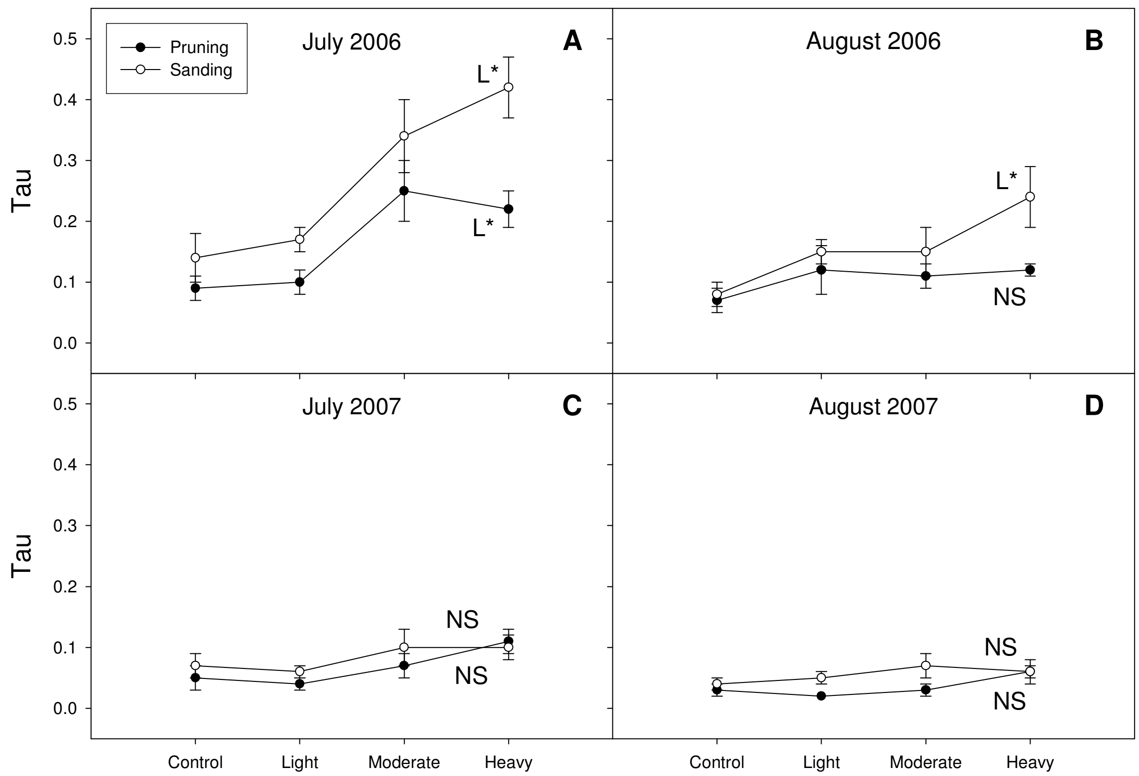

Figure 6: The effect of sanding and pruning intensities in April 2006 on light penetration into the canopy in 'Stevens' cranberry in (**A**) July 2006 (**B**) August 2006 (**C**) July 2007 (**D**) August 2007. SE is represented by vertical bars. Tau = below canopy light reading / above canopy light reading. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

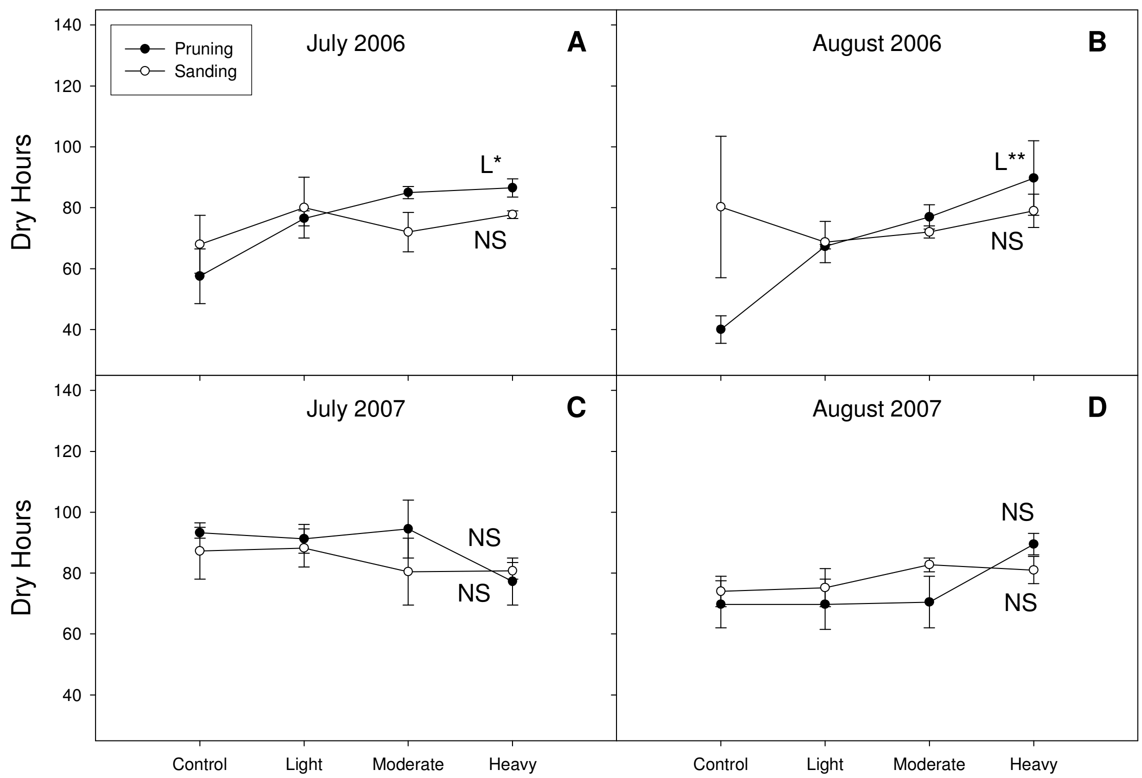

Figure 7: The effect of sanding and pruning intensities in April 2006 on leaf wetness in 'Stevens' cranberry. Dry hours in (**A**) July 2006 **B**) August 2006 (**C**) July 2007 (**D**) August 2007. SE is represented by vertical bars. Dry Hours = the average number of hours per week that leaf wetness sensors recorded less than 20% moisture. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

