Water requirements and subirrigation technology design criteria for cranberry production in Quebec, Canada

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Elmi, A., Madramootoo, C., Handyside, P. and Dodds, G. 2010. **Water requirements and subirrigation technology design criteria for cranberry production in Quebec, Canada**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada. 52: 1.1–1.8. Cranberry (*Vaccinium macrocarpon* Aiton) is a wetland crop grown commercially in natural or constructed sandy and peat soils basins. An excessive amount of water is used in cranberry farming systems compared with other irrigated crops, which has heightened growers' interest in improved drainage and irrigation management practices that conserve water resources with optimal yields. The objective of this study was to assess water needs for cranberry beds from a water balance analysis and develop a design criterion for subirrigation requirements in the Saint-Louis-de-Blanford region of Quebec, Canada. Crop evapotranspiration (ET_c) was computed from Hargreave's equation of reference evapotranspiration (ET_o) and a crop consumptive use coefficient (K_c). Different irrigation rates were determined when the root-zone soil moisture was allowed to reach 25, 50, and 75% depletion of available water (AW). Depending on the level of AW depletion, irrigation requirements ranged from 4 to 13 mm per day for a sandy soil, and from 10 to 23 mm for a peat soil. We concluded from our study that the level of AW depletion that should be used to calculate irrigation requirements was between 25 and 50% for both soil types. These crop requirement values can be used as a guide to determine when to irrigate and how much with minimum water loss, without compromising crop yields. We have shown that subirrigation technology using subsurface drainage pipes has the potential to meet irrigation requirements for cranberry production. We found that the ideal pipe spacing would be approximately 22 m for sandy soil, and 5 m for peat soil. More work is needed to ascertain how different lateral spacings can satisfy cranberry water requirements under different climatic conditions. **Keywords:** cranberries, peat soils, available water, irrigation water requirements, crop evapotranspiration, reference evapotranspiration.

L'atoca (*Vaccinium macrocarpon* Aiton) est une culture de terres humides produite de manière commerciale dans des bassins naturels ou construits dans des sols sablonneux ou organiques. Des quantités plus importantes d'eau sont utilisées dans les systèmes de production d'atocas comparativement à d'autres cultures irriguées. Les producteurs ont donc développé un intérêt pour l'amélioration des pratiques de gestion du drainage et de l'irrigation qui conservent les ressources en eau tout en permettant d'optimiser les rendements. L'objectif de cette étude était de déterminer les besoins en eau des plants d'atocas sur une base d'analyse de bilan d'eau et de développer un critère de design pour les besoins d'irrigation souterraine dans la région de Saint-Louis-de-Blanford, Québec, Canada. L'évapotranspiration des plants (ET_c) a été calculée à partir de l'équation de Hargreave d'évapotranspiration de référence (ET_c) et du coefficient d'utilisation de l'eau de la culture (K_c). Différents taux d'irrigation ont été déterminés quand la teneur en eau du sol dans la zone racinaire pouvait atteindre 25, 50, et 75% de déficit en eau disponible (AW). Dépendant du niveau de déficit AW, les besoins en irrigation variaient entre 4 et 13 mm par jour dans le sol sablonneux et de 10 à 23 mm dans le sol organique. Les résultats de notre étude nous ont permis de conclure que le niveau de déficit AW qui devrait être utilisé pour calculer les besoins en irrigation était entre 25 et 50% pour les deux types de sol. Ces valeurs de besoin en eau des cultures peuvent être utilisées comme lignes directrices pour déterminer quand irriguer et combien fournir d'eau pour minimiser les pertes en eau et ce sans compromettre les rendements de la culture. Nous avons démontré que la technologie d'irrigation souterraine qui utilise des tuyaux de drainage a le potentiel de combler les besoins en irrigation de la production d'atocas. Nous avons déterminé que l'espacement idéal entre les tuyaux serait d'environ 22 m pour les sols sablonneux et de 5 m pour les sols organiques. Plus de travaux sont nécessaires pour déterminer comment différents espacements latéraux peuvent subvenir aux besoins en eau des atocas dans différentes conditions climatiques. **Mots clés:** atocas, sols organiques, eau disponible, besoin en eau d'irrigation, évapotranspiration de culture, évapotranspiration de référence.

