

Final Research Report
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Project Title: Characterization of Cranberry Field Decline in British Columbia Cranberry Beds

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Summary

In recent years, several cranberry beds across British Columbia have exhibited symptoms that have been attributed to Cranberry Field Decline (CFD). Affected fields have 'patches' of vines that have significantly reduced vigor or in some cases complete death. As the cause of CFD had not been identified, this three-year project was conducted to better understand the physiological aspects of plants exhibiting symptoms and the soil conditions that may be related to the condition. In addition to better understanding the causes of CFD, this study also aimed to develop some diagnostic tools to help growers identify fields that may be at risk for developing CFD.

The current project was started in 2015 and built on preliminary work that was conducted in 2014. The results of upright density and canopy depth data suggest that CFD may begin to develop much earlier than expected as the brown canopy exhibits significant decline prior to any symptoms being observed in the green canopy. The carbohydrate analysis showed the lower starch reserve in the more severely affected CFD areas, supporting that the hypothesis that the collapse of the brown canopy was due to the depletion of the carbohydrate reserve, which might be due to the reduced photosynthetic capacity caused by the poor root health.

Evaluation of sanding as a management strategy indicated that although sanding did not show a significant improvement in most of the plant characteristics, the stressed bed showed an improved upright density which was not seen in the healthier bed. The development of the Pull-test, a method for estimating the root health, showed a significant relationship with the CFD conditions and may be a valuable tool to help growers identify fields at risk for CFD prior to observing symptoms in the canopy.

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Introduction

In recent years, several cranberry fields in British Columbia have exhibited severe decline of canopy density and, in extreme cases, dieback patches that affect most of the field. This canopy death, attributed to Cranberry Field Decline (CFD), has been investigated for its cause; however, previous studies ruled out pathogenic and insect damage as a cause. In 2014, field observations found severely stunted and degenerated roots in many of the CFD affected cranberry fields. This observation led to the formulation of the hypothesis that root growth was inhibited due to unfavorable growing conditions in the soil caused by the rapid degradation of organic soil. The current project aimed to better understand the physiological conditions of the plant and the soil environment in fields affected by CFD in order to identify possible causes and management strategies for fields impacted by CFD and strategies to prevent the development of this condition.

In 2015, field studies were started to characterize the soil condition and the plant growth status in the CFD affected cranberry fields. The overall result showed high heterogeneity of soil characteristics and no consistent trend between soil characteristics and CFD. On the other hand, the plant growth characteristics showed a correlation with CFD. Results showed that total upright density gradually decreased as CFD progressed, with little or no change in the height of the upper portion of the canopy (green canopy), until CFD is very severe and the canopy dies back completely. Unlike the green canopy, the depth of the lower portion of the canopy (brown canopy) showed a declining trend as the CFD conditions progressed. Although these observations were not statistically significant due to the high data variability, the overall trend indicated that the reduction of brown canopy depth was related to the development of CFD.

In 2016 and 2017, the collection of field data continued to meet the objectives of the project with the addition of carbohydrate analysis of CFD affected cranberry plant tissue as an objective. The rationale for the carbohydrate analysis was based on the hypothesis that the previously observed decline of brown canopy depth was due to the depletion of carbohydrate reserve in vines. Sanding trials were also performed as the evaluation of management practice. And the development and assessment of the efficacy of the pull test as a CFD risk indicator continued.

This project represents one of the most comprehensive physiological assessments of cranberries in British Columbia to date and has resulted in valuable information that will not only help address the challenges of CFD, but also to improve cranberry production practices in general. The results of this study indicate that the CFD is likely due to the development of low rooting capacity relative to the canopy (root:shoot ratio) which may be caused by several different factors or a combination of factors. The recommendations resulting from this study are to monitor the cranberry canopy for balanced root and shoot development and to carry out management practices such as sanding and/or pruning to maintain a desirable canopy architecture and rooting capacity. The use of the pull test that was developed through this project will also provide growers with a tool to assess mature fields for their risk levels of developing CFD.

Research Objectives

1. Detailed characterization of cranberry beds to evaluate correlations between cranberry field decline symptoms and soil and plant characteristics
 - a. Validation of soil diagnostic tools to identify the correlation between pH, oxygen/redox potential, and cranberry field decline
 - b. Collection of plant growth data to determine the impact of canopy architecture and carbohydrate status of cranberry plant tissue

2. Conduct field trials to evaluate management techniques on beds affected by Cranberry Field Decline
 - a. Evaluate bed establishment/renovation practices that optimize root establishment
 - b. Evaluate management practices to remediate cranberry beds affected by cranberry field decline
 - c. Evaluate current management practices to formulate appropriate recommendation for management practices

Field Locations and Objective Assignments

In both 2016 and 2017 seasons, a total of 5 farms and 7 fields (Bed A-G, [Figure 1](#)) participated in the project. The details of the objective assignments are shown in [Table 1](#).



Figure 1: Map of study bed locations. Bed G was retracted from the list of study bed in 2017.

Table 1: List of Beds (ID) and assigned objectives in 2016 and 2017

Objectives	Bed ID								*1
	A	B	C	D	E	F	G	H	
1a	Soil Characteristics	✓	✓	✓	✓	*4		*4	
1b	Plant Characteristic		✓	✓	✓	✓	*4		*4
	Carbohydrate Analysis	✓	✓	✓	✓	✓*5			
2a	Renovation Trial								*1
2b	Management Trial						✓	*2	✓
2c	Management Evaluation	✓	✓	✓	✓	✓	✓	*3	✓

*1: Renovation trial was cancelled.

*2, 3: Bed G was retracted from the assignment due to the pretreatment with sawdust before the project.

*4: Some of the measurements were combined with the indicated objectives to increase sample sizes.

*5: Additionally assigned: samples were only collected in 2017.

Progress Status of the Objectives (Final)

Objective 1a and 1b (Characterization of the Cranberry Bed in BC) and Objective 2b (Evaluation of Management Trials) have been completed. However, Objective 2a (the Evaluation of Bed Establishment/Renovation) was cancelled due to some logistic challenges. One of the challenges was to find a bed available and suitable for the establishment/renovation trials. At the beginning of 2016 season, we were unable to find a collaborating farm with a bed that was subjected to be a renovation. In 2017, there was a bed undergoing a renovation in one of the collaborating farms. However, due to the following concerns, we decided to cancel the trials. First, a newly harvested peat had been brought in to cap the existing soil on the bed. One of the criteria we were looking for in the trial bed was that the soil would be the same as or similar to the pre-renovation condition to see the effectiveness of soil amendments. We suspected that it would be difficult to evaluate the effectiveness of the soil amendments as cranberry plants were expected to grow very well on the newly harvested peat. Another concern in this particular bed was that the cultivar that was going to be planted was rare in BC, which might be difficult to be compared with the other cultivar common in BC. Additionally and importantly, due to the cost of the cultivar, it was difficult to secure a sufficient size of experimental plots which would have been essential to eliminate the external factors from the edge of each plot. Objective 2c (Evaluation of Current Management Practices) is currently in progress.

Section 1: Soil Characteristics (Obj. 1a)

Materials and Methods

Soil core samples ($\phi=2\text{cm} \times 15\text{cm}$ deep) were taken at declining (A), transition (T), and non-symptomatic (N) areas in the beds (*Table 1*). Sampling was done once in June 2016 (36 samples collected) and in May and June in 2017 (108 samples collected). For each sample, Redox potential and pH were measured in 2016 and pH was measured in 2017 (*Figure 1-1 and 1-2*).



Figure 1-1, 1-2: Measuring soil pH at UBC soil lab.

Results

Both the mean Redox potential and soil pH showed no consistent trend among beds or CFD conditions (*Figure 1-3 and 1-4*). Mean soil pH was between 4.0 and 5.0 for all CFD conditions at all beds (*Figure 1-4*).

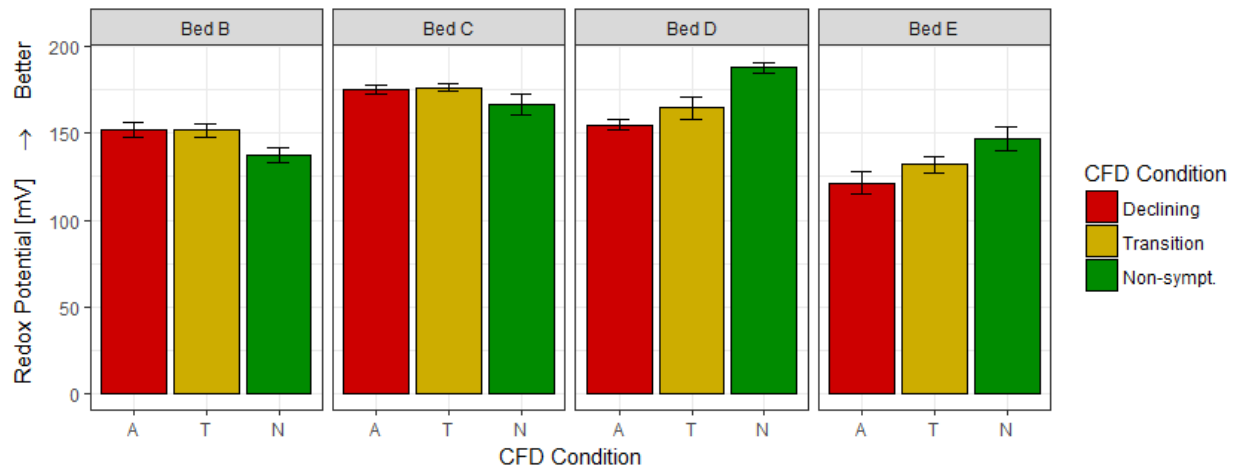


Figure 1-3: Mean Redox potential was compared among the CFD conditions for each bed ($n=3$). Error bars indicate standard error of the mean.

