Assessing On-Farm Irrigation Water Use Efficiency in Southern Ontario

Marie-Hélène Bernier, Chandra A. Madramootoo, Bano B. Mehdi, and Apurva Gollamudi

Abstract: For high-value horticultural crop production in southern Ontario, irrigation is an essential ingredient in overcoming insufficient rainfall and achieving stabilized crop production. In a context where competition for limited water resources intensifies due to the expansion of the agricultural sector, increasing urban development and tourism, and potential climate change impacts, conserving water through efficient irrigation has become a key solution in addressing this growing challenge. The implementation of advanced soil water monitoring technologies and water budgeting methods for improved irrigation scheduling is examined with regard to water conservation and thus as a means to cope with competing demands for limited water supplies. During the 2007 growing season, soil moisture was measured using two sensors at four field sites (comprising a total of six irrigated zones as two sites include two different irrigation/production systems) in southern Ontario. Irrigation water consumption was measured by flow meters at three sites. In addition, a survey was administered to collect information on growers' current irrigation scheduling practices. On-farm irrigation performance was assessed by comparing calculated tomato, green bell pepper, strawberry and peach water requirements (using the water budget method) with growers' estimates of irrigation water use and with soil moisture measurements taken during the growing season. Four out of the six irrigated zones were excessively irrigated, while in one zone, water was insufficiently applied. The crop water requirements were met efficiently exclusively in one zone where tomatoes were grown. Overall, the results of this research show that by implementing advanced soil moisture monitoring technologies, growers can increase precision in water application and reduce the uncertainty in their current irrigation scheduling practices.

Résumé : Dans le sud de l'Ontario, l'irrigation est essentielle à la production de cultures horticoles à haute valeur ajoutée afin de compenser l'insuffisance de précipitations et stabiliser la production des cultures. Dans un contexte où la compétition pour les ressources limitées en eau s'intensifie en réponse à l'expansion du secteur agricole, à la croissance du développement urbain et du tourisme, ainsi qu'aux impacts potentiels des changements climatiques, conserver l'eau grâce à des techniques d'irrigation économes est devenue une solution incontournable pour affronter ce défi grandissant. L'implémentation de technologies avancées de surveillance de la teneur en eau dans le sol et d'un bilan hydrique, pour améliorer

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les pratiques d'irrigation programmée, est examinée afin de conserver l'eau et ainsi mieux faire face aux demandes concurrentielles pour les ressources limitées en eau. Au cours de la saison de croissance de 2007, l'humidité du sol a été mesurée avec deux sondes pour quatre sites (comprenant un total de 6 zones irriguées) situés dans le sud de l'Ontario. Les quantités d'eau utilisées pour irriguer étaient mesurées par des compteurs de débit installés sur trois sites. De plus, les producteurs ont répondus à un questionnaire ayant pour mandat de recueillir de l'information concernant leurs pratiques actuelles d'irrigation programmée. La performance d'irrigation à l'échelle de la ferme a ensuite été évaluée en comparant les besoins en eau de tomates, poivrons verts, fraises et pêches (calculés à l'aide d'un bilan hydrique) avec la quantité d'eau d'irrigation utilisée telle qu'estimée par les producteurs, ainsi qu'avec les mesures d'humidité du sol prises au cours de la saison de croissance. Dans cinq des six zones irriguées, la quantité d'eau appliquée était soit excessive, soit insuffisante. Une application d'eau d'irrigation excessive a été détectée dans quatre des zones alors qu'une application insuffisante a été observée dans une des zones. Les besoins en eau des cultures ont été comblés efficacement dans une seule zone. Somme toute, les résultats de cette étude montrent qu'en implémentant les technologies avancées de surveillance d'humidité dans le sol, les producteurs pourraient généralement économiser de l'eau en réduisant l'incertitude actuellement imbriquée dans leurs pratiques d'irrigation programmée.

Introduction

High-value horticultural production occupies an important part of Ontario's landscape where 25,780 ha are under fruit production and 62,967 ha are under vegetable production (Statistics Canada, 2006). This land is geographically concentrated in the southwestern part of the province where a unique blend of climate, geography and soils allows producers to grow a wide variety of high-quality fruits and vegetables. Irrigated horticulture currently faces considerable competition for limited water resources; this condition is exacerbated by expansion of the agricultural sector (accounting for 20% of total annual water use), increasing urban development and tourism, and potential climate change impacts (Miller *et al.*, 2000). Increasing competition for water emphasizes the importance of adopting appropriate on-farm water management strategies to conserve water and at the same time meet crop water requirements. As a result, optimizing irrigation efficiency has become a very pertinent practice in Ontario (de Loë *et al.*, 2001). This is especially crucial during the prevailing low flow conditions of the summer months, when most of the irrigation water is consumed (54%) and demand from other sectors peaks at the same time (Environmental Commissioner of Ontario, 2001).

Persistent concerns over the availability of water for irrigation are heightened by increasing evidence that climatic conditions are changing in the region (Tan and Reynolds, 2003). An increase in average temperature of approximately 1˚C has been observed over the past 20 years and precipitation has declined by about 225 mm/year. The aforementioned is associated with a rapid increase in growing season water deficit (currently ranging from 80–275 mm) which is of particular concern since average crop yields have shown a considerable decline during this period due to water stress (Tan and Reynolds, 2003). If the current climate change trend continues and crop productivity is to achieve its full potential, irrigation water applications may need to increase significantly over the latter half of this century in order to cope with crop water deficits that are expected to double in some parts of southwestern Ontario.

Today, most growers schedule irrigation by drawing on past experience: observing the condition of the plants, examining and feeling the soil to determine the soil moisture content, and adhering to weather forecasts. Even if this subjective method of determining soil moisture can become fairly accurate with practice and diligence, UMA Engineering Ltd. (2007) showed that with few exceptions, this technique largely overestimates the crop water needs. The report indicates that in 2007, in the Leamington area, the producers' water demand exceeded the 1:10 year drought risk demand estimated by the Ontarian private company Weather Innovations Incorporated (WIN), which works closely with agricultural growers in the region.