INTRODUCTION

Cranberry (*Vaccinium macrocarpon* Aiton) is a moderately high value crop, whose production in Canada has been increasing significantly in recent years, showing impressive gains among fruit crops in Canada. According to the 2001 census of agriculture, the total area cropped to cranberries increased by 64.6% (from 1832.3 to 3016 ha) from 1996 to 2001 (Statistics Canada 2001). The health benefits (Habash et al. 1999; Kerr 1999; Raloff 2000; Vivian et al. 2009) associated with cranberry juice and snack floors are likely to be the main driving factor of increasing demand for cranberry production. For example, Guthrie (2000) reported that cranberry juice and its products can reduce human breast cancer cell growth. Cranberry cultivation in Canada is concentrated mainly in regions of acidic soils along waterways and within bogs in Nova Scotia, British Columbia and Quebec. In Quebec, growers are concentrated in the region of Saint-Louis-de-Blanford (lat. 46°15′N and long. 72°00′W) situated within the Bécancour River watershed, between Montreal and Quebec City. As the climate, soil conditions, and availability of adequate water make it an ideal area for cranberry production, the region has become the home to Quebec's largest cranberry producers.

Cranberries, being native to wetland habitats, require plentiful water for their cultivation. Total water requirements for cranberry production, including irrigation, frost protection at harvest, and flooding vary from 15 000 to 25 000 m^3 ha^{-1} yr^{-1} (Eck 1976). As little as 4000 m^3 ha^{-1} yr^{-1} may be used if water is used more efficiently (Robinson and Hanson 1997). With the industry's intensive use of water and the application of fertilizers and pesticides in a wet environment, impacts to streams and lakes can be more direct than for other agricultural operations, leading to water quality degradation.

Management practices that conserve water should be a priority to cranberry growers to improve yields and minimize environmental impacts associated with potential off target movement of agrochemicals into receiving water bodies. Currently there is emphasis on the management of controlled drainage and subsurface drainage systems to reduce pollutant levels in effluents and protect environmental quality. Controlled drainage can reduce nutrient and pesticide losses while maintaining desired water table levels. In Quebec, for example, controlled drainage/subsurface irrigation has been shown to reduce pesticides and nitrate concentrations in soil and in drainage effluent under soybean (*Glycine max* L.) (Madramootoo et al. 1993) and grain corn (*Zea mays* L.) (Elmi et al. 2002; Elmi et al. 2004). Despite agronomic and environmental advantages, this proven technology has yet to be adopted by cranberry growers. Subirrigation through existing subsurface drainage pipes has the potential to meet irrigation requirements for cranberry production at a lower cost to the farmer and to the environment than currently used conventional drainage methods. From the economic perspective, research has shown that the energy costs of subsurface irrigation are significantly lower than other traditional irrigation techniques such as sprinkler irrigation (Massey et al. 1983).

Water management practices have largely been the result of a trial and error process on the part of the growers (Dana 1989; Stang 1993). This holds true for the Saint-Louis-de-Blanford region (Binet and Laperriere 1997). Rational design and operations criteria for subsurface irrigation are needed for this region. The primary objective of this study was to assess irrigation needs and the manner by which subirrigation requirement can be implemented, based on soil hydraulic conductivity data and typical meteorological conditions in the Saint-Louis-de-Blanford region of Quebec, Canada.

