EFFECT OF SOIL WATER POTENTIAL THRESHOLD FOR IRRIGATION ON CRANBERRY YIELD AND WATER PRODUCTIVITY

V. Pelletier, J. Gallichand, J. Caron

ABSTRACT. *As the cranberry industry implements irrigation automation, thresholding based on real-time monitoring of soil moisture to initiate irrigation is lacking. This study was conducted to determine the optimum soil water potential for starting sprinkler irrigation (SWP_I) that would optimize water productivity (WP) without decreasing yield. During the 2011 and 2012 growing seasons, three sites in Québec and one site in Wisconsin were equipped with tensiometers, flowmeters, and weather stations for testing wet (-5.5 kPa), dry (-7.0 to -10.0 kPa), and control (-6.0 to -6.5 kPa) treatments. The experimental designs were developed to evaluate the impact of irrigation treatments on yield and WP. Dry treatments required 21% to 93% less irrigation water than the control treatments; wet treatments needed 54% to 186% more irrigation water than the control treatments. Irrigation treatments had no significant effect on yield when SWP_I values ranged from -5.5 to -8.0 kPa; however, a significant yield reduction of 11% was observed for a SWP_I value of -10.0 kPa. The WP values in dry treatments were always higher than those in control and wet treatments. Dry treatments, with SWP_I ranging from -7.0 to -8.0 kPa, significantly improved the water productivity without decreasing yield.*

Keywords. *Cranberry, Irrigation, Irrigation thresholds, Matric potential, Soil water tension, Tensiometers, Water productivity, Water stress.*

The state of Wisconsin is the world leader in production of cranberries (*Vaccinium macrocarpon* Ait.), with 200,450 tons for a cultivated area of 7300 ha (Kashian, 2012). In the province of Québec, Canada, the area cropped to cranberry has grown from 105 ha in 1992 to 2400 ha in 2011. Québec is the third largest cranberry producer with 54240 tons, and the largest producer of organic cranberries with 7240 tons (APCQ, 2012).

Traditionally grown on peat moss, cranberries are now being successfully planted on sandy soils over low-permeability beds to allow flooding during harvest. Each year, the cranberry, a perennial plant, produces fruiting uprights that set 1 to 3 berries from 2 to 7 flowers and vegetative uprights that bear no fruit (Baumann and Eaton, 1986). Flower buds are formed in the fall of the previous year. Mature cranberry beds may need to be pruned to remove the excessive vegetative growth that may suppress fruit set (Strik and Poole, 1991). A low fruit set may also result from a selective abortion of inferior quality fruits when resources are limited (Brown and McNeil, 2006).

One of the most important resources in cranberry production is water, used both for irrigation and harvest flooding. However, too much water results in a deficit of soil oxygen and in root rot (Roper, 2006). Adequate soil aeration is achieved by surface and subsurface drainage (Sandler and DeMoranville, 2008), and supplemental sprinkler irrigation is used for controlling soil moisture during the growing season when rainfall fails, for frost protection in spring and autumn, and for heat protection in summer. Due to the expansion of the crop and to the large amounts of water needed at critical growth stages, irrigation strategies are required for saving water while optimizing yield.

Water productivity (WP) is defined as the fresh crop yield per unit area of cultivated land per unit depth of rainfall and irrigation. Values of WP range from 122 to 169 kg ha^{-1} mm^{-1} for onions (Zheng et al., 2013) and from 380 to 1010 kg ha^{-1} mm^{-1} for citrus (Quiñones et al., 2012) depending on climatic conditions, irrigation technology, and field water management. Water productivity can be improved by either increasing crop yield or reducing water consumption (Cai and Rosegrant, 2003). Cranberry production is highly dependent on large amounts of water, yet its industry is controlled by environmental laws protecting water resources (CCCGA, 2001).

Tensiometers measure the soil water potential (SWP) and are valuable for timing irrigations (Richards and Marsh, 1960). Coupling soil water potential probes with a wireless communication system and internet access allows online monitoring and, potentially, real-time irrigation management and automation. In cranberry production, literature is scarce on the SWP threshold required for irrigation onset (SWP_I) and on the relationship between cranber-

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ry yield and SWP_I. In a growth chamber study on organic and sandy soils, Bonin (2009) found photosynthesis and stomatal conductance of cranberry fruiting uprights to be maximum at SWP_I values ranging from -4.0 to -6.5 kPa. General recommendations for mineral soils (Sandler et al., 2004) state that irrigation should be started either the same morning of a SWP morning reading or the morning following a midday SWP reading. In the former case, an optimal SWP_I value of -5 kPa is suggested, whereas in the latter case, SWP_I values of -8 and -6 kPa are used under normal and high evaporative demand, respectively. The main objective of this study was to determine the optimal value of SWP_I for improving water productivity without affecting yield during a two-year cycle of cranberry production.

