Final Research Report Prepared for the BC Cranberry Marketing Commission

Critically Assessing Available Soil Moisture Sensors for use in British Columbia Cranberry Production

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Project Title: Critically Assessing Available Soil Moisture Sensors for use in British Columbia Cranberry Production

Project Objectives

1. Provide an objective summary on available soil moisture technology as relevant to British Columbia cranberry growers.
2. Provide a demonstration area at the BC Cranberry Research Farm for soil moisture technology to maximize grower engagement and knowledge transfer.
3. Provide cranberry growers with affordable and practical irrigation management tools to improve overall crop health, yield, and canopy management.

Project Summary

The use of soil moisture sensing technology has the potential to allow cranberry growers to optimize their irrigation practices and better serve crop water demands throughout the season. Through grower extension and farm visits, it was observed that the majority of BC cranberry farms have not yet adopted any kind of soil moisture sensing technology and are relying primarily on visual/textile observation of soil moisture conditions, if any, to gauge to irrigation timing. The small number of farms that have adopted soil moisture sensing technology have opted for the Hortau tensiometer system, which is an effective and accurate system, but is out of economic reach for many BC cranberry producers.

This project sought to test and demonstrate several alternative soil moisture sensing technologies in a field setting, with the goal of providing BC cranberry producers with more affordable soil moisture sensing technology options. This will allow growers to make informed equipment purchasing decisions and analyze sensor compatibility with their unique farm and irrigation needs with the end goal of optimizing irrigation practices. During the initial market, industry, and literature review, a total of eighteen soil moisture sensors were considered for this project. For field-testing, nine sensors were eventually chosen, and were deployed and assessed over the course of the 2019 growing season.

The top performing sensors were the Meter T8 Tensiometer and the Spectrum FieldScout TDR 350 Moisture Meter. These systems accurately measured soil moisture conditions at the BC Cranberry Research Farm (peat soils) during the growing season, were user-friendly, and are significantly less expensive than the Hortau tensiometer system. The Spectrum SM 100 Soil Moisture Sensor and the Acclima 310H Sensor also showed promise in their performance and value, and will be assessed an additional year in the field to solidify recommendations surrounding their use.

At this time, tensiometers are considered the better option for the BC cranberry industry versus volumetric water content (VWC)-type sensors. VWC recommendations are currently not well established for the BC growing region and depending on sensor characteristics, they tend to encounter performance and reliability issues in organic soils.

Project Background

Research over the last decade, primarily out of Université Laval in Quebec and the University of Massachusetts, has shown that irrigation automation using a soil water potential threshold between either 2-5 kPa or 4-7 kPa can successfully increase cranberry yields and optimize water productivity (Bonin 2009, Pelletier *et al.* 2013, Jabet *et al*. 2016). It has also been demonstrated that exposure to hypoxic soil conditions can significantly reduce photosynthetic activity in cranberries, with particularly damaging effects during bud elongation and flowering stages (Bulot *et al.* 2016 and Pelletier *et al.* 2016). Soil water potential can be very simplistically thought of as the amount of energy required to transport water out of the soil (Cooper and Cuenca 2016).

The Quebec-based irrigation automation company, Hortau, has been deploying their irrigation technology using these research-based thresholds in several cranberry growing regions, primarily Quebec and Wisconsin. The technology is particularly useful and reliable in mineral soils, which are commonplace in these growing regions. However, there is less known about the usefulness of this technology and irrigation threshold in growing regions with organic soils, like those in the majority of cranberry fields in British Columbia.

While there are a handful of British Columbia growers attempting to use the Hortau system on their farms, they are primarily using the sensors only for frost protection and data tracking. The growers do not yet trust the technology to rely on it for irrigation automation. The concerns expressed by growers include:

1.) a lack of information on irrigation automation in organic (peat) soils,
2.) the notorious "floating canopies" of this region are not compatible with this technology,
3.) lack of root interaction with the actual soil moisture due to compromised canopies, and
4.) a fear of collapse when fields are relying on aerial roots and canopy humidity for sustenance.

Soil moisture data obtained from several farms hosting Hortau sensors in 2017 and 2018 showed that fields spent <10% of the growing season within Hortau's ideal moisture range of 4-7 kPa (Elsby unpublished data 2018). For the rest of the season, soils were almost completely saturated (0-2 kPa), with occasional peaks of extremely dry soils in hot summer weather. Based on research showing the negative impacts of hypoxic soil conditions, it is reasonable to think that the chronically saturated soil on these farms is not contributing to high yields. Additionally, these conditions are not conducive to the deep, healthy root systems that are an integral part of a sustainable cropping system; one which can withstand stressors such as drought, mechanical damage, and resource-demanding phenological windows.

It is evident that British Columbia cranberry growers would benefit from optimizing their irrigation regimes to serve crop moisture needs more effectively, and to improve the overall health of the cropping system. It has also become evident, through grower extension and outreach, that while the Hortau system appears to perform well and deliver accurate soil moisture data, it is outside of many growers' operating budgets and some apprehension still exists in adopting this technology. It should also be noted that a number of BC growers experimented with Irrometer® brand tensiometers a number of years ago, with limited success, due to the instrument's lack of sensitivity, which is required for cranberry production. This failure contributed further to growers' skepticism in soil moisture sensing technology and their willingness for adoption.

