Determining Irrigation Needs by Monitoring On-Farm Soil Moisture

COWSEP Project 014

April 9, 2008

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Acknowledgements

The Brace Centre for Water Resources Management of McGill University gratefully acknowledges the funding support for this project from COWSEP. This project was funded in part through contributions by the Government of Canada and the Province of Ontario under the Canada-Ontario Water Supply Expansion Program (COWSEP), an initiative of the federal-provincial-territorial Agricultural Policy Framework designed to position Canada's agri-food sector as a world leader. The Agricultural Adaptation Council administers COSWEP on behalf of the Government of Canada and the Province of Ontario.

The authors are obliged to all McGill team members who provided their valuable expertise; they are especially appreciative of Apurva Gollamudi's skills in managing the installation of sensor equipment, and of Sajjad Ali assistance in managing all of the many field sites, and ensuring all the data collection. The writers are thankful for the contribution of equipment and expertise provided by AAFC-PFRA, OMAFRA and WIN who contributed to the success of this project. In particular, the contribution of expertise from Bruce Shewfelt, Wade Morrison, Steve Sager, Anne Verhallen, Janice LeBoeuf, Ken Slingerland, Pam Fisher, John Cline, and Ian Nichols.

The writers are also grateful for the use of the University of Guelph's soil laboratory facilities at Vineland and at Ridgetown, and to field assistants Trevor Fraser, Wayne Heinen, Kevin Leclaire, Ashley Macdonald and Karen Martens for collecting data during the growing season. The writers gratefully acknowledge the growers who participated in the project, and without whom, this project would not have been possible: Wayne Palichuk, Peter & Ellen Jennen, John Cooper, John Fedorkow, David Epp, Peter Epp, Paul Tiessen, Ken Hamm, Perry Furlan, Frank Furlan, Dave van Segbrook, Mary Shabatura, Fred & Sharon Judd, Dave & Jenn Vandevelde, Anne Muir, Earl Muir, Erwin Wiens, Tim Andrew and Kevin Buis. Finally, the authors acknowledge the accommodations made by OMAFRA staff Anne Verhallen and Ken Slingerland for allocating office space, on the occasional rainy day, to the local project field staff.

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Executive Summary

Crop producers are in need of more efficient and timely ways of determining when to apply irrigation water, and for how long; a practice known as irrigation scheduling. This is particularly relevant in the humid regions of Eastern Canada, where supplemental irrigation is often necessary for the reliable production of high value horticultural crops. The problem of irrigation scheduling is further complicated for the irrigator, if and when rainfall occurs during the growing season. Given that water scarcity due to a changing climate and other competing needs for water, irrigation water may be less readily available in the future. Therefore, there is an urgent need to develop and implement techniques of real time irrigation scheduling, taking into account crop type, growth stage, soil type, and soil moisture status. There are now several advanced soil moisture sensors capable of providing information on soil water status on a real time basis. However, most growers do not have the resources (time, money and skills) to fully understand how to use the equipment, nor how to interpret the data, and to determine their irrigation requirements. This project assessed soil moisture sensor technology on large growers' fields, received grower feedback, and trained the growers on the technologies. The results of the project were disseminated to a variety of stakeholders, including federal and provincial government officials, agribusiness, and other crop growers.

On-farm field sites in four Ontario locations (Leamington, Dresden, Simcoe, Niagara-on-the-Lake) were selected which served as "hub sites", on which several permanent soil moisture sensors were installed. An additional 15 farms, representing "satellite sites" located in proximity to a hub site were used for measuring weekly soil moisture through gravimetric soil sampling and a portable TDR.

At each hub site, six commonly used soil moisture sensors were installed, that are widely available; these included time domain reflectometers, water content reflectometers, tensiometers, electrical resistance blocks and capacitance probes. Growers were consulted on the best location of equipment on their farms, their field management practices, irrigation systems and practices, and the location of benchmarks for soil moisture comparison. Data from the sensors was collected throughout the 2007 growing season. Equipment malfunctioning was recorded. Two grower surveys were administered; the first one to collect data on current irrigation practices and another one on the usefulness of the soil moisture sensors.

From the data and information collected during the season, in the NOTL, Dresden and Leamington hub sites, water was under applied at the beginning of the season, and in peaches not sufficiently long applications were being made during the remainder of the season for the water to penetrate deeper than 20 cm into the soil profile. Using crop water requirement calculations, over the total growing season it was determined that there was a lack of almost 120 mm irrigation water relative to peach water needs. The hub pepper grower also under irrigated, by 45 mm for the season. Over irrigation occurred on some sites; the berry grower over irrigated by 330 mm inside high tunnels, and by 210 mm in the field. Although the tomato grower under irrigated at the beginning of the season, he over

irrigated by about 50 mm for the whole season; information he will find useful for consequent years, since he ran out of water. The current practices indicate that there is room to improve irrigation water management and soil moisture sensors can provide valuable information. During the project, all growers recognized the usefulness of the sensors.

The first survey results draw attention to how current irrigation practices have room for fine-tuning, to be brought more in line with actual crop water requirements (by calculating ETc or by calculating a water balance for example, growers can better check their irrigation accuracy). Therefore, by implementing soil moisture sensors and being trained on how to use the technology, growers are able to take away a large part of the present guess work when it comes to irrigating.

The survey on soil moisture sensors brought to the forefront the importance of the sensor training aspect for the growers. They would like to have soil moisture readings available in the field, and they would also like to know how to access the data, and some would like to know how to download the data. The near real-time data is important to enable growers to make timely irrigation decisions. Currently, most growers used the plant and the weather as their gauge of when to apply irrigation water.

Before choosing a soil moisture sensor or a monitoring system, the grower should consider the advantages and drawbacks of a sensor, a logger, and the information flow, according to how they can best use the information to make decisions for their operations. From the project results, sensor information delivery and cost were key factors when choosing a sensor. For most of the growers, the data is most useful to them when they can obtain it directly from the field, or to have the data delivered to their computer.

CHAPTER 1. Introduction and Background

Introduction

Ontario is the 4th province in terms of the area of irrigated land in Canada. In Ontario, irrigation occurs almost exclusively in the southern part of the province (Marshall Macklin Monaghan et al 2003). Some of Ontario's most valuable vegetable and fruit crops are located in and around the Leamington, Essex Kent, Norfolk, and Niagara regions. Irrigation is necessary for the production of high value horticultural crops. Irrigation systems are becoming more affordable, and are imperative to combat soil moisture deficiencies. Ontario has experienced several bouts of warm, dry weather during recent summers (especially since 1998) and this causes growers to irrigate more than in the past. For all of these reasons, more fruit and vegetable growers are installing irrigation systems on their farms.

Water supply in any given region is finite. There are two mechanisms for managing on farm water in Ontario; the first is the Permits to Take Water (PTTW) under the *Ontario Water Resources Act*. Agricultural water users who extract more than 50,000 litres per day are required to obtain a Permit to Take Water (PTTW) from the Ontario Ministry of the Environment. These users are required to record data on the volume of water taken daily (starting in 2007, all agricultural irrigators are regulated to record the daily volume taken and report those daily records to the Minister of the Environment. This monitoring and reporting requirement is new and will be required from now on (Shortt, 2008 *pers. comm*.). The second mechanism is the community based Ontario Low Water Response Plan based on volunteer grower participation (Shortt et al. 2004). Both these means help to manage water during shortages during the warm summer months. In spite of these, summer low flows are particularly challenging for irrigators to supply adequate amounts of water. In addition, they are finding it necessary to demonstrate environmental stewardship in order not to come under scrutiny. Competing use of water in rural and urban areas may be intensified in the future with warming summers, and with growing urban centers. Producers are already experiencing chronic summer water constraints in some regions, in part due to water conflicts arising with greenhouse production and domestic (tourist) demands.

Therefore, there remains a real need to reduce water consumption whenever possible. Saving water in the agriculture sector through efficient irrigation is one way to reduce water consumption. From past observations on irrigation projects undertaken in southern Ontario, it was noticed that growers are mostly under-irrigating because for the most part they irrigate too late, and once they start to apply water, they tend to over-irrigate in order to compensate for the lack of water.

Agricultural producers have few rapid ways of accurately determining the right time to irrigate their crops, and are in need of more efficient and timely ways of determining when to apply water, and for how long. Even with all the technology available on the market today to monitor soil moisture, most growers still decide when to apply water based on the "feel method", which is a method that may be an acceptable indicator of determining the degree of soil dryness, but it leaves much to be desired in terms of knowing how much water to apply and for how long. Given that irrigation water may be less readily available in the future, there remains a need to determine when to apply irrigation to different crops, at a variety of growth stages, and based on different soil types. Growers would like to know when to start their irrigation events, and for how long they need to irrigate (when to turn the tap off). There are now several advanced soil moisture sensors capable of providing information on soil water status. However, most growers do not have the resources (time, money and familiarity) to fully understand how to use the equipment, nor how to interpret the data, and to determine their irrigation requirements.

To assist in providing more targeted information to growers regarding the use of various soil moisture sensors for irrigation water applications, on different soil types and for various crops, this project assessed soil moisture sensor technology on farms, trained growers on the technologies, received grower feedback and also provided the information to other irrigation stakeholders.

Although irrigation resources exist on scheduling, efficiencies, and on monitoring, none specifically address issues surrounding accurately measuring soil moisture, in near real-time, detailing the requirements, and engage in discussions of the practical applicability of these tools (advantages and drawbacks for producers). Furthermore, there is little training available on these instruments (apart from few suppliers of some sensors who do provide training).

The project focused on portable and permanent instrumented techniques for monitoring soil moisture and receiving grower feedback of the evaluation of these technologies, on their farms. The technologies tested consisted of:

- portable (volumetric based) equipment; time domain reflectometers (TDR);
- permanent (tension/volumetric based) equipment TDR probes, water content reflectometers, electrical resistant blocks, and tensiometers;
- permanent (trend/volumetric based) equipment where data delivery was via a website: echo probes, and capacitance probes.

The technologies were evaluated with respect to ease of use, cost, reliability and ability to record data.

The crops tested with the sensors in the project included peaches, berries (strawberries and raspberries), peppers and tomatoes. Most of the farms in this project used ponds to obtain their irrigation water. Some farms used municipal sources, and others obtained the water directly from a ditch or creek. The irrigation systems used were mostly drip tape (mainly placed on the surface, but some were buried), some used an overhead gun, and fewer used solid set sprinklers.

Training was an important component of the project. As part of the training, six field demonstration days were held that were organized by OMAFRA and McGill staff at the hub regions, with excellent grower attendance. The sensors were showcased and explained, and the recent data was presented by

McGill and WIN staff. Meetings with individual growers were also held throughout the growing season to share data as it became available.

Growers were keen to "see" what was happening in their soil with respect to moisture levels. The biggest challenge in the project was to distribute and explain the results of each site to the respective grower in a timely manner. Most of the growers only received the sensor data a week or two after the data was downloaded and compiled. This lag was not very helpful in allowing the growers to adjust their irrigation based on the soil moisture sensor readings. Nevertheless growers used the information to validate their decisions.

The results from the two surveys we conducted with growers indicated that by the end of the growing season, growers were more aware of how to use the sensors and how to schedule their irrigation. They were also willing to invest more time in irrigation scheduling and also invest in acquiring the sensors. Through project vehicles, such as demonstration days, handout material, presentations, articles and papers written, the outreach and training of components of the project were exceeded. Over 2000 growers, researchers, agriculture extensions workers and agri-businesses were informed about the project, and about the soil moisture sensors, as well as assisted growers in determining the appropriate amounts of irrigation water application to the crops.

The project outcomes were all achieved, and the greatest outcome was that the project facilitated Ontario growers to utilize water in a more efficient and timely manner for their crops. The repercussions of using water more wisely will also be felt in other sectors which use water (e.g. greenhouse horticulture production, tourism, hydro-power). The longer term outcomes remain yet to be seen, beyond the first year of the project. However, growers have acknowledged the benefits of the sensors as tools for irrigating, and some peach growers who participated in the project have joined forces and are willing to invest in a soil moisture monitoring network to gauge when to irrigate their orchards.

Project Partners

This one-year project provided information and outreach on optimizing irrigation timings based on soil moisture sensor information. The project also assessed the sensors for efficiency and reliability as tools for managing water on-farms. Finally, the project calculated current on-farm irrigation water use compared to crop water demands. The ultimate longer-term aim of the project is to realize water conservation strategies for irrigation, especially for those times when there is little of the resource available. To realize these objectives, several important players were implicated in the research.

The endeavour involved horticultural growers, researchers and agriculture extension workers to address the need for current information on the various soil moisture measurement tools available. The initiative was a collaborative effort, involving Federal and Provincial government stakeholders, as well as local stakeholders, and growers. Specifically, the undertaking was a partnership between McGill University, and Agriculture and Agri-Food Canada (AAFC)-PFRA, the Ontario Ministry for Agriculture, Food and Rural Affairs (OMAFRA), Weather Innovations Network (WIN) and a number of growers and grower groups in Ontario.

Several field sites in four locations in Ontario (Leamington, Dresden, Simcoe, Niagara-on-the-Lake) were selected with the help of OMAFRA and the project partners. Four main farm sites served as "hub sites", and had several permanent soil moisture sensing devices installed. An additional 15 sites, representing "satellite sites" around the "hubs" were used for measuring regular soil moisture through gravimetric soil sampling and a portable TDR. A total of 19 field sites were involved in the project. OMAFRA also provided equipment (Gro-Point sensors, portable TDR) and crop expertise on the project. As a partner on the project, WIN provided expertise on their equipment (capacitance probes, echo probes and weather stations), a web portal for viewing their equipment data. PFRA- AAFC provided equipment (Watermark sensors, flow meters, weather stations) and expertise. The Brace Center of McGill University provided the lead on the project, contributing most of the staff, some equipment (water content reflectometers, tensiometers, portable TDR) and conducted the data sampling coordination, all the soil analysis and compilation of the sensor data.

For the most part, the work took place during the summer months, when equipment was installed at the beginning of the growing season, and intensive soil and sensor data collection at all 19 sites (in 4 regions) continued throughout the season, well into the autumn months. The tremendous collaboration between the partners was essential to achieving all of the project goals. Outlined in Table 1.1 are the project collaborators and their roles.

Table 1.1. Directly Involved Project Staff

Name	Organization	Role
Chandra Madramootoo	McGill University	Principal Investigator & Water management, Irrigation specialist
Bano Mehdi	McGill University	Project Director & Soil specialist
Sajjad Ali	McGill University	Project Field Manager & Crop specialist
Apurva Gollamudi	McGill University	McGill Equipment Manager & Water sensor specialist
Kenton Ollivierre	McGill University	McGill Equipment Assistant & Water engineer
Marie-Hélène Bernier	McGill University	Water Use Specialist
Rufa Doria	McGill University	Irrigation Specialist
Caitlyn Chappell	McGill University	Soils Analyst
Rhami Ali	McGill University	Database Technician
Trevor Fraser	McGill University	Technical Assist. (Vineland)
Karen Martens	McGill University	Technical Assist. (Ridgetown)
Kevin Leclaire	McGill University	Technical Assist. (Ridgetown)
Ashley Macdonald	McGill University	Technical Assist. (Dresden)

Wade Morrison	AAFC – PFRA	PFRA Administrative Contact & Water resource engineer
Bruce Shewfelt	AAFC – PFRA	PFRA Technical Contact & Irrigation specialist
Steve Sager	AAFC – PFRA	PFRA Equipment Manager & Soil resource specialist
Sonja Fransen	AAFC – PFRA	PFRA Equipment Specialist
John Warbick	OMAFRA	Irrigation Specialist
Anne Verhallen	OMAFRA	Soil Management Specialist
Janice Leboeuf	OMAFRA	Vegetable Crops Specialist
Ken Slingerland	OMAFRA	Tender Fruit and Grape Specialist
Pam Fisher	OMAFRA	Berry Crop Specialist
Ian Nichols	WIN	WIN Equipment Manager
Ron Pitblado	WIN	WIN Technical Contact
Tracy Rowlandson	WIN	WIN Irrigation specialist
Wayne Heinen	WIN	Technical Assist. (Simcoe)
Wayne Palichuk	Leamington	Grower
David and Peter Epp	Leamington	Grower
Paul Tiessen	Leamington	Grower
Ken Hamm	Leamington	Grower
Peter & Ellen Jennen	Dresden	Grower
Perry & Frank Furlan	Dresden	Grower
Dave van Segbrook	Dresden	Grower
Ridgetown campus station	Dresden	OMAFRA Research site
John Cooper	Simcoe	Grower
Mary Shabatura	Simcoe	Grower
Fred & Sharon Judd	Simcoe	Grower
Dave & Jenn Vandevelde	Simcoe	Grower
Simcoe research station	Simcoe	OMAFRA Research site
John Fedorkow	NOTL	Grower
Anne Muir	NOTL	Grower
Earl Muir	NOTL	Grower
Erwin Wiens	NOTL	Grower
Tim Andrew	NOTL	Grower
Kevin Buis	NOTL	Grower

Project objectives

The principal objective was to undertake a comparison of soil moisture sensors on-farms to determine the amount and timing of irrigation, and to transfer this information to growers and irrigation stakeholders.

Detailed objectives included:

- Deriving efficient methods of the timing of water applications and water conservation methods
- Providing growers with on-site water management tools
- Testing soil moisture monitoring equipment on high value horticultural crops in conjunction with growers
- Obtaining grower feedback on equipment
- Conducting training with researchers, agricultural extension workers, agri-businesses on equipment
- Provide information to project growers to improve their knowledge of irrigation timing and the amount of water to apply

The Leamington, Essex Kent, Niagara and Norfolk County regions were focused on as these constitute the areas of intense irrigated vegetable and fruit production in Ontario (processing vegetables, berries, tender fruit, grapes and fresh vegetables) and are also on different soil types (heavier clay soils to sandy soils).

Methodology

Site selection and soil sensors

At the onset of the project, a meeting was held with the project partners (OMAFRA, AAFC-PFRA, WIN), where the hub sites were chosen and the equipment for installation was finalized. In spring, the equipment was procured, tested and installed. Sensors included portable equipment (TDRs); permanent equipment (Gro-point TDR probes, water content reflectometers, Watermark probes, manual tensiometers); and web based real time monitoring equipment (echo probes, and C-probes). The rainfall, relative humidity and ambient air temperature was recorded at each location through an on-site mini weather station.

The hub sites chosen were located in the areas of Leamington, Essex Kent, Norfolk, and Niagara Region (Figure 1.1); these belong to the primary regions of horticultural activity in Ontario, and require irrigation for high-value crops. All sites were on existing producers' fields with irrigation already set up for their crops. Field crops tested included processing tomatoes, fresh peppers, berries and peaches.

The six soil moisture sensors were installed at all hub sites by the beginning of June. They were inserted at the appropriate rooting depth for each crop. Data from soil moisture measurements was collected from May to the time of harvest, at least twice a week for the portable TDR and gravimetric sampling, and more often for the continuously recorded sensors. The soil sensors at the hub sites served as demonstrations for growers in a given area to monitor moisture, and to compare the different technologies whereby one may determine irrigation needs. Up to five additional growers in each region participated in the project. At these "satellite sites", TDR readings and gravimetric samples were taken twice a week.

Soil Data

Soil data was obtained at the beginning of the growing season at each site, including particle size, bulk density, organic matter and the water retention characteristics (field capacity and permanent wilting point) from 0-5 cm depth at all sites, and from 20-25 cm depth at the hub sites.

To obtain base-line soil moisture data, soil gravimetric water content was measured throughout the growing season (twice a week) on grab samples taken from 0-10 cm and 10-30 cm at each field location, and at four benchmark locations at each site for determining field variability purposes. These samples were analyzed in the laboratory at the University of Guelph.

Weather Data

The weather data (precipitation, air temperature, wind speed, relative humidity) was collected from automated mini weather stations on each hub site. This data was used to calculate a complete water budget for each crop. This data was used as an input to determine irrigation scheduling for the crops.

Irrigation Water Use

Irrigation water volumes applied to three of the hub sites (NOTL, Simcoe and Dresden) were metered with flow meters. The NOTL hub site water use was calculated by calibrating the water application rate and recording the rate and length of time of the application.

Based on the soil moisture sensors, data was analyzed to help interpret water application needs. Individual soil moisture graphics from the demonstration sites, and access to WIN real time output were available to the growers. Growers were provided with this decision support information throughout the project. Hub growers were particularly exposed to the sensors installed and their data. Some of the sensor was more available than others (e.g. the WIN website hosted the C-probe and Echo probe data continuously). While the satellite growers did not have direct access to the information at all times, some did consult the data available (e.g. when the field technicians took bi-weekly TDR readings) to varying extents for their operations.

To generate post irrigation season analysis of irrigation timing and scheduling, the soil moisture budget was analyzed and tracked by water budget method involving ETc, effective precipitation, irrigation and soil moisture depletion. Crop water requirements were also calculated for each site.

Technology transfer

Demonstration field days in conjunction with WIN and OMAFRA were conducted throughout the summer 2007 to show other producers, grower groups and agri-businesses the functionality of the equipment and how to use the equipment.

In order to gauge grower satisfaction with using the equipment, meetings with growers were held and two surveys were administered (one at the beginning of the season and one after harvest) to obtain comprehensive feedback. The surveys determined producer satisfaction with irrigation scheduling decision support information, producer needs regarding irrigation scheduling and which irrigation scheduling techniques producers have decided to adopt for future years (if any).

Project results were presented throughout the project duration at various conferences and disseminated via Brace and grower newsletters and websites.

The project achieved all of its intended outcomes in the given timeframe. As a result of this project, several hundreds of growers in Ontario were directly informed on how to use soil moisture sensors for measuring soil moisture for the purpose of irrigating different crops on various soil types, in Ontario. Through the project, McGill staff trained not only growers, but also researchers, agri-businesses and agricultural extension workers on using the sensors, and how to determine when and how much water to apply.

Figure 1.1. Location of the four hub regions, in southern Ontario

CHAPTER 2. Literature Review

Irrigation Trigger Points

1.0 Introduction

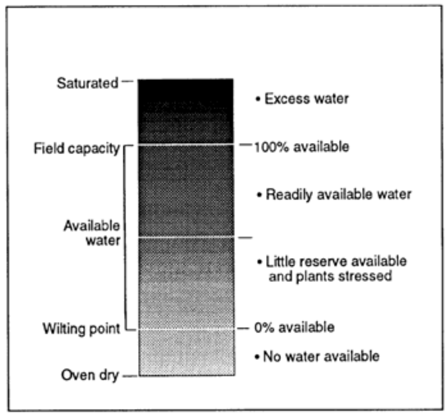
In southern Ontario, there is a need for fruit and vegetable growers to use water in a more efficient and timely manner. Through past experience working with growers in the area, they have also expressed the need to have better knowledge on when to start irrigating, and how much water to apply. Whereas most of them still rely on intuition or subjective irrigation scheduling techniques, scientific irrigation scheduling (SIS), defined as the use of crop evapotranspiration data and soil moisture sensors to accurately determine when and how much to irrigate, remains mostly unpractised (Leib et al., 2002). In fact, the growers in the region are mostly scheduling irrigation primarily "by the seat of the pants". As a result of years of past experience, by observing the condition of their plants, observing and feeling their soil to determine the soil moisture content and following the weather forecasts, they are able to estimate fairly well when to irrigate and how much water to apply. However, as this subjective technique is not the most accurate, reinforcement through the use of soil moisture monitoring and crop water use calculation is highly recommended. In order to widely implement SIS, understanding soil moisture levels and crop response is inevitably the first step.

1.1 Available Soil Water (ASW)

Water uptake by roots is critical for fruit and vegetable growth. Excessive or insufficient soil water in the root zone is definitely detrimental to crop production. Indeed, when the soil moisture level exceeds the condition known as the "field capacity"; the level at which the soil water retained after the gravitational water has drained, the soil becomes waterlogged and roots begin to perish from the lack of oxygen. Whereas when soil moisture is at or below the "permanent wilting point"; the level at which the roots cannot extract water anymore from the soil because the remaining water is being held too tightly by soil particles, the plants begin to permanently wilt, beyond the recovery point. Water that plants can use is known as the available soil water (ASW), and is held in the soil profile between field capacity and permanent wilting point (Figure 2.1 a and 2.1 b).

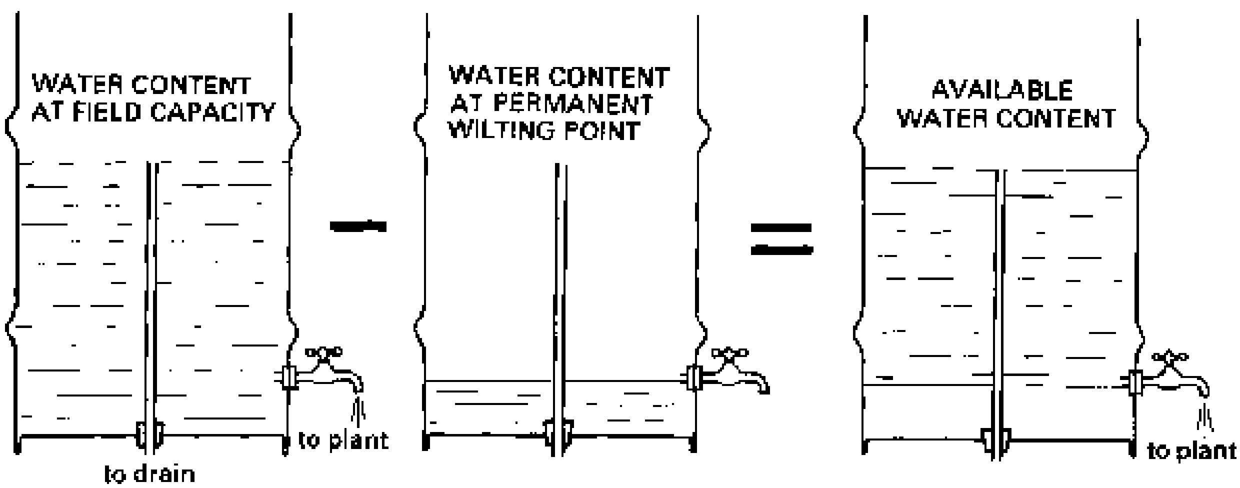
Soil texture (i.e. particle size) and soil structure (i.e. pore spacing and organic matter content) both affect the water storage capacity. Indeed, Table 2.1 and 2.2 clearly show that sandy soils have a poorer capacity to retain water than clay soils. Table 2.3, in which ASW is expressed as a volumetric water content percentage for various textures also supports this. Well-structured soils with high organic matter content, containing many pores, will retain water better.

Figure 2.1 a) Soil moisture profile



Source: Werner (1993)

Figure 2.1 b) Schematic of Available Soil Water (ASW)



Source: www.fao.org

Table 2.1 Available Soil Water (ASW) for various soil textures

Soil Texture	Available Soil Water (mm of water / cm of soil depth)									
	Tan (1990)	Werner (1993)	Ley et al. (1994)	Nyvall (1998)	Hanson et al. (2004)	Dexcel (2006)	AgriMet (2007)	California University (2007)	Leboeuf et al. (2007)	Average
Corse										
Coarse Sand	---	---	---	---	---	---	0.6	---	---	0.6
Sand	---	---	0.4 - 0.7	0.8	0,6	1.5	---	0.7	0.5 - 0.8	0.8
Fine Sand	0.5-0.8	0.6 - 0.8	0.5 - 0.8	---	---	---	0.8	---	---	0.7
Loamy Sand	---	0.8 - 1.3	0.6 - 0.9	0.9	0,8	1.8	---	1.1	0.7 - 1.0	1.0
Gravel/Cobble in Coarse Texture	---	---	0.5 - 0.7	---	---	---	---	---	---	0.6
Moderately Corse										
Loamy Fine Sand	0.7-1.0	---	0.8 - 1.1	---	---	---	---	---	---	0.9
Sandy Loam	0.9-1.2	1.1 - 1.5	1.0 - 1.3	1.2	1,1	2.3	1.0	1.4	0.9 - 1.2	1.3
Fine Sandy Loam	---	---	1.0 - 1.4	---	---	2.2	1.3	---	---	1.6
Medium										
Gravel/Cobble in Medium Texture	---	---	0.9 - 1.1	---	---	---	---	---	---	1.0
Very Fine Sandy Loam	---	---	1.3 - 1.8	----	---	---	---	---	---	1.6
Loam	1.3-1.7	1.5 - 2.1	1.3 - 1.9	1.6	1,5	---	1.5	1.8	1.3 - 1.7	1.6
Moderately Fine										
Sandy Clay Loam	---	---	1.4 - 2.0	---	1,0	---	---	1.3	---	1.3
Silt Loam	1.4-1.7	1.5 - 2.2	1.5 - 2.1	---	1,7	2.2	1.7	1.8	1.4 - 1.7	1.7
Silty Clay Loam	1.5-2.0	---	---	---	1,6	---	---	1.9	1.5 - 2.0	1.7
Clay Loam	1.5-1.8	1.5 - 2.1	1.5 - 2.1	---	1,2	1.8	1.8	1.6	1.5 - 1.8	1.6
Fine										
Sandy Clay	---	---	1.6 - 2.1	---	0,9	---	---	1.6	---	1.4
Silty Clay	---	---	1.6 - 2.1	---	1,4	---	---	2.4	---	1.8
Clay	1.5-1.7	1.5 - 2.0	1.7 - 2.1	---	1,3	1.8	---	2.2	1.5 - 1.7	1.7
Peats and Mucks	---	---	1.7 - 2.5	---	---	2.0 - 2.5	2.0	---	---	2.1

Table 2.2 Field capacity and permanent wilting point values for various soil textures

Soil Textures	Field Capacity (mm of water / cm of soil depth)			Permanent Wilting Point (mm of water / cm of soil depth)		
	Hanson et al. (2004)	California University (2007)	Average	Hanson et al. (2004)	California University (2007)	Average
Sand	1.0	1.0	1.0	0.4	0.4	0.4
Loamy Sand	1.4	1.6	1.5	0.6	0.7	0.6
Sandy Loam	1.9	2.1	2.0	0.8	0.9	0.9
Loam	2.7	2.7	2.7	1.2	1.2	1.2
Silt Loam	3.0	3.0	3.0	1.3	1.5	1.4
Sandy Clay Loam	2.5	2.9	2.7	1.5	1.8	1.7
Sandy Clay	2.4	2.8	2.6	1.5	1.5	1.5
Clay Loam	3.2	3.2	3.2	1.9	1.8	1.9
Silty Clay Loam	3.6	3.6	3.6	2.0	2.0	2.0
Silty Clay	4.1	4.0	4.0	2.7	2.0	2.3
Clay	3.9	4.0	4.0	2.6	2.2	2.4

Table 2.3 Volumetric soil moisture content (%) at field capacity, permanent wilting point and available soil water for various soil textures

Soil Texture	Field Capacity (%)	Permanent Wilting Point (%)	Available Soil Water Content (%)
Sand	10	4	6
Loamy Sand	16	7	9
Sandy Loam	21	9	12
Loam	27	12	15
Silt Loam	30	15	15
Sandy Clay Loam	36	20	16
Sandy Clay	32	18	14
Clay Loam	29	18	11
Silty Clay Loam	28	15	13
Silty Clay	40	20	20
Clay	40	22	18

Source: Hanson et al. (2004)

1. 2 Management Allowable Depletion (MAD)

In the past, irrigators were given a simple rule-of-thumb to trigger irrigation, when about half of the ASW was depleted. However, recent research has proved this rule to be inadequate for intensively managed, high-value crops (Werner, 1993; Bierman, 2005; Dexcel, 2006). The management allowable depletion (MAD), corresponding to the percentage of ASW which may be safely depleted before yield-reducing stress occurs, is now precisely recommended depending of the crop grown, the development stage as well as the irrigation system used. Table 2.4 shows MAD for various crop types.

Table 2.4 Management allowable depletion (MAD) for various crops

Crop	Management allowable depletion (%)						
	Sanders (1993)	Ley et al. (1994)	Nyvall (2002)	Planner (2003)	Hanson et al. (2004)	AgriMet (2007)	Range
Peaches	---	50-65	40	50	50	50-65	40-65
Raspberries	---	50	50	---	---	---	50
Strawberries	---	50-65	50	---	15	---	15-65
Tomatoes	50	40-50	40	30-35	40	---	30-50
Peppers	50	---	50	30-35	25	---	25-50

The recommended soil moisture depletions are indeed directly related to the crop grown, as the rooting depth varies. A deep-rooted crop such as peaches will use a greater volume of the soil profile than a shallow-rooted crop, such as peppers, and thus have access to more water in between irrigations (Table 2.5). In the end, the deep-rooted crops will have larger allowable depletions and thus require less frequent irrigations.

Table 2.5 Crop rooting depth for various crops

Crop	Rooting Depth (cm)
Peaches	75
Raspberries	60
Strawberries	30
Tomatoes	30
Peppers	30

Source: OMAFRA (2004)

Plant growth is most sensitive to water stress during the critical growth stages listed in Table 2.6. During these stages, the recommended allowable depletion is smaller, since sufficient water has to be available to compensate the higher crop water use. For example, during cell division, 30-40 days after bloom, and cell expansion, a few weeks before predicted harvest, peaches should be irrigated when MAD reaches 40-50%, while at other times of the season it can reach 65% before irrigation is triggered.

Table 2.6 Critical growth stages for various crops

Crop	Critical growth stages
Peaches	Cell division and cell expansion.
Raspberries	Fruit development to ripening.
Strawberries	Fruit development to ripening.
Tomatoes	Flowering, fruit set and enlargement.
Peppers	Flowering, fruit set and enlargement.

Source: Slingerland (2005); Hanson et al. (2004); Verhallen and Roddy (2002)

The irrigation system used will also influence the MAD. Indeed, drip systems, designed and operated to keep the soil moisture content at a level above MAD by irrigating very frequently, should have a lower MAD ranging between 10 and 30%. As for the sprinkler irrigation systems, operated to let the soil moisture deplete up to MAD before replenishing the soil profile to the field capacity, should have a higher MAD range of 30 to 50% (Table 2.7). Finally, climate, which is intimately linked to the crop water use, also has an effect on recommended allowable depletion; some parts of Ontario experience warm and dry growing seasons, in which case MAD should be lower.

Table 2.7 Management Allowable Depletion (MAD) for several irrigation systems

Irrigation System	Management Allowable Depletion (%)				
	Nyvall (2002)	Nyvall (2005)	Bierman (2005)	Leboeuf et al. (2007)	Range
Drip, Trickle and Micro-Jet	25	15	10-30	10	10-30
Sprinkler	30	40-50	---	50	30-50

Knowing the factors which affect the ability of the soil to retain water include soil texture (particle size), soil structure (pore spacing, organic matter content), the rooting depth, the crop type as well as its stage of development will help growers to better understand how much water is held in the rootzone of their soil, how fast the water is being used by the crop, and therefore help them to make wise irrigation decisions.

1.3 Soil Moisture Monitoring

Once a basic knowledge of understanding soil moisture levels and crop response is acquired, the adoption of soil moisture monitoring is suggested to reinforce the current irrigation scheduling technique. By indicating how much soil water is stored in the root zone, the soil moisture monitoring sensors allow growers to consequently schedule irrigation events when necessary. The two methods to measure soil water are described in the following section.

1.3.1 Soil Water Content Measurement

The amount of water in the soil, which can be determined by measuring the soil water content is commonly expressed in two ways, as follows:

Gravimetric water content

$$\theta_G = \frac{mw}{ms} = \frac{mwet - mdry}{mdry}$$

Where:

θ_G = Gravimetric water content
mw = Mass of water [g]
ms = Mass of soil sample [g]
mdry = Mass of dried soil [g]
mwet = Mass of wet soil [g]

Volumetric water content

$$\theta_v = \frac{Vw}{Vs} = \frac{\frac{mw}{\rho w}}{\frac{ms}{\rho s}} = \frac{\theta G \times \rho s}{\rho w}$$

Where:

θ_v = Volumetric water content
Vw = Volume of water in the soil sample [cm^3]
Vs = Volume of soil sample [cm^3]
mw = Mass of water [g]
ms = Mass of soil sample [g]
ρw = Density of water [g/cm^3]
ρs = Soil bulk density [g/cm^3]
θ_G = Gravimetric water content

Here, the soil bulk density is calculated with the following formulae.

$$\rho s = \frac{ms}{Vs}$$

Where:

ρs = Soil bulk density [g/cm^3]
ms = Mass of soil sample [g]
Vs = Volume of soil sample [cm^3]

Even if gravimetric water content is easier and more directly measured than volumetric water content, it is the latter which is used for water budget calculations; the equivalent depth of water in the soil sample being calculated by multiplying it with the depth over which the sample was collected.

Methods to measure soil water content (usually expressed at a percentage of volumetric water content or VWC %) include gravimetric (detailed above), time domain reflectometry (TDR), electrical conductivity and capacitance devices.

1.3.2 Soil Water Potential Measurement

The second method to determine the amount of water in the soil is to measure the soil water potential, which corresponds to the energy status of the soil water. The total potential in a soil region is actually the sum of gravitational, matric and osmotic potentials as shown below. Note that soil water potentials (suction or tension) are negative pressures commonly measured in bars or centibars (cbars).

$$\psi_t = \psi_g + \psi_m + \psi_o$$

Where:

ψ_t = Total soil water potential
ψ_g = Gravitational potential
ψ_m = Matric potential
ψ_o = Osmotic Potential

However, since it is the matric potential which generally has the greatest effect on water release from the soil to the plants, methods to measure soil water potential - namely, tensiometry and electrical resistance blocks - only measure this component and hence provides arguably a more realistic measure of the actual plant water stress. Table 2.8 shows the tension levels at which irrigation should be triggered.

Table 2.8 Tension at which irrigation should be triggered

Reference	Irrigation System	Soil Type	Crop	Trigger Level (cbars)
Bierman (2005)	---	Most soils	---	25-30
Nyvall (2005)	Drip/Trickle and Micro-Jet	Sand	---	10-15
		Loamy Sand		10-15
		Sandy Loam		15-20
		Loam		25-30
	Sprinkler*	Sand	---	20
		Loamy Sand		25
		Sandy Loam		30
		Loam		35
Thomson and Ross (1996)	---	Medium textured soil	---	45-70
		Sandy soils		20-35
Hanson et al. (2004)	---	---	Peach	50-80
			Strawberry	20-30
			Tomato	60-150

* For rooting depth of 600 mm

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Soil Moisture Sensors

2.0 Introduction

Soil moisture sensors provide the opportunity to nondestructively gauge and record soil water content at a specific point in the field or greenhouse. The water content is related to the unique characteristics of the soil and can depict plant-water relationships at a specific soil site; according to the crop grown, the specific weather conditions and the situation of the field. Growers can use this information to determine when to irrigate, and how much water to apply to their crops.

The first type of soil moisture sensor that was adopted by growers and which is still perhaps the most widely used piece of equipment (Campbell and Mulla 1990), is the basic manually-read soil tensiometer which displays soil matric potential, or soil water suction, or soil tension. Since the adoption of the tensiometer, sensors have evolved into innovative electric, continuously recording, user friendly sensors. Today, sophisticated electronic monitoring equipment exists which can relay data directly to a home personal computer or for posting to a website.

2.1. Soil Moisture Sensor Types

Electronic soil moisture sensor types can be categorized into the following:

- Electrical resistance sensors, which express a soil water tension of the soil. These include the gypsum block, which have gypsum cast around two concentric electrodes, and also include granular matrix sensors, manual tensiometers and electric tensiometers.
- Sensors using dielectric properties, which take into account the dielectric constant of dry mineral soil (value rarely exceeds 12), and the dielectric constant of water (value of approximately 80) and that of air (which has a dielectric constant of 1). Therefore, as the soil water content increases, the dielectric constant of the soil increases significantly. For the purpose of this project ,these sensors broadly include two types:
    - Sensors that use the time domain reflectometry principal to measure the velocity of an electromagnetic traveling wave, and where output values are expressed as a volumetric water content. These sensor types include time-domain reflectometers (TDR) and water content reflectometers (WCR).
    - Sensors that measure electrical capacitance of a soil volume, measure the dielectric constant, and where data output was expressed as a trends in this project. These sensors include capacitance probes.

Regardless of the type of soil moisture sensor used, a given sensor only has the capability of providing indirect water content at a particular, specific, location; hence a value from only one particular point and depth at a given site. Given that soil hydrological properties are highly spatially variable, more than one sensor may need to be installed. Especially if a field is highly variable in terms of soil type, organic matter, or has undulating topography, or is variable in any other way. Therefore, the question of how representative the spot measurement is, compared to the rest of the field must be asked. Placement of sensors in the field or greenhouse is of particular importance when making irrigation decisions for a larger area based on a spot value. It has been recommended that future research be targeted at sensors being able to sense volumes of soil large enough to encompass a representative elemental volume (Evett and Parkin 2005).

To get blanket measurements for the entire field, there are two options: set up a grid system of monitoring equipment (this can be costly and is certainly not very practical), or calculate crop water needs based on a water balance (budget) approach. Neither of these approaches are very enticing for growers. Nevertheless, sensors installed at a particular site with careful consideration to site chosen can be used with excellent results, but careful consideration has to be given to the sensor location (Coelho and Or 1996); choosing a representative site in the field, as well as placing it correctly (not too close or far away from a drip emitter, etc.).

Some of the methods used to measure soil water contents are explored below. The methods involve obtaining moisture based on a soil volumetric water content reading, given in % water; other methods obtain soil moisture based on a soil matric potential reading, which measures the amount of tension under which the water is held to the soil particles. The readings are given in kPa or in cbars. It has been put forward that for on-farm use, soil matric potential is a more practical measurement for irrigation decisions, rather than the volumetric soil water content (Thompson et al 2006). The reason for this is because the soil matric potential triggers for irrigation are known amongst different soil types, and no knowledge of the available soil moisture amount is necessary (which is calculated by knowing the field capacity and permanent wilting point, and the rooting depth of a given crop; the former two require analysis of soil, usually in a lab, in order to be able to calculate all these amounts).

One of the objectives of this project was to test both types of sensors (volumetric water content types and soil matric potential types) and obtain grower feedback on sensor preferences for irrigating.

