Characterization of Cranberry Decline in British Columbia Cranberry Beds
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Summary

The overall aim of this project is to characterize cranberry field decline across the region and identify contributing factors in order to develop a strategy and tools that will allow growers to identify beds that are at risk, develop best management practices to prevent the occurrence of CFD and to provide recommendations for fields that have symptoms of CFD. Previous research suggest no pathogens or insects are involved as the primary cause. However, it does appear that altered soil characteristics resulting from an increased rate of peat degradation as well as reduced oxygen content are more closely correlated with this syndrome. The data that has been collected over the past field season has provided valuable information about the soil environment that is related to the occurrence of cranberry field decline.

Over the past field season, the research team has completed a comprehensive survey of the study sites which included a survey of peat depth, plant growth analysis and detailed soil analysis, historical production practices survey and climate survey at the 6 study sites.

Defining BC Cranberry Production Systems:

BC cranberry beds have several unique characteristics that are not shared with other growing regions. Two major factors that contribute to this difference are the peat based beds, compared to sand based systems in other regions and the thickness of the canopy. As most of the research carried out on cranberries has been conducted in sand based systems, many of the standard definitions and characterization of production systems are not applicable in BC. The establishment of terminology and methodologies to characterize BC's cranberry production systems is critical to developing baseline data to begin to systematically develop a research-based understanding of BC cranberry beds in order to ensure new technologies and production practices are utilized appropriately to enhance the sustainability of the BC cranberry industry. In this project, the characterization of canopies and soils and the use of satellite imagery as a diagnostic tool to identify areas that are affected by CFD is providing valuable data to develop management practices related to CFD and also to develop a deeper understanding of BC's unique production system.

Objective 1: Examine, map and describe the distribution and spread of cranberry field decline over the past 10 years in BC cranberry beds

1. Examine, map and describe the distribution and spread of cranberry field decline over the past 10 years

> **1.1.** Assemble a collection of satellite and aerial imagery for affected cranberry production areas in Richmond and Pitt Meadows areas for the past 10 years.
>
> **1.2.** Map areas within cranberry beds affected with cranberry field decline using current and historic aerial and satellite imagery to determine the rate and pattern of spread.
>
> **1.3.** Using a GIS approach, collect soils maps and hydrologic data as well as land use/land cover layers to evaluate landscape level patterns in the development of cranberry field decline.
>
> **1.4.** Identify 5 affected beds to be used for ground based investigations. In addition, identify at least 5 non-affected beds that can be used as healthy comparisons

In the site selection process, there were 6 farms that were identified as ideal for site investigations. These six sites represented a range in severity of CFD symptoms and also represented different aged beds. During the site selection process, it was determined that due to the high degree of variability across all the sites, the non-symptomatic comparisons would be taken from the same farm in the vicinity of the field in order to allow the identification of key variables that differ between symptomatic and non-symptomatic areas. Therefore, at each site, there were more samples collected and analyzed from three defined areas; 1) CFD affected areas 2) transitional areas (adjacent to the CFD affected areas) and 3) non-symptomatic areas. This approach has allowed for the understanding of the physiological plant characteristics and the soil characteristics that are associated with the appearance of CFD.

Image analysis was carried out using the exhibit A imagery provided by ocean spray. The image analysis indicated that many of the occurrences of CFD appear to be related to irrigation and drainage while other fields appeared to develop in a more random pattern. This relationship between soil moisture and CFD is supported by the soil analysis data that is presented below. The occurrence of CFD does not appear to be related to geography as there are fields where one has extreme CFD symptoms while adjacent field shows no indication of symptoms.

Analysis of the study sites using NDVI indicates that there is great potential to use this type of imagery as a diagnostic tool to determine the development of CFD prior to the symptoms being obvious in the field. With the increased accessibility of aerial imagery, there is great potential to utilize this this imagery as a diagnostic tool for early detection of CFD. Future work would be focused on correlating the diagnostic data collected in the field on a wide range of beds to NDVI imagery.

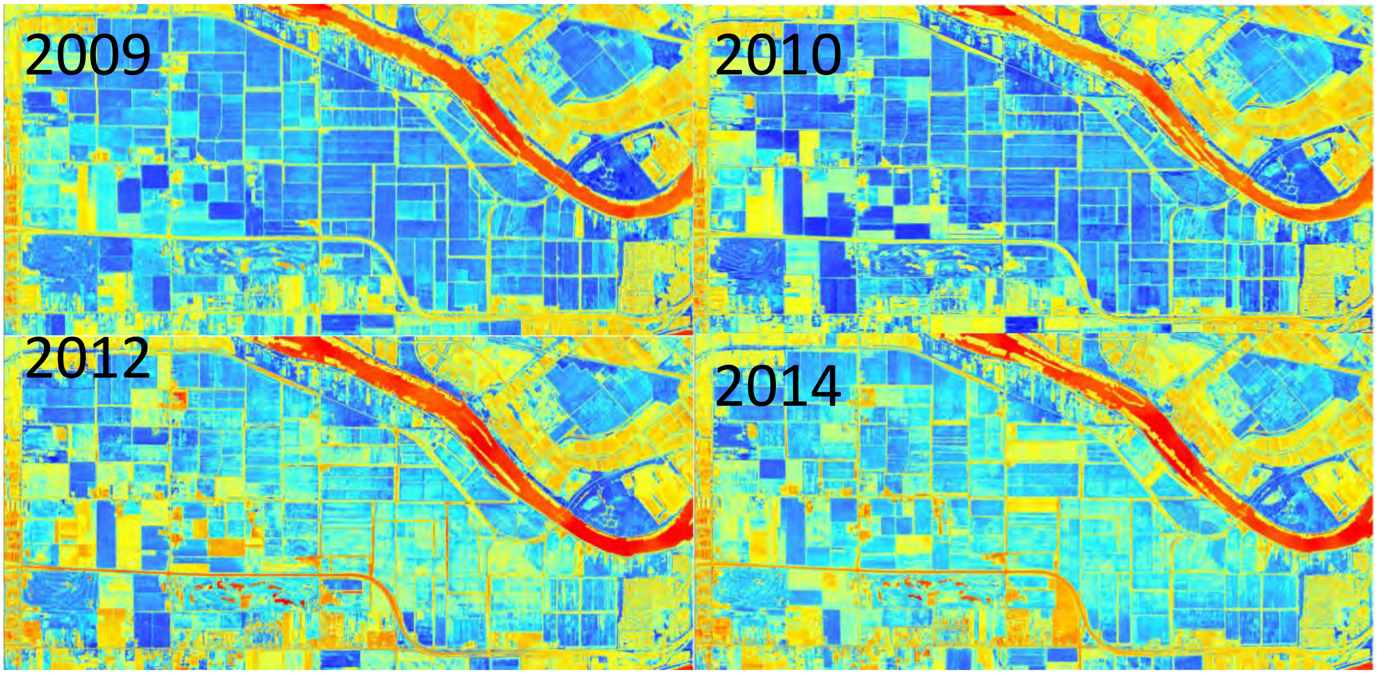

Fig.1 NDVI imagery of cranberry beds in Richmond, BC. Dark blue indicates high vegetation with decreasing vegetation with lighter colour.

Objective 2: Detailed characterization of cranberry beds to evaluate correlations between cranberry decline symptoms and soil and plant characteristics

2.1. Develop a bioassay to evaluate the rooting capacity of affected vines and soil

2.2 Assemble detailed soil data to establish the rate of soil decomposition and baseline oxygen/redox potential for soils with and without cranberry field decline.

2.3 Determination of soil profile characteristics by ground penetrating radar and core analysis.

2.4 Collection of plant growth data to evaluate correlation between plant characteristics and cranberry decline

2.5 Collection of historical and current crop management records and weather data for the 5 intensive sampling sites.

During the field season, much of the research carried out was focused on characterizing the soil and plants in cranberry beds with and without CFD symptoms to identify the factors contributing to the decline. The soil and plant work will allow for the development of best management practices to prevent, manage and treat CFD.

2.1. Develop a bioassay to evaluate the rooting capacity of affected vines and soil

This objective was intended to identify if there are chemical components in the soil that may be preventing the rooting of cranberry plants in the soil. As a preliminary test, samples of the rooting medium in a severely affected area were taken with as little disturbance as possible and placed in plastic bags, and in a plug tray. Cuttings of plants from an unaffected plant in the same bed were stuck in the trays to determine if rooting occurred. Rooted cranberry plugs were planted into this rooting medium and seeds of cranberries taken from the same bog were dropped on the soil medium in sealed plastic bags. From the same site a 3 inch core was taken to a depth of 20 centimeters. Into each of the top profiles we placed two cranberry cuttings to root.

Cranberry cuttings rooted in the soil profiles and in the soil from the affected area in the plug trays did not appear to be inhibited as rooted developed in a normal time frame. In the sealed bags the cranberry seeds germinated and grew to one leaf stage before the bags were opened. Plugs continued to grow out and appeared with no signs of stress. There appeared to be little effect of the soil on germination of cranberry seeds or the growth of the seedlings.

The results of these tests suggested that from these in vitro trials there may not be immediate effects from the soil like toxic gases or components. It was determined that although the cores were taken carefully, the disturbance was sufficient to change the rooting environment which may have contributed to the development of CFD. As a result it was decided to pursue other areas of the cranberry field decline project.

Soil Profile Characterization across study beds

One of the most unique aspects of BCs cranberry production system is that cranberries are grown on peat soils. Peat is a challenging medium to grow crops as peat requires saturated conditions in order to maintain its structure and prevent decomposition whereas cranberries required well drained soils.

Methods

In order to develop an understanding of the conditions of the peat, one meter soil cores were collected across each of the 6 study sites to determine the depth of the peat and the degree of dehumification at each site. The soil cores that were sampled at each site were taken from the entire field and therefore include areas that were showing symptoms of CFD and other areas that were not. Dehumificaiton is measured using a method called the VanPost scale, which is a ‘squeeze test’ commonly used to quantify the state of decomposition of a soil. This was carried out for each of the soil cores (Appendix D). The scale ranges from 1 (raw, undecomposed peat) to 10 (highly decomposed peat). For each site, a map was generated that illustrates the depth of peat and a data table (Appendix E) was generated defining the degradation of the peat at varying depths of the soil. The data was analyzed to develop histograms that depict the frequency of a certain Van Post rating.

Results

The 1 meter soil cores provided an overview of the depth to the underlying clay layer and also provided information about the soil horizons throughout the site. Most of the sites had varying depth to the clay layer across the beds. It does not appear that the depth to the clay layer is a consistent factor in developing CFD as the fields were highly variable. However, a shallow soil layer may increase the risk of developing the soil conditions that contribute to CFD due to poor drainage through the soil profile and it is likely an important factor.