Irrigation set points for VWC are even less well understood than soil water potential and can vary greatly depending on soil characteristics. This has created discrepancies in recommendations between cranberry growing regions which have opposing soil structures, such as sand versus peat. Correlations of soil water potential and VWC have been published for Massachusetts and Quebec, but not for other growing regions that could be found (Pelletier *et al.* 2015 and Jeranyama *et al.* 2017). While the soil water potential recommendations from other regions seem consistent and reasonable in the context of BC growing conditions (2-5 kPa or 4-7 kPa), the VWC threshold seems too dry for peat soils (10% VWC) (Jeranyama 2014 and Tilberg 2017). The simplified definition of VWC is the volume of water within a given unit of soil (Cooper and Cuenca 2016).

Considering the influence that soil characteristics such as electrical conductivity, organic matter, porosity, and temperature can have on VWC readings, it is unsurprising that recommendations are not standardized for industry (Evett 2016). Field data specific to the region should be generated to better understand the correlation between soil water potential and VWC in BC cranberry production before any irrigation set points or thresholds are relied upon exclusively for irrigation timing.

Summary of Project Activities

Summary of 2019 Activities			
January - March	**April - June**	**July - September**	**October - December**
Project proposal submitted and funding approval received	Market, industry, and literature review conducted; sensors chosen for study; sensors ordered and installed in Field 3 at BCCRF; project introduced to growers at BCCRF drop-in event	Any remaining sensors installed in field; ongoing data collection; project presentation at NACREW/Field Day combined event in August	Sensors removed just prior to harvest flood; cleaned and stored at OSC Richmond; data downloaded and analyzed; progress report submitted to BCCMC

Summary of (and Proposed) 2020 Activities			
January - March	**April - June**	**July - September**	**October - December**
Continued data analysis; final report submission to BCCMC; project presentation at 2020 BC Cranberry Congress	Purchase additional sensors and telemetry packages for selected devices (Meter and Spectrum); re-install selected sensors in Field 3 at BCCRF	Continued data collection and sensor validation in field; present project results/devices at BCCRF drop-in events and OSC grower meetings	Sensor removal prior to harvest; data analysis; progress and final report submission to BCCMC

Project Methods

A market survey and literature review of available soil moisture sensors were conducted. Industry contacts were consulted and sensor companies were contacted for information on available sensors. Irrigation companies were asked for quotes on automation/sensor systems (Southern Irrigation, Iconix (formerly Corix), Argus Controls, Nelson Irrigation, RainBird, MyRanch, WaterTec, and AgSense). Additionally, the network of Ocean Spray Agricultural Scientists in each of the cooperative's growing regions were asked to provide insights on their growers' sensor usage/preferences (Massachusetts, New Jersey, Quebec, Wisconsin, Oregon, and Washington). Based on the information obtained from this market and industry review, the following soil moisture sensors were considered as initial candidates for the project:

1. Acclima 310H Sensor
2. Aquacheck Soil Moisture Probe
3. Decagon EC5 Sensor
4. Decagon Teros 21 Sensor
5. GroPoint Lite Sensor
6. HS2 HydroSense
7. Irrometer LT (Low Tension)
8. Meter T8 Tensiometer
9. Meter Teros 12
10. Onset EC5 Soil Moisture Smart Sensor
11. Rain Bird RB40 Soil Moisture Probe
12. Sentec EnviroScan A
13. Sentec EnviroScan C
14. Soilvue 10
15. Spectrum FieldScout TDR 350 Moisture Meter
16. Spectrum SM 100 Soil Moisture Sensor
17. Teralytic Soil Probe
18. WaterMark Soil Moisture Sensor

Sensors were screened out based on various factors such as cost, probe depth/length, redundancy, compatibility with automation systems, and overall suitability for cranberry production. Some sensors were identical in technology/function, but had different manufacturers, so only one sensor of those technologies was chosen to move forward with (for example, Onset and Decagon manufacture the same EC5-type sensor). The following sensors were ultimately chosen for testing:

1. GroPoint Lite Sensor (Figure 1)
2. Spectrum SM 100 Soil Moisture Sensor (Figure 2)
3. Onset EC5 Soil Moisture Smart Sensor (Figure 3)
4. Irrometer LT (Low Tension) (Figure 4)
5. Meter Teros 12 (Figure 5)
6. Meter T8 Tensiometer (Figure 6)
7. Acclima 310H Sensor (Figure 7)
8. WaterMark Soil Moisture Sensor (Figure 8)
9. Spectrum FieldScout TDR 350 Moisture Meter (Figure 9)

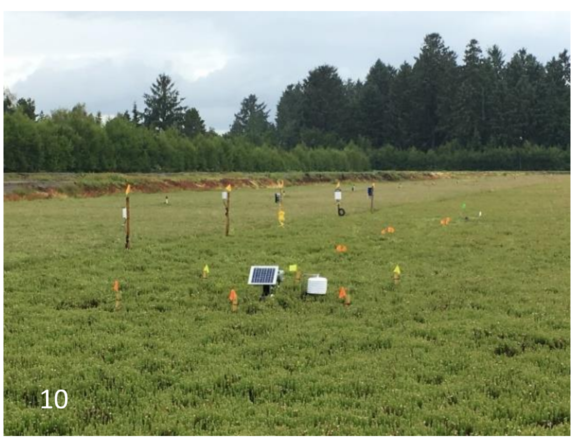
Figures 1 to 9 (top to bottom, left to right): Gro Point Lite Sensor, Spectrum SM 100 Soil Moisture Sensor, Onset EC5 Soil Moisture Smart Sensor, Irrometer LT (Low Tension), Meter Teros 12, Meter T8 Tensiometer, Acclima 310H Sensor, WaterMark Soil Moisture Sensor, Spectrum FieldScout TDR 350 Moisture Meter.