2.1.1 Methods for measuring soil volumetric moisture content

<u>Gravimetric sampling</u> involves oven drying a soil sample to constant mass. This involves auguring the soil to the desired depth. Then determining the water content based on the oven drying method; which involves weighing the soil sample, putting in the oven for 24 hours at 105^{o}C, and then reweighing the sample to determine the mass of water at the time of sampling.

Typically, errors related to gravimetric sampling lie in the accuracy of the weighing scale used, however these are usually very small compared to the variability in the field (Campbell and Mulla 1990). If an undisturbed soil sample is obtained, the volumetric water content can be calculated if the mass wetness, density of water, and soil bulk density of the soil are known by using the relation of:

$$\Theta = (\rho b / \rho w)\, w$$

Where: Θ is the volumetric water content of the soil;
ρb is the soil bulk density (g/cm^3)
ρw is the density of water (g/cm^3)
w is the mass of water per mass of dry soil (gravimetric water content)

This direct measurement is the only true method of obtaining actual volumetric soil moisture content. However, this method is not practical for growers as it is laborious and takes too much time to determine results. Hence, sensors are used which can indirectly, accurately and quickly give an indication of the water content of the soil. None measure water content directly.

Nuclear methods such as neutron scattering techniques, or gamma-ray attenuation can be used to estimate water content. These are probably amongst the most accurate methods however, due to the safety regulations requiring costly licensing and training, and laboratory burdens of working with radioactive material, these methods are being used less and less (Huang et al 2004). Due to its drawbacks these methods are not a practical choice for grower applications on-farm, and therefore have remained mostly confined to research tools.

Dielectric methods determine soil moisture by measuring the dielectric constant of the soil (the dielectric constant of dry soil is <10; air is 1; water is about 80) (Fares and Polyakov 2006). Methods such as time-domain reflectometry (TDR) provide measurements of soil volumetric water content by using this principle. The TDR is a microwave method that determines the soil dielectric constant and is based on relating changes in permittivity of the soil to changes in soil water content. The principal of measurement is based on sending an electromagnetic wave into the soil via the two or three parallel steel rods (called waveguides), and measuring the travel time of the electromagnetic pulse up and down these waveguides of a given length. The larger the dielectric constant, the longer the pulse travel time (Prichard et al 2004).

Water content reflectometry (WCR) is a method which also uses time-domain reflectometry to obtain soil water content. The WCR consists of two stainless steel rods connected to a printed circuit board which is encapsulated in epoxy. The two rods on the sensor measure dielectric permittivity of the soil. It also propagates an electromagnetic pulse along two rods which act as a wave guide (Campbell Scientific 2006). The WCR works at frequencies between 15 and 45 MHz. The WCR uses capacitance of the soil to predict the dielectric constant (Ka), hence it can also be classified as an frequency domain reflectometer (FDR) sensor (Czarnomski et al. 2005).

Capacitance probes (C-probes) consist of two electrodes separated by a dielectric (a material that does not readily conduct electricity). Capacitance probes are usually cylindrical in shape, and have multisensory capabilities. When they are inserted into the soil, the soil becomes part of the dielectric. An oscillator applies frequency (50 to 150 MHz) to the electrodes which in turn provides a resonant frequency. The greater the soil moisture content, the smaller the resonance frequency (Prichard et al 2004). The capacitance sensors have the ability to oscillate over 100 MHz inside the plastic tube, in free air. The output of the sensor is the frequency response of the soil's capacitance due to the soil moisture level (Fares and Polyakov 2006). The C-probe design and installation process are very effective in not disturbing the soil. The C-probe tube may remain in the ground during the winter allowing identical inter-annual comparisons. The C-probe sensors use a look-up table to convert output to a VWC%. The accuracy of the output number is largely determined by how closely the table's baseline soil matches the grower's soil.

2.1.2 Methods for measuring soil matric potential

A tensiometer consists of a sealed, water-filled plastic tube with a porous ceramic cup at one end, and a gauge on the top, that measures soil suction. As the soil dries, water is pulled out of the tube and seeps into the surrounding soil to reach an equilibrium, thus creating a vacuum in the tube and reading higher tensions. Tensiometers are easy to read and can be installed at different depths. However, they have a number of practical limitations; they require careful installment, and regular maintenance. If the tube dries up, air enters the tube and the tensiometer stops working. They have a restricted working range of 0 to -80 kPa. If the soil continues to dry past this point, tensiometer readings drop to 0 because the cup desaturates and allows air to enter the tube. Tensiometer function can be restored by filling the tube with water and thoroughly saturating the surrounding soil, before sealing the tube (Prichard et al 2004).

Tensiometers are most commonly known to be manually-read via a gauge reading, but they can be electric (e.g. a Hortimeter), whereby an electronic display shows the reading in cbars, and an antennae on the tensiometer relays the data to a home computer.

Electrical resistance methods includes electrical resistant blocks which are inexpensive, simple to install and require minimal maintenance and they have a wider working range of 0 to -200 kPa (Thompson et al 2006). These can be composed of gypsum (gypsum blocks) or a ceramic-sand mixture (granular matrix blocks). Pore sizes of the blocks are similar to the soil matrix and hence "blend in" with soil (Yoder et al. 1998). They work on the principal of measuring the electrical resistance to current flow between electrodes embedded in gypsum; as the gypsum dries the electrical resistance increases between the rods. Thus, the wetter a block is, the lower the resistance measured across two embedded electrodes. The electrical resistance is due more to the permeating fluid, rather than the block matrix (Hillel 1980).

Manual tensiometers, electronic tensiometers as well as electrical granular matrix block sensors were used in the project, which all gave readings of soil water potential. It is difficult to relate soil suction to soil volumetric water content because the relationship is hysteretic (Evett and Parkin 2005). Therefore results were reported as tension. To relate volumetric water to soil to tension, in-situ conversions need to be undertaken by the instantaneous profile method to obtain the soil water release curve.

2.2 Moisture Sensors for the COWSEP Project

The COWSEP funded project entitled: ”Determining irrigation needs based on soil moisture monitoring” led by McGill University and conducted in partnership with AAFC-PFRA, OMAFRA, WIN, and growers (13 farms in total) tested several types of equipment used to measure soil moisture. The equipment was set up during spring 2007, and measurements were obtained throughout the 2007 growing season. The project tested a range of soil moisture monitoring equipment (tensiometers, time-domain reflectometers (TDR), water content reflectometer (WCR), electrical resistant blocks, capacitance probes, and voltage meters) to determine which sensors provided growers with on-site water management tools.

For the purpose of project discussion, the equipment sensor types used in the project can be categorized according to their data display types, which means what units the data was recorded in; namely into the following categories of; volumetric content output, tension based output, and trend based outputs:

VOLUMETRIC BASED

- Portable TDR (FieldScout 300)
- TDR sensor (Gro-Point Moisture Sensor)
- Water content reflectometer (Campbell CS625)

TENSION BASED

- Manual tensiometer (Irrometer)
- Electronic tensiometer (Hortimeter-T)
- Electrical resistance blocks (Watermark)

TREND BASED

- Capacitance probe (AquaSpy)
- Echo probe (EC-20 Decagon)

Note that electrical capacitance sensors can give readings in volumetric based units, however in this project the trend lines were displayed by default on the WIN website, and this is what the growers had access to when they initially logged into the site and when all three sensor depths were displayed. Hence, this category of trend-based data displays is discussed. To determine when to irrigate using trend lines, a field capacity level must be determined; usually at the time of sensor installation. This is done by thoroughly wetting the soil and leaving it for 48 hours to drain. The reading shown by the sensor after 48 hours is the field capacity. To determine when to stop irrigating a value of 85% of the field capacity can be used.

Table 2.9 gives detailed descriptions of the sensors and recording equipment that were installed at the sites.

Table 2.9 Soil Moisture Sensors used in the COWSEP project

	TDR BASED – VOLUMETRIC			SOIL TENSION			DIELECTRIC - VOLUMETRIC	
	Water Content Reflectometer	**Gro-Point**	**Portable FieldScout TDR**	**Tensiometer**	**Watermark**	**Hortau Wireless Tensiometer**	**Capacitance probe**	**Echo Probe**
Brand name	CS625 Water Content Reflectometer	Gro-Point Moisture Sensor	FieldScout 300	Irrometer	Watermark	Hortimeter-T	C Probe	EC-20
Manufacturer	Campbell Scientific	Environmental Sensors Inc.	Spectrum Technologies	Irrometer	Irrometer	Hortau	AquaSpy	Decagon
Principle of operation	Based on time domain reflectometry, sensors measure soil moisture and record % volumetric water content	Based on time domain reflectometry, sensors measure soil moisture and record % volumetric water content	Portable, measures site-specific soil moisture levels using time domain reflectometry principles	Measures actual soil water tension, which indicates the effort required by root systems to extract water from the soil	Solid state, electrical resistance type sensor. Output in centibars of soil suction	Determines substrate water tension similar to the manual tensiometer	Capacitance measurements are converted to volumetric soil moisture	Sensor measures dielectric permittivity of the soil to determine volumetric water content.
Power supply	Solar panel charges a 12 V 10.5 A-hr battery	Alkaline batteries	Alkaline batteries	None required	Alkaline batteries	Alkaline batteries	Solar panel powers sensors and telemetry system	Solar panel powers sensors and telemetry system
Wireless communication	Radio link (RF400)	N/A	N/A	N/A	N/A	Irricom wireless	Adcon telemetry	Adcon telemetry
Datalogger / acquisition	Campbell Scientific (CR205)	Gro-Point Datalogger	Built-in datalogger	None (direct measurement)	Watchdog 400 & 2800	None (direct to PC through wireless)	None (to server through wireless)	None (to server through wireless)
Software	LoggerNet	GroGraph	FieldScout	None	SpecWare	Irrolis Light	addVANTAGE web system	addVANTAGE web system

2.3 Description of Sensors Installed

The equipment and sensors were either portable, or were permanently installed in the field for the duration of the growing season (installed in May or June and removed at crop harvest). Technically, the sensors varied in their level of sophistication; from those having gauges or dials which required to read and record manually, to others being electronically wired to dataloggers and requiring a certain level of computer knowledge to view the data. Technical adeptness to install and download the data was required for some of the more sophisticated sensors. The equipment had different types of data downloading and viewing options; from electrical displays on the equipment, to viewing the data on a home computer.

Tensiometers

Manually-read tensiometers (Irrometer Co., Riverside CA) were installed permanently at two depths of the root zone. They provide a reading of the soil water suction, or tension, caused by the soil water moving away from the ceramic cup (in a drying soil), or moving towards the ceramic cup (in a wetted soil). The water tension is related to the soil water that is available to plants. Electronic tensiometers (Hortau, St-Romuald, QC) which display the tension on cbars and the soil temperature on an electronic display, and which can send the date by radio frequency to a personal computer were installed permanently at two depths at the tomato hub site only.

Portable and fixed time-domain reflectrometers

The time-domain reflectrometer (TDR) equipment included the portable Field Scout TDR300 (Spectrum Technologies Inc., Plainfield, IL); and permanently installed electronic Gro.point probes (Environmental Sensors Inc., Sidney, BC). The portable TDR had a port for connecting an external GPS system that can be used to pin-point previously sampled locations, which is helpful for re-sampling, however this function was not used for the project. The Gro.point probes were installed in the soil for the duration of the growing season.

Water content reflectometers

Water content reflectometers (WCR) use the TDR principal to estimate the permittivity of the soil (Kelleners et al. 2005). The two rods on the WCR measure the dielectric permittivity of the soil. The WCR also propagates a signal along two parallel rods, but uses the capacitance of the soil to predict the dielectric constant. The WCR measures dielectric properties with circuitry embedded within the instrument which reduced the cost, and also allows the sensor to be deployed a greater distance from the datalogger (Chandler et al. 2004). The WCR CS625 (Campbell Scientific Inc., Logan UT) probes were used in this project, which is the latest model of this sensor currently in widespread use. They were installed permanently, at two depths, for the complete growing season.

Electrical resistant blocks

Electrical resistant blocks are installed and remained in the soil for the complete growing season, and determine soil matric potential at selected depths. Watermark granular matrix sensors (Spectrum

Technologies Inc., Plainfield, IL) were used which come with 3 sensors per datalogger. According to the manufacture, Watermark sensors are operable over a range of 0 to -200 cbars. The Watermark granular matrix material contains an internal gypsum tablet that buffers against salinity levels, as well as being surrounding by a protective synthetic membrane (Campbell Scientific, 2005).

Capacitance sensors

C-probes (AquaSpy, Thebarton, SA. Australia) with three multisensor capabilities were inserted into the ground for the duration of the season and measured volumetric moisture content at three depths, simultaneously, in the soil. Capacitance sensors measure the electrical capacitance of a soil volume. Because the capacitance probe is enclosed in an access tube, it does not come into direct contact with the soil. Readings can be converted to soil volumetric water contents, however in this study growers had access to the output data on WIN website, displayed as trend lines of each sensor corresponding to the appropriate soil depth (during the season, some upgrades were undertaken to the website and the grower had the option of toggling a button to get 15 minute VWC% readings). Nonetheless, during presentations of data to growers, the trend lines were used as through its many years of experience, WIN liked the trends which they found were easy for growers to understand. The access to the C-probe graphs was provided by WIN.

Echo probes are also a capacitance type sensor that measures the dielectric constant of the soil. They consist of copper electrodes sealed in an epoxy-impregnated fiberglass (Fares and Polyakov 2006). The EC-20 (Decagon Devices, Inc., Pullman, Washington, USA), were installed for the season and measure moisture content from the dielectric permittivity of the soil were tested. The Echo probe measures the soil moisture through the dielectric permittivity of soil expressed in volts, by measuring the charge time of a capacitor in the soil (Czarnomski et al 2005). The applied voltage is displayed. The Echo probe displays readings in Volts on the WIN website, which the growers could access by logging in to the website. Although conversion to VWC% is possible, for the purpose of this project (and to remain consistent with what the growers saw), the volts readings will be interpreted as trends (since they are neither VWC% or cbars). The Echo probes and C-probes delivered the data via cellular base stations to a website. Web delivery was the best option for WIN, so the grower, his consultant, and the equipment supplier can all monitor the system, however web delivery is just one option.

2.4 Sensor Placement

The placement of sensors is critical to obtaining accurate soil-moisture information as it relates to crop water uptake and needs. Often it is stated that sensors should be placed at the top and bottom of the active rooting zone (e.g. Prichard et al. 2004). This is especially the case for manual tensiometers, as they are relatively inexpensive. For the more expensive types of equipment, placing the sensor at the depth of the maximum active root zone makes more sense.

Different types of moisture sensors have different zones of influence from where the measurements are taken. Echo probes have a 2 cm zone of influence extending from its flat surface and decreasing with distance away from the probe (Fares and Polyakov 2006). Hence, the contact between the soil and the sensors is crucial to obtain representative readings. Too many air spaces surrounding the sensors will give inaccurate readings. The dielectric sensors have a zone of influence that is amongst the largest, however it is still restricted to a narrow disk shaped area surrounding the sensors and centered in the space between the electrodes (Prichard et al 2004). When installing C-probes, special attention must be given to avoid pockets of air between the tube and the soil (Fares and Polyakov 2006).

When monitoring soil water content in surface drip or buried drip irrigation, the appropriate radius at which sensors (either tensiometers or soil water content sensors) can obtain realistic measurements of soil water content was found to be up to 0.25 m away from the dripper for surface drip tape; and up to 0.15m for buried drip tape (inserted to the appropriate depth) (Coelho and Or 1996).

Due to the spatial variability of soil hydrological properties, and because of different crop water use, it is recommended to install sensors in each crop type on the farm, as well as to install at least two monitoring stations for every 16 hectares (Prichard et al 2004).

2.5 Equipment Costs

Costs of the sensors varied according to the type of sensor, its sophistication, and the neccessary equipment required to view the data. A summary (Table 2.10) of sensors compares the cost of the various components of the equipment required to monitor soil moisture that were used in the project. The electronic equipment costs do not include the cost of a laptop which can be used for downloading data from some of the sensor recorders in the field.

It should also be noted that one datalogger can be used to connect more than one sensor, which is useful when measuring water content at different depths simultaneously, or different locations in the same site.

As a point of interest, it should also be noted that the WCR, Gro-Point and Watermark electrical resistant block sensors used in the project have the capability to transmit the data readings via a wireless data transmission option; with the addition of communication components , a datalogger and required software. Due to limitations in budget and partner contributions this was not undertaken.

Table 2.10. Comparison table of soil moisture monitoring equipment costs as used on the project

Sensor brand name & Manufacturer	Sensor cost (for 1 sensor)	Data download equipment	Software
Manual tensiometer (Irrometer)	$ 100- 150	None required	None required
Portable TDR (FieldScout 300)	$ 1000	Cable included	$ 200
TDR moisture sensor (Gro.point, ESI)*	$ 250	$ 380 datalogger** $ 180 shuttle (optional)	$ 140
Water content reflectometer* (CS625, Campbell Scientific)	$ 200-300	$1500-2000 datalogger**	$ 650
Electrical resistant block* (Watermark, Irrometer)	$ 500 (for a 3 sensor station)	Logger is included	$ 300
Electronic tensiometer (Hortimeter-T, Hortau)	$ 900	$ 2000 field station $ 900 office base unit	included
Echo Probe (EC-20, Decagon)	$ 400	Wireless transmission	Website
C-probe (C-probe, AquaSpy)	$ 1000-3000	Wireless transmission	Website

*Equipment requires a laptop to download and view the data
**One datalogger can handle several sensors at a time

2.6 Calibration

All soil moisture sensors provide indirect measurements of soil water, and as such, each sensor type is dependent upon the calibration equation used (Thompson et al. 2006). The factors which most impede proper sensor electrical conductivity readings are: high clay contents, salinity and temperature (Evett and Parkin 2005).

The TDR has the advantage of having one calibration curve for all soils, which is unaffected by soil texture, salinity, bulk density, temperature, or organic matter content (Campbell and Mulla 1990).

The WCR sensor is significantly affected by temperature, and the effect increases in absolute value with the volumetric water content (Seyfried and Murdock 2001). Hence, soil temperature probes were inserted at the same depth as the WCR sensors, and the temperature-dependant calibration equation provided by Campbell Scientific was used to adjust the VWC readings.

The Campbell WCR performs well in sand soils (<10% clay). In one study, the CS 616, model agreed with the standard calibration provided by the manufacturer (Seyfried and Murdock 2001). In another field study (Chandler et al. 2004) on a soil with <10% clay, the WCR readings were also found to be precise and reliable at a range of soil moisture contents for 4 years, and to have strong correlations to TDR volumetric water contents. According to the manufacturer, their calibration curve should work well in soils with electrical conductivity <0.5 dS m^{-1}, bulk density <1.55 g cm^{-3} and clay content < 30% (Campbell Scientific 2006).

In sandy soils, with low EC and clay content, the standard manufacturers' calibration can be used for WCR sensors (Seyfried and Murdock, 2001; Kelleners et al. 2005). When the EC is >0.1 S m^{-1} alternative calibration (i.e. in the field) is required for the WCR, and for the Echo probe.

Since the WCR measures the dielectric permittivity of the soil, the WCR tends to be more sensitive to variations in soil salinity concentration, and variations in clay content and type, as these affect electrical conductivity and thus have an effect on the dielectric properties at low frequencies (Chandler et al. 2004) (the measurement frequency of the WCR is generally between 15 and 45 MHz (Seyfried and Murdock 2001), whereas the TDR is up to 1 GHz. It was found that in a soil with higher clay content, the WCR tended to overestimate VWC (Chandler et al. 2004). Individual, in-situ calibrations in these circumstances will improve VWC readings.

In a study by Thompson et al. (2006), the Watermark sensor readings were found to be a function of two factors: 1) the general sensor performance under the given environmental and soil water conditions (the sensors tended not to perform well in very wet conditions, or in rapid soil drying conditions); and 2) the calibration equation used (they found the manufacture calibration curve for the Watermark 200SS sensor was found to work best under the range of -30 to -80 kPa) suggesting that they work best in less frequently irrigated sites.

To optimize the accuracy of Watermark sensor data, Thompson et al (2006) recommend undertaking in-situ calibrations and developing or verifying calibration equations, specific to the growing conditions.

It was reported that site-specific calibration of the capacitance probe improves its accuracy of soil water content measurement (Evett and Parkin 2005). Since the dielectric constant is sensitive to air spaces, soil fissures, or insect holes this may lead to measurement errors and therefore, soil bulk density can also have an effect on sensor readings (Huang et al. 2004).

Calibration of manual tensiometers requires soil sampling and analysis in the lab with pressure plates to determine the soil moisture release curve, and associate tension values with water content values.

The calibration of the soil sensors is a step which growers do not often have the time, know-how, or training to do since it does require a knowledge of certain soil parameters, and furthermore the calibration of some sensors is not always obvious and may require soil analysis. The calibration of moisture sensors is perhaps more important from a scientific point of view. Even when sensors are not calibrated, they will give suitable readings to determine when to irrigate.

2.7 Sensor Performance

Few studies have looked at comparing sensor performances to each other. Overall, these comparisons are very dependent on the soil type used.

In a study by Yoder et al (1998), they found electrical capacitance sensors (especially the Troxler Sentry sensor) to perform better (taking into account soil type and drainage patterns) compared with electrical resistant sensors and TDRs. The electrical resistant sensors studied (Watermark sensors, gypsum blocks) tended to be more erratic and were sensitive to soil type and water content range. The Watermarks provided more accurate readings in the sandy loam soil than in the loams (Yoder et al. 1998).

The soil matric potential was found to be most stable at 6 a.m. which is the period shortly after sunrise. This is when Watermark sensor measurements were obtained by Thompson et al. (2006) to minimize erratic data readings. When electric tensiometers were compared to Watermark sensor recordings, in a side by side comparison experiment (Thompson et al. 2006), the values were found to corroborate very well with each other; the absolute differences in soil matric potential values were not statistically different. However, the Watermark sensors did not perform well in a rapidly drying soil (Thompson et al. 2006), they responded much slower compared to tensiometers.

In very sandy soils, manual tensiometers may operate poorly due to the coarseness of the sand causing less than ideal contact between the soil and the ceramic up and therefore hindering the flow of water into the tube. One solution is to use a course porous cup (Prichard et al. 2004)

The objectives of this project were not to compare sensor performances to each other. Rather to gauge the ease of use and reliability of each sensor.

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CHAPTER 3. Site Location and Information

Hub Site Descriptions

At the Simcoe hub site, strawberries were grown under high tunnels, as well as in the open field. In both strawberry production systems, the raised beds were covered with a white plastic mulch and were drip irrigated. The strawberry fields were well established, having been planted in 2006. The soil type was mainly a sandy loam (some loamy sand pockets) with sand contents ranging between 57-80%, and clay contents between 2-18%. Organic matter contents in the top 5 cm ranged from approximately 1.5-3.0%. Any mulch on the surface was removed before the sample was taken. It should be noted that these organic matter values may differ from what growers might expect on their fields because the samples were obtained from the top 5 cm; normally growers would sample the top 15 cm of their soil. Field capacity varied from 11 to 18%. Both systems had surface drip irrigation tape. The grower used a pond to obtain his irrigation water, which was filled with well water and supplemented with drainage water. The grower would not be able to grow berries without applying irrigation water in his climate zone, therefore he relies heavily on a reliable source of water for the duration of the growing season, especially because he irrigated regularly every 2-3 days.

The hub site located in Leamington contained processing tomatoes grown with both buried and surface drip irrigation. In the case of the buried drip, the irrigation tape was located approximately 20 cm below the soil surface. The soil type was a very deep sand, with sand ranging between 88-98%. The field capacity was measured between 13-21% with the pressure plate apparatus, which was high for sand, mostly due to the unbelievably high organic matter contents from 0-5 cm measured of up to 8% (which was probably due to the grower applying copious amounts of compost, annually). The grower used a clay lined pond to obtain his irrigation water, which he filled with drainage water and municipal water. The pond had a capacity of 56, 775 m^3, which is not always adequate to irrigate his tomatoes for the full season. He must therefore closely manage the water deliveries to his various fields over the growing season, in order not to run short. Good quality processing tomatoes require irrigation applications at the right time; quality is closely tied to judicious irrigation.

At both these hub farm sites (Simcoe and Leamington), comparison locations of sensor installations were set up side-by-side to gauge the different growing practices' effects on soil moisture. At the Simcoe site, the strawberries inside high tunnels were compared to open fields (tunnels keep more heat inside, and prolong the growing season). At the Leamington site, the tomatoes that were using surface drip irrigation were compared to the buried the drip tape at 20 cm. The buried drip tape was a practice the grower favoured and wanted to move towards.

Therefore, to compare the different management practices, exact replicates of the soil moisture sensors were installed in these systems, to see how irrigation water application might vary between the practices.

At the Niagara-on-the-Lake hub site, the peach orchards where the sensors were located were planted in 2002. The soil was a loamy sand for the most part (some sandy loam areas), with sand content that ranged from 63-85%, clay contents from 4-15% and average organic matter contents in the top 5 cm of 3-4%. Field capacities were mostly around 15%. The irrigation was applied with an overhead gun, from a pond located on his farm, which had a storage capacity of 3,785 m^3. Historically, the grower practice was to only irrigated twice, maybe three times a year (dry year), and only at the crucial times for peaches: at flowering, cell division and fruit sizing.

The Dresden hub site was planted to bell peppers. The soil consisted of a loamy sand, with sand contents ranging from 67-87% and clay from 3-11%. Organic matter content at 0-5 cm was 2.4 –4.6%. The field capacity varied from 12-22%. The grower applied irrigation water from a pond (9,462.5 m^3), either by drip tape, or by travelling overhead gun – depending on how dry the season was shaping up to be. In 2007, he decided to use drip tape at the beginning of July, which he only laid down in mid July. Irrigating is important for fresh market vegetables to obtain optimum fruit sizing and quality.

For each hub site, up to five “satellite” farm sites were chosen to participate in the study. At these sites, soil moisture was measured with the portable TDR and gravimetric samples were obtained for comparison purposes. The reason for including satellite sites in the project was to reach as large a grower-audience as possible. By involving the satellite sites in the training, and obtaining readings from their fields, they became aware of the larger suite of sensors that we were implementing.

At each farm where we tested for soil moisture, four benchmark locations were sampled within the same management zone (i.e. the same crop and same irrigation system). These benchmarks represented variability in the field (different soil type, topography, organic matter, etc.). Their purpose was to look at how soil moisture varied across a given field, for managing irrigation water applications and to illustrate the importance of site selection for sensor installation. These benchmarks were chosen in conjunction with the grower, who knew the variability of the fields the best. Appendix A shows detailed site maps of each site, with the benchmark locations. The benchmarks highlight the extreme ranges of soil organic matter, field capacity and, in some cases, soil texture ranges measured. The differences in field capacities are significant and pose challenges when managing water applications for an entire field, especially determining when to irrigate based on one spot measurement.

The site descriptions including the soil type, weather information for the 2007 growing season, irrigation systems used, and crop data for each site, are presented in the next sections.

Weather Station Data at Hub Sites

Weather stations were installed at the hub sites (Adcon weather stations were installed at each hub site; and Watchdog 900 ET stations at the Leamington and Niagara-on-the-Lake hub sites as well). The weather data for the 2007 growing season (precipitation, air temperature, wind speed and direction, relative humidity) was collected on a continuous basis, every 15 minutes, and logged by dataloggers. This data was downloaded regularly and used to calculate a complete water budget for each of the four crops at the hub sites.

By most accounts, the 2007 growing season was to one of the driest on record; although generally the nights were cool allowing crops a reprieve. According to Environment Canada's Weather Review (http://www.on.ec.gc.ca/press.cfm?Year=2007&Lang=e) for July 2007, most of southern Ontario experienced "very dry conditions". This continued into August, where conditions remained warm and dry, with very few exceptions. According to Environment Canada's August 2007 Weather Review, the temperatures generally remained slightly above normal, mostly by a degree or so, but there was still a lack of rainfall. Only some areas (e.g. Windsor and Sarnia) received much-needed moisture. Environment Canada's September 2007 Weather Review stated that September broke a number of high temperature records in Ontario, as the continuing trend of warm temperatures continued into the fall and the drought-like conditions in southern Ontario persisted.

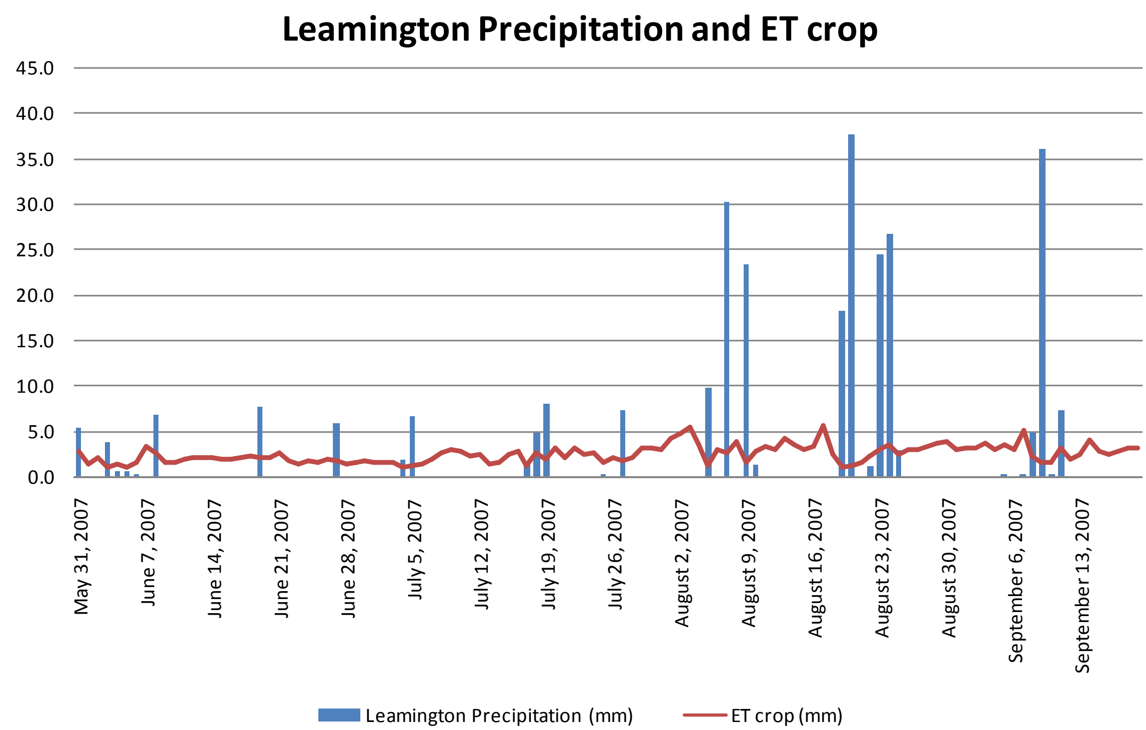


Figure 3.1.a. Precipitation and ET crop for Leamington Hub site

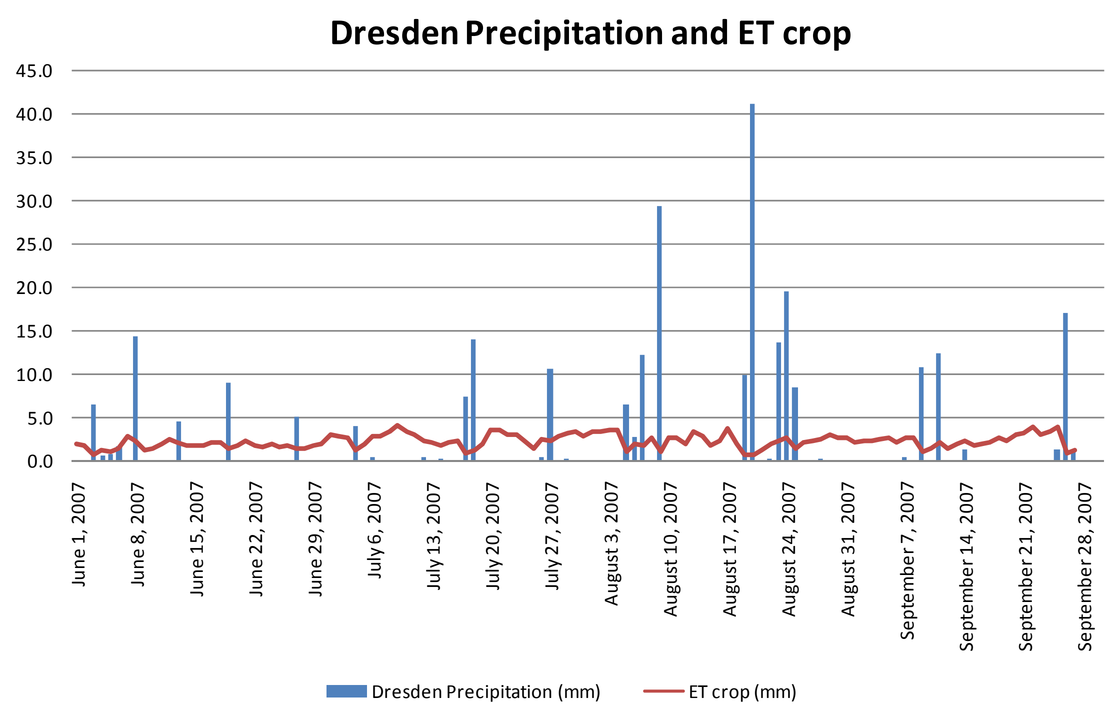


Figure 3.1.b. Precipitation and ET crop for Dresden Hub site

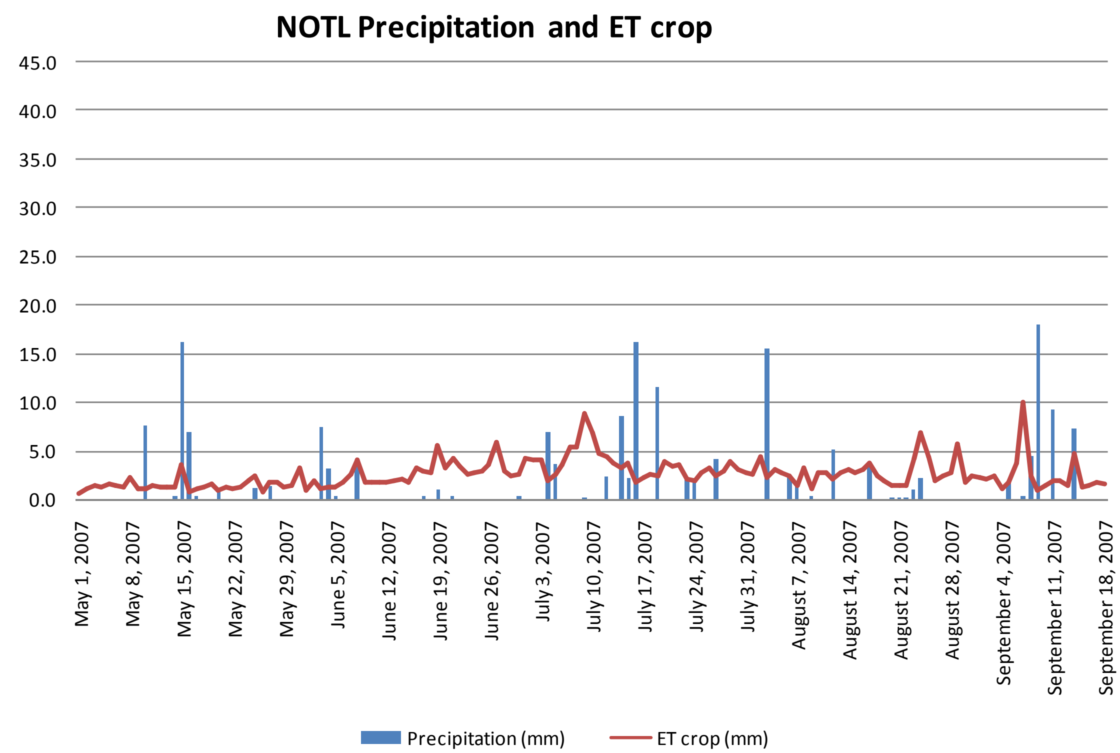


Figure 3.1.c. Precipitation and ET crop for Niagara-on-the-Lake Hub site

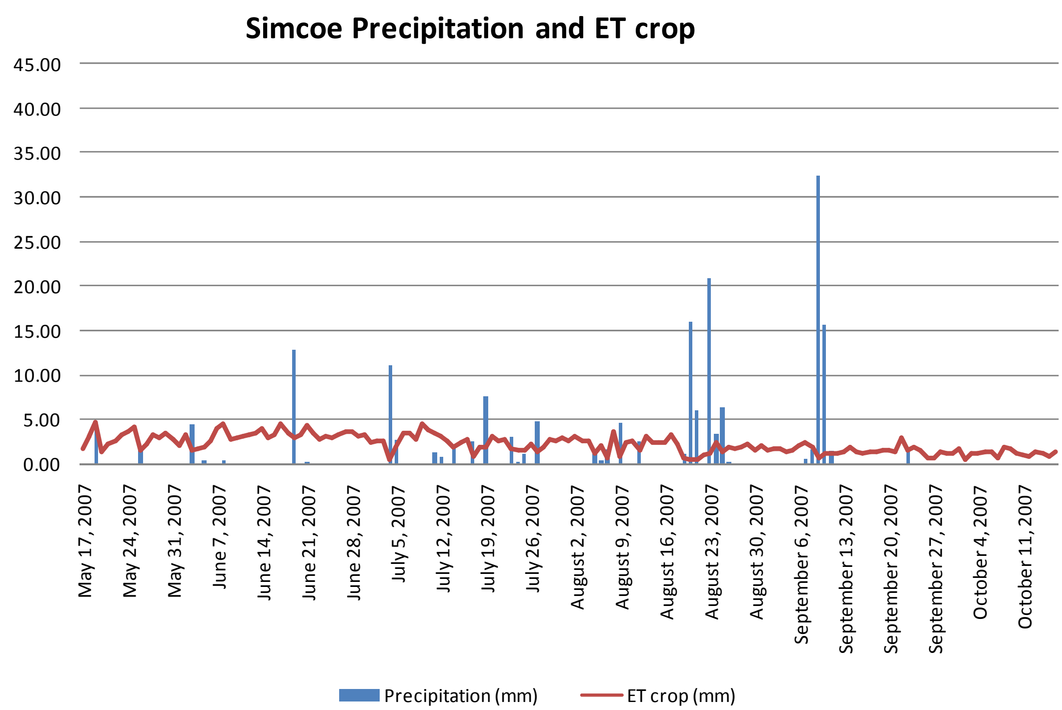


Figure 3.1.d. Precipitation and ET crop for Simcoe Hub site

Soil Analysis of Each Site

Determining triggers for irrigation

Finding the trigger for irrigation or the management allowable depletion (MAD) (Chapter 2) is important for knowing when to turn the tap on. This consists of determining the soil available water (AW) at each site. Once the AW is determined, irrigation is triggered no later than when the soil moisture corresponds to the depletion of half of the soil AW (this is a general rule of thumb for all crops and represents a lower level of soil moisture). The soil AW is analogous to a reservoir, and is the amount of water held between the upper and lower limits of water holding capacity, which correspond to the field capacity (FC) and the permanent wiling point (PWP), respectively. Through detailed soil analysis, soil texture was determined from soil samples, and then using pressure plate apparatus in the lab, the field capacity (FC) and permanent wilting point (PWP) were determined for the hub site soil, on a volumetric water content (VWC) percentage basis.

Chapter 2 discusses how using a crop specific MAD soil moisture level at each site is more accurate than using half the AW as a trigger for irrigation. Table 2.4 shows the ranges for MAD for the various crops in the project. From this table, the 50%MAD was chosen as a lower moisture value that was common to all four crops. Coincidently, this also coincides with the rule of thumb for triggering irrigation at half of the AW.

In this project, the trigger for irrigation was deemed be at 50% MAD, or half of the AW. This was a more conservative water management strategy, knowing that realistically the tomatoes, peppers and berries would be triggered before this critical value. It was made known to the grower that he/she ought to irrigate before his/her soil moisture content reached this soil moisture value corresponding to 50% MAD. In most cases, the grower irrigated well before this value, and unbeknownst to them, kept soil moisture in the upper MAD ranges identified for their crop in Table 2.4.

Therefore, the trigger-values for irrigation were determined using 50% MAD (or half of the AW), and the corresponding soil moisture contents at these thresholds was calculated. These calculated soil moisture triggers also agreed well with the value based on 65%-85% of the field capacity measured. During the growing season, the growers were shown the graphed sensor data with the soil moisture irrigation trigger threshold depicted as 65% -85% FC, because soil analysis had not been completed and MAD could not be inferred. Comparing the 65% - 85% FC trigger value to 50% MAD, and to half of the AW, all were judged to be accurate soil moisture thresholds for triggering irrigation (Tables 3.1 to 3.4).

For tension based sensors, 50%MAD has little meaning since soil matric potential measures the amount of tension under which the water is held to the soil particles and readings are given in kPa or in cbars. The soil matric potential triggers for irrigation are more or less uniform amongst different soil types (except for sand soils they are higher), and no knowledge of the available soil moisture amount is necessary. A trigger of -10 cbars was used in sand soils (or for drip irrigation systems), and -30 cbars in other soil types (and for overhead gun systems).

For the trend based sensors, WIN likes using trends because growers can easily understand them, and with some experience, they see (and remember) the picture. Maybe it is reasonable to say that most sensors are trending tools until they are calibrated for the precise point in the field where they are installed - which is not generally done - so WIN helps the growers understand the trends, set limits, etc. WIN also provides training to the growers on their probes and how to view the data.

Soil Sampling and Analysis

In order to determine the available water at each of the four hub site farms, as well as the 15 satellite sites, the soil physical characteristics were determined. Specifically, soil samples were taken from 4 benchmark (BM) locations in these fields. Soil samples were taken in triplicate at each BM location, and values were averaged. The samples were taken at the 0-5 cm depth at all of the site locations. In addition to this, soil samples were taken from the 20-25 cm depth at the hub sites, where the sensors (and root depth) were located. All of the sample cores were carefully packaged in cheese cloth, and placed in airtight, plastic, re-sealable bags, and kept cool in a cooler with ice while transported to the McGill University laboratory where they were stored in a fridge and analyzed promptly.

At each sampling location, three steel soil cores 2.5 cm high, and 5 cm in diameter were used to obtain bulk density samples. Once the bulk density was determined from these cores, the soil was removed from the core and used for particle size analysis, and for organic matter analysis (loss on ignition method).