Material and Methods

Experimental Sites

The experiments were conducted on three sites in the Canadian province of Québec and one site in the U.S. state of Wisconsin. The locations are shown in figure 1, and detailed characteristics of each site are listed in table 1. Soil texture of the four sites is fine sand with mean values of 0.4% for organic matter and 4.2 for pH. Site D is cropped to the Grygleski 1 cultivar, which was developed for better budding and quality preservation than the Stevens cultivar (Gilmore, 1999).

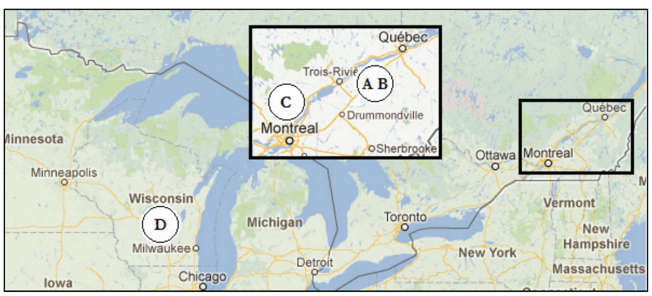

Figure 1. Location of experimental sites in North America.

Experimental Design

All experimental setups were randomized complete block designs, with details given in table 1. A typical layout, showing blocks and treatments, is shown in figure 2. Irrigation lines, in addition to the existing lines, were installed to allow independent control of irrigation treatments. Sprinklers wetted a radius of approximately 14 m with a pressure of 350 to 400 kPa at the sprinkler heads and distribution uniformity (DU) of 80%. Each irrigation event applied between 10 and 15 mm of water.

The wet and dry treatments were based on SWP_I. The control treatments at sites A and C were based on Bonin (2009) with a SWP_I of -6.5 kPa, whereas at site D, a -6.0 kPa SWP_I value was used. In addition, a 20 min cooling irrigation was applied when the canopy temperature reached 33°C at midday. At site B, irrigation of the control treatment was independent of SWP_I and canopy temperature; in this case, the grower systematically irrigated for two hours every two days**.** This corresponded to SWP_I values of -5.1 kPa in 2011 and -5.8 kPa in 2012. There was no wet treatment at sites B and D.

Soil and Climatic Data

All SWP readings were made with tensiometers (model HXM80, Hortau, Lévis, Canada) installed at a depth of 10 cm below the soil surface, and canopy temperature readings were made with temperature probes (model THM, Hortau, Lévis, Canada). Readings were taken at 15 min intervals and sent, via a wireless communication system, to the Irrolis website (www.hortau.com, Lévis, Canada) for processing. There were nine tensiometers per site (six for site D). For each treatment, a tensiometer was installed in the center of three blocks selected for maximum coverage of the bed. Irrigation was initiated when the average of the three measured SWP values reached SWP_I, unless at that time the rainfall probability exceeded 80%, in which case irrigation was postponed until the rainfall probability dropped below 80%. Considering weather forecasts in real-time irrigation management is known to improve water

Table 1. Characteristics of the experimental sites.

Characteristic		Site A	Site B	Site C	Site D
General Information					
Production		Organic	Conventional	Conventional	Conventional
Cultivar		Stevens	Stevens	Stevens	Grygleski 1
Average temperatures (2011-2012) (°C)					
June		17.2 to 17.9	17.3 to 18.1	18.3 to 18.8	19.0 to 21.3
July		20.5 to 20.1	20.9 to 20.5	21.7 to 21.2	23.2 to 25.1
August		18.5 to 19.9	18.6 to 19.9	18.8 to 19.7	19.6 to 20.5
1-15 September		16.0 to 16.7	16.0 to 17.0	16.3 to 16.9	16.9 to 18.2
Bed properties					
Dimensions (m × m)		479 × 52	457 × 46	472 × 46	200 × 55
Subsurface drains:	Spacing (m)	15.2	11.4	6.5	3.7
	Depth (m)	0.8	0.8	0.3	0.5
	Slope (%)	0.14	0.07	0.00	0.10
Sprinkler spacing (m)		15	18	15	18
Irrigation line spacing (m)		18	15	13	18
Experimental design					
Number of blocks		9	8	4	8
Number of treatments		3	3	3	2
SWP_I of treatments (kPa):	Control	-6.5	2 h / 2 days	-6.5	-6.0
	Wet	-5.5	-	-5.5	-
	Dry	-10.0	-7.0 / -8.5	-8.0	-7.5
Number of sprinklers by experimental unit		2	2	6	1