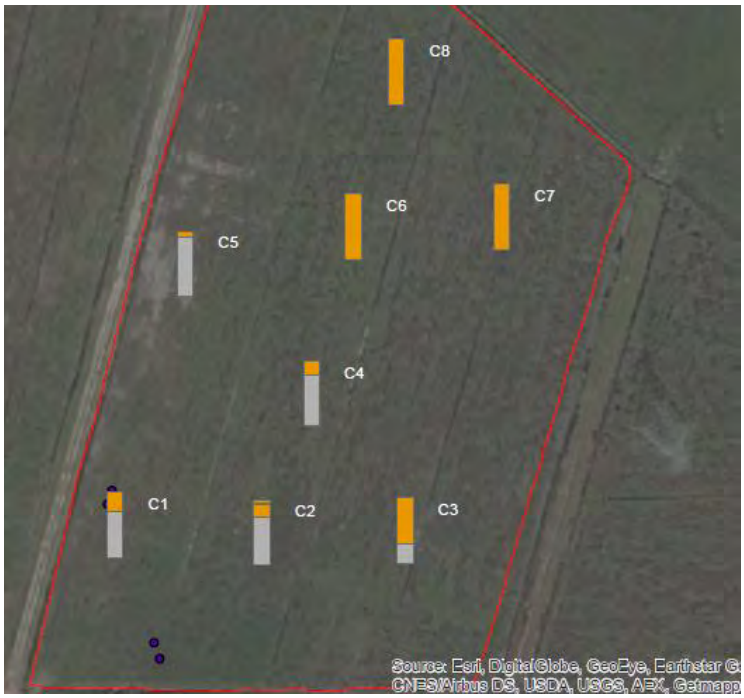

Fig 2. Example of soil core map for site 4. Each bar represents one 1m core collected at the site. Yellow bar indicates peat and grey portion of the bar represents clay.

2.2 & 2.3 Assemble detailed soil data to establish the rate of soil decomposition and baseline oxygen/redox potential for soils with and without cranberry field decline. Determination of soil profile characteristics by ground penetrating radar and core analysis.

L.M. (Les) Lavkulich and J.E. (Julie) Wilson

INTRODUCTION

Cranberry fields in the Lower Mainland of British Columbia are experiencing “field decline”. Some cranberry fields that were healthy have developed a network of “patches” where the vines no longer produce a crop and eventually die off (Figure 3). Preliminary results suggest that the soil in the decline areas does not have a root environment that provides the appropriate balance between available water and oxygen for effective root respiration. It has been found that the soil substrate and the rooting zone is heterogeneous and variable, which is believed to result in inadequate rates of air exchange in the rooting zone. The origin of organic soils (peat) are known to be horizontally layered through a vertical crosssection. Individual layers of varied origin of organic matter and degree of decomposition accumulated as the peat bog developed. The thickness of the peat is not uniform but varies as affected by the underlying mineral terrain on which the organic material has accumulated. In the Delta area of BC, peat deposits are found mainly as accumulations of organic materials over floodplain deposits (alluvium), and can have a thickness from a few centimeters to over a meter.

The horizontal layering is the result of the variable growth conditions from open water to fen to bog over the past 10,000 years. The original fen materials, derived from sedges and rushes, are more readily decomposed than the bog plant remains derived from mosses, willows and a few coniferous species. The hypothesis is that this, in addition to management practices of leveling, drainage, and fertilization, has resulted in a heterogeneous rooting zone for the cranberry vines.

For healthy root growth, atmospheric air enriched with oxygen must diffuse from above the soil surface into the rooting zone; in addition, the carbon dioxide from root respiration within the rooting zone must diffuse to the atmosphere. As the diffusion of air is directly related to soil porosity, adjacent thin layers of differing porosity retard the uniform rate of air diffusion (see Appendix A). If the rooting zone environment becomes deficient in oxygen it will become anaerobic. This can be assessed by measuring the oxidation-reduction, or redox, status of the soil. Preliminary results of two fields sampled in 2014 provided evidence that there is greater humification, or presence of clay layers, with lower porosity and lower “redox” potential in the decline soil areas in comparison to the adjacent non-symptomatic areas (Table 1). Typical soil redox potential ranges are presented in Appendix B.

Table 1.Preliminary soil data collected from Affected (A) and Non-Symptomatic (NS) patches at Site 1 OM=Organic Matter

Sample Number	pH in water	pH in $CaCl_2$	Redox in water (mV)	Redox in $CaCl_2$ (mV)	Ammonia (mg/kg)	Nitrate (mg/kg)
A1a	4.15	2.83	210	298	0.73	1.14
A1b	4.20	2.97	211	301	0.70	1.26
A2a	4.26	3.19	207	279	0.55	2.90
A2b	4.28	3.17	205	282	0.40	2.70
A3a	4.47	3.02	198	289	0.47	0.46
A3b	4.44	2.89	198	293	0.52	0.47
NS1a	4.42	2.78	203	298	0.18	0.12
NS1b	4.39	2.92	201	295	0.15	0.13
NS2a	4.24	2.86	211	298	-	-
NS2b	4.20	2.88	212	304	0.13	0.12
NS3a	3.90	2.65	227	308	0.14	0.13
NS3b	3.94	2.66	229	308	0.18	0.13

This research report focuses on the soil aeration/water/nutrient conditions in the cranberry root environment between decline ("Affected") areas and adjacent "Non-Symptomatic" areas.

Figure 3. Cranberry field exhibiting patches of decline (dark grey) in Richmond, BC.

METHODS

Six (6) sites (fields) exhibiting the range of severity of cranberry field decline were selected in collaboration with research partners. At each site, a transect of approximately 5 metres long was laid out, intersecting both an Affected (A) area and an adjacent Non-Symptomatic (NS) area, resulting in two "plots" per field (Figure 4).

Around each transect, soil cores were taken to a depth of one metre (the photographs in Appendix C show only the top 50 cm) to record the stratigraphic layers underlying the A versus NS areas. The stratigraphic core analysis provided an assessment of the number and thickness of layers within the soil column, as each layer has a unique porosity and hence a gaseous diffusion rate.

Samples were collected from all depths examined. Photographs were taken of the cores in the field and the morphologically different layers were identified, Samples were taken to the UBC Soil-Water-Environment Lab (SWEL) and analyzed for pH and estimation of organic matter content by the method of Loss on Ignition (LOI). Samples from two sites were examined for a preliminary assessment of redox (Eh) and degree of humification In addition, an exploratory assessment of field electrical conductivity was done with a remotely operated above-ground mobile unit that traversed a total distance of about 50 metres. The transect included a decline area and the adjacent NS region.

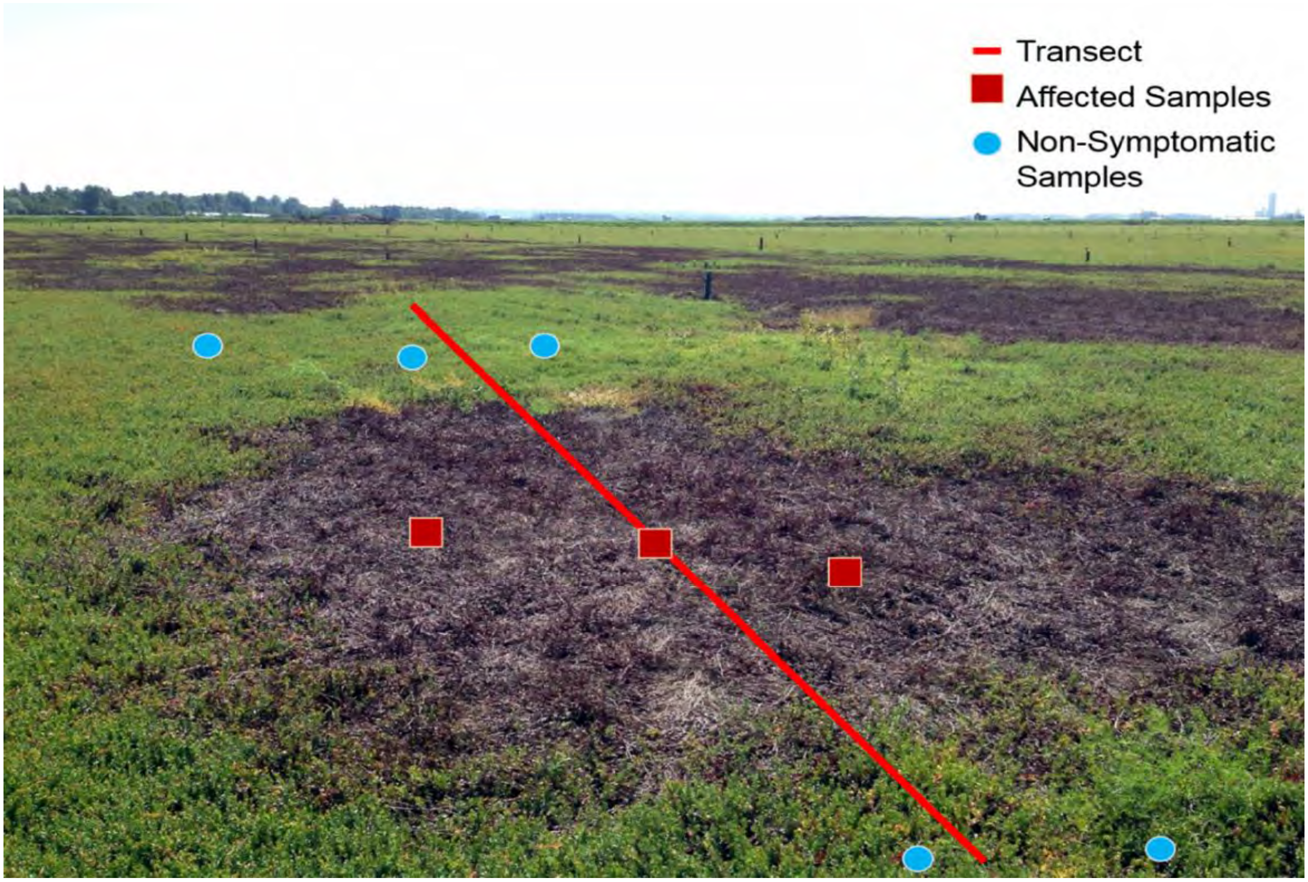

Figure 4. Example of field transect and soil core sample locations. Each site contains 3 samples from affected areas (1 sample directly on transect), and 5 samples from non-symptomatic areas.

Note: In January 2016, each transect will be re-sampled at the 6 sites for detailed measurement and analysis of water level, redox potential, pH, and available nitrate (NO_3) and ammonium (NH_4). These measurements will be done at 0 to 15, 15 to 30 and 30 to 45 cm depth intervals.

To ascertain if ground penetrating radar can be employed to assess the degree of humification, water content and porosity "remotely", a mobile unit will be employed at each transect to allow the calibration of the ground penetrating radar signature to measured root zone conditions.

RESULTS

Soil Organic Matter

Percent organic matter was measured in each distinct layer of the soil profile down to 50 cm for each sample (all data presented in Appendix C). Results presented here focus on the soil depths directly associated with cranberry rooting zone (0-15 cm), and the layers immediately below this

(15-30 cm). Percent organic matter values presented here represent a weighted average for these two soil depths (Table 2, Figures 5 & 6). The results show clearly the variability among the six sites including by depth and thickness of visibly different layers of the soil material. Although not conclusive decline sites tended to contain lower amounts of organic matter than adjacent NS sites and there appears to be a slight increase in organic matter with depth in the NS sites. The opposite seems to occur in the decline sites. Appendix C provides more comparative data.

Table 2. Weighted average percent organic matter on both affected and non-symptomatic samples, at 0-15 cm and 15-30 cm depth.