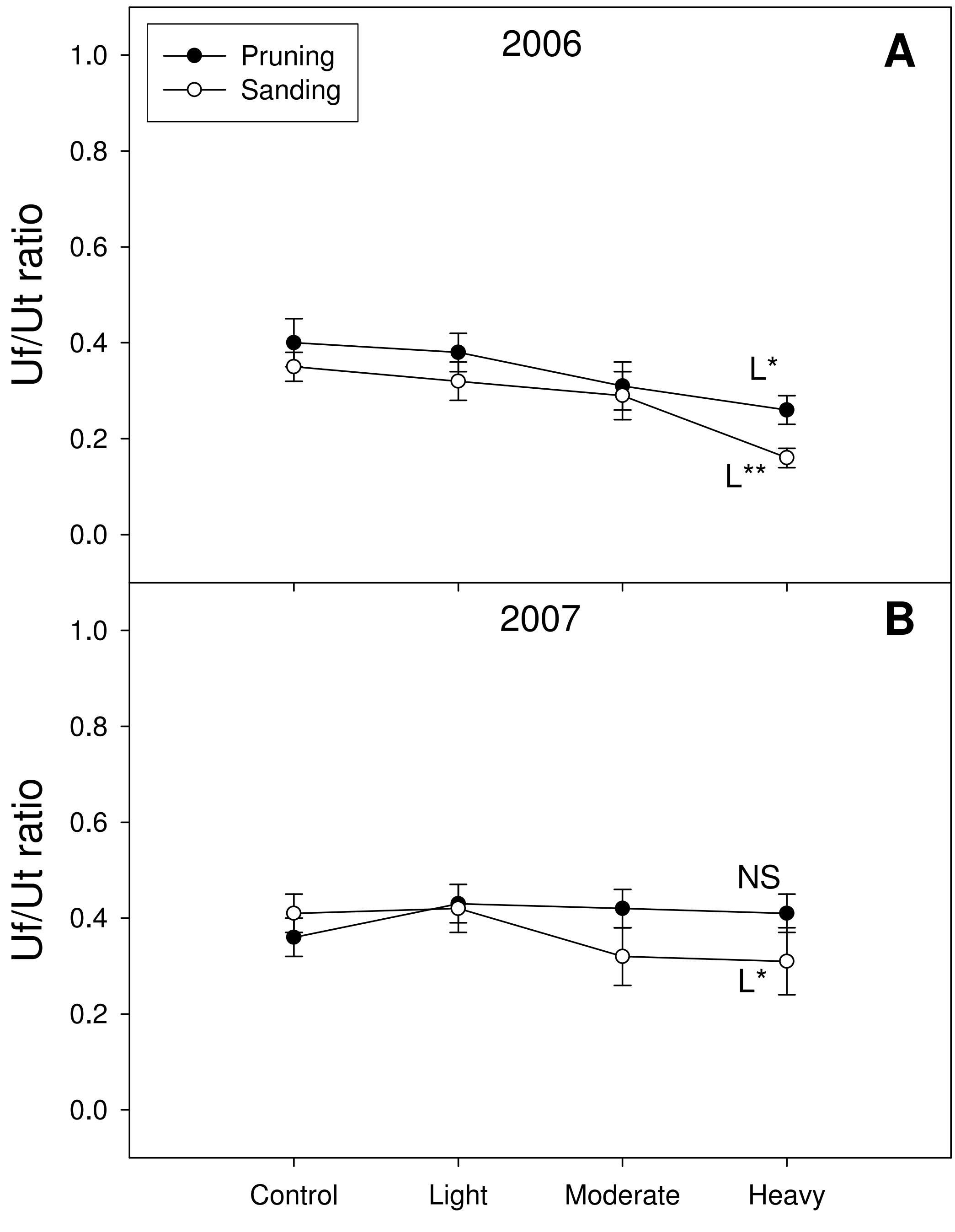

Figure 8: The effect of sanding and pruning intensities in April 2006 on the fruiting upright / total upright ratio (U_f / U_t) in (**A**) 2006 (**B**) 2007. SE is represented by vertical bars. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

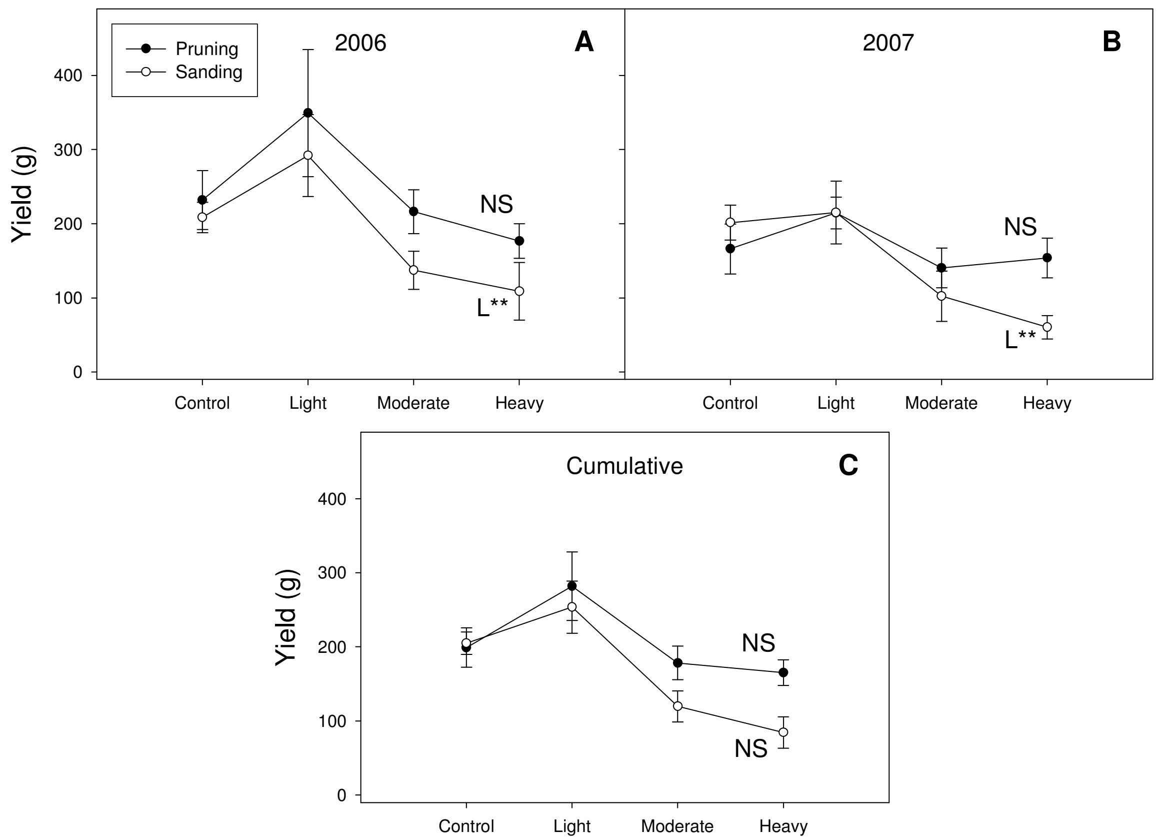

Figure 9: The effect of sanding and pruning intensities in April 2006 on yield in 'Stevens' cranberry for (**A**) 2006 (**B**) 2007 (**C**) 2006 and 2007 (cumulative average yield). SE is represented by vertical bars. Yield = berry weight (g) per 182 cm^2. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects

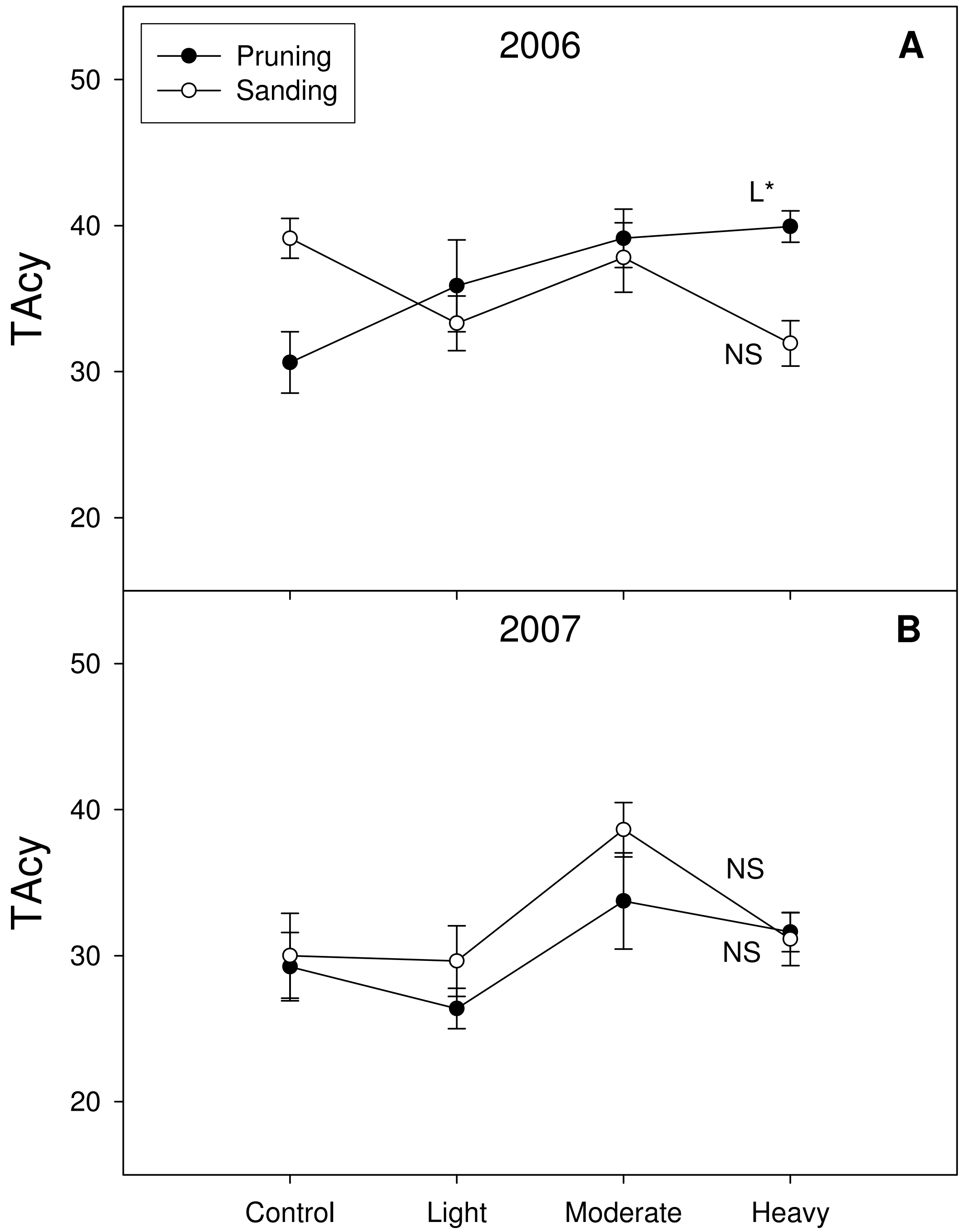

Figure 10: The effect of sanding and pruning intensities in April 2006 on total anthocyanin content (TAcy) in 'Stevens' cranberry fruit for (**A**) 2006 (**B**) 2007. SE is represented by vertical bars. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

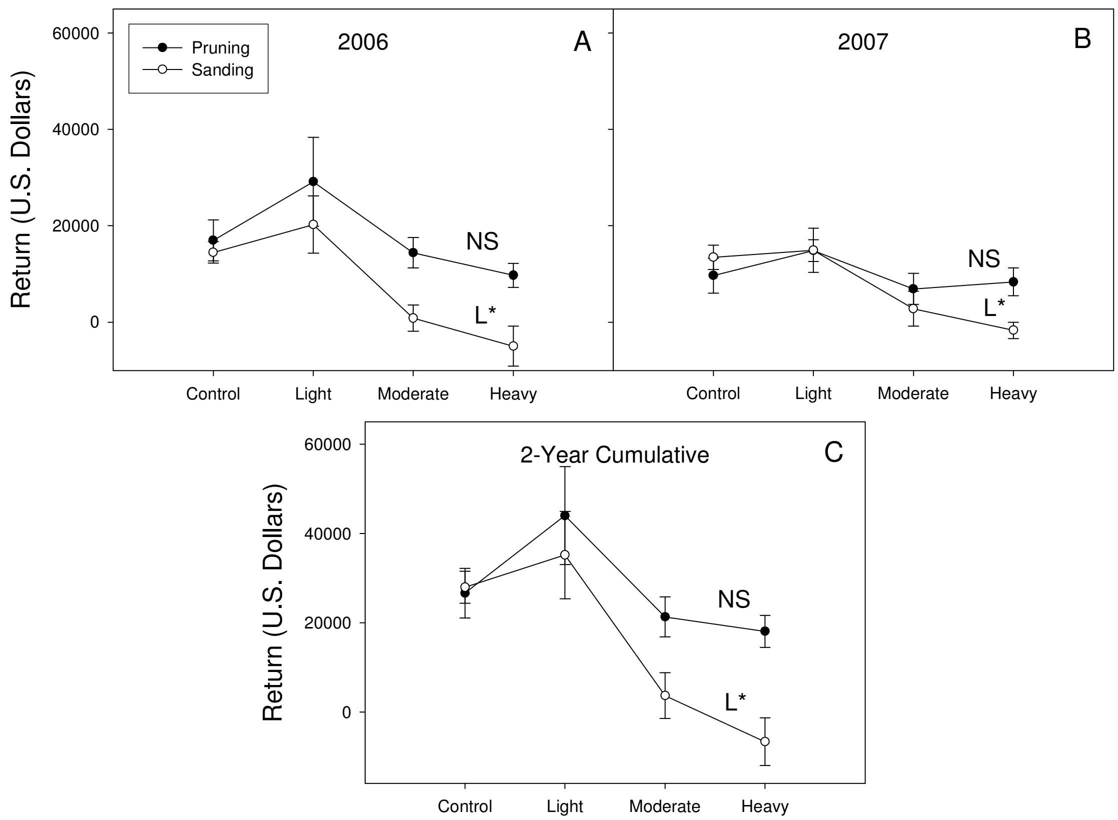

Figure 11: Net returns on ‘Stevens’ cranberry harvest. SE is represented by vertical bars. Returns as seen in Table 2. Returns in (**A**) 2006 (**B**) 2007 (**C**) 2006 and 2007 (cumulative return). [NS, *, **] Nonsignificant and significant at P = 0.05 and P = 0.01 for linear (L) effects.

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APPENDIX

Appendix

Table 3: Sanding vs. Pruning differences in canopy density and microclimate in 2006 and 2007 in 'Stevens' cranberry. Data for all intensities combined.

