Grape Growers of ONTARIO

SOIL MOISTURE MANAGEMENT FOR QUALITY IN VINE PRODUCTION

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100% Grown by Grape Growers of Ontario

INTRODUCTION

Grape-growing regions around the world routinely practice irrigation in their vineyards. Unlike many of these viticulture areas, however, Ontario is considered a cool-climate grape growing region. As such, vine water stress is not as prevalent. Growing-season rainfall in Ontario typically suits cultivation of juice grapes (*Vitis labruscana*), but exceeds levels required by wine grapes (*V. vinifera and French-American hybrids*). Growers in this province, consequently, also battle with excess vigour.

Despite Ontario's cool climate and the fact that *V. vinifera* can benefit from mild water stress, severe soil water deficits have occurred during critical growth stages over the past decade. Recent research outcomes have shown that deficit irrigation strategies implemented during these dry stages can be beneficial in Ontario.

IRRIGATION IN VITICULTURE

IS IRRIGATION IN VITICULTURE A NECESSITY IN ONTARIO'S COOL CLIMATE?

V. labruscana grapes differ from *V. vinifera* in that they are better suited to high growing-season rainfall accumulations. Abundant moisture is desirable in achieving high yield while maintaining quality. In Ontario, therefore, irrigation is often required for *V. labruscana* vines even during years with high rainfall. *V. vinifera* cultivars are better suited to low growing-season rainfall accumulations in order to maintain quality. Ontario often receives significant rainfall throughout the growing season, which leads to the production of dense, shaded canopies that reduce fruit exposure, air movement, and wine grape quality. In these years of excessive moisture, irrigation of *V. vinifera* should be avoided.

Alternatively, in years with severe moisture deficits, irrigation should be considered. The seasonal rainfall totals for the past 13 years suggest that irrigation in Ontario is beneficial, on average, in approximately 1 out of every 2 years. In the Niagara region, for example, the years 2001, 2002, 2003, 2005, 2007, 2011 and 2012 would have benefited from irrigation during one or more stages in the growing season (Figure 1). Compounding the necessity for irrigation, the years 2002, 2005, 2007, 2011 and 2012 were very warm growing seasons (Figure 2). Conversely, the following 6 years received adequate or excessive moisture during the most critical growth stages: 2000, 2004, 2006, 2008, 2009 and 2010.