SITE	Affected Sample Mean (n=3)		Non-Symptomatic Sample Mean (n=5)	
	% Soil Organic Matter (0-15 cm)	% Soil Organic Matter (15-30 cm)	% Soil Organic Matter (0-15 cm)	% Soil Organic Matter (15-30 cm)
Site 1	22.4	22.0	32.5	28.0
Site 2	24.2	21.5	27.8	21.3
Site 3	9.1	18.0	11.6	16.1
Site 4	17.1	12.2	16.3	11.8
Site 5	15.4	21.3	21.3	19.6
Site 6	14.7	18.1	28.9	24.5

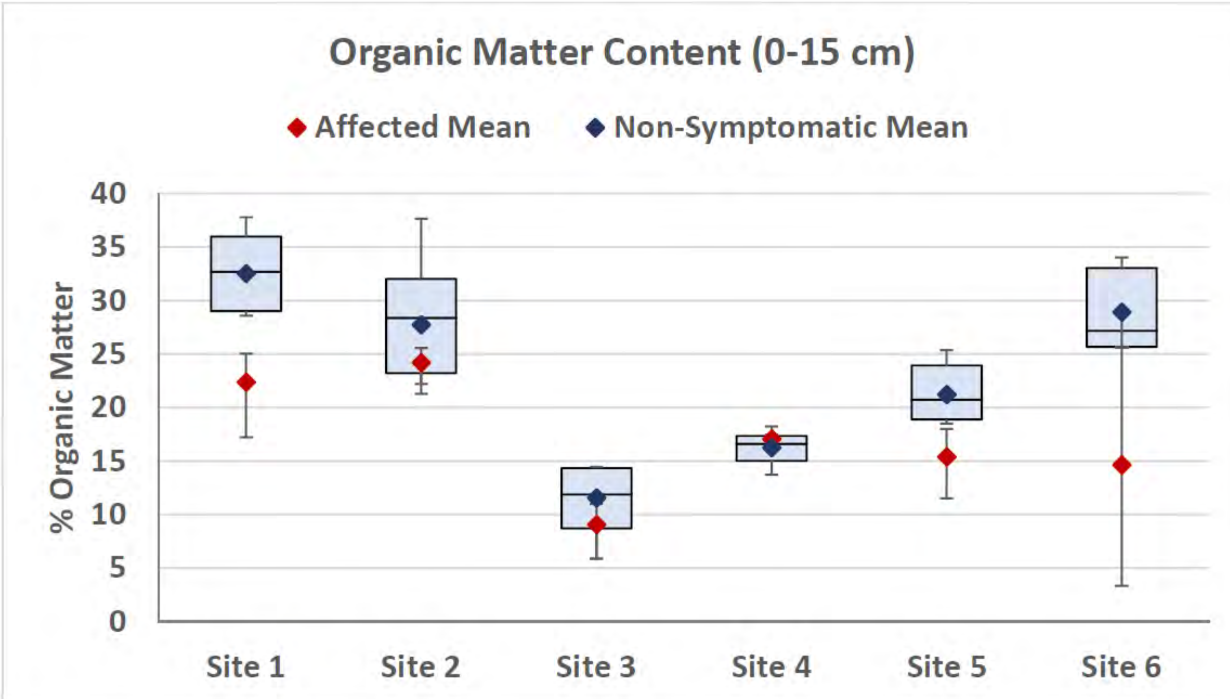

Figure 5. Weighted average % OM content, 0-15 cm. Affected samples in red (n=3), non-symptomatic (NS) samples in blue (n=5). Boxplots presented only for NS samples. Whiskers represent minimum/maximum values.

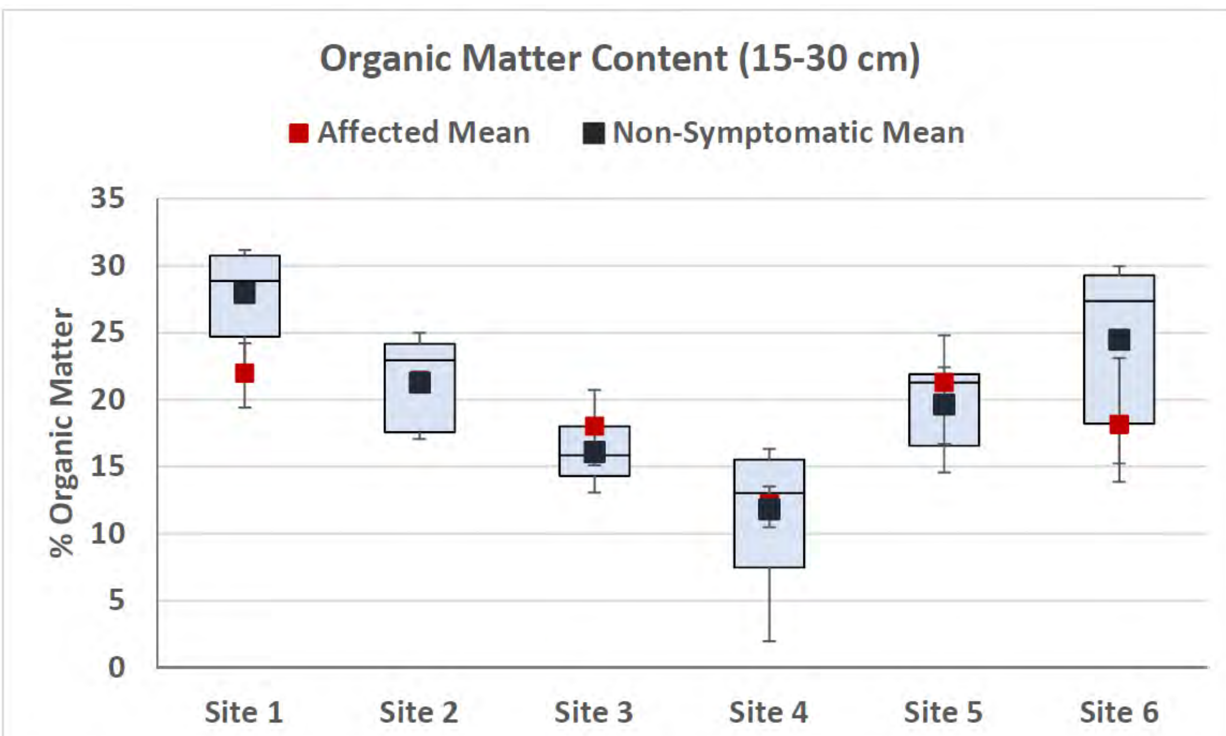

Figure 6. Weighted average % OM content in the 15-30 cm depth. Affected samples in red (n=3), non-symptomatic samples in blue (n=5).

Soil pH

Soil pH was measured in both water and $CaCl_2$. Figure 5 shows a strong correlation between pH in water and pH in $CaCl_2$ and the rest of our results are reported for pH in water (Table 3, Figures 7, 8 &9). Not surprisingly there is a strong relationship between pH measured by the two methods. The major difference noted is that the affected decline sites have a greater range of pH and tend to be greater than the NS sites. The NS sites values are clustered between pH 3 and 4.5

($CaCl_2$) in the NS sites. This suggests that the soil conditions are less variable in the NS sites when compared to the A (decline) values.

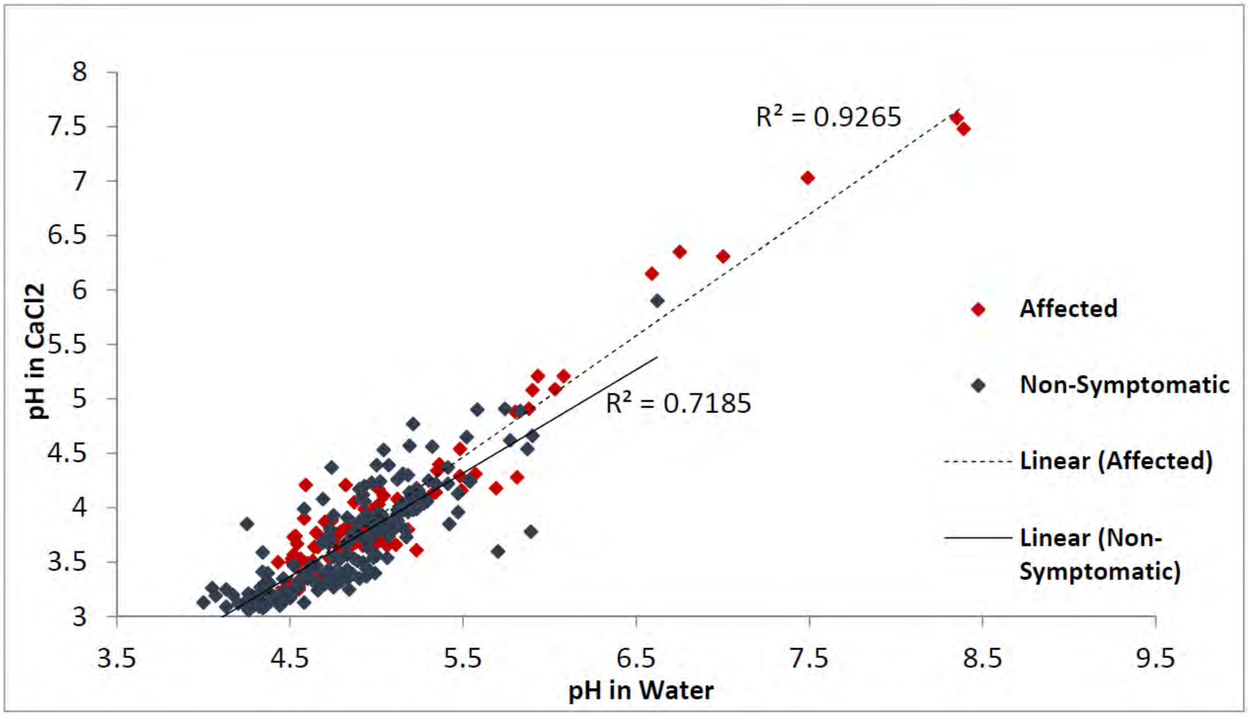

Figure 7. pH measured in water versus pH measured in $CaCl_2$ for all samples collected on affected and nonsymptomatic sites.