Year	Treatment	Upright No. [z]	Light Pen. (Tao) [y]		Leaf Wetness (Dry Hrs.) [x]	
			July	August	July	August
2006	Pruning	69 a	0.16 a	0.10 b	76.38	68.50
	Sanding	45 b	0.27 b	0.15 a	74.44	75.00
2007	Pruning	96 a	0.07	0.04	89.06	74.88
	Sanding	88 b	0.08	0.05	84.19	78.25
2006 - 2007 average	Pruning	83	0.09		77.20	
	Sanding	66	0.14		77.97	

[z] Sample area = 182 cm^2
[y] Tao = Below Canopy Light Intensity / Above Canopy Light Intensity
[x] Hours under 20% moisture per week
[w] Mean separations within columns and year by Duncan New Multiple Range Test, P = 0.05

Table 4: Treatment intensity differences in canopy density and microclimate in 2006 and 2007 in 'Stevens' cranberry. Sanding and pruning treatment data combined.

Year	Intensity	Upright No. ^{z}	Light Pen. (Tao) ^{y}		Leaf Wetness (Dry Hrs.) ^{x}	
			July	August	July	August
2006	Control	58 a	0.11 b	0.07 b	62.75 b	60.13 b
	Light	69 a	0.14 b	0.14 ab	78.25 ab	68.00 ab
	Moderate	64 a	0.29 a	0.13 ab	78.50 ab	74.50 ab
	Heavy	38 b	0.32 a	0.18 a	82.13 a	84.38 a
2007	Control	89 bc	0.06 b	0.03 b	90.25	71.88 b
	Light	104 a	0.05 b	0.04 ab	89.75	72.50 b
	Moderate	92 b	0.08 ab	0.05 ab	87.50	76.63 ab
	Heavy	82 c	0.11 a	0.06 a	79.00	85.25 a
2006 - 2007 average	Control	74 a	0.07 b		71.25	
	Light	86 a	0.09 ab		77.13	
	Moderate	78 a	0.14 ab		79.28	
	Heavy	60 b	0.17 a		82.69	

[z] Sample area = 182 cm^2
[y] Tao = Below Canopy Light Intensity / Above Canopy Light Intensity
[x] Hours under 20% moisture per week
[w] Mean separations within columns and year by Duncan New Multiple Range Test, P = 0.05

Table 5: The change in light penetration and leaf wetness over the course of 2006 and 2007 in 'Stevens' cranberry. Treatment and intensity data combined.

Date	Light Pen. (Tao) [z]	Leaf Wetness (Dry Hrs.) [y]
July 2006	0.22 a	75.41
August 2006	0.13 b	71.75
July 2007	0.07 c	86.63
August 2007	0.04 d	76.56

[z] Tao = Below Canopy Light Intensity / Above Canopy Light Intensity
[y] Hours under 20% moisture per week
[x] Mean separations within columns and year by Duncan New Multiple Range Test, P = 0.05

Table 6: The effect of sanding vs. pruning on yield, fruiting upright to total upright ratio, and total anthocyanin concentration (TAcy) in 'Stevens' cranberry over two growing seasons. Data for all intensities combined.

Year	Treatment	Yield [z]	Fruiting Uprights (U_f / U_t) [y]	TAcy [x]
2006	Pruning	243.55 a	0.34 a	36
	Sanding	186.09 b	0.28 b	36
2007	Pruning	168.65	0.40	30
	Sanding	144.78	0.36	32
2006 - 2007 average	Pruning	206.10	0.37	33
	Sanding	165.73	0.32	34

[z] Yield = g / 929 cm^2
[y] U_f / U_t = Number of fruiting uprights / total number of uprights
[x] TAcy = Total anthocyanin concentration
[w] Mean separations within columns and year by Duncan New Multiple Range Test, P = 0.05

Table 7: Intensity of treatments affect yield, ratio of fruiting uprights to total uprights, and total anthocyanin concentration (TAcy) in 'Stevens' cranberry. Sanding and pruning treatment data combined.

Year	Intensity	Yield [z]	Fruiting Uprights (U_f / U_t) [y]	TAcy [x]
2006	Control	220.30 b	0.37 a	35
	Light	320.75 a	0.35 a	35
	Moderate	176.73 b	0.30 a	38
	Heavy	142.70 b	0.21 b	36
2007	Control	183.79 a	0.38	30 b
	Light	214.79 a	0.43	28 b
	Moderate	121.21 b	0.37	26 a
	Heavy	107.06 b	0.36	31 b
2006 - 2007 average	Control	202.05 ab	0.38 a	32 b
	Light	267.77 a	0.39 ab	31 b
	Moderate	148.97 b	0.33 b	37 a
	Heavy	124.88 b	0.28 c	34 ab

[z] Yield = g / 929 cm^2

[y] U_f / U_t = Number of fruiting uprights / total number of uprights

[x] TAcy = Total anthocyanin concentration

[w] Mean separations within columns and year by Duncan New Multiple Range Test, P = 0.05

Table 8: The difference in yield, ratio of fruiting uprights to total uprights, and total anthocyanin concentration (TAcy) over the course of two growing seasons after sanding and pruning treatments in 'Stevens' cranberry. Data from all treatments combined.

Year	Yield [z]	Fruiting Uprights (U_f / U_t) [y]	TAcy [x]
2006	215.12 a	0.31	36
2007	156.71 b	0.38	31

[z] Yield = g / 929 cm^2
[y] U_f / U_t = Number of fruiting uprights / total number of uprights
[x] TAcy = Total anthocyanin concentration
[w] Mean separations within columns and year by Duncan New Multiple Range Test, P = 0.05

Table 9: Cost calculations of pruning treatments based on values provided by commercial cranberry growers (M. Beaton and R. Gilmore, personal communication).

Treatment	Equipment/ Personnel	Cost•hr^{-1}	Cost•day^{-1}	Total (day)	Total•acre^{-1}	Total•ha^{-1}
Pruning						
(10 acre	Machine	$40 (8)	$320			
per day)	Buggy	$40 (8)	$320			
	Operator	$75 (8)	$600			
	Laborers	$14 (8) each	$560	10 acres/day		
				$1,800		
Light			x1	$1,800	$180	**$445**
Moderate			x2	$3,600	$360	**$890**
Heavy			x3	$5,400	$540	**$1,334**

Table 10: Cost calculation of sanding treatments based on values provided by commercial cranberry growers (M. Beaton and R. Gilmore, personal communication) and the cost of sand ($12/yd^3) (**A**) Cost of light sanding labor per day (7 acres) (**B**) Cost of light, moderate, and heavy sand labor based on light sanding figures (**C**) Cost of sand for sanding treatments (**D**) Total cost for treatment

A.

Treatment	Equipment/Personnel	Cost•hr^{-1}	Cost•day^{-1}	Total (day)
Sanding	Front-end loader	60 (8)	$480	
	3 Sanders	27.50 (8) each	$660	
	4 Laborers	30.50 (9) each	$1,098	
	Move-in charge	150	$150	7 acres/day
				$2,388

B.

	7 acres•day^{-1}	Total (day)	Total•acre^{-1}	Total•ha^{-1}
Light sanding	Cost x1	$2,388	$340	**$840**
Moderate Sanding	Cost x1.5	$3,582	$510	**$1,260**
Heavy Sanding	Cost x2	$4,776	$680	**$1,679**

C.