In a questionnaire-based survey in southern Ontario, Dolan *et al.* (2000) found that the most popular water conservation measure among irrigators was scheduling irrigation according to water needs (94%). More than half of the respondents reported that they used rainfall or soil moisture monitoring or both for scheduling irrigation as a water-saving practice. Another area with potential for achieving increased water savings is upgrading the irrigation system; however, this option was not as popular among growers due to higher investment costs associated (Dolan *et al.,* 2000). Pitblado *et al.* (2007) reviewed several studies and found that irrigation system application efficiencies are highly variable and could range from as low as 50 to 95%, depending on the irrigation system (overhead gun, sprinkler, drip, etc.), and to a lesser extent site conditions and management practices (Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2004). This research thus looks at the option that is most likely to be adopted by growers as a water conservation strategy, i.e., scientific irrigation scheduling.

Scientific irrigation scheduling (SIS), defined as the use of climate and crop evapotranspiration data and soil moisture sensors to accurately determine when and how much to irrigate (Leib *et al.,* 2002), remains predominantly unpracticed. By providing plants with sufficient water at the right time, SIS is one of the most important tools for developing best irrigation management practices (Mermoud *et al.,* 2005). The intent of this paper is to demonstrate how the implementation of SIS can successfully improve irrigation water use efficiency and consequently achieve substantial water savings. On-farm irrigation performance was thus assessed by comparing growers' water consumption estimates with calculated crop water requirements for four crops—tomato, bell pepper, strawberry and peach. In addition, water budget calculations were compared with actual soil moisture measurements taken over the course of the growing season to determine the quantity of water that could be economized.

Materials and Methods

Study Area

The study was conducted in four counties of southern Ontario: Essex, Chatham-Kent, Norfolk-Haldimand, and Lincoln (Figure 1).

These counties were chosen based on two criteria: areas of intense irrigated vegetable and fruit production and water scarcity for irrigation. The Essex and Chatham-Kent counties constitute the largest population of growers dedicated to irrigated vegetable production in Ontario (de Loë *et al.,* 2001). The region benefits from a longer growing season than other Ontario regions and has rich, relatively light soils and stable soil moisture patterns which are all desirable traits for vegetable production. Yet, irrigation activities are constrained by water availability (UMA Engineering, 2007), requiring local initiatives such as the Leamington Area Drip Irrigation Association (LADIA), which was given the mandate to build a distribution system to deliver raw water from Lake Erie to 1,000 hectares of existing and potentially irrigable land (Stantec Consulting Ltd., 2005). The Norfolk-Haldimand County is another pocket of extensive cash crops including tobacco, berries, apples and a large array of market vegetables and canning crops (OMAFRA, 2005). Agricultural activities take place in the Norfolk Sand Plain where the underlying geology, consisting of glaciolacustrine well-drained sands, forms an important local aquifer (Wong and Bellamy, 2005). The Niagara Peninsula, where Lincoln County is located, has a unique climate due to two of its natural boundaries: Lake Ontario and the Niagara Escarpment. These features cause moderate temperature fluctuations and provide higher levels of precipitation, creating an ideal microclimate to grow temperature-sensitive and water-intensive crops such as peaches (Gardner *et al.,* 2006). The region also benefits from well-drained sands and gravel-type soils that are suitable for tender fruit production (OMAFRA, 2006). Although Lincoln County is in an enviable position in terms of availability of water resources and suitable soils for high-value horticultural production, difficulties in accessing irrigation water due to competing demands may prevent its growth (Stantec Consulting Ltd., 2005).

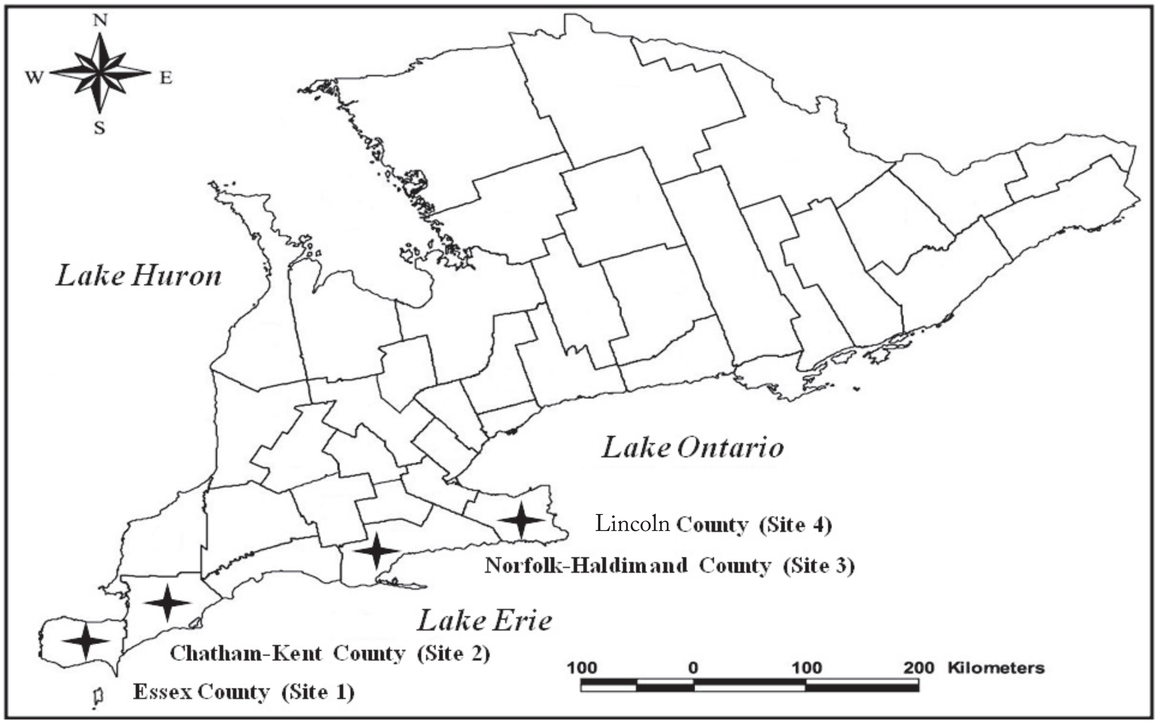


Figure 1. Map of the four counties in southern Ontario where field sites were selected.