Table 3. Weighted average pH in water on both affected and non-symptomatic samples, at 0-15 cm and 15-30 cm depth

SITE	Affected Sample Mean (n=3)		Non-Symptomatic Sample Mean (n=5)	
	pH in water (0-15 cm)	pH in water (15-30 cm)	pH in water (0-15 cm)	pH in water (15-30 cm)
Site 1	4.63	4.51	4.23	4.30
Site 2	4.66	4.64	4.16	3.73
Site 3	5.13	4.84	5.07	4.83
Site 4	4.83	4.74	5.17	4.94
Site 5	6.87	4.96	5.36	5.01
Site 6	4.74	4.68	5.01	5.12

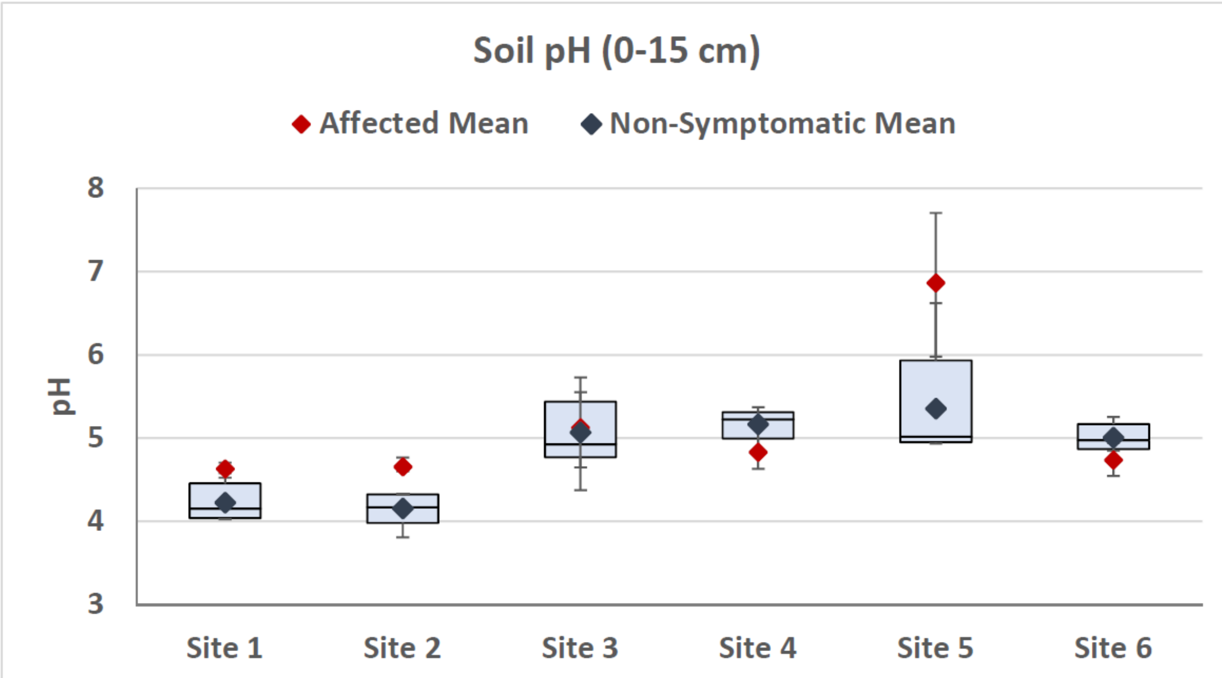

Figure 8. Weighted average pH measured in water, 0-15 cm. Affected samples in red (n=3), non-symptomatic samples in blue (n=5). Boxplots presented only for NS samples. Whiskers represent minimum/maximum values.

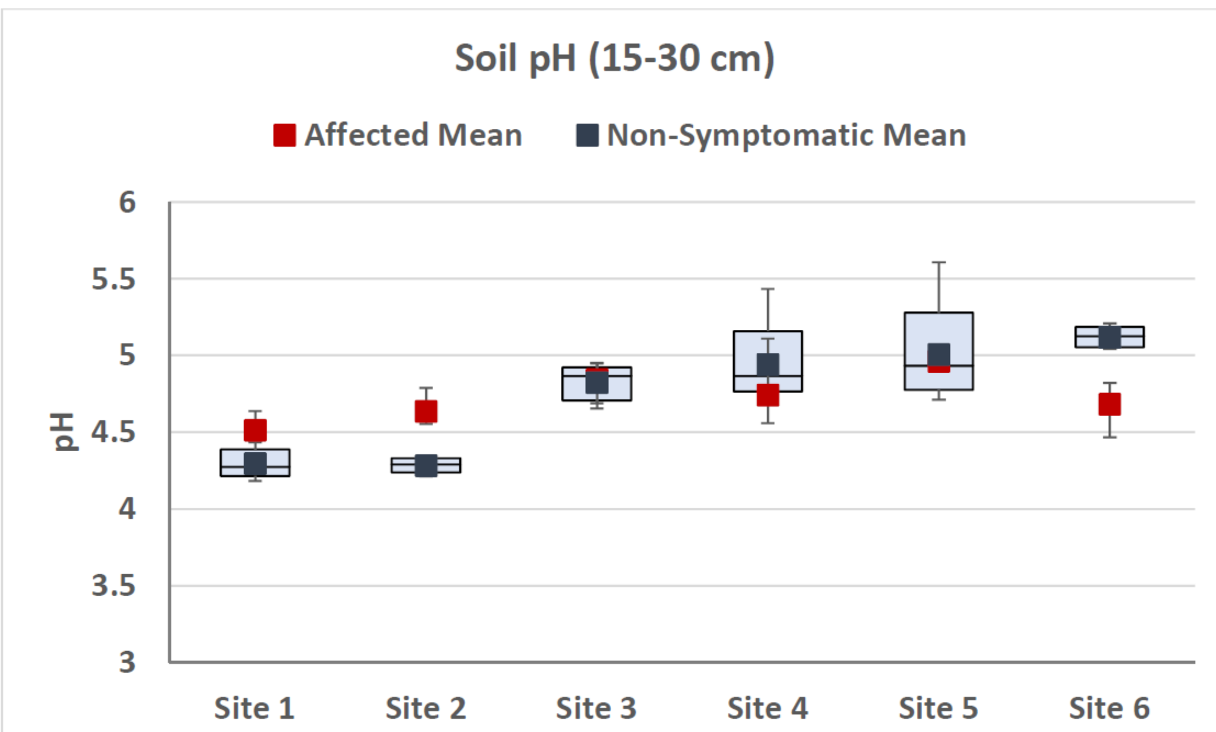

Figure 9. Weighted average pH measured in water, 15-30 cm. Affected samples in red (n=3), non-symptomatic samples in blue (n=5). Boxplots presented only for NS samples. Whiskers represent minimum/maximum values.

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Soil Organic Matter and pH Relationship

Anomalous soil characteristics were investigated by first identifying outliers in a correlation of soil pH and soil OM at both 0-15 cm depth (Figure 10), and 15-30 cm depth (Figure 12).

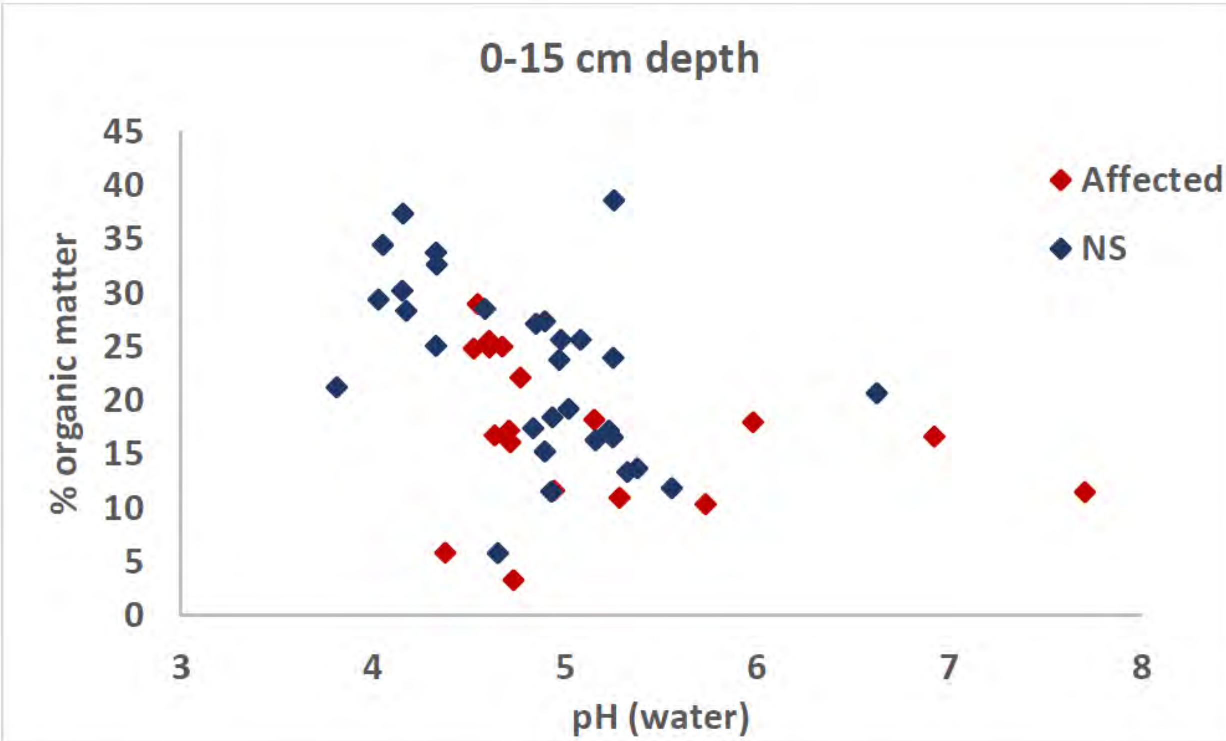

Figure 10. Comparison of the weighted average pH and % organic matter of affected and non-symptomatic (NS) samples, 0-15 cm.

At the 0-15 cm depth, there were four samples with unusually high pH values (_ 6). In general, the high pH was observed to be associated with high degrees of decomposition or presence of mineral material (e.g., Site 5). It also appears that this field has been sanded. Mineral horizons in the rooting zone correlate with higher pH values.

In addition, there were three samples with low soil OM (<10%), two of which were found in Site 3. Here, a distinct sand layer was observed, contributing to the reduced % OM (Figure 11). The third sample with low OM was collected at site 6, but upon visual verification of the soil core photo, this calculation appears to be a laboratory error: the OM content is expected to be much higher based on the dark blackish-brown soil color from 0-20 cm depth.

Sample ID	Interval (cm)	Color	pH in water	pH in CaCl2	% LOI
S3-NS4-A	0-3	7.5YR 2.5/2	4.34	3.59	3.78
S3- NS4-B	3-10	7.5YR 2.5/1 to 5YR 2.5/2	4.69	4.08	1.95
S3- NS4-C	10-13	10YR 2/1	4.83	3.91	9.32
S3- NS4-D	13-19	10R 2.5/1	4.69	3.68	17.35
S3- NS4-E	19-23	5YR 2.5/2	4.70	3.71	16.15
S3- NS4-F	23-27	5YR 2.5/1	4.63	3.45	16.33

Figure 11. Example of a soil core sampled at Site 3, NS plot, with a clearly visible sand layer in the cranberry rooting zone from 3-10 cm.