	Material	Ft. depth	ft^3 •acre^{-1}	yd^3	$12•yd^{-3}	Total•ha^{-1}
Light sanding	1.5 cm sand depth	0.04921	2143.59	79	$951	**2350**
Moderate Sanding	3.0 cm sand depth	0.09843	4287.61	159	$1,904	**4705**
Heavy Sanding	4.5 cm sand depth	0.1479	6429.46	238	$2,855	**7055**

D.

Treatment	Labor cost•ha^{-1}	Sand cost•ha^{-1}	Total cost•ha^{-1}
Light Sanding	$840	$2,350	**$3,190**
Moderate Sanding	$1,260	$4,705	**$5,965**
Heavy Sanding	$1,679	$7,055	**$8,734**

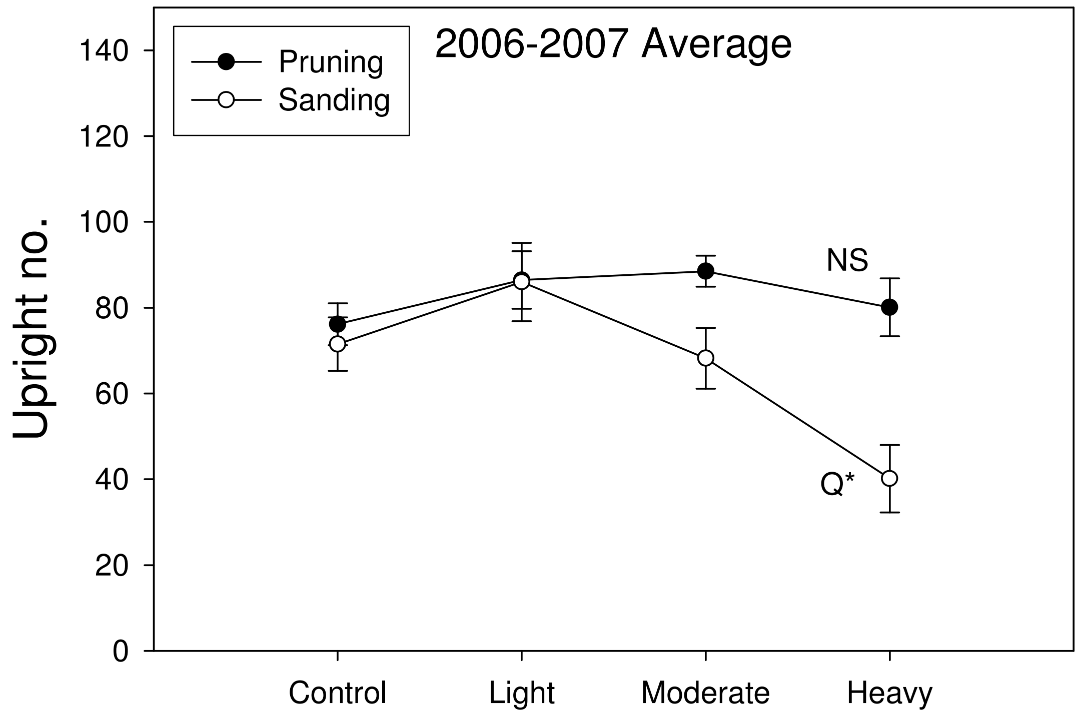

Figure 12: The effect of sanding and pruning intensities in April 2006 on canopy density in 'Stevens' cranberry averaged over 2006 and 2007. SE is represented by vertical bars. Number of uprights per 182 cm^2 area. $^{NS, *, **}$ Nonsignificant and significant at $P = 0.05$ and $P = 0.01$, respectively for quadratic (Q) effects

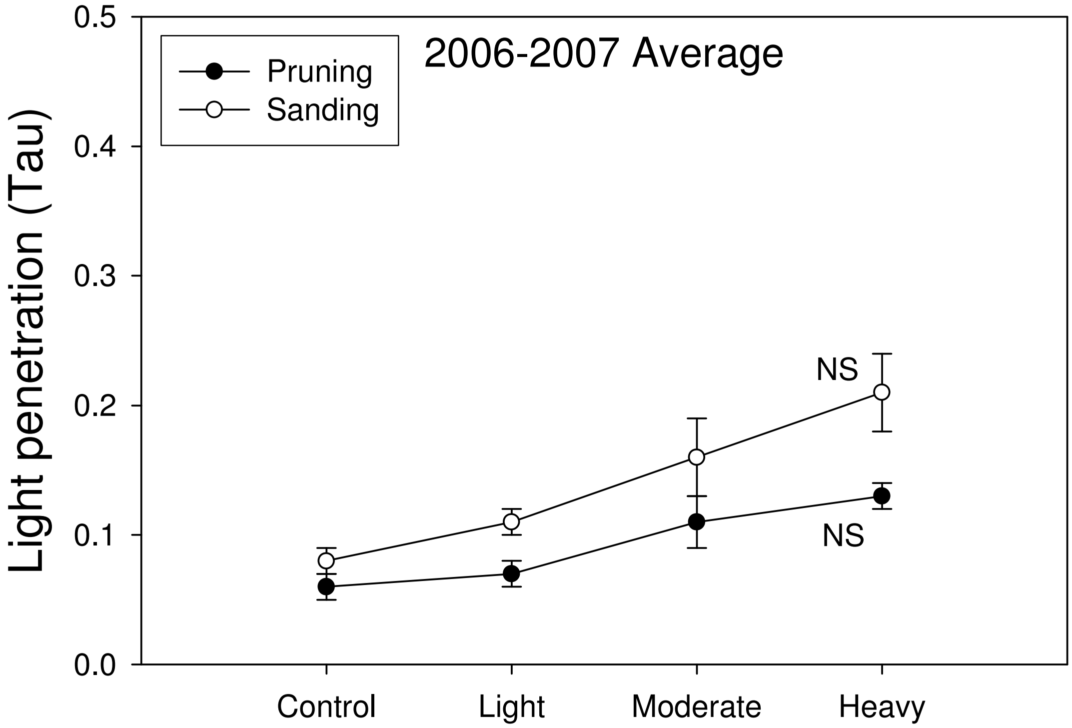

Figure 13: The effect of sanding and pruning intensities in April 2006 on light penetration (Tau) in ‘Stevens’ cranberry averaged over 2006 and 2007. SE is represented by vertical bars.