Site Descriptions

In each of the above counties, a field site was selected. The participant grower in Essex grew tomatoes (site 1) while the one at Chatham-Kent (site 2) was under bell pepper production. Site 3 in Norfolk-Haldimand County produced strawberries while a peach orchard comprised site 4 in Lincoln. Sites 1, 2, and 3 were all drip irrigated whereas site 4 employed an overhead gun to irrigate the peaches. The tomato grower (site 1) irrigated using both surface drip (zone 1) and subsurface drip (zone 2); hence data were collected for both types of systems. Similarly, the strawberry grower (site 3) produced strawberries in an open field (zone 4) as well as under plastic high tunnels (zone 5), and both management practices were monitored. Crop water requirements are recognized to be approximately 30% lower in production systems under a high tunnel (Monterro *et al.,* 1985; Rosenberg *et al.,* 1989; Fernandes *et al.,* 2003; Harmanto *et al.,* 2005). It was therefore relevant to compare how water requirements were met by the participant producer in these different production systems. In all, the study comprised six zones for which data were collected, as detailed in Table 1 (within four field sites, four counties and four crops).

Data Collection

Data were collected by three different means: a grower survey, *in situ* monitoring, and lab analyses.

Survey: In July 2007, a survey on irrigation water use was administered to the participant growers at sites 1, 2, 3, and 4 to obtain baseline information on current irrigation scheduling practices and perceived irrigation water needs. The type of information collected in the survey was related to: the irrigated acreage (crop and soil types; size of irrigated area; number of rows; row length and width; plant spacing; planting and harvesting dates), the irrigation system (system type and brand; number of emitters or sprinklers; emitter and drip line spacing; emitter or nozzle and system flow rate), the irrigation scheduling practices (daily system operating time and amount of water applied) and irrigation water (source; reservoir capacity; constraints; anticipation of water shortages). The collected data was used to determine whether crop water requirements were being met efficiently while preventing water losses.

In situ monitoring: Meteorological parameters (air temperature, relative humidity, wind speed, and rainfall) were collected on-site during the growing season from automated weather stations; the data were used to calculate a water budget. Soil moisture sensors were installed in each of the six zones (Table 1) at the beginning of the growing season and soil moisture was continuously measured until harvesting was completed at the site. The soil moisture sensor used was a Campbell Scientific water content reflectometer (CS625), which was installed in the effective root zone of the crop. Flow meters were installed at three sites (site 1, 2, and 3) to record the quantity of irrigation water used. One was not installed at site 4 because the irrigation system was different (overhead gun). Flow meters provide more accurate information than the estimated usage provided by the growers via the survey.

Lab analyses: Soil samples were collected at each site at the beginning of the growing season to determine bulk density (ρ_s), textural class, and water retention characteristics (field capacity, FC_v, and permanent wilting point, PWP_v). Triplicate samples were taken from the topsoil (0–5 cm) and the effective root depth (20–25 cm) in each zone. Since samples from the top layer were highly variable, only the 20 to 25 cm depth was considered in ascertaining mean values for the zone. In addition to baseline soil data, samples were collected twice per week and analyzed in the lab for gravimetric water content (θ_g). These samples were taken at 0 to10 cm and 10 to 30 cm in the soil profile, at depths similar to the location of the CS625 sensor. Volumetric moisture contents (θ_v) were calculated by multiplying θ_g with ρ_s. These moisture measurements were used to determine how much water could be saved through scientific irrigation scheduling.

Literature values: Some data were estimated from the literature due to time constraints or errors in lab analyses. The effective crop rooting depth (ECRD), the zone in the soil profile where plants derive most of their water requirements, was derived for each crop (Table 2) from a technical report published by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2004). Management allowable depletion (MAD) values for these crops were also obtained from the literature (Sanders, 1993; Ley *et al.*, 1994; Nyvall, 2002; Planner, 2003; Hanson *et al.*, 2004 and AgriMet, 2007). MAD corresponds to the percentage of available soil water (ASW)–water that plants can use and is held in the soil profile between field capacity and permanent wilting point–which may be safely depleted before yield-reducing stress occurs. In the past irrigators used a simple rule of thumb to trigger irrigation when about half of the ASW was depleted (Evans *et al.*, 1996; Hill, 2002). However, recent research has proved this rule to be inadequate for intensively managed high-value crops which are more sensitive to water stress (Home *et al.*, 2002; Kashyap and Panda, 2003). The MAD is now

Table 1. Field site description summary.

Site	County	Crop	Zone	Planting/Harvesting Dates	Soil Texture	No. of Plant Rows	Plant Row Length (m)	Plant Spacing Length (m)	Plant Spacing Width (m)
1	Essex	Tomato	1	May 23/Sept. 20	Sand	30	335.3	0.4	0.4
			2	May 23/Sept. 20	Sand	30	335.3	0.4	0.4
2	Chatham-Kent	Bell Pepper	3	May 21/Oct. 9	Loamy Sand	180	548.6	0.4	0.5
3	Norfolk-Haldimand	Strawberry	4	April 10/Nov. 5	Sandy Loam	80	213.4	0.3	0.3
			5	April 10/Nov. 5	Sandy Loam	80	213.4	0.3	0.3
4	Lincoln	Peach	6	April 1/Aug. 1	Loamy Sand	27	152.4	5.5	3.1

precisely recommended depending on the crop grown, the development stage, as well as the irrigation system used (Reddy and Reddy, 1993; Panda *et al.,* 2004). Table 2 shows MAD averaged values for various crop types. Lastly, application efficiencies (AE) for different irrigation systems were derived from the study of Pitblado *et al.* (2007), also shown in Table 2.

Calculating Irrigation Water Requirements

Before calculating irrigation water requirements at each site, the irrigation trigger at the site was determined, using the following three steps:

(i) Calculate maximum soil water storage (MSWS): the maximum amount of soil water stored in the root zone at field capacity must be determined prior to tracking water additions and losses. MSWS is calculated by multiplying FC_v with ECRD.

(ii) Calculate maximum soil water deficit (MSWD): defined as the amount of soil moisture that can be safely depleted before triggering irrigation, MSWD is calculated by multiplying MSWS with MAD.