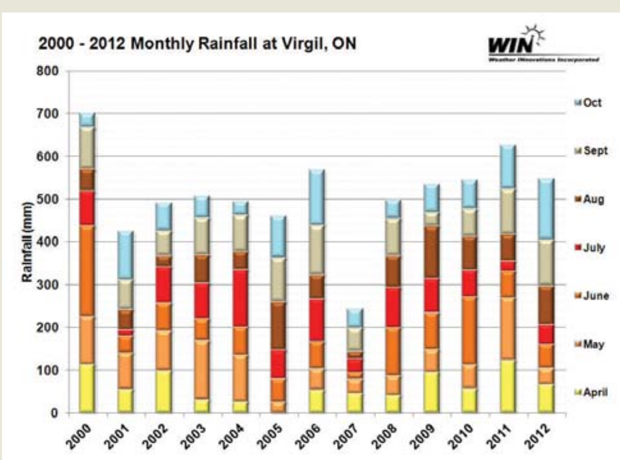

FIGURE 1: MONTHLY RAINFALL PATTERN AT VIRGIL, ONTARIO DURING 2000-2012

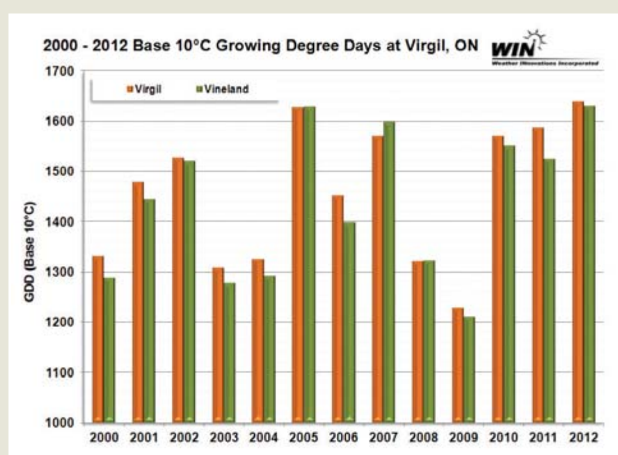

FIGURE 2: GDD AT VIRGIL AND VINELAND, ONTARIO DURING 2000-201

IRRIGATION TIMING

DEFICIT IRRIGATION

Soil moisture and precipitation patterns in the Niagara region typically suffice to render irrigation unnecessary before the bloom stage of the growing season. During dry summers, when rainfall is inadequate between post bloom and veraison (typically between the end of June and the end of August), regulated deficit irrigation (RDI) can be practiced to improve grape composition, prevent excess canopy growth and maintain vine health. RDI is defined as limiting the amount of irrigation water applied to a percentage less than the ETc, keeping the soil moisture above wilting point and significantly below field capacity. This is the available moisture range for plants. Typical levels of RDI for *v. vinifera* cultivars are 25%, 50% or 75% of ETc. One research outcome showed RDI levels of 25 and 50% ETc applied at lag phase or veraison had the most beneficial effect on fruit composition and wine sensory profile (Balint, 2011). Producers should not hesitate to experiment with different levels of RDI for varying vine ages and soil types.

Another deficit irrigation strategy is known as Partial Rootzone Drying (PRD), in which water is added to alternating sides of the vine. The rationale is to expose each vine to both dry and wetted soil, thereby achieving the benefits of vine responses to both full and deficit irrigation. Nonetheless, it has been found that RDI irrigation is more consistent and provided a greater benefit than PRD in terms of yield, vine physiology and fruit composition (Balint and Reynolds, 2010).

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It is important to keep in mind the different levels of water consumption required at each growth stage:

- BUDBREAK TO BLOOM – Adequate water is required to promote even budbreak, root growth, shoot growth, and nutrient uptake. Available water during bloom is critical for continued nutrient uptake, increasing fruitfulness, and potentially increasing berry size.
- POSTBLOOM TO VERAISON – Adequate water is required post-bloom, when the following growing season's clusters are formed. From fruit set to veraison, water is required for cell division, which determines berry size. Shoots and roots are still growing. Canopy size is at its maximum and so is water demand. Evapotranspiration values are also highest during this period and volumes of replacement water can be high. This is normally the most crucial period to apply water.
- VERAISON TO HARVEST – Limited water is preferable after veraison. Water is still required by the berries for cell expansion, but excessive moisture may promote shoot growth, hindering the vine acclimation process. Evapotranspiration values are much lower than earlier in the season, and root and shoot growth have essentially ceased, hence water demand is much

MOISTURE

IMPACT OF MOISTURE EXTREMES AND POTENTIAL MOISTURE BENEFITS

Severe water stress and excessive moisture adversely affect the growth, production and quality of *V. vinifera* grapes. Proper soil moisture management is essential for maintaining grape quality and vine health. The benefits of irrigation versus water stress have been extensively examined in the Niagara region through numerous local research studies (Reynolds et al., 2005, 2007, 2009, Balint and Reynolds 2010). These research outcomes revealed the following benefits of mild water stress, the benefits of deficit irrigation during moderate to high water stress and the risks of excessive irrigation:

BENEFITS OF MILD WATER STRESS:

- Reduced vegetative growth/ excess vigour
- Reduced competition for carbohydrates by growing shoots
- Increased concentration of flavor compounds
- Increased anthocyanins and phenols
- Increased soluble solids
- Reduced TA

BENEFITS OF DEFICIT IRRIGATION DURING MODERATE TO HIGH WATER STRESS:

- Increased yield (full irrigation and RDI higher than PRD)
  – Primarily via increased berry weights
  – Secondarily via increased vine size
- Increase berry size, increase sugar, lower acid and increase colour intensity in table grapes
- Increased clusters per vine
- Advance fruit maturity (early season deficits, in particular) in extremely dry conditions
- Occasional* increased intensity of many desirable wine flavor and aroma attributes
  – Increased anthocyanins and phenols
- Occasional* increased soluble solids

**research inconsistent primarily due to seasonal weather variations*

RISKS OF EXCESSIVE IRRIGATION:

- Excess vigour
- Reduced brix
- Increased susceptibility to disease
- Increased susceptibility to winter injury

CALCULATING IRRIGATION REQUIREMENTS

Two main components in calculating irrigation requirements are evapotranspiration (ETo) and the crop coefficient (Kc). ETo is the potential amount of water used by the combination of plant transpiration and evaporation from the soil. ETo increases with increasing wind speed, solar radiation and temperature values and decreasing relative humidity. The ETo is multiplied by a crop coefficient Kc to account for the canopy size and the "thirsty-ness" of different plant types. For example, celery is a very "thirsty" crop whereas grapes don't use as much water. Also, a small plant canopy relates to lower evapotranspiration. Kc is a calculated value specific to each crop accounting for the volume of canopy present and thus, needs to be adjusted throughout the growing season.

Actual evapotranspiration of the crop =
ETc = ETo x Kc

Knowing how much water to apply and when to apply it has always been a challenge. Surprisingly, however, the calculation of irrigation needs is reasonably straightforward. The ETo needs to be multiplied by a Kc value, a soil water storage factor, and plant area to calculate a volume per vine. This volume figure can be converted to a value in irrigation hours based upon the irrigation system output.(Reynolds et al., 2007)

The following irrigation scheduler was found to adequately calculate irrigation needs for *V. vinifera* cultivars. The scheduler calculates the amounts of water to apply in any particular week based on the previous week's conditions. It was found to work well in dry years; however, a disadvantage occurs if significant rainfall was received between irrigation events, reducing the water volume required for a potentially dry upcoming week. In this instance, the daily water use for the upcoming week was adjusted downward based on the amount of precipitation received (Reynolds et al., 2007).

ET-BASED GRAPE IRRIGATION SCHEDULER

(ADAPTED FROM REYNOLDS ET AL., 2007)

STEP 1 – Sum the daily ETo values for one week

Calculated daily ETo values are provided by Weather INnovations' Vine and Tree Fruit Innovations website (vineinnovations.com). A less precise but alternative method is to use the historical ETo averages provided in Figure 3, as in the following:

- Example:

Vineland: June 30 – July 6
Weekly ETo = 5.3 + 5.3 + 4.7 + 4.7 + 4.7 + 4.7 + 4.7 mm = 34.1 mm

NOTE: Alternatively, skip Step 1, use the daily ETo and follow through the example calculating only the DAILY water demand and DAILY run time as opposed to the WEEKLY water demand and run time.

STEP 2 – Determine the crop coefficient (Kc)

i. Measure the length of the shadow produced by the canopy at solar noon
ii. Measure the row spacing
iii. Divide canopy shadow by the row spacing (from Williams and Ayars,2005)

- Example:

Canopy shadow = 6 ft
Row spacing = 8 ft
Kc = canopy shadow ÷ row spacing
Kc = 6ft ÷ 8ft = 0.75