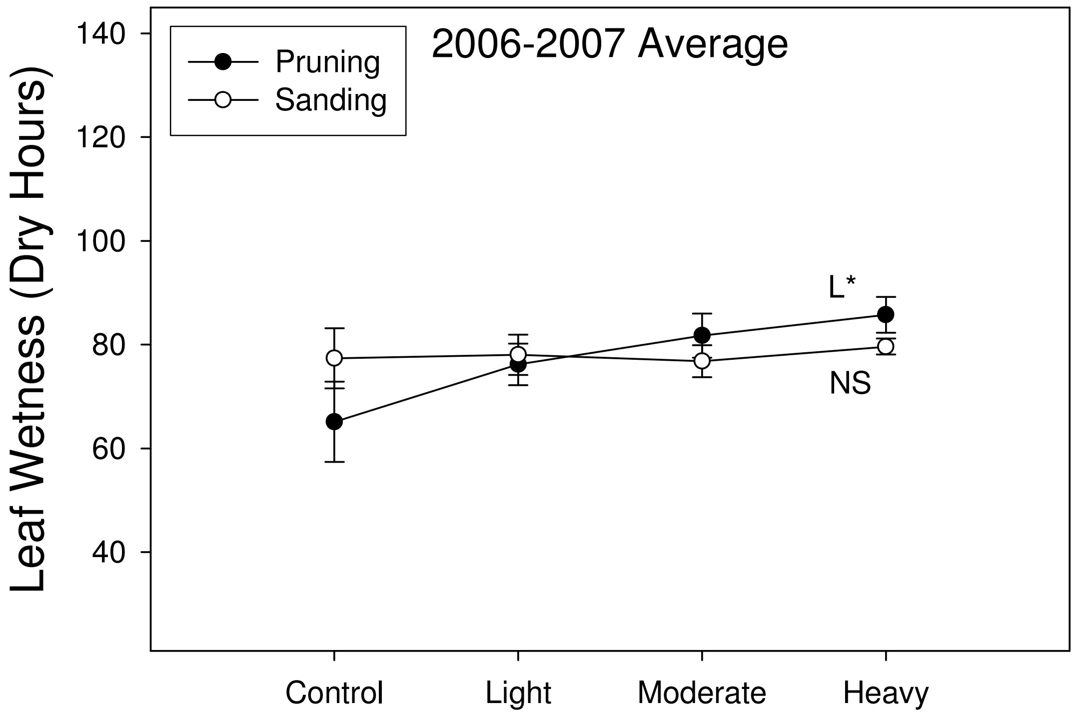

Figure 14: The effect of sanding and pruning intensities in April 2006 on leaf wetness in 'Stevens' cranberry. SE is represented by vertical bars. Dry Hours = the average number of hours per week that leaf wetness sensors recorded less than 20% moisture. Average dry hours for 2006-2007. NS, *, ** Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

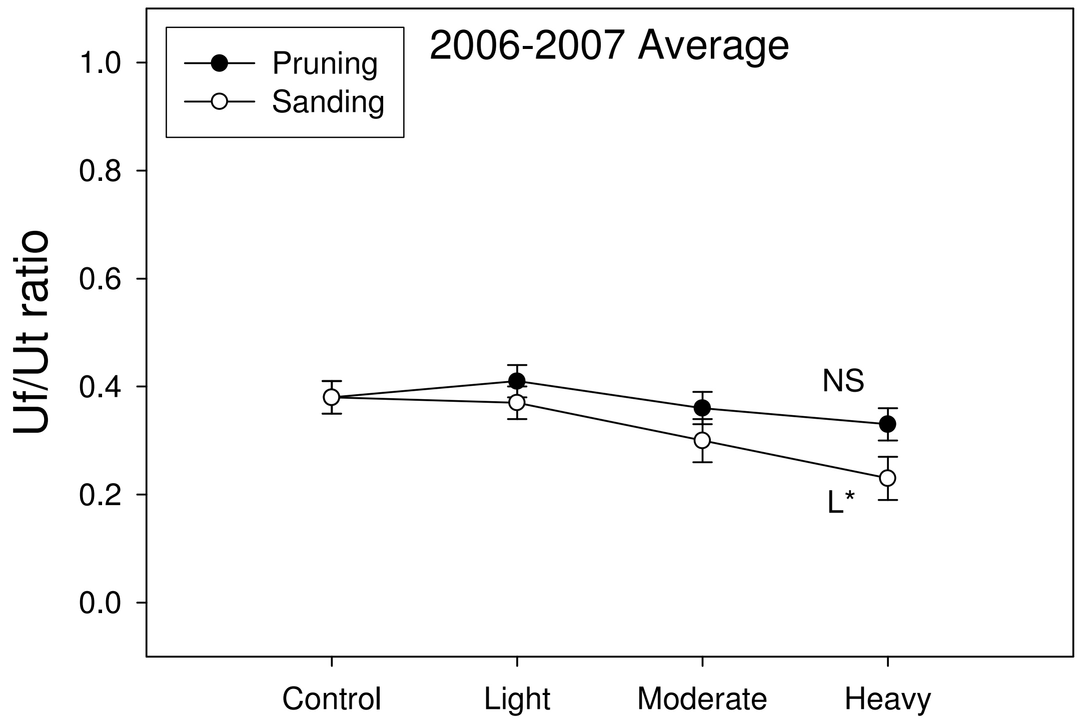

Figure 15: The effect of sanding and pruning intensities in April 2006 on the fruiting upright / total upright ratio (U_f / U_t). SE is represented by vertical bars. U_f / U_t ratio average for 2006-2007. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

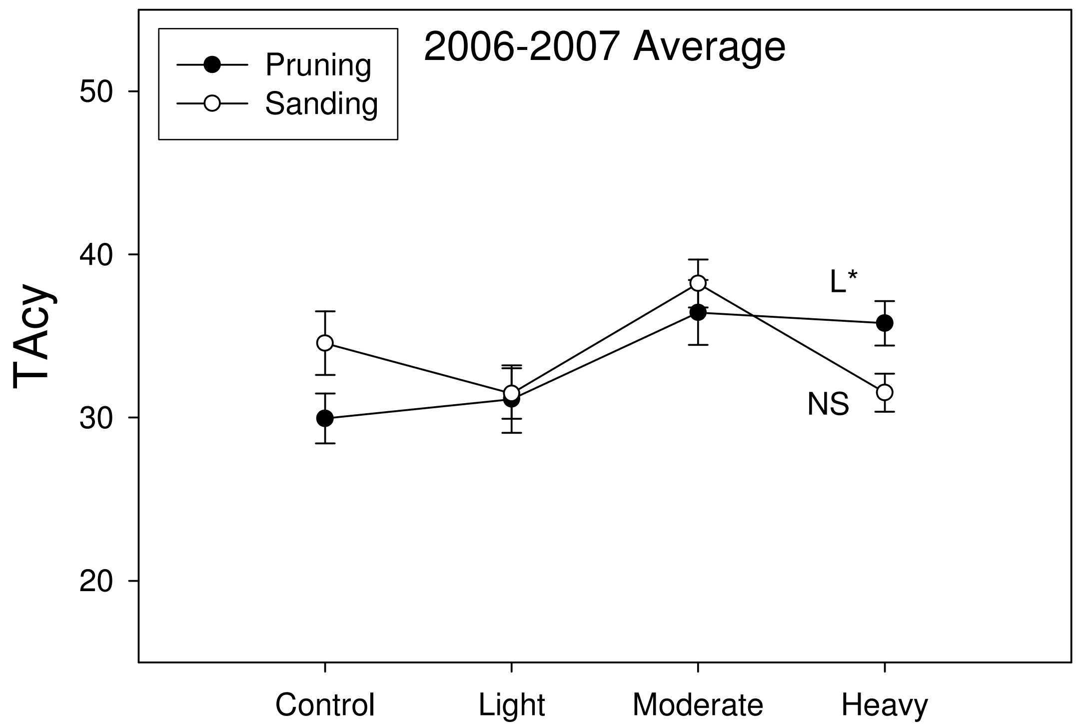

Figure 16: The effect of sanding and pruning intensities in April 2006 on total anthocyanin content (TAcy) in 'Stevens' cranberry fruit. SE is represented by vertical bars. Average TAcy for 2006 and 2007. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) effects.