Sensors were ordered primarily through Hoskin Scientific Ltd. in May/June and were installed in the field as they arrived. The Acclima sensors were ordered directly from the manufacturer, WaterMark sensors were donated by EagleView Farms, and the Spectrum FieldScout TDR 350 was borrowed from the Massachusetts Ocean Spray Agricultural Scientist. All stationary sensors were installed in the south end of Field 3 at the BC Cranberry Research Farm in Mullica Queen vines (Figure 10). Sensors were positioned so that they were away from foot traffic and parallel with the Hortau tensiometer. Data loggers were positioned on wooden stakes near the foot path in the field so that growers were able to easily view the equipment when visiting the farm and walking through the field.

There was a delay in the installation of the GroPoint Lite sensor, as the initial data logger received was defective. After communicating directly with GroPoint, they sent a new Bluetooth-enabled data logger and their field technician visited the farm to personally install the equipment in August.

Growers were first exposed to the project at the June 5th Research Farm Drop-In event. A brief in-field presentation was given explaining the equipment set up and the importance of soil moisture monitoring and precise irrigation practices. A second in-field presentation was given at the BC Cranberry Field Day event on August 20th, 2019. This event was in conjunction with the North American Cranberry Researcher and Extension Workers conference (NACREW), so both growers and researchers were in attendance.

Sensors were removed from the field just prior to October harvest flooding (Figure 11). All data were downloaded from loggers and uploaded either to excel or to the sensor-specific software systems. All sensors are currently being stored at Ocean Spray in Richmond and select sensors will be re-deployed in the field in spring of 2020.



Figures 10 and 11: Field 3 at BCCRF with installed sensors during growing season (left) and sensors just prior to removal before harvest in dormant vines (right).

Results and Discussion

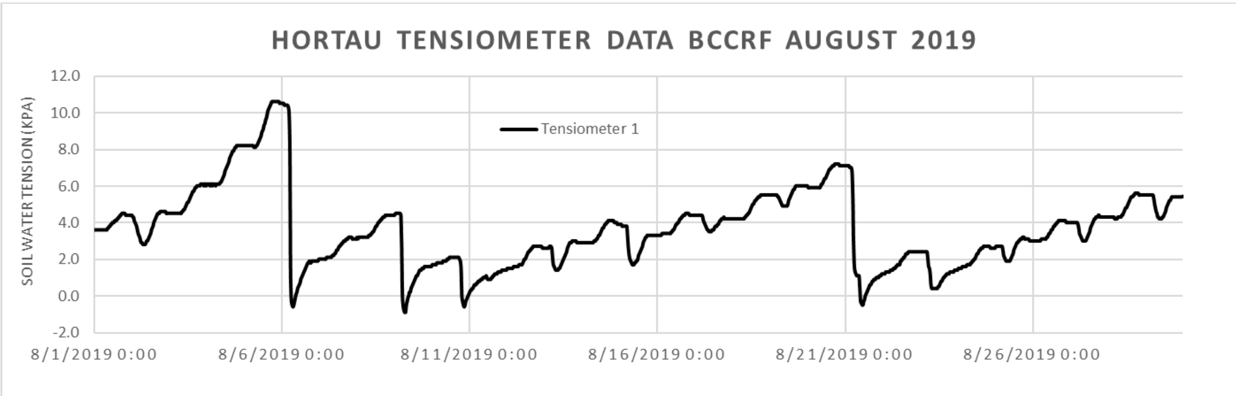


Figure 12: Hortau Tensiometer (soil water tension-type sensor)

The Hortau sensor is the industry standard for soil moisture sensing in cranberry production. This graph will be used as a reference point by which to compare other sensor data throughout this report. For graph interpretation, please note that higher values indicate drier soil conditions, while lower values indicate saturated soils. For example, on August 6th, soils were reaching dry status until an irrigation event occurred, at which time they quickly reached saturation point. The Hortau recommended "optimal" range is 4-7 kPa.

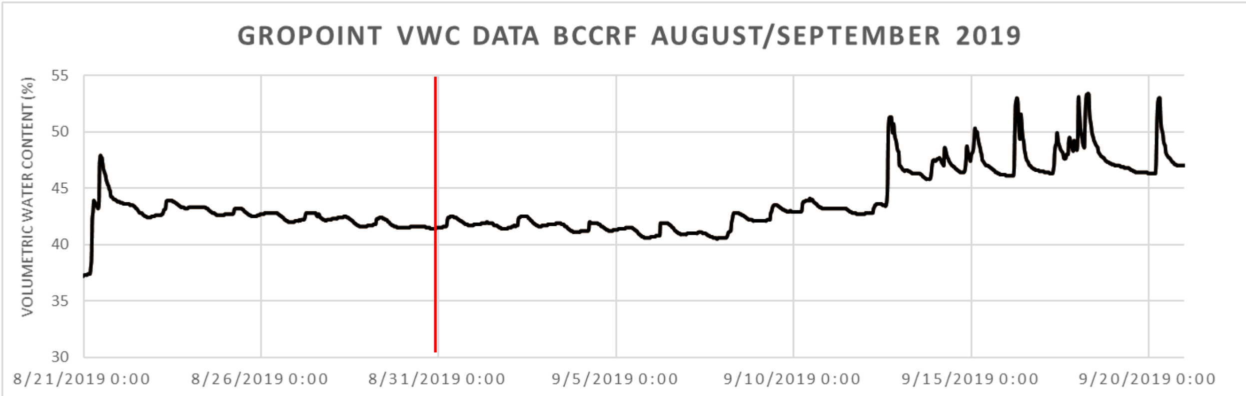


Figure 13: GroPoint Lite Sensor (time domain transmission-type sensor).