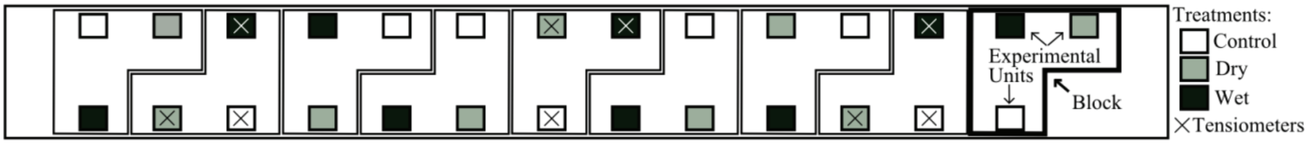

Figure 2. Experimental design of site A.

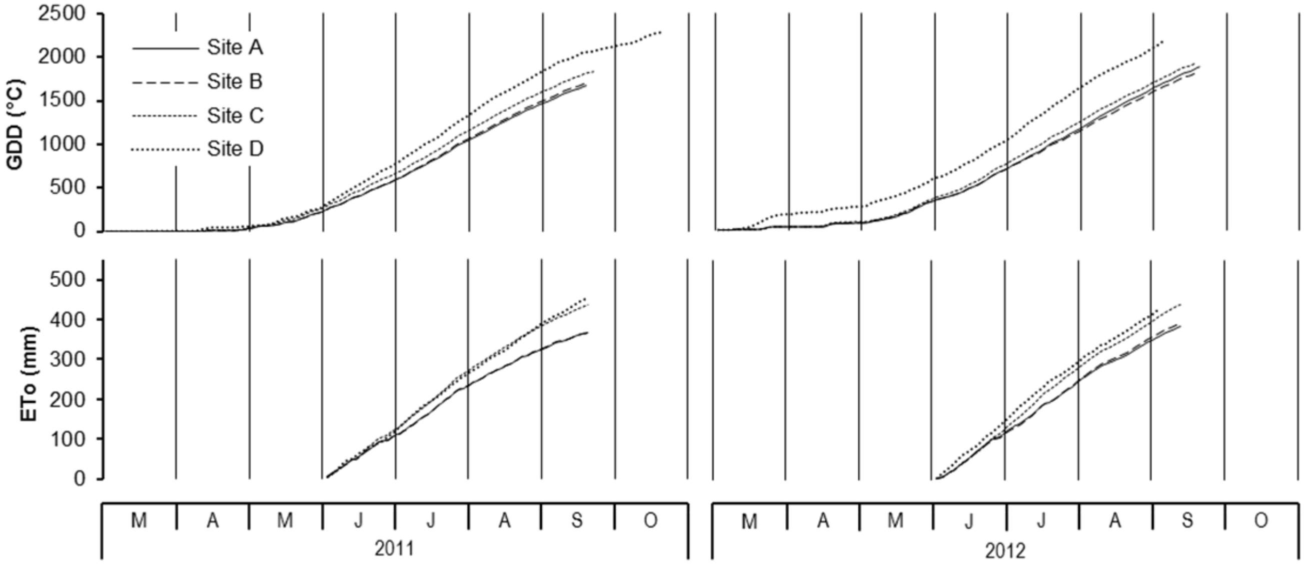

Figure 3. Growing degree days (GDD) and reference evapotranspiration (ET_o) in 2011 and 2012.

productivity (Gregory, 2004).

For sites A, B, and C, climatic data were collected by Irrolis automated weather stations (Hortau, Lévis, Canada) and were available online on the Irrolis website. For site D, data were downloaded monthly from a weather station (WatchDog 2700, Spectrum Technologies, Plainfield, Ill.). Missing data were estimated from the nearest meteorological weather station. Growing degree days (GDD) were calculated on a 5°C basis, and reference evapotranspiration (ET_o) was calculated with the Penman-Monteith equation (Allen et al., 1998). Results are shown in figure 3. The differences in GDD and ET_o between 2011 and 2012 were mainly due to the warm spring in 2012.

Yield Measurements

For each experimental unit, yield was measured on subsamples collected from a 929 cm^2 surface area. For each site, a preliminary analysis of variance (ANOVA) was performed to determine the number of subsamples required per experimental unit (SEU) to detect a significant yield difference of 3400 kg ha^{-1}, i.e., the amount that would represent an economic benefit for the growers. The number of SEU was 15, 17, and 30 for sites A, B, and C, respectively. For site D, there were five SEU in 2011 and three in 2012. For each site, experimental units were divided into equal-sized rectangular subunits based on the predetermined number of SEU required. The subunits were then subdivided into as many subsample areas that could fit into a subunit. One of these subsample areas was selected randomly for yield measurement. Berries were counted and weighed in the laboratory.