A further set of triplicate soil core samples was obtained at each location used for determining the water holding capacity of the soil, and these cores were measured for water retention characteristics in the pressure plate apparatus at McGill University. It is important for irrigation scheduling to determine the field capacity and the permanent wiling point of each of the samples. Knowing this information, the water holding capacity of the soil can be calculated.

From the laboratory results, the pressure plates gave good readings for field capacities which corresponded well with literature values; however, for the permanent wilting points, the values appeared to err on the high side. Furthermore, the permanent wilting points were not determined for any of the benchmark sites, so a small sample size resulted. Therefore, the values were decided to be unreliable and were not used in this study. Instead, literature values of permanent wilting points (Table 2.3) were used along with the measured field capacities, to calculate the triggers for irrigation at each site. Literature values are valuable in as far as they represent an average typical soil classification; however the reality is that rarely does a given soil sample fit its “average” criteria. Soil water holding capacities are determined mainly by particle size composition, but are also very much influenced by organic matter and pore size distribution, so these values were taken with a grain of salt when applied to the sites.

The results of the soil analysis are presented below, by region (Tables 3.1 to 3.4). The hub sites have samples obtained at 0-5 cm as well as at 20-25 cm (this is the depth the triggers were determined for - where the majority of the roots are located). “BM” stands for benchmark sites. Some values are missing due to sample disturbance during transport, or insufficient soil remaining to carry out the analysis.

Leamington Soil Analysis Results

Table 3.1 Soil Characteristics for Leamington Hub and Satellite farms (all samples obtained from 0-5 cm unless indicated in red from 20-25 cm)

Site	Sample	average FC VWC %	average PWP VWC %	average bulk density g/cm3	average o.m. %	Irrigation trigger soil VWC % 50% MAD	65-85% FC	Soil classification % sand	% silt	% clay	soil class
Leamington Hub Surface	LH-M1	19.1	4.0	1.2	5.0	**12**	12 -16	90.4	5.5	4.1	sand
	LH-M1-25cm	13.4	4.0	1.6	1.7	**9**	9 -11	92.5	2.8	4.7	sand
	LH-M1-BM1	17.3	4.0	1.3	8.0	**11**	11 -15	98.9	0.5	0.6	sand
	LH-M1-BM2	16.7	4.0	1.3	5.6	**10**	11 -14	90.9	6.0	3.1	sand
	LH-M1-BM3	21.5	4.0	1.2	6.4	**13**	14 -18	88.2	7.5	4.3	sand
	LH-M1-BM4	16.4	4.0	1.3	4.8	**10**	11 -14	88.2	7.8	4.0	sand
Leamington Hub Buried											
	LH-M2	16.6	4.0	1.3	4.9	**10**	11 -14	90.4	5.9	3.7	sand
	LH-M2-25cm	11.2	4.0	1.4	1.6	**8**	7 -10	91.4	5.0	3.6	sand
	LH-M2-BM1	25.6	4.0	1.6	7.5	**15**	17 -22	92.9	5.2	1.9	sand
	LH-M2-BM2	17.7	4.0	1.2	6.0	**11**	12 -15	95.8	2.9	1.3	sand
	LH-M2-BM3	18.6	4.0	1.2	4.8	**11**	12 -16	89.9	6.8	3.3	sand
	LH-M2-BM4	19.7	4.0	1.3	5.6	**12**	13 -17	89.7	6.2	4.2	sand
Satellite 1	L-S1-BM1	9.4	7.0	1.5	2.4	**8**	6 -8	81.3	12.5	6.2	loamy sand
	L-S1-BM2	21.8	9.0	1.4	3.8	**15**	14 -19	70.9	19.1	10.0	sandy loam
	L-S1-BM3	11.9	7.0	1.6	2.1	**9**	8 -10	84.6	11.4	4.0	loamy sand
	L-S1-BM4	19.9	9.0	1.5	3.5	**14**	13 -17	72.5	18.8	8.7	sandy loam
Satellite 2	L-S2-BM1	16.0	7.0	1.5	3.1	**11**	10 -14	83.9	10.7	5.4	loamy sand
	L-S2-BM2	13.3	4.0	1.3	2.8	**9**	9 -11	90.9	5.9	3.2	sand
	L-S2-BM3	14.8	4.0	1.4	3.3	**9**	10 -13	89.3	6.2	4.5	sand
	L-S2-BM4	14.5	4.0	1.4	3.4	**9**	9 -12	90.2	5.9	3.9	sand
Satellite 3	L-S3-BM1	15.9	4.0	1.4	3.2	**10**	10 -14	87.7	8.1	4.2	sand
	L-S3-BM2	21.2	7.0	1.3	4.0	**14**	14 -18	81.6	12.7	5.7	loamy sand
	L-S3-BM3	9.9	4.0	1.5	2.1	**7**	6 -8	92.8	3.6	3.5	sand
	L-S3-BM4	19.2	9.0	1.6	3.7	**14**	12 -16	67.5	19.2	13.2	sandy loam
Satellite 4	LS4-BM1	13.4	4.0	1.5	3.3	**9**	9 -11	89.3	6.9	3.8	sand
	LS4-BM2	11.2	4.0	1.4	2.1	**8**	7 -10	88.6	9.7	1.7	sand
	L-S4-BM3	10.7	7.0	1.5	3.0	**9**	7 -9	82.7	15.2	2.1	loamy sand
	L-S4-BM4	10.2		1.5	2.5		7 -9				

Dresden Soil Analysis Results

Table 3.2 Soil Characteristics for Dresden Hub and Satellite farms (all samples obtained from 0-5 cm unless indicated in red from 20-25 cm)

Site	Sample	average FC VWC %	literature PWP VWC %	average bulk density g/cm3	average o.m. %	Irrigation trigger soil VWC % 50% MAD	Irrigation trigger soil VWC % 65-85% FC	Soil classification % sand	% silt	% clay	soil class
Dresden Hub site	DH	11.6	5.0	1.5		**8**	8 -10				
	DH-25cm	12.6	5.0	1.5	2.9	**9**	8 -11	86.9	8.7	4.4	loamy sand/sand
	DH-BM1	16.0	7.0	1.4	2.5	**11**	10 -14	82.9	11.7	5.5	loamy sand
	DH-BM2	12.3	7.0	1.4	2.4	**10**	8 -10	86.3	9.2	4.5	loamy sand
	DH BM3	22.0	9.0	1.3	4.6	**15**	14 -19	67.5	21.1	11.4	sandy loam
	DH BM4	12.2	7.0	1.4	2.8	**10**	8 -10	85.7	10.9	3.4	loamy sand
Satellite 1	D-S1-BM1	13.3	4.0	1.4	3.8	**9**	9 -11	93.0	3.7	3.2	sand
	D-S1-BM2	15.0	7.0	1.4	3.7	**11**	10 -13	83.8	9.0	7.2	loamy sand
	D-S1-BM3	16.5	7.0	1.5	4.6	**12**	11 -14	83.0	10.0	7.0	loamy sand
	D-S1-BM4	15.8	4.0	1.4	3.9	**10**	10 -13	90.2	5.3	4.5	sand
Satellite 2	D-S2-BM1	20.9		1.4	2.9		14 -18			19.2	
	D-S2-BM2	19.8		1.4	2.7		13 -17			18.1	
	D-S2-BM3	23.3		1.4	3.0		15 -20			18.9	
	D-S2-BM4	21.4	12.0	1.4	2.6	**17**	14 -18			22.7	loam
Satellite 3	D-S3-BM1	29.9	9.0	1.0	9.2	**19**	19 -25	63.2	24.1	12.7	sandy loam
	D-S3-BM2	24.9	9.0	1.2	8.1	**17**	16 -21	64.7	23.3	12.0	sandy loam
	D-S3-BM3	24.7	9.0	1.3	7.3	**17**	16 -21	71.8	18.4	9.9	sandy loam
	D-S3-BM4	28.1	9.0	1.3	8.6	**19**	18 -24	61.0	23.5	15.5	sandy loam

Niagara-on-the-Lake Soil Analysis Results

Table 3.3 Soil Characteristics for Niagara-on-the-Lake Hub and Satellite farms (all samples obtained from 0-5 cm unless indicated in red from 20-25 cm)

Site	Sample	average FC VWC %	average PWP VWC %	average bulk density g/cm3	average o.m. %	Irrigation trigger soil VWC % 50% MAD	65-85% FC	Soil classification % sand	% silt	% clay	soil class
Niagara Main Equip											
	NH	14.7	7.0	1.4	3.5	**11**	10 -12	80.3	13.9	5.8	loamy sand
	NH-ME-25cm	15.4	7.0	1.4	2.8	**11**	10 -13	85.0	11.3	3.7	loamy sand
	NH-BM1	17.0	7.0	1.3	3.8	**12**	11 -14	78.1	16.3	5.6	loamy sand
	NH-BM2	21.0	9.0	1.5	4.0	**15**	14 -18	63.1	21.9	15.0	sandy loam
	NH-BM3	14.7	7.0	1.3	3.2	**11**	10 -13	83.1	11.9	5.0	loamy sand
	NH-BM4	14.2	9.0	1.3	3.5	**12**	9 -12	76.2	17.0	6.8	sandy loam
Satellite 1	N-S1-BM1	17.5	9.0	1.3	3.7	**13**	11 -15	71.4	24.4	4.2	sandy loam
	N-S1-BM2	14.1		1.3	3.4		9 -12				
	N-S1-BM3	15.5	7.0	1.2	3.7	**11**	10 -13	78.7	15.2	6.1	loamy sand
	N-S1-BM4	19.3	7.0	1.2	4.0	**13**	13 -16	78.3	15.4	6.3	loamy sand
Satellite 2	N-S2-BM1	25.4	9.0	1.2	4.7	**17**	17 -22	63.6	25.2	11.2	sandy loam
	N-S2-BM2	21.9		1.3	4.6		14 -19				
	N-S2-BM3	20.8	9.0	1.7	5.0	**15**	14 -18	59.0	25.5	15.5	sandy loam
	N-S2-BM4	18.7	9.0	1.3	4.4	**14**	12 -16	59.6	26.3	14.1	sandy loam
Satellite 3	N-S3-BM1	24.6	7.0	1.2	4.3	**16**	16 -21	79.7	15.7	4.7	loamy sand
	N-S3-BM2	18.2		1.2	4.5		12 -16				
	N-S3-BM3	19.0	5.0	1.2	5.1	**12**	12 -16	76.9	16.5	6.6	loamy sand/sand
	N-S3-BM4	17.5	9.0	1.3	4.3	**13**	11 -15	75.4	18.2	6.4	sandy loam
Satellite 4	N-S4-BM1	16.5	9.0	1.3	2.5	**13**	11 -14	70.1	21.1	8.7	sandy loam
	N-S4-BM2	19.8	9.0	1.4	3.7	**14**	13 -17	74.1	18.2	7.8	sandy loam
	N-S4-BM3	16.5	7.0	1.3	3.4	**12**	11 -14	77.2	17.2	5.6	loamy sand
	N-S4-BM4	16.7	9.0	1.2	3.3	**13**	11 -14	73.1	19.6	7.4	sandy loam

Simcoe Soil Analysis Results

Table 3.4 Soil Characteristics for Simcoe Hub and Satellite farms (all samples obtained from 0-5 cm unless indicated in red from 20-25 cm)

Site	Sample	average FC VWC %	average PWP VWC %	average bulk density g/cm3	average o.m. %	Irrigation trigger soil VWC % 50% MAD	Irrigation trigger soil VWC % 65-85% FC	Soil classification % sand	Soil classification % silt	Soil classification % clay	Soil classification soil class
Simcoe Hub Tunnel	S-H1-ME	15.3	7.0	1.5	2.3	**11**	10 -13	80.5	15.6	3.9	loamy sand
	S-H1-ME-25cm	18.3	9.0	1.8	2.0	**14**	12 -16	57.4	24.8	17.9	sandy loam
	S-H1-BM1	11.2	7.0	1.4	2.2	**9**	7 -9	81.5	10.1	8.4	loamy sand
	S-H1-BM2	17.2	9.0	1.3	3.1	**13**	11 -15	66.3	32.1	1.7	sandy loam
	S-H1-BM3	18.1	9.0	1.4	3.0	**14**	12 -15	65.4	25.7	8.8	sandy loam
	S-H1-BM4	11.2	7.0	1.4	1.9	**9**	7 -10	76.7	19.8	3.4	loamy sand
Simcoe											
Hub Outside	S-H2-ME	12.0	9.0	1.4	2.6	**11**	8 -10	57.2	39.6	3.2	sandy loam
	S-H2-ME-25cm	18.9	9.0	1.5	1.4	**14**	12 -16	69.6	14.7	15.7	sandy loam
	S-H2-BM1	14.7	7.0	1.4	2.3	**11**	10 -12	80.2	13.1	6.7	loamy sand
	S-H2-BM2	21.5	9.0	1.4	3.3	**15**	14 -18	67.0	23.8	9.2	sandy loam
	SH2-BM3	16.4	9.0	1.2	2.3	**13**	11 -14	66.7	30.6	2.7	sandy loam
	SH2-BM4	15.6	9.0	1.5	3.0	**12**	10 -13	73.0	18.9	8.1	sandy loam
Satellite 2	S-S2-BM1	16.7	9.0	1.6	3.0	**13**	11 -14	67.6	22.2	10.2	sandy loam
	S-S2-BM2	14.3	9.0	1.5	2.7	**12**	9 -12	74.6	19.4	6.1	sandy loam
	S-S2-BM3	14.5	9.0	1.7	2.5	**12**	9 -12	73.9	17.1	9.0	sandy loam
	S-S2-BM4	18.6	7.0	1.4	3.2	**13**	12 -16	88.8	2.3	8.9	loamy sand
Satellite 3	S-S3-BM1	22.7		1.5	3.5		15 -19			11.2	
	S-S3-BM2	22.6		1.4	2.9		15 -19			11.8	
	S-S3-BM3	23.1	12.0	1.3	3.4	**18**	15 -20	47.1	44.4	8.5	loam
	S-S3-BM4	14.0	9.0	1.4	2.8	**11**	9 -12	83.1	11.1	5.8	loamy sand
Satellite 5	S-S5-BM1	9.5	4.0	1.4	3.1	**7**	6 -8	89.2	6.5	4.3	sand
	S-S5-BM2	11.4	4.0	1.5	2.9	**8**	7 -10	91.3	6.5	2.2	sand
	S-S5-BM3	11.2	7.0	1.4	2.2	**9**	7 -10	85.1	10.8	4.2	loamy sand
	S-S5-BM4	9.6	7.0	1.5	1.6	**8**	6 -8	85.2	9.6	5.2	loamy sand

Crop Planting Dates and Kc Values

The crop coefficients (Kc) values for peaches, tomatoes and peppers were calculated by using actual crop physiology information obtained from the growers, any missing information was taken from data in the Best Management Guide for Irrigation Scheduling, by OMAFRA (2004). The raspberry and strawberry values were obtained from data taken from Van der Gulik (2001). These values were used for calculating crop water requirements which were used to calculate the water balance. For more detailed information on this and the Kc calculations see Chapter 5.

Table 3.5 Summary of Kc Values and Crop Physiology Dates

Peaches

Month	Crop Coefficient (Kc)
April	0.2
May	0.3
June (1-15)	0.4
June (16-30)	0.6
July	1
August	1
September	0.95

Growing Season	Date (John Fedorkow)
Start	May 01
End	August 12

Peppers

Growing Season	Crop Coefficient (Kc)
Seeding - 1st flower	0.4
1st flower - fruit sizing	0.7
Remainder of crop	1

Growing Season	Date (Peter Jennen)
Transplanting - 1st flower	May 21 to May 31
1st flower - fruit sizing	July 1 to July 19
Remainder of crop	July 20 to October 23

Tomatoes

Growing Season	Crop Coefficient (Kc)
Seeding - 1st flower	0.4
1st flower - max. row fill	0.7
Remainder of crop	1

Growing Season	Date (Wayne Palichuk)
Transplanting - 1st flower	May 23 to July 14
1st flower - max. row fill	July 15 to July 31
Remainder of crop	August 1 to September 16

Strawberries

Kc Stage	Crop Coefficient (Kc)
Kc ini	0.4
Kc mid	1.05
Kc end	0.7

Growing Season	Date (John Cooper)
Kc ini	April 10 to May 14
Kc mid	May 15 to September 30
Kc end	October 1 to October 31

Raspberries

Kc Stage	Crop Coefficient (Kc)
Kc ini	0.4
Kc mid	1.2
Kc end	0.75

Growing Season	Date (John Cooper)
Kc ini	May 15 to June 19
Kc mid	June 20 to July 9
Kc end	July 10 to October 21

Irrigation Systems

Through the administration of two surveys to the growers, significant amounts of information on irrigation practices and on-farm crop water requirements were obtained. The first survey (Appendix B) set out to gauge growers' current irrigation systems, their sources of water, irrigation water use, and how they determined when to apply irrigation water. This first survey was administered to all participating growers during the months of July and August. The detailed irrigation record information for each site can be found in Appendix D. A thorough discussion of irrigation water use is considered in Chapter 5. This section outlines some of the main irrigation practices at each of the farms, and describes the irrigation systems used.

Table 3.6 Summary of Irrigation Water Applied in 2007

#	Location	Crop Type	Irrigation System	Information	Area (ha)	Time (hrs)	IRR (mm)	Volume (m^3)
1	Leamington	Tomato	Surface Drip	Flow Meter	1.21	144.8	191.4	2323.8
		Tomato	Subsurface Drip	Flow Meter	1.21	144.8	191.4	2323.8
		Tomato	Surface Drip	Irrigation	1.21	176.5	198.7	2412.4
		Tomato	Subsurface Drip	Irrigation	1.21	176.5	198.7	2412.4
2		Tomato	Surface Drip (1st Zone)	Irrigation	8.09	66.0	32.3	2614.3
		Tomato	Surface Drip (2nd Zone)	Irrigation	9.71	114.0	51.8	5031.2
3		Tomato	Surface Drip	Irrigation	5.26	140.0	164.0	8628.1
4		Tomato	Subsurface Drip	Irrigation	3.24	133.5	184.3	5966.8
5	Dresden	Pepper	Subsurface Drip	Flow Meter	7.69	42.0	28.1	2160.7
6		Pepper	Subsurface Drip	Irrigation	0.40	98.0	629.5	2547.5
7		Pepper	Boom	Irrigation	4.05	56.0	88.2	3569.4
8	Simcoe	Strawberry	Surface Drip (Outside)	Irrigation	0.88	121.5	710.7	6183.8
		Strawberry	Surface Drip (Tunnel)	Irrigation	0.87	121.5	699.0	6082.0
		Strawberry	Surface Drip (Tunnel)	Flow Meter	0.87	112.4	616.9	5442.7
		Raspberry	Surface Drip (Tunnel)	Irrigation	1.54	155.5	217.7	3347.9
9		Strawberry	Solid Set Sprinkler	Irrigation	1.78	13.5	62.7	1116.5
10		Strawberry	Solid Set Sprinkler	Irrigation	1.21	22.3	167.7	2036.0
11	NOTL	Peach	Overhead Gun	Irrigation	2.43	25.5	114.3	2775.4
12		Peach	Sprinkler PTO Pump	Irrigation	1.01	15.0	54.0	546.3
13		Peach	Solid Set Sprinkler	Irrigation	1.21	4.0	101.6	1233.5
14		Peach	Overhead Gun PTO	Irrigation	0.40	1.3	50.8	205.6
15		Peach	Overhead Gun	Irrigation	4.05	126.0	212.1	8583.6

* Multiply values in m^3 by 264.2 to convert to USG

Table 3.6 illustrates the variability in the amounts of irrigation water applied even within the same crop (IRR (mm) column). Some crops, such as the peppers had relatively less variation in total water application than the peaches, for example. The peach growers had the largest amount of difference in terms of total water applied, possibly because they do not irrigate frequently and use an overhead gun.

In general, these differences in irrigation amounts applied to the same crop, demonstrate the variability in grower management practices as well as irrigation efficiency of application. Furthermore, it reveals the huge discrepancies in irrigation application as related to demands or requirements for their crops, showing that there is currently indeed a fair amount of guess work involved. However, some variation is expected due to climate differences between sites (e.g. from discussions with growers and anecdotal information, pepper grower 5 received more precipitation in 2007 than his contemporaries (growers 6 and 7); hence he did not need to apply as much water as they did). Nevertheless, sensors can reduce the amount of guess-work involved in irrigation applications.

Table 3.7 Irrigated Acreage on Project Sites (information as provided by the growers)

#	Site	Crop Type	No. Rows	Area (ha)	Plant Spacing		Row		Total No. Plants	First/Last Day	
					Length	Width	Width	Length		Initial Planting	Harvesting
1	Leamington	Tomato	30	1.21	0.41	0.41	1.52	335.3	24750	May 23	Sept. 20
			30	1.21	0.41	0.41	1.52	335.3	24750	May 23	Sept. 20
2			124	8.09	0.41	0.41	1.52	365.8	111600	May 15	End Aug.
			136	9.71	0.41	0.41	1.52	396.2	132600	June 14	End Sept.
3			121	5.26	0.41	0.51	1.63	265.5	79043	May 19	End Sept.
4			66	3.24	0.43	0.76	1.52	335.3	51247	May 25	Sept. 15
5	Dresden	Pepper	180	7.69	0.43	0.51	1.02	548.6	228706	May 21	Oct. 23
6		Pepper (Plastic Bed)	13	0.40	0.41	0.30	1.52	243.8	7800	May 29	End July
7		Pepper	52	4.05	0.41	0.84	0.84	975.4	124800	May 29	Sept.
8	Simcoe	Strawberry (Tunnel)	80	0.87	0.30	0.25	1.83	213.4	56000	April 10	Oct. 31
		Strawberry	80	0.88	0.30	0.25	1.83	213.4	56000	April 10	Oct. 31
		Raspberry	52	1.54	2.13	0.46	1.83	137.2	3343	May 15	Oct. 21
9		Strawberry	78	1.78	0.46	1.22	1.22	219.5	37440	May 28	July 20
10		Strawberry	70	1.21	0.41	1.17	1.17	167.6	28875	May 1	June
11	NOTL	Peach	27	2.43	5.49	3.05	3.05	152.4	750	May 1	Aug.12
12			80	1.01	3.05	5.79	5.79	170.7	4480	April	Mid Sept.
13			9	1.21	3.66	6.10	6.10	201.2	495	April	July 18
14			4	0.40	3.05	5.49	5.49	121.9	160	April	Mid Sept.
15			17	4.05	4.88	2.13	2.13	243.8	850	April	Mid Sept.

Table 3.8 Irrigation Systems on Project Sites (information as provided by the growers)

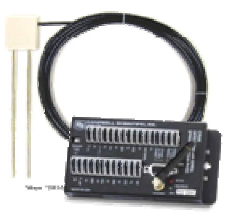
#	Site	System	No. Emitters		Depth	Brand	Nozzle		Spacing	Pressure	EFR	NFR	SFR
			Row	Total	(cm)		No.	Size (cm)	(m)	(psi)	(L/hr)	(L/hr)	(L/hr)
1	Leamington	Surface Drip	1100	33000	NA	Rolldrip	NA	NA	0.30	15	0.41	NA	13 626
		Subsurface Drip	1100	33000	20.32	Rolldrip	NA	NA	0.30	15	0.41	NA	13 626
2		Surface Drip	1200	148800	NA	Aquatrack	NA	NA	0.30	13	0.31	NA	45 420
		Surface Drip	1300	176800	NA	Netafim	NA	NA	0.30	13	0.26	NA	45 420
3		Surface Drip	871	105391	NA	Netafim	NA	NA	0.30	13	0.58	NA	61 317
4		Subsurface Drip	1100	72600	20.32	Netafim	NA	NA	0.30	11	0.64	NA	46 714
5	Dresden	Subsurface Drip	1200	216000	2.54	Netafim	NA	NA	0.46	13	0.61	NA	130 810
6		Subsurface Drip	2400	31200	7.62	QueenGill	NA	NA	0.10	20	0.83	NA	25 980
7		Boom	NA	NA	NA	NA	Unknown	Unknown	NA	30	NA	2 193	63 588
8	Simcoe	Surface Drip	700	56000	NA	Netafim	NA	NA	0.30	10	0.91	NA	50 870
		Surface Drip	700	56000	NA	Netafim	NA	NA	0.30	10	0.91	NA	50 870
		Surface Drip	450	23400	NA	Netafim	NA	NA	0.30	10	0.91	NA	21 257
9		Solid Set Sprinkler	NA	NA	NA	NA	Unknown	0.56	NA	100	NA	Unknown	82 437
10		Solid Set Sprinkler	NA	NA	NA	NA	30	Unknown	27.43	65	NA	4164	90 840
11	NOTL	Overhead Gun	NA	NA	NA	NA	1	2.79	NA	115	NA	70 174	70 174
12		Sprinkler PTO Pump	NA	NA	NA	NA	44	Unknown	NA	50-70	NA	818	35 973
13		Solid Set Sprinkler	NA	NA	NA	NA	20	3.81	54.86	110	NA	15 420	308 402
14		Sprinkler PTO Pump	NA	NA	NA	NA	1	Unknown	NA	Unknown	NA	68 130	68 130
15		Overhead Gun	NA	NA	NA	NA	1	Unknown	NA	Unknown	NA	68 130	68 130

* Multiply values in L/hr by 0.004 to convert to USGPM
NA = Not Applicable
EFR = Emitter Flow Rate [L/hr]
NFR = Nozzle Flow Rate [L/hr]
SFR = Irrigation System Flow Rate [L/hr]

CHAPTER 4. Soil Moisture Monitoring Sensors

At each hub site, six soil moisture sensors were installed for the duration of the growing season and one portable sensor was used (Table 4.1). The Hortimeter was an additional piece of equipment that was installed only at the Leamington hub. All sensors are commercially available. Growers were consulted on the best location of equipment on their farms, their field management and irrigation practices, and the location of benchmarks for soil moisture comparison. Data from the sensors was collected from May to October. At the end of the project, growers were surveyed on how useful they found the sensors to be.

Table 4.1 Permanent and Portable Soil Moisture Sensors Tested

Manual Tensiometer	Electrical Resistant Blocks	Time Domain Reflectometer
		
Water Content Reflectometer	Echo Probe	Capacitance Probe
		
Manual Portable TDR	Hortimeter (Leamington)	
		

Sensors Installed Permanently at Hub Sites

Leamington Hub Site

Background
Crop: Tomato
Planting Date: May 22, 2007
Irrigation: Drip Irrigation tape (last week of June)
Irrigation Water – clay lined pond

Soil Moisture Monitoring
This site provides an opportunity to compare buried drip tape and surface drip tape production systems on processing tomatoes.

Table 4.2 Sensors Installed in the Buried Drip Irrigation Site

Soil Moisture Sensor	Depth(s) installed cm	#Sensors	Data Logger	Comments
Capacitance	10, 30, 50	1 sensor, 3 depths	WIN ftp site	
Echo Probe	0-20 (avg. 10)	1	WIN ftp site	1 sensor, 20 cm reading length
WaterMark	15, 30, 45	3	Watchdog 400	3 separate sensors
WaterMark	15, 30	2	Watchdog 400	2 separate sensors
Hortimeter	6" and 12" (inches)	2	Networked directly to computer	2 sensors for buried drip zone
Gro-Point	15-20	1	Gro-Point Data logger	Horizontal
Tensiometers	20, 45	2	Manually read	2 depths
Campbell WCR	15, 30	2	TDR datalogger	2 sensors

Table 4.3 Sensors Installed in the Surface Drip Irrigation Site

Soil Moisture Sensor	Depth(s) installed cm	#Sensors	Data Logger	Comments
Capacitance	10, 30, 50	1	WIN ftp site	
Echo Probe	0-20 (avg. 10)	1	WIN ftp site	
Hortimeter	6" (inches)	1	Networked directly to computer	Only 1 for buried zone. Data is read from Wayne's computer
WaterMark	15, 30, 45	3	Watchdog 400	3 separate sensors
Gro-Point	15-20	1	Gro-Point Data logger	Horizontal
Tensiometers	20, 45	2	Manually read	2 depths
Campbell WCR	15, 30	2	TDR datalogger	2 sensors

Simcoe Hub Site

Background
Crop: Strawberries
Planting Date: Already planted, fall of 2006
Irrigation: Drip Irrigation

- Under tunnels (starts May 1- irrigates 1 hour every day)
- Outside tunnels (starts May 15-irrigates 1 hr every 5th day)

Irrigation Water – pond

Soil Moisture Monitoring

This site provides an opportunity to compare drip irrigation under two types of strawberry production (high tunnels vs. open field). Both systems have strawberries planted in raised beds. Each bed is 40 inches wide, 650 feet long and has 4 rows of strawberries planted.

Table 4.4 Sensors Installed in the Tunnel under Surface Drip Irrigation

Soil Moisture Sensor	Depth(s) installed cm	#Sensors	Data Logger	Comments
Capacitance	10, 20, 40	1 sensor, 3 depths	WIN ftp site	
Echo Probe	0-20 (avg. 10)	1	WIN ftp site	1 sensor, 20 cm reading length
WaterMark	15, 30, 45	3	Watchdog 400	3 separate sensors
Gro-Point	15-20	1	Gro-Point Data logger	Horizontal
Tensiometers	20, 45	2	Manually read	
Campbell WCR	15, 30	2	TDR datalogger	2 sensors

Table 4.5 Sensors Installed in the Open Field under Surface Drip Irrigation

Soil Moisture Sensor	Depth(s) installed cm	#Sensors	Data Logger	Comments
Capacitance	10, 20, 40	1 sensor, 3 depths	WIN ftp site	
Echo Probe	0-20 (avg. 10)	1	WIN ftp site	1 sensor, 20 cm reading length
WaterMark	15, 30, 45	3	Watchdog 400	3 separate sensors
Gro-Point	15-20	1	Gro-Point Data logger	Horizontal
Tensiometers	20, 45	2	Manually read	
Campbell WCR	15, 30	2	TDR datalogger	2 sensors

Niagara-on-the-Lake Hub Site

Background
Crop: Peaches
Tree age: 5 years
Irrigation: Stationary gun
Irrigation Water – pond

Soil Moisture Monitoring
This site provides an opportunity to monitor soil moisture under peach production using a stationary gun.

Table 4.6 Sensors Installed in the Peach Orchard Site

Soil Moisture Sensor	Depth(s) installed (cm)	#Sensors	Data Logger	Comments
Capacitance	15, 30, 50	1 sensor, 3 depths	WIN ftp site	
Echo Probe	0-20 (avg 10)	1	WIN ftp site	1 sensor, 20 cm reading length
WaterMark	15, 30, 45	3	Watchdog 400	3 separate sensors
Gro-Point	15-25	1	Gro-Point Data logger	Horizontal
Tensiometers	20, 50	2	Manually read	2 depths to span root zone
Campbell WCR	15, 30	2	TDR datalogger	2 sensors

Dresden Hub Site

Background
Crop: Peppers
Planting Date: May 24, 2007
Irrigation: Surface drip tape (in mid-July)
Irrigation Water – pond

Soil Moisture Monitoring
This site provides an opportunity to monitor soil moisture under pepper production using drip irrigation.

Table 4.7 Sensors Installed in the Pepper Site with Surface Drip Irrigation

Soil Moisture Sensor	Depth(s) installed cm	#Sensors	Data Logger	Comments
Capacitance	15, 30, 50	1 sensor, 3 depths	WIN ftp site	
Echo Probe	0-20 (avg. 10)	1	WIN ftp site	1 sensor, 20 cm reading length
WaterMark	15, 30, 45	3	Watchdog 400	3 separate sensors
Gro-Point	15-20	1	Gro-Point Data logger	Horizontal
Tensiometers	20, 45	2	Manually read	
Campbell WCR	15, 30	2	TDR datalogger	2 sensors

Sensors Placement at the Hub Sites

The sensors were installed at ¼ of the distance from drip emitters, in between crop rows for the peppers and tomatoes. In the strawberries, a hole was punched in the plastic mulch to insert the sensors also at a set distance from the emitter in the middle of the raised bed. In the peaches, the sensors were installed in the same row, between trees.

At the Dresden site, the drip tape was laid down later in the growing season (mid-July) whereas the sensor equipment was installed at the beginning of June. Therefore some of the sensors are not placed accurately with respect to the emitters (Figure 4.1).

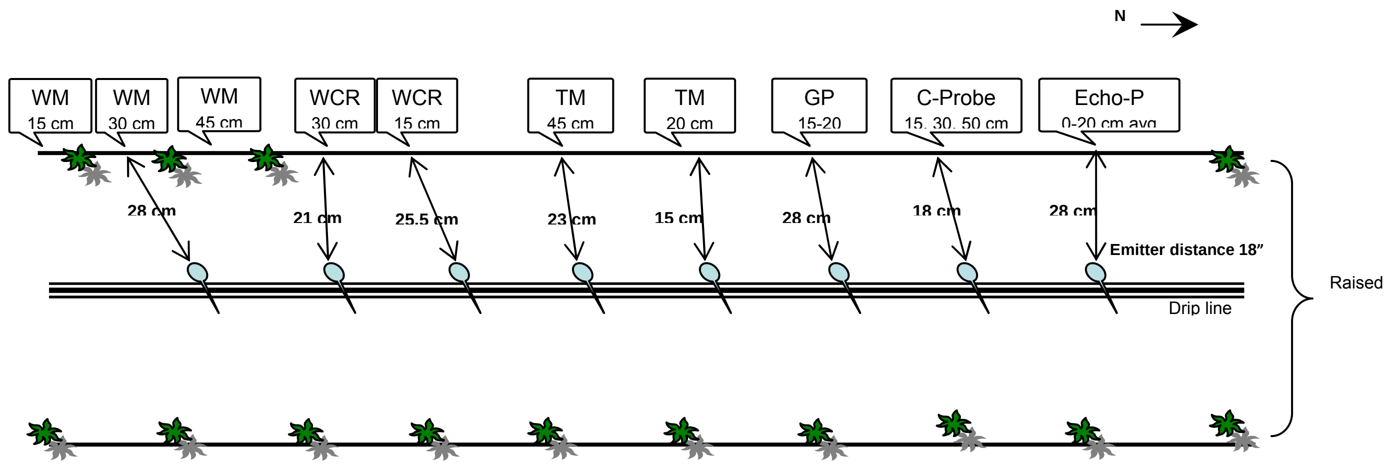
The buried drip tape in the tomato plots was also offset from the tomato rows. PFRA field notes indicate that the buried irrigation tape offset was 30 cm from the row with the sensors in it (and 10 cm from the west row with no sensors). Row spacing between the tomatoes was 40 cm. Unfortunately no sensor layout map was available from the tomato hub site because the sensors were removed before this could be completed.

Sensor placement is crucial for obtaining representative soil moisture readings. The sensors were installed at the depth of the average active root zone. This varies from crop to crop. It was chosen to install sensors at several depths, the shallower depths to gauge different growth stages of roots, and deeper depths to check for excessive moisture irrigation.

It is impossible to compare sensor readings for "accuracy", simply because the distance to the emitters varies and therefore each sensor will show a different water content reading based on proximity to the water source.

To determine how useful the soil moisture sensors were as a tool for irrigation, a second survey (Appendix C) was administered to all growers at the end of the project, in December. This second survey asked questions related to how practical they found the sensor information to be for their operations; which sensors they preferred; and also if they were willing to invest in the sensor technology in the future. The complete survey responses on the soil moisture sensor information can be found in Appendix E.

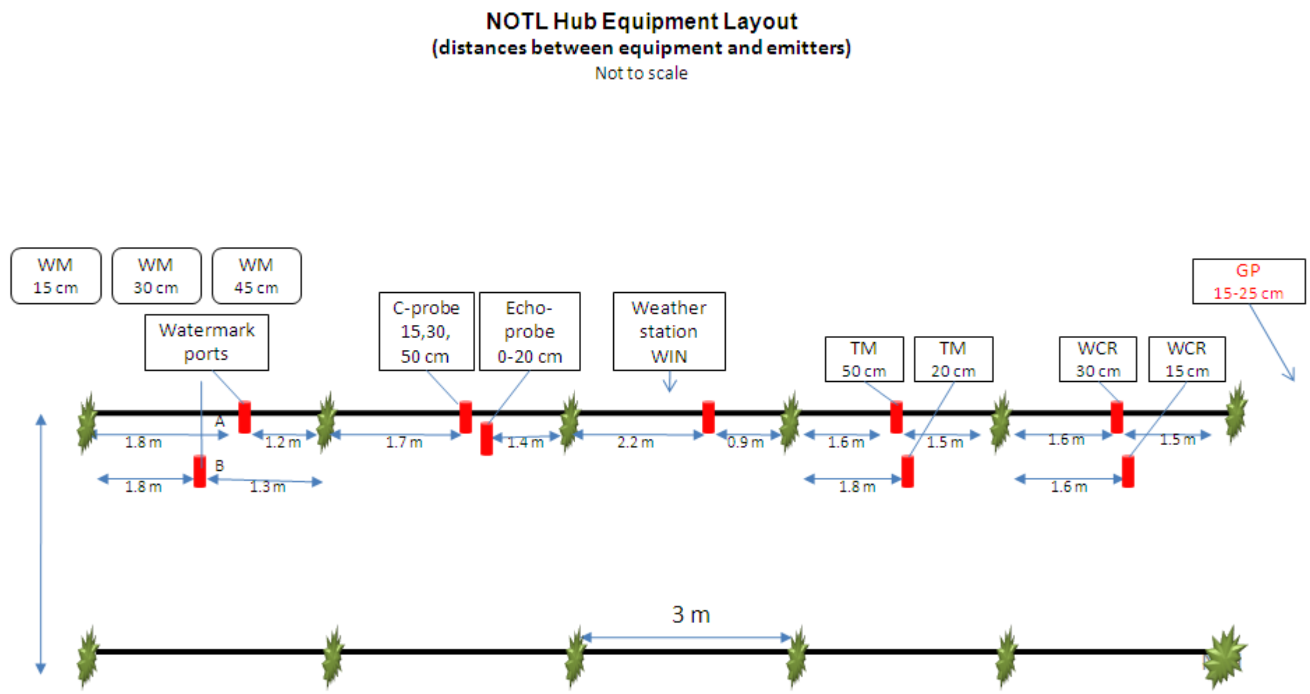
Dresden Hub Equipment Layout
(distances between equipment and emitters)
Not to scale



Legend:
WM: Watermark
WCR: Water Content Reflectometer
TM: Tensiometer
GP: Gro-Point
C-Probe: Capacitance probe
Echo-P: Echo probe

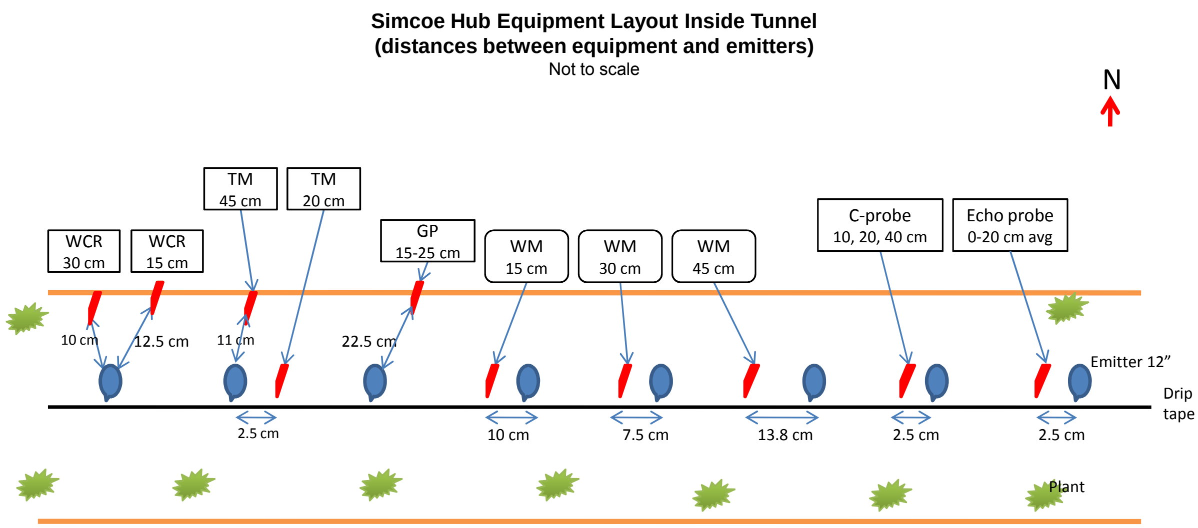
Notes: Distance between plants is 18"
The drip tape depth varies from 0 (surface) to 2/3 inches depth.
The 15 cm WCR sensor is located diagonally almost exactly below the emitter, at 2/3 inches depth.