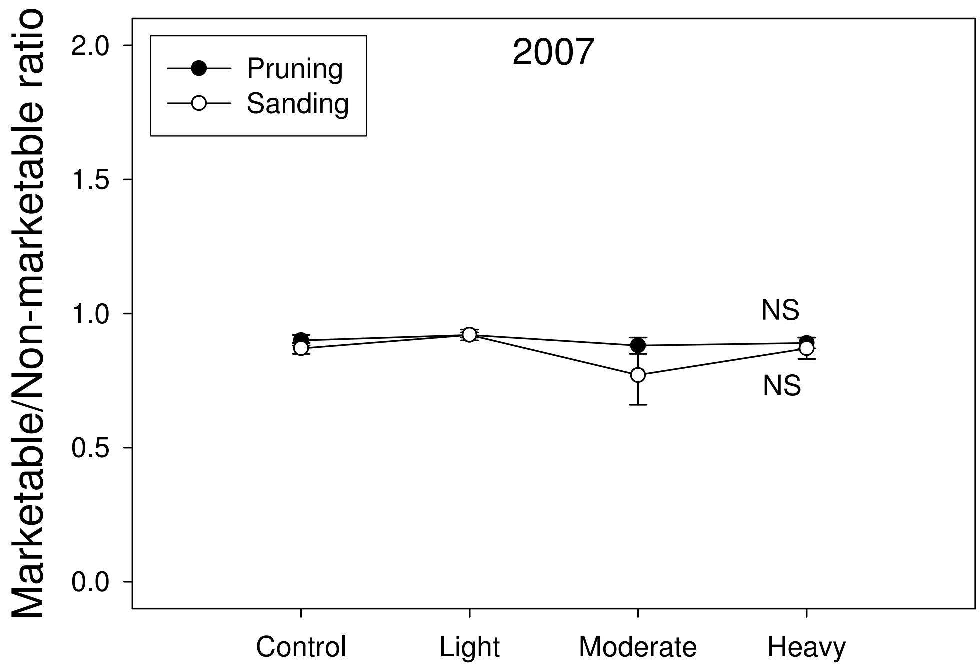

Figure 17: The effect of sanding and pruning intensities in April 2006 on the marketable/non-marketable berry ratio in 2007. SE is represented by vertical bars.

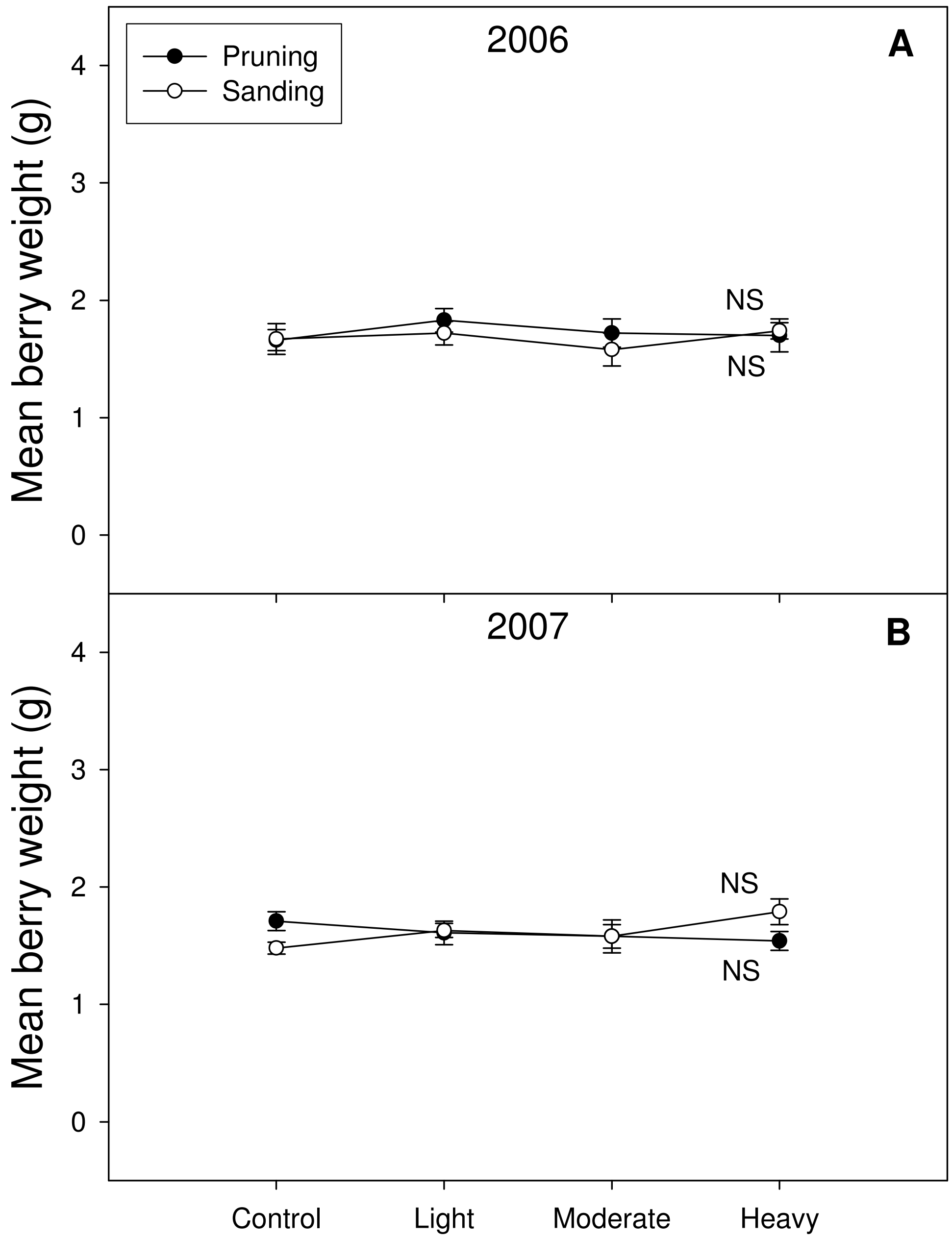

Figure 18: The effect of sanding and pruning intensities in April 2006 on mean berry weight (g) in (**A**) 2006 (**B**) 2007. SE is represented by vertical bars.