WEEK OF	WINDSOR	RIDGETOWN	SIMCOE	VINELAND	TRENTON
MAY 07	2.1	2.2	2.8	2	2.1
MAY 14	3.5	3.7	3.7	3.6	3.5
MAY 21	3.6	3.8	4.6	3.2	3.6
MAY 28	4.1	4	4.9	3.3	3.3
JUN 04	4.2	4.3	4.8	3.9	4.3
JUN 11	4.3	4.2	5.2	4.4	4.1
JUN 18	4.2	4.3	5.4	4.3	4
JUN 25	4.9	4.7	5.5	5.3	4.8
JUL 02	4.6	4.7	5.3	4.7	4.5
JUL 09	5.4	5.2	5.5	5.2	5.1
JUL 16	4.9	4.9	5	4.8	4.4
JUL 23	4.7	4.6	5.6	4.4	4.5
JUL 30	4.8	4.2	5.1	3.3	4.2
AUG 06	4.8	4.7	4.6	4.3	4.1
AUG 13	3.6	3.8	4.5	3.3	3.3
AUG 20	3.4	3	3.5	3.2	3.4
AUG 27	3.5	3.3	4.3	3.3	3
SEP 03	3.5	3.2	4.5	3.2	3.2
SEP 10	3.3	3.4	3.9	2.7	2.6
SEP 17	2.4	2.4	3	2.5	1.7
SEP 24	2.3	2.4	2.9	2.2	1.7

FIGURE 3: HISTORICAL AVERAGE DAILY ETO VALUES (MM)

NOTE: As the growing season progresses, the length of shadow will increase, thus increasing the Kc values from ~ 0.5 to 0.8. Examples of measured Kc values for 2005 were: June 23: 0.58, June 30: 0.63, July 7: 0.67, July 14: 0.71, July 21: 0.75, July 28: 0.75, Aug 4: 0.80 (Reynolds et al. 2009)

STEP 3 - Determine the weekly water demand (ETc week) by multiplying the potential (ETo) by the crop coefficient (Kc)

● Example:
ETc week = ETo week x Kc
ETc week = 34.1 mm x 0.75
ETc week = 25.6 mm (1.0 in)

STEP 4 – Subtracting rainfall

If rain falls during the week add up the amounts that are over 5mm and subtract this number from the weekly water demand (ETc week)

● Example:
Tuesday 15mm rain, Wednesday 3mm rain
Effective Rainfall = 15mm

Weekly water demand = ETc – Rain
= 25.6 mm – 15mm
= 10.6 mm (0.4 in)

STEP 5 - Determine the volume of irrigation water needed by multiplying by the crop area (A) and a soil storage factor (S)

S = 0.75 for most grape soils
(for sandy soils use S = 0.8)
(from Van der Gulik, 1999)

● Example:
A = 5 acres
S = 0.75
ETc week = 10.6 mm (0.4 in)

Volume of water required per week =
ETc x A x S (eq2)
= 0.4 in x 5 acres x 0.75
= 1.5 acre-inches

= 1.5 acre-inches x 27 160 US gal/acre-inch
= 40,740 US gal

STEP 6 – Determine the irrigation system run time

Drip System

● Example:
Drip system runs at 25 US gallons per minute (gpm)
Number of irrigation days per week = 7 days/week
System Efficiency = 0.90

Irrigation application = volume of water required per week ÷ efficiency
= 40,740 US gal ÷ 0.90
= 45,267 US gal per week

Daily drip volume = Irrigation application for a week ÷ # irrigation days per week
= (45,267 US gal per week ÷ 7 days per week)
= 6,467 US gal per irrigation event

Daily run time = Daily drip volume ÷ irrigation system flow rate
= 6,467 US gal ÷ 25 US gpm
= 259 min
= 4.3hrs

Traveling Gun System

● Example:
Traveling gun runs at 350 US gallons per minute (gpm)
Run system 1 day per week
System Efficiency 0.65

Irrigation application = weekly water volume ÷ efficiency
= 40,740 US gal ÷ 0.65
= 62,677 US gal

Weekly run time = Irrigation application ÷ irrigation system flow rate
= 62,677 US gal ÷ 350 US gpm
= 179 min
= 3 hrs

DRIP SYSTEM

TRAVELING GUN SYSTEM

MEASUREMENTS

SOIL AND PLANT-BASED MEASUREMENTS

Irrigation requirements calculated by an irrigation scheduler can be easily verified using soil moisture monitoring technologies and plant-based measurements (e.g. pressure chambers). Utilizing a combination of soil and plant-based monitoring to validate that vines are properly irrigated is ideal. These tools will assist in avoiding either under-irrigation or over-irrigation.