Figure 4.1 Layout of Sensors at Dresden Hub Site



Legend:
WM: Watermark
WCR: Water Content Reflectometer
TM: Tensiometer
GP: Gro-Point
C-Probe: Capacitance probe
Echo-P: Echo probe

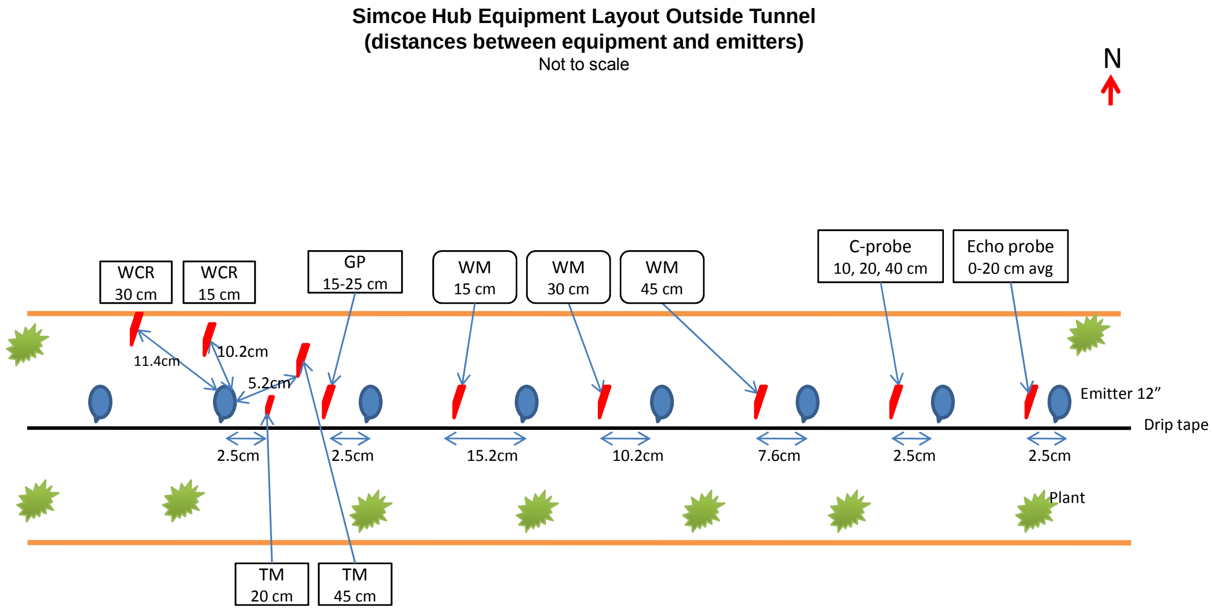
Figure 4.2 Layout of Sensors at the Niagara-on-the-Lake Hub Site



Legend:
TM: Tensiometer
GP: Gro-Point TDR
WM: Watermark
WCR: Water content reflectometer
C-Probe: Capacitance probe
Echo P: Echo probe

Notes: Plant spacing is 12" and emitter spacing is 12"

Figure 4.3 Layout of Sensors at Simcoe Hub Site, in the Open Field



Legend:
TM: Tensiometer
GP: Gro-Point TDR
WM: Watermark
WCR: Water content reflectometer
C-Probe: Capacitance probe
Echo P: Echo probe

Notes: Plant spacing is 12", emitter spacing is 12
WCR 15 cm was inserted at an angle below the emitter

Figure 4.4 Layout of Sensors at Simcoe Hub Site, Inside the Tunnel

Soil Moisture Readings from the Sensors

Finding the irrigation trigger in a given soil consists of determining the soil available water at each site. Through detailed soil analysis, soil texture was determined from auger samples, and using pressure plate apparatus in the lab, the field capacity (FC) and permanent wilting point (PWP) were determined for each of the hub sites. The soil moisture was determined by oven dry weight calculation. The available water is the amount of water the soil can hold between the FC and the PWP. At half of the soil available water (AW), or 50% MAD, or 65-85% of the FC, the soil should be irrigated to reduce stress to the crop.

The triggers for irrigation (red lines) on the sensors output graphs were calculated based on half of the soil AW (or 50% or MAD, also equivalent to 65-85% of the FC) as we found this to be an accurate low indicator for triggering irrigation for all crops. This trigger was based on soil sample analysis conducted at the 20-25 cm depths at all hub sites. Although not all sensor placement depths may correspond to the appropriate depth at which the trigger for irrigation was calculated (20-50 cm), most of the sensors covered this depth, and furthermore the root zone of most of the crops was located at this depth. It is difficult to say how the trigger would have been different at other depths.

The primary objective of the project was to examine efficient, practical and reliable tools for managing water application for growers. From the sensor outputs, it could be determined that all equipment was useful and performed well, overall. The sensors all showed similar trends in soil moisture, to varying degrees of correspondence with the soil auger samples tested for volumetric water content (VWC).

All the sensors proved useful. However, they ranged in terms of maintenance needs, data delivery methods and time and effort required to “see” the data. Therefore, before choosing a sensor or a monitoring system, the grower should consider the advantages and drawbacks of a sensor, a logger, and the information flow, according to how he/she can best use the information to make decisions for their operations. At all the hub sites, growers had a preferred sensor which they consulted, and it was not the same sensor at each site. The choices were based on preference for viewing the readings; ease of reading data in the field, or ease of viewing outputs on their computer.

Although the soil moisture monitoring equipment was deemed very useful by the growers, at some point, almost all sensor types broke down, malfunctioned or gave error readings. The level of support provided was important, as was the speed at which the equipment was able to be fixed and back up and running again. This is discussed in the next section. The following section highlights some of the key soil moisture sensor results found at each of the hub site, and relates this to how growers were managing their irrigation water applications.

Leamington Hub Site

The irrigation trigger is depicted as a red line on the graph, which represents the trigger for irrigation at 20-25 cm on sand soils (-10 cbars tension or 50% of MAD determined at 20-25 cm depth in VWC%). Soil moisture should not fall below this threshold; it is the level at which the grower should turn the irrigation system on. At the Leamington hub site, the grower applied irrigation water daily by buried tape (starting on June 14) and surface drip tape (starting on June 21). Thus, soil moisture was relatively constant except for the odd precipitation events, which were only truly significant in August (Figure 4.5).

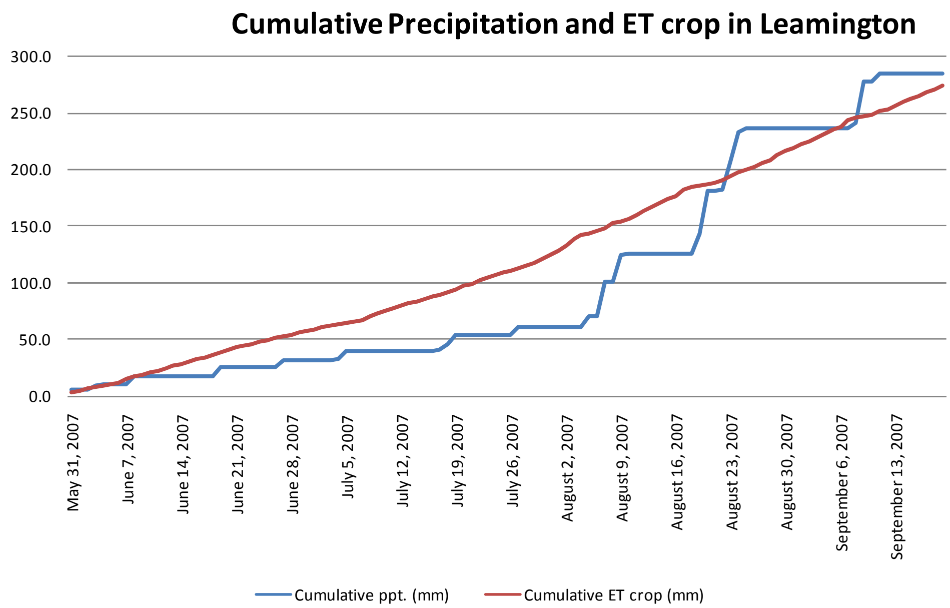
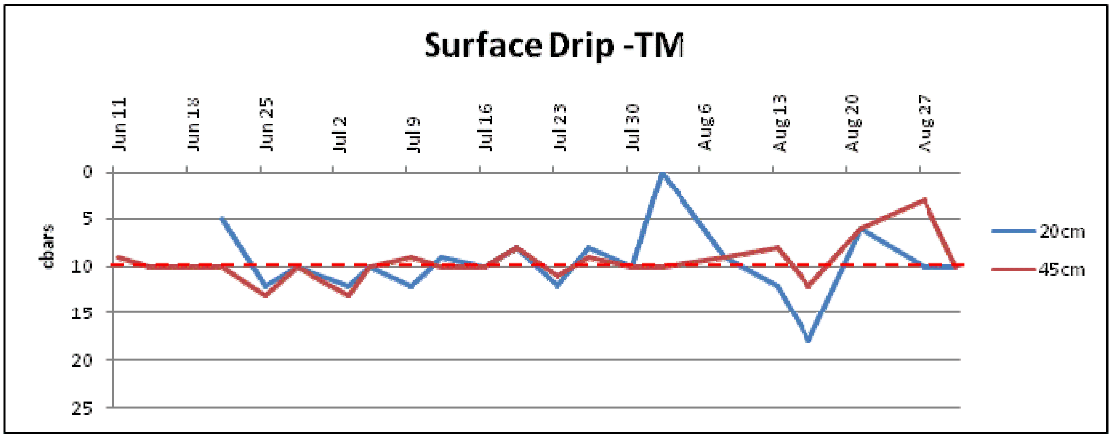


Figure 4.5 Cumulative precipitation and ETc at the Leamington hub site

From the tensiometer data, the surface drip tape at both 20 and 45 cm remained well wetted and hovered right around the irrigation threshold, which is desirable. Overall, no over- or under- irrigation was evident at this site. For the buried tape site, the 20 cm depth was drier than the 20 cm surface drip tape which was probably because the buried tape was lower than 20 cm. This can be confirmed by the 45 cm depth, where the soil moisture was at -5 cbars which is above the field capacity, so over irrigation was occurring throughout the growing season (Figure 4.6). Most tomato roots are located around 40-50 cm depth; therefore this is the depth at which maintaining the optimum soil moisture level is critical.



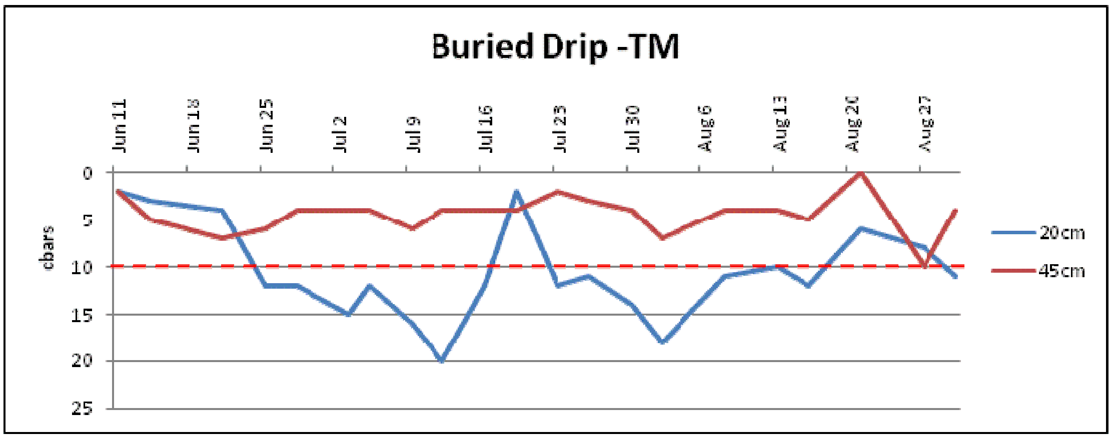
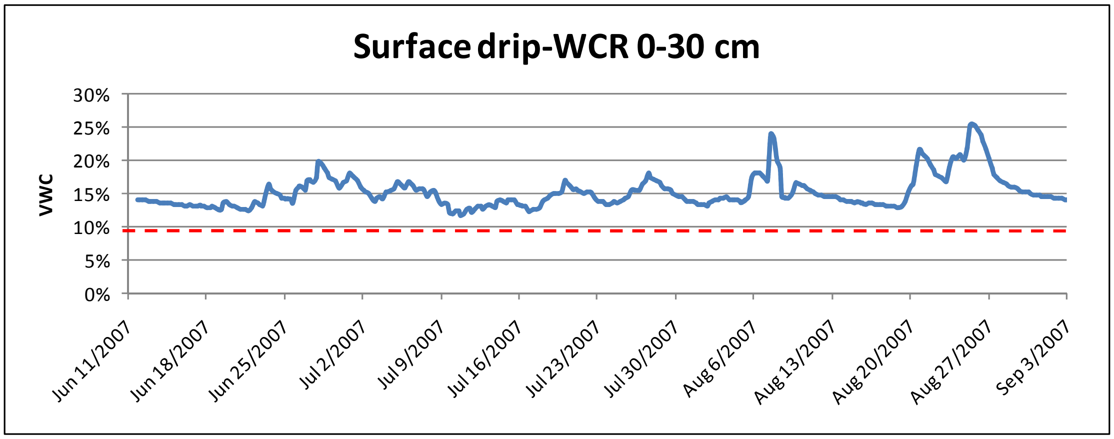


Figure 4.6 Tensiometer data at 20 cm and at 45 cm at the Leamington Hub site for the surface and buried drip tape sites. Trigger for irrigation is red dotted line (represents trigger at 20-25 cm depth)



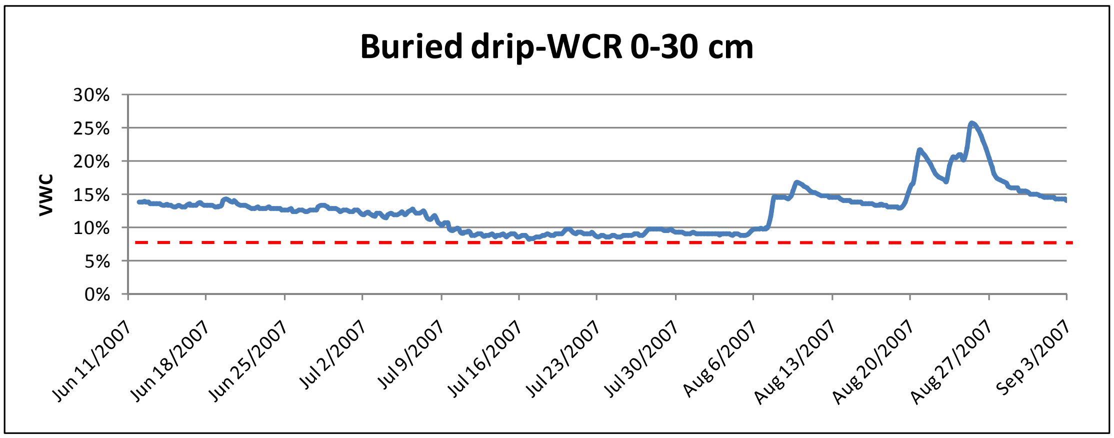


Figure 4.7 Water Content Reflectometer (WCR) data from 0-30 cm at the Leamington Hub Site for the surface and buried drip tape sites

The WCR sensor data shows continuous (15 minute increment) recordings of average soil moisture from 0-30 cm depth (Figure 4.7), which is not directly comparable to the manual tensiometer readings that were taken twice a week (Figure 4.6). From these more detailed graphs, the surface drip tape site shows greater soil moisture fluctuation than the buried site does because the surface installed tape is more exposed to the daily fluctuation in soil moisture through evaporation, precipitation and wind. The buried tape does not show fluctuations caused by the weather, except for diurnal cycles of soil drying and wetting in synch with the daily temperature.

At both sites, the soil moisture is being maintained above the critical threshold. At 0-30 cm, the surface drip tape site shows greater soil moisture than the buried tape, which is a factor of most of the soil moisture from the emitters in the buried tape being located below the 20 cm depth (this reflects that the top 30 cm is drier for the buried tape, and thus the average VWC is lower for buried than drip; and is reflected in the 20 cm tensiometer graph). From Figure 4.6, the 45 cm manual tensiometer is able to pick up this deeper moisture. It is difficult to quantify the amount of over irrigation occurring because different sensors are picking up different readings at different depths. However, trends can be inferred. The grower can attempt to save water in the future by keeping the surface drip applications at a more constant soil moisture. In particular, after precipitation events the grower can reduce irrigation, as there is very high soil moisture in August due to the rain events (Figure 3.1a).

The C-probe is able to show the deeper moisture from the buried tape site, as it has multi sensors installed at 10, 30 and 50 cm depths. The trend graphs from the C-probe graph also show less soil moisture fluctuation in the buried site. However in both sites, at the 10 cm depth, the line fluctuates as a result of inputs from precipitation and losses from evaporation. At the buried tape site, the 30 cm line reacts to irrigation events as the individual peaks are visible during the growing season, especially in July. The 50 cm line also reacts to precipitation events, indicating the soil profile drains well (sand soil) and is well wetted throughout (Figure 4.8).

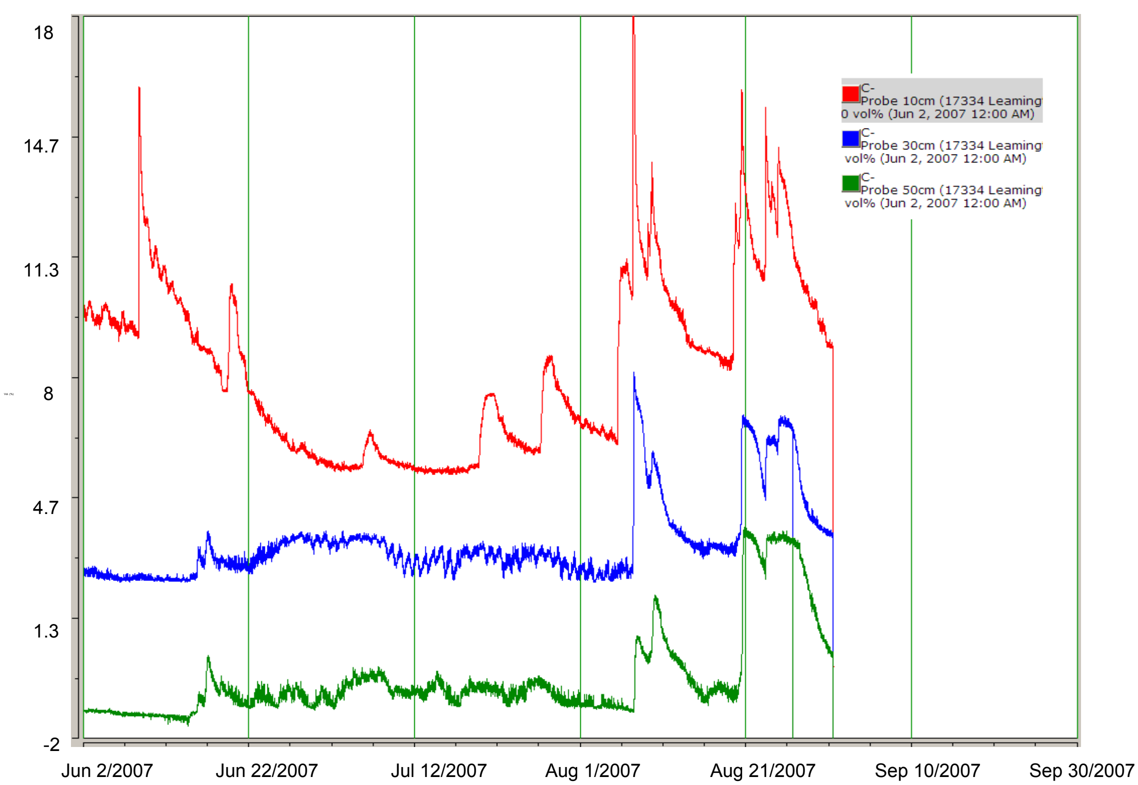


Figure 4.8 C-Probe trend readings at the Leamington hub Site, for surface drip tape site

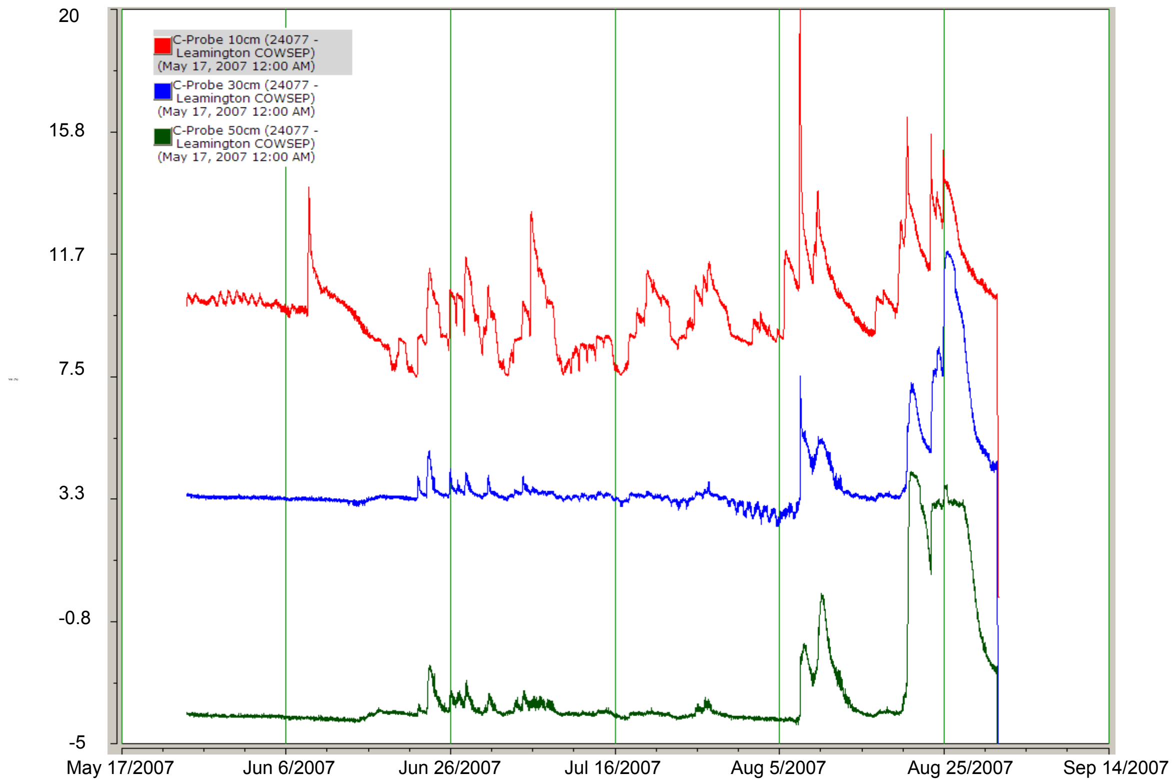
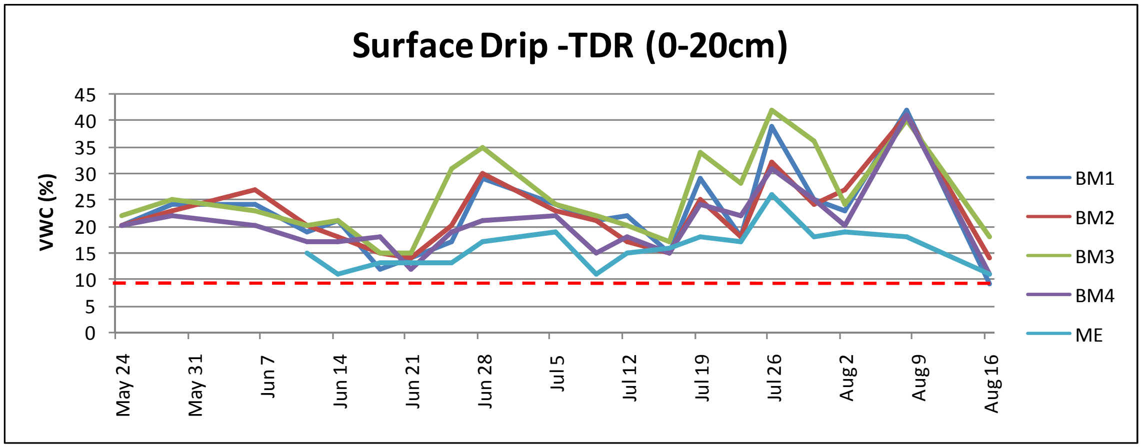


Figure 4.9 C-Probe trend readings at the Leamington hub Site, for buried drip tape site

The portable TDR was used to take measurements at the main equipment installation, and also on the four benchmarks around the main equipment site. The benchmark sites varied somewhat, but were not overly different from each other, mainly because the soil type was sand on all the benchmark sites, as well as at the main equipment site (Figure 4.9). Towards the end of July and in the month of August, the portable TDR was not giving realistic values; this can be due to a number of factors such as keeping the probes parallel during insertion, or general malfunctioning of the TDR. The operator error was minimized by the same person taking the readings in a consistent manner. The instrument was more likely the source of error as it malfunctioned at several other sites. The anomaly readings can be seen from peaks of 40% VWC which was not measured by any other sensor, followed by a drop in VWC reading values. At the Dresden hub site the same portable TDR was used and similar trends were recorded



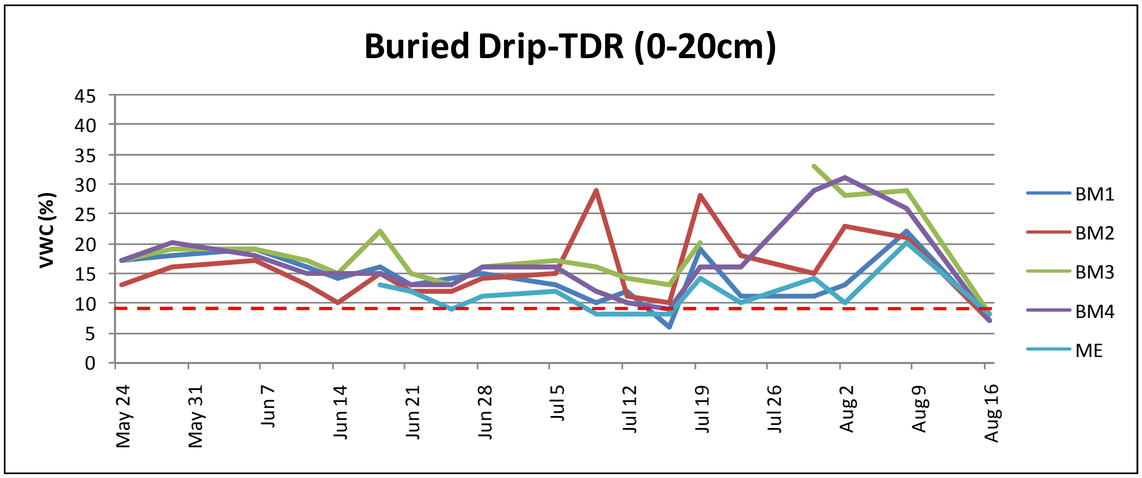
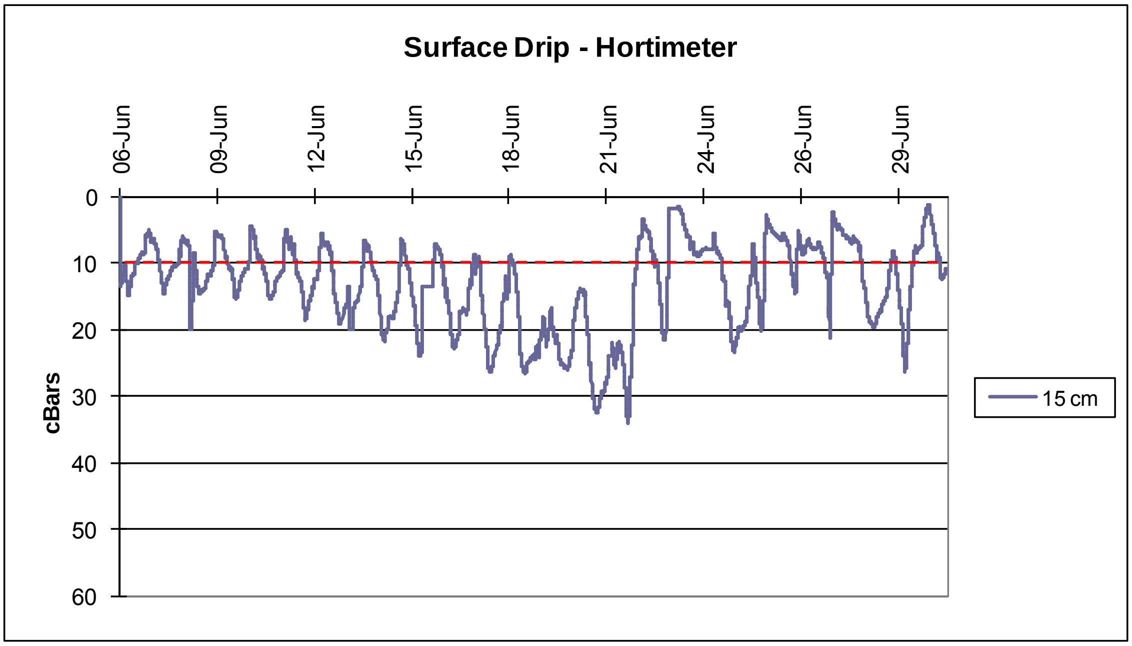


Figure 4.10 Portable TDR data (average from 0-20 cm) for the Leamington Hub Site at the main equipment (ME) and benchmark sites (BM)

The tension based sensors also performed well on this site. When irrigation started in the surface tape site on June 21, this was picked up by both the Hortimeter and the Watermarks (Figure 4.10). The buried tape site shows constant soil moisture at 30 cm, but the 15 cm is drying out constantly for the month of June, and only gets rewetted once a rainfall event of 4.4 mm occurs in July. Both the Hortimeter and the Watermarks at 30 cm depth showed higher water content for the above ground drip tape site, which may indicate the tape is below 30 cm depth. The water content at 15 cm depth was maintained right around the irrigation threshold with the surface drip tape (Figure 4.11 and 4.12).

From Figure 4.11, the diurnal effects of temperature and ET are clearly distinguishable at 15 cm depth in both the buried and the surface sites. As temperature rises during the day, there is more ET loss through the soil by capillary rise to the surface. At 30 cm, in the buried tape, the moisture content is high and remains so due to depth of drip tape (average placement of 20 cm below surface) wetting the soil at this depth, as well as the lack of capillary rise due to the sand soil which has large pore spaces preventing the natural upward flux of water.



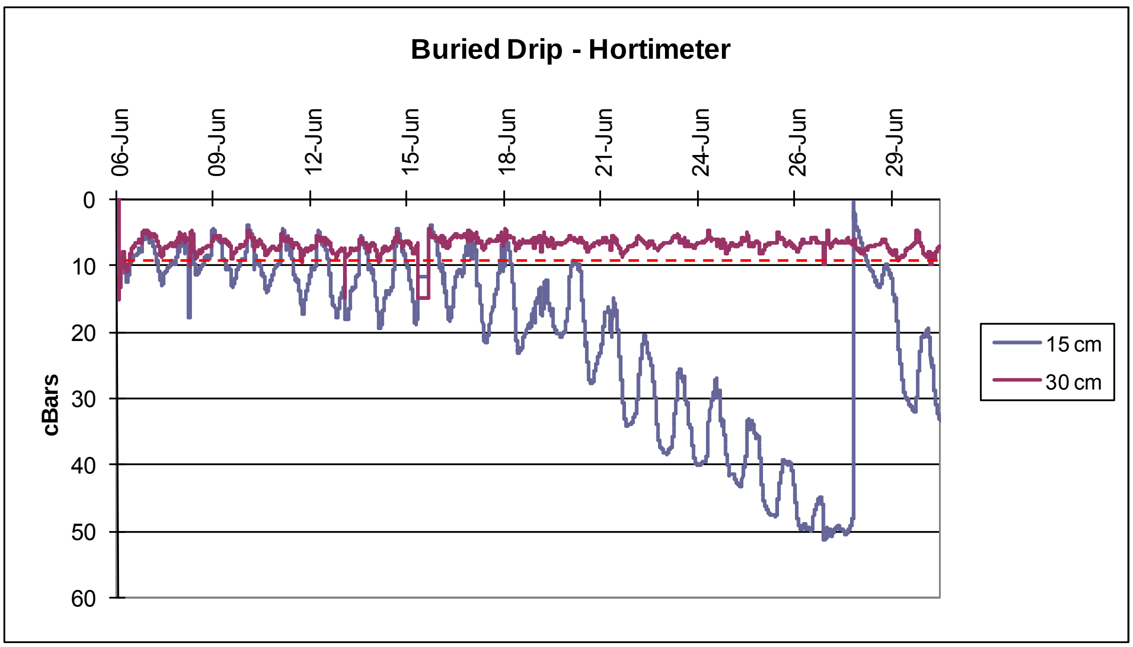
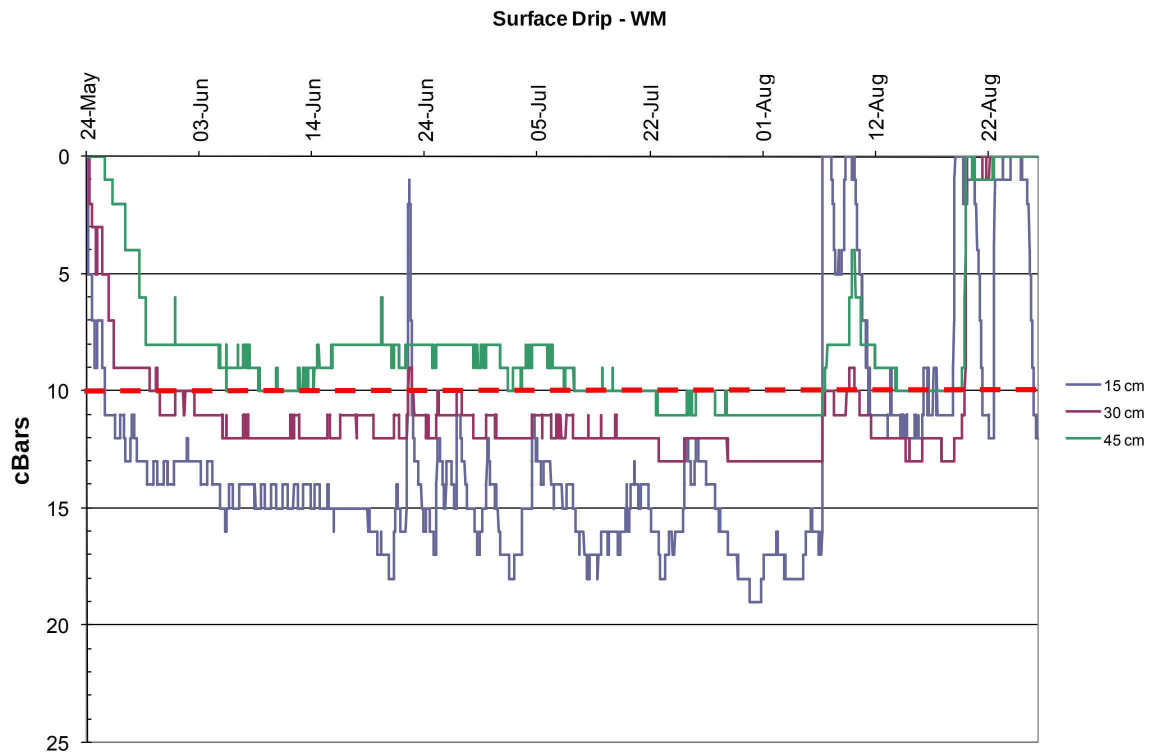


Figure 4.11 Hortimeter data for Leamington for the surface and buried drip tape sites



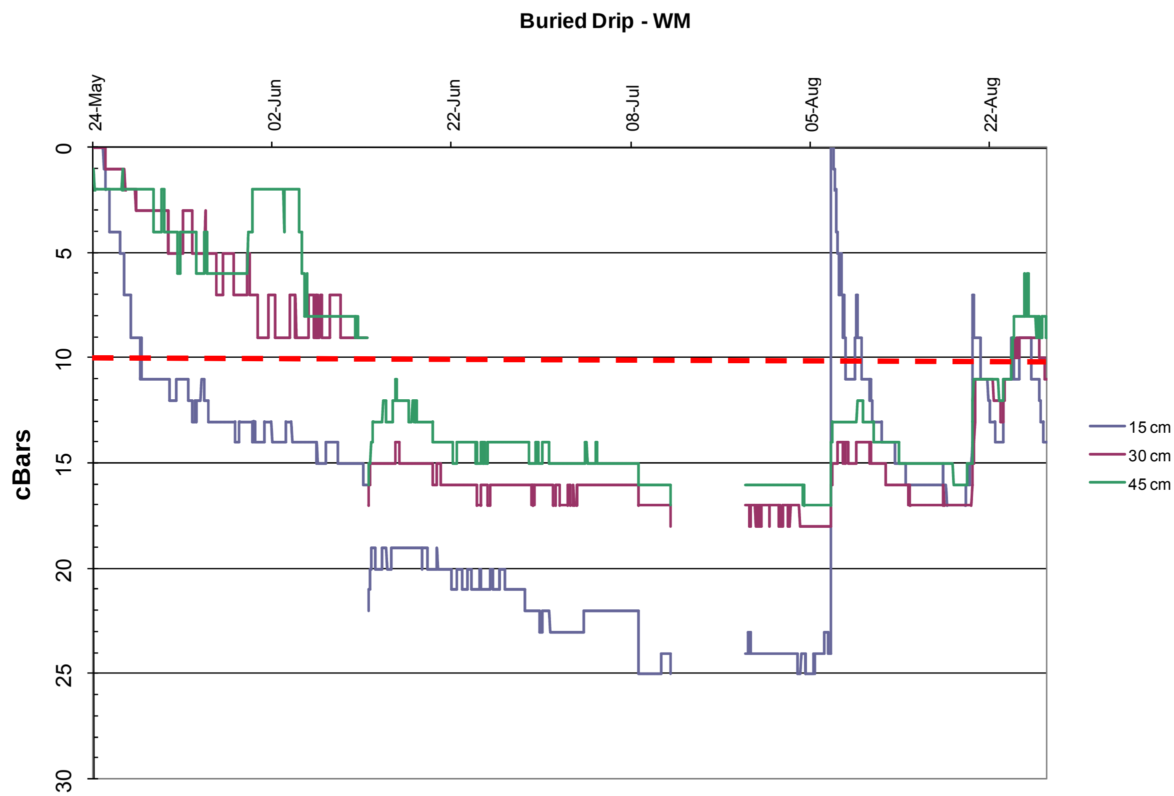


Figure 4.12 Watermark readings at 15 cm, 30 cm and 45 cm for the surface and buried drip tape

Dresden Hub Site

The grower irrigated with surface drip that he laid down at the end of June. All sensors performed well at his site and showed peaks during the many rainfall events he received during the season, especially in August when large rainfall events were experienced. Triggers for irrigation (9 VWC%) were calculated based on half soil AW at 20-25 cm depth, or at -30 cbars tension (for loamy sand soil). This site experienced sufficiently spaced precipitation events that the ETc needs were not spaced far apart and could be readily supplemented with irrigation.

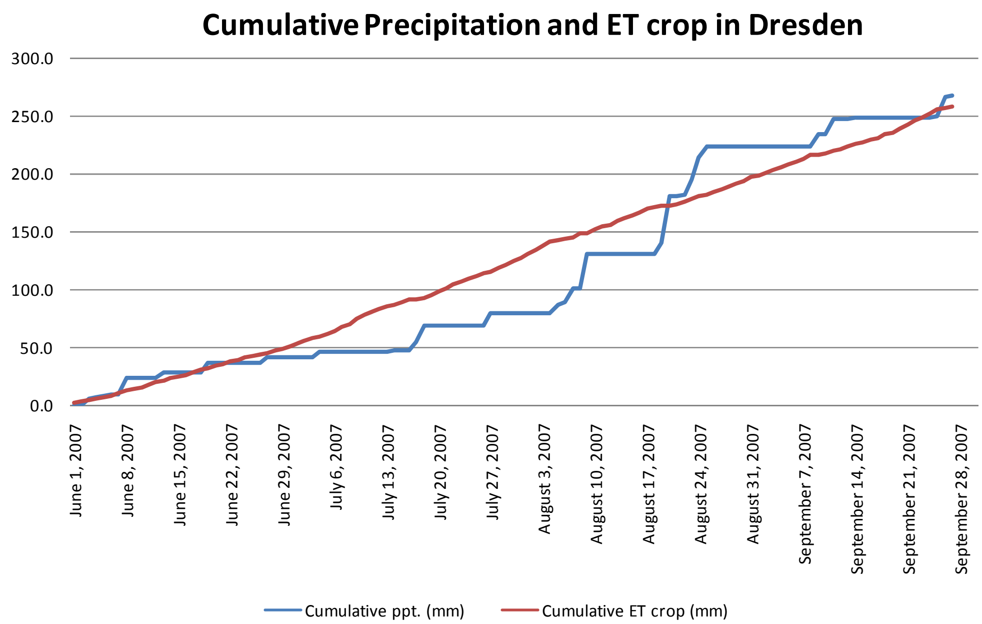


Figure 4. 13. Cumulative precipitation and ETc at the Dresden hub site

The tensiometers were consulted most often by the grower as he was able to read the display directly in the field. His moisture content was well above the threshold for triggering irrigation (-20 cbars). In fact, the 45 cm depth was wetter than the 20 cm depth (Figure 4.14) which indicates that soil moisture was being held in the root zone by the soil (loamy sand) while it was probably evaporating from the surface a lot more readily. This grower did not have a problem with too little moisture, despite the warmer than usual growing season.

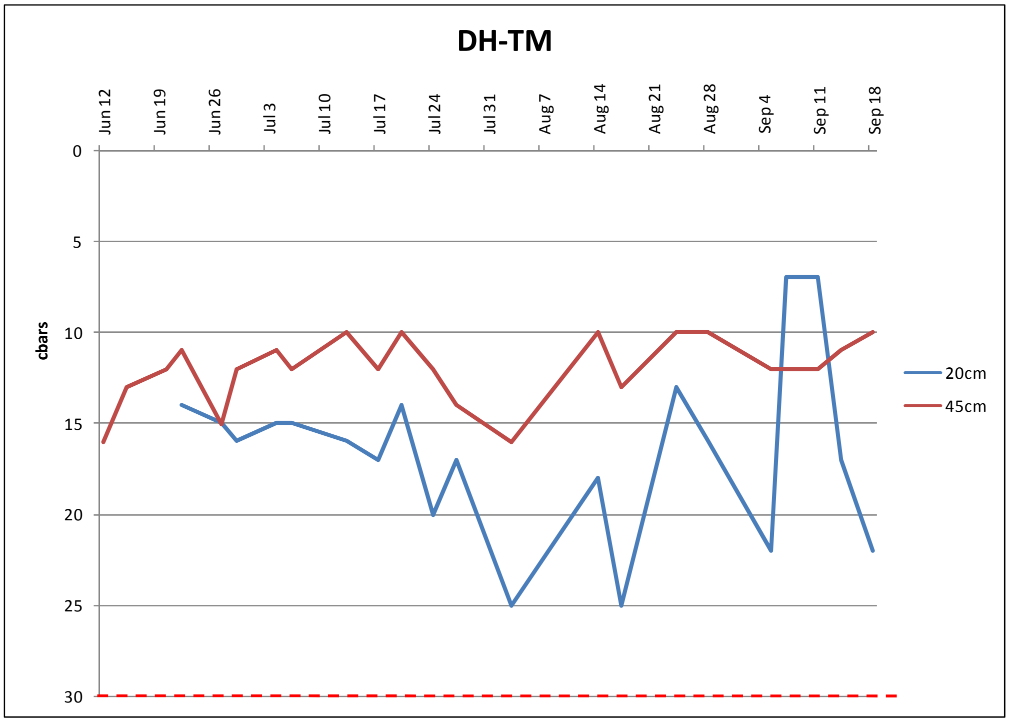


Figure 4.14 Manual tensiometer readings at the Dresden Hub site at 20 cm and at 45 cm

The WCR data and the Gro-Point data corroborated very well at the site (Figures 4.15 and 4.16). This is expected given that both sensors were placed approximately the same distance from the emitters (Figure 4.1). Since the WCR takes an average value from 0-30 cm, it is also expected to show lower overall values that the Gro-Point which is placed horizontally in the soil at around 20 cm depth.