The GroPoint Lite Sensors seemed promising at the beginning of the project, as they are reasonably priced and the company is based locally (RioT Technology Corp. in North Saanich, BC). However, there were issues with the setup of the sensors (malfunctioning data logger) and the data extraction at the end of the season proved quite difficult. While the Bluetooth function of the logger is an attractive feature, it is limited in its functionality to growers by its sole compatibly with Android devices. There also seemed to be a glitch with the data, whereby only one sensor's worth of information showed up in the data file, despite having three sensors logging in the field. This sensor setup is not recommended for cranberry producers at this time. However, the company is relatively new, gave excellent customer service and field support (sent out their technician to BCCRF), and made honest efforts to correct issues, so their products may evolve to suit industry needs better in the future.

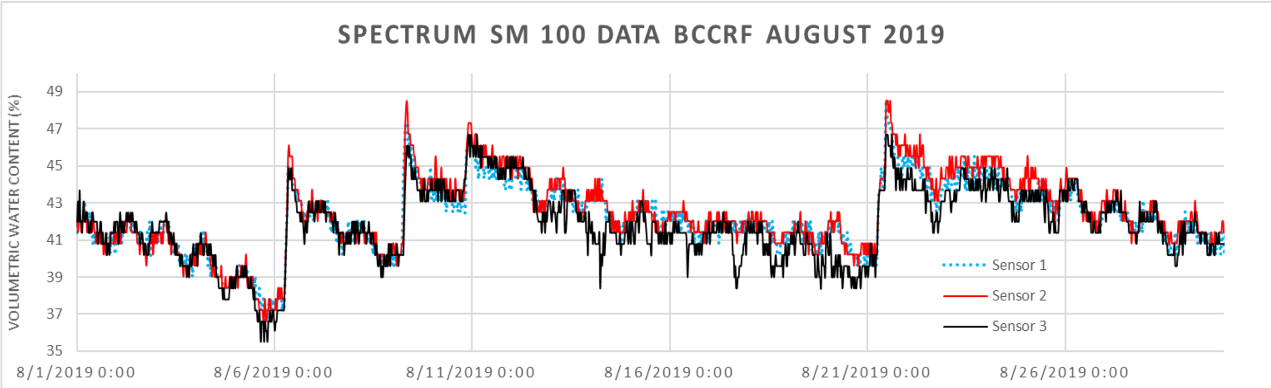


Figure 14: Spectrum SM 100 Soil Moisture Sensor (capacitance-type sensor)

The sensors, logger, and software were straightforward and easy to set up in the field. The sensors gave consistent readings to each other (the only VWC sensors to not have an outlier) and responded to wet/dry events in the field. Data retrieval at the end of the season was also straightforward. While VWC sensors tend to have some inherent difficulties in organic soils like those at BCCRF, the Spectrum SM 100 sensors performed the best of any of the stationary VWC sensors. One potential drawback to this sensor is that if the grower chooses to install telemetry capabilities (remote/phone/computer data access), it would require the installation of a separate cellular modem at an additional cost (taking it above the price point of the Meter tensiometer). Based on field performance, base price (no telemetry), and user-friendliness, these sensors could be recommended if a grower prefers VWC readings over soil water tension and is growing in mineral soils (however, VWC recommendations for BC are not yet very well understood).

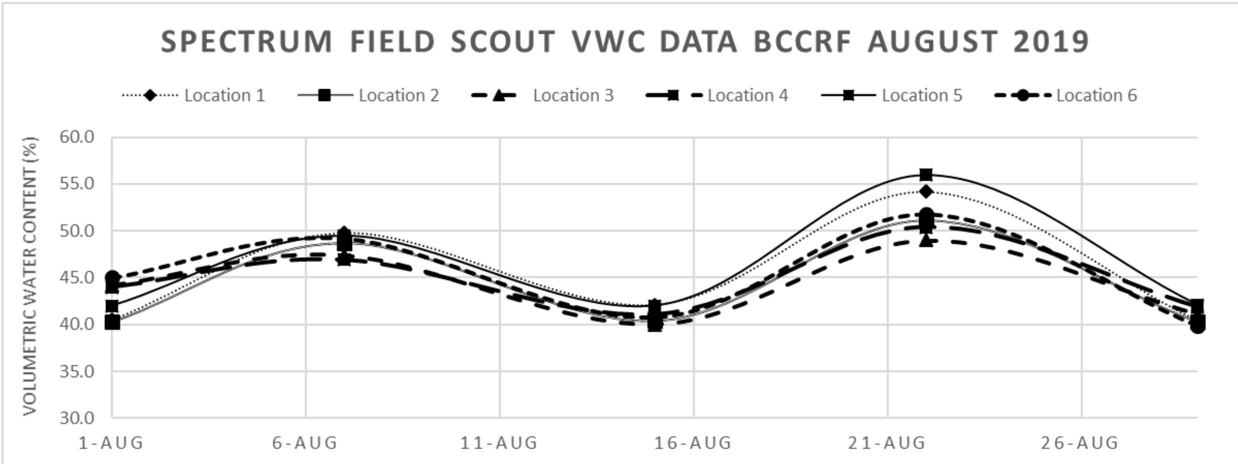


Figure 15: Spectrum FieldScout TDR 350 Moisture Meter (time domain reflectometer-type sensor)