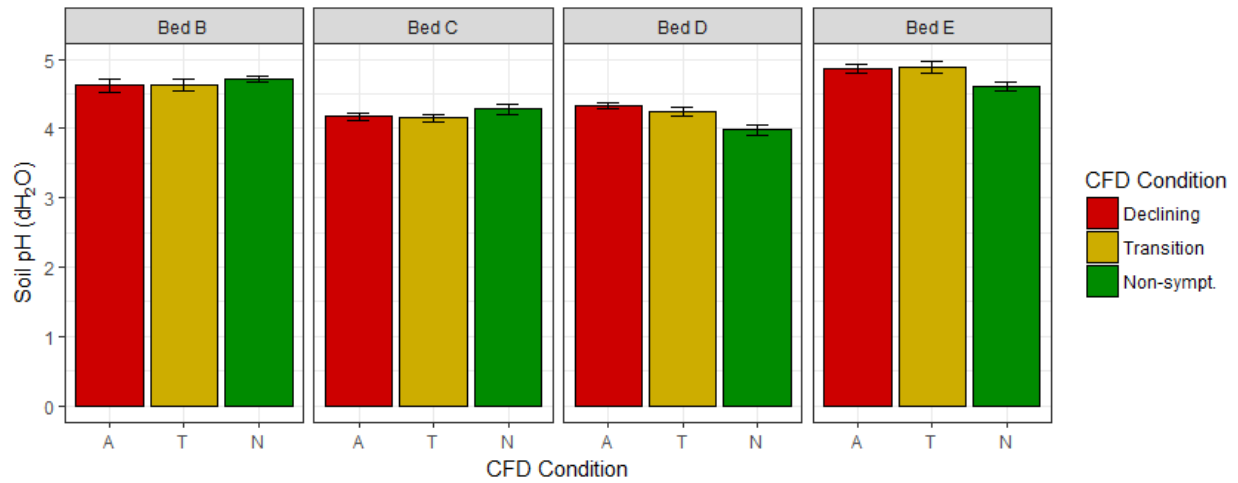


Figure 1-4: Mean pH measurements were compared between the CFD conditions for each bed (n=12). Error bars indicate standard error of the mean.

Discussion

Soil Redox potential was measured to assess the soil oxygen availability. If soil degradation was causing hypoxic or anoxic conditions, lower Redox potential readings would be observed in more severely affected CFD conditions. However, the results were inconsistent. For example, Beds B and C showed lower Redox potential in non-symptomatic (N) areas, whereas Beds D and E showed the opposite trend. This result may suggest that soil degradation was not a dominant factor causing the CFD symptoms among the study beds. It may be possible that some other confounding factors (currently unknown) may synergistically be acting with the soil conditions. Soil pH data were found to be in the 'normal' range for cranberry fields and showed similar results with an inconsistent relationship between CFD conditions and pH.

Section 2: Plant Growth Characteristics (Obj. 1b)

Materials and Methods

Upright Density (Obj. 1b.1)

The number of uprights within 30 x 30 cm² quadrat was counted for both vegetative and flowering uprights at A, T, and N areas in each of assigned beds (*Table 1*). The sampling was replicated 3 times, yielding the total of 36 samples (3 replication x 3 treatment x 4 beds) in each year. Sampling was done once in mid-Jun, during the flowering timing (*Figure 2-1*).

Canopy Depth (Obj. 1b.2)

The depth of both green and brown canopy was measured with a ruler in the A, T, and N areas of the beds (*Table 1*). The green canopy is the portion of uprights where leaves were still attached, and the brown canopy is between the bottom of the green canopy and the surface of the soil. The measurements were replicated 3 times, yielding the total of 36 samples (3 replication x 3 treatments x 4 beds) in each year. Sampling was done once in mid-Jun, during bloom (*Figure 2-2*).

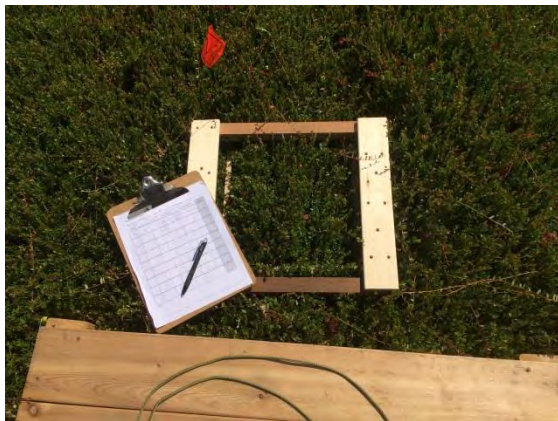


Figure 2-1 (left): Setting of the upright counting at a bed. Wooden platforms around and behind the quadrat (1 ft²) were used to minimize damage to the shoots and fruits.

Figure 2-2 (right): Measuring canopy depth from the bottom of the canopy to the approximate boundary between green and brown canopy and to the top of upright (average height).

Root Health (Obj. 1b.3)

Root health was estimated by using the Pull-test which is conducted by grasping the canopy from the bottom, pulling the canopy up until resistance occurs (*Figure 2-3*) and then measuring the pulled height and the pulled area (*Figure 2-4*). The approximate volume was calculated from the measurements. The unrooted volume under the canopy was calculated for the T and N areas in each bed (*Table 1*). The measurement was replicated 3 times at as many times as possible, yielding the following sample sizes: Bed B and C: n=39, Bed D: n=36, Bed E: n=21.



Figure 2-3 (left): Conducting pull-test to measure the height of the canopy lifted.

Figure 2-4 (right): Measuring the area of the canopy lifted by the test. (Pictures are from 2016 season)

Tissue Nutrient Analysis (Obj. 1b.4)

The uprights of current season's growth were sampled at A, T, and N areas in each of assigned bed for the tissue nutrient analysis. The samples were analyzed at a lab for N, P, K, Ca, Mg, S, Fe, Zn, Mn, Cu, and B content. 36 samples (3 replication x 3 treatments x 4 beds) were collected in late August each year.

Yield Analysis (Obj. 1b.5)

Berries were collected within a 30 x 30 cm² quadrat at A, T, and N areas in each of the assigned bed. 9 yield samples were collected from 4 different beds for a total of 36 samples (3 replications x 3 treatments x 4 bed). Berries were counted, weighed and sorted into marketable and unmarketable.

Carbohydrate Analysis (Obj. 1b.6)

Three sampling areas were identified in each bed (A, T and N) where plant tissues were collected each month, between May and October/November for carbohydrate analysis. In addition to carbohydrates, data was also collected for canopy depth, rooting capacity (Pull-Test), and soil characteristics (see previous sections for the methods for each measurement and sampling). At each sampling location, a handful of vines consisting of the 3⁺-year-old growth were collected. A total of 216 samples were collected for carbohydrate analysis (3 replication x 3 treatments x 6 months x 4 beds). Canopy samples were placed in paper bags, sealed in the airtight bag, and placed in the insulated box with ice packs to suppress the respiration of the plant samples. In the lab, vines were rinsed and separated into the green canopy (current and previous year's growth) and brown canopy (>2 years-old growth) and placed in the dryer at 80°C for at least 48 hours. Dried samples were ground and stored with silica gel desiccation agent in an airtight box (*Figure 2-5~2-10*). Samples were sent to an analytical chemistry lab to determine concentration of glucose, fructose, sucrose, and starch of each sample.