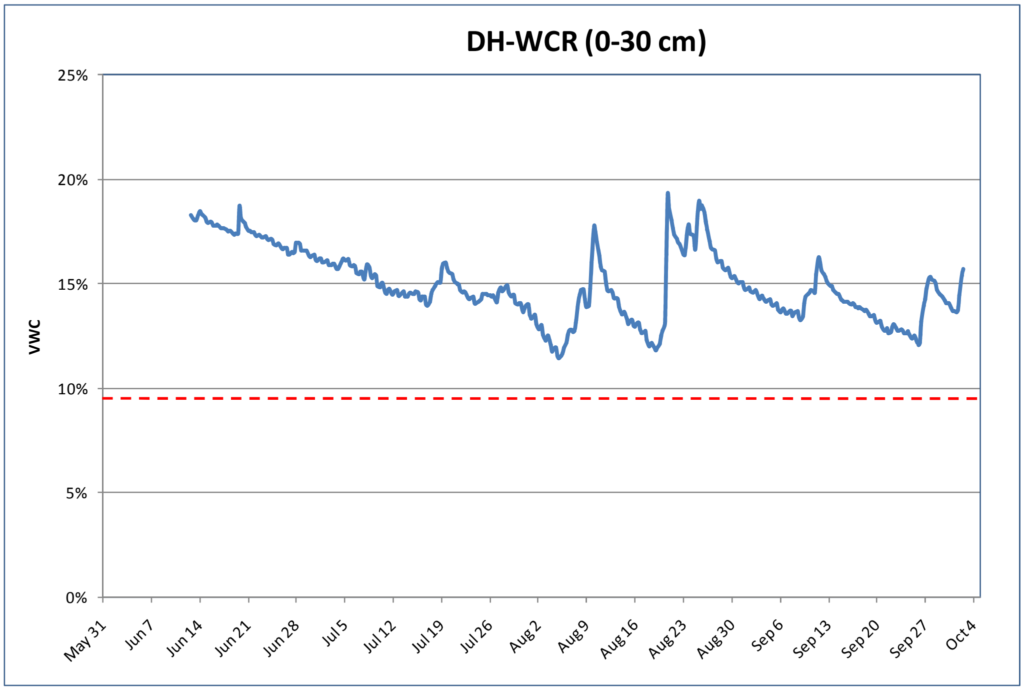


Figure 4.15 Water Content Reflectometers readings from Dresden Hub Site (average 0-30 cm depth)

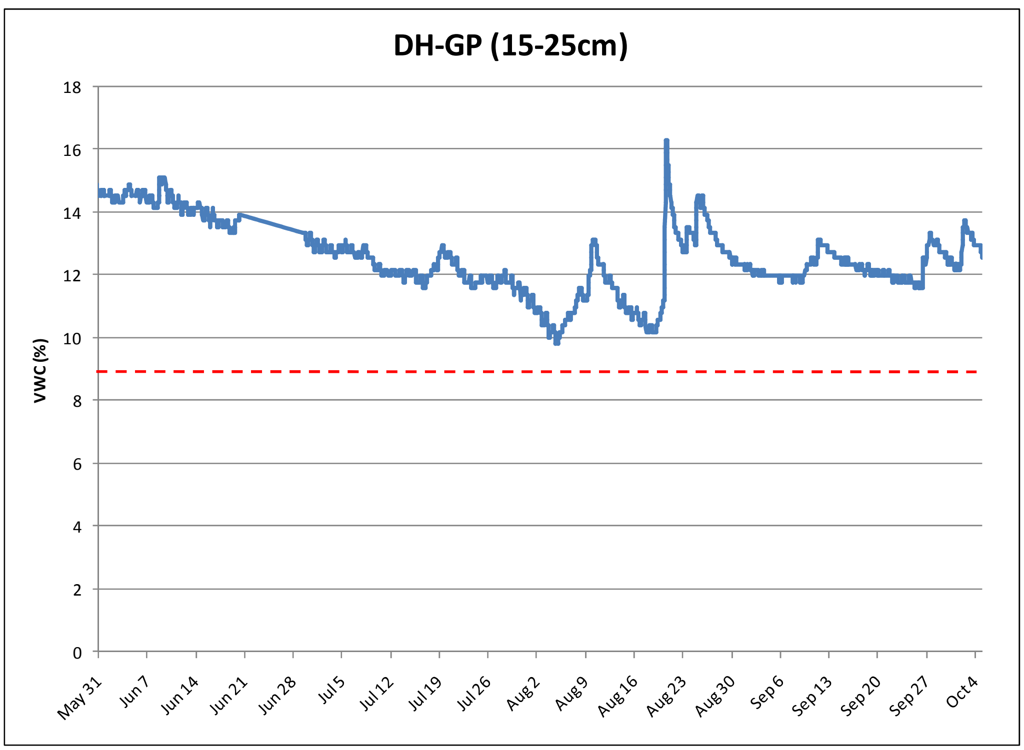


Figure 4.16 Gro-Point readings from the Dresden Hub Site (at approximately 20 cm depth)

Niagara-on-the-Lake Hub Site

Peach growers typically only irrigate at two, possibly three, times during the growing season; at flowering, at cell division and at fruit sizing. Therefore, the timing of the irrigations events are crucial, as are the amounts applied. In order to ensure sufficient water is penetrating their soil they must irrigate long enough. The triggers for irrigation were calculated based on half soil AW at 20-55 cm depth; 11% VWC; or -30 cbars tension for a loamy sand soil. This hub grower used an overhead gun to apply his irrigation water. For the most part, he applied irrigation water at the right time, but was under-irrigating; most likely because it was a very dry year (Figure 3.1c) and the water applications he normally applied were not penetrating past 20 cm depth, which is not deep enough into the soil to be effective for the entire root zone. Peach roots can go up to 75 cm deep in the soil, however most of the roots are located within the top 45 cm of the surface.

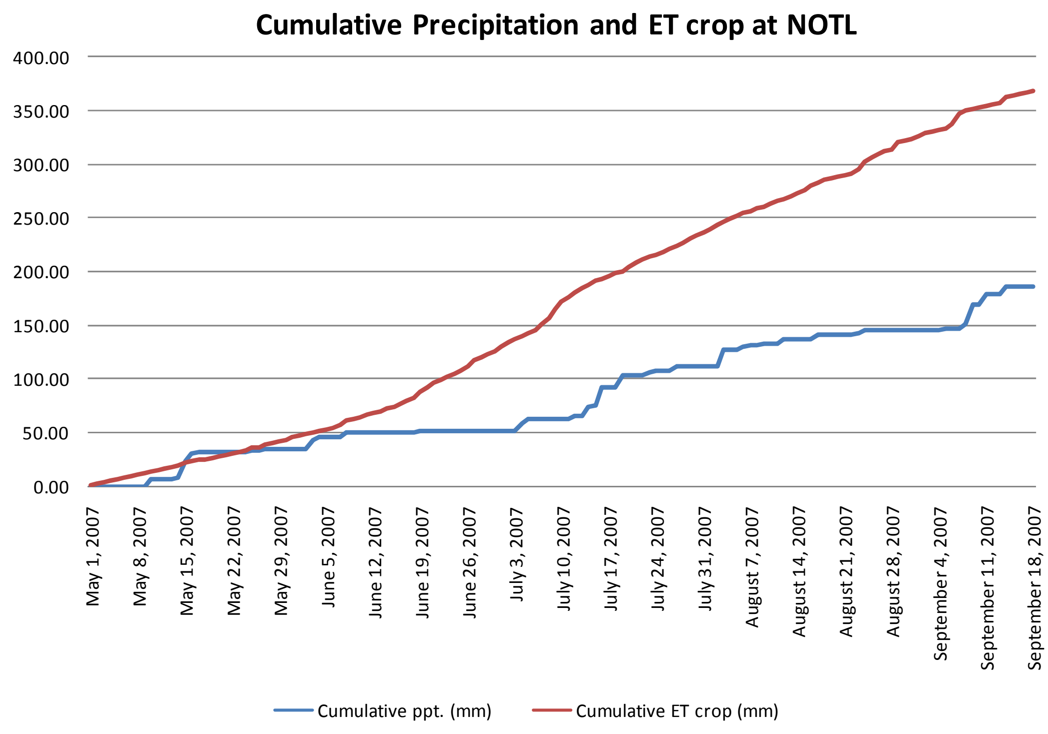


Figure 4. 17. Cumulative precipitation and ETc at the Niagara-on-the-Lake hub site

The cumulative ETc for peaches was about 370 mm, which is far from the 190 mm received from rain events (Figure 4.17). At 45 cm depth (Figure 4.18), it is evident that after mid June, the moisture moves below the critical irrigation threshold (this is when irrigation should have been applied); the deeper depth continues to dry despite irrigation. Once the soil moisture reaches such low levels at this depth, it is very difficult to move water into this zone to being moisture levels back up.

Figure 4.18 Manual tensiometer readings at Niagara-on-the-Lake hub site, at 20 cm and 45 cm depth

The tension based equipment is not ideal for overhead gun irrigation practices, because the tensiometers tend to dry out in between the irrigations. Once they dry out, they do not always function optimally again, even if the soil is rewetted. The manual tensiometers require the tube to be filled with water to prevent drying out, however even once it is filled up after it has dried, this does not always ensure it will function again. The 45 cm tensiometer dried out at the beginning of July and was unable to be salvaged (Figure 4.18). The tensiometers lower functioning limit is -80 cbars as described in Section 2. At 45 cm depth the soil moisture would be greater than 80 cbars and would not be able to keep suction.

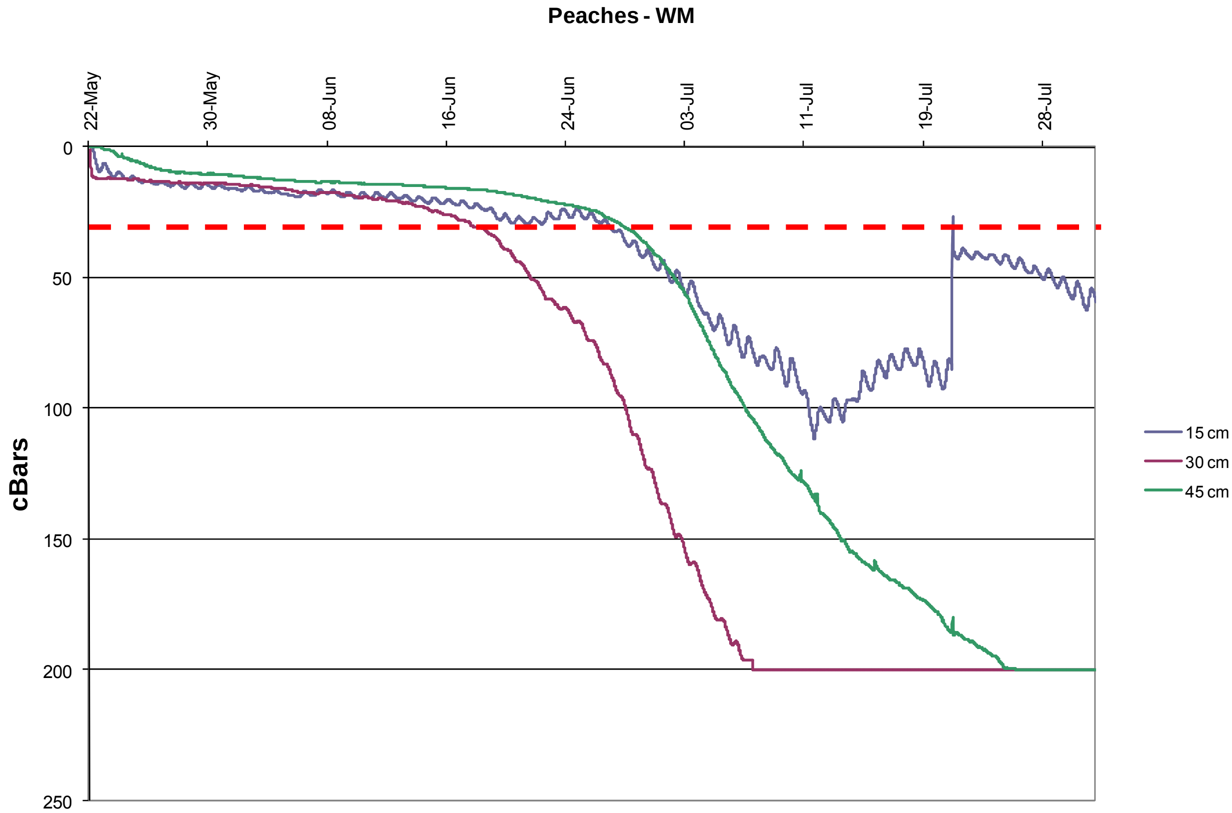


Figure 4.19 Watermark readings at 15 cm, 30 cm and 45 cm depth, Niagara-on-the-Lake hub site

The Watermark readings at 30 cm and 45 cm also dried out; after -200 cbars they are not able to take readings (Figure 4.19). The 15 cm depth however reacted to irrigation and precipitation events which were sparse and also showed continuous soil moisture depletion from basically May 22 to July 11 (July 11 was the first irrigation event). At 30 cm and 45 cm, the sensors are drying out which is a function of poor irrigation practices; inability of getting the water past 15 cm.

The C-probe graph shows how soil moisture was depleted until the third irrigation which caused a blip at the 30 cm depth although not enough to bring soil moisture near field capacity. The 50 cm depth shows drying throughout the summer without recharging from precipitation or irrigation (Figure 4.16). The Echo-probe which shows average soil moisture at 0-20 cm depth, also shows the drying out of the upper soil layer, especially after July 25th when the peaches were harvested (Figure 4.20).

The satellite sites showed similar trends with the gravimetric and portable TDR sampling carried out. Although sampling was restricted to the upper 30 cm, the soil moisture drying trend could still be observed.

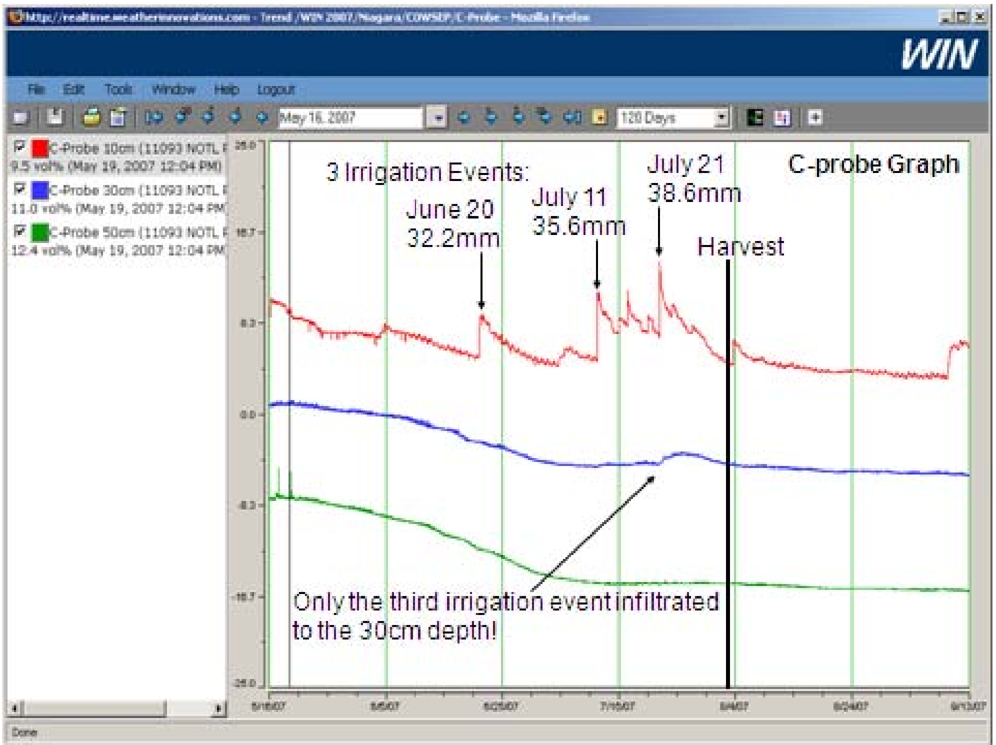


Figure 4.20 C-probe readings for Niagara-on-the-Lake hub site as seen on the WIN website

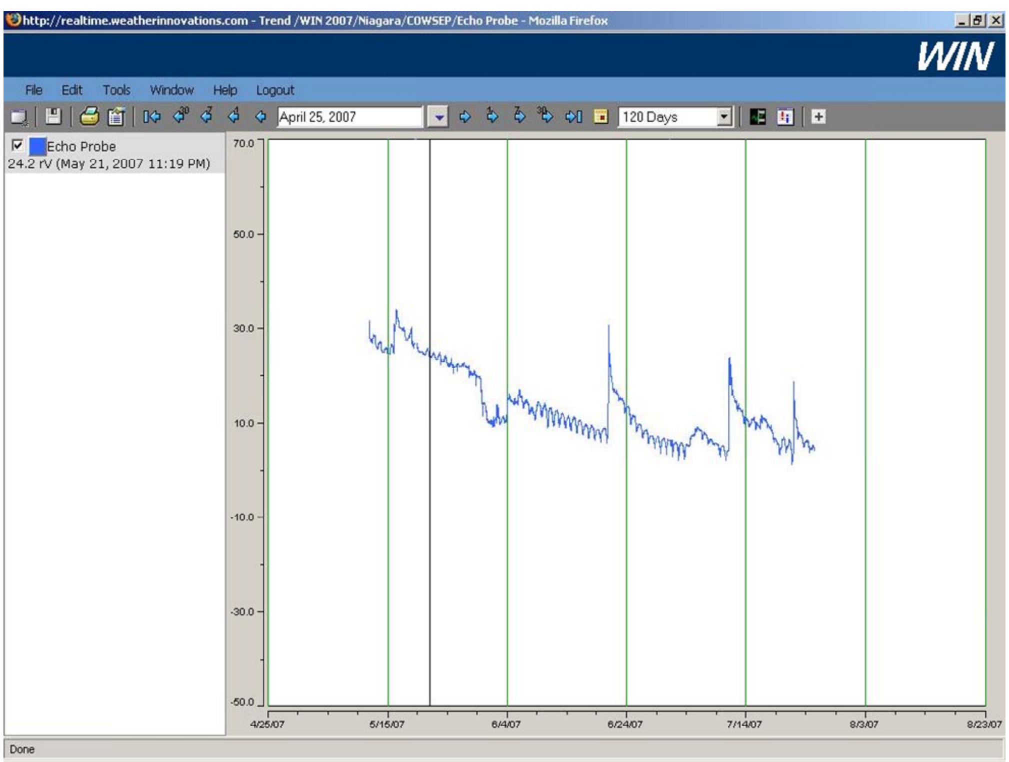


Figure 4.21 Echo-probe readings (Volts) for Niagara-on-the-Lake hub site as seen on the WIN website

Simcoe Hub Site

Figure 4.22 shows cumulative ETc and precipitation, however the precipitation amounts are not relevant inside the high tunnels, as such more frequent irrigation applications were made inside the tunnels. The grower irrigated for 1 hour every other day inside the tunnels, and he irrigated 1 hour every 5 days in the open field. At this site, however the water requirements inside the tunnels were lower than in the open fields (Table 5.8) because the micro climate inside the tunnels had a high relative humidity, and less direct sunlight exposure, as well the plants were less subject to ET losses from wind. Chapter 5 discusses irrigation amounts related to crop requirements and the water balance method in detail.

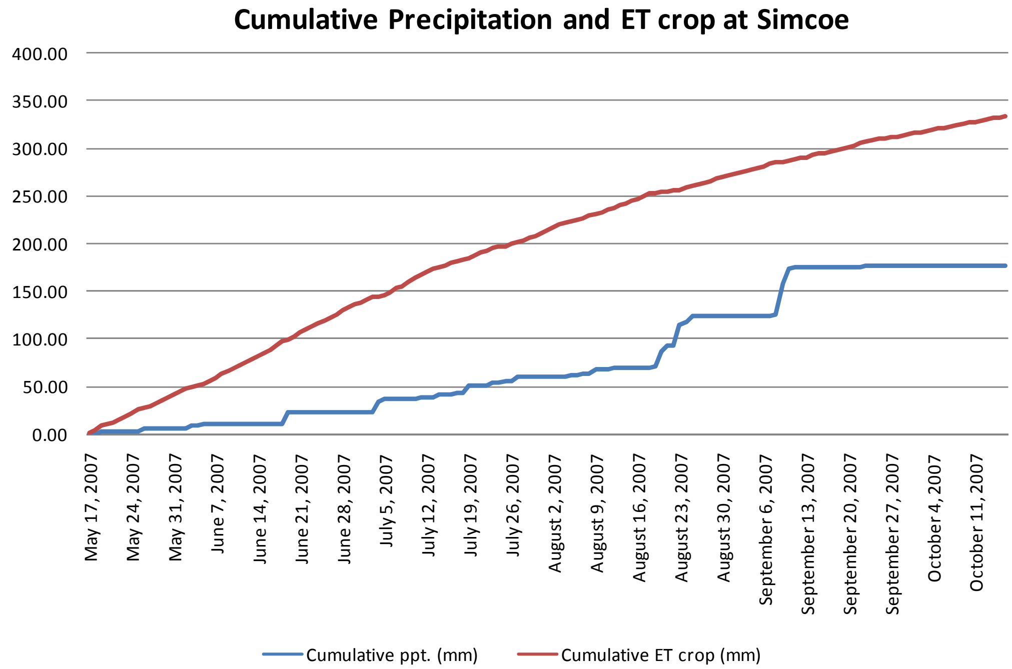


Figure 4.22 Cumulative precipitation and ETc at the Simcoe hub site

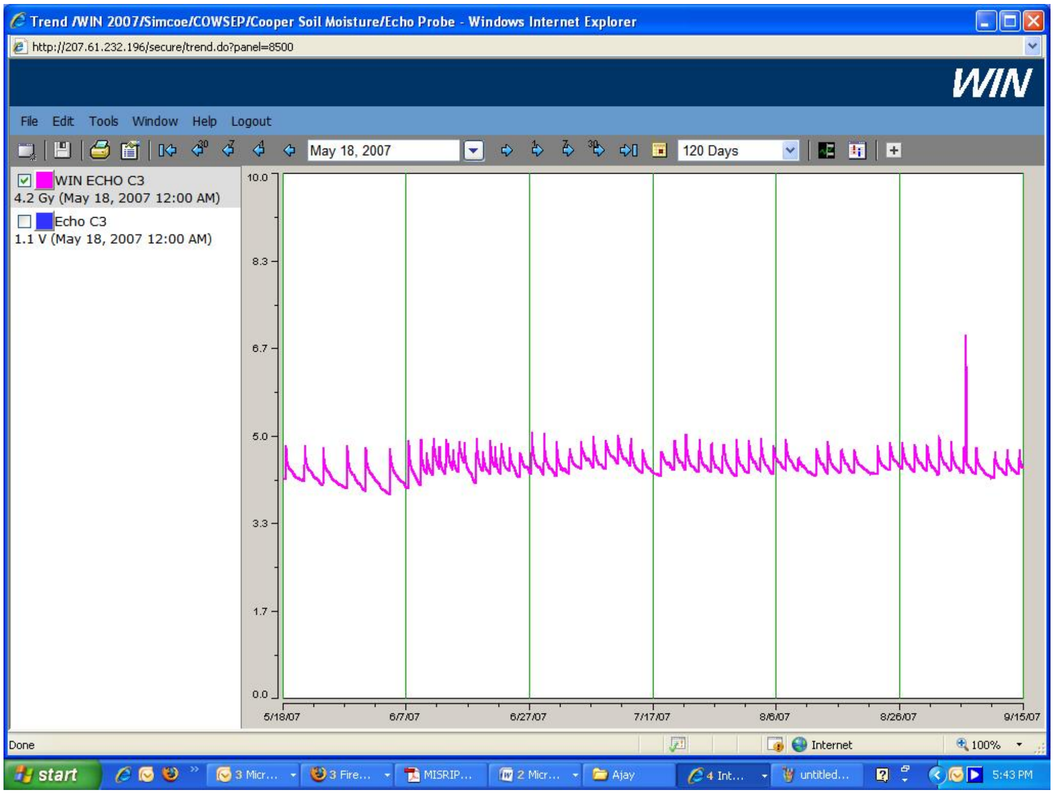
Triggers for irrigation (half of AW calculated for 20-25 cm depth; 14 % VWC or -30 cbars tension for a sandy loam soil) showed that too much irrigation water was being applied at this site, inside as well as outside the tunnels. The water content readings from the sensors remained well above the threshold for triggering irrigation, especially inside the tunnels.

At the onset of the project, the grower was irrigating inside the tunnels more frequently than outside; he irrigated every day inside the tunnel, compared with every fifth day outside. This led to soil VWC remaining high, around 30% inside the tunnel, whereas outside the tunnels, the VWC % fluctuated a bit more and was also lower; between 20 and 30% (Figure 4.23). He appeared to be maintaining an average around 30% VWC inside the tunnels, whereas the trigger was at 14%. When the grower was presented with the initial results around mid-June, he decreased his irrigation applications inside the tunnel to every other day. This brought down the VWC to between 20 -25%. The irrigation peaks can clearly be denoted on several of the sensor output graphs, for example the Echo probe (Figure 4.23).

If the grower had used the crop water requirement calculations to check his irrigation needs, he would have realized that these are lower for strawberries inside the tunnel, so there is really no need to apply more water inside the tunnels than he does to the outside field. In fact, he should apply less water.

There were some sensors reading differences at this site; they did not all give the same VWC readings. The Water Content Reflectometers (WCR) showed steady VWC % hovering around 30% inside the high tunnels; whereas the Gro-Points showed readings based around 25% VCW. However, the overall trends were very similar. The reason for this difference may be related to the placement of sensors (Figure 4.3); the Gro-Points inside the tunnels were installed relatively far away from the dripper, at a distance of 22.5 cm. The WCRs were located at a closer distance from the emitters; at 10 cm and 12.5 cm, for the 30 cm and 15 cm WCR, respectively. This is more representative of where the bulk of the roots would be located. Reading discrepancies can also be due to sensor calibration issues.

The open field sites were drier than inside the tunnels because they were irrigated less often, and because there was more wind action and diurnal fluctuation. The peaks inside the tunnels, visible on the WCR sensors (Figure 4.24) and the Gro-Points sensors (Figure 4.25), represent irrigation events since the temperature and humidity was constantly high inside the tunnels. Before mid-June, the frequency of the irrigation events was higher as can be seen by the peaks. The peaks on the outside site also represent irrigation events because they are not evenly spaced.



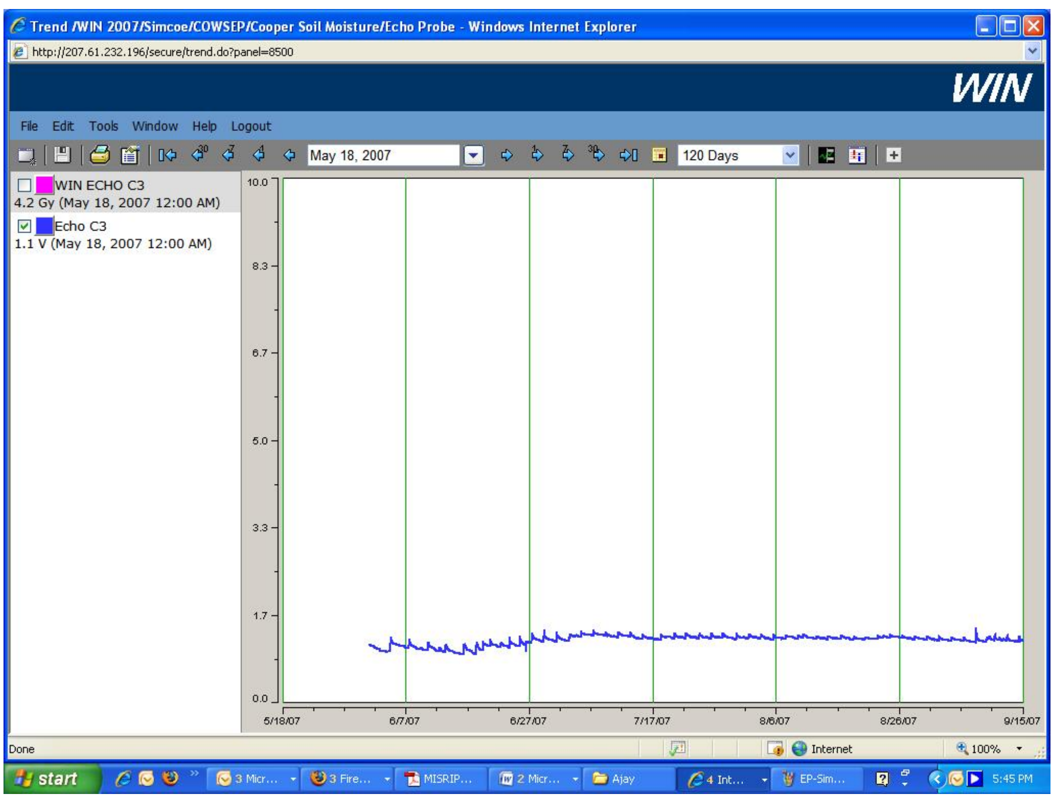
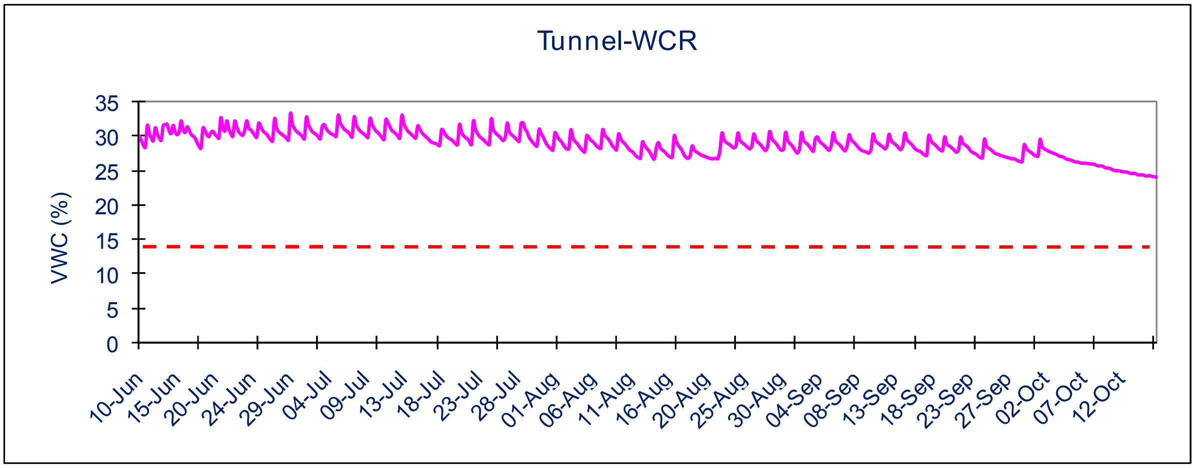


Figure 4.23 Echo probe data (Volts) for Simcoe hub site as seen on WIN website, inside and outside the tunnel



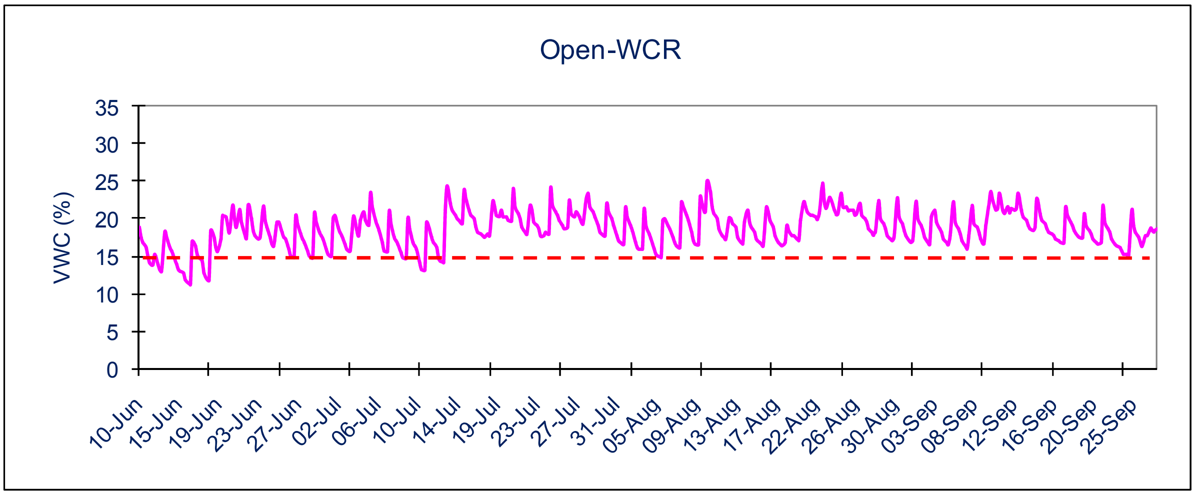
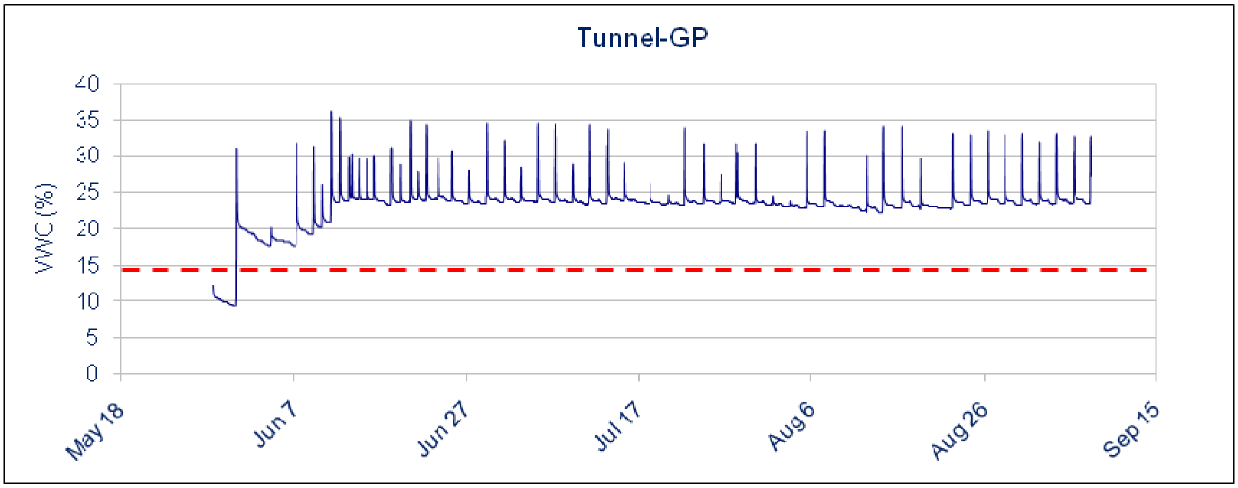


Figure 4.24 Water Content Reflectometer data for Simcoe hub site, inside and outside the tunnel



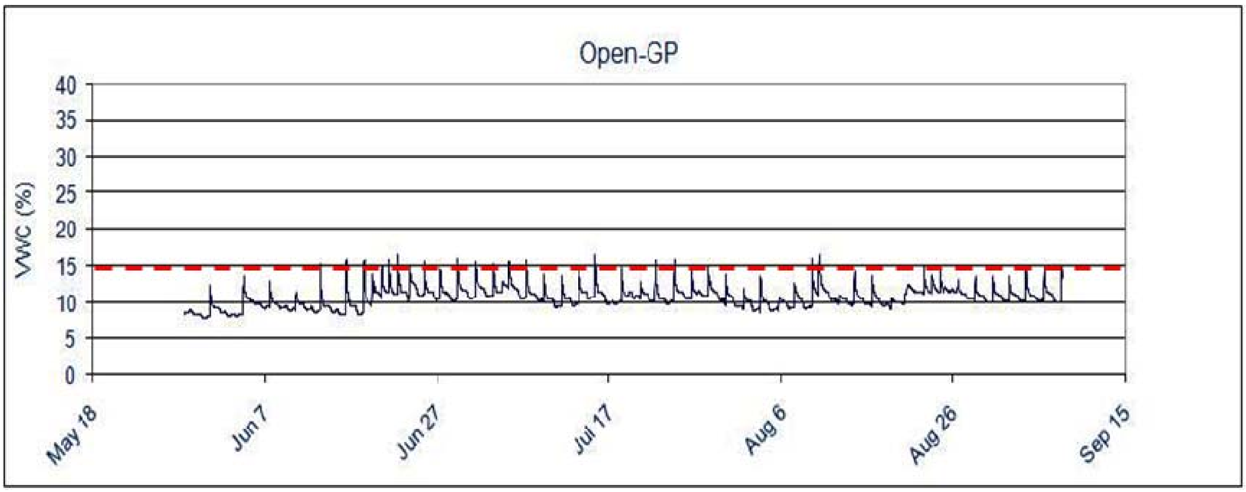


Figure 4.25 Gro-Point data for Simcoe hub site, inside and outside the tunnel

From the bi-weekly soil samples obtained and tested for volumetric water content, the difference between the benchmark sites can be showcased at Simcoe (Figures 4.26 and 4.27). The irrigation trigger pertains to the main equipment (ME) site only; not the benchmark sites. The benchmark sites were not all the same soil type, therefore some variation was found among the benchmark moisture contents. For example, Benchmark 3 (BM3) was a sandy loam, and showed the lowest water holding capacity, and therefore it may need to be irrigated somewhat longer in the future to keep the moisture above the trigger for irrigation. Whereas Benchmark 2 (BM2), also a sandy loam, consistently had the wettest soil, comparative to the other benchmarks, and therefore may not need to be irrigated as long as the other benchmarks. Differences in benchmarks may also be due to organic matter, or topographic differences.

The importance of selecting a representative site to install the sensors is critical, and this is highlighted by the difference in the benchmark sites. The growers are familiar with their fields and are able to choose relatively well the sites which are drier, or wetter, compared to the average area on the field. Usually a grower would install a sensor at a drier site on his farm, as these are the warning sites (canary in the coal mine analogy).

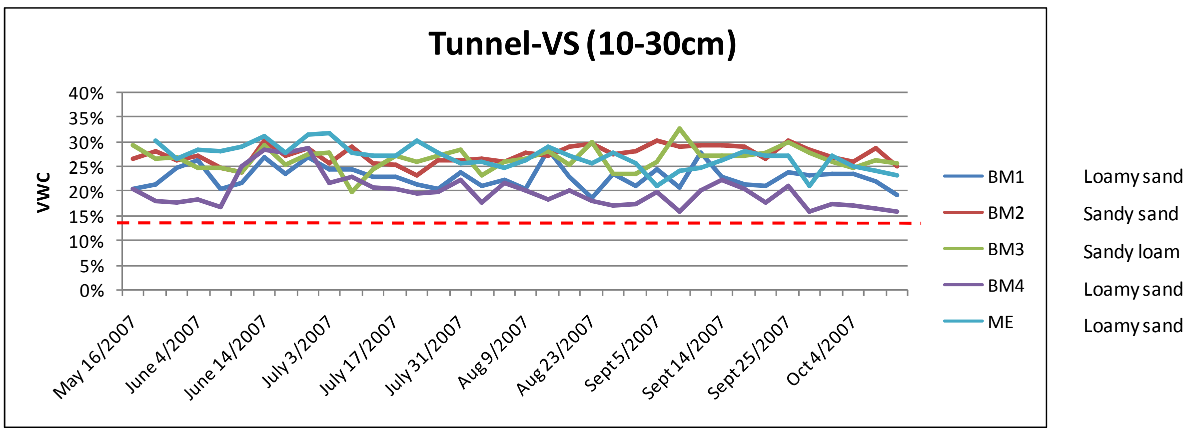


Figure 4.26 Soil volumetric water content determined from soil auger samples from Simcoe high tunnels

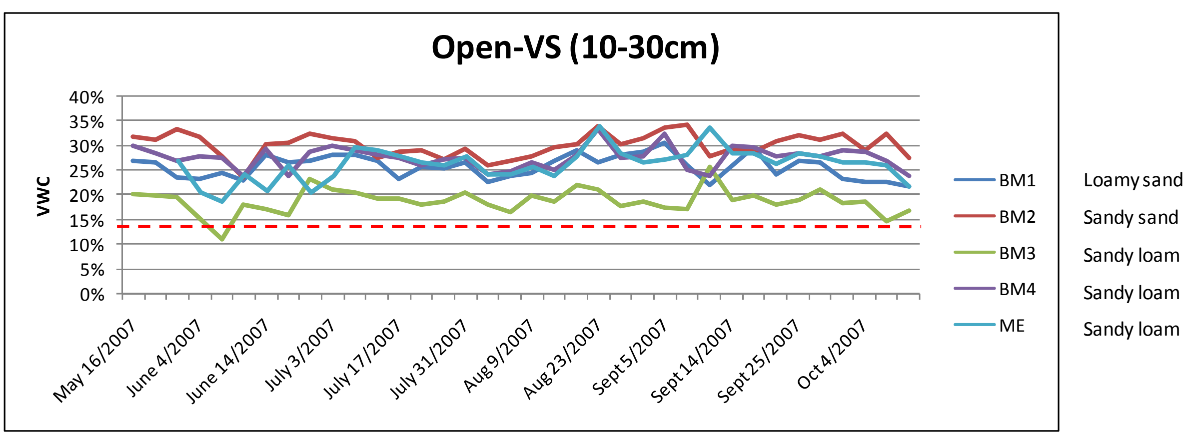


Figure 4.27 Soil volumetric water content determined from soil auger samples from Simcoe open field

Sensor Performance

Seven different types of soil moisture sensors were used in the project, covering over 4 hub sites all in different regions in Ontario, including two paired studies, which amounted to a total of 6 monitoring sites. With such a diverse range of conditions, several factors played a significant role in influencing sensor performance over the monitoring season.