(iii) Determine irrigation trigger (IT): this corresponds to the difference between MSWS and MSWD, and is the minimum allowable level of water in the soil prior to irrigation.

To calculate irrigation water requirements, a mathematical water budget model was used:

$$SWC_{i+1} = SWC_i - ET_c + EP - DP - RO + IRR \quad (1)$$

where SWC_{i+1} = soil water storage in the ECRD on day '*i+1*' (mm); SWC_i = soil water storage in the ECRD on day '*i*' (mm); ET_c = crop evapotranspiration or crop water use (mm); EP = effective precipitation; DP = deep percolation (mm); RO = runoff; and IRR = irrigation water applied (mm).

SWC: Typically, fields are at or above field capacity at the start of the growing season. Hence, the initial SWC (day 0) is the storage at field capacity. Subsequently, the daily soil water balance is calculated by estimating all the other parameters. The soil is brought to field capacity after a saturating rainfall event or after an irrigation application, which is governed by the derived irrigation trigger (IT) for the site.

ET_c: To estimate the rate of evapotranspiration of a specific crop (ET_c)—a measure of the crop water use—the reference evapotranspiration (ET_o) must be first calculated. A large number of empirical methods have been developed to estimate ET_o, and their performance depends directly on the climate data quality and availability (Jabloun and Sahli, 2008). When all required climatic parameters are available, as in this study, the FAO56-PM method is recommended to calculate ET_o (Irmak *et al.,* 2003; Zhao *et al.*, 2004; Bois *et al.,* 2005) according to the procedure established by Allen *et al.* (1998).

To determine ET_c, the influence of crop type and growth stage must then be considered by applying the proper crop coefficient K_c (Howell, 1996; Norman *et al.,* 1998; Burt *et al.,* 2005). For this study, crop coefficients were derived from OMAFRA (2004) and Van der Gulik (2001). The influence of a greenhouse on

Table 2. Literature values used in the study for effective crop rooting depth (ECRD), management allowable depletion (MAD), and irrigation system application efficiencies (AE) (Sanders, 1993; Ley *et al.,* 1994; Nyvall, 2002; Planner, 2003; Hanson *et al.,* 2004; OMAFRA, 2004; AgriMet, 2007; Pitbaldo *et al.,* 2007)

Site	Crop	ECRD (mm)	MAD (%)	Zone	Irrigation and Production System	AE (%)
1	Tomato	300	25	1	Surface Drip	84
				2	Subsurface Drip	84
2	Bell Pepper	300	25	3	Subsurface Drip	84
3	Strawberry	300	25	4	Surface Drip/Plastic Mulch	84
				5	Surface Drip/Plastic Mulch - High Tunnel	84
4	Peach	750	50	6	Overhead Gun	68

the calculated ET_c was considered for the strawberry crop grown under the high tunnels. It has been shown that water requirements of any crops are generally lower in a greenhouse than in the open field; the difference of ET_c would be around 70% of that found outside (Rosenberg *et al.,* 1989; Fernandes *et al.,* 2003; Harmanto *et al.,* 2005).

EP, DP and RO: Effective precipitation is defined as rainfall higher than five millimetres which does not evaporate entirely before infiltrating the soil and thus adds moisture to the soil profile. EP may be determined as follows (Nyvall and Tam, 2005):

$$EP = (R - 5) \times 0.75 \qquad (2)$$

where EP = effective precipitation [mm]; R = rainfall (mm).

With the above method, the remaining precipitation (R – 5) is multiplied by a factor of 0.75 to account for runoff (RO) and deep percolation losses (DP). This efficiency factor is comparable to that determined by Pitblado *et al.* (2007) who performed a similar study in the Niagara region; the averaged efficiency for different soil types was 79%.

IRR: The depth of irrigation water applied must be calculated prior to tracking water additions and losses in the soil profile. This is equal to MSWD in an ideal scenario, but in order to account for irrigation system application efficiencies (AE), IRR is calculated by dividing MSWD with site-specific AE values (Table 2).

Calculating Irrigation Water Use

The quantity of irrigation water used during the growing season can be calculated according to three different methods: design (irrigation system specifications); direct (flow meter or grower records); and mathematical water balance.

Design method: The first method involves using irrigation system information and system operating time records as follows:

$$\text{Water Use} = \frac{\text{System Flow Rate} \times \text{Operating Time}}{\text{Irrigated Area}} \times 1000 \qquad (3)$$

where Water Use = irrigation water used per growing season (mm); System Flow Rate = irrigation system flow rate (m^3/hr) (values in Table 3); Operating Time = irrigation system operating time (hrs); Irrigated Area = size of the irrigated zone (m^2).

Direct method: The second method of determining the amount of irrigation water used is by using the flow meter readings installed at the inlet of the irrigation pipes. It is relevant to also consider the growers' irrigation records which are usually based on water use estimations.

Water balance method: In the third method, the quantity of irrigation water used can be calculated using a simple soil water balance equation (Gardner *et al.,* 1999):

$$IWU = ET_c + DP + \Delta S + RO - EP \qquad (4)$$

where IWU = irrigation water use (mm); ET_c = crop water use (mm); DP = deep percolation (mm); ΔS = difference in soil moisture storage (mm); RO = runoff (mm); EP = effective precipitation (mm).

Note that the above water balance equation to calculate irrigation water use is identical to Equation (1) used for calculating irrigation requirements; the difference here is that irrigation water use is calculated by monitoring actual changes in soil moisture storage (ΔS), using soil moisture sensors or gravimetric soil samples. The gravimetric method was given priority as it is the only absolute technique used to measure soil moisture content. The choice of the technique was based on two additional criteria: data quality (depth at which the sensor measured relative to the ECRD; sensor proximity to the emitters) and data availability (equipment failures, sample acquisition). Gravimetric data sets were thus used for every site except at Essex (Zone 2) where the data set collected with the water content reflectometer (WCR) sensor was more reliable.