This device is a handheld mobile soil moisture sensor that can be used to take spot readings throughout a field. It serves a slightly different purpose versus a stationary sensor. It can be used to “diagnose” wet areas in a field, and can also be linked to GPS data to create soil moisture maps of fields. It gives measurements in VWC, and has interchangeable probe lengths, so you can measure at different soil depths if you choose. This is definitely a recommended tool to growers as a way to better understand wet and dry areas in the field.

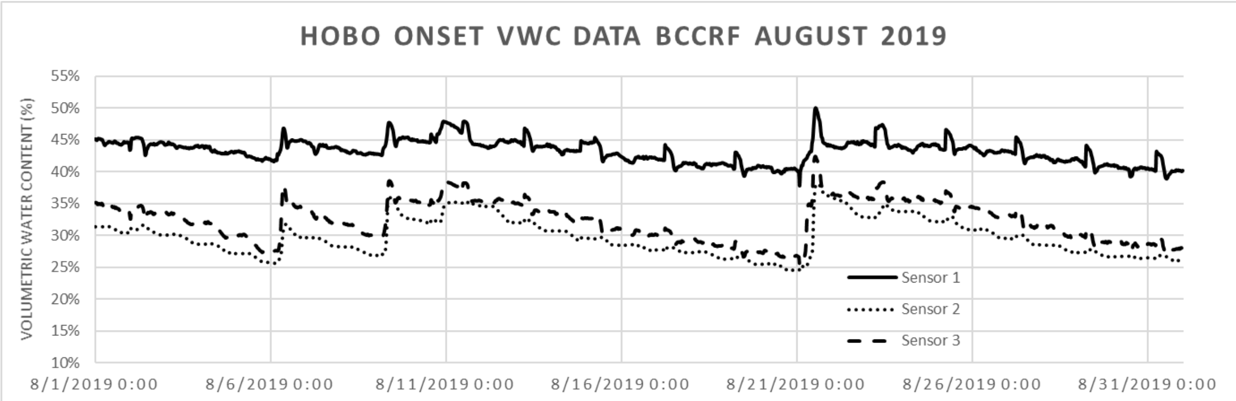


Figure 16: Onset HOBO EC5 Soil Moisture Smart Sensor (capacitance-type sensor)

The software and deployment of these sensors was straightforward, and the cost of the equipment is relatively low. Onset is also a well-known brand and is used extensively in the research community for data collection. These sensors, however, did not perform very well in the peaty soils at BCCRF. They did seem to respond to wet and dry events in the field, but there was an outlier sensor (like several of the other systems). Again, this shows the lack of reliability of VWC sensors in peat/organic soils. To compensate for the lack of consistency/reliability in sensor readings, there would likely need to be multiple sensors in any given area. This soil moisture sensor is not recommended at this time for BC cranberry producers.

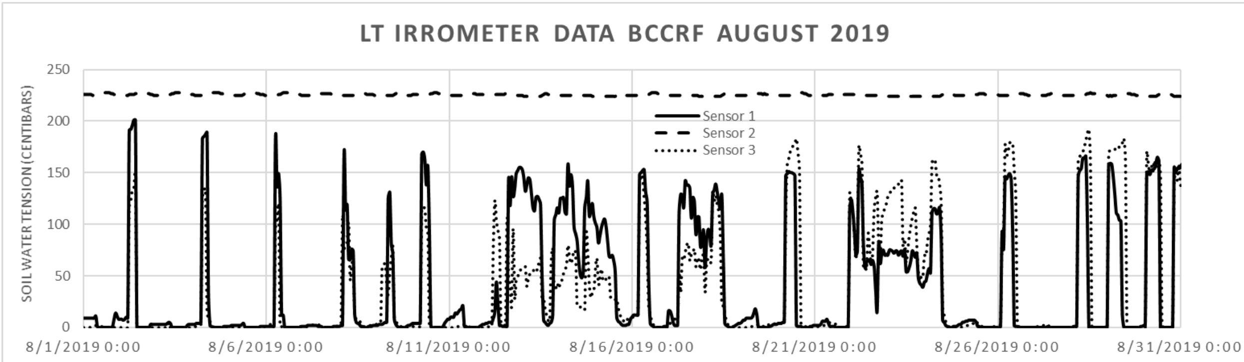


Figure 17: Irrometer LT (soil water tension-type sensor)

With other regions having success with Irrometer products, and the company having developed a "Low Tension" version of their traditional Irrometer product that was marketed to BC growers a number of years ago, this sensor seemed like it would do well in cranberries. The price point is also attractive. However, there are several drawbacks to this product that make it unsuitable to cranberry production: a finicky installation process that requires priming the porcelain sensor tips and filling with solution, low accuracy readings (at least in the peaty soil at BCCRF) as can be seen in the season's data readings, and the complete failure of one sensor. While these devices seem to be working well in other regions like Wisconsin and Oregon where they have the benefit of mineral soils, they do not seem to be suitable, reliable, sensitive, or accurate enough for BC cranberry production.