METHODOLOGY

Characterization of selected sites

Field sites located in Nicolet and Mégantic counties, on the South shore of the Saint Lawrence River, Quebec, were selected. The climate in this region is sub-humid, with cold winters and hot summers. The average annual precipitation is approximately 900 mm, and rainfall during growing season (May–September) is approximately 490 mm, with the total frost-free periods ranging from 120 to 130 d (Laflamme et al. 1989). Two peat and two sandy soil sites were selected for the study. Undisturbed soil samples were collected using aluminum cylinders at depth increments of 0–0.10 m and 0.1–0.20 m below the soil surface. This depth was selected because maximum root-depth ranges from 0.15 to 0.30 m, but the majority of cranberry roots are located in the top 0.1 to 0.15 m below the soil surface (Handyside 2003). Saturated hydraulic conductivity (K_{sat}) was measured using the falling-head soil core method (Klute and Dirkensen 1986).

Evapotranspiration for the cranberry crop

Climatic data were obtained from an Environment Canada weather station located 50 km northeast of Saint-Louis-de-Blanford in Nicolet, Quebec. Weather data for the 2000 and 2001 growing seasons (May–September), and the 30-yr mean (1970–1999) were used to determine crop evapotranspiration (ET_c). Daily minimum, maximum and mean air temperatures were available. However, solar radiation, relative humidity and wind speed were not available; therefore, the reference evapotranspiration (ET_o) was calculated according to a modified version of the Hargreave's equation (Allen et al. 1998):

$$ET_0 = 0.0023(T_{mean} + 17.8\sqrt{T_{\max} - T_{\min}}\frac{R_a}{\lambda\rho_w} \quad (1)$$

where ET_0 is the reference evapotranspiration (mm d^{-1}), T_{max} is the maximum daily temperature (°C), T_{min} is the minimum daily temperature (°C), T_{mean} is the mean daily temperature (°C), R_a is the mean extraterrestrial solar radiation (MJ m^{-2} d^{-1}) determined at a latitude of 40°N, the Nicolet weather station being situated at about 46°N, λ is the latent heat of vaporization, 2.45 (MJ kg^{-1}) ρ_w is the density of water, i.e., 1.0 Mg m^{-3}.

The crop evapotranspiration was then computed as:

$$ET_c = K_c \times ET_0 \quad (2)$$

where K_c is the crop coefficient (unitless) and ET_c is the crop evapotranspiration (mm d^{-1}). The K_c is defined as the ratio of ET from any specific crop or soil surface to some reference and, therefore, represents potential ET. Because ET_0 represents nearly all effects of weather, K_c varies primarily with specific crop characteristics. This enables the transfer of K_c values between locations and climates, leading to a widespread use of the K_c approach. Hattendorf and Davenport (1996) estimated a cranberry K_c of 0.55 by measuring actual ET_c for blueberry (*Vaccinium angustifolium* L.). Haman et al. (1997)

proposed that 0.30–0.55 represented a reasonable range for K_c. We chose a value of 0.5 to estimate cranberry evapotranspiration (ET_c), because cranberry is anatomically similar to blueberry.

Irrigation requirements

A soil's capacity to store available water has significant implications for managing irrigation requirements. Total available water in the soil was determined by two soil parameters: the soil moisture content at field capacity (θ_{fc}) and moisture content at the permanent wilting point (θ_{pwp}). The (θ_{fc}) and (θ_{pwp}) level varies according to soil type. Total available water (T_{aw}) in a given soil depth can be determined from (θ_{fc}), (θ_{pwp}) and the effective root-zone of the crop (D_{rz}) using the following formula:

$$T_{aw} = D_{rz}\,(\theta_{fc} - \theta_{pwp}) \tag{3}$$

The T_{aw} for sandy and peat soils were calculated as 16.5 mm and 31.5 mm, respectively. However, plants can utilize only a portion of the T_{aw} before plant growth and, consequently, crop yields are affected. This portion is known as the readily available water (R_{aw}), which can range between 40 and 65% of T_{aw} (Schwab et al. 1993), but can be as low as 20% for shallow root crops such as strawberry (Allen et al. 1998). Consequently, irrigation scheduling is commonly based on a threshold fraction of available water (% AW) remaining in the soil at a given time. A water balance approach was used to determine% AW (mm) on a daily basis:

$$\%AW = P_{t-1} - ETc_{t-1} + \%\,AW_{t-1} \tag{4}$$

where% AW is today's soil water content, ETc_{t-1} is yesterday's ET_c (mm), P_{t-1} is yesterday's effective rainfall (mm), and $\%\ AW_{t-1}$ is yesterday's soil water content (mm).

Subsurface irrigation system and design criteria

Subsurface irrigation is one system providing two functions: drainage and irrigation. Water can be supplied through the same subsurface pipes used for drainage. The same materials are used to construct both drainage and subirrigation system and, therefore, existing drainage systems can potentially be modified to provide subsurface irrigation. Control structures can be used to regulate water table depth (WTD). Irrigation water would then be supplied below the soil surface, thus raising and maintaining an appropriate WTD to provide optimum moisture conditions in the effective root-zone. The features required for a successful water table management (WTM) include a permanent water table at a reasonably shallow depth to minimize seepage losses, flat topography, high soil hydraulic conductivity to allow sufficient drainage during excessively wet periods and high infiltration of irrigation water during dry periods, and reliable source of water supply. Cranberry farms constructed on sandy soils meet these requirements, although peat soils may pose greater technical challenges.

In the region of our study, the width of cranberry fields ranged 40 from 50 m for sandy soils and from 35 to 40 m for peat soils. Each basin typically had two or three subsurface drainage pipes, installed at a depth of 1.0 m for sandy soils and 0.6 m for peat soils. Drainage spacing designed to operate as a subirrigation system is roughly 30% closer than that for drainage alone (Brown et al. 1997). Modification of an existing drainage system would simply involve installing additional pipes between existing laterals, when necessary. Horizontal pipe spacing, S, for a subsurface irrigation system is determined as (Schwab et al. 1993):

$$S = \sqrt{\frac{4K_{sat}m\dfrac{2h_0 - h_0 m}{D_0}}{q}} \tag{5}$$

where S is the pipe spacing (m), K_{sat} is the saturated hydraulic conductivity (m d^{-1}), m is the depth of water table sag between pipes (m), q is the irrigation requirement (m d^{-1})

$$h_0 = d_e + y_0$$

where d_e is the equivalent depth from the drain bottom to the impermeable layer (m) and y_0 is the depth from the desired water table depth to that of the supply pipe (m)

$$D_0 = d + y_0$$

where d is the depth from the supply pipe bottom to the impermeable layer (m).

RESULTS and DISCUSSION

Climatic conditions and irrigation requirements

Total annual precipitation in 2000 was 908.5 mm, roughly the same as the 30-yr normal (899.9 mm). Rainfall during growing season (May–September) was 475.7 mm (Table 1). In 2001, total annual precipitation was 746.0 mm, with growing season (May–September) receiving 357.5 mm (Table 1). It is also important to note here that, with the exception of July, when temperatures were all close, the 2001 growing season was hotter than the 2000 growing season as well as seasonal normal temperatures (Fig. 1). Irrigation water requirements were calculated for cranberry plants grown on both sandy and peat soils at available water thresholds of 25, 50 and 75%. These calculations were based on water balance analysis, using the reference evapotranspiration (ET_o) estimates with appropriate crop coefficient (K_c) for cranberry. In both growing seasons, irrigation frequency was greatest between July–August, hot summer months when water demand was greatest.

Figure 2 and 3 present irrigation frequencies and total seasonal (May–September) depth of irrigation for the two soils and under different water depletion-based criteria. Total seasonal irrigation requirements were greater for 2001 than 2000. This was not surprising given the fact that 2001 season was, on average, drier (Table 1) and hotter (Fig. 1) than 2000. These observations indicate that irrigation recommendations based on evaporative losses

Table 1. **Monthly and total seasonal rainfall (mm) and cranberry evapotranspiration (mm/day) at Nicolet, Quebec, for May–September 2000, 2001, and 30-yr (1970–1999) long-term average.**

	Rainfall (mm)						Crop evapotranspiration (mm/day)					
Year	May	June	July	August	Sept.	Seasonal total	May	June	July	August	Sept.	Seasonal total
2000	138.8	130.7	37.6	73.2	95.4	457.7	1.7	2.1	2.3	2.1	1.4	9.4
2001	29.9	65.5	108.4	106.8	46.9	357.5	2.3	2.4	2.3	2.3	1.6	10.5
1970–1999	83.1	86.0	96.2	96.8	89.2	451.3	1.2	1.2	1.1	1.0	1.1	5.4

would better reflect changing daily and seasonal weather conditions.

Depth of individual irrigations, however, varied between the 2 yr for a given soil type-AW depletion threshold combination (Figs. 2 and 3), depending on the soil type. For sandy soil, we calculated irrigation requirements for irrigation threshold levels of 25, 50, and 75% depleted AW to be 4, 6 and 13 mm d^{-1}, respectively. For the peat soil, irrigation requirements were calculated to be 9.8, 15.3 and 22.6 mm d^{-1}, respectively. These findings are in close agreement with the findings of Binet and Laperriere (1997) who estimated irrigation requirements to be about 7.6 mm per application, three times a week from June to August, and two times a week in September. Under peat soils where irrigation depth levels are high, cranberry operations discharge excess water into receiving waters. Based on the analysis of annual water usage for cranberry in Quebec (Binet and Laperriere 1997) and our computed soil drainage parameters for 25, 50, and 75% AW depletion (Table 2), we can conclude that the level of AW depletion that should be used to calculate irrigation requirements is between 50 and 25%. This is particularly true for the sandy soil, reducing the amount of available water to nearby waterways and lakes. It should be noted that the cumulative amount of irrigated water was only slightly greater in sandy soil than in peat soil during both growing seasons (Fig. 3). The dissimilarity can be explained by the differences in soil physical properties, with peat soils showing lower hydraulic conductivity than coarse-textured (sandy) soils. We should point out here that, regardless of soil type on which cranberry is planted, large volumes of water are crucial in growing cranberries, and to avoid deleterious effects of high soil moisture, drainage is also essential to remove excess water. Combinations of these factors represent potential problem for water quality degradation. If this observation becomes true (after multiple tests), it is plausible to conclude that the considerable amounts of water used for irrigation, frost protection, winter flooding and harvest applied to cranberry beds can lead to increased levels of nutrients and other agrichemicals in the sensitive wetland areas in which

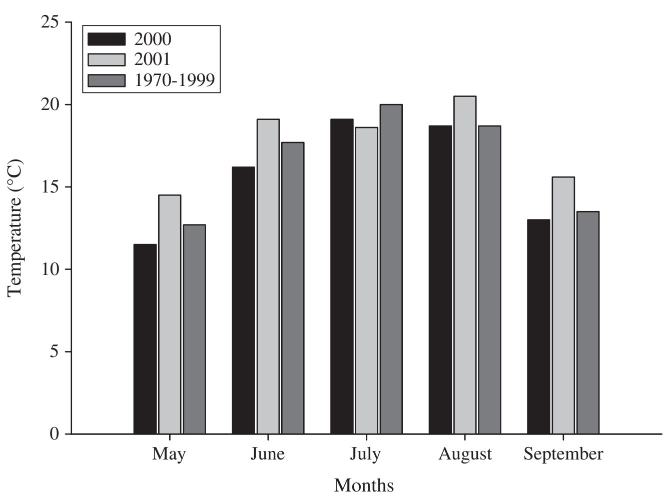

Fig. 1. Monthly temperatures during 2000 and 2001 growing seasons as compared with seasonal normal temperature (1970–1999).

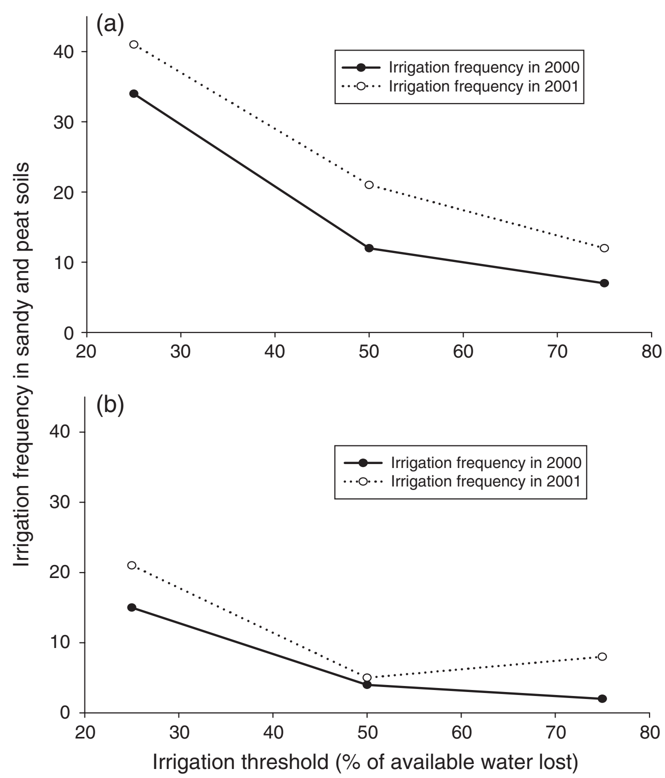

Fig. 2. Irrigation frequency and total seasonal irrigation for irrigation thresholds of 25, 50 and 75% of available water (AW) depletion in (a) sandy and (b) peat soil.

Table 2. **Parameters for subsurface irrigation pipe spacing calculations for sandy and peat soils.**

	Soil drainage parameter					
Soil Type	Drain depth (m)	K_{sat} (m d^{-1})*	d (m)**	y_0 (m)†	D_0 (m)§	q (m d^{-1})¶
Sandy soil	1.0	0.4	3–5	0.50–0.65	3.50–5.65	0.0064
Peat soil	0.6	1.9	3–5	0.0	3.0–5.0	0.0165

*Saturated hydraulic conductivity (m d^{-1}).
**The depth from the supply pipe bottom to the impermeable layer (m).
†The depth from desired water table depth to that of the supply pipe (m).
§The depth from desired water table depth to the impermeable layer (m).
¶The irrigation requirement (m d^{-1}).

cranberry grows. The increased nutrients may cause excessive weed and algae growth, which can reduce dissolved oxygen in downstream surface waters into which these waters discharge (Botelho and Vanden Heuvel 2005).

Subirrigation design criteria

Experiments conducted with undisturbed soil columns obtained from sandy and peat soils of cranberry production system in the St. Louis se Blanford region suggest that for sandy soils a WTD of 0.35–0.5 m would best maintain optimal soil moisture conditions in the root zone (Handyside 2003). For the peat soil, the most critical issue was how to ensure that the WTD remains at or below 0.6 m to avoid root zone water saturation for long periods of time. The findings of our study from soil columns correspond fairly closely to those from the literature with respect to sandy soils, whereas findings with the peat soil columns were significantly deeper than those in the literature. This discrepancy may be due to the fact that the peat soils used in our study were somewhat coarse.

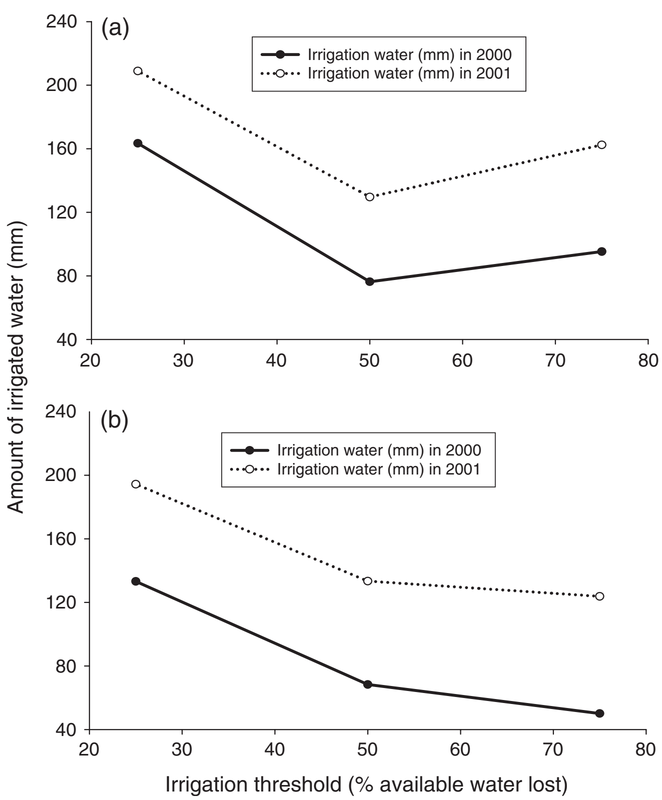

Fig. 3. Irrigation thresholds of 25, 50 and 75% of available water (AW) depletion in (a) sandy and (b) peat soil.

Table 2 provides the parameters necessary to determine irrigation drain spacing for a subsurface system installed on the sandy or peat soil under study (Eq. 5). Table 3 presents drainage pipe spacing (S) for subirrigation of each soil type calculated at indicated values of water table sag, m, and depth from the supply pipe bottom to the impermeable layer, d. The value y_o for a sandy soil was taken as the mean of the range indicated in Table 2. Estimated spacing (S) was used to determine the value of the equivalent depth (d_e) through interpolation, using the relationship developed by Van Schilfgaarde (1963). A sag value of 0.1 m is recommended to determine S and maintain a relatively uniform water table. At this value, ideal pipe spacing would be approximately 22 m in a sandy soil, when the value of d falls within the 3–5 m range, as occurs for the region under study. The calculated pipe spacing for peat soil is much narrower, approximately 5 m, when m is 0.1 m and d is 3–5 m.

We estimated the quantity of additional pipes required to meet irrigation requirements through subsurface irrigation in basins of varying widths, for each soil type, provided that the WTD is limited to a minimum of 0.1 m sag between pipes. This suggests that subsurface irrigation can be a cost effective method to meet irrigation requirements when existing drain pipes are used, thus reducing infrastructure and operating costs. Under peat soils, however, 4–6 additional pipes may be required, making it economically unattractive to implement subirrigation on those fields. If, however, the maximum allowable sag was 0.2 m or greater as suggested by Brown and McNeil (2006) then a peat soil basin constructed with a minimum of existing subsurface drainage pipes could satisfy both drainage and irrigation requirement. This would provide a considerable savings and promote better soil conservation since subirrigation can slow land quality degradation in peat soils by enhancing oxidation conditions. In an extensive study in Massachusetts, Chandler (1951) concluded that a WTD of 0.30 m was optimal. A WTD of 0.3–0.38 m resulted in significantly higher fruit yields in 4 out of 5 yr compared with cranberry basin WTD of 0.46–0.54 m (Eck 1976). In Quebec, a WTD of 0.3–0.38 m was recommended for cranberry (Binet and

Table 3. Subsurface irrigation pipe spacing developed for sandy and peat soils.

	Parameters for pipe spacing determination					
Soil type	m (m)*	y_0 (m)**	d (m)†	S (m)§ estimated	d_e (m)¶ determined	S (m)‡ calculated
Sandy soil	0.05	0.575	3	15	1.35	15.03
			5	15	1.40	15.24
	0.10	0.575	3	22	1.50	21.99
			5	22	1.60	22.57
	0.15	0.575	3	30	1.90	29.30
			5	30	2.10	30.58
	0.20	0.575	3	34	1.95	34.05
			5	34	2.20	35.88
Peat soil	0.05	0	3	2	0.30	1.76
			5	2	0.30	1.76
	0.10	0	3	4	0.65	3.65
			5	4	0.65	3.66
	0.15	0	3	5	0.70	4.62
			5	5	0.70	4.64
	0.20	0	3	6	0.85	5.85
			5	6	0.85	5.89

*The depth of water table sag between pipes (m).
**The depth from desired water table depth to that of the supply pipe (m).
†The depth from the supply pipe bottom to the impermeable layer (m).
§The estimated pipe spacing (m).
‡The equivalent depth from the drain bottom to the impermeable layer (m).
¶The calculated pipe spacing (m).

Laperriere 1997). Eck (1976) compiled a number of studies on cranberry and concluded that plants grown with shallow WTDs developed a dense root mat near the soil surface, rendering them susceptible to dry conditions.

For a sandy soil basin that is typically 40–50 m wide, a minimum of two drainage pipes, evenly spaced at 13.5 to 16.7 m are all that is needed to provide irrigation requirements via subsurface irrigation. Depending on the width and number of existing subsurface drainage pipes, a peat soil basin would require four to six additional pipes to convert it to successful subsurface irrigation system (Table 4). Additional inputs in terms of pipes are not prohibitively costly and create an ideal environment to grow and harvest larger yields of cranberry. This is particularly true for sandy soil, whereas in peat soils, as mentioned earlier, additional cost may prevent farmers from adopting this environmentally friendly technology.

SUMMARY and CONCLUSIONS

Cranberry cultivation is an important and growing industry in Quebec. As with any agricultural practice, Cranberry cultivation has the potential to impact surface water quality. The cranberry industry is working on best management practices and other methods to better protect surface waters. The aim of the study was to integrate subirrigation and drainage management strategies and provide baseline information about the potential for subirrigation technology in cranberry production systems.

Table 4. Number of additional lateral pipes required for a basin constructed on a sandy or peat soil.

Soil type	Basin width (m)	Typical No. of existing drainage pipes	Drainage pipe spacing (m)	Subsurface rrigation lateral pipe spacing at 0.1 WTD sag (m)	No. of additional lateral pipes required
Sandy soil	40	2	13.3	22	0
		3	10.0		0
	50	2	16.7		0
		3	12.5		0
Peat soil	35	2	11.7	4	6
		3	8.8		4
	40	2	132.3		6
		3	10.0		4

We describe empirical methods for determining cranberry subirrigation requirements and rational for water table management. Based on soil hydraulic conductivity data, we propose that existing subsurface drainage can be used successfully as subirrigation with no additional pipes for sandy soils and, on average, two additional pipes for peat soils. However, we note that since our findings are based on limited samples, further study is required to verify that pipe spacing reflects accurately upon water needs under particular climatic conditions. While a subsurface irrigation system would meet irrigation requirements, it must be noted that a sprinkler system would still be needed to protect plants against spring and fall frost damage, and supply nutrients and pesticides. It can be concluded from our calculations that between 25 and 50% of available water depletion may be used to determine irrigation requirements under Quebec conditions. Cranberries grow in very acidic soil environments that generate little nitrate due to the inability of nitrifying bacteria to thrive in the low soil pH environment. Consequently, water quality benefits associated with water table management in cranberry production systems may be realized primarily by controlling pesticide discharge into the surface water systems.

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