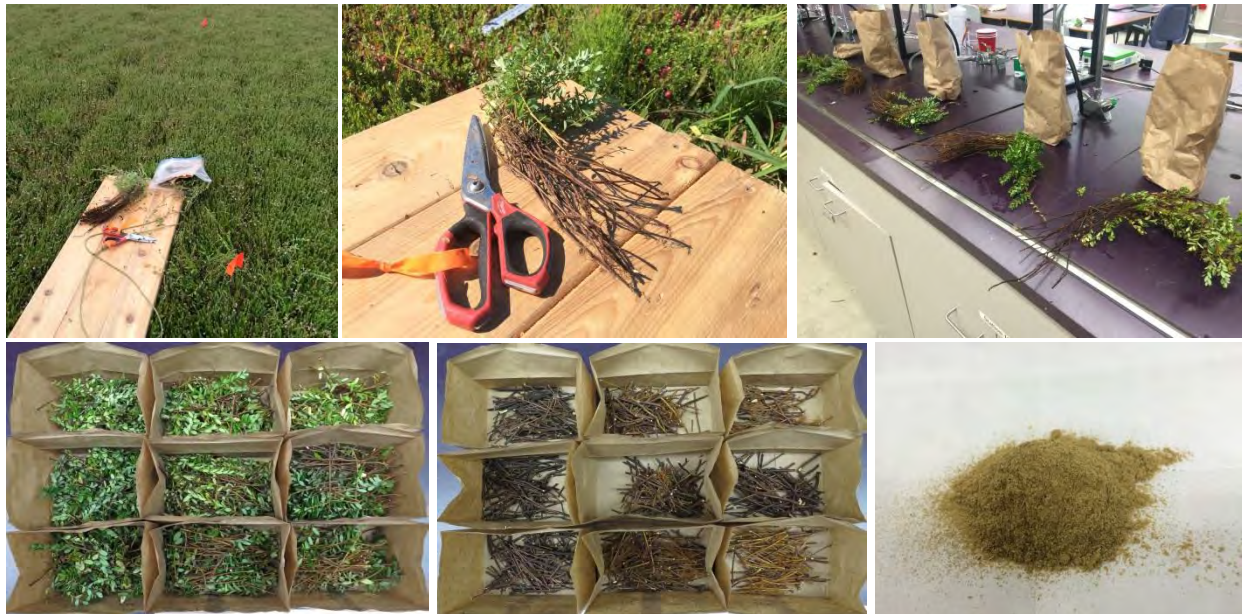


Figure 2-5 (top-left): Sampling equipment setting at a field; **Figure 2-6** (top-center): vines cut out from the bed; **Figure 2-7** (top-right): samples were rinsed and ready for further processing; **Figure 2-8** (bottom-left) and **Figure 2-9**(bottom-center): samples are separated into green and brown canopy, respectively; **Figure 2-10**(bottom-right): samples were dried in an oven for 5 days and ground to powder. (Pictures are from 2016 report)

Results

Upright Density (Obj. 1b.1)

Total upright density was significantly lower in the A areas compared to T and N areas in all beds in both years. Total upright number was slightly lower in the T area than in the N area in Beds B and C, while Beds D and E showed similar number of the total uprights in the T and N areas. The differences in the mean number of flowering uprights were generally proportional to the mean number of total uprights (positive correlation) in all beds, except for Bed C showing a disproportionately higher flowering upright ratio in the T area (*Figure 2-11*).

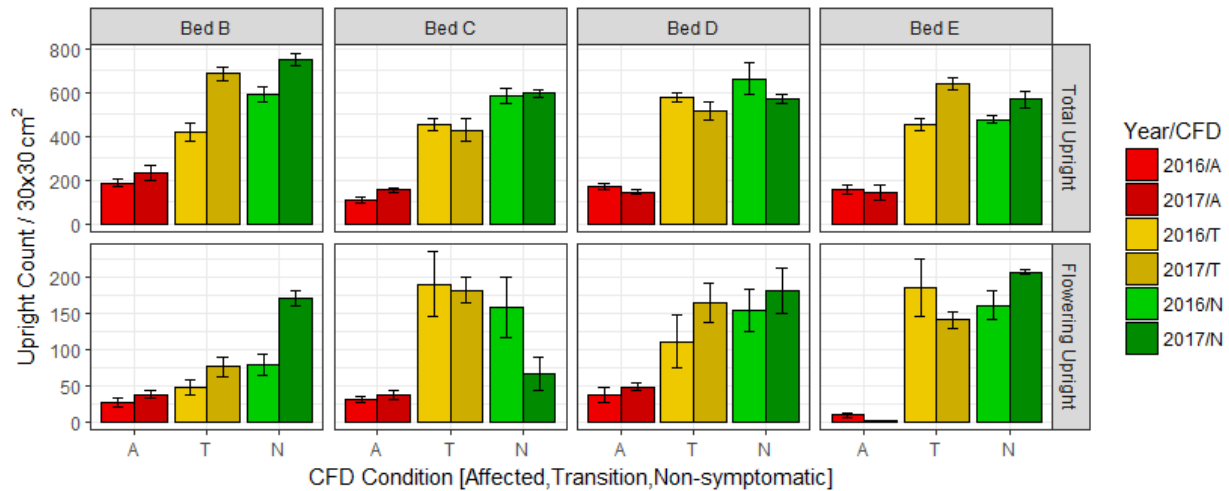


Figure 2-11: Mean number of total and flowering uprights (number per 30x30cm²) was compared between the CFD conditions and between years (2016 and 2017) in each bed. (n=3). Error bars indicate standard error of the mean.

Canopy Depth (Obj. 1b.2)

All canopy depth data measured in each of the A, T and N areas between May and August (including the result from both objective 1a and 1b) in both years were pooled for the analysis. The mean brown canopy depth in the T area was significantly lower than the N; while the mean green canopy depth in the T area was slightly lower (insignificant) than N area. These trends were consistent among all the beds, except for Bed E (Figure 2-12).

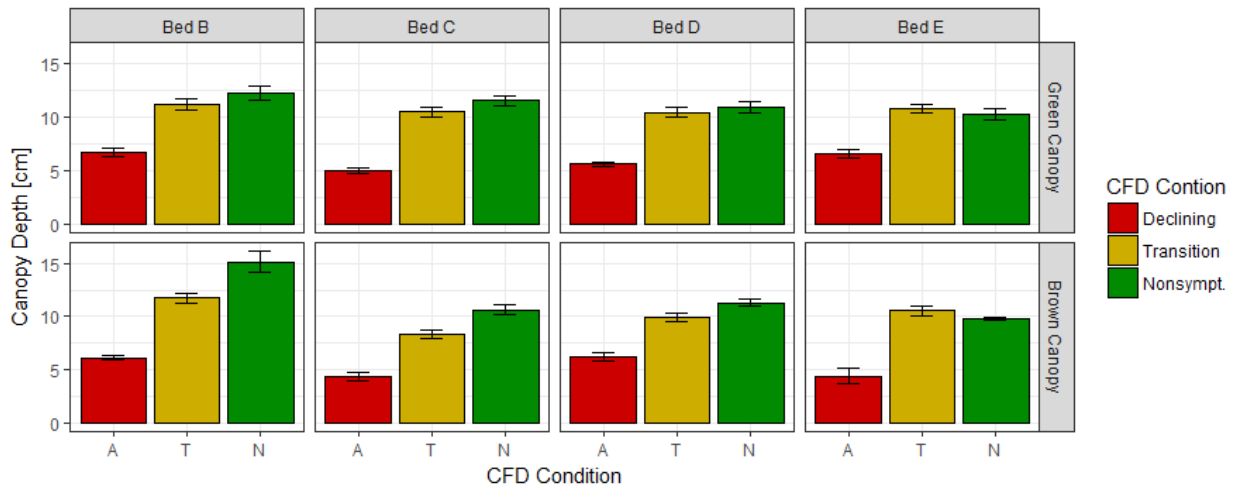


Figure 2-12: The mean green and brown canopy depth were compared between CFD conditions for each bed. (n=8) Error bars indicate standard error of the mean

Root Health (Obj. 1b.3)

The mean unrooted volume under canopy (VUC) determined by the pull test was lower in the T area than in the N area in all beds, except for Bed E which showed the significantly smaller VUC which were similar between the T and the N areas. The differences in the unrooted volume were significant in Bed B and Bed D, while the difference was insignificant in Bed C (Figure 2-13).

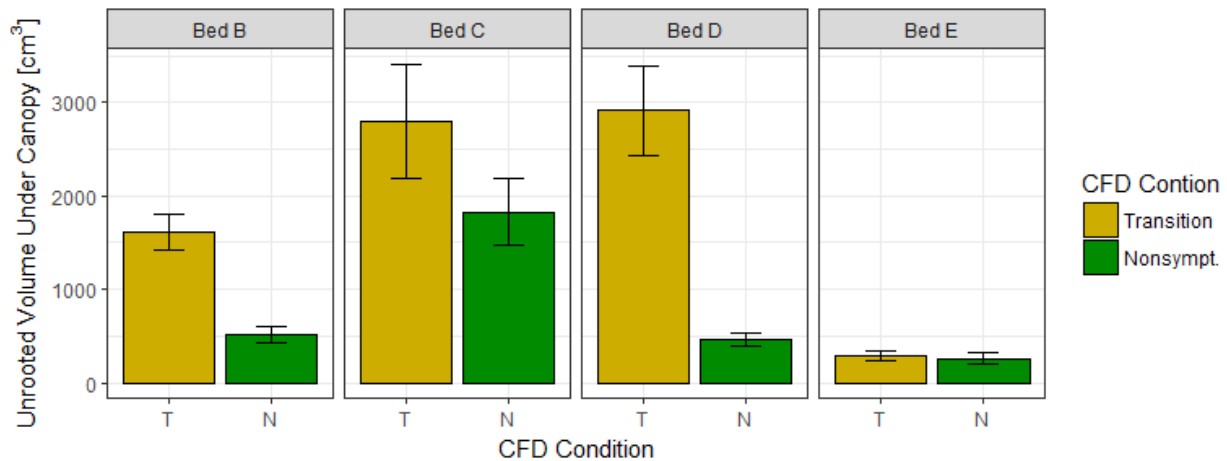


Figure 2-13: The mean unrooted volume under canopy measured by pull-test compared between CFD conditions (T and N) in each bed. (Bed B and C: n=39, Bed D: n=36, Bed E: n=21) Error bars indicate standard error of the mean.