Assessing On-Farm Irrigation Performance

Assessing on-farm irrigation performance is crucial in detecting over- or under-irrigation. Irrigation performance is generally measured through indicators, such as the ratio of the amount of irrigation water needed by the plants to the amount of water applied to the field (Bos *et al.,* 1994, 2005; Stevens, 2007). Such an indicator is appropriate for determining if there is over- or under-irrigation. According to the irrigation system assessment guide of British Columbia, if the deviation in the ratio exceeds +/-10% from 1.0, the irrigation system should be reviewed (Nyvall and Tam, 2005). However, since evaluating how much water was applied to the field remains complex and inaccurate (data cannot be verified and validated for each property), further checks should be performed before concluding that SIS can achieve water savings when over-irrigation is detected. This can be done by comparing irrigation water requirements obtained through water budget calculations with soil moisture measurements taken over the course of the growing season. When such measurements are not available, comparisons can be made with growers' estimates of water applications.

Before defining this supplementary evaluation, it is important to first define what is considered to be a *potential water saving*. For the purposes of this paper, a potential water saving is the unnecessary amount of irrigation water applied after the soil profile (effective crop root depth) reaches field capacity. Because such water application is excessive and damaging to crops, eliminating such water application curbs water expenditure, thus saving water and associated costs.

Each time an increase of soil moisture content was detected (as measured by gravimetric sampling or the WCR sensor) and at the same time the field capacity of the soil was exceeded, the equivalent depth of water applied was recorded as either precipitation or irrigation. Then, to differentiate the events where soil moisture was replenished by irrigation from those replenished by rainfall, the measured augmentations in soil moisture were compared with those of the water budget; if the measured soil moisture increases were also noticed in the water budget while no irrigation was triggered, the equivalent depth of water added to the soil profile was considered to be due to rainfall and not irrigation. As rainfall is deemed an inherent water addition and must not be "applied" as such, these augmentations were not thought to be potential water savings. Conversely, where measured soil moisture increases were not noticed in the water budget, then the soil moisture increase could be attributed to irrigation, and the equivalent depth of water added to the soil profile can be thought to be a potential water saving. The same procedure was also performed to identify days where soil moisture content was below the irrigation trigger point and in doing so detect under-irrigation practices.

Results and Discussion

Assessing Water Consumption

The calculated irrigation water requirements and amounts of irrigation water consumed are shown in Table 4. The quantities of irrigation water consumed obtained with the flow meter readings were given priority followed by values calculated using irrigation system information and recorded system operating time, the soil water balance equation and, lastly, using values based on irrigators' water use estimation. This order was based on the degree of confidence in the data that was collected. The information given by the

Table 3. Irrigation system information (provided by the growers' survey).

Site	Zone	Irrigated Area (ha)	Irrigation and Production System Type	No. Emitters Row	No. Emitters Total	Emitter/Nozzle Flow Rate (L/hr)	System Flow Rate (m^3/hr)
1	1	1.2	Surface Drip	1 100	33 000	0.4	14
	2	1.2	Subsurface Drip	1 100	33 000	0.4	14
2	3	7.7	Subsurface Drip	1 200	216 000	0.6	131
3	4	0.9	Surface Drip/Plastic Mulch	700	56 000	0.9	51
	5	0.9	Surface Drip/Plastic Mulch, High Tunnel	700	56 000	0.9	51
4	6	2.4	Overhead Gun	n/a	n/a	70 170	70

Table 4. Comparison of irrigation water requirements and irrigation water used at the sites in 2007.

Site	Zone	Data Source	Water Budget Dates	Quantity Required			Quantity Used		
				(mm)	(m^3)	(m^3/ha)	(mm)	(m^3)	(m^3/ha)
1	1	Flow Meter	May 24/Aug. 30	144	1 748	1 457	191	2 319	1 932
	2	Flow Meter	June 12/Sept. 4	140	1 700	1 416	191	2 319	1 932
2	3	Soil Water Balance	May 30/Oct. 9	165	4 674	607	180	4 589	596
3	4	Irrigation System Info.	May 23/Oct. 12	384	3 341	3 712	711	6 186	6 874
	5	Flow Meter	May 23/Oct. 12	320	2 823	3 137	620	5 470	6 078
4	6	Irrigation System Info.	May 15/Aug. 13	136	3 302	1 376	74	1 797	749

growers about their irrigation system, system operating time records and personal water use estimates which could not be verified was consequently less valued.

By investigating the results presented in Table 5, it can be seen that in five out of six irrigated zones the deviation of the ratio of the amount of irrigation water needed by the plants to the amount of water applied to the field exceeds the recommended deviation of 10%. The irrigation system in these zones was therefore considered to be inefficient; water was either excessively or insufficiently applied to meet the crop water requirements. The tomato grower (site 1) over-irrigated the two zones by about 50 mm (25%) and the strawberry grower (site 3) over-irrigated by 330 mm (48%) inside the greenhouse and by 300 mm (46%) in the open field. As for peaches (site 4), they appeared to be particularly water stressed compared to other crops; the grower would have needed to apply about 65 mm (almost twice as much water as he had) to meet the crop water requirements. The bell pepper grower (site 2) is the only one who according to this assessment effectively met the crop water requirements; slightly over-irrigating by 25 mm (8%).