Water Productivity

The seasonal depth of irrigation water applied to the blocks of a given treatment was calculated from the volume of water measured by a totalizing rotary flowmeter installed on the irrigation line dedicated to that treatment. The flowmeters used measured flow rate with an accuracy of ±2%. The total amount of irrigation water applied during one season (IW) for a given treatment was obtained by dividing the total volume of water applied by the total surface area of all blocks of that treatment. WP was calculated as total yield divided by total IW and rainfall for that treatment during the growing season.

Statistical Analysis

Yield and WP were analyzed by analyses of variance using the Mixed procedure of SAS (SAS Institute, Inc., Cary, N.C.). The Bonferroni-Holm test was used for comparing treatment means. An ANOVA was done separately for each site, and years were analyzed both together and separately. The results of these statistical tests are reported for a significance level of 0.05. At the experimental unit level, multiple regressions evaluated the relationships between yield and several crop parameters with a significance level of 0.0001.

Results and Discussion

Rainfall, Irrigation, and Soil Water Potential

Cumulative seasonal rainfall and irrigation water are shown in table 2, and in figure 4 in relation to SWP, for the 2011 and 2012 growing seasons. Hurricane Irene in 2011

Table 2. Irrigation water (mm) and rainfall (mm) at each treatment and site.

Site	Treatment	2011	2012
A	Control	163	365
	Wet	325	1044
	Dry	34	80
	Rainfall	558	228
B	Control	90	214
	Dry1	17	64
	Dry2	16	14
	Rainfall	519	249
C	Control	250	423
	Wet	427	652
	Dry	216	336
	Rainfall	406	187
D	Wet	325	663
	Dry	90	307
	Rainfall	223	225

accounted for about 150 mm of rainfall at sites A and B, and for 50 mm at site C. The dry treatments required 21% to 93% less IW than the control treatments (table 2). In 2011, SWP_I was never reached for any dry treatments at sites A and B, nor for the dry2 treatment at site B in 2012. In those four cases, irrigations were done only for crop cooling. Wet treatments received 54% to 186% more IW than the control treatments; this represents more than 1 m of water during the season, much more than the 300 mm recommended (Asselin et al., 1997; Sandler and DeMoranville, 2008).

The mean seasonal SWP values for each treatment are shown in table 3. The difference in mean seasonal SWP for any two treatments in a given site ranged from 0.01 to 1.46 kPa, which is small considering that differences in SWP_I varied between 1.0 to 4.5 kPa. For all sites and treatments, the mean seasonal SWP was greater in 2012 than in 2011 due to more rainfall in 2011.

For site A in 2011 (fig. 4a), variations in SWP are similar for all treatments, except for the dry treatment between July 11-17 and August 19-20, when the soil was drier than in the other two treatments. Similar differences were observed at that site in 2012 (fig. 4b), with drier periods between July 12 and August 5 and between August 21 and September 1. For site C (figs. 4e and 4f) and site D (figs. 4g and 4h), SWP differences between treatments were apparent in both 2011 and 2012, with larger values corresponding to drier treatments.

At site B (figs. 4c and 4d), differences in SWP were small among all treatments, except for the dry2 treatment in 2012, for which SWP values were about 1.5 to 2.0 kPa lower than those of the other two treatments between July 28-31 and August 24 to September 5. In 2012, the dry2 treatment at site B never reached the -8.5 kPa SWP_I value and was never irrigated.

We were able to document the response of soil water potential to rainfall and irrigation. When using SWP as the irrigation trigger, increased seasonal rainfall resulted in higher soil water potential, and less irrigation water applied. Drier treatments, using SWP_I values lower than -8.0 kPa, resulted in the need for almost no irrigation except for cooling, which represents savings of water, energy, and labor compared to the wetter treatments. Online monitoring allowed real-time estimation of soil water status, and therefore the potential effects on cranberry production.

Yield

Mean values of yield are given in table 4. Yield was significantly greater in 2012 than in 2011 at the Québec sites (A, B, and C) but significantly less at the Wisconsin site (D). The mean yield at site A under organic production (28,170 kg ha^{-1}) was greater than the 2006-2010 average yield of organic cranberries in Québec (15,232 kg ha^{-1}) (APCQ, 2012). The mean yields at site B (42,108 kg ha^{-1}) and site D (35,275 kg ha^{-1}) were greater than the 2006-2010 average yield in Québec (24,134 kg ha^{-1}) (APCQ, 2012) and in Wisconsin (25,415 kg ha^{-1}) (Kashian, 2012).