Tissue Nutrient (Obj. 1b.4)

The mean tissue nutrient concentrations were compared with the concentration range (Table 1) recommended by Hart *et al.* (2015).

Nitrogen (N): The concentrations were generally within the range, except for Bed D and E. Bed D showed slightly lower concentration than the lower limit of the range in all CFD conditions in 2016. Bed E showed significantly higher concentration in the A and T areas in 2017. No consistent trend among the CFD conditions was found (Figure 2-14).

Phosphorus (P): The concentrations were generally within the range. Bed E showed relatively higher concentration than the other beds. No consistent trend was seen among the CFD conditions (Figure 2-14).

Potassium (K): The concentration was slightly lower than the lower limit of the range in all CFD conditions in Bed B, in the T and the N areas in Bed C and D for both years. In Bed E, the concentration exceeded the upper level of the range in the A area in 2016 and the A and T areas in 2017. No consistent trend among the CFD conditions was found (Figure 2-14).

Calcium (Ca): The Concentration was above the lower limit of the range in all beds. The concentration exceeded the upper limit of the range in the N area in Bed C and Bed E in 2016 and Bed B and Bed E in 2017. The concentration was generally lower in the A area than T and N areas and becomes higher towards the N area. This trend was generally consistent and seen in both years (Figure 2-14).

Magnesium (Mg): The concentration was generally within the range in all beds in both years. Bed D showed relatively lower concentration in all CFD conditions compared to the other beds in both years. The concentration was generally lower in A areas than the other CFD conditions in all beds in both years (Figure 2-14).

Sulphur (S): The concentration was generally within the range in all beds in both years. Bed E showed a significantly higher concentration than other beds in both years. No consistent trend among CFD condition was found in both years (*Figure 2-14*).

Iron (Fe): The concentration was well-above the lower limit of the range in all beds in both years. Concentration was generally higher in A area than T and N areas in all beds in both years, except for Bed B in 2017 (*Figure 2-15*).

Zinc (Zn): The concentration was generally within the range in all beds in both year; however, the concentration varied significantly among the beds and no consistent trend was found in both years. Bed D showed relatively lower concentration in both years (*Figure 2-15*).

Copper (Cu): The concentration was generally lower than the lower limit of the range in all beds in both years, except the A area in Bed B in 2016 and the A and the T areas in Bed E in 2017. No consistent trend was found in both years (*Figure 2-15*).

Manganese (Mn): The concentration was well-above the lower limit of the range in all beds in both years. Bed E showed significantly higher concentration in all CFD conditions in both years compared to the other beds. No consistent trend was found in both years (*Figure 2-15*).

Boron (B): Concentration was within the range in all beds in both years. Bed B showed relatively lower concentration than other beds in both years. No consistent trend was found in both years (*Figure 2-15*).

Table 2: Cranberry plant tissue nutrient concentration guidelines

Nutrient	Sufficient range [%]	Nutrient	Sufficient range [µg/g]
N	0.9 – 1.1	Fe	> 20
P	0.1 – 0.2	Zn	15 – 30
K	0.4 – 0.75	Cu	4 – 10
Ca	0.3 – 0.8	Mn	> 10
Mg	0.15 – 0.25	B	15 – 60
S	0.08 – 0.25		

Source: Hart *et al.* (2015)

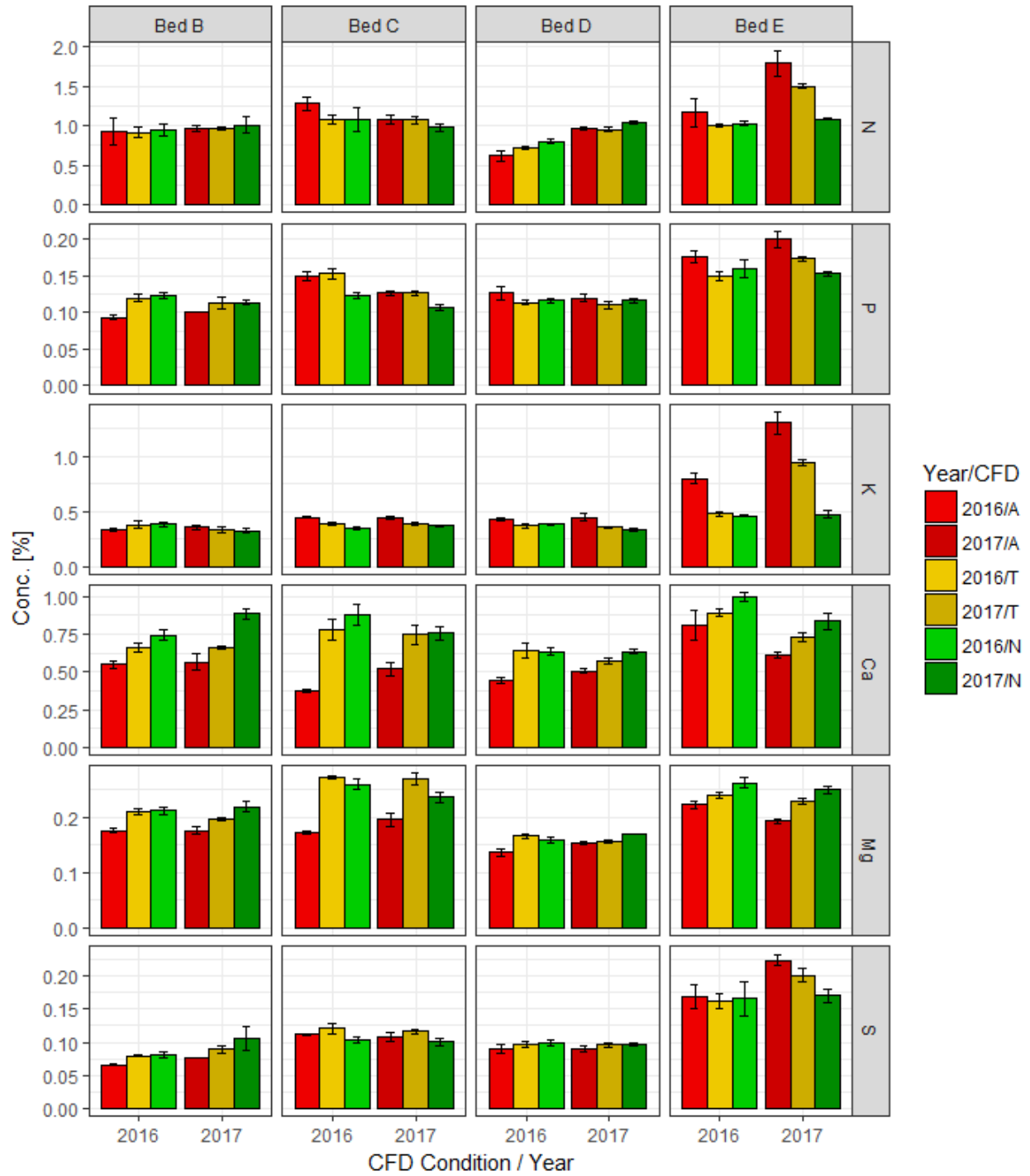


Figure 2-14: The mean cranberry plant tissue nutrients (N, P, K, Ca, Mg, S) compared between CFD condition and years (2016 and 2017) in each bed.(n=3) The error bars indicate standard error of the mean.