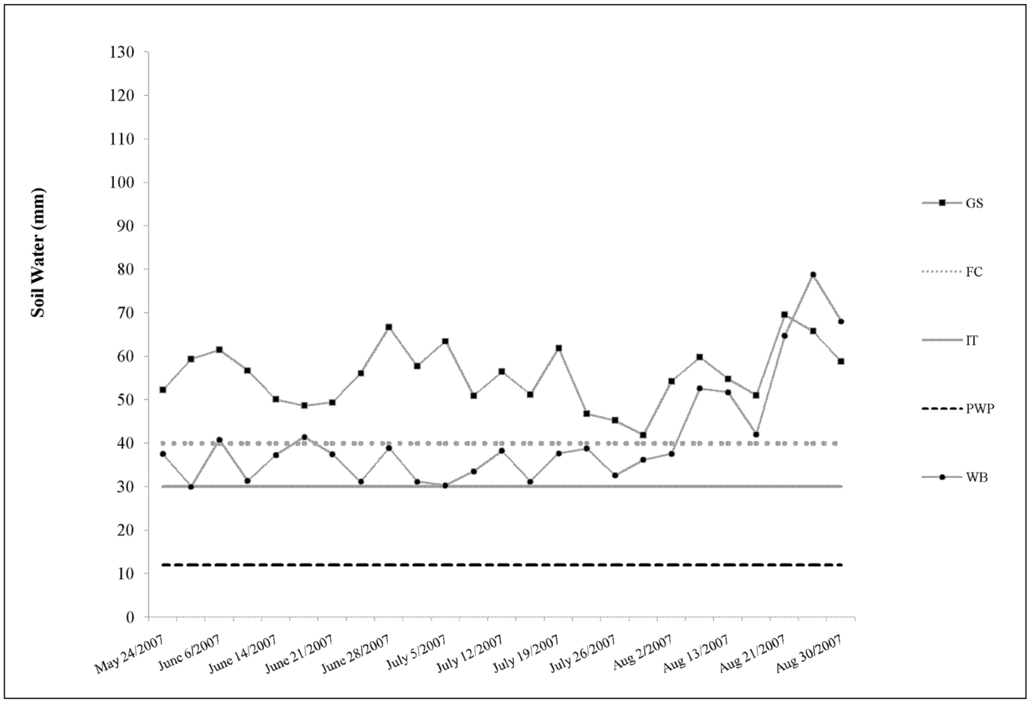
Estimating Potential Water Savings

As the first step was to detect over- or under-irrigation practices due to the difference between growers' estimated use and water budget calculations as shown in the previous evaluation, the next step was to compare water budget calculations with soil moisture content measurements to determine how much water is excessively or insufficiently applied. Figure 2 illustrates how the soil moisture content measurements taken over the course of the 2007 growing season by gravimetric sampling (GS) or with the water content reflectometer (WCR) compares with irrigation water requirements calculated with the water budget method (WB). On each graph, three reference moisture levels are indicated including field capacity (FC), irrigation trigger (IT) and permanent wilting point (PWP).

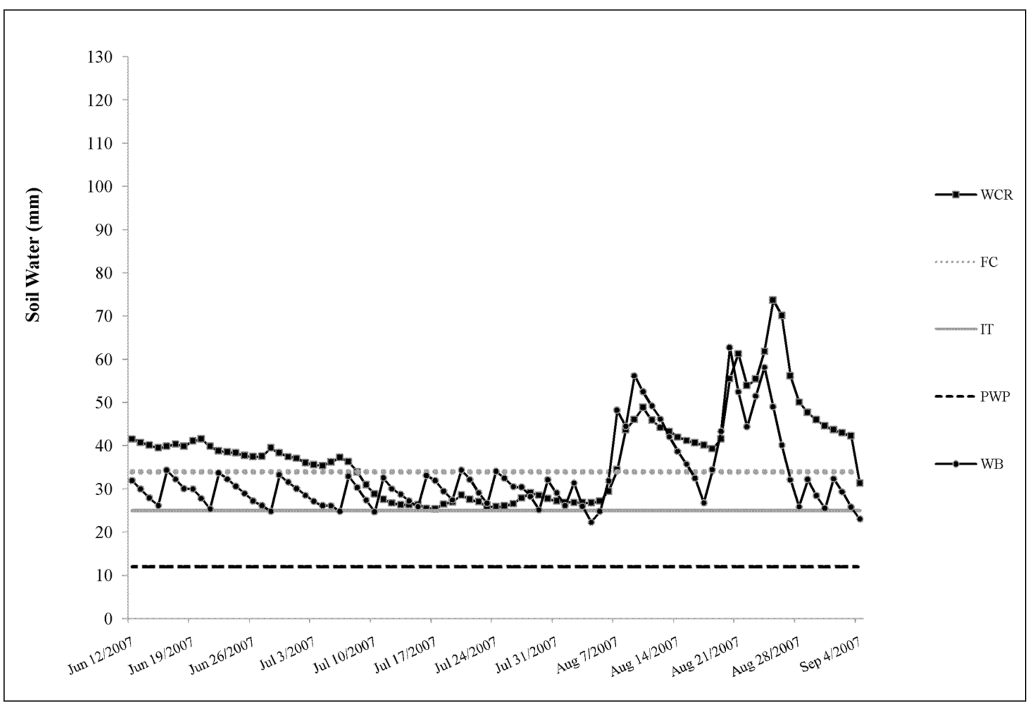
Figure 2 supports the findings obtained from the previous comparison of water budget calculations with growers' estimates of water consumption drawn from uncertain information: most growers over-irrigated (some less than others) except the peach grower (site 4) who under-irrigated. Figure 2 shows that the soil moisture content measured by gravimetric sampling or with the water content reflectometer at a depth of 0 to 30 cm was maintained over field capacity for the entire growing season except for Essex (site 1, zone 2, Figure 2b) and Lincoln (site 4, Figure 2f).

As shown by Figure 2b, at the Essex site the tomato grower maintained the soil moisture content in zone 2 (subsurface drip) between the irrigation trigger point and field capacity range for almost a month. In this case, the extent to which water was excessively applied differs from the previous assessment (Table 4). According to Table 5, which complements Figure 2 by providing the actual water saving estimations, crop water requirements were properly met by the tomato grower; only 6 mm were over-applied in zone 2 compared to 50 mm formerly detected.