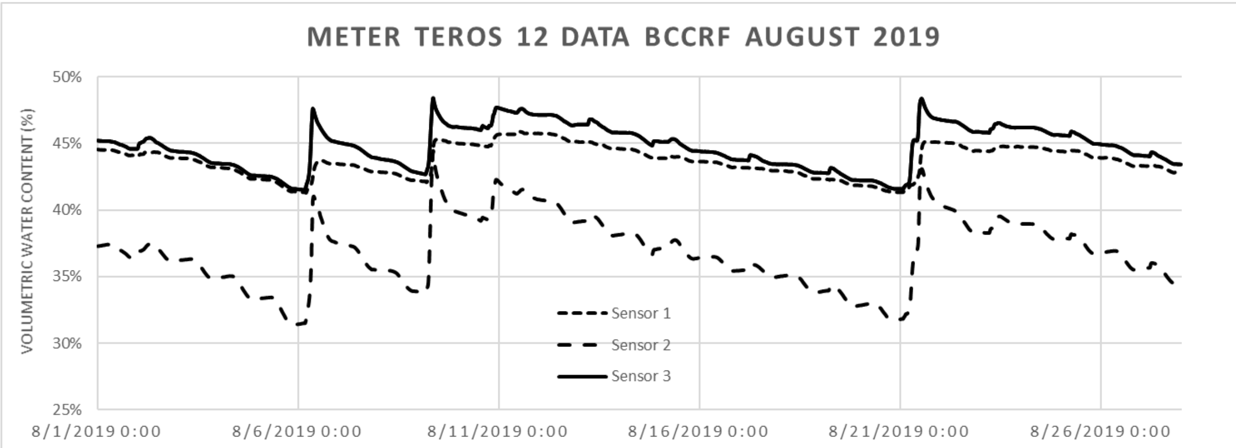


Figure 18: Meter Teros 12 (capacitance-type sensor)

The Meter ZL6 data logger and sensors were extremely easy to set up and deploy in the field. The software was easy to navigate. The sensors themselves seemed to record soil moisture trends to some degree of accuracy (VWC), but one of the three sensors gave an inconsistent reading to the other two. While I would definitely recommend the Meter ZL6 data logger (this is the same logger used for the Meter tensiometers), the Teros 12 VWC sensors do not seem to be the logical choice over the Meter tensiometer options that are available.

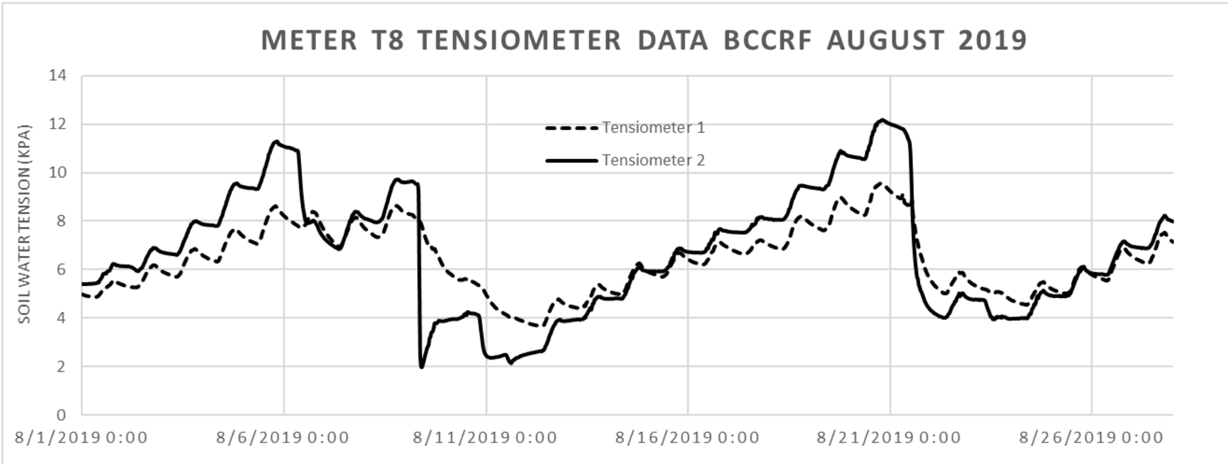


Figure 19: Meter T8 Tensiometer (soil water tension-type sensor)

The Meter T8 Tensiometers were the best performing sensors of the project. They accurately recorded soil water tension throughout the season, and numbers correlated extremely well to the Hortau tensiometers installed nearby. The ZL6 data logger is exceptionally easy to use, and has the benefit of built-in telemetry capabilities. This means the logger just requires a yearly subscription to be activated, and the data can be viewed remotely. So, while upfront costs are a few hundred dollars more than some other data loggers, there are cost savings to be had in not having to purchase a separate external cellular modem to enable telemetry (as would be the case for systems like Spectrum and Onset). The logger also has a small built-in solar panel which prolongs battery life. The unit held up well in the field and showed no signs of wear from the season's data collection. The tensiometers themselves required no prep work (like filling or priming) and were robust in the field. Altogether, this is an extremely nice system and piece of easy-to-use technology, and is the most suitable sensor/logger package for the BC cranberry industry that was reviewed during this project.