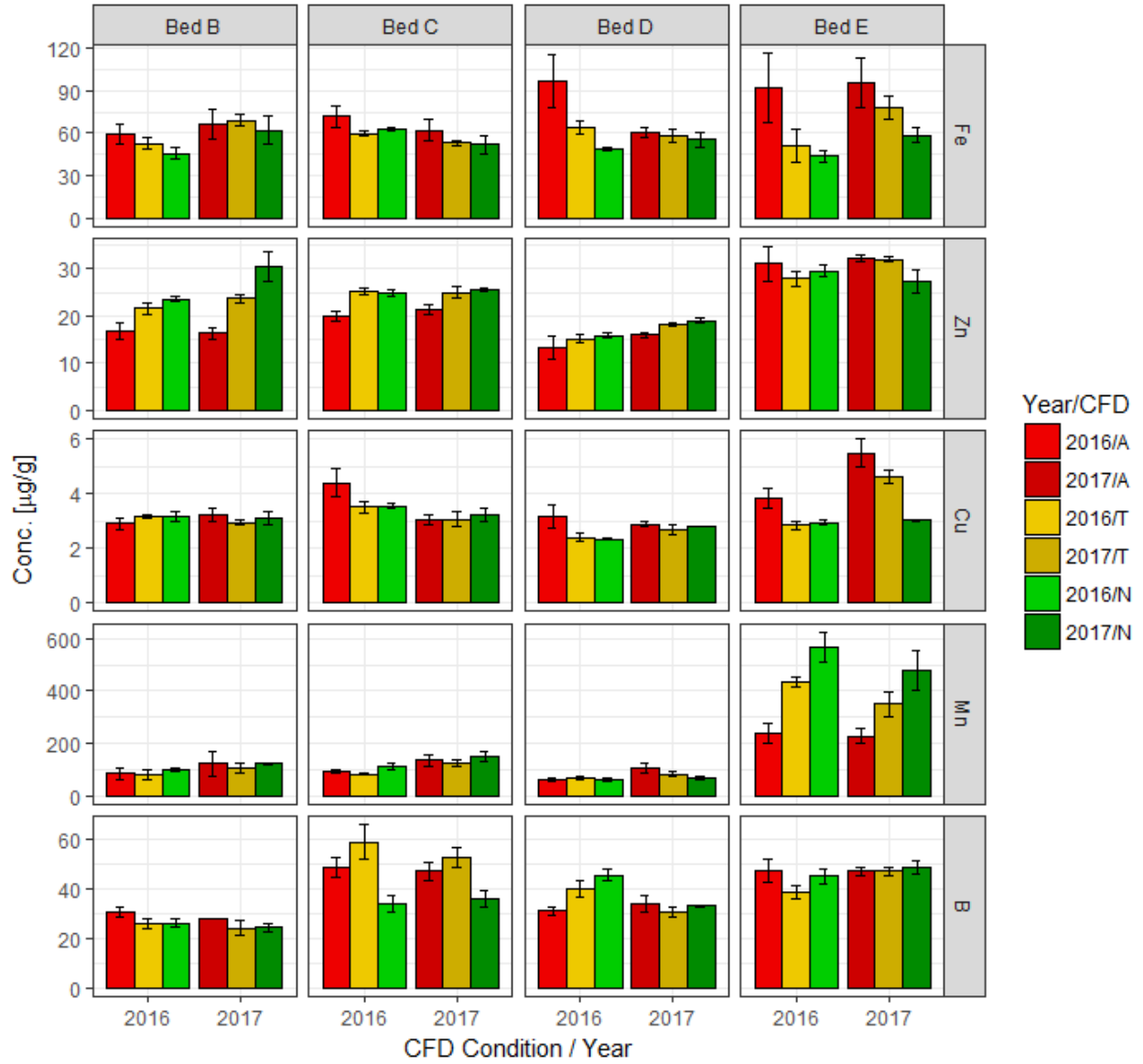


Figure 2-15: Cranberry plant tissue nutrients (Fe, Zn, Cu, Mn, B) compared between CFD condition and years (2016 and 2017) in each. (n=3) The error bars indicate standard error of the mean.

Yield Analysis (Obj. 1b.5)

Mean yield estimate was highly variable among the beds. Bed B showed the lowest yield estimate in both years at all CFD conditions. Bed C showed a significantly greater yield estimate in the T area than in the N area in both years. The yield estimate in both T and N areas declined significantly in 2017 in Bed C. Bed E showed relatively consistent yield estimate in the N area between 2016 and 2017, while that in T area declined significantly in 2017 (*Figure 2-16*).

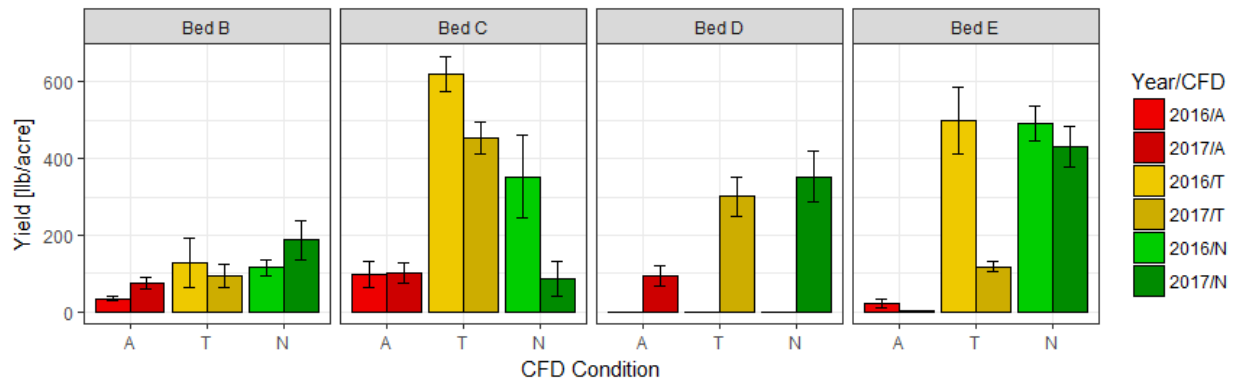


Figure 2-16: The mean yield estimate compared between CFD conditions and years (2016 and 2017) in each bed. (n=3) The error bars indicate standard error of the mean.

Carbohydrate Analysis (Obj. 1b.6)

The mean hexose (sum of glucose and fructose) concentration in the green canopy was, in general, highest in the A area followed by the T and N areas throughout the growing season in 2016. The mean sucrose concentration in green canopy did not show a consistent trend between the beds, except for bed C where sucrose concentration was higher in the A area compared to T and N areas between July and November. However, the starch concentration in green canopy showed a significant increase in the post-harvest sample in all CFD conditions in all Beds. The mean starch concentration in the green canopy was significantly higher in the A area than in the T and N areas early in the season but declined to levels similar to the T and N areas at the end of the season in each bed (*Figure 2-17*).

In the brown canopy, the mean hexose and sucrose concentrations were, in general, slightly higher in the A area than in T and N areas early in the season. However, the significance of the differences was not consistent among the beds. The hexose and sucrose concentrations at all CFD conditions generally increased towards the end of the season. The mean starch concentration in the brown canopy was, in general, significantly lower in the A areas followed by T and N areas in both beds throughout the season. In the brown canopy samples collected after the harvest, the difference of the starch concentration between A and N area remained significant; however, the difference between the T and N areas became insignificant towards the end of the season in all beds as the starch concentration in the T area increased (*Figure 2-18*).

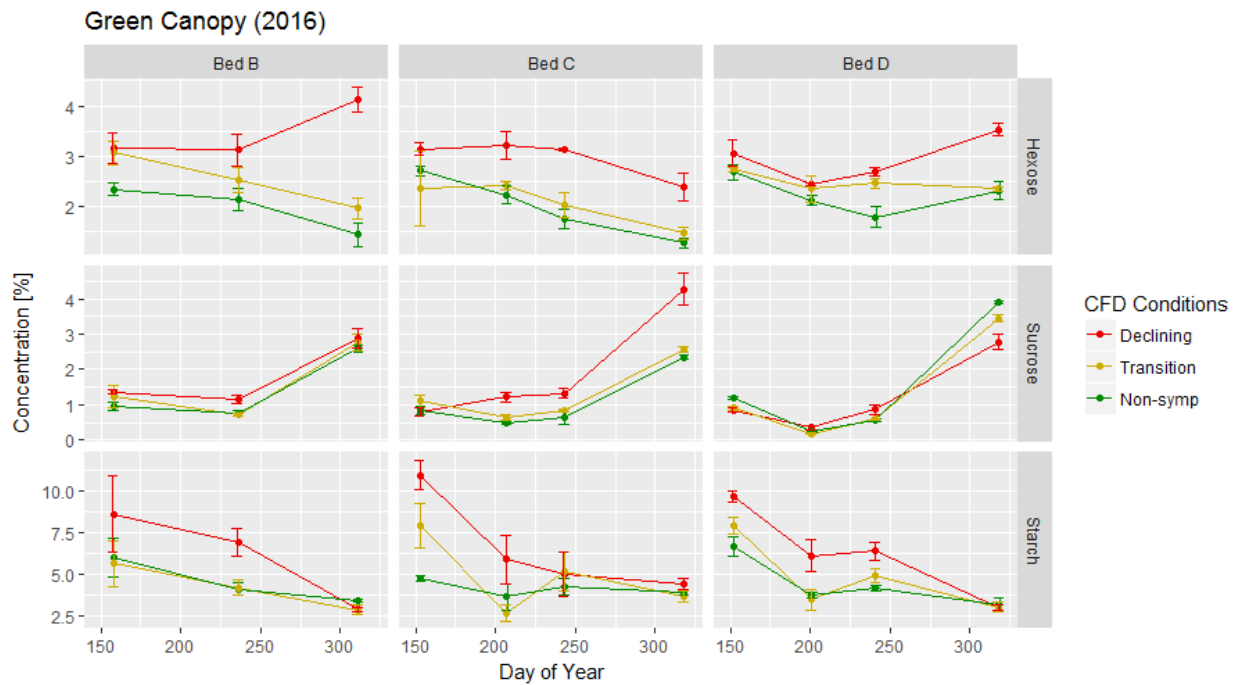


Figure 2-17: The mean nonstructural carbohydrate concentration (hexose, sucrose, starch) in green canopy compared between CFD conditions and months (Jul and Oct-Nov) in each bed (Bed C and D). (n=3) The error bars indicate standard error of the mean.