At site A, the large difference in mean yield between 2011 (13,781 kg ha^{-1}) and 2012 (42,559 kg ha^{-1}) might be due to the severe pruning that occurred in 2010. Yield can be reduced by 23% to 40% the year following a severe pruning (Suhayda et al., 2009; Strik and Poole, 1991) but increased by 45% in the two subsequent years (Chambers, 1918). A light pruning may have no depressing effect on the next year's yield (Strick and Poole, 1991) and may even increase yield by as much as 50% (Suhayda et al., 2009). Since site C was only lightly pruned in 2011, this might explain the high yield in 2012 (31,460 kg ha^{-1}). Sites B and D had not been pruned since 2010. These observations emphasize the importance of taking into account the severity of previous-year pruning in evaluating the effect of irrigation on yield. Variations in pruning timing and intensity may mask differences in yield from site to site.

For all sites, the irrigation treatments within the site had no significant effect on yield, except for site A in 2012, for which yield was significantly less for the dry treatment than for the wet treatment. Although it was not significant, the yield at site A in 2011 was less for the dry treatment compared to the other treatments. At site A, the -10.0 kPa trigger value was never reached in 2011, perhaps explaining why yield in the dry treatment was not significantly impacted in that year. When pooling both years for site A, the dry treatment resulted in a significantly lower yield than either the wet or the control treatment. While the dry treatments at sites B, C, and D had SWP_I values between -7.0 and -8.5 kPa, the dry treatment at site A was drier, with a SWP_I of -10.0 kPa.

In order to relate SWP to the significantly lower yield of the site A dry treatment, the percentage of the time when SWP was lower than -7.5 kPa is shown in figure 5, in increments of -0.5 kPa, compared to the average of all other dry treatments. In 2011, the SWP of dry treatments at sites B, C, and D never exceeded -8.0 kPa and only exceeded -7.5 kPa during less than 2% of the season. The SWP of the site A dry treatment was greater, but as at the other sites, not for much of the 2011 season (~3%). In that year, yield in the dry treatment at site A was lower than in the other treatments, but not significantly. However, in 2012, SWP of the dry treatments exceeded -7.5 kPa with much greater frequency at all sites, particularly at site A (>12% of the season), where ~6% of the SWP data were <-8.5 kPa (compared to <1% in 2011). In that year, yield was significantly reduced in the dry treatment at site A.