Each of the following factors was taken into account while evaluating sensor performance in the project:

1. **Installation**: Experienced personnel coordinated installations of the sensors at all sites. Installations of the C-probe and Echo probe were carried out by WIN staff; Watchdog Watermark sensors and flow meters were installed by PFRA staff; Gro-point sensors were installed by OMAFRA; Campbell water content reflectometers and manual tensiometers by McGill University staff; and the Hortimeter installations were done by the Hortau company staff. By having individual expert teams responsible for the sensor install, chances for errors in installation were minimized.

2. **Sensor location:** Choosing the appropriate location for the sensor vis-à-vis the emitter location and crop rooting system is paramount for accurate measurements. Efforts were made to ensure that all sensors were installed at consistent distances from the emitter and the crop. However, this was not always possible (*for e.g. while installing sensors for the buried drip in Leamington*). In another instance, unanticipated leakages from the drip emitter resulted in a wet zone around some sensors giving excessively high soil moisture readings (*for e.g. the open field in Simcoe*). Also, if the sensor was installed in a zone with too many roots, error will be introduced. When such errors were detected, the field technical assistants were informed to relocate / re-install the sensor.

3. **Monitoring and Maintenance:** Field technical assistants visited the sites once or twice weekly to download data, and perform necessary site maintenance. The assistants were trained to detect faulty sensors in the field or possible sources of error. If they were unable to resolve the problem themselves, they called the field manager or the responsible equipment manager from the field to resolve the problem (*for e.g. flow meter in Simcoe; tensiometer in Niagara-on-the-Lake)*.

4. **Equipment Failure**: There were instances when equipment broke down and had to be sent to the supplier for repair (*e.g. Portable FieldScout TDR*). During this period, measurements from that particular sensor were not recorded. In the particular case of the FieldScout, the service provided by the manufacturers was unsatisfactory, since the "repaired" instrument did not function reliably. There were few other instances of sensor failure, in which case new sensors were obtained and installed within a week or two (*e.g. tensiometer in Niagara-on-the-Lake)*. Table 4.8 summarizes the extent of data collected and Table 4.9 shows the extent of equipment malfunctions and breakdowns.

Table 4.8 Monitoring Extent of and Data Collection (excluding gravimetric sampling)

Region	Site (No.)	Sensor	# of sensor measurements	Measurement frequency	Download frequency
Dresden	Hub (1)	C Probe	3	15 min	Real time
		Campbell WCR	2	4 hours	Twice a week
		Echo Probe	1	15 min	Real time
		FieldScout TDR	5	Twice a week	Twice a week
		Gro-Point TDR	1	20 min	Twice a week
		Tensiometer	2	Twice a week	Twice a week
		Watermark	3	30 min	Twice a week
		Weather station (Adcon)	6	15 min	Real time
		Flow meter	1	On-off switch	monthly
	Satellites (3)	FieldScout TDR	4	Twice a week	Twice a week
Leamington	Hubs (2)	C Probe	3	15 min	Real time
		Campbell WCR	2	4 hours	Twice a week
		Echo Probe	1	15 min	Real time
		FieldScout TDR	5	Twice a week	Twice a week
		Gro-Point TDR	1	20 min	Twice a week
		Tensiometer	2	Twice a week	Twice a week
		Watermark	3	30 min	Twice a week
		Hortau	2	1-3 min	Real time
		Weather station (Adcon)	6	15 min	Real time
		Weather Station (Watchdog)	6	15 min	Twice a week
		Flow meter	1	4 minutes (during flow)	monthly
	Satellites (4)	FieldScout TDR	4	Twice a week	Twice a week
NOTL	Hub (1)	C Probe	3	15 min	Real time
		Campbell WCR	2	4 hours	Twice a week
		Echo Probe	1	15 min	Real time
		FieldScout TDR	5	Twice a week	Twice a week
		Gro-Point TDR	1	20 min	Twice a week
		Tensiometer	2	Twice a week	Twice a week
		Watermark	3	30 min	Twice a week
		Weather station (Adcon)	6	15 min	Real time
		Weather Station (Watchdog)	6	15 min	Twice a week
	Satellites (5)	FieldScout TDR	4	Twice a week	Twice a week
Simcoe	Hubs (2)	C Probe	3	15 min	Real time
		Campbell WCR	2	4 hours	Twice a week
		Echo Probe	1	15 min	Real time
		FieldScout TDR	5	Twice a week	Twice a week
		Gro-Point TDR	1	20 min	Twice a week
		Tensiometer	2	Twice a week	Twice a week
		Watermark	3	30 min	Twice a week
		Weather station (Adcon)	6	15 min	Real time
		Flow meter	1 (inside tunnel)	4 minutes (during flow)	monthly
	Satellites (5)	FieldScout TDR	4	Twice a week	Twice a week

Even while taking the above factors into consideration, the overall sensor performance through the monitoring season is highly creditable. Numbers put the record into perspective:

Between 12 – 14 soil moisture sensors were installed per hub site, totalling 76 sensors over the 6 hub sites. In addition, there were 2 portable instruments used. Also, 6 mini weather stations and 3 flow meters were installed totalling over a 100 measurements at the hub sites alone. Over the 4-5 month monitoring season, there were only 2 instances of complete equipment failure (one portable TDR, and one manual tensiometer in Niagara-on-the-Lake), and less than 5% of data was lost due to sensor down time.

During the growing season, the soil moisture sensors were kept track of for long period of time, four months, and this requires that the sensor work continuously.

However, during monitoring, some of the sensors experienced unexpected technical errors/failures that were observed during regular field checks. These were recorded in the field logbooks as follows, on a regional basis.

Table 4.9 Sensor troubleshooting at the Dresden hub site

Sensor	Malfunction Date	Fixing Date	Remarks
Gro.Point	June 07	End of season	Compatibility problem with Windows Vista on laptop, cannot download the data
C-probe	June 07	July 05	Height problem in field mechanical challenge
Watermark	July 04	end of August	Was sporadically showing error in connection/downloading data could not fix until later
Tensiometer (20 cm)	June 07	20 June	Showed unknown error, replaced by other TM
WCR	mid July	mid August	Showed connection problem, Unknown error

Table 4.10 Sensor troubleshooting at the Leamington hub site

Sensor	Malfunction Date	Fixing Date	Remarks
Tensiometer	June 06	June 06	TM was changed if suspected to be broken or not properly working
Watermark	June 06 July 03 July 23 August 16	June 14, July 13	WM was replaced, but kept showing connection problem. Getting PFRA staff to fix in field challenge. Compatibility problems with Windows Vista
Hortimeter (15 cm)	July 03	July 20	Was refilled and started working; soil contact problem
Gro.Point	From installation	To end of season	Compatibility problem with Windows Vista

Table 4.11 Sensor troubleshooting at the Niagara-on-the-Lake hub site

Sensor	Malfunction Date	Fixing Date	Remarks
TDR	June 11 and July 04	18 July	OMAFRA TDR was showing unknown error, sent back to manufacturer
Watermark	June 11	June 22	Software problem, showed zero reading, but no data missing when downloaded
Gro.Point	June 18	Sept 07	Compatibility problem with Vista, not connecting
Tensiometers	July 29	Sept 07	Kept showing 0 readings, changed several times
WCR	August 18	Sept 07	Connection problem, sent back to Brace for fixing

Table 4.12 Sensor troubleshooting at the Simcoe hub site

Sensor	Malfunction Date	Fixing Date	Remarks
TDR	June 06	June 19	OMAFRA TDR was showing reading error sent back for fixing
WCR	June 12	July 10	WCR outside the tunnel was showing connection error, sent back to Brace
Watermark	July 03	Sep 21	WD kept showing connection problem, fixed by telephone assistance from PFRA staff
Tensiometers	June 02	Oct 07	Both inside and outside the tunnel both showed problems, replaced accordingly
Gro-Point	July 06	Oct 07	Compatibility problem with Windows vista.

At some point during the growing season, almost every piece of equipment broke down, malfunctioned or gave error readings. The level of technical support available (by supplier or other) is decisive when choosing a sensor, as is the rate at which the equipment was able to be fixed, to get it up and running again. This information is considerably important in the evaluation of sensor performance and reliability, or selection and use in the long run as part of an irrigation strategy for scheduling efficient water use. Professional support for sensor installation, training and maintenance made available to the growers will significantly help to reduce frustration and down time when implementing some of the sensors.

All sensors types (TDR, WCR, tensiometers, electrical resistant blocks, and capacitance probes) had some form of problem or challenge that required overcoming. The tensiometers required regular maintenance, the Watermark electrical resistance blocks malfunctioned a few times mainly due to connection problems, the Gro-Points had connections problems to the laptop, the WCR cable was not connecting properly, the C-probe was installed too high in one instance, just to name a few examples.

Comparing Sensor Performances

An evaluation of the sensors' performance against one another was not carried out in the project, taking into view the factors outlined in the previous section, such as location differences. Despite being installed in the same management zone (under the same crop, soil and irrigation conditions), soil moisture sensors are sensitive to 'local' changes in soil moisture. The inherent variability of soil moisture at different distances from emitters and depths in the soil profile prevents an equal comparison from being made. While visual or graphical comparisons were completed giving the growers a fair idea of each sensor's outputs, a statistical comparison cannot be made between sensors. In addition, the principle of measurement for each sensor is different with some measuring volumetric water content while others measure soil tension. Therefore no conclusions can be drawn, from this project, about the accuracy of one sensor versus another.

The following section however does show trends of the sensor readings plotted against gravimetric samples obtained at the same time. Composite gravimetric samples taken at two depths in the field were another benchmark against which sensor performance could potentially be evaluated. Gravimetric moisture values were converted to volumetric content using soil bulk density values. Again, one must be careful when such comparisons are made, as the locations at which soil samples were taken may have had different soil moisture compared to the sensor locations. Also, the depths for gravimetric sampling were not always the same as sensor depths, so all sensors could not be evaluated by this method. Figures 4.23 to 4.29 show evaluations of some of the sensors that gave VWC% readings (Portable TDR, Gro-Points and WCR), with the gravimetric samples obtained, to look at general performance and trends.

From the graphs, the gravimetric samples show quite clearly the performance of the sensors was scientifically accurate. When the soil was wetted, this was picked up by the sensors, with an order of magnitude of difference. When the soil dried, the same decreasing trend in soil moisture was picked up by the sensors. Hence, the responses of the sensors were validated by the gravimetric soil sample. All sensors showed similar trends in soil moisture, and all moisture readings were very comparable to correspond with the soil gravimetric samples.

It should be noted that the portable TDR that was used in the Leamington and Dresden regions was not as reliable towards the end of season, this can be seen by the comparison with the gravimetric samples becoming weaker towards the beginning of August, and then giving very low VWC readings at the end of August, which are most likely not reliable (Figure 4.23 and 4.24).

Figure 4.28 and 4.29 show the portable TDR readings (average of 0-20 cm) and gravimetric soil samples obtained at the main equipment site (ME) at 0-10 cm and at 10-30 cm at the Leamington hub. Notice how the readings follow the same trend, but at the beginning of August they do not corroborate anymore.

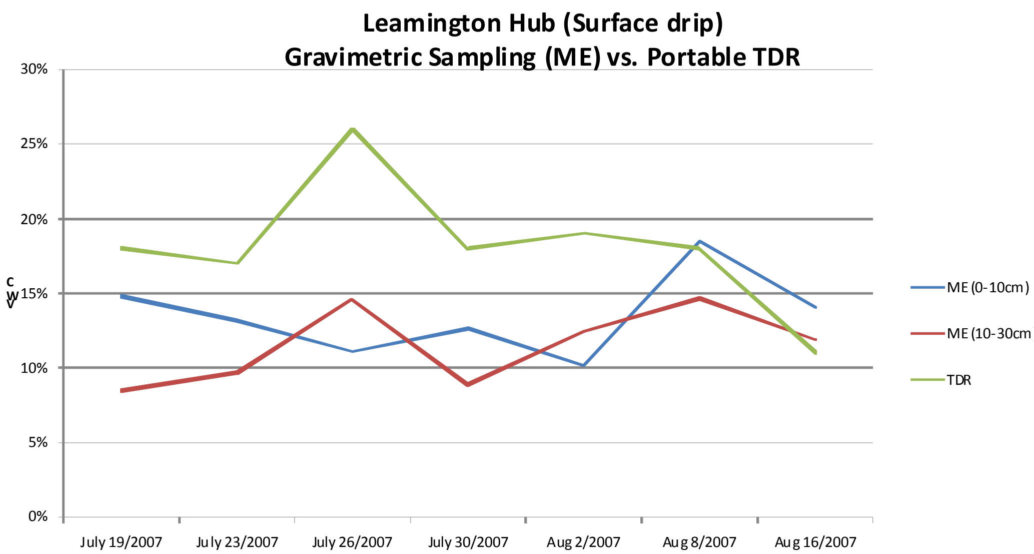


Figure 4.28 Gravimetric samples at 0-10 cm and 10-30 cm with portable TDR readings at Leamington in surface drip irrigation

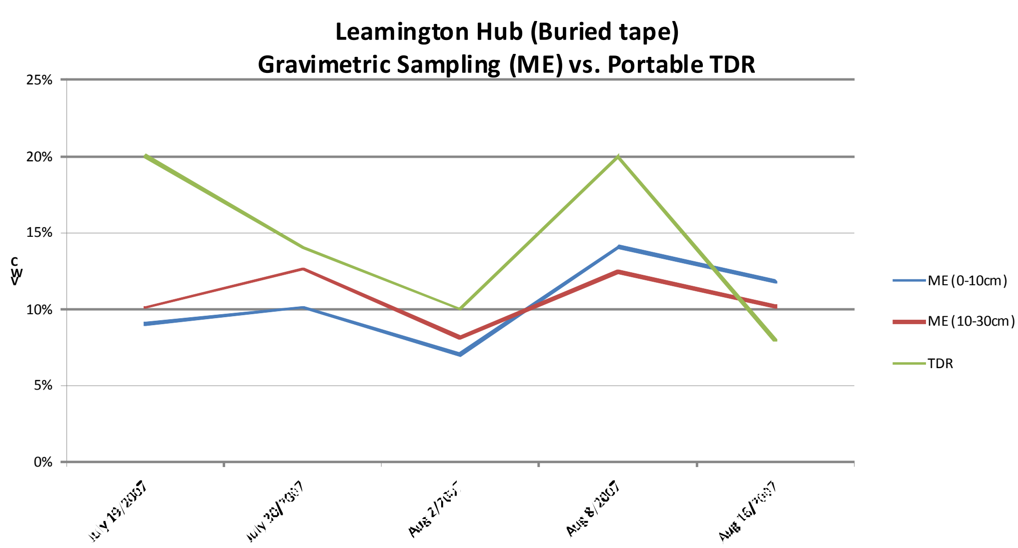


Figure 4.29 Gravimetric samples at 0-10 cm and 10-30 cm with portable TDR readings at Leamington in buried drip irrigation

Figures 4.30 and 4.31 show the Gro-Point sensor readings (at 20 cm) compared with gravimetric samples. The Gro-Point sensor data follows the 10-30 cm gravimetric samples more closely, which is to be expected since this depth is more representative of where the sensor was buried. Differences may be due to different sampling locations and times in the day when readings were taken.

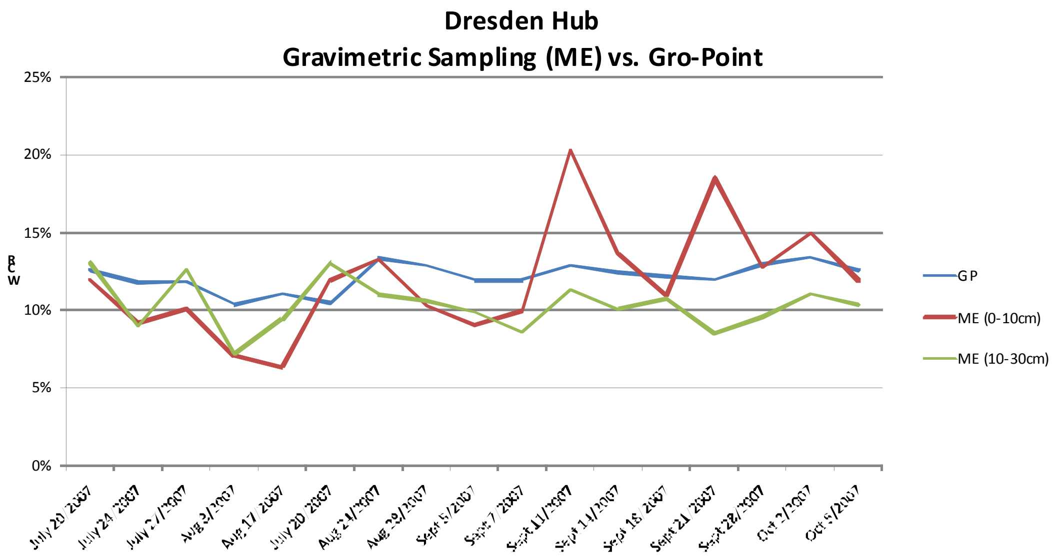


Figure 4.30 Gravimetric samples at 0-10 cm and 10-30 cm plotted with Gro-Point readings at Dresden

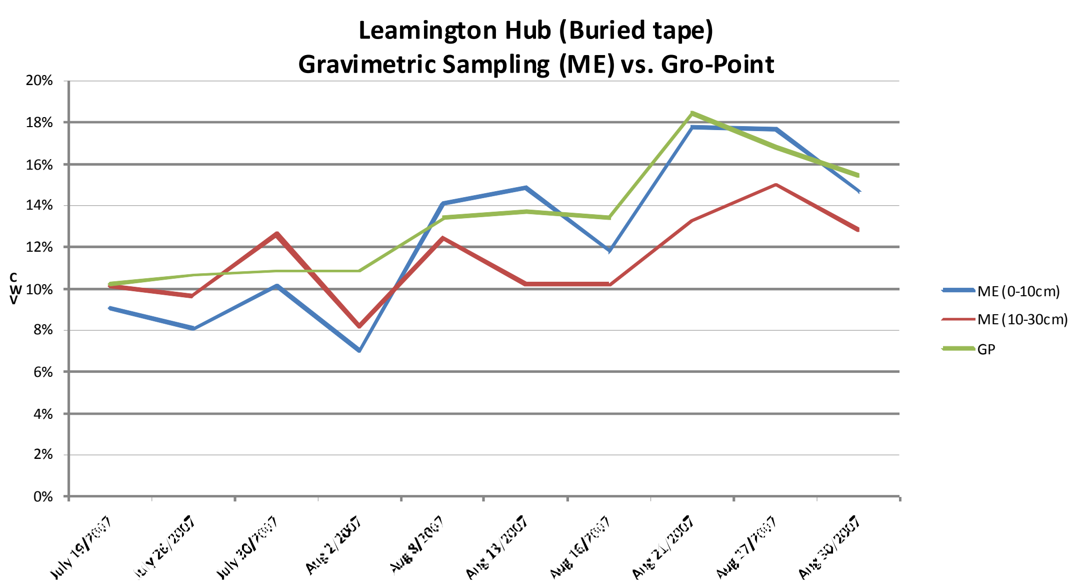


Figure 4.31 Gravimetric samples at 0-10 cm and 10-30 cm plotted with Gro-Point readings in Leamington (buried tape)

Figures 4.32 to 4.33 show the water content reflectometers (average reading from 0-30 cm) compared with gravimetric samples, at both the Dresden and Leamington hub sites. There is relatively good corroboration and fit in trends for all graphs. The WCR takes an average reading of the probe length, in this case it was installed from 0-30 cm, hence it would be expected that the WCR readings would match up with the gravimetric readings which were also taken up to 30 cm. Indeed, the trends are the same.

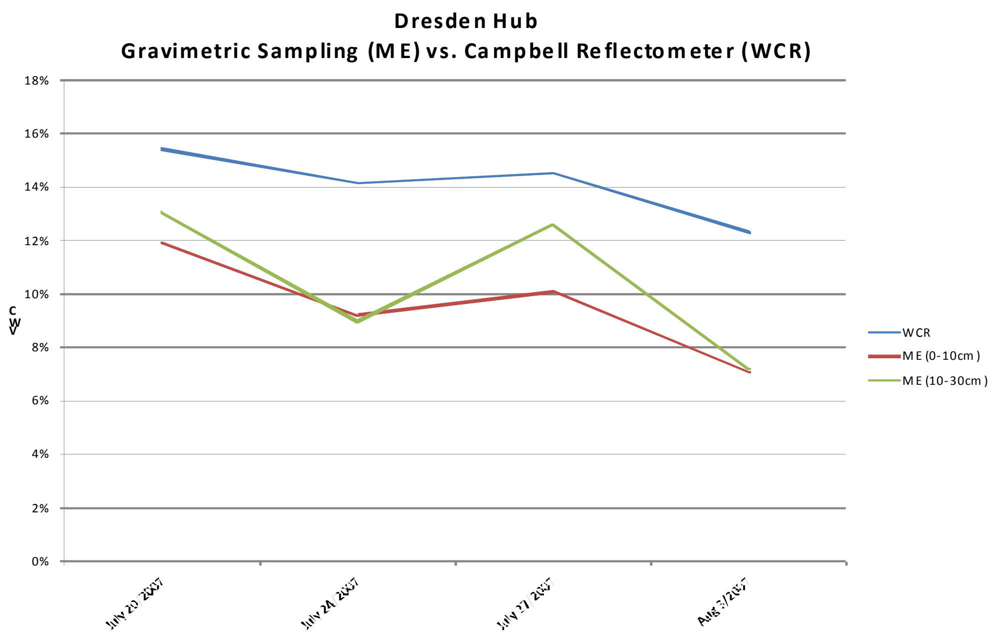


Figure 4.32 Gravimetric samples at 0-10 cm and 10-30 cm plotted with WCR readings at Dresden

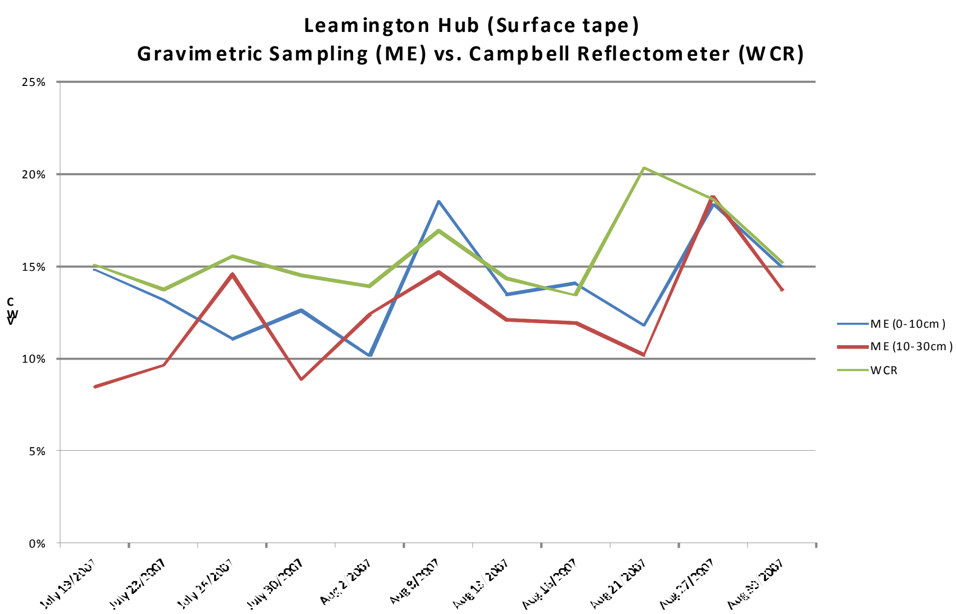


Figure 4.33 Gravimetric samples at 0-10 cm and 10-30 cm against WCR data at Leamington (surface)

Sensors as Tools for Soil Moisture Monitoring

Assessment of Soil Moisture Sensors

From the perspective of the researchers and field technicians, the following broad evaluations of the sensors were rendered (Tables 4.13 to 4.15). Each piece of equipment has its unique characteristics, which include positive features as well as the negative attributes. These assessments remain general and are based on one year of field experience. Assessments are based on general functioning of the sensors during the growing season installed under four different crops, and include evaluations based on installation, data recording reliability and maintenance of the sensors.

It should be noted that the data downloadable sensors (WCR, Gro-Point, Watermarks) can be converted to wireless capability with addition of communication components , dataloggers and software. For example, the Gro-Points can provide the same capability as the C-probe if inserted to a datalogger and communication devices, they will display similar to how WIN set up the C-probes and Echo probes.

Table 4.13 Manually-read sensors

Sensor type	Relative cost of 1 sensor + equipment to record and view data	Positive aspects	Drawbacks
FieldScout Portable TDR	Medium	Portable Easy to use GPS system built in	Calibration for different soils may be required Support not readily available
Manual tensiometer (Irrometer)	Low	Low cost Relative easy to install Easy to read in field	High maintenance If soil dries out, not reliable Limited reliability in sand

Table 4.14 Data-downloadable sensors

Sensor type	Relative cost of 1 sensor + equipment to record and view data	Positive aspects	Drawbacks
Gro-point (TDR)	Medium	Continuous Reliable Wireless capability	No display in field Calibration for different soils. Support not readily available
Water content reflectometer (WCR)	Mid-high	Continuous Multiple depths Wireless capability	No display in field Back up battery good idea Cable length max. 100ft, otherwise custom order
Watermark (electrical resistant block)	Low	Continuous Easy installation Multiple depths	Variable sensitivity May need calibration Not reliable in rapidly drying soils

Table 4.15 Computer-relayed sensors

Sensor type	Relative cost of 1 sensor + equipment to record and view data	Positive aspects	Drawbacks
Echo Probe	Low	Continuous Wireless capability	Durability is questionable Gives readings in Volts
Hortimeter (electronic tensiometer)	High	Continuous Easy to install Wireless Data viewed on computer	Keep computer on Very dry soil problematic Requires some maintenance
C-probe	Mid-high	Continuous Multi sensors Wireless Support readily available Data viewed on website	Need expert to install Readings displayed as trends Sometimes get erratic readings

Grower satisfaction with soil moisture sensor information

The second survey administered to the growers on soil moisture sensors was the main tool used to collect information addressing the following specific objectives of the project:

- Determine producers' satisfaction with soil moisture monitoring information.
- Find out which devices producers have decided to adopt for future years, if any.
- Establish producers' needs regarding irrigation scheduling.

Fifteen participants responded out of the total of 19 participating farms (two of the sites were OMAFRA research sites; one berry grower plowed the field mid season, and one farm in NOTL was not irrigated). All were interviewed by phone except one, who filled out the questionnaire and sent it in by e-mail.

The soil moisture monitoring information collected included soil moisture monitoring data provided to the growers during the growing season through the sensors and equipment data, the face to face meetings with the growers, the handouts distributed during field days and the meeting at the end of the project where the complete data set was presented to the individual growers.

The findings showed that the growers were satisfied with the equipment and that the growers consulted at least one specific piece of equipment (if not two) regularly during the season to validate their decisions to irrigate. The hub peach growers used tensiometers for consultation because he walked the fields regularly. The berry grower consulted the C-probes as theses gave him a detailed, continuous reading for fine-tuning his irrigation decisions. The pepper grower used the tensiometers to confirm (validate) his decision to irrigate or not during the season. The tomato grower liked the electronic tensiometer (Hortimeter) because it provided a digital display in the field when he walked the field, and it also provided a graphical depiction of results that he could easily access from his home.

All equipment was useful and generally performed well. There was a range of costs associated with the various equipments, as well as a range of data viewing capabilities. Some equipment had to read manually, while others were automated to log the data and store it, and some even went a step further and displayed the graphs of soil moisture in near real-time. All the sensors except the tensiometers and portable TDR can be converted to near real-time with addition of necessary components. For this trial only the C-probes and the Echo probe were set up for this capability due to costs and equipment availability through partners.

There is no “best” piece of equipment for monitoring soil moisture; all have their own positive aspects as well as drawbacks, and a lot of these depend on grower preference. Therefore, some key points for consultants to ask growers and for growers to take into consideration before investing in soil moisture monitoring sensors are:

- How much money are you willing to invest?
- Do you require real-time readings, or just the occasional verification of what the soil moisture is?
- Do you require actual volumetric water content readings, or will a trend line be sufficient?
- What are your management needs; how much of irrigation precision do you require for your crops?
- What are your preferences and practices (do you like to walk your fields and check the equipment readings, or would you rather look up the data on a computer)?
- How much time can you spend on downloading and maintaining the equipment? Check the amount of maintenance that may be required for the instrument.
- How much “down” time can you afford if the sensor malfunctions? Maybe have two or more sensors installed. Look into the after sales services offered.
- Finally, how much time are you willing to put into gathering the data from the system?

The following section contains the summary responses and discussions of the growers’ answers to the second survey questions, organized by category of question asked.

Usefulness of soil moisture monitoring information

Growers seemed to prefer the sensors which displayed information to their computer in near-real time, as this eliminated the need to download any data. They also stressed the importance of being able to read the sensors when they walk their fields. At the onset of the project, all of the hub growers were shown the weather station, and informed how to obtain actual weather readings from the displays. They were also shown how to read the displays of the sensors that were installed in their fields (if the sensors had displays to read). However, we cannot be sure how often these sensors were consulted. From discussions with the growers, it was clear that due to the myriad of sensors installed on the hub sites, they were not always able to distinguish one sensor from the other. As well, some of the sensors displays were located at a distance from where the senor was buried, and this led to some confusion. In the field, the growers tended to favor sensors which were visible (i.e. sticking out of the soil) and which had dials or displays directly on them.

Survey results to this question confirmed the difficulty experienced delivering on-time soil moisture data to every grower regularly during the growing season. Indeed, as mentioned previously, the project was very ambitious; there was too much data to compile and distribute for the resources allotted to this task. As a result, many satellite site growers, who did not receive data during the growing season, were unable to answer some of the questions (Not Applicable).

In Table 4.13, grower satisfaction with soil moisture monitoring information they received is shown. The participants were asked to rate from 1 (poor) to 5 (great) several criteria. Overall, the table showed that when the frequency of data delivery was on-time, the information received was very useful, fairly clear and user friendly while the criteria with which growers were definitively less satisfied is the time required to assimilate and understand the data. Since the growers are extremely busy during the growing season, they would appreciate to minimize the amount of time spent on irrigation scheduling by implementing techniques which are not time consuming.

Table 4.13 Satisfaction with soil moisture information received

Criterion	Average Growers' Satisfaction
Usefulness	4.4
Clarity	4.0
User friendliness	4.0
Time required to assimilate and understand the data	3.8
Frequency of data delivery	3.4

Scale of 1 (poor) to 5 (great)

Using soil moisture monitoring to facilitate current irrigation scheduling and improve irrigation efficiency

The usefulness criterion was then further investigated to determine if the soil moisture monitoring data facilitated their irrigation scheduling and helped them irrigate more efficiently. The results, in Table

4.14, show that 5 (33%) growers have decided to modify their current irrigation scheduling practices in response to the data they received and thus, the data facilitated their irrigation scheduling while 4 (27%) estimated it helped them to irrigate more efficiently. According to the growers, because they were better informed to make decisions regarding the timing and amount of water to apply, they improved their irrigation efficiency. Whereas, a grower in the region of Niagara-On-The-Lake, where water is delivered to the irrigators through a municipal drainage system, explained that although he considers the soil moisture monitoring data facilitated his irrigation scheduling by guiding his decisions, he was not able to adjust his irrigation timing. The non-flexibility of his system was definitively a limiting factor for improving his irrigation efficiency. Interestingly, this grower who was part of the satellite farm participants met with the field technicians frequently to get readings with the portable FieldScout TDR. This explains why, contrary to others satellite site growers; he had access to soil moisture data during the growing season and used it to guide his decisions.

Table 4.14 Usefulness of soil moisture monitoring information

	Usefulness	No. of Growers
Improve Irrigation Efficiency	Yes	4
	No	1
	NA	10
Modify Current Irrigation Scheduling Practices (Facilitate IS)	Yes	5
	No	0
	NA	10

Saving or spending water by using soil moisture sensors

For the remaining growers who answered that they improved their irrigation efficiency, it is all the more relevant in the framework of this project to determine whether they considered having saved or spent water as a result of using the soil moisture monitoring data. Indeed, water economies have been performed according to two out of the four hub site growers. Although one grower was not able to express his water savings as a percentage, he affirmed that the soil moisture monitoring information has allowed him to shorter his irrigation runs, while the other grower estimated he saved 25-30% by using the information. On the other hand, one of the growers who claimed that he has spent 30% more water, suspected that his increase in water use might be better explained by the fairly hot and dry summer experienced, rather than because he used the soil moisture data to guide his decisions. Finally, the last grower said that he used more water because he realized he was not irrigating deep enough into the soil profile. In this sense, he estimated he would have used 30-50% more water than usually by irrigating four times instead of three and much heavier, if the sensors had been in place earlier. They all agreed however that the quantity of water saved or augmented during the growing season was worth the investment in soil moisture monitoring sensors, since these management tools help to obtain better quality crops. This brings out the importance of the growers being able to access near real-time information in order to adjust their irrigation amounts.

Usefulness of soil moisture monitoring devices

Once the growers' satisfaction with soil moisture monitoring information was assessed, it was determined which of the installed sensors on the four hub sites were useful or the most helpful. Here, it is important to note that one grower was not able to tell the difference between sensors and therefore could not distinguish which sensor the data he was using was coming from, although the data he was looking at on internet was very useful to him. As he was not able to rate any other devices the results show an average of the scores that were allotted by the three other participants. The same goes for the flow meters, as they were installed only on three of the four hub sites.

Table 4.15 shows usefulness scores of each sensor according to the growers. From the results, the C-probe received the highest score. However, it is important to note that at the start of the project trial, the C-probe and manual tensiometer data was the main data provided to the producers in order to not overwhelm them with data. By mid-season, all data outputs were provided. Therefore this may have influenced the results. Also the C-probe data has real-time capability, which other sensors could do if equipped to do so. Therefore it may not be the sensor but the availability of the information which is preferred.

The growers' preference is detailed in the last section where the growers needs regarding irrigation scheduling are explained.

Table 4.15 Averaged usefulness score for each device installed on the four hub sites

Equipment	Averaged Usefulness Score
Manual Tensiometer	3.3
Manual Portable FieldScout TDR	2.5
Echo Probe	3.2
C-Probe	4.3
Gro-Point TDR	3.2
Watermark (Watchdogs)	2.8
Campbell Water Content Reflectometer	2.3
Hortau	3.3
Flow Meter	4.0

Scale of 1 (poor) to 5 (great)

According to the survey results, only one grower was totally unsatisfied with the sensors which he qualified as too complicated and too detailed. His opinion was shared by another grower who, although he appreciated the manual tensiometer because it was not complex and easy to read, found that the other devices were not user friendly and thus, not useful. On the other hand, the two other growers, for whom the data provided to be useful, claimed that it definitively helped them to reduce guesses in terms of irrigation timing and amounts of water to apply.

Growers estimates of yield and irrigation requirements

Growers were asked to estimate how their yields would have faired without irrigation and how their yields and irrigation water requirements were this year compared to other years. Generally, yields are a good indicator of how successfully growers provided on-time, and sufficient water to their crops to replenish moisture before yield-reducing stress occurred. Furthermore, knowing how irrigation water requirements were different this year from other years due to climate variance may explain why water use of some growers was augmented, even though the soil moisture sensors were used to guide decisions.

Table 4.16 shows, not surprisingly, that irrigation is essential to high value horticultural production in Southern Ontario. Indeed, the growers estimate that their yields would have been ranging from average to very low in the case where they would not have irrigated. The importance of irrigation is further illustrated by this grower statement: “I would never have grown strawberries without irrigation”.

Table 4.16 Quality of yields in 2007, compared to other years and without irrigation

	Yields	No. of Experimental Irrigated Area
Without irrigation	Excellent (much better than expected)	0
	Good (above average)	0
	Average (normal)	4
	Poor (below average)	9
	Very Low (much below what was expected)	6
This year compared to other years	Excellent (much better than expected)	3
	Good (above average)	8
	Average (normal)	4
	Poor (below average)	2
	Very Low (much below what was expected)	2

From these results, four (21%) of the growers estimated their yields, in the experimental irrigated area, were below average this year, compared to other years. However, it is impossible to determine whether it was due to inappropriate irrigation scheduling practices or to the very hot and dry summer that the region has experienced. Indeed, 14 growers mentioned that they irrigated more frequently and much heavier this year, compared to other years, to compensate for the hotter and drier summer they experienced. The degree to which their irrigation needs were higher however varied from grower to grower. For one grower, the irrigation need was one of the highest it has ever been since he started irrigating 5 years ago, for another who cultivates peppers under plastic beds; the crop water requirements which are similar from year to year needed just a bit more water this year. While in the case where the grower affirmed he had the same irrigation need, he justified it by the fact that he has to deal with a very limited water supply. He cannot irrigate more if crop water needs increase. He has to stretch his supply to ensure that he will not run the pond dry and thus that he has enough water to finish the growing season. Thus, it is important for the growers to be able to know how much water they will be requiring for irrigation purposes in a typical growing season.

Improving overall understanding of soil moisture levels and crop responses to irrigation scheduling

Finally, as a result of this project, 14 (93%) growers found that their overall understanding of soil moisture levels and crop response and irrigation scheduling has improved. Aside from the fact that the knowledge facilitated irrigation scheduling; it showed them what is going on in the soil profile, how the soil dries out and how soil water holding capacity varies with soil texture. They also mentioned that their understanding of concepts such as field capacity, permanent wilting point and irrigation trigger point improved. In the end, they estimated it helped them to better understand how to irrigate. However, when the growers were asked what their field capacity value was, only 3 (20%) growers were able to answer, of which only one answered correctly. The score was higher for knowing the irrigation trigger point. Out of the 8 (53%) growers who answered, only one did so incorrectly and another grower, who did not know the exact figure off the top of his head, stated it was around 50% of his field capacity value.

Sensors that growers have decided to adopt for future years

The second part of the survey determined which sensors (if any) growers have decided to adopt for future years. Table 4.17 shows that 7 (47%) growers have decided to adopt a sensor, whereas 3 (20%) have estimated it was not necessary and 5 (33%) were interested, but have not decided as yet which one they would like to install on their farm. Again, the C-Probe appears to be the growers' preferred device so far (not possible to distinguish the reason why).

Two growers who decided not to adopt a device estimate that their current irrigation scheduling practices are satisfactory. They consider that by feeling and observing the soil to determine the soil moisture content and by examining plant conditions and weather forecasts, they can adjust irrigation to meet the crop water requirements fairly well while preventing water losses. While, the third one found that each device has its own specific problems related to its usage, and that although the C-Probe appeared to be the best device, it is too expensive to install, especially since the results showed him that he was irrigating efficiently.

Table 4.17 Growers willing to adopt soil moisture technology

Yes	No	Undecided about sensors	Unsure which sensor to choose	Sensor	Explanation
X				C-Probe	He found that the C-Probes were handier. To him, it is very important to be able to access the soil moistures levels at anytime. As he his very busy, he prefers to look at the data during lunch times and evenings. Probes data on internet were allowing him to do so.
			X	Hortau or Portable FieldScout TDR	He is not fixed yet, he was interested by the manual portable FieldScout TDR or the Hortau tensiometer but he has to evaluate if it will be cost effective to install them.
			X	C-Probe or Hortau	He was interested by the C-Probe and the Hortau tensiometer because they seem fairly easy to use, they have low maintenance, they are not intrusive and the data can be downloaded easily on a computer.
	X			None	He will continue using the ET model, adjusting irrigation to weather and crop stage with in-field monitoring to make sure that the water being applied is sufficient and not excessive. Soil moisture monitoring would facilitate this.
X				Manual Tensiometer	Tensiometer, easy to read, very simple and cost effective.
X				Flow Meter	He would install a flow meter to know exactly how much water he applies.
X				Portable FieldScout TDR	It has to be cost effective; since he has too many stations to irrigate, the portable TDR might be better than the c*probe. However, he would prefer to install a c*probe than to use the portable TDR. Money is definitively an issue.
			X	C-Probe	He was looking on internet to some very useful data to him (he doesn't from which equipment it was, (i.e. C-Probe) but no decisions was taken yet concerning the adoption on an irrigation scheduling technique.
	X			None	They do not think they need to adopt any of these equipments.
			X	Manual Tensiometer or C-Probe	He preferred the Manual Tensiometer because it is portable and relatively inexpensive. However depending on the budget (i.e. acres/cost) he would invest in a C-Probe.
X				C-Probe	The C-Probe is the more userfriendly tool.
	X			None	They all have to seem to have their specific problems with them all. The C-Probe seems to be the best choice, but it is too expensive, especially since she knows she is doing a good job without it.
X				C-Probe	He is interested by the C-Probe because it seems easy to access the data and it worked better than the other equipments.
		X		Not Sure Which	He would possibly adopt one of them, but he is not sure which one.
X				C-Probe Network	He is not interested to install any of the equipments for itself on his field but he would be interested in a C-Probe network where he could access by internet the moisture trends of the soil profile.
47% (7/15)	20% (3/15)	14% (2/15)	20% (3/15)		

Growers irrigation scheduling needs

Preferences in soil moisture data delivery method

Most of the growers surveyed preferred obtaining the results from the internet, or their personal computer (table 4.18). This may help to explain why the C-probe was one of the most preferred instruments. Otherwise, they preferred to get the information directly from the field. This does not mean that both are mutually exclusive as some growers prefer both (however, in the survey they were only allowed one choice). The survey further revealed that those who were comfortable with computers found that the C-probe was handier and fairly user friendly. One grower mentioned that the internet was allowing him to access the soil moisture levels at anytime he needed - whether it was during lunch times or evenings. On the other hand, one grower who was not familiar with computers preferred to access the soil moisture monitoring data directly in the field with equipment such as a manual tensiometer, which he qualified has easy to read.