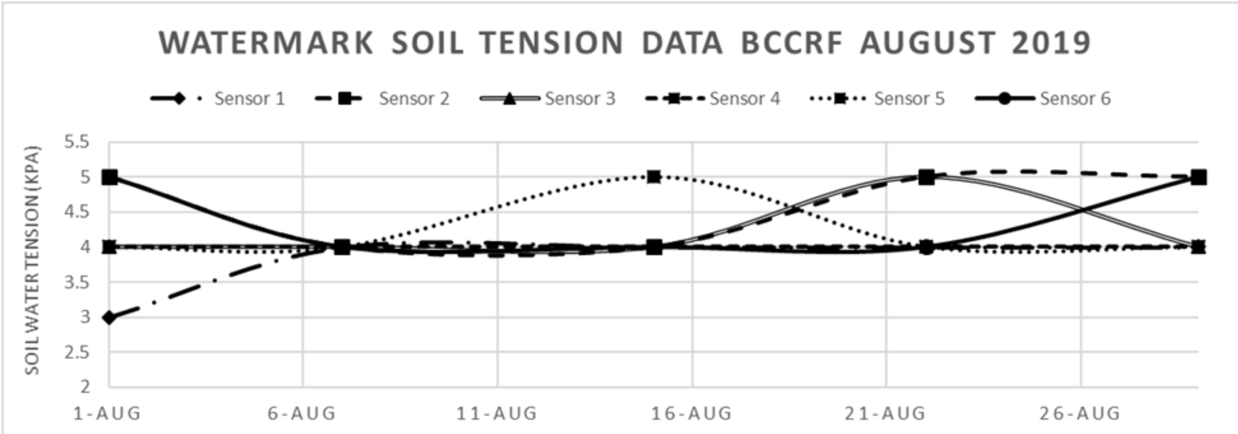


Figure 20: WaterMark Soil Moisture Sensor (soil water tension-type sensor)

The WaterMark sensors are the least expensive sensors that were included in the project. They required some priming before being placed in the field (overnight soaking), but were relatively straightforward to get in the ground. The six sensors were installed around the Hortau tensiometer in the field, and hand readings were taken on a weekly basis throughout August (rather than the sensors being hooked up to a data logger). The sensors did not appear to have very good sensitivity to varying soil moisture conditions, and gave readings of 4-5 kPa throughout the entire duration of the study. While they seem to perform in other soil systems, and are even sometimes used in research studies (Plumblee, 2019), they do not offer the sensitivity or accuracy that the cranberry crop demands. These sensors are not recommended for cranberry production in BC.

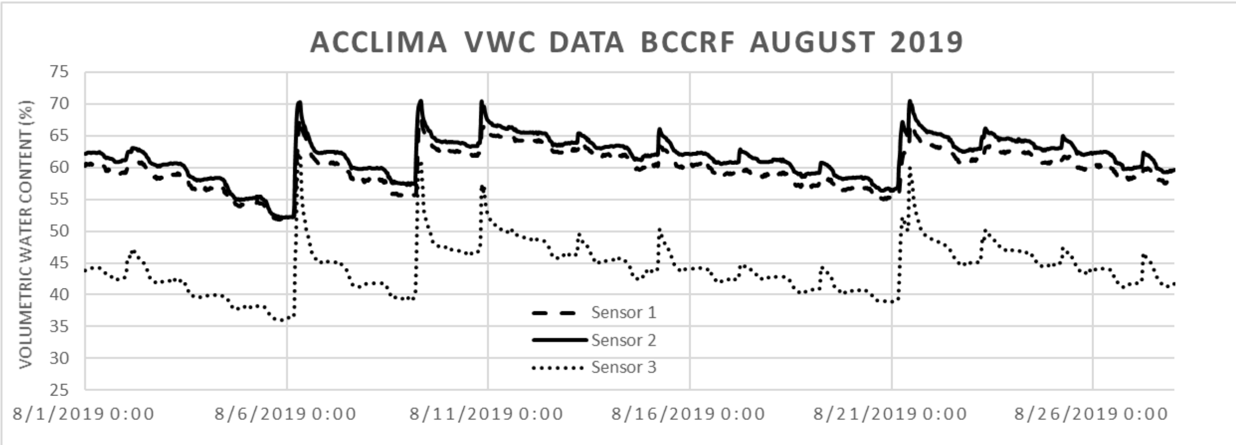


Figure 21: Acclima 310H Sensor (time domain reflectometer-type sensor)

The Acclima sensors offer good value for money, and have bundle pricing options as the number of sensors purchased increases. The sensors also take measurements beyond VWC (EC, soil temperature, permittivity, pore water EC). One drawback encountered was that the data logger is not meant for outdoor use, so a weatherproof case must be purchased separately. The wiring of the sensors to the logger was also slightly tricky, and not as straightforward as some of the other systems (not impossibly hard, just not a “plug and play” technology). The VWC readings from the Acclima sensors had similar issues to other systems, whereby two sensors gave similar readings and the third sensor was an outlier. The porous, bulky nature of peat soils makes it inherently difficult for VWC readings to be taken. The installation of the sensors also likely contributed to the inconsistent readings, whereby some sensors may have been placed far enough into the soil to reach water table depth, giving higher than normal readings. Despite the issues encountered, the Acclima sensors proved to be good VWC measurement devices. Like other VWC devices, they are likely best suited for use in mineral soils, however, Acclima does also have a handheld mobile sensor that could serve a similar purpose in peat fields to the Spectrum TDR FieldScout, which was not tested in this project.