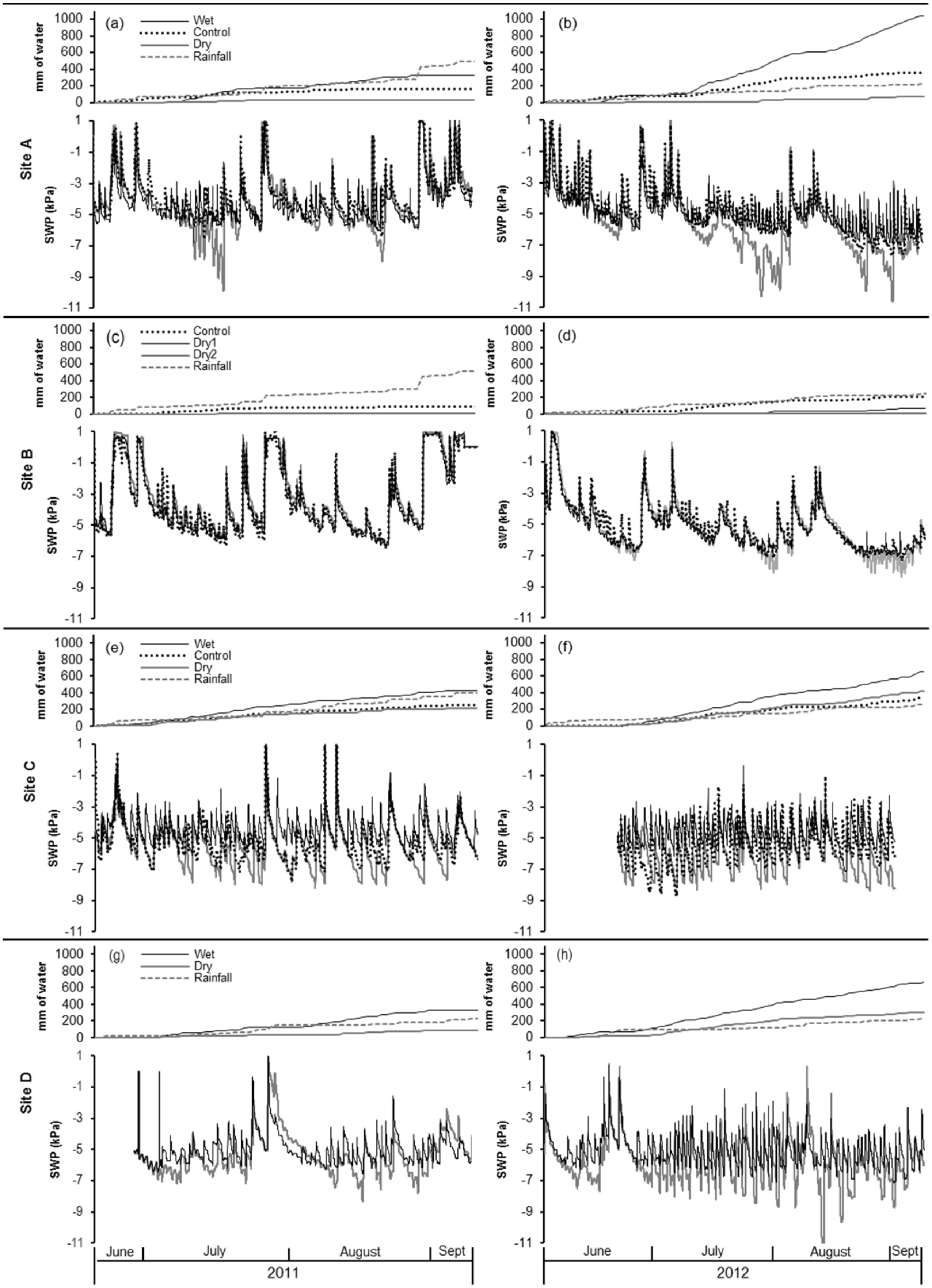

Figure 4. Soil water potential (SWP), cumulative rainfall, and cumulative irrigation water in the treatments for 2011 and 2012.

Table 3. Mean seasonal and average standard deviation (SD) of SWP readings (kPa) for each year, site, and treatment.

Site	Treatment	2011 Mean	2011 SD	2012 Mean	2012 SD
A	Control	-3.93	0.55	-4.80	0.60
	Wet	-4.28	0.30	-5.02	0.48
	Dry	-4.29	0.74	-5.63	0.93
B	Control	-3.47	0.50	-5.13	0.46
	Dry1	-3.18	0.26	-5.23	0.46
	Dry2	-3.51	0.62	-5.28	0.74
C	Control	-5.21	0.46	-5.61	0.30
	Wet	-4.42	0.51	-4.74	0.48
	Dry	-5.59	0.40	-6.20	0.24
D	Wet	-5.03	0.95	-5.10	1.36
	Dry	-5.31	0.72	-5.91	1.18

Table 4. Cranberry yield (kg ha^{-1} ± standard error) for each year, site and irrigation treatment.[a]

Site and Treatment	2011	2012	2011-2012 Mean
Site A (9 blocks)			
Control	14,612 ±1238 a	43,006 ±1357 ab	28,809 ±945 a
Wet	14,202 ±1238 a	46,066 ±1357 a	30,134 ±945 a
Dry	12,527 ±1237 a	38,603 ±1357 b	25,565 ±944 b
Mean	13,781 ±714 b	42,559 ±783 a	28,170
Site B (8 blocks)			
Control	37,652 ±2319 a	47,680 ±2319 a	42,666 ±1671 a
Dry1	38,327 ±2319 a	45,434 ±2319 a	41,881 ±1671 a
Dry2	39,299 ±2319 a	44,258 ±2319 a	41,778 ±1671 a
Mean	38,426 ±1389 b	45,791 ±1389 a	42,108
Site C (4 blocks)			
Control	19,810 ±1339 a	33,913 ±1403 a	26,862 ±999 a
Wet	18,995 ±1339 a	29,339 ±1403 a	24,167 ±999 a
Dry	22,482 ±1339 a	31,128 ±1403 a	26,805 ±999 a
Mean	20,429 ±808 b	31,460 ±843 a	25,944
Site D (8 blocks)			
Wet	37,959 ±1792 a	29,156 ±1330 a	33,558 ±1135 a
Dry	38,808 ±1839 a	31,177 ±1330 a	34,992 ±1116 a
Mean	38,383 ±1284 a	30,167 ±941 b	34,275

[a] For each site, means followed by the same letter are not significantly different.