Table 4.18 Growers' preference to accessing soil moisture sensor data

Means to Access Data	No. of Growers
Directly in the field	5
Fax	0
Internet	6
Consultant	0
E-mail	1
Directly in the field or E-mail	1
Internet or E-mail	1
Fax or E-mail	1

Willingness to invest money and time in the sensors

Sensor cost was also an important issue regarding the choice of equipment; a few growers chose non-permanently installed equipment, such as the portable FieldScout TDR, or the manual tensiometer to the C-Probe because they are relatively inexpensive. One of the growers has to irrigate many stations; the portable FieldScout TDR would thus be more cost effective than adopting a C-Probe. The growers of peaches in Niagara-On-The-Lake mentioned they would be interested to be part of a C-Probe network which would allow them to access the moisture trends of various regional soil profiles without having to install their own equipment.

All participants mentioned that while they do not have extra time; they are extremely busy during the whole growing season, most of them consider that irrigation scheduling is important and that it worth to spend some extra time on it. While most prefer spend as little as time as possible on it, some consider it as part of their job and they will spend the time it requires to get it done. In this sense, one grower said: "These sensors are management tools which help to get better quality crops, I don't mind to spend extra time on it due to the benefits I get."

Table 4.19 Extra time that growers would be willing to spend on irrigation scheduling

Extra Time	No. of Growers
Whatever	4
Some daily	1
50% more	1
A bit more	1
10 minutes/day	3
10-15 minutes/day	1
20 minutes/day	1
1 hr/week	1
1-1.5 hr/week	1
Not applicable	1

Intentions of using soil moisture information in the future

When the growers were asked how they intend to use the soil moisture monitoring equipment, most of them (33%) answered they would use it to schedule irrigation; that they would adjust their irrigation timing and amount (Table 4.20). They would use the information to decide when to trigger irrigation and how much water to apply to maintain soil moisture at the right level. Two growers further mentioned that irrigation scheduling using soil moisture monitoring information would allow them to avoid over/under irrigation. In addition, 2 growers, being confident on the amount of water applied, intend to use the information to adjust their irrigation frequency by better determining when to water, whereas for a peach grower, who cannot be flexible in terms of irrigation timing, intended to use the information to better determine the amount of water applied he should apply. Indeed, he is aware of the two critical development stages when peaches need a boost of water (i.e. cell division and fruit sizing before harvest), he is however limited by his irrigation system. Even if he recognizes the perfect timing for irrigating, it takes 7-10 days to irrigate the whole field with his overhead gun. The soil moisture monitoring information would in this case allow the adjustment of the amount of water applied, since the timing remains inflexible. Furthermore, 3 growers who were using the results presented to them at the end of the season, stated they would use the data to continue irrigating in their way and validate their decisions with the sensors. One has specified he would use it to look at the trends in the soil profile to see if water reaches the root zone deep enough and to see if the crops need water sooner than what he expects from his observations of the plants conditions and the soil feel and appearance. Another grower clearly stated he was intending to use the soil moisture monitoring information to improve his on-farm water use efficiency. Only one grower has not been involved enough in the project to know about the kind of information he was able to obtain with the different sensors.

Table 4.20 Details on how the growers intend to use the soil moisture information

Intention to Use Soil Moisture Monitoring Information	No. of Growers
Adjust Irrigation Timing & Amount	6
Adjust Irrigation Timing & Amount to Avoid Over/Under Irrigation	2
Adjust the Amount	1
Adjust the Timing	2
Validate her Current Irrigation Scheduling Practices	2
Improve On-Farm Water Use Efficiency	1
None	1

Recommendations by growers to improve the project

Although the grower participants were satisfied with the overall project, a few recommendations they has when asked, were addressed towards improving the project if funding is available in the future. The first one, suggested by most of the satellite sites growers was to receive the data in a timelier manner during the growing season to be able to use the data for adjusting their irrigation. Even though the data helped them to validate their current irrigation practices in terms of timing and amounts of water applied, the project would have yielded better results with on-time delivery of sensor data. In addition to this, one of the hub site growers claims that better results would definitively have be obtained if explanations of how the different sensors worked and how to access the data had been given earlier on in the project. The second recommendation stated by a few cooperators is that the project which was well undertaken should be re-tried only with the growers' preferred sensors, or more specifically, as mentioned earlier, with the C-Probe. Other recommendations includes, indicating the benchmarks on the graphs so that they could remember theirs, and debugging the data gaps due to equipment failure and technical errors to get a complete data set. According to one of the hub site growers, research should be emphasized on the development of equipment pieces which are more practical, user friendly and cost effective; a tool which would give on-site data showing whether the soil moisture is above or below the irrigation trigger level, and this for the different benchmarks.

Other grower comments

When the growers were asked to share any other last comments, most of them demonstrated enthusiasm with the overall project outcomes by saying how it was a really good, comprehensive project which was well run and organized. Being very concerned about limited water resources, one of the growers found the project very helpful whereas another claimed that being part of this interesting project helped him to manage irrigation for future years. Some of the comments such as "It has been a great experience to have these equipments, it showed how much guessing is involved in irrigation scheduling at the moment and how crucial the probes are to help reducing the guesses." or simply "Thank you for teaching us!" further emphasize their satisfaction for being part of the experience.

CHAPTER 5. Irrigation Water Use

Assessment of Irrigation Performance

The first survey administered to the growers (on irrigation water use) was conducted to obtain baseline information on current irrigation scheduling practices and growers' perceived water needs. The information collected was used to determine whether crop water requirements were being met efficiently while preventing water losses. Assessing on-farm irrigation performance is important to determine when implementing scientific irrigation scheduling techniques, such as soil moisture monitoring, as these tools may help achieve on-farm water savings.

A copy of the survey given to the growers can be found in Appendix B. The names of the participants have been removed to preserve confidentiality. 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), and the irrigation system (system type and brand; number of emitters or sprinklers; emitter and drip line spacing; emitter or nozzle and system flow rate; system pressure; pump brand, model number, flow rate, rpm, impellor size and horsepower), as well as the irrigation scheduling (daily system operating time and amount of water applied).

The next sections in this Chapter outline some of the key information collected in the survey, including current water management practices from the growers, and actual crop water requirements for 2007.

5.1 Irrigation System Peak Flow Rate

Irrigation systems should be designed and operated to efficiently match crop water requirements. This can be verified by comparing current irrigation system flow rates with the estimated peak flow rate requirement, based on historical daily evapotranspiration (ET) peak values, as follows.

- Estimated Peak Flow Rate Requirement

Estimated Peak Flow Rate Requirement = Estimated Peak Flow Rate Requirement per hectare × Irrigated Area

Where:
Estimated Peak Flow Rate Requirement = Irrigation System Peak Flow Rate Requirement [m^3/hr]
Estimated Peak Flow Rate Requirement per hectare = Values in Table 5.1 [m^3/hr/ha]
Irrigated Area = Values in Table 5.3 [ha]

- Current Irrigation System Flow Rate

Sprinkler ⇒ Current Irrigation System Flow Rate = Nozzle Flow Rate × No. Nozzles
Drip ⇒ Current Irrigation System Flow Rate = Emitter Flow Rate × No. Emitters

Where:
Current Irrigation System Flow Rate = Irrigation System Output Flow Rate [m^3/hr]
Nozzle Flow Rate = Values in Table 5.2 [m^3/hr]
No. Nozzles = Values in Table 5.2
Emitter Flow Rate = Values in 2 [m^3/hr]
No. Emitters = Values in 2

Table 5.1 Maximum daily ET values and estimated peak flow rate for several locations in Southern Ontario

Location	Daily ET Peak Values (mm/day)	Estimated Peak Flow Rate Requirement per hectare (m^3/hr/ha)*
Dresden (London)	4.9	2.0
Leamington (Ridgetown)	5.2	2.2
Simcoe	5.6	2.3
NOTL (Vineland)	5.3	2.2

Source: Maximum Daily ET Values are taken in OMAFRA (2004)

* Multiply values in m^3/hr/ha by 1.78 to convert to USGPM/acre

Table 5.2 Irrigation System Information per zone (as provided by the growers)

#	Site	System	Irrigated Area (ha)	No. Emitters	Emitter Flow Rate (m^3/hr)	No. Nozzles	Nozzle Flow Rate (m^3/hr)	System Flow Rate (m^3/hr)
1	Leamington	Surface Drip	1.2	33000	0.00041	NA	NA	13.6
		Subsurface Drip	1.2	33000	0.00041	NA	NA	13.6
2		Surface Drip	8.1	148800	0.00031	NA	NA	45.4
		Surface Drip	9.7	176800	0.00026	NA	NA	45.4
3		Surface Drip	5.3	105391	0.00058	NA	NA	61.3
4		Subsurface Drip	3.2	72600	0.00064	NA	NA	46.7
5	Dresden	Subsurface Drip	7.7	216000	0.00061	NA	NA	130.8
6		Subsurface Drip	0.4	31200	0.00083	NA	NA	26.0
7		Boom	4.1	NA	NA	29	2.2	63.6
8	Simcoe	Surface Drip	0.9	56000	0.00091	NA	NA	50.9
		Surface Drip	0.9	56000	0.00091	NA	NA	50.9
		Surface Drip	1.5	23400	0.00091	NA	NA	21.3
9		Solid Set Sprinkler	1.8	NA	NA	Unknown	Unknown	82.4
10		Solid Set Sprinkler	1.2	NA	NA	30	4.2	90.8
11	NOTL	Overhead Gun	2.4	NA	NA	1	70.2	70.2
12		Sprinkler PTO Pump	1.0	NA	NA	44	0.8	36.0
13		Solid Set Sprinkler	1.2	NA	NA	20	15.4	308.4
14		Sprinkler PTO Pump	0.4	NA	NA	1	68.1	68.1
15		Overhead Gun	4.1	NA	NA	1	68.1	68.1

The system flow rates in Table 5.2 were calculated with irrigation system information given by the growers. The growers for the most part were very busy and therefore the questionnaires were answered quickly, and sometimes the surveyor was taking notes directly in the field with the grower. None of these responses have been validated. This may explain the large discrepancies between estimated and current peak flows in the next table (Table 5.3).

Flow rates can be compared using the following formulae.

$$\text{Difference [\%]} = \frac{\text{Current Value}}{\text{Estimated Value}} \times 100\%$$

Where: Difference = Difference between Current Irrigation System Flow Rate and Estimated Peak Flow Rate Requirement [%]
Current Value = Current Irrigation System Flow Rate [m^3/hr]
Estimated Value = Estimated Peak Flow Rate Requirement [m^3/hr]

Table 5.3 shows that current irrigation system flow rate of every grower is largely exceeding estimated peak flow rate requirements (see last column on difference %). However, this estimation, which is based on local ET peak, does not represent the on-farm irrigation water requirement. It only gives an estimate for regional requirements. Further checks should be made before stating that the crops are over irrigated.

Table 5.3 Percent difference between estimated peak flow rate requirement (calculated) **and current irrigation system flow rate** (information from grower)

#	Crop Type	Irrigated Area (ha)	Estimated Value (m^3/hr)* *(calculated per zone)*	Current Value (m^3/hr)* *(grower information)*	Difference (%)
1	Tomato (Surface Drip)	1.2	2.6	13.6	258
	Tomato (Subsurface Drip)	1.2	2.6	13.6	258
2	Tomato (1st Zone)	8.1	17.5	45.3	129
	Tomato (2nd Zone)	9.7	21.0	50.5	120
3	Tomato	5.3	11.4	61.5	270
4	Tomato	3.2	7.0	36.9	263
5	Pepper	7.7	15.7	130.7	416
6	Pepper	0.4	0.8	25.7	1572
7	Pepper	4.1	8.3	63.6	384
8	Strawberry (Outside)	0.9	2.0	50.2	1236
	Strawberry (Tunnel)	0.9	1.4	51.5	1791
	Raspberry (Tunnel)	1.5	2.5	21.3	422
9	Strawberry	1.8	4.2	82.4	992
10	Strawberry	1.2	2.8	90.5	1603
11	Peach	2.4	5.4	70.2	654
12	Peach	1.0	2.2	36.0	806
13	Peach	1.2	2.7	307.3	5751
14	Peach	0.4	0.9	67.3	3811
15	Peach	4.1	8.9	68.0	380

* Multiply values in m^3/hr by 4.4 to convert to USGPM

Table 5.3 draws attention to how much guess work is involved in the grower's current irrigation system layout and output capacity. More importantly, it emphasizes how water applications based on irrigation system setup and operation does not correspond to how crop water needs are gauged by the growers. Soil moisture monitoring through sensors can play a significant role to help growers manage their soil moisture in a straight forward way, and reduce unnecessary calculations and guessing.

5.2. Annual Irrigation Water Use

The next step is to compare current annual irrigation water use with annual irrigation water requirement, based on crop water needs. According to the irrigation system assessment guide, if current annual irrigation water use exceeds annual irrigation water requirement by 10%, the system should be reviewed (Nyvall & Tam, 2005).

5.2.1. Annual Irrigation Water Requirement

Annual water requirement is determined using system application efficiency, effective precipitation, crop water requirements and maximum amount of soil water in the root zone.

First, Table 5.4 shows application efficiency for several irrigation systems (Pitblado et al., 2007; Nyvall & Tam, 2005).

Table 5.4 Application efficiency for several irrigation systems

Irrigation System		Application Efficiency (%)
Sprinkler	Undertree Solid Set	75
	Overhead Solid Set	72
Gun	Travelling	68
Drip	Surface	84
	Subsurface	84

Then, effective precipitation (EP) defined as rainfall higher than five millimetres, which does not evaporate entirely before infiltrating the soil and thus add moisture to the soil profile, is determined as follows (Nyvall & Tam, 2005). The Irrigation System Assessment Guide of British Columbia suggests multiplying the remaining precipitation by a factor of 75% to account for runoff and percolation losses. This efficiency factor is also comparable to the one determined by Pitblado et al. (2007); the averaged efficiency for the different soil types being of 79%.

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

Where: EP = Effective Precipitation [mm]
R = Rainfall [mm]

Thereafter, to estimate the rate of evapotranspiration of a specific crop, called the crop evapotranspiration (ETc) or the crop water use, the *reference evapotranspiration (ETo)* have to be calculated first. ETo is defined by Brouwer and Heibloem (1986), as being the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. During the last fifty years, a large number of empirical methods have been developed and used to estimate ETo including, the Blaney-Criddle, Thornthwaite, Hamon, Penman-Monteith, Priestley-Taylor, Hargreaves and Turc method. Their performance is highly variable and depends directly on the climate data quality and availability. Generally, if all the required climatic parameters are available (i.e. the air temperature, the solar radiation, the wind speed and the relative humidity), the Penman-Monteith method is recommended (Allen et al., 1998; Irmak et al., 2003; Irmak et al., 2003; Bois et al., 2005). Since, the necessary climate data were provided for the hub sites from the on-site weather stations, the Penman-Monteith method was used to calculate ETo.

Next, one must consider the influence of crop type and growth stage on the calculated ETo by applying the proper crop coefficient (Kc) (Table 5.5). The growth stages for the crop coefficient are defined in Table 5.5.

$$ETc = ETo \times Kc$$

Where: ETc = Crop evapotranspiration or crop water use [mm]
ETo = Reference evapotranspiration [mm]
Kc = Crop coefficient (Values in Table 5.5)

Table 5.5 Crop coefficients (Kc)

Crop Type	Growth Stage	Kc
Peaches	April	0.2
	May	0.3
	June (1-15)	0.4
	June (16-30)	0.6
	July	1
	August	1
	September	0.95
Tomatoes	From seeding to 1st flower	0.4
	From 1st flower to maximum row fill	0.7
	Remainder of crop	1
Peppers	From seeding to 1st flower	0.4
	From 1st flower to maximum row fill	0.7
	Remainder of crop	1
Raspberries	Initial	0.4
	Mid season	1.2
	Late season	0.75
Strawberries	Initial	0.4
	Mid season	1.05
	Late season	0.7

Source: Peaches, tomatoes and peppers crop coefficients data are taken from OMAFRA (2004) while raspberries and strawberries data are taken from Van der Gulik (2001).

Table 5.6 Growth stages and associated indicators

Growth Stage	Indicator	Kc
Initial	Planting date (or start of new leaves for perennials to 10% ground cover).	Kc_{ini}
Mid season	Effective full cover to maturity, indicated by yellowing of leave, leaf drop, browning of fruits.	Kc_{mid}
Late Season	Maturity to harvest.	Kc_{end}

Finally, to determine annual irrigation water requirement, the assumption that the soil is at field capacity at the start of the growing season is typically made. The maximum amount of soil water stored in the rooting depth (MSW) at the start of the growing season can be calculated using the following formulae.

$$MSW = \frac{FC \times CRD}{100}$$

Where: MSW = Maximum amount of soil water in the rooting depth [mm]
FC = Field Capacity [Volumetric Soil Water Content, %] (Values in Table 7)
CRD = Crop rooting depth [mm] (Values in Table 6)

Table 5.7 Crop rooting depth for several crop types at the start of the growing season

Crop Type	CRD (mm)
Tomato	300
Pepper	300
Strawberry	300
Raspberry	600
Peach	750

Source: OMAFRA (2004)

Finally, to determine annual irrigation water requirements, the total amount of effective precipitation that was received during the growing season and the maximum amount of soil water stored in the rooting depth at the start of the growing season are both subtracted to the crop water use while the system application efficiency is also taken into account as follows. Table 5.8 shows the calculated annual irrigation water requirement for each grower.

$$\text{Annual Water Requirement} = \frac{ETc - EP - MSW}{AE} \times 100\%$$

Where: Annual Water Requirement = Annual Water Required by the Irrigation System [mm]
ETc = Crop Water use [mm] (Values in Table 5.8)
EP = Effective Precipitation [mm] (Values in Table 5.8)
MSW = Maximum of Soil Water Stored in the Rooting Depth at the Start of the Growing Season [mm] (Values in Table 5.8)
AE = Application Efficiency [%] (Values in Table 5.3)

Table 5.8 Annual irrigation water requirements for 2007

#	Crop Type	AE (%)	ETc (mm)	EP (mm)	FC (%)	MSW (mm)	Annual Irrigation Water Requirement (mm)*
1	Tomato (Surface Drip)	84	286.5	133.8	13	40	135
	Tomato (Subsurface Drip)	84	286.5	133.8	11	34	140
2	Tomato (1st Zone)	84	286.5	133.8	16	48	125
	Tomato (2nd Zone)	84	286.5	133.8	15	44	130
3	Tomato	84	286.5	133.8	11	34	140
4	Tomato	84	286.5	133.8	17	50	120
5	Pepper	84	334.0	133.3	13	38	190
6	Pepper	84	334.0	133.3	21	64	160
7	Pepper	72	334.0	133.3	15	46	215
8	Strawberry (Outside)	84	562.1	109.1	12	36	495
	Strawberry (Tunnel)	84	291.3	0	15	46	290
	Raspberry (Tunnel)	84	269.7	0	16	96	205
9	Strawberry	74	415.6	109.1	21	62	330
10	Strawberry	74	415.6	109.1	10	31	370
11	Peach	68	367.6	120.8	15	116	190
12	Peach	74	367.6	120.8	17	130	160
13	Peach	74	367.6	120.8	20	149	130
14	Peach	68	367.6	120.8	17	125	180
15	Peach	68	367.6	120.8	22	163	120

*This is a simplification of the actual water requirement for several factors, notably the assumptions in irrigation water application efficiency estimates which vary depending on individual irrigation systems, as well as the EP calculation based on using 0.75 as an efficiency factor which may change from region to region.

5.2.2 Annual Current Irrigation Water Use

Annual current irrigation water use can be calculated using two different methods. It can be determined using irrigation system information and system operating time records as follows.

$$\text{Annual Current Irrigation Water Use} = \frac{\text{System Flow Rate} \times \text{Irrigation System Operating Time}}{\text{Irrigated Area}} \times 1000$$

Where: Annual Current Irrigation Water Use = Irrigation Water Use per Year [mm]
System Flow Rate = Current System Flow Rate [m^3/hr] (Values in Table 5.2)
Irrigation System Operating Time = Values in Table 5.9 [hrs]
Irrigated Area = Values in Table 5.3 [m^2]

Another way of determining the annual current irrigation water use is by using the flow meter readings installed at three of the hub sites. It is relevant to also consider the irrigators' personal water use estimation. Table 5.9 shows the calculated annual irrigation water uses, obtained in three different ways, including the irrigators' personal irrigation records, which are usually based on water use estimations.

Table 5.9 Calculated current water use for 2007

#	Crop Type	Irrigation System Info. & System Operating Time Records		Flow Meter Data		Personal Irrigation Records		Difference (%)
		Time (hrs)	Water Use (mm)	Time (hrs)	Water Use (mm)	Time (hrs)	Water Use (mm)	
1	Tomato (Surface Drip)	176.5	197.7	144.8	191.4	---	---	3
	Tomato (Subsurface Drip)	176.5	197.7	144.8	191.4	---	---	3
2	Tomato (1st Zone)	66.0	37.0	---	---	---	---	---
	Tomato (2nd Zone)	114.0	53.3	---	---	---	---	---
3	Tomato	140.0	163.1	---	---	---	---	---
4	Tomato	133.5	192.6	---	---	---	---	---
5	Pepper	42.0	71.4	42.0	77.0	---	---	-9
6	Pepper	98.0	629.6	---	---	---	---	---
7	Pepper	56.0	88.0	---	---	---	---	---
8	Strawberry (Outside)	121.5	710.8	---	---	---	---	---
	Strawberry (Tunnel)	121.5	701.0	112.4	619.9	---	---	12
	Raspberry (Tunnel)	155.5	215.4	---	---	---	---	---
9	Strawberry	13.5	62.5	---	---	13.5	114.8	45
10	Strawberry	23.6	176.9	---	---	---	---	---
11	Peach	25.5	73.7	---	---	25.5	114.3	36
12	Peach	15.0	53.4	---	---	---	---	---
13	Peach	4.0	Unknown	---	---	4.0	101.6	---
14	Peach	1.3	21.9	---	---	1.3	50.8	57
15	Peach	126.0	212.0	---	---	---	---	---

From Table 5.9, when comparing the water use calculated with irrigation system information provided by the first 8 growers with the data based on flow meter readings, the differences are quite small. So, it appears that the information provided by the growers is quite accurate, since it more or less matches the flow meter data. However, this table also reveals that some growers personal irrigation water use estimates (growers 9, 11, 13, 14) are not the same as what was calculated with their irrigation system information. The table highlights the extent of the guessing involved in some water managment practices. The water growers perceive as being applied, does not match with what the system is actually applying. But then again, the question is raised of how reliable the information provided is used to calculate the "Irrigation Systems Information" column (based on data in Table 5.2), which was information provided by growers and not verified in the field. For individual grower irrigation record details refer to Appendix D.

5.2.3 Comparing the Annual Irrigation Water Requirement to the Annual Current Irrigation Water Use

To compare annual irrigation water requirements (calculated in Section 5.2.1) to annual current irrigation water use (calculated in Section 5.2.2), which was determined using flow meter readings (this data was given priority), or using values calculated using irrigation system information and recorded system operating time, or lastly using values based on irrigators' personal water use estimation. This order was based on the degree of confidence we had in the data. Indeed, the information given by the growers about their irrigation system, system operating time records and personal water use estimates cannot be verified.

Table 5.10 Comparison of the annual irrigation water requirement (based on Table 5.8) to the annual current irrigation water use (based on growers)

#	Crop Type	Annual Irrigation Water Requirement (mm)	Annual Current Irrigation Water Use (mm)	Irrigation water difference (%)
1	Tomato (Surface Drip)	134	191	30
	Tomato (Subsurface Drip)	142	191	26
2	Tomato (1st Zone)	126	37	-71
	Tomato (2nd Zone)	130	53	-59
3	Tomato	141	163	13
4	Tomato	123	193	36
5	Pepper	194	77	-60
6	Pepper	162	630	74
7	Pepper	215	88	-59
8	Strawberry (Outside)	496	711	30
	Strawberry (Tunnel)	292	620	53
	Raspberry (Tunnel)	207	215	4
9	Strawberry	331	63	-81
10	Strawberry	372	177	-52
11	Peach	193	74	-62
12	Peach	158	53	-66
13	Peach	132	102	-23
14	Peach	180	22	-88
15	Peach	124	212	42

From Table 5.10, the growers with flow meters (growers 1, 5 and 8) had more reliable data to work with than the others. The tomato grower 1 over irrigated by about 50 to 60 mm per year; and the pepper grower under irrigated by 45 mm per year; and the berry grower over irrigated by 330 mm inside the tunnels, and by 210 mm in the open field. The water requirements inside the tunnels were lower than in the open fields because the micro climate inside the tunnels had a high relative humidity, and less direct sunlight exposure, as well the plants were less subject to ET losses from wind.

Most of the tomato growers over irrigated, except grower 2 who had a lower irrigation amounts compared to the other tomato growers because he is constrained by his reservoir's size. He was very concerned with his limited water supply; he tended to stretch his water use to make sure he had sufficient water for the growing season. That may explain why he under irrigated so much. Most of the peach growers under irrigated.

Again, the differences (last column) are due to annual current irrigation water use, which was calculated based on irrigation system information provided by the growers (this information was not validated); flow meter data; and in one case (grower 13) it was based on an estimate of irrigation water use. It is difficult to validate this column of data (except where flow meters were installed; growers 1, 5 and 8), so the reliability in the differences column remains questionable. For more information on irrigation applications, see Appendix D which has the details of the individual grower's irrigation records.

By examining the basis of how growers currently schedule irrigation the reason for over or under irrigating becomes clearer; almost all growers based their decisions on the plant growth stage and on the weather; few used the soil moisture sensors.

Table 5.11 Factors considered by growers to base their irrigation scheduling decisions on

Grower	Site	Growth Stage	Weather	Energy Cost	Data Moisture Sensors	Outcome Other Moisture Tests	Other
1	Leamington	5	5	2	4	3	None
2		5	5	1	NA	NA	None
3		5	5	2	NA	NA	Experience/Knowledge Field
4		4	5	1	NA	3	None
5	Dresden	5	5	3	5	4	None
6		5	5	2	NA	NA	None
7		5	3	3	NA	5	Capacity
8	Simcoe	5	5	1	1	1	None
9		3	5	1	NA	NA	Plant Stress State
10		5	5	1	1	1	Visual Inspection plants/soil
11	NOTL	5	4	1	4	3	None
12		5	5	1	1	1	None
13		4	5	3	2	1	None
14		5	5	1	NA	NA	None
15		5	5	1	NA	NA	WIN Online/Rain Gage

Scaled ranking from 1 = least important to 5 = most important
NA: not applicable

5.3 The Water Budget Method

The water budget method is an irrigation scheduling technique relying on estimated daily crop water use. The principle behind it is straightforward. The grower has to keep track of water additions (i.e. effective precipitation and irrigation) and losses (i.e. crop water use) in the root zone to determine the balance which is represented by the available soil water (ASW) stored in the root zone. This approach will allow the grower to determine with accuracy exactly when irrigation should be triggered before yield-reducing stress occurs. In the end, by comparing the calculated annual irrigation water requirement with the current annual irrigation water use, one can determine if over or under irrigation is performed and thus if water saving can be performed by implementing soil moisture monitoring.

To use the water budget approach, the irrigator has to determine the management allowable soil water depletion (MAD). Table 5.12 shows the values that were applied.

Table 5.12 Management allowable depletion values for several crop types

Crop Type	MAD (%)
Tomato (drip irrigation)	25
Pepper (drip irrigation)	25
Strawberry (drip irrigation)	25
Raspberry (drip irrigation)	35
Peach (overhead gun irrigation)	50

Then, once the soil profile has been brought to field capacity which is to say right after a saturating rainfall event or irrigation, the daily budget calculations can begin. Using this field capacity value, the grower has to subtract the daily crop water use (ETc) and add the daily effective precipitation to the maximum amount of soil water in the root zone.

When MAD is reached, irrigation should be triggered to replenish soil moisture to field capacity. The amount of water to be applied in this case can be estimated as follows.

$$IRR = \frac{MSW \times MAD \times 100}{AE}$$

Where: IRR = Depth of irrigation water to be applied [mm]
MSW = Maximum amount of soil water in the root zone [mm] (Values in Table 5.8)
MAD = Management allowable depletion [mm] (Values in Table 5.11)
AE = Irrigation system application efficiency [%] (Values in Table 5.4)

The grower can then determine the application time necessary for applying irrigation water calculated above by using the following formulae. The results are shown in Table 5.13.

$$T = \frac{E \times S \times IRR \times 100\%}{SFR \times AE \times 1000}$$

Where:
T = Irrigation System Operating Time [hrs]
E = Emitter Spacing along the Drip Line [m]
S = Drip Line Spacing [m]
IRR = Depth of irrigation water to be applied [mm]
SFR = Irrigation System Flow Rate [m^3/hr] (Values in Table 2)
AE = Irrigation system application efficiency [%] (Values in Table 3)

Table 5.13 Zone operating time required to apply the net depth of irrigation water with drip systems (Water Budget Requirement)

#	Crop Type	Emitter Spacing (m)	Emitter flow rate (m^3/hr)*	Line Spacing (m)	AE (%)	IRR (mm)	Irrigation Time (hr)
1	Tomato (Surface Drip)	0.3	0.00041	0.41	84	12	4.3
	Tomato (Subsurface Drip)	0.3	0.00041	0.41	84	10	3.6
5	Pepper	0.46	0.00061	0.51	84	11	5.2
8	Strawberry (Outside)	0.3	0.00091	0.25	84	11	1.1
	Strawberry (Tunnel)	0.3	0.00091	0.25	84	14	1.3
	Raspberry (Tunnel)	0.3	0.00091	0.46	84	40	7.2

* Multiply values in m^3/hr by 4.4 to convert to USGPM

Where:
AE = Application Efficiency [%]
IRR = Net Depth of Irrigation Water [mm]

Then, the grower has to add the calculated depth of irrigation water to be applied to the budget before continuing to track the soil water additions and losses in the root zone and determine the timing and amount of the following irrigation. The water budget method results are shown in Table 5.14.

Table 5.14 Comparison of current irrigation water use with irrigation water requirement using the water budget method for 2007

#	Crop Type	Rooting Depth (mm)	FC (%)	MSWS (mm)	MSWD (mm)	IT (mm)	IRR (mm)	IR - WBA (mm)	Current Irrigation Water Use (mm)	Difference (%)
1	Tomato (Surface Drip)	300	13.36	40	10	30	12	144.0	191.4	25
	Tomatoes (Subsurface Drip)	300	11.22	34	8	25	10	150.0	191.4	22
5	Peppers	300	12.58	38	9	28	11	155.0	77.0	-50
8	Strawberry (Outside)	300	12.01	36	9	27	11	429.0	710.8	39
	Strawberry (Tunnel)	300	15.40	46	12	35	14	280.0	619.9	55
	Raspberry (Tunnel)	600	16.04	96	34	63	40	200.0	215.4	7
11	Peach	750	15.43	116	58	58	85	170.0	73.7	-33

Where: FC = Field Capacity [%]
MSWS = Maximum Amount of Soil Water Stored in the Rooting Depth [mm]
MSWD = Minimum Soil Water Deficit [mm]
IT = Irrigation Trigger Point [mm]
IRR = Net Depth of Irrigation Water Applied [mm]
IR-WBA = Calculated Irrigation Water Requirement with Water Budget Method [mm]
EP = Effective Precipitation [mm]

5.5 References

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CHAPTER 6. Extending the results beyond the field

Discussion

All the soil moisture sensors proved to be useful in their own regard. In order to recommend a sensor, one must get an understanding of how the grower is going to use the information as well as how they want to receive the information. It is critical to determine how the grower uses the information for decision-making and how much time and effort will they truly devote to collecting and interpreting the information, before suggesting a system.

In terms of providing regular results, a portable TDR or a portable capacitance unit is only going to provide one time readings, therefore if consistent results are required, a fixed soil moisture sensor unit is more suitable as it is able to read soil moisture values constantly (at set time intervals) in the same location in the field. The portable sensors are useful when testing several fields, or when taking the occasional spot measurements to validate a decision to irrigate or not.

The choice of sensor is not related to the choice of a data logger, and the delivery of the data is yet another option. All sensors used in this project (except the manual tensiometers) had the capability to transmit the data to a computer directly. However, only the Hortimeter, the C-probe and the Echo probe transmitted the data to computers in near-real time during the 2007 growing season. The other sensors had to have their data downloaded via a shuttle or a laptop and then uploaded to a computer for viewing.

The general grower preference for sensors was for those which were able to transmit the data via radio telemetry or radio frequency to a website, or directly to the growers' computer for ease of access to the data. The survey brought to the forefront the importance to growers of obtaining near real-time data in order to make decisions that are important for their crops. Also, a very popular method was to obtain the data directly from the field, which the tensiometers were able to provide. Some sensors had encasing where displays could be read (e.g. Watchdogs), but this did not appear to be convenient for the growers because they could not see where the sensor was buried. Other sensors, such as the Gro-Points and WCRs, did not have a display in the field (data required downloading to view for this project), however they do have an option to enable data to be transmitted wirelessly to a computer, as for all of the sensors installed except the manual tensiometers. Sensors such as the Hortimeter (electronic tensiometer) in this project, proved to be versatile in this sense as they provided the option of viewing the soil moisture reading directly in the field on the digital display, and at the same time data was transmitted to a home computer where it was graphed.

The survey highlighted the importance of the sensor training aspect for the growers. They would like to have soil moisture readings available in the field, and they would also like to know how to access the data, and some would like to know how to download the data. The near real-time data is important to enable growers to make timely irrigation decisions. Currently, most growers used the plant and the weather as their gauge of when to apply irrigation water.

Almost all of the growers who participated in the project recognized the usefulness of the sensors. During the course of the project, all hub growers used at least one piece of equipment to validate what they were making in terms of irrigation choices. The strawberry hub grower consulted the C-probes, as theses gave him a continuous reading of his drip irrigation practices and the data was accessible via his computer. The peach grower consulted the manual tensiometer because he walked his orchards regularly, and found it convenient and easy to use, furthermore his use of the overhead gun made it not essential for him to have access to real-time data. The pepper hub grower used manual tensiometers to confirm (validate) his decision to irrigate or not during the season because he walked his fields daily, and also because it was the only piece of equipment on his field that allowed him to immediately read off the dial what the soil-water relationship was at that particular location. The tomato hub grower preferred the electronic tensiometers (Hortimeters) because they provided a digital display in the field when he walked the field, and they also provided a graphical depiction of results that he could easily access from his home at any time when he wanted to know what was going on in the soil.

At the tomato hub site, water in the growers' storage ponds ran out towards the end of the season (in September) and this prevented him from irrigating when he would have liked to. Some growers who lacked water (for example the peach growers and the tomato growers) were willing to set up soil moisture monitoring networks next season with the C-probes, Hortimeters or other radio telemetry transmittable data sensors, and invest in the equipment; they recognized the value of moisture sensors.

The growers who did not experience any water shortages this year (most of the berry growers) did not see any need to invest in the sensor technology in the near future. Since the data from the sensors was not consulted regularly, neither were they maintaining water budgets, or calculating ETc, they were not aware if indeed they were over or under irrigating. As long as there was no water stress for their plants, they were not overly concerned.

Because 2007 was such a dry year, no significant water savings could be made in any of the regions. In the NOTL, Dresden and Leamington hub sites, water was under applied at the beginning of the season, and in peaches not sufficiently long applications were being made during the remainder of the season for the water to penetrate deeper than 20 cm into the soil profile. Over the total growing season, there was a lack of almost 120 mm irrigation water compared to peach water requirements. The hub pepper grower under irrigated by 45 mm in the season. Over irrigation occurred on some sites; the berry grower over irrigated by 330 mm inside the tunnels, and by 210 mm in the open field. Although the tomato grower under irrigated at the beginning of the season, he over irrigated by about 50 mm for the season; information he will find useful for consequent years, since he ran out of water.

Growers based their decisions to irrigate on the crop stage and the weather. The sensor technology was very new to them (apart from some grower's limited experience with manual tensiometers), and as such the growers implemented their current irrigation practices for the most part, even during the course of the project. It was only at the end of the project, when they were able to see the complete season of soil moisture data that they fully realized how they were managing their water (over or under irrigating). Therefore, another year of this study would be very interesting to gauge what the growers have really taken away from their understanding of the moisture sensors as tools to better manage their irrigation water applications.

The amount of seasonal irrigation water used for field crops is highly dependent on a number of factors, such as the amount of winter precipitation received (to replenish soil moisture); the weather during the growing season (i.e. how much rain falls); and how much water is available to irrigate (the source of water). Therefore, the amount of irrigation water applied to crops each year will vary. The year the study was undertaken in 2007, was considered a dry year and generally growers irrigated much more than usual to maintain crop vigour.

The agricultural sector consumes 20% of total water withdrawn in Ontario (de Loë et al. 2001). This water use is very seasonal with most of it (54%) being consumed in the summer months (June, July and August). Although most farms in Ontario implement some type of water conservation strategy (Dolan et al. 2000), it is important to ensure that irrigators are utilizing water resources in the most conservative way possible, while obtaining optimum yields and the highest product quality. Since irrigation is a real need for vegetable and fruit production Ontario, efficient water use needs to be implemented as part of a routine strategy.

Irrigation scheduling is part of a solution that will benefit growers and the agricultural sector through potentially fewer conflicts arising amongst water users, due to less water consumption amongst those who adopt the technology. Soil moisture sensors are a key tool for growers for determining when to start irrigating and when to stop. By adopting this technology producers will demonstrate water stewardship and water use efficiencies for the sector.

Table 6.1 Benefits of Irrigation Scheduling

Local (farm) benefits	Municipal benefits	Sector (agriculture) benefits
Water savings on farm	Water savings at the municipal level	Water savings in the agricultural sector
Energy savings	Energy savings by reducing the demand on equipment, such as water pumps for example.	Technology transfer and training in the areas of monitoring soil moisture and irrigation scheduling
Higher quality of produce	Improved water quality for the environment by meeting in stream flow requirements for ecosystems	Potential yield increases and crop quality improvement in the horticultural sector

Potential higher crop yields	Adaptation strategies to soil moisture deficiencies
More timely water application to crops	Increased and advanced knowledge base in water savings
When used with fertigation, can lead to greater nutrient use efficiency by crop, and nutrient application savings	Establish a road map for training and extension materials that will accelerate producer and agri-business uptake of technology available

Irrigation scheduling promotes best management practices in the area of water use efficiency for agricultural producers. Water use efficiency is also a strategy for reducing vulnerability to dry soil moisture condition and low water flows. By adopting efficient irrigation scheduling techniques, growers are adapting to decreases in water availability which may be more prevalent in the future. Growers agree, soil moisture sensors are an excellent tool to aid in decision making for when to turn the tap on, and for how long to irrigate as they allow the opportunity to look into the soil profile and follow the soil-plant-water relationships. The reports draws attention to how current irrigation practices have room for fine-tuning to be brought more in line with actual crop water requirements (by calculating ETc or by calculating a water balance for example, growers can better check their irrigation accuracy). Therefore, by implementing soil moisture sensors and being trained on how to use the technology, growers are able to take away a large part of the present guess work when it comes to irrigating.

Before choosing a sensor or a monitoring system, the grower should consider the advantages and drawbacks of a sensor, a logger, and the information flow, according to how they can best use the information to make decisions for their operations. From the project results, it appears that sensor information delivery was a key choice for a sensor. For most of the growers, the data is most useful to them when they can obtain it directly from the field, on a clearly marked display, preferably on the sensor itself. Alternatively, if a grower prefers to have the data delivered to their home/office computer that was also a very preferred method, to be able to view the graphs of data output from the sensors at their leisure. This would enable the technology to meet the grower needs and demands for managing their operations.

6.1 REFERENCES:

De Loë, R., Kreutzwiser, R. & Ivey, J. (2001) Agricultural water use in Ontario. Canadian Water Resources Journal, 26(1), 17-42.

Dolan, A. H., Kreutzwiser, R. & de Loë, R. (2000) Rural water use and conservation in southwestern Ontario. Journal of Soil and Water Conservation, 55, 161-171.

Project Focus on Technology Transfer

The primary targets of this project are the growers and the extension specialists. The project promotes best management practices of water use efficiency for high-value horticultural crop production. The soil moisture sensors will help growers to supply sufficient and optimum quantities of water to obtain a higher quality crop, and in some cases increased yields, which will directly benefit the grower and ultimately the consumers and/or the processors. Through the project, researchers and agriculture extension workers learned about the sensor technology and how to schedule irrigation. As well, the OMAFRA, AAFC-PFRA and WIN staff benefited from the data obtained and how to best interpret it for the use of the growers.

Through the field days, newsletters, web-sites, articles published and conferences presented at, we reached well over 2000 growers, agricultural extension workers and researchers in Ontario.

- A total of 19 farms were directly involved in the project, in the areas of NOTL, Simcoe, Dresden and Leamington. Four of them had sensors and equipment installed on a permanent basis. Fifteen farms had access to this data, and had bi-weekly soil moisture measurement readings taken.
- The Field Days held reached over 250 growers in the four regions directly to communicate the results of the project to them, and to show them how the soil moisture equipment functions. At least 3 journalists were present, who wrote follow-up articles on the project.
- During the Field Day in Leamington, the lunch BBQ was hosted by the Essex Kent Junior Farmers Association who got exposure to the project through this event.
- Presentations on the project were given at several Ontario conferences, targeting a further 300 growers and extension workers and industry representatives.
- A total of 5 summer assistants were hired to work on the field sites, on-farms, collecting data and maintaining the sensors. They all have a sound knowledge of the sensors and how they operate. This is very valuable if they choose to remain in agriculture extension work.
- Furthermore, there are four project partners (McGill University, AAFC-PFRA, OMAFRA, and WIN), for a total of over 20 researchers who are directly involved in this project.
- Several articles pertaining to the project were written and distributed by OMAFRA staff to their growers, reaching over 1500 growers.