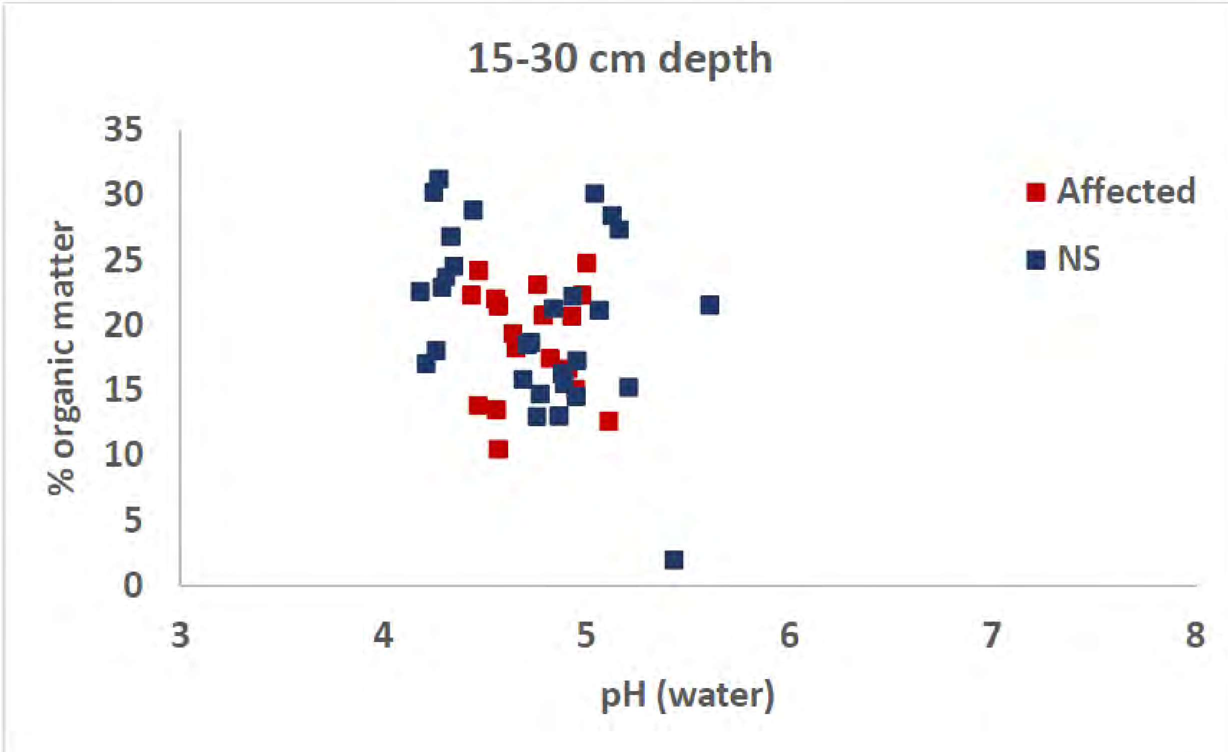

Figure 12. Comparison of the weighted average pH and % organic matter of affected and non-symptomatic (NS) samples, 15-30 cm.

At the 15-30 cm depth, one sample from Site 4 had very low % OM (<2%), due to the presence of a thick clay layer extending from ~13 cm deep to the bottom of the profile (>50 cm) (Figure 13).

Sample ID	Interval (cm)	Color	pH in water	pH in CaCl2	% LOI
S4- NS4-A	0-10	7.5YR 2.5/1	5.22	4.16	20.00
S4- NS4-B	10-13	7.5YR 2.5/2	5.20	4.12	18.03
S4- NS4-C	13-24	2.5Y 4/2	5.29	4.06	2.29
S4- NS4-D	24-28	2.5Y 5/1 to 4/1	5.54	4.24	1.72
S4- NS4-E	28-40	2.5Y 5/1	5.87	4.54	1.03
S4- NS4-F	40-51	2.5Y 4/1	5.41	4.37	1.61

Figure 13. Example of a soil core sampled at Site 4, NS plot, with a distinct, extensive clay layer from 13 cm to >50 cm depth.

Number of Soil Layers

The average number of visibly distinct soil layers in the 0-30 cm depth was generally higher in Affected samples than in Non-Symptomatic samples (in all sites except Site 2) (Table 4). Although the total number of visibly distinct layers do not differ between the two sites there is a suggestion that the number of layers in the upper 30 cm of the rooting zone are greater in the A (decline) sites. This observation needs to be quantified by more detailed sampling and measurements of redox conditions within each distinctive layer. This will be one of the major tasks during the next field studies to be conducted in January 2016.

Table 4. The average number of soil layers (distinguishable by observed color differences) found in the top 30 cm of affected and non-symptomatic soil samples at all sites.

	Average number of layers in top 30 cm	
Site Number	Affected Samples	Non-Symptomatic Samples
Site 1	3.3	2.8
Site 2	3.3	3.6
Site 3	6.0	5.8
Site 4	5.0	4.2
Site 5	5.3	4.2
Site 6	4.3	4.0
Overall	4.6	4.1

Electrical Conductivity

Figure 14 provides a preliminary evaluation of utilizing above-ground surface measurements of electrical conductivity as a measure of dissolved ions or chemicals, in soil solution in the upper portion of the rooting zone of a cranberry bed. Blue and green colors indicate low levels of dissolved ions, or and correlate with NS patches, while yellow and red are illustrative of increased ion concentrations, and correlate with Affected patches. The higher the concentrations of the measured ions, the lower the oxygen content. The figure illustrates the heterogeneity of the surface of the cranberry field over a distance of approximately 50 m.

The high degree of agreement between the preliminary conductivity measurements and the observed patches of cranberry field decline indicate the potential utility of this tool to measure the susceptibility of fields that could be transitioning into an affected state (symptoms of decline).

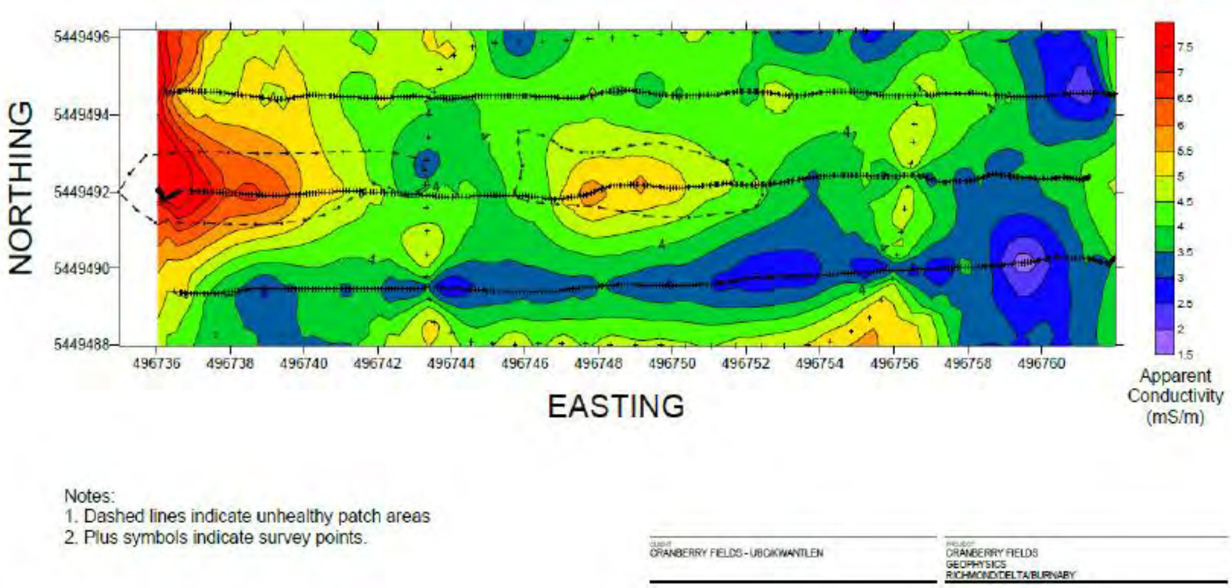

Figure 14. Example of a heat map of electrical conductivity (red = high, blue = low) values. High values are correlated with observed cranberry field decline affected areas (dashed lines).

SUMMARY

The results confirm the hypothesis that the observed decline areas within the cranberry beds have soil characteristics that restrict the exchange of air between the cranberry rooting zone and the atmosphere. Root respiration and microbial activity within the rooting zone produce carbon dioxide and other gases such as hydrogen sulfide, which result in a deficiency of oxygen required for healthy root growth. The deficiency of oxygen contributes to anaerobic conditions within the rooting zone. This may be assessed by measuring the redox potential (an indicator or the presence of oxygen).

The major concern that requires remediation is to enhance the exchange of air from the root zone and the atmosphere. The fields are inherently variable as a result of the history of the bog prior to the establishment of cranberry beds. The original layering of the organic materials of different degrees of decomposition (humification), and variable thicknesses to the underlying mineral subsoil, modified by leveling and bed preparation has exacerbated the heterogeneity of the soil medium, especially the active rooting zone (0-15 cm). Soil core samples and the electrical conductivity survey confirm this heterogeneity. Soil pH tends to be higher in affected areas, as well as the number of contrasting layers. Soil pH indicated anaerobic conditions and increased humification and contrasting layers of different degrees of humification, or organic layers interspersed with mineral (clay) layers restricts air (and water) movement within the active rooting zone.

Future investigations to be conducted prior to the next field season include a detailed examination of the transects within the six fields to assess field measurements of redox potential and degree of humification between Non-Symptomatic and adjacent Affected areas.

2.4 Collection of plant growth data to evaluate correlation between plant characteristics and cranberry decline

The symptoms of CFD include weak plant growth, brittle vines, abnormal root growth and development, low root:shoot ratio, and in severe cases, death of the vines. Plant growth data was collected in both non-symptomatic areas, transition areas and CFD affected areas to determine the characteristics that exist as the bed moves towards showing CFD symptoms. This analysis was carried out on the same 6 sites as the detailed soil data collection. When the research team began the field work to characterize the growth parameters, it became quickly apparent that the methodologies typically used in cranberry growth analysis were not appropriate for BC cranberry beds. Therefore, new methodologies and terminology was developed to describe the beds.

Canopy Characterization

Methods

The canopy structure of BC cranberry beds is unique compared with any other growing region due to both the depth and composition of the canopy. In most regions, the canopy is limited to the depth of the uprights and a minor amount of older runner growth beneath. The cranberry beds that were included in the study appear to be fairly typical for the growing region with canopies that are 20-30cm in depth. In order to describe the canopy, it was necessary to divide the canopy into two distinct sections, the ‘green canopy’ and the ‘brown canopy’ depth. This separation is necessary due to the different physiological function of the two components of the canopy.

Green Canopy (Fig.15A)– this is the photosynthetically active component of the canopy that represents the portion of the canopy that contributes to accumulating new carbohydrates through photosynthesis. The effectiveness of the green canopy is partially dependent on the overall health of the plant as well as the microclimate in the canopy particularly in regards to light, temperature and humidity as all these factors directly influence photosynthesis.

Brown Canopy (Fig. 15B) – this portion of the canopy is composed of non-photosynthetically active material and does not contribute to the assimilation of carbon, but plays an important role in the storage of carbon in the plant. This woody tissue can provide a source of carbohydrate for plants during early spring growth, and can provide a source of carbohydrates if either photosynthesis or root function is compromised.

Runner length – although the research team had planned to collect data on runner length and number, the architecture of the canopy and the length of the runners made this a very difficult variable to quantify.

Results

There are two key observations related to the measurements of canopy depth. The first is that the depth of the green canopy remains relatively constant between the areas that were non-symptomatic and the transition areas but then shows a significant drop (Fig.15A). The second key observation was that although the green canopy depth did not change much between the transitional and non-symptomatic areas, the brown canopy showed a constant decrease in depth as you moved from non-symptomatic to affected areas (Fig.15B). The decreased depth in the brown canopy is likely caused by an increase in dead wood which becomes brittle and compresses with the weight of machinery that moves over the bed (ie. sprayer, beaters). As previously mentioned, the brown canopy can function as a carbohydrate reserve. If the plant is unable to meet carbohydrates (due to reduced rooting capacity or other stress) the plant will utilize carbohydrates stored in the brown canopy. If the plant continues to use reserve carbohydrates faster than it is able to replenish them the tissue will die. This relationship between the canopy health and carbohydrate reserve is an important factor in the development of CFD.