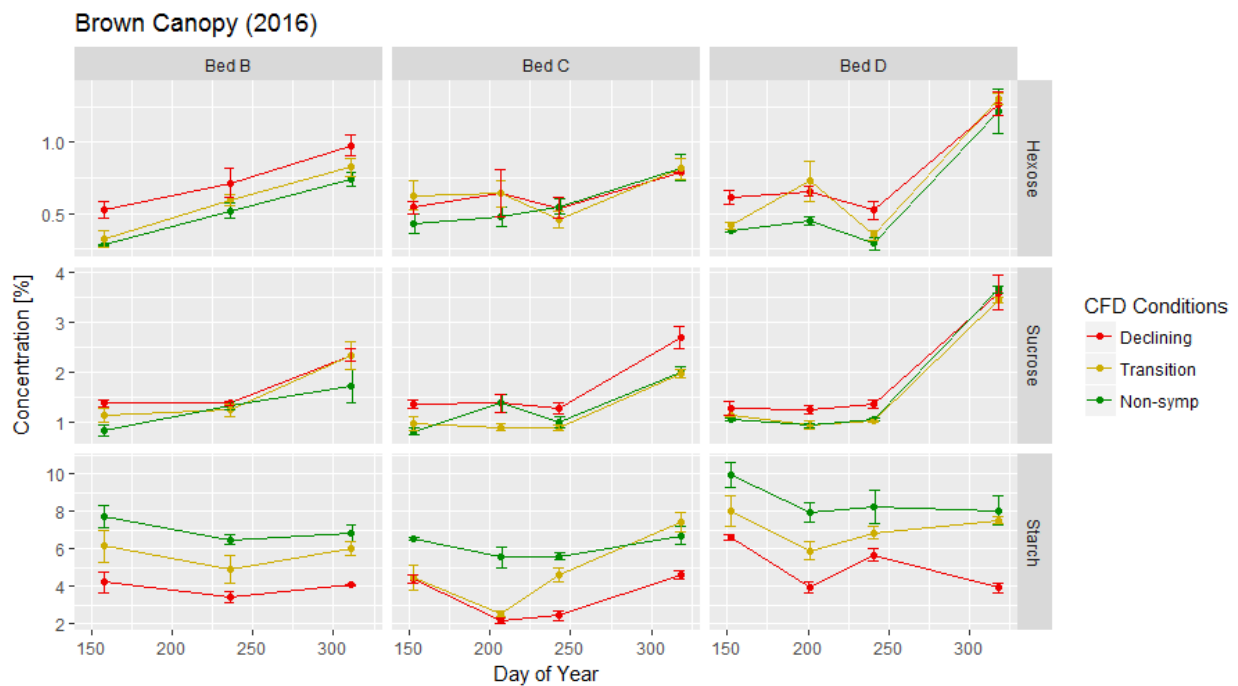


Figure 2-18: The mean nonstructural carbohydrate concentration (hexose, sucrose, starch) in brown canopy compared between CFD conditions and months (Jul and Oct-Nov) in each bed (Bed C and D). (n=3) The error bars indicate standard error of the mean.

Discussion

Decline of the Brown Canopy is Masked by the Green Canopy

The total upright density was significantly lower in the A area compared to the T and N areas; however, there was not often a very big difference between the N and T areas in upright density. There was a similar observation in the green canopy depth data. This would suggest that the health of the canopy between the N and T areas was quite similar. However, there was a significant decline in the brown canopy depth between the N to T areas indicating that there was a significant difference in the canopy architecture and health of the canopy in the N and T areas. The similar trends between the upright density and the green canopy depth suggested relatively stable biomass of the top portion of the canopy in the N and T areas even though the brown canopy depth was steadily declining between these areas. This result may explain the sudden appearance of the dieback patches in the cranberry fields. The relatively unchanged upright density and the green canopy depth would mask the declining health of the brown canopy for a long time, possibly years, until the brown canopy has been depleted of carbohydrate reserves so that it is no longer be able to sustain the growth and maintenance of the green canopy. Beyond this “threshold” the density of the upright and the depth of the green canopy dramatically collapse which leads to the manifestation of the visual CFD symptoms.

Relationships between Root Capacity and Cranberry Field Decline Conditions

The results of the Pull-test showed significantly lower rooting capacity in the T areas. The insufficient root growth in T area causes the lower uptake of nutrient and water from the soil which may be causing the reduction of photosynthetic capacity. Water-stressed plants, for example, close stomata to prevent loss of water by evaporation, which reduces the uptake of carbon dioxide, the substrate of photosynthates. Magnesium and iron deficiency, for instance, can down-regulate the synthesis of chlorophylls, causing the reduction of capacity to convert photon energy to the chemical energy which is required to operate the carbon assimilation. The physiological mechanisms occurring between the lack of healthy roots and the canopy reduction may be explained by the depletion of carbohydrate reserve in the vines. The pull test may be a valuable in-field assessment tool to identify fields that have declining root capacity and are at risk for developing CFD.

Alteration of Carbohydrate Allocation Balance and Reduction of the Reserve

The general seasonal trends of carbohydrate concentrations seen in the results were consistent with the previous studies on the carbohydrate dynamics of cranberry plants. In uprights, soluble sugars increase towards dormancy for developing cold hardiness, while starch content decreases. In vines, total non-structural carbohydrate (hexose, sucrose, and starch combined) increase towards dormancy (Hagidimitriou & Roper, 1994). As to the response of the carbohydrate contents to the CFD conditions, in both green canopy and brown canopy, the soluble sugars (hexose and sucrose) showed, in general, a higher concentration in A area than T and N areas. As for starch, green canopy showed relatively higher concentrations in A area compared to the other CFD areas early in the season; however, was consistently lowest in A areas and higher in the T and N areas in the brown canopy. These results are likely due to the plants’ physiological response to stress factors.

Plants lacking a healthy root system experience water stress and deficiency of nutrients. Under such conditions, plants photosynthetic capacity is reduced which decreases the readily available soluble carbohydrate, the hexose pool. In order to maintain growth, plants will reallocate starch to meet the needs of the plants, this leads to the degradation of the starch in reserve to maintain an adequate hexose pool during the growing season. In the N area, where rooting capacity was higher, the

photosynthetic capacity might be relatively unaffected; hence, the degradation of starch in reserve was minimal. In the T areas, however, reduction of photosynthesis was significant, which causes the significantly greater degradation of starch in reserve. The N and T areas, were able to maintain a steady total upright density and the green canopy was able to carry on with photosynthesis to replenish the deficit of starch content in reserve by the onset of dormancy. However, the reduced rooting capacity that was indicated by the pull test results may suggest that the need to replenish starch reserves in the canopy reduced the amount of root growth that was able to occur during the post harvest period, a critical time for cranberry root growth. In the A area, reallocated starch in reserve from the brown canopy are not efficiently utilized due to the limited photosynthetic capacity of the minimal green canopy, as a result, the reallocated carbohydrates and starch tend to accumulate in the green tissue, but are not used for growth resulting in the inability to replenish the carbohydrates in the brown canopy which leads to canopy collapse.

Section 3: Evaluation of Management Practices (Obj. 2b)

Materials and Methods

Experimental Design

Experimental plots were established in May 2016 in the two study beds (bed F and H: see [Field Locations and Objective Assignment](#)). In each bed, 12 1m² plots isolated by 50cm margins were established in 2 grids layed out with 3 treatments x 4 reps for a total of 8 reps per treatment. ([Figure 3-1](#)). Three treatments, 1.25 cm and 2.54 cm sand applications and a control (no sand application), were randomly assigned to each plot. Sand was applied by hand. Data collected included; upright density, canopy depth, root capacity (pull-test), and yield. The plot markers were removed before the commercial harvest in 2016 and replaced to establish the plots in May 2017.