PLANT-BASED MONITORING

A pressure chamber is a commonly used plant-based monitoring device in validating whether irrigation applications have been effective and vines are satisfied. It can also be useful in determining if vines are foraging for deep water in instances when an irrigation scheduler or shallow-depth soil moisture status indicate that irrigation is required, yet vines appear satisfied.

A pressure chamber provides an indication of vine water stress based on the level of pressure that is required to extract moisture from a leaf. The process involves removing a mature, healthy, sunlight-exposed leaf at midday, including the stem, and bagging the leaf to retain its moisture until it can be inserted in a pressure chamber (Reynolds, 2008). This steel chamber applies increasing pressure until a water droplet is extracted from the stem. The pressure at which

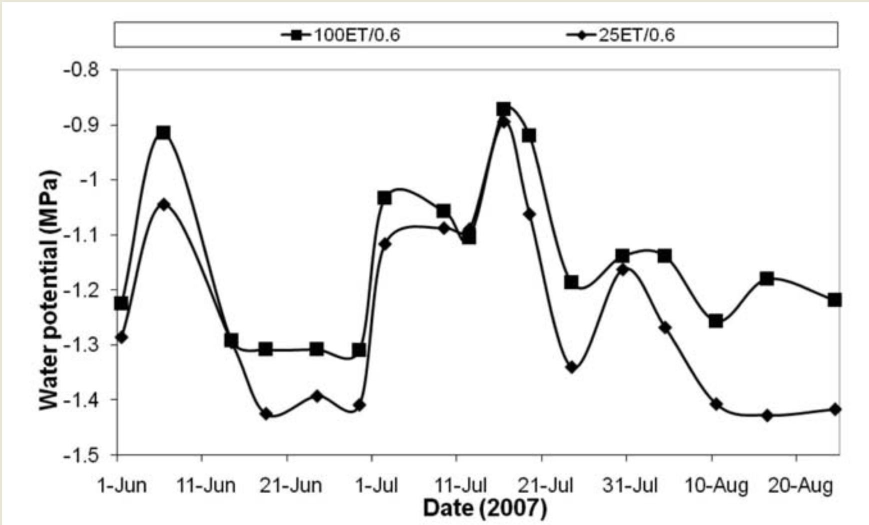

FIGURE 4: AN EXAMPLE OF LEAF WATER POTENTIAL VALUES (MPA) MEASURED ON SYRAH GRAPE LEAVES BETWEEN 1 JUNE AND 30 AUGUST 2007. VINES WERE GIVEN FULL IRRIGATION (100% ET) OR WERE DEFICIT IRRIGATED (25% ET). BOTH HAD A FIXED 0.6 KC (CROP COEFFICIENT).

this occurs is known as the leaf water potential (Ψ). Knowledge of the leaf Ψ correlates with the level of vine water stress: increasingly negative values equate to increasing water stress, as greater water tension exists within the leaf. Leaf Ψ values typically range between -0.8MPa (-8 bars) during wet years and-1.6MPa (-16 bars) during dry summers in heavy clay soils with shallow root zones. A leaf Ψ value of less than -1.2MPa (-12 bars) is considered water stress for vines. Figure 4 displays actual leaf Ψ values measured for vines receiving full or deficit irrigation during the summer of 2007 in Niagara – a notably dry growing season.

Hence, a grower can compare measurements before and after irrigation events to confirm both whether vines are water-stressed and if the irrigation application was effective. Unfortunately, inaccuracies can occur within the sampling process as extreme temperatures and wind speeds, and the incidence of solar radiation on the sampling day can skew the results. Care should be taken to consistently sample between 11:30AM and 1:30PM on sunny, average temperature days with light wind speeds. Pressure chambers give excellent results when used properly but are also very expensive to purchase and cannot be left in vineyards throughout the summer.