Field days:

- June 19 at Peter and Ellen Jennen's farm in Dresden, This was held for the Ontario Soil Management Research and Services Committee. The field day attracted 20 researchers, extension, agribusiness and a few growers.
- July 12 at John Fedorkow's farm in NOTL, 50 people attended; mostly growers and 1 journalist
- July 30 at Ridgetown and Jennen's for the Vegetable Open House, 55 people, mixed researchers, growers, agribusinesses and 2 journalists

- August 2 at Wayne Palichuk's in Leamington, 50-60 people, mostly growers. Lunch catered by the Essex Kent Junior Farmers Association
- August 14 at John Cooper's in Simcoe as part of NASGA, over 80 people, mostly growers.
- September 12 at Andrews Scenic Acres in Milton, part of OBGA, 20 people, researchers and growers

Promotional material:

- **Handout package on sensor outputs** for the Ontario Soil Management Research and Services Committee field day (June 19). Distributed to 20 researchers, extension, agribusiness and a few growers.
- **Handout package on sensor outputs** for Field Day at John Fedorkow's (July 12). Distributed to 50 people, mostly growers.
- **Handout package on sensor outputs** for Field Day at Peter Jennen's (July 30). Distributed to 55 people, mostly growers.
- **Handout package on sensor outputs** for Field Day at Wayne Palichuk's (August 2). Distributed to 60 people, mostly growers.
- **Poster** displaying results was presented at the Field Day at Wayne Palichuk's (August 2).
- **Handout package on sensor outputs** for Field Day at John Cooper's (August 14), part of the NSAGA tour. Distributed to 80 people, mostly growers.
- **Handout package on sensor outputs** for Field Day at Andrews Scenic Acres in Milton, (September 12), part of OBGA tour. Distributed to 20 people, mostly growers.

Web-sites:

- The Brace Centre for Water Resources Management website, of McGill, hosted the project objectives, description and preliminary results for the duration of the project:
    - http://www.mcgill.ca/brace/activities/cowsep/
- WIN website hosted C-probe and Echo probe data for the growers involved in the project:
    - http://www.ontarioweathernetwork.ca/

Conferences presentations:

Ontario Fruit and Vegetable Convention, February 20, 2008 at Brock University, in St. Catharines.

- ✓ Niagara peach & grape general session; water management and irrigation theme
    - "**Irrigation tools: soil moisture sensors**" B. Mehdi (90 growers attended)
- ✓ Berry grower session
    - "**Soil moisture monitoring sensors: Knowing when to irrigate**" B. Mehdi (60 growers attended)

Brace Annual Graduate Student Colloquium, February 14, 2008 at McGill University, in Montreal

- ✓ "**Evaluating on-farm irrigation to improve water use efficiency**" M-H. Bernier (30 researchers attended)

Processing Vegetable Conference, January 28, 2008 at Convention Centre, in London

- ✓ Tomato session
    - o "**Take the guess-work out of irrigating: soil moisture monitoring tools (tomato results)**" B. Mehdi (60 industry reps and growers attended)
- ✓ Cucumber/pepper session
    - o "**Take the guess-work out of irrigating: soil moisture monitoring tools (pepper results)**" B. Mehdi (40 industry reps and growers attended)

ASABE Conference, October 2007, Beltsville, Maryland

- ✓ "**Real Time Irrigation Scheduling Using Capacitance and Time Domain Reflectance Soil Water Sensors**" C.A. Madramootoo (50 researchers attended)

Conference papers accepted and future presentations:

- ➢ "A Comparison of Soil Moisture Monitoring Technologies for Irrigation Scheduling" paper accepted for presentation at the American Society for Agricultural and Biological Engineers (ASABE) conference in Rhode Island.
- ➢ "Wireless Communications Technologies for Irrigation Scheduling" paper accepted for presentation at the ASABE conference in Rhode Island, July 2008
- ➢ Paper accepted for presentation at 8th World Tomato Congress conference in Toronto, ON.

Articles written:

- **IRRIGATION: WHEN DO YOU TURN IT ON?** Bano Mehdi and Ken Slingerland OMAFRA's Tender Fruit and Grape Vine, May 2007. Target audience is tender fruit and grape growers. Sent to 1000 tender fruit and grape growers.
- **MONITORING SOIL MOISTURE FOR IRRIGATION NEEDS PROJECT,** by Bano Mehdi C-CIARN Water Resources Newsletter. June 2007. Target audience is Canadian researchers and stakeholders in water resources. Sent to over 500 members by email.
- **MONITORING SOIL MOISTURE FOR IRRIGATION,** by Bano Mehdi and Anne Verhallen, HortMatters, May 2007. Target audience is the horticultural crop growers. Sent to 100 growers
- **CLOSELY MONITORING SOIL FOR IRRIGATION NEEDS** by Bano Mehdi, Ontario Berry Grower Newsletter, Volume 4 July 2007.
  The target audience is berry growers. This newsletter is published in 2 places: The GROWER, (trade publication of the Ontario Fruit and Vegetable Grower's Association) volume 57 number 7, July

2007, page 13 and on line at:
http://www.omafra.gov.on.ca/english/crops/hort/news/allontario/ao0407.htm

- **A CLOSER LOOK AT SOIL MOISTURE FOR DETERMINING IRRIGATION NEEDS,** by Bano Mehdi, Vegetable Crop Update: Tomato and Pepper edition. July 18, 2007
  The newsletter is issued on-line whenever there is information to deliver - averaging about once a week during the growing season and less often during the winter. The target audience is the Ontario Vegetable industry and growers.
  http://apps.omafra.gov.on.ca/scripts/english/crops/agriphone/article.asp?ID=1483
- **NO EASY BUTTON FOR IRRIGATION** by Anne Verhallen, HortMatters August 1, 2007.
  This newsletter is prepared monthly and delivered electronically from October to February, bi-monthly from March to May, and on a weekly basis through the summer. The target audience is Ontario horticultural industry and vegetable growers
- **REAL TIME IRRIGATION SCHEDULING USING CAPACITANCE AND TIME-DOMAIN REFLECTANCE SOIL WATER SENSORS** by C.A. Madramootoo et al., published in the 2008 Ontario Fruit & Vegetable Convention guide. February 19-20, 2008. Distributed to over 1200 participants, mostly growers

Master thesis:

Two M.Sc. theses will be written up on the project results and submitted in December 2008:

- "Determining soil moisture differences between high tunnel and field strawberries for irrigation scheduling" By Sajjad Ali, McGill University
- "Assessing irrigation performance for fruit and vegetable producers of Southern Ontario" by Marie-Hélène Bernier, McGill University

Final Comments and Conclusions

The project findings showed that the growers were satisfied with the soil moisture equipment and that the growers consulted at least one specific piece of equipment (if not two) regularly during the season to validate their decisions to irrigate. All equipment was scientifically factual and generally performed well. There was a range of costs associated with the various equipments, as well as a range of data viewing means. Some equipment had to read manually, while others were automated to log the data and store it, and some even displayed the graphs of soil moisture in near real-time.

All equipment was useful and performed well, all showed similar soil moisture results, to varying degrees of correspondence with the soil auger samples. There is no magic "best" piece of equipment for monitoring soil moisture; all have their own positive aspects as well as drawbacks, and a lot of these depend on grower preference. Therefore, some key points to take into consideration by growers when thinking of installing soil moisture monitoring equipments are:

- How much money are you willing to invest? (sensors we tested ranged from $100 to +$4000 for one sensor + necessary supporting equipment).
- Do you require real-time readings, or just the occasional verification of the soil moisture?
- Do you require actual volumetric water content readings, or will a trend line be sufficient?
- Check the amount of maintenance that may be required for the instrument.
- Look into the after sales services that is offered, should it malfunction.
- What are your management needs; how much of irrigation fine-tuning do you require for your crops?
- What are your preferences and practices (do you like to walk your fields and check the equipment readings, or would you rather look up the data on a computer)?
- Finally, how much time are you willing to put into gathering the data from the system?

The project promoted water use efficiency and, in wet years especially, will help to conserve water. Growers are currently not using any method (sensors, water budget methods, or ETc calculations) to help guide them with their irrigations. We anticipate longer-term water savings to be realized with the implementation of the monitoring technologies, which will reduce the risk of water shortages.

The outcomes of the project are part of a longer term water management strategy because it provided tools and training sessions for growers to assist in using soil moisture instruments on farms for irrigation scheduling. The project had far-reaching stakeholders, for example, through AAFC-PFRA, the LADIA group was aware of our project and the sensor technology.

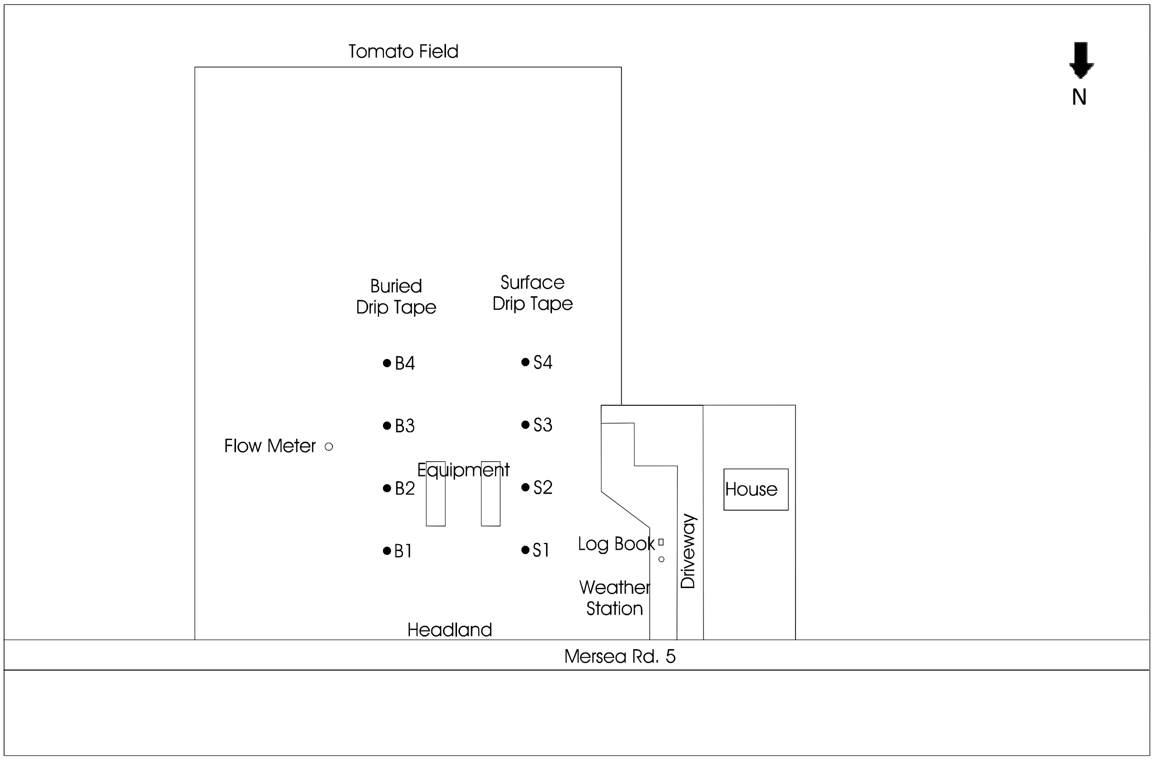
Ontario growers will be able to gain better crop yield and quality and conserve water as well as energy. Other beneficiaries are agri-businesses, agriculture extension workers, researchers, and irrigation advisory councils, who will gain from this knowledge and be able to apply it to their respective areas of work.

APPENDIX A

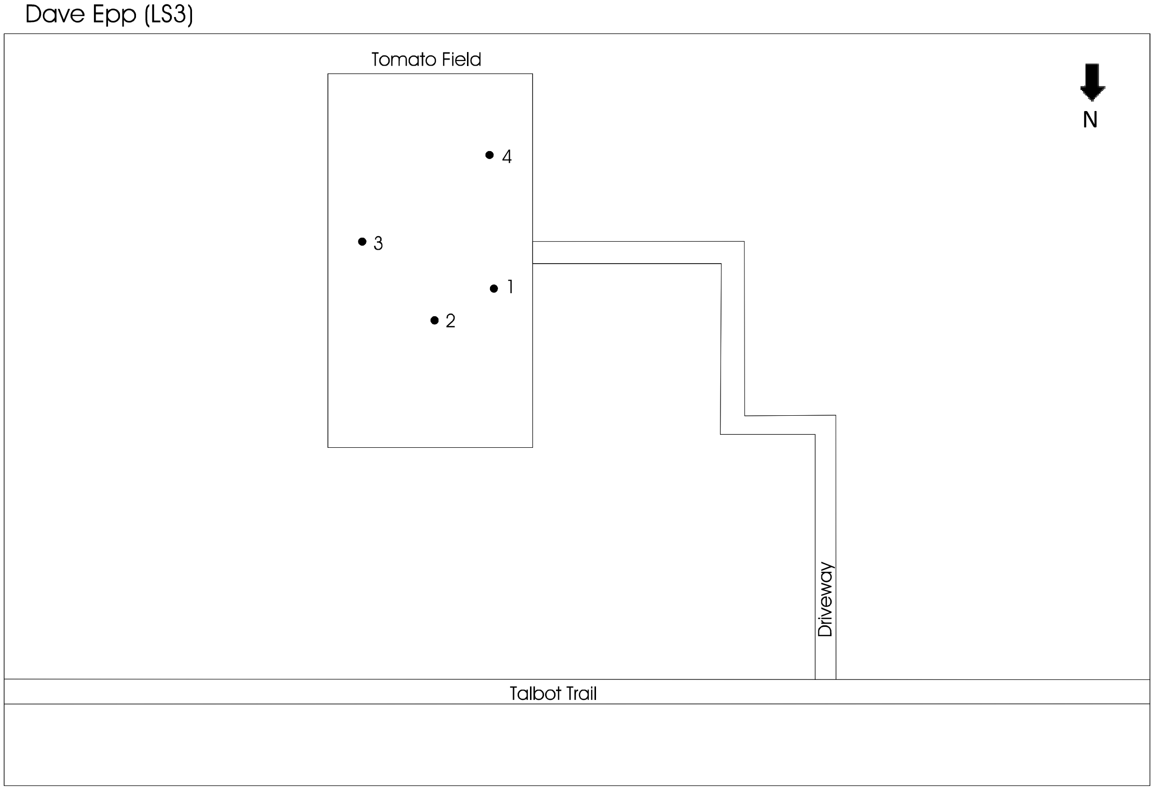
Layout of On-Farm Sampling Sites of Main Equipment Installations and Benchmarks at the Hub Sites, and Benchmark Locations at Satellite Sites

Leamington hub and satellite sites

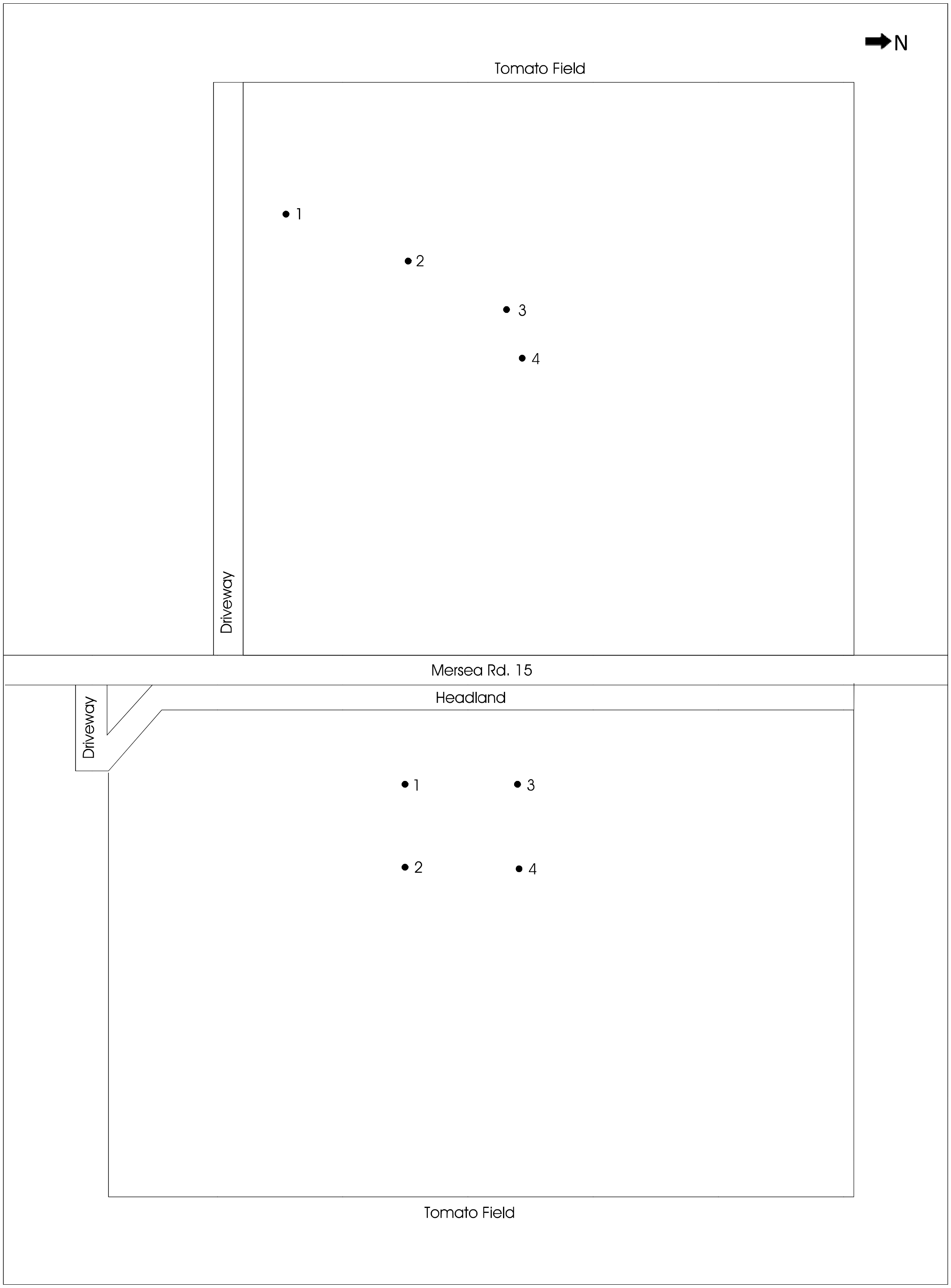
Wayne Palichuk (LH)



Dave Epp (LS3)

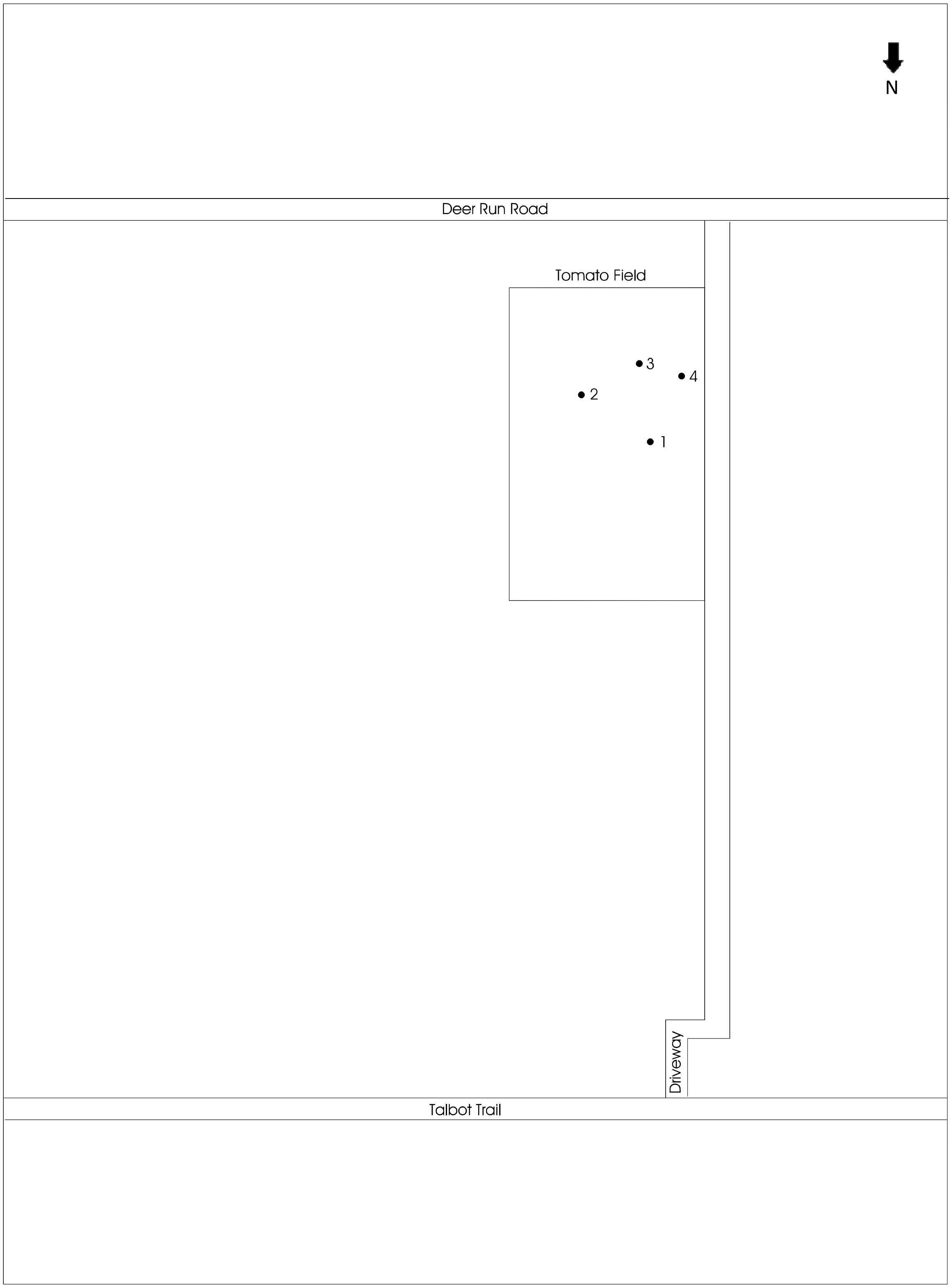


Ken Hamm (LS2)



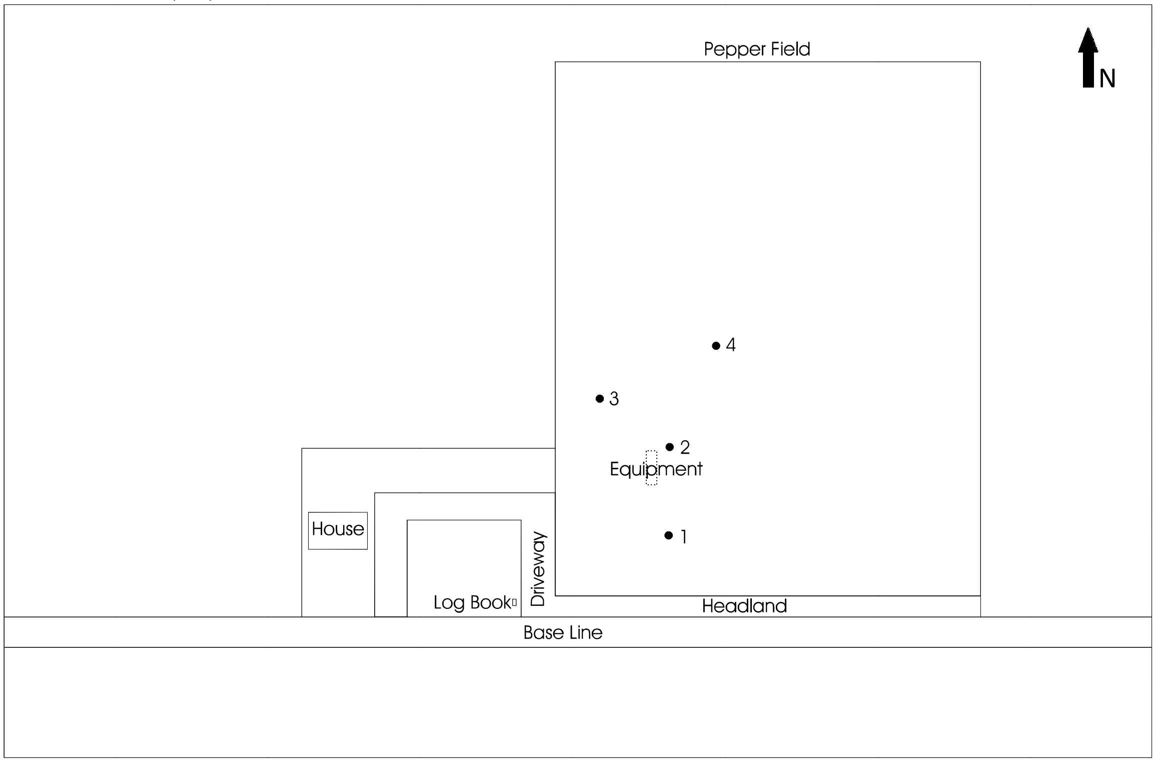
Ken Hamm (LS1)

Paul Tiessen (LS4)

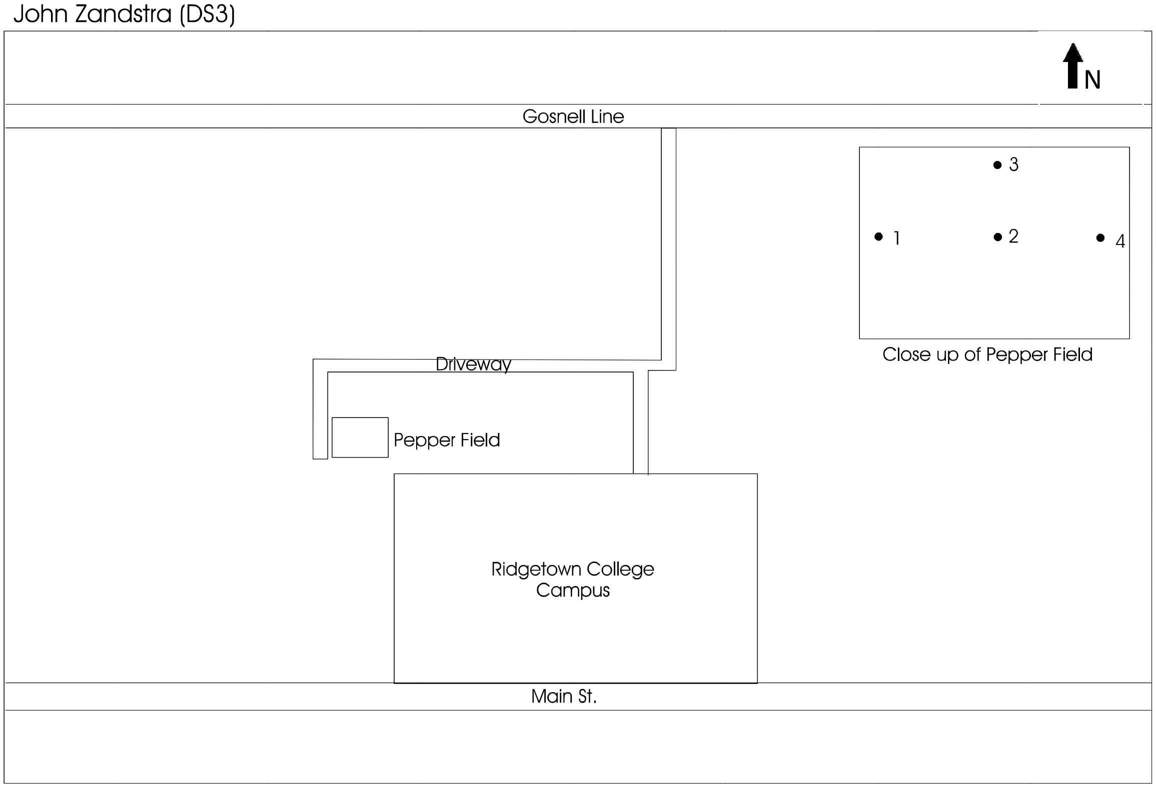


Dresden hub and satellite sites

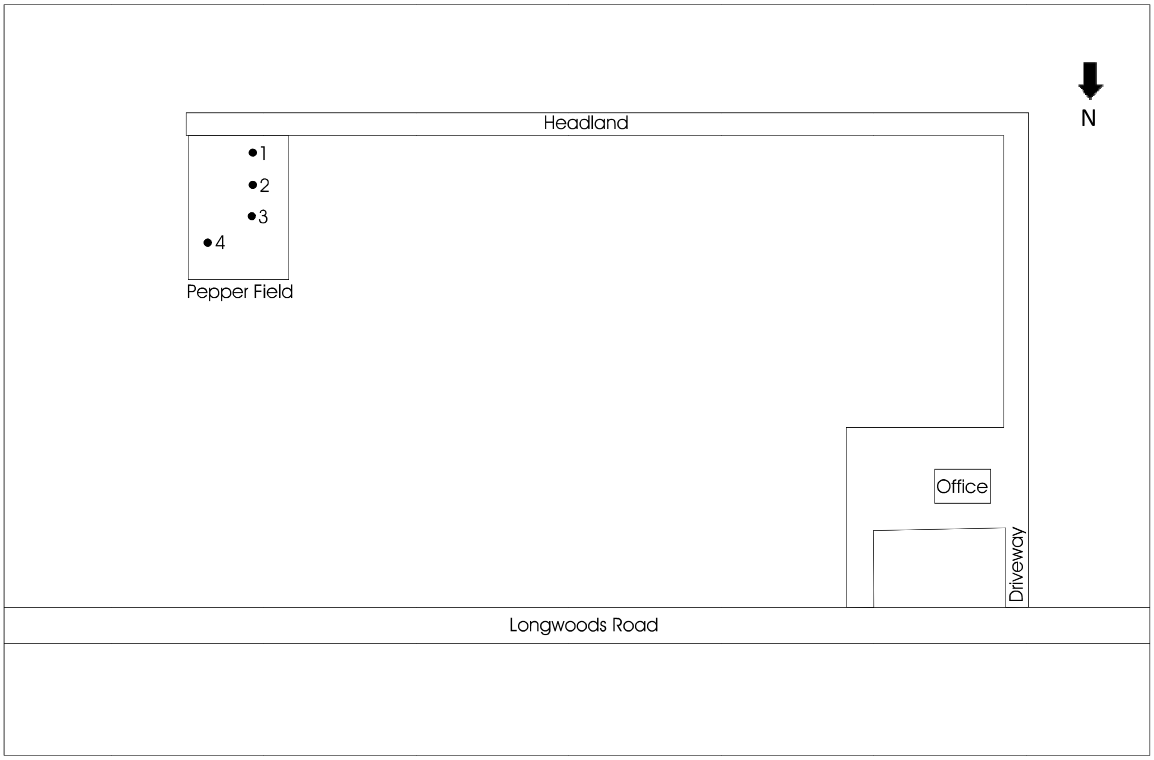
Peter Jennen (DH)



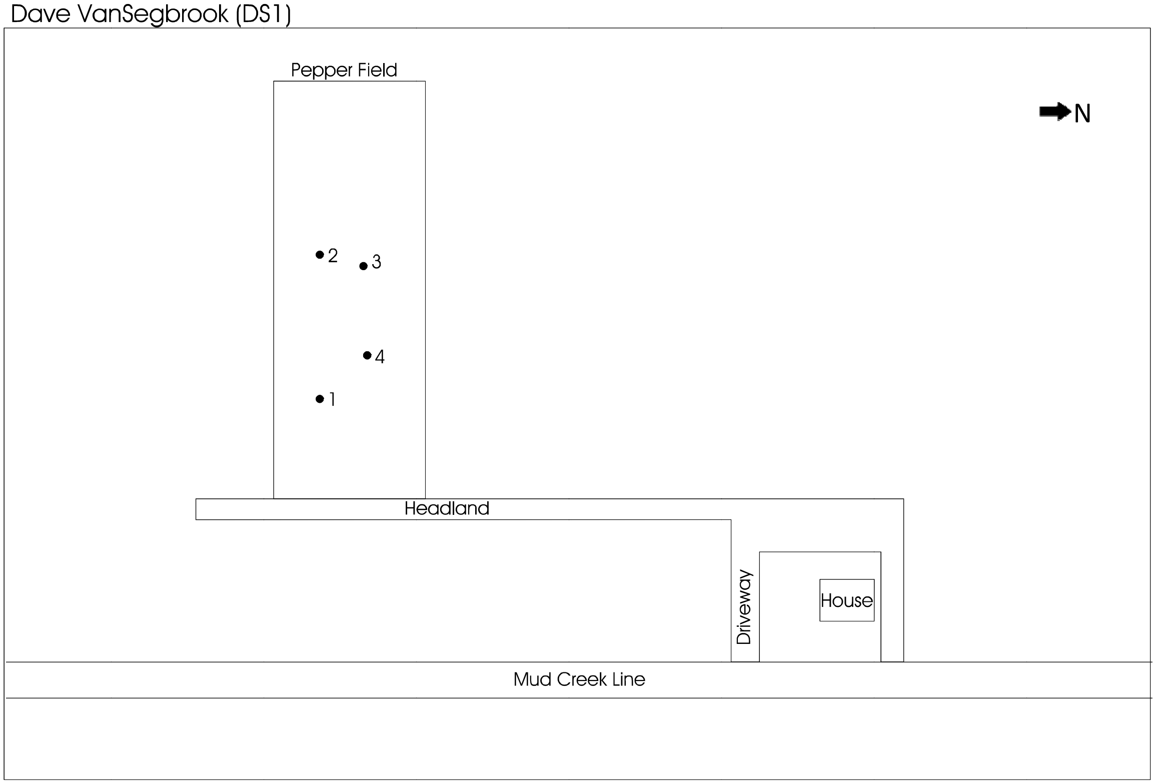
John Zandstra (DS3)



Perry Furlan (DS2)

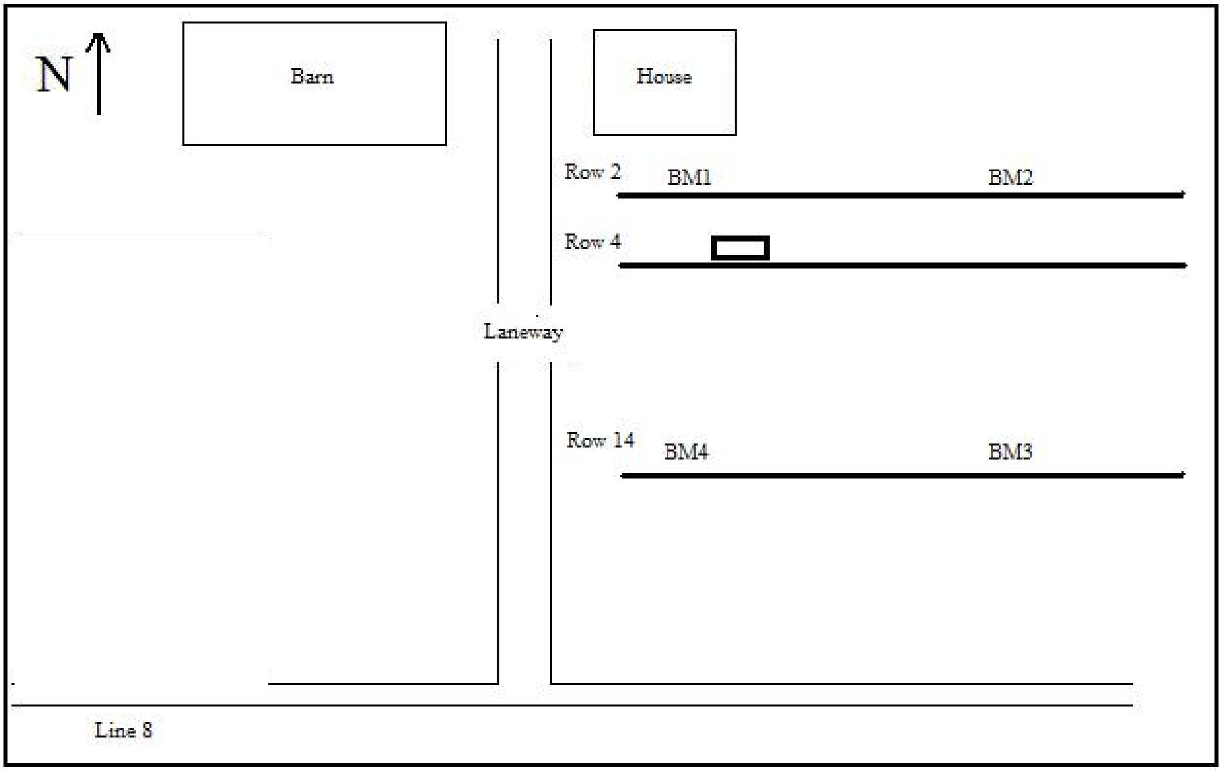


Dave VanSegbrook (DS1)

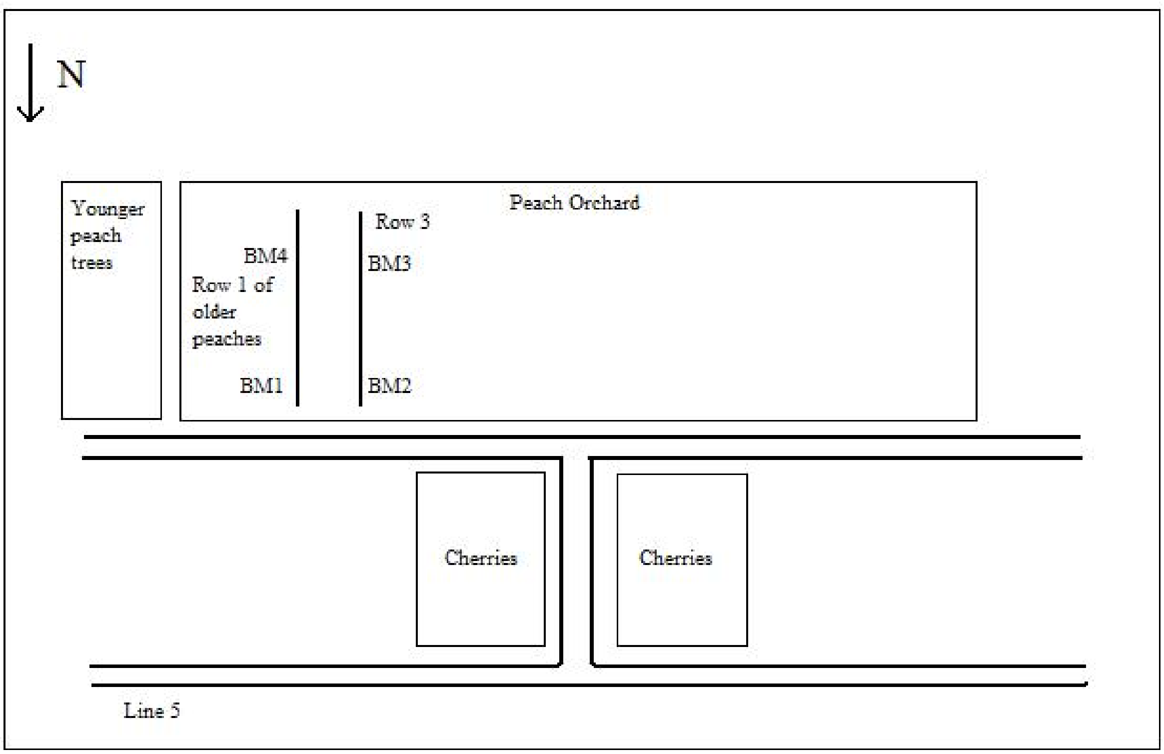


Niagara-on-the-Lake hub and satellite sites

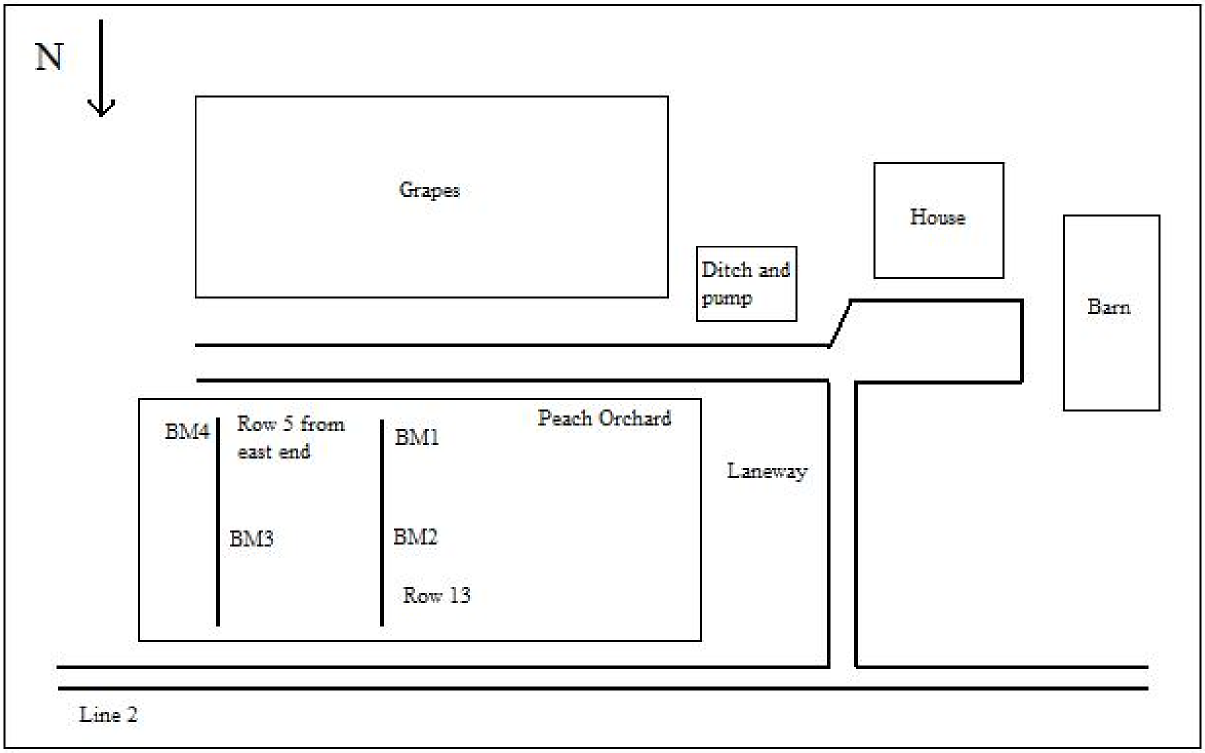
John Fedorkow (NH)