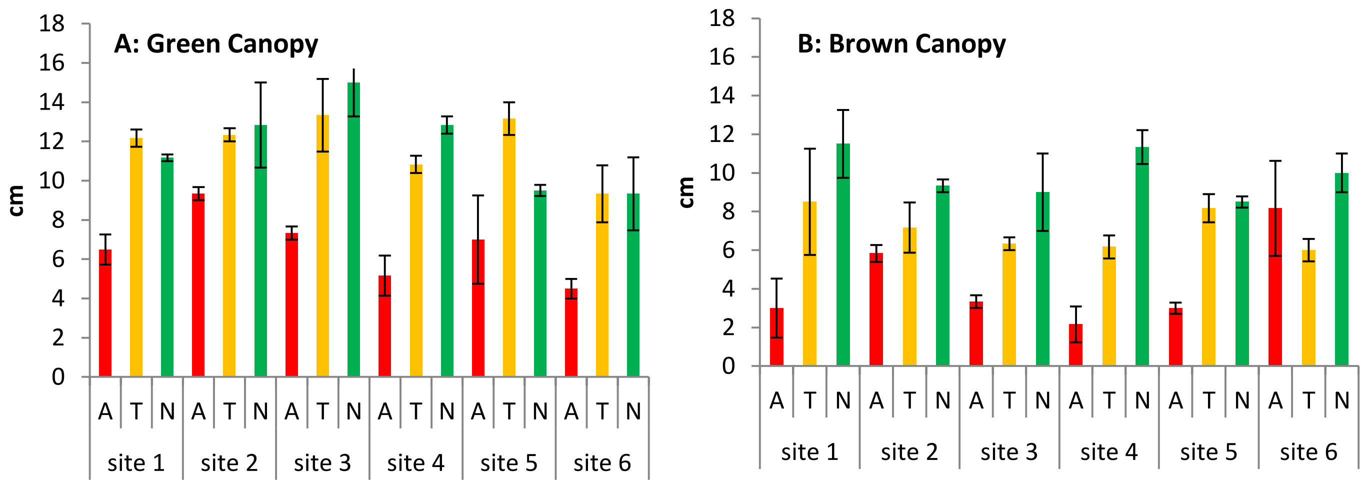

Fig.15: Green canopy depth (A) and Brown Canopy Depth (B) recorded in areas with a range of CFD symptoms (A: affected, T: transition, N: non-symptomatic) at each study field (site 1 to 6). Black error bars indicate standard error (variability) around each mean value.

The resource allocation of carbohydrates from the brown to the green canopy is further supported by the data collected on upright density (Fig. 16). Square foot counts were carried out at all six sites and in 5 of the 6 sites, there was no decrease in upright density until the canopy was severely affected by CFD when upright density dropped dramatically. This is again consistent with the tendency for plants to allocate resources to plant components that are actively growing and therefore have the highest need for carbohydrates.

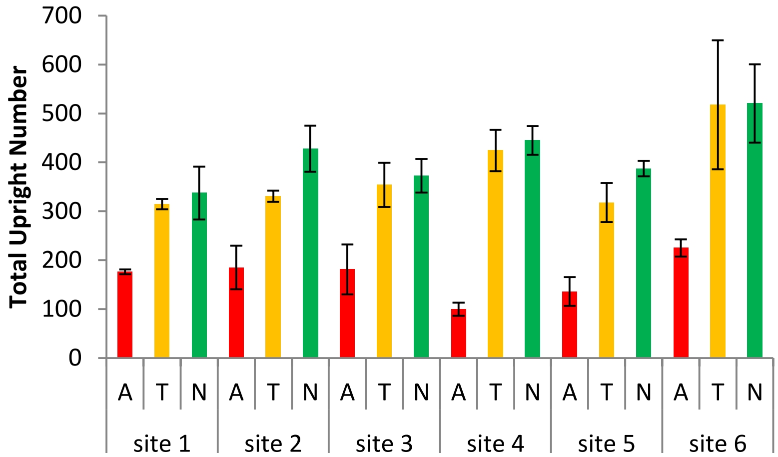

Fig.16: Mean total upright count per ft^2 for each condition (A: affected, T: transition, N: non-symptomatic) at each study field (site 1 to 6). Error bars indicate standard error (variation) around the mean.

Whole Plant Growth Analysis

Methods

Prior to harvest a destructive plant analysis was carried out to quantify growth on a fresh weight and dry weight basis. 4 3" core samples were collected from each area (non-symptomatic, transitional and affected), washed and separated into roots, brown canopy and green canopy and weighed for fresh weight (Fig. 17). Plant material was then placed in a drier at 70^0 C and dried until constant weight. Yield data was collected at each site using a square foot quadrat. Three separate square foot measurements were collected in each of the areas (affected, transitional and non-symptomatic) at each site.

Results

Consistent with the canopy depth data, plant biomass was significantly reduced in the affected areas compared to the transitional and symptom free area. There was no significant decline in the green canopy between the transitional and symptom free area, but there was a significant decrease in the amount of brown canopy. As the brown canopy is a major source of stored carbohydrate, the maintenance of the green canopy may have been facilitated by the stored carbohydrate in the brown canopy. As the reserves in the brown canopy are depleted, the tissue dies and becomes more brittle resulting in reduced depth and mass. This may provide some evidence as to the hypothesis that the canopy is likely under stress for a significant period of time before showing symptoms and the symptoms suddenly appear when the reserves in the plant have been depleted causing the canopy to collapse.

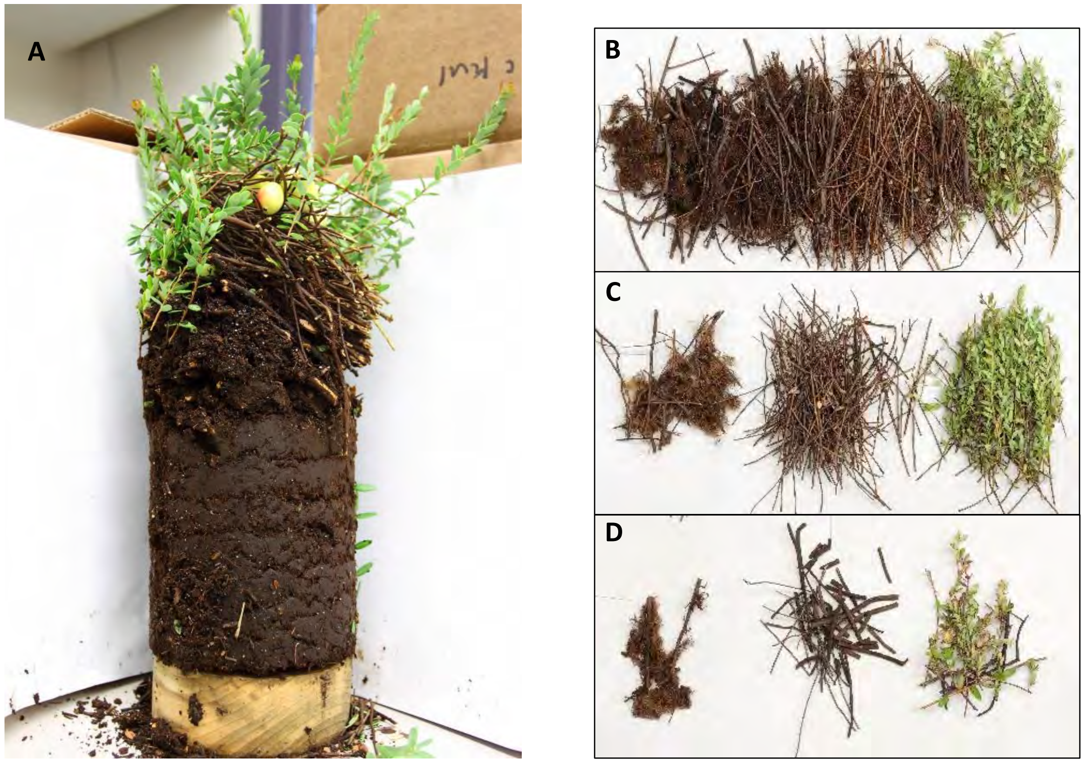

Figure 17. Plant material from the canopy growth (above soil material) from a non-symptomatic site (B), transitional site (C) and the affected site (D).

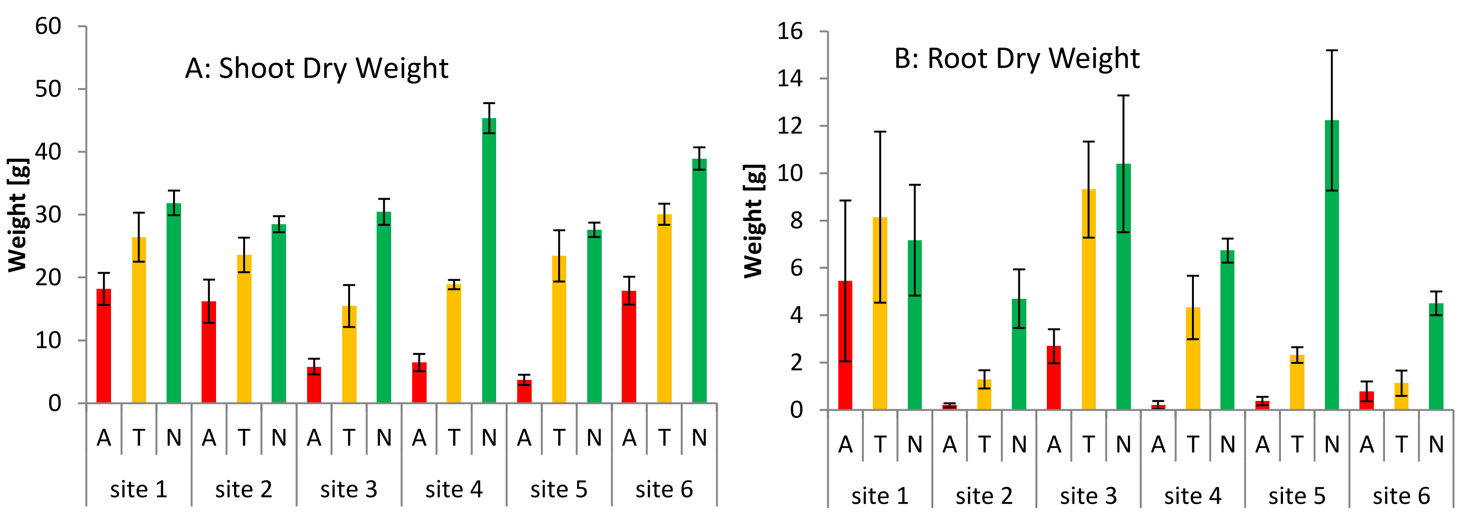

Figure 18. Dry weight of (a) shoot and (b) root for each condition (A: affected, T: transition, N: non-symptomatic) at each study field. Error bars indicate standard error around the mean.

Yield data from the same plots showed significantly reduced yields in areas that were highly affected by CFD, however in the transition areas, only one site (site 3) had reduced yields in the transition area with 3 sites showing higher yields in the transition areas (Fig.19). This increase in yield is consistent with the upright counts collected earlier in the season. When plants are under extreme stress they will respond by allocating resources to reproductive growth. The data was consistent with the flowering upright and total flower number collected earlier in the season as well.

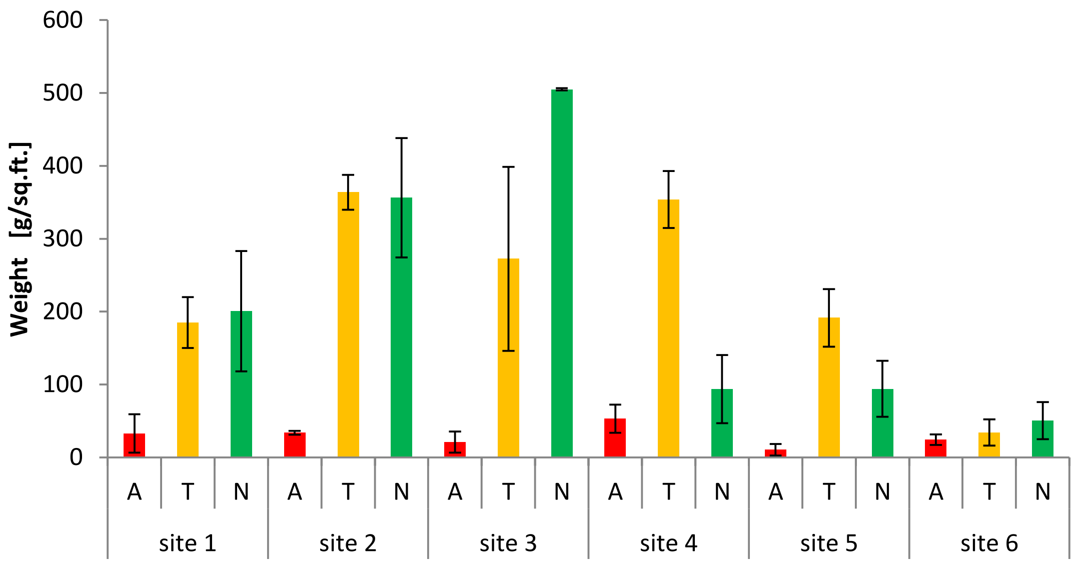

Fig. 19. Total yield per ft^2 for each condition at each study field. Error bars indicate standard error around the mean.

Conclusion

The canopy of cranberries growing in BC are unique due to the existence of the brown canopy which can act as a storage reserve but also can create a physical barrier to the soil surface which may contribute to the poor rooting density of the canopies. The ability for the brown canopy to provide a reserve allows the plantings to continue producing crops even under conditions where the rooting capacity is not sufficient to meet crop demands. As a result, the appearance of CFD symptoms are not seen until the planting has been under significant stress for a long period of time. The symptoms associated with CFD do not occur until the planting has reached a point where the reserves in the canopy are depleted and the plant unable to meet the crop needs due to the compromised root system and reduced rooting capacity.

2.5 Collection of historical and current crop management records and weather data for the 5 intensive sampling sites.

The historical and current management records were collected for the all study sites that are included in the 5 intensive sampling sites. Weather data is also being collected from the closest weather station available for each site. Management data requested includes nutrient, water and pest management, yield, sand applications, renovations, etc. Weather data will include precipitation, temperature, light and where available, soil moisture. Data will be used to inform the interpretation of soil and plant data collected and with the image analysis.

A survey with each of the growers for the six decline study sites were carried out through the fall of 2015. Survey areas of concern are shown in Appendix A. We asked for the history of the beds in question, and for the last 4 years the fertilizers applied and any upgrades to irrigation and drainage systems. We reviewed the last 4 years of pesticide use reports filed with Ocean Spray of Canada, Ltd. and grouped pest management into 4 groups for comparison. The survey information was derived from in person interviews and exchanges of information when all the information was not available.

We targeted those farm practices and infrastructure that may contribute to cranberry field decline.

The age of beds with decline ranged from 12-30 years with no apparent connection to the appearance of the problem. Previous crops or vegetation could only suggest that some of the decline sites could be linked to changes in the soil structure especially when clearing the land with trees. Examining imagery of the sites prior to clearing the vegetation may be worth pursuing. It is interesting that in most cases the decline symptoms were first noted in the past 5 years. Fertilizer rates are between 40-50 pounds of nitrogen per acre for 4 of the 6 sites. Combined with the release of nitrogen from the peat and deposition from the atmosphere these may be contributory factors. In most cases the bed yields did not warrant this level of nitrogen. A few of the sites had tissue analysis available and growers did not see any levels of nutrients that would warrant concern. Most of the solid set irrigation systems were similar in design, but operation during frost protection irrigation and harvest did differ and was constantly changing on any one site. Sources of irrigation water were the north arm of the Fraser River for 5 of the 6 sites and one site was supplied water from the main arm of the Fraser River via the No. 6 Road intake. Water contamination was possible but no other foliar symptoms appeared except at Site 5 where we think high electrical conductivity caused some desiccation during 2014 and 2015. Sub-surface drain frequency across the fields did vary considerably, mostly due to the time of planting as a result of the current thinking of that particular year. Some growers have sanded these fields but most have not. Spot treatments were prevalent mostly as a means to counter the cranberry decline.

Pesticide use was looked at initially and again in this survey. Applications of herbicides were of particular interest. Applications of a pre-emergent herbicide, dichlobenil (Casoron), were in the middle of the recommended amounts and most of the product was applied in very early spring. Its herbicidal effect is known to last only about 8 weeks. Test from the previous year's study showed levels of 1 ppm in August after an application of 50 pounds per acre. Assuming a rooting depth of 7.5 cm. this would represent an application amount of 16.5 ppm dichlobenil. Mesotrione (Callisto) applications are known to have pre-emergence effects on young seeds and seedlings. All of the sites only used spot treatments to control weeds. Many of these sites may have been in decline areas. In 2014 no mesotrione residues were found in the soil on severe decline sites. No further documentation is available from each site.

Table 5. Summary data from the grower survey from the 6 sites evaluated.

SITE	1	2	3	4	5	6
AGE OF PLANTING	13	14	30	30	18	25
CASORON	55	55	30-45	50	35-50	50-60
NITROGEN	40-50	40-50	35-40	40-50	6-15	15-20
DRAINAGE SPACING	18	18	40	30-45	15	Sides only

Soil moisture data was collected at three of the sites, however due to malfunctioning soil moisture probes, the data were not reliable for analysis. Weather data was collected from Environment Canada's weather station at YVR for the past 15 years (2000-2015). The data was used to calculate growing degree days, and key weather variables were collected that are most likely to impact plant growth; winter highs, summer lows, GDD and precipitation. Light measurements were not available. Over the period of time that we have seen cranberry field decline develop, there have not been any major weather events that can be determined to have had a significant impact on the decline.

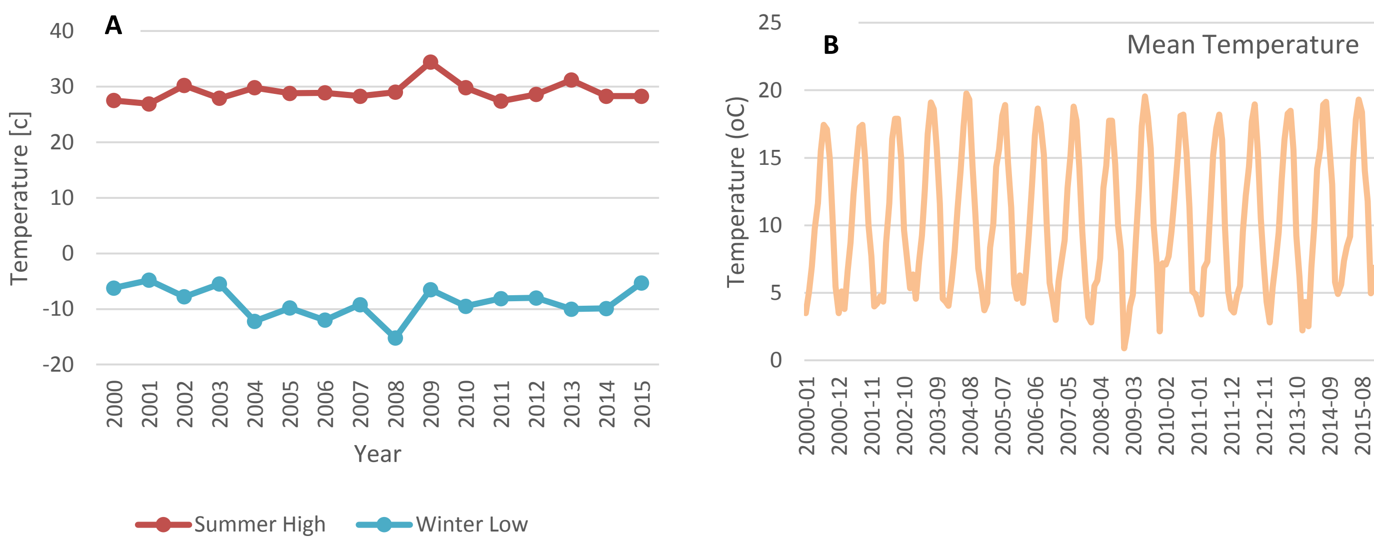

Figure 20. Summer high and winter low temperatures for 2000-2015 (A) and average monthly temperatures (B) Source: Environment Canada

Growing degree days is an important variable that has a significant impact on the development of the crop (Fig.21). The cumulative GDD has not showed any constant trends over the past 15 years with some of the seasons with the highest GDD being from 2004, 2007 and 2014. However, it is important to note that the average winter temperatures in the region are well above freezing and therefore it is likely that there is metabolic activity that continues to occur in the plants. This is important because as opposed to other regions, it means that the plants are not photosynthesizing but continue to require energy to maintain the low level of metabolic activity throughout the winter.

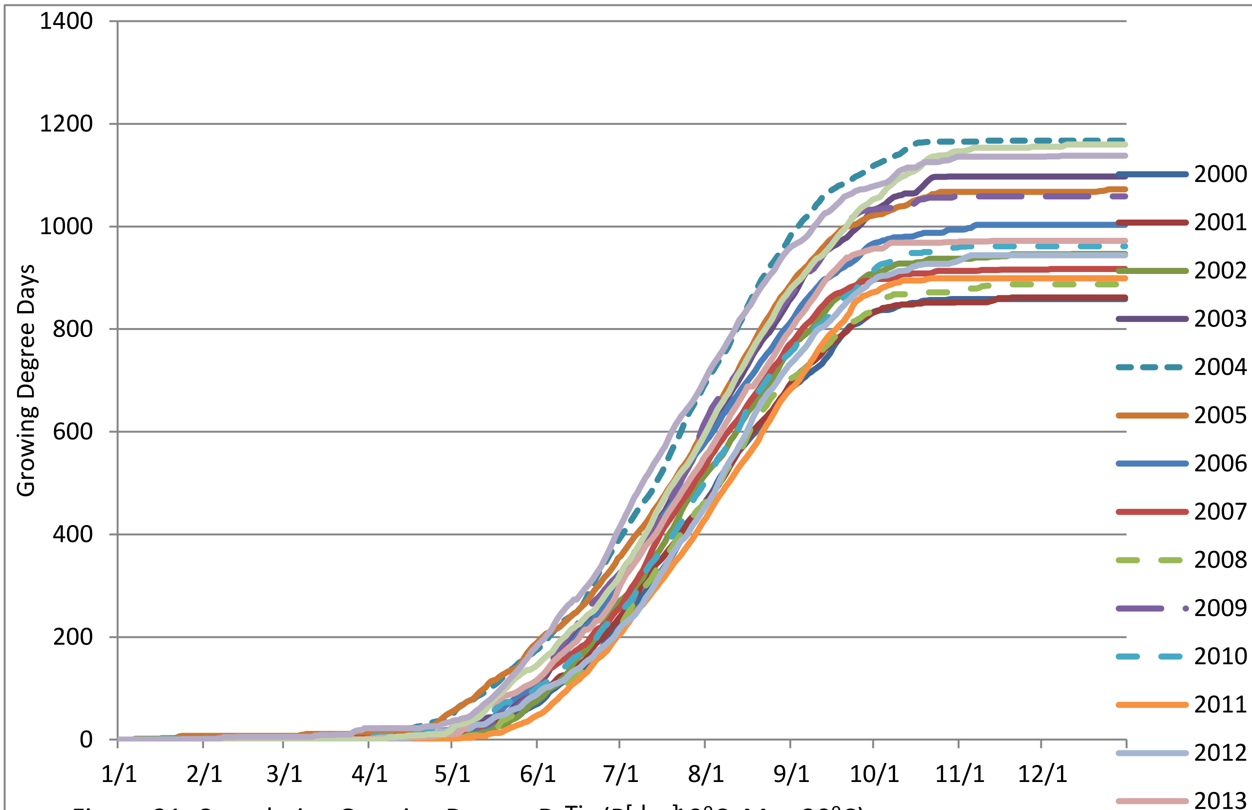

Figure 21. Cumulative Growing Degree Days (Base 10^{0}C, Max 30^{0}C).
Source: Environment Canada