SOIL MOISTURE MONITORING

Irrigation requirements calculated by an irrigation scheduler can also be validated using soil moisture monitoring technologies to ensure that water remains available within the effective rooting zone. Soil moisture sensors can both assist growers in determining when irrigation is necessary and also in providing feedback on the effectiveness of an irrigation event (did the rooting zone receive adequate moisture or was excessive moisture applied).

Soil moisture is a result of the water balance, which means the balance between rainfall and ETc. During dry days or when rainfall is less than ETc, the soil moisture will decrease. While the soil water content is high, the decrease will be fast, but as the soil gets drier the slope of the moisture line starts to diminish. When it becomes flat it means that plants are not extracting enough water from soil for their metabolism.
Of course, the user needs to keep in mind the current growth stage of the plant and whether vine water uptake is expected to be high or low at any given time. On the other hand, when rainfall is greater than ETc or irrigation is applied, soil moisture will increase. When a heavy rainfall happens, soil moisture can increase quickly and if sufficient rainfall occurs the soil moisture rises above the field capacity, into the saturation point, resulting in water drainage and run-off.

A wide array of soil moisture sensors exists, rendering the selection of an appropriate sensor a challenge. A list of commercially available soil moisture sensors and their characteristics (Figure 5) provides some basic background; however, one should consult a specialist to assist in the decision process. One must first choose between portable devices and a fixed installation. Hand-held portable devices provide the ability to have numerous sampling locations; however, they require intensive labour, travel, time and maintenance inputs to be effective. In addition, these devices only provide intermittent point data outputs which may not give a clear picture of the entire growing season if irrigation or rainfall events are missed. A fixed installation with continuous soil moisture monitoring can provide an automated graphical output (Figure 6) displaying exactly how soil moisture at various depths changes with time. A multi-depth soil moisture sensor is superior to a single-depth sensor as it provides a more comprehensive picture of soil moisture status.

Careful consideration into soil moisture sensor placement is essential. Site selection should avoid outside rows, atypically high or low-lying land, and be placed in the most prevalent soil texture a grower will base their irrigation decisions upon. Unfortunately, it is impractical and cost-prohibitive to implement high-density soil moisture monitoring (one sensor for every knoll, swale, variation in soil type, variety, etc). Generally, as long as the grower knows the susceptibility of the monitored location to drought, in reference to the unmonitored locations, relative irrigation requirements can be inferred for the unmonitored locations. Typically, sensors should be placed near the portion of the plant's root zone that draws the most water from the soil. WIN often installs moisture sensors at 10 cm (4 in), 30 cm (1 ft) and 50 cm (2 ft), bearing in mind that some established vines can establish roots beyond 1 metre beneath the soil surface.

SOIL MOISTURE

NAME OF DEVICE	PORTABLE DEVICE?	MEASUREMENT DEPTH	MULTI-DEPTH?	INSTALLATION/MAINTENANCE REQUIRED	COST SCALE
PROFILE PROBE	No	0-100cm	Yes	Augered access tube; reinstallations possibly required	$$$
PROFILE PROBE	Yes	0-100cm	Yes	Augered access tube; reinstallations possibly required	$$$
CAPACITANCE PROBE (C-PROBE)	No	0-100cm	Yes	Augered access tube; reinstallations possibly required	$$$
THETA PROBE	No	0-40cm	With Multiple Sensors	Installed directly in soil	$$$
HYDRA PROBE	No	0-40cm	With Multiple Sensors	Installed directly in soil	$$$
TDR (TIME DOMAIN REFLECTOMETRY)	No	0-40cm	With Multiple Sensors	Installed directly in soil	$$$
TDR (TIME DOMAIN REFLECTOMETRY)	Yes	0-20cm	No	Hand-held device; bent rod replacements required	$$
GYPSUM BLOCK	No	0-40cm	With Multiple Sensors	Installed directly in soil	$$
TENSIOMETER	No	0-100cm	No	Installed directly in soil; water refills required	$