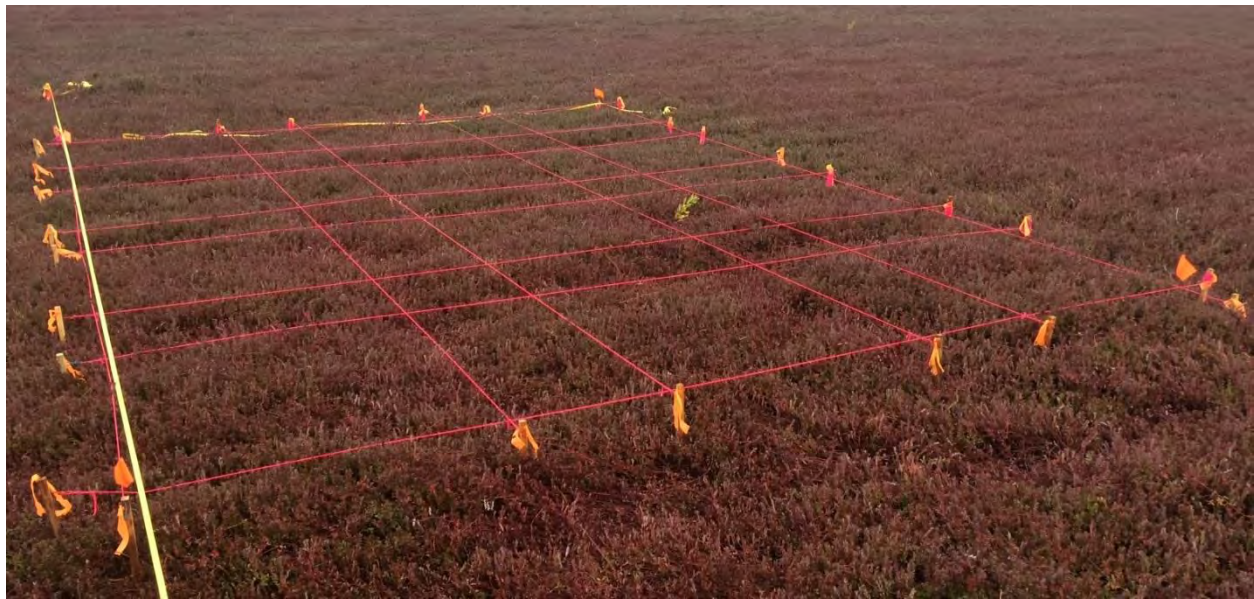


Figure 3-1: A set of experimental plots for the sanding trial (Obj. 2b) in Bed F consisting of 3 x 8 plots. Each plot is 1m x 1m. Plots were isolated by 50cm wide buffers.

Upright Density (Obj. 2b.1)

Upright density was measured in June 2017 by counting the number of uprights within 30 x 30 cm² quadrat for both vegetative and flowering uprights within each plot.

Canopy Depth (Obj. 2b.2)

Canopy depth was measured June 2016 and 2017 for both green and brown canopy with a ruler. Four subsamples were taken at random locations within each plot, which were averaged to represent the canopy depth of each plot.

Root Health Estimate (Obj. 2b.3)

Root health was estimated by performing Pull-test at each plot. (see [1b.3. Root Health](#) for the details).

Yield Analysis (estimate in bbl/acre) (Obj. 2b.4)

Yield was measured in 30 x 30 cm² quadrats in each plot. Berries were sorted into marketable and unmarketable groups and were counted and weighted for the analysis. Sampling was done in early October, before the commercial harvest, in 2017.

Results

Upright Density (Obj. 2b.1)

The mean number of total uprights between treatments in Bed F did not differ, while that in Bed H showed a significant difference between the control and 2.54 cm of sand treatment. The mean number of the flowering uprights between the treatments in Bed F as well as Bed H did not differ significantly (*Figure 3-2*).

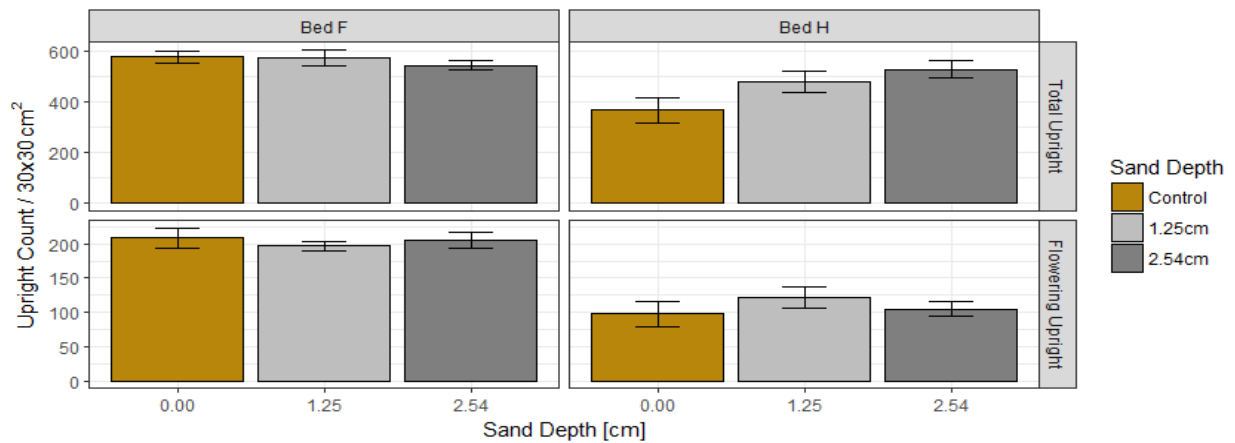


Figure 3-2: Total and flowering upright counts were compared between the different sanding depths in each bed. (n=8) The error bars indicate standard error of the mean.

Canopy Depth (Obj. 2b.2)

Canopy depth did not show any significant difference between the treatments in both Bed F and Bed H (*Figure 3-3*).

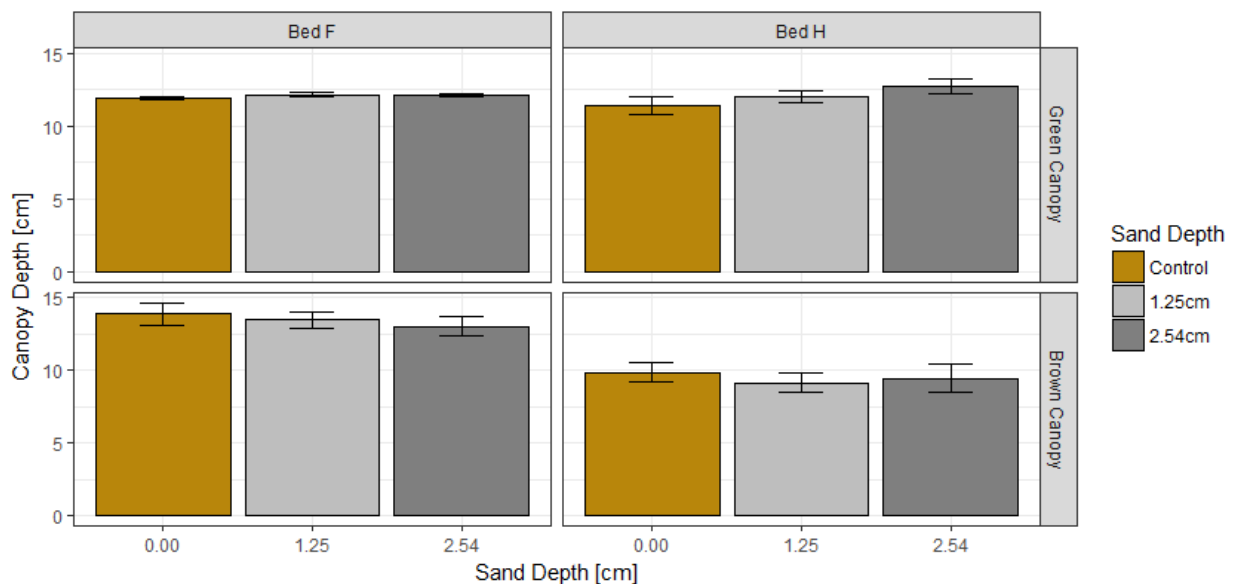


Figure 3-3: Green and brown canopy depths were compared between the different sanding depths in each bed. (n=8) The error bars indicate standard error of the mean.

Root Health Estimate (Obj. 2b.3)

The mean unrooted volume under the canopy (VUC) between the treatments did not differ significantly in either of the beds. However, in Bed H, the mean VUC was slightly decreasing (insignificant) as the sand treatment becomes deeper, while that in Bed F showed no trend. The mean VUC was significantly lower in Bed F than Bed H at all levels of sand depths (Figure 3-4).