Objective 3. Conduct field trials to evaluate management techniques on beds affected by CFD

This objective was intended to be carried out on a large field that had severe CFD symptoms where different management strategies could be carried out and evaluated for impact. However, there were two factors that resulted in the decision to eliminate objective 3 from the project. In order to address the worsening CFD symptoms, the grower decided to carry out substantial sanding on the bed. As this resulted in a non-uniform field, it would be difficult to carry our controlled experiments where only one management practice was evaluated.

The second factor was that the research team felt that there was not sufficient understanding of the conditions contributing to the CFD to strategically select management practices that should be evaluated. Based on the results of the studies carried out in 2015, the research team has discussed different management options that may address the soil conditions that have been identified as contributors to CFD.

Conclusions

The results of the 2015 data collecting have provided a baseline of information about the cranberry canopy and the soil conditions that are associated with CFD. There are a few key conclusions that can be drawn:

- There is great potential to use NDVI imagery as an early detection tool for identifying fields at high risk for developing CFI.
- The development of the canopy in many cases is resulting in a thick 'brown canopy' which acts as a carbohydrate reserve, but also provides a physical barrier to new growth coming into contact with the soil which would prevent rooting.
- The reduced capacity for new growth to establish roots puts increased need for the development of a strong root system during planting establishment and to maintain the health of the root system.
- The results of the soil analysis indicate that the conditions in the rooting zone are not optimal for healthy root growth due to poor aeration.
- The poor conditions in the soil compromise the root system and result in increased dependence on the carbohydrates reserve in the brown canopy.
- Soil parameters such as pH and redox, humification and layering are potential indicators of risk for developing CFD
- Plant characteristics such as depth of brown and green canopy, rooting density are important indicators or risk for the development of CFD.

Future Work:

- Evaluation of diagnostic tools as indicators for risk of CFD on cranberry beds throughout the region.
- Determine management practices that optimize the soil conditions to promote and maintain healthy root growth.
- Identify management practices that encourage the establishment of a strong root system during the establishment of a new plantings.
- Identify management practices that would optimize the canopy architecture to allow for sufficient carbohydrate reserve while facilitating root establishment.

ACKNOWLEDGEMENTS

The research team would like to thank the BCCMC and Ocean Spray for supporting this project and the growers that have served on the advisory committee for this project.

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Investment Agriculture Foundation of British Columbia

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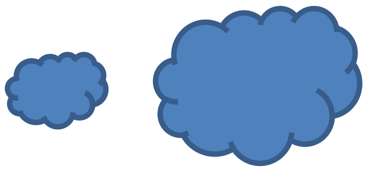
Appendix A. Characteristics of soil pore size and their influence of gaseous movement.

$$\text{Flow} = \pi\, \mathbf{r}^4\, (8\eta)^{-1} \bullet \Delta\Psi_p\, \Delta x^{-1}$$

Most important "**r** "radius of the pore

The rate of flow is proportional to the 4th power of the radius of the pore size or increasing the pore radius by **2** will increase the flow rate by **16**.



0.5"   1.0''

The Effective Diffusion (**D*e***) for transport through pores, is estimated by :

$$\mathbf{D}_e = \underline{\mathbf{D}\,\boldsymbol{\varepsilon}\,\mathbf{t}\,\boldsymbol{\delta}} / \tau$$

Where;

D = the diffusion coefficient of the pores

ε = the porosity ;

δ = the constrictivity , &

τ = the tortuosity

D is about 10,000× greater in air than in water.

IN ONE DAY - air in empty pore can move over 1,400 meters, air in a water filled pore will move about 0.14 meters (5-6 inches)

APPENDIX B. Typical soil redox potential (Eh) value ranges.

	Eh (mV)
Normal Range	-300 to +900
Aerated (well drained)	> 400
Moderately drained	+100 to +400
Poor Aeration (reduced)	-100 to +100
Reduced (water logged)	+100 to -100

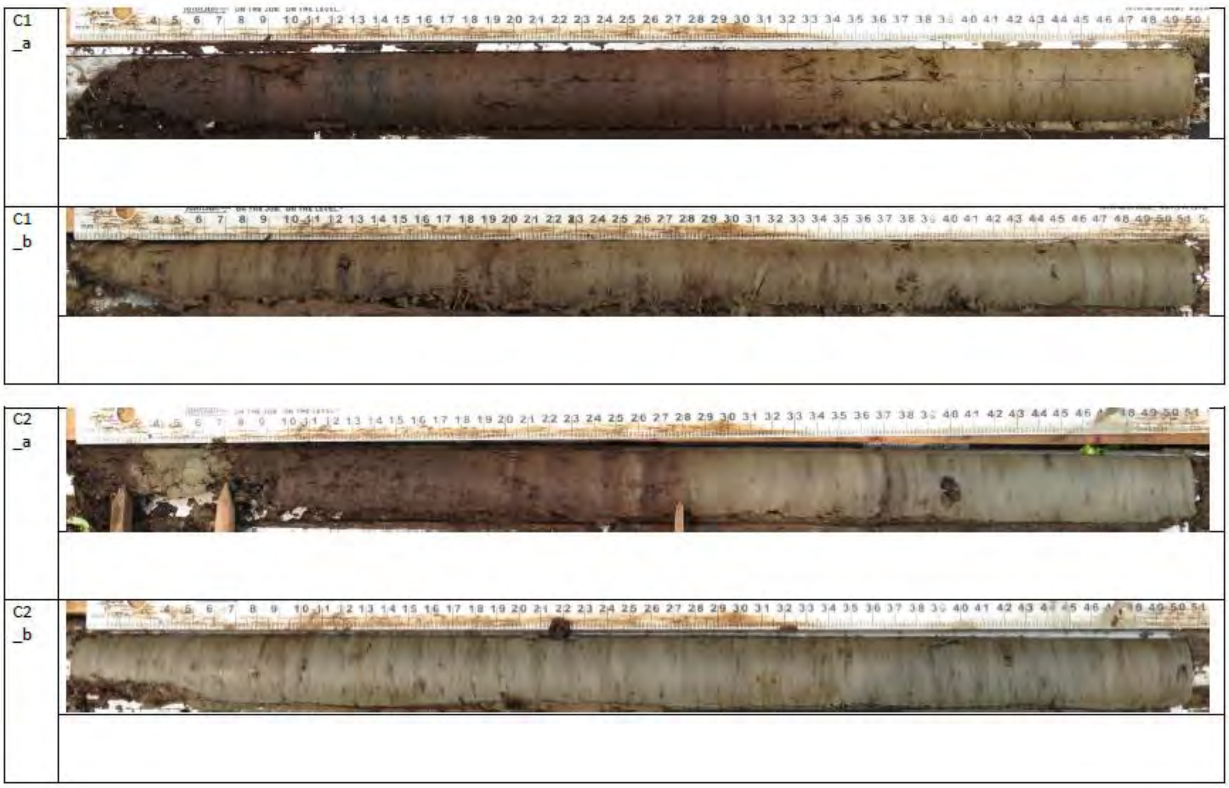
< +350 becomes limiting for most plants
As Eh decreases, bacteria are more adapted than fungi.

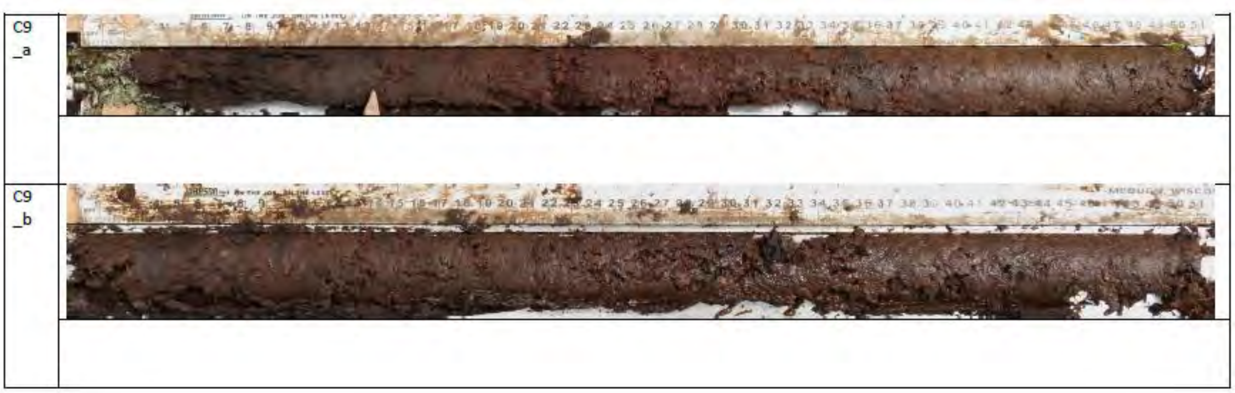
APPENDIX C. Soil sample cores (to 50 cm depth) and associated layer thickness, loss on ignition values (%) and pH (water, $CaCl_2$). Number of soil cores = 48 (3 x Affected and 5 x Non-Symptomatic for each of 6 sites).
Sample labeling scheme: S = Site number, A = Affected (decline) sample, NS = Non-Symptomatic Sample

Attached as a separate PDF file.

APPENDIX D.

Example of soil core photographs taken at each site. Images shown are from site 4 and represent core #C1, #C2 and # C9. Core images allow for detailed documentation of the transition from peat to clay and also provides information regarding horizon development.





APPENDIX E.

Vanpost data for all study sites. Each column represents one soil core with depth intervals from 0- 100 cm. Brown colour indication vanpost rating (1, undecomposed peat – 10, highly decomposed peat) with darker brown indicating higher rates of decomposition. Dark blue colour indicates a mixture of peat and clay, green indicates large pieces of plant material present in the core, light blue indicates sand layer, grey indicates clay.