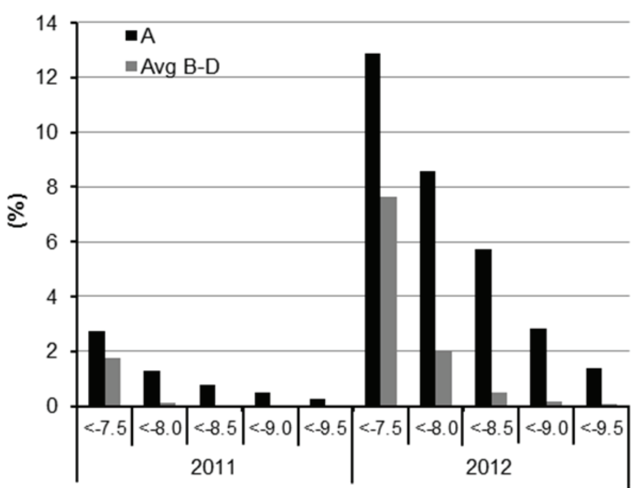

Figure 5. Percent of SWP data in the dry treatment at site A compared to the average of the other dry treatments.

Despite large differences in the amount of irrigation water applied, the non-significant effect of the irrigation treatments on yield for sites B, C, and D might be caused by the high rate of capillary rise of soil water in those fine sands when SWP is greater than -8.0 kPa. Below -8.0 kPa, the rate of capillary rise is likely too low to meet plant water requirements and could even result in plant water stress, stomatal closure, a decline in the rate of photosynthesis (Tuteja, 2010), and a decrease in carbon fixation (Kramer, 1983). Water supplied to the root zone may come from either sprinkler irrigation or capillary rise. Water table measurements at each site, performed outside of the experimental units, indicated a depth ranging from 60 to 80 cm, except at site C, where the water table was deeper than 200 cm. The cranberry fields at site C are built at the top of a hillock, which could explain why irrigation water in the dry treatment at site C was much more important than in the dry treatments at the other sites (table 2).These observations suggest that proper water table management may reduce the need for sprinkler irrigation in cranberry production.

At sites B, C, and D in 2011 and at site D in 2012, there was a trend for greater yield in the dry treatments compared to the control and wet treatments. Conversely, at sites B and C in 2012, the control treatments produced higher yields. Rainfall was more abundant in 2011 than in 2012 at sites B and C (table 2) but was similar for both years at site D. Contrarily to rainfall, reference evapotranspiration was greater in 2012 at sites B and C and less at site D (fig. 3). These climatic conditions are reflected in table 3, where seasonal mean SWP values are less at sites B and C in 2012 compared with 2011. At site D, the mean SWP was similar for the wet treatments in 2011 and 2012; however, the mean SWP was greater for the dry treatment in 2012 compared to 2011. This suggests that, in addition to pruning, the climatic conditions and the resulting mean SWP affect yields.

A multiple regression showed, at the experimental unit level, a significant relationship between yield, pruning, SWP, rainfall, and ET_o, with an R^2 of 0.83:

$$Y = 3224\times10^{3} \times10^{\left[\left(-169R-315\mathrm{ET}_o+9119\mathrm{ASWP}+10{,}052P\right)\times10^{-5}\right]} \quad (1)$$

where Y is the yield (kg ha^{-1}), R is the cumulative seasonal rainfall (mm), ET_o is the cumulative seasonal reference evapotranspiration (mm), ASWP is the average SWP during the growing season (kPa), and P is the number of years after pruning (if $P > 3$, then $P = 3$). While increasing R and ET_o negatively affected Y, increasing P and ASWP positively affected Y. This shows the importance of maintaining cranberry soil water status that is neither too saturated nor too dry.

Water Productivity

Mean values of WP are given in table 5. The mean values for 2011-2012 at site A are not shown; the heterogeneity of variance residues in the ANOVA prevented the comparison between 2011 and 2012. For sites B and C, WP was significantly greater in 2012 than in 2011, whereas it was the opposite for site D. In both years at site A, WP for the dry and control treatments was significantly greater than for the wet treatment, and in 2012, WP for the dry treatment was also significantly greater than for the control treatment. At site B, there was no significant difference in WP in

Table 5. Effect of irrigation treatment on water productivity (kg ha^{-1} mm^{-1} ± standard error).[a]