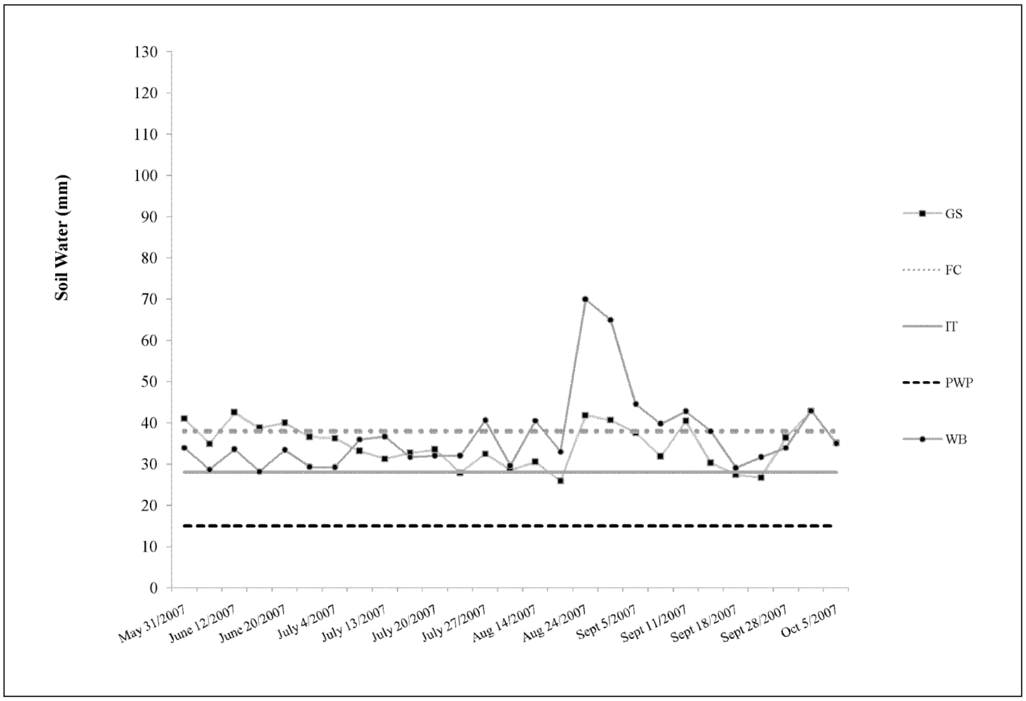
The bell pepper grower (site 2, Figure 2c), who was properly meeting the crop water requirements by slightly over-irrigating by the soil water balance method (25 mm), was shown to have over-irrigated by 46 mm according to the moisture measurements (Table 5).



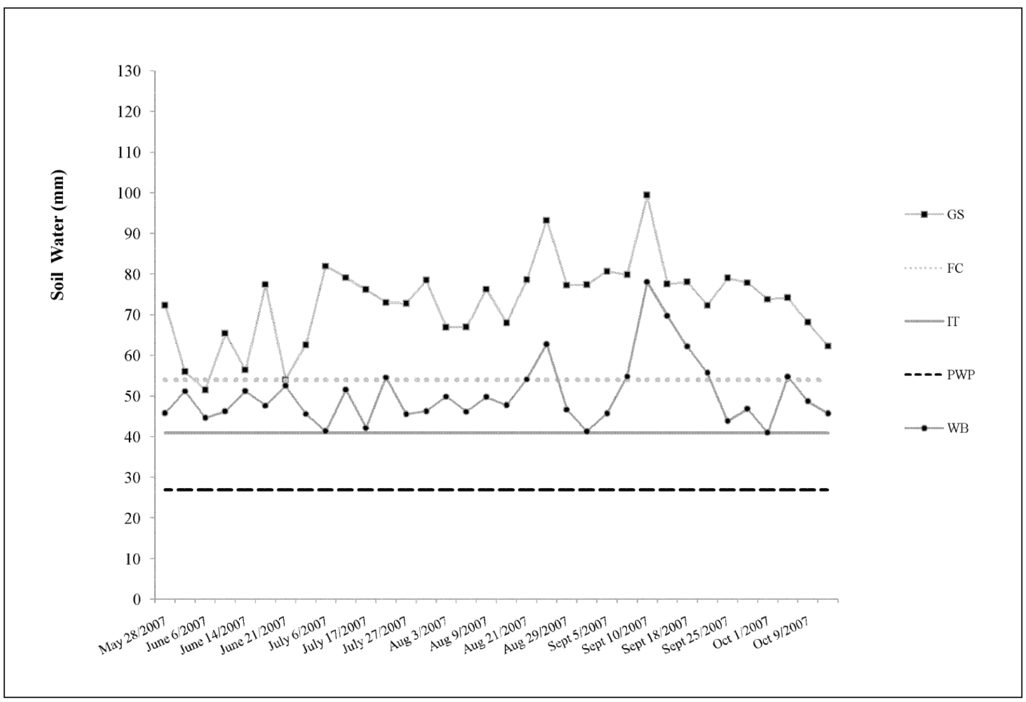
a) Essex (Site 1, Zone 1) – Tomato Crop.



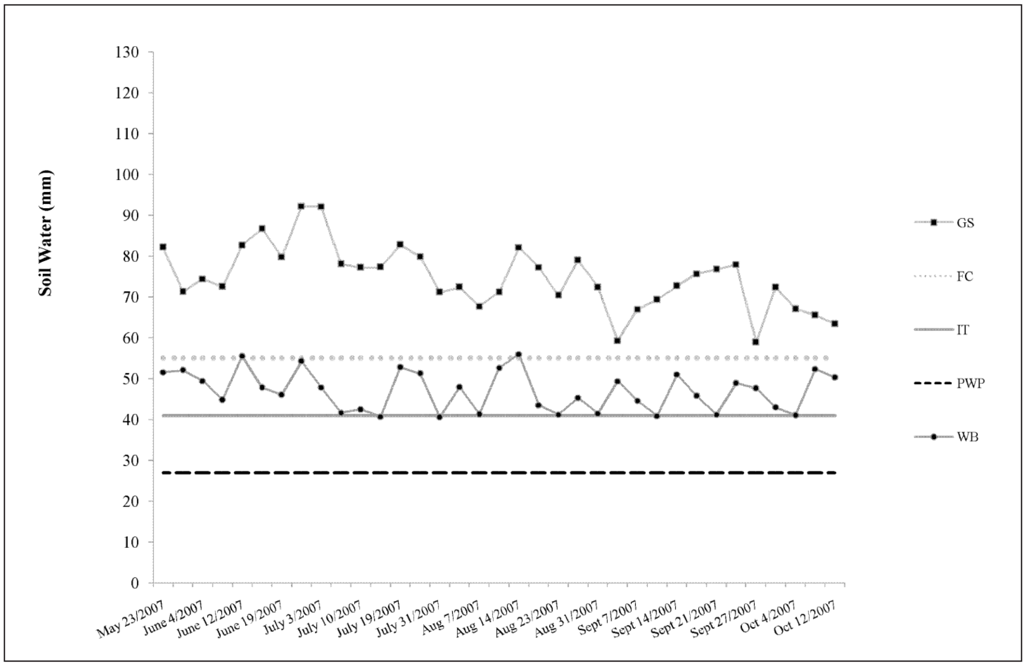
b) Essex (Site 1, Zone 2) – Tomato Crop.