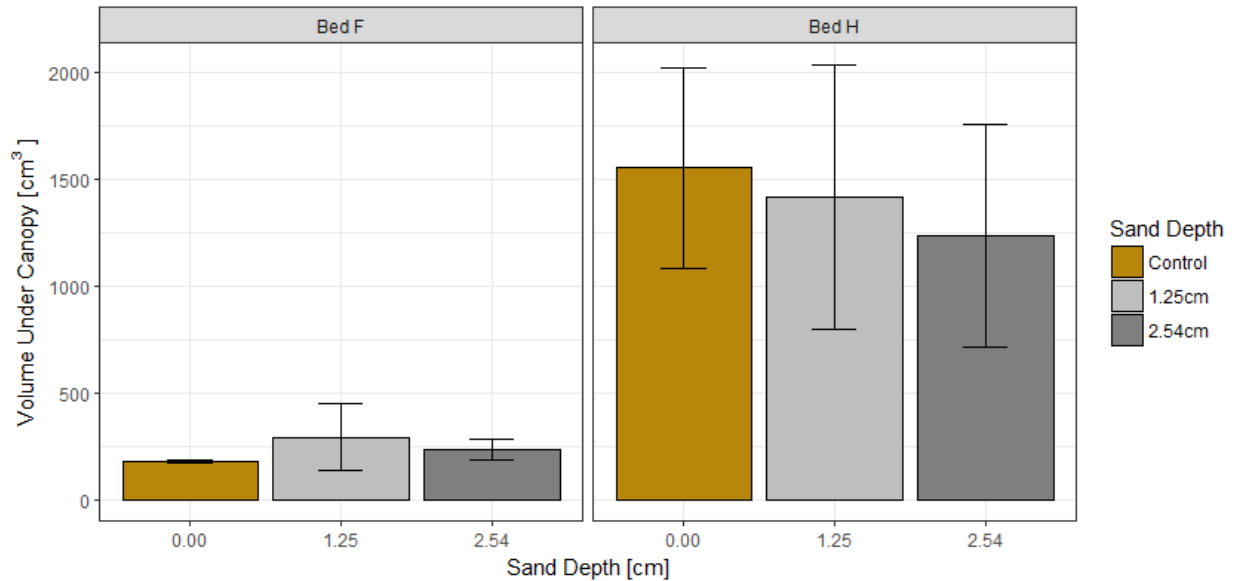


Figure 3-4: Unrooted volume under canopy was measure by pull-test and compared between different sanding depths in each bed. (n=8) The error bars indicate standard error of the mean.

Yield Analysis (estimate in bbl/acre) (Obj. 2b.4)

The mean yield estimate did not differ significantly between the treatments in both beds. However, the mean yield estimates were significantly higher in Bed F than Bed H at all sand depths (Figure 3-5).

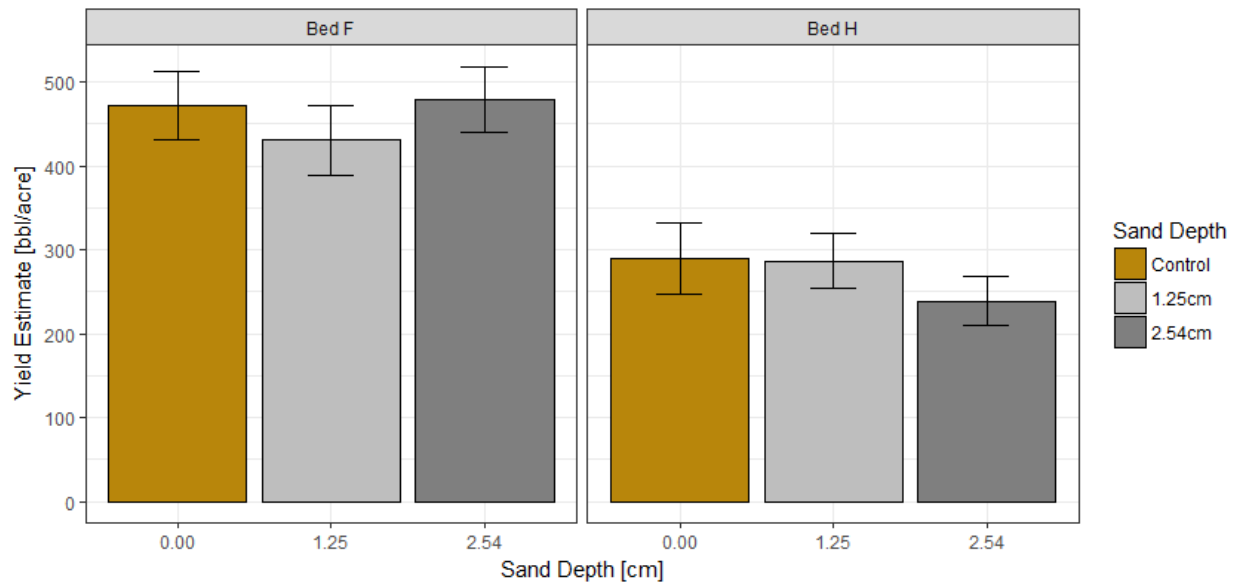


Figure 3-5: Yield estimate was compared between the different sanding depths in each bed. (n=8) The error bars indicate standard error of the mean.

Discussion

Plant growth characteristics, in general, did not show any significant difference between the 3 different sand depths, except for the slight increase in upright density with 2.5cm of the sand treatment in Bed H compared to the control. The lack of response by the plant growth to the sand application may be due to the relatively small amount of sand applied in comparison to the total canopy depth. In many other regions, a sand application of 2.5cm would have a significant impact on plant growth and yield, however that sand depth represents a much larger proportion of the canopy depth due to the much smaller canopies.

As for the root health, the slight decrease in VUC in bed H may indicate an improvement of root density; however, the result is inconclusive due to the high variability. As for the differences in the root health between the bed, the significantly lower VUC in Bed F than Bed H at all sand depths indicated the significantly better bed condition in Bed F than Bed H. This observation in root health is consistent with the result of yield analysis that yield in Bed F was significantly higher than that in Bed H in all sand depths. The significant relationships between the VUC and bed conditions are also observed in the previous section that the size of VUC was significantly related to the CFD conditions (see [Root Health, Obj. 1b.3](#)).

The significantly higher total upright density under the 2.5 cm sand treatment was only seen in Bed H which indicated the different response from the plant growth to the sand application depending on the degree of root health in beds. It is likely that the headroom for the improvement regarding the biomass per area is significantly lower in healthy beds with sanding treatment. The resource acquisition by the existing roots in Bed F was sufficient to maintain the optimal growth and development of the shoots, which did not have as much headroom as the plant in Bed H did for the improvement. The increase of rooting seen in the declining VUC in the 2.5 cm sand treatment in Bed H, although the difference was statistically insignificant, may have improved the resource supply to the photosynthesis and the metabolism which increased the total upright density. This result carries a significant implication on the management practices as results of root health estimate by Pull-test can be a deciding factor for the sanding treatment.

Recommendation on Management Practices

The current study indicated the rooting capacity in the CFD affected areas was significantly reduced. The differences in CFD conditions were shown to be highly correlated with the reduction of the non-structural carbohydrate stored in the vines. These results suggest that the plants growing in CFD affected areas have reduced photosynthesis due to the insufficient resource uptake through their degraded and stunted roots, which causes the depletion of the carbohydrate reserve, leading to the reduction of structural integrity and eventually the declining symptom. Based on this analysis, three main aspects can be considered for the formulation of management practices: monitoring of the canopy depth and rooting capacity, improving rooting ability and improving energy use by the plants.

Canopy may become excessively deep over time. Brown canopy alone can be more than 15-20 cm deep above the soil surface, and it is challenging to manage the canopy in such depth. To avoid such situation, we recommend monitoring the canopy by measuring the canopy every year to track the change in the canopy architecture. As well, we recommend watching the rooting capacity by performing Pull-test which current study demonstrated its effectiveness in detecting the reduced rooting capacity and the degree of CFD development.

The most critical factor for improving the rooting capacity is the provision of growing medium to the young vines. We recommend sanding before the depth of brown canopy becomes excessive. Sand presses the canopy down and forces the young canopy to have good contact with the soil surface. Ideally, the first sanding may be done in the third year after the planting, and the following sand application may be every 2-3 years afterwards. It is essential to keep in mind that excessively deep canopy requires a more considerable amount of sand to be effective as old vines located near the existing soil surface have a low rooting capability. Therefore, beds with deep canopy may be benefited from the combination of mid-heavy pruning and sanding. Thinned canopy is more easily to be pressed down by the weight of the sand and has good contact between the younger vines and the sand.

The efficiency of energy use by plants can also be improved by the canopy management. Excessively accumulated old vines require more energy to maintain their functionality than the upright can generate through photosynthesis. Also, plants tend to prioritize the replenishment of energy reserve in the vines than in growing roots, and therefore, the excessive canopy depth can lower the root/shoot ratio. Additionally, pruning reduces the upright density and decreases mutual shading, which is beneficial for the canopy management as pruning not only improves the light interception but also prevent uprights from growing excessively tall.

Reference

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