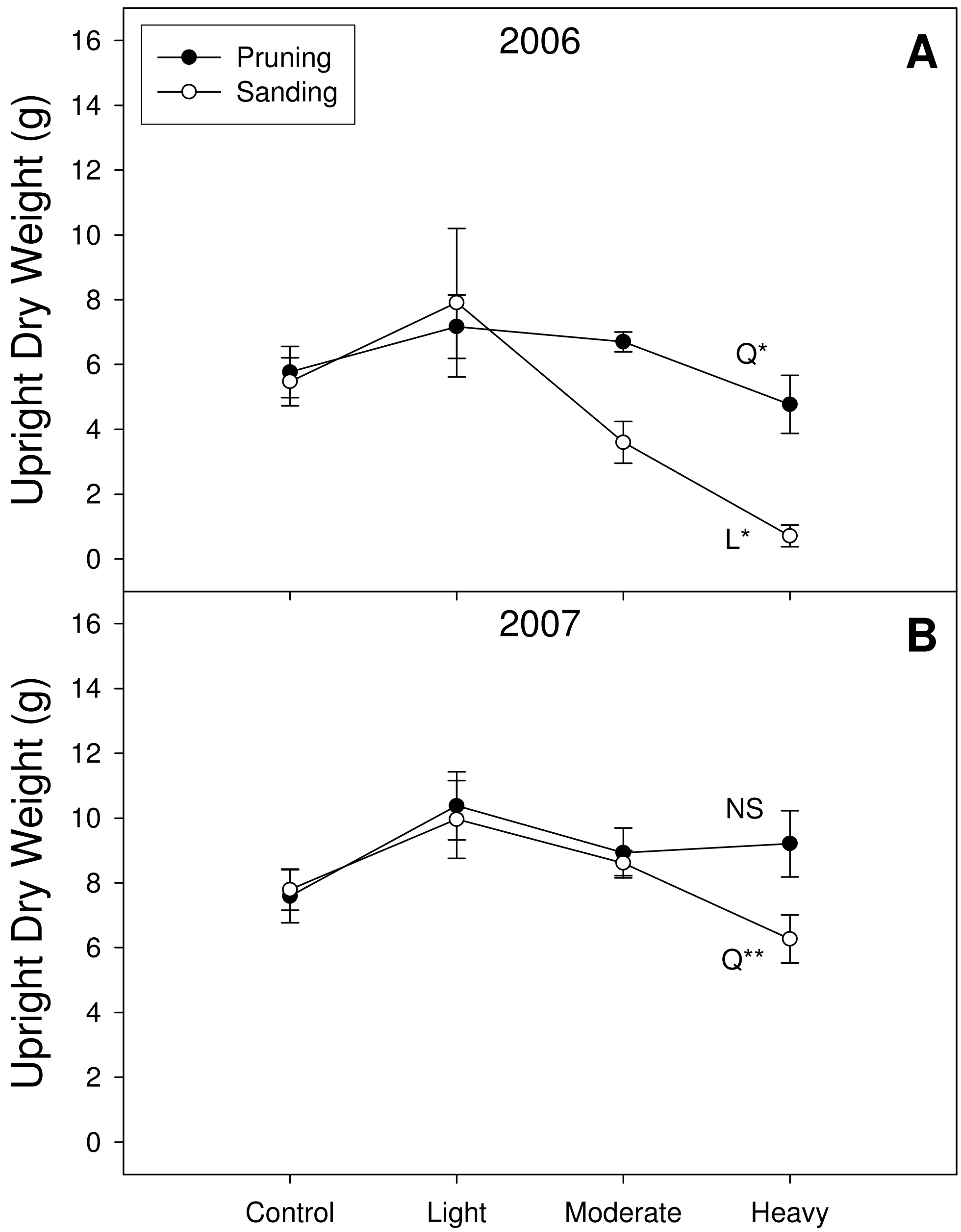

Figure 19: The effect of sanding and pruning intensities in April 2006 on upright dry weight in 'Stevens' cranberry in (**A**) June 2006, (**B**) June 2007. SE is represented by vertical bars. Number of uprights per 182 cm^2 area. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) and quadratic (Q) effects.

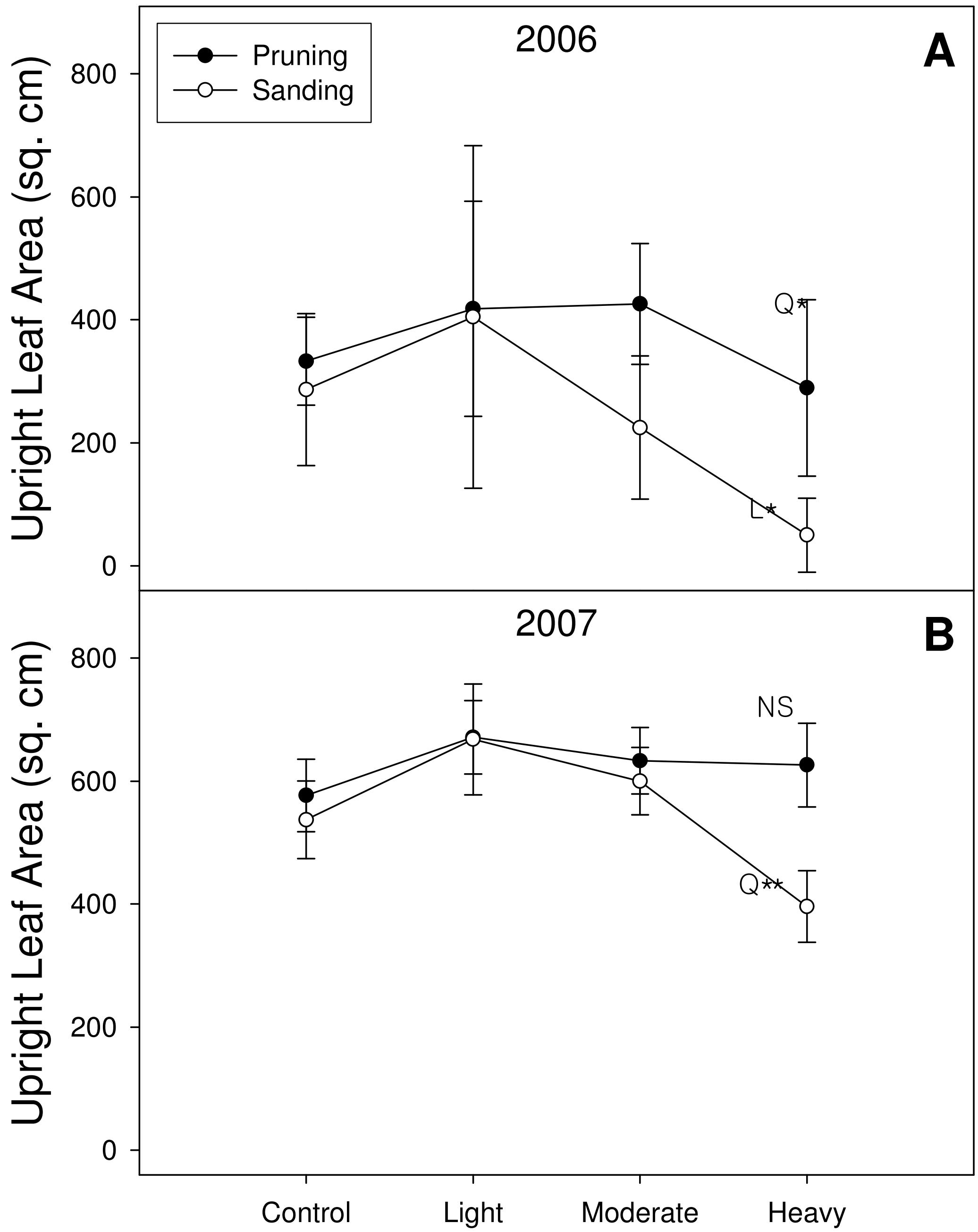

Figure 20: The effect of sanding and pruning intensities in April 2006 on upright leaf area in 'Stevens' cranberry in (**A**) June 2006, (**B**) June 2007. SE is represented by vertical bars. Number of uprights per 182 cm^2 area. $^{NS, *, **}$ Nonsignificant and significant at P = 0.05 and P = 0.01, respectively for linear (L) and quadratic (Q) effects.

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