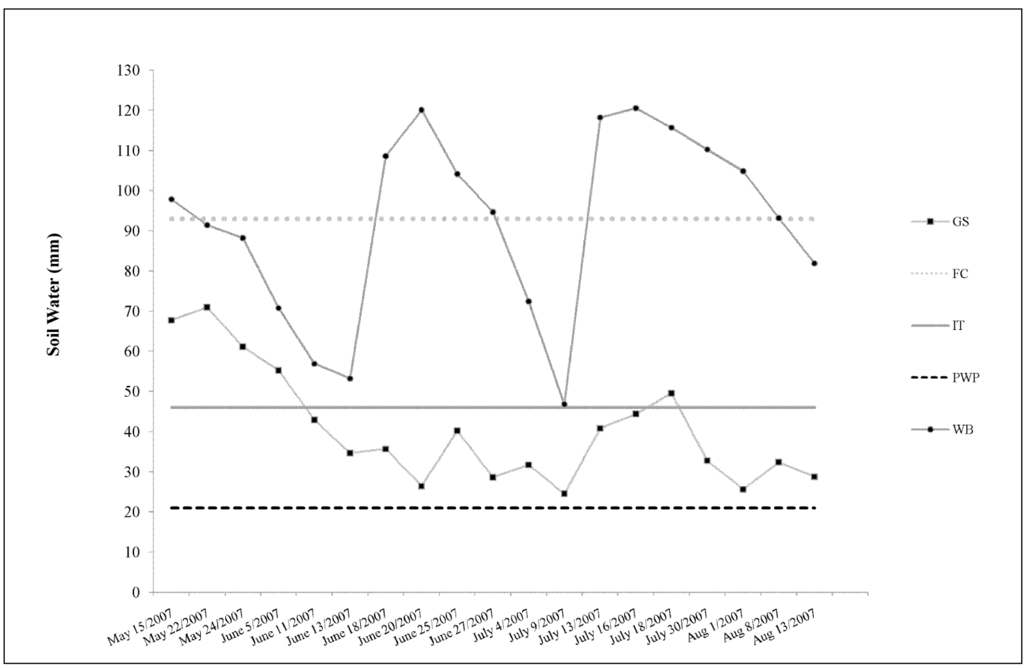
c) Chatham-Kent (Site 2) – Bell Pepper Crop.



d) Norfolk-Haldimand (Site 3, Zone 4) – Strawberry Crop.



e) Norfolk-Haldimand (Site 3, Zone 5) – Strawberry Crop.



f) Lincoln (Site 4) – Peach Crop.

Figure 2. Comparison of calculated irrigation water requirements with measured soil moisture content at the sites for 2007: (a) Essex (Site 1, Zone 1) – Tomato Crop; (b) Essex (Site 1, Zone 2) – Tomato Crop; (c) Chatham-Kent (Site 2) – Bell Pepper Crop; (d) Norfolk-Haldimand (Site 3, Zone 4) – Strawberry Crop; (e) Norfolk-Haldimand (Site 3, Zone 5) – Strawberry Crop; (f) Lincoln (Site 4) – Peach Crop.

Table 5. Potential savings at each site (in 2007) through scientific irrigation scheduling.

Site	Zone	Ratio Irrigation Water Requirements and Irrigation Water Used (%)	Ratio Deviation (%)	Potential Water Saving (mm)	(m³)	(m³/ha)
1	1	75	25	50	1 416	1 180
	2	73	27	6	53	44
2	3	92	8	46	1 303	169
3	4	54	46	98	1 190	1 322
	5	52	48	91	1 105	1 228
4	6	184	84	-75*	-1 821*	-759*

* Negative numbers represent water quantities that would need to be supplemented to the actual amount of irrigation water used to properly meet the crop water need.

As for the peach grower, (site 4, Figure 2f) even though the grower irrigated during flowering, cell division and fruit sizing (critical growth stages during which the crop water needs are higher), the soil moisture content dropped close to the permanent wilting point and remained below the irrigation trigger point during most of the season. This could be attributed to the overhead gun system on the site, which has lower application efficiency (65%), compared to drip irrigation (85%). Nevertheless, it is clear that this grower needed to irrigate more frequently with more water as indicated by the previous assessment where the amount of irrigation water needed by the plants was compared to the amount of water applied to the field.

Conclusions

This study was carried out to assess on-farm irrigation water use efficiencies in four counties of southern Ontario. Data were collected to quantify irrigation water use by three different methods (flow meters, grower surveys, soil moisture measurements), and these data were compared with site-specific irrigation water requirements, as calculated by a water balance. These comparisons were used to determine potential water savings at the sites. The comparison of water budget calculations with growers' irrigation water use estimates established that with current irrigation scheduling practices, water was either wasted or insufficiently applied in five out of six irrigated zones. Water applications based on irrigation system setup and operation do not correspond to how crop water needs are gauged by the growers. However, conversion from less efficient to more efficient irrigation scheduling practices does not always result in decreased water consumption as revealed by the results of this study; the grower in Lincoln is indeed expected to irrigate more frequently and with more water in the coming years to better meet peach water requirements.

To lessen the impact of increasing competition and conflicts over scarce water resources, the horticulture industry needs to adopt on-farm water management practices that will improve water use efficiency. This research demonstrated that scientific irrigation scheduling could help irrigate more efficiently and in the end, achieve water savings and enhance water resource management. The study was limited to a single season (2007), four crops and four counties, hence, the projected water savings cannot be translated to other fields, irrigation systems or regions directly. Nevertheless, these results highlight the need for improved agricultural water management and identify the potential for substantial water savings in southern Ontario's agricultural sector, which can be achieved through the adoption of technologies such as soil moisture monitoring for scientific irrigation scheduling. Given the growers' positive feedback about the usefulness of the soil moisture monitoring sensors and their willingness to adopt several devices, scientific irrigation scheduling does emerge as a promising solution which will allow the horticultural sector to adapt to increasing competition for limited water resources.

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