FIGURE 5: COMMON SOIL MOISTURE SENSORS - ALL INSTRUMENTS HAVE THE OPTION TO LINK WITH TELEMETRY EQUIPMENT, WITH INFORMATION TRANSMITTED TO FARM COMPUTER. SOME COMPANIES OFFER THIS AS A PACKAGE OPTION

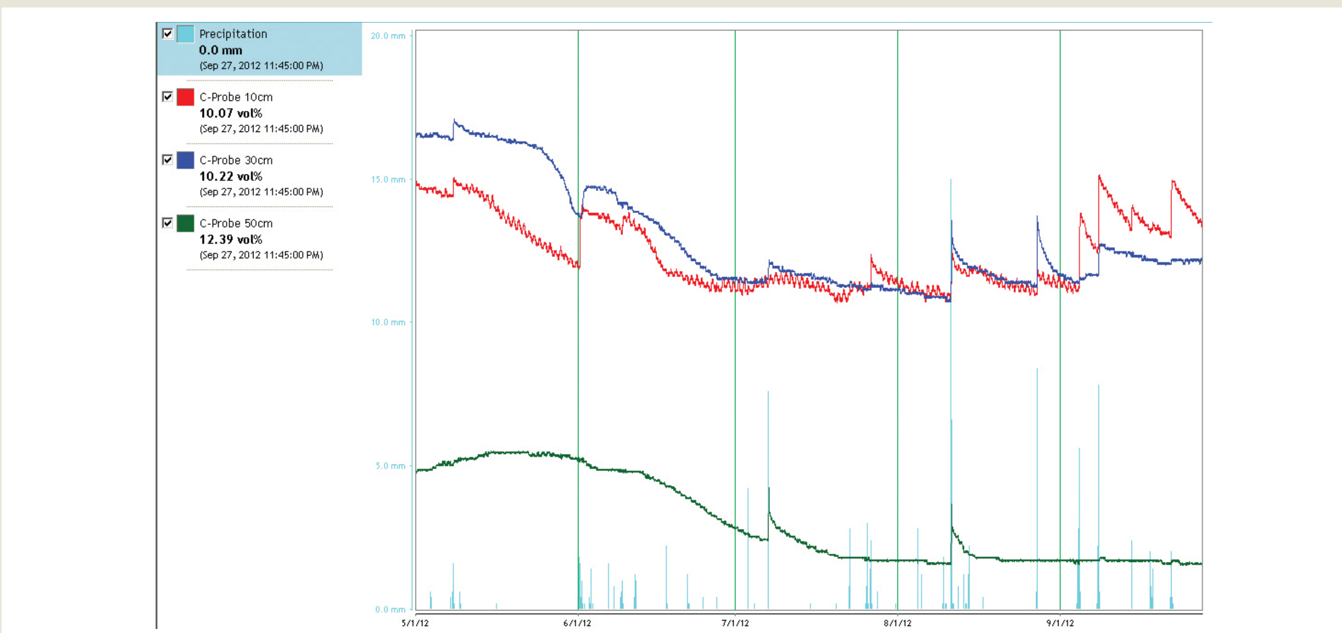

FIGURE 6: AN EXAMPLE OF THE GRAPHICAL OUTPUT FROM A C-PROBE AND RAIN GAUGE IN A VINEYARD BETWEEN 1 MAY AND 30 SEPTEMBER 2012

CONCLUSION

Severe water deficits during critical growth stages in several years since the year 2000 in the Niagara region were clearly illustrated through analyzing monthly rainfall accumulations. Irrigation in these years is beneficial in maintaining vine health, boosting yields and improving wine quality. Numerous irrigation studies conducted between 2000 and 2009 in the Niagara region led by Reynolds et al. (2005, 2007, 2009), Balint (2011), and Balint and Reynolds (2010) highlight the benefits of irrigation for *V. vinifera* cultivars during these critical periods. Irrigation water requirements for *V. vinifera* cultivars can be easily and accurately determined via an irrigation scheduler. Pairing irrigation scheduling with plant-based and soil moisture monitoring provides producers with a definitive understanding of viticulture irrigation requirements.

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