Conclusions

The Meter T8 Tensiometer was the clear top performer of this study, with extremely consistent results compared to the Hortau tensiometer (Figures 12 and 19). The Spectrum FieldScout TDR 350 Moisture Meter gives VWC readings, but makes up for this less reliable measurement with its versatility and mobility, and its usefulness as a "diagnostic" tool in the field. Both sensors are suitable for BC cranberry producers.

The Spectrum SM 100 Soil Moisture Sensor was the top performing VWC stationary sensor. The Acclima 310H Sensor also showed promise, despite some data inconsistencies. These sensors can only be recommended tentatively, at this time, due to the knowledge gaps surrounding VWC irrigation recommendations in BC. Further field research will need to be completed to solidify the recommendation of these two stationary sensors. Additionally, based on the success of the mobile Spectrum FieldScout TDR 350 Moisture Meter, and the performance of the stationary Acclima 310H Sensor, it is likely that the similar mobile/handheld sensor manufactured by Acclima would be similarly useful to BC cranberry growers, and it is less expensive than the Spectrum sensor.

A summary of recommendations as well as a price breakdown of each sensor setup can be found in Table 1. Detailed commentary on each sensor is included in the Results and Discussion section of this report.

As a general observation, soil water potential sensors (tensiometers) are more reliable and more suitable to peaty or organic soils, which are commonplace in the BC cranberry industry. Sensors giving VWC readings tend to be more vulnerable to interference from bulky, porous soils and temperature fluctuations, which are inherent in this shallowly rooted, primarily peat-grown crop. The irrigation threshold recommendations for VWC are also more varied than those for soil water potential, and are not well developed for BC. For these reasons, tensiometers are the preferred soil moisture sensing equipment for BC cranberry farms, at this time, versus VWC-type sensors.

In summary, at this time, in this author's opinion:

1. The following sensors are viable options for BC cranberry producers:
    A. Meter T8 Tensiometer (now Meter Teros 32 Tensiometer)
    B. Spectrum FieldScout TDR 350 Moisture Meter
2. The following sensors are potential options for BC cranberry producers, and will be confirmed after further field validation:
    A. Spectrum SM 100 Soil Moisture Sensor
    B. Acclima 310H Sensor
3. The following sensors can be ruled out as options for BC cranberry producers:
    A. Meter Teros 12
    B. WaterMark Soil Moisture Sensor
    C. Onset EC5 Soil Moisture Smart Sensor
    D. Irrometer LT (Low Tension)
    E. GroPoint Lite Sensor

Pending approval, the telemetry (remote data access) components of the Meter and Spectrum systems will be assessed in the 2020 growing season to give a comprehensive review of these products to industry. The above recommendations are based on field performance of the sensors and their ability to accurately measure soil moisture conditions. By including the telemetry component of the systems, a more complete comparison can be given between the Hortau system and these products, as the Hortau program allows for remote data access.

Table 1: Qualitative and Quantitative Summary of Soil Sensor Performance

Qualitative Soil Moisture Sensor Review

	Logger	Sensor	Relative Cost	User-Friendliness	Accuracy	Overall Suitability	Overall Score	Recommended
Meter T8 Tensiometer (now Teros 32 Tensiometer)	$965	$600	Fair	Good	Good	Good	Good	Yes
Spectrum FieldScout TDR 350 Moisture Meter	$1,700		Fair	Good	Fair	Good	Good	Yes
Spectrum SM 100 Soil Moisture Sensor	$860	$130	Good	Good	Fair	Good	Good	TBD
Acclima 310H Sensor	$450	$370	Good	Fair	Fair	Poor	Fair	TBD
Onset EC5 Soil Moisture Smart Sensor	$295	$215	Good	Good	Fair	Poor	Fair	No
Meter Teros 12	$965	$185	Fair	Good	Fair	Poor	Fair	No
Irrometer LT (Low Tension)	$725	$150	Good	Poor	Poor	Poor	Poor	No
WaterMark Soil Moisture Sensor	$330	$60	Good	Poor	Poor	Poor	Poor	No
GroPoint Lite Sensor	$650	$295	Fair	Poor	Fair	Poor	Poor	No

Poor
Fair
Good

Quantitative Soil Moisture Sensor Review

	Logger	Sensor	Relative Cost	User-Friendliness	Accuracy	Overall Suitability	Total Score (out of 5)	Recommended
Meter T8 Tensiometer (now Teros 32 Tensiometer)	$965	$600	3	5	5	5	4.5	Yes
Spectrum FieldScout TDR 350 Moisture Meter	$1,700		3	5	3	5	4.0	Yes
Spectrum SM 100 Soil Moisture Sensor	$860	$130	5	5	3	3	4.0	TBD
Acclima 310H Sensor	$450	$370	5	3	3	3	3.5	TBD
Onset EC5 Soil Moisture Smart Sensor	$295	$215	5	5	3	1	3.5	No
Meter Teros 12	$965	$185	3	5	3	1	3.0	No
Irrometer LT (Low Tension)	$725	$150	5	1	1	1	2.0	No
WaterMark Soil Moisture Sensor	$330	$60	5	1	1	1	2.0	No
GroPoint Lite Sensor	$650	$295	3	1	3	1	2.0	No

Relevant Literature

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