Site and Treatment	2011	2012	2011-2012 Mean
Site A (9 blocks)			
Control	20 ±0.7 a	72 ±3.7 b	-
Wet	16 ±0.5 b	36 ±3.1 c	-
Dry	21 ±0.7 a	125 ±3.7 a	-
Mean	19	78	
Site B (8 blocks)			
Control	62 ±5.0 a	103 ±5.4 c	82 ±3.7 c
Dry1	71 ±5.0 a	145 ±5.4 b	108 ±3.7 b
Dry2	73 ±5.0 a	168 ±5.4 a	120 ±3.7 a
Mean	69 ±2.9 b	139 ±3.1 a	
Site C (4 blocks)			
Control	30 ±2.2 ab	55 ±2.2 a	43 ±1.6 a
Wet	23 ±1.9 b	35 ±1.9 b	29 ±1.4 b
Dry	36 ±2.2 a	59 ±2.2 a	48 ±1.6 a
Mean	30 ±1.3 b	50 ±1.3 a	
Site D (8 blocks)			
Wet	69 ±6.7 b	33 ±2.1 b	55 ±3.5 b
Dry	124 ±6.5 a	58 ±2.1 a	99 ±3.4 a
Mean	97 ±4.7 a	46 ±1.5 b	

[a] For each site, means followed by the same letter are not significantly different.

2011, whereas in 2012 and 2011-2012, WP for dry2 was significantly greater than for dry1, with both being significantly greater than the control. At site C, the dry treatment always had a greater WP value than either the wet or control treatments, and that difference was significant compared to the wet treatment. For this same site, the control always had greater WP values than the wet treatment, and that difference was significant in 2012. At site D, WP and yield for the dry treatment were always significantly greater than for the wet treatment.

Regardless of the site, WP values for the dry treatments were always significantly greater than for the wet treatments. At site A, the dry treatment also showed a significantly reduced yield, indicating the importance of considering both WP and total yield in selecting irrigation regimens. In a study on the impact of irrigation treatments on yield components, Pelletier et al. (2013) found a reduction of the total number of berries in that treatment in 2012 and a reduction of fruit set and number of berries per upright in the dry2 treatment at site B in 2012. These three yield components were the most important in relation to yield.

Dry treatments resulted in greater WP values compared to the control treatments, but these differences were not always significant. Since WP is the ratio of yield and total water applied, and because there were no significant differences in yield between the wet and control treatments at site A and for all treatments at the other sites, the differences in WP values within each year are primarily due to the large differences in the amount of irrigation water applied. Except for the dry treatment at site A, irrigation water was wasted in the wet and control treatments, when compared to the dry treatments, because this excess water did not result in yield increase. The pumping of this water resulted in a waste of energy and manpower, and it could lead to fertilizer leaching into groundwater. In addition, excess water could impede aeration in the root zone, which could affect plant productivity. Since the objective of this project is to improve water productivity without affecting yield, treatments with SWP_I lower than -8.0 kPa have been proven to significantly reduce yield and yield components, treatments with SWP_I from -5.5 to -6.5 kPa have been proven to significantly reduce water productivity, but treatments with SWP_I from -7.0 to -8.0 kPa have improved water productivity without affecting yield.

In highbush blueberry (*Vaccinium corymbosum*), the driest treatment with SWP_I at -20 kPa resulted in a reduced yield in comparison with treatments at -10 and -15 kPa (Haman et al., 1997). Centano et al. (2010) proposed using a threshold of -12 kPa to trigger irrigation in grapes (*Vitis vinifera*), while the optimum SWP in a sandy soil is -27 kPa for blackcurrant (*Ribes nigrum*) cultivation (Hoppula and Salo, 2005). The optimal SWP_I is lower in all those studies than in our results, which means that cranberries could be a more sensitive crop to water stress or that cranberry soils support less capillary rise than other soils for the small berries cited above.

CONCLUSION

Irrigation water savings of 21% to 93% were observed for the dry treatments compared to the control treatments under the conditions of this study. Higher seasonal mean soil water potentials and reduced amounts of irrigation water resulted from the rainier season of 2011 compared to that of 2012. Yield was not affected by the dry irrigation treatments with soil water potential thresholds ranging from -7.0 to -8.0 kPa, but the dry treatment with SWP_I at -10.0 kPa resulted in a significant yield reduction of 11%. In addition to irrigation treatments, pruning and climate affected yield. Water productivity was significantly greater in the dry treatments than in the control and wet treatments. In fine sands and under Québec and Wisconsin conditions, we recommend starting irrigation when soil water potential is between -7.0 and -8.0 kPa, the value that resulted in increased water productivity without decreasing yield. Further studies are needed to determine the water table depth that would optimize capillary rise in different cranberry soils in order to enhance yield and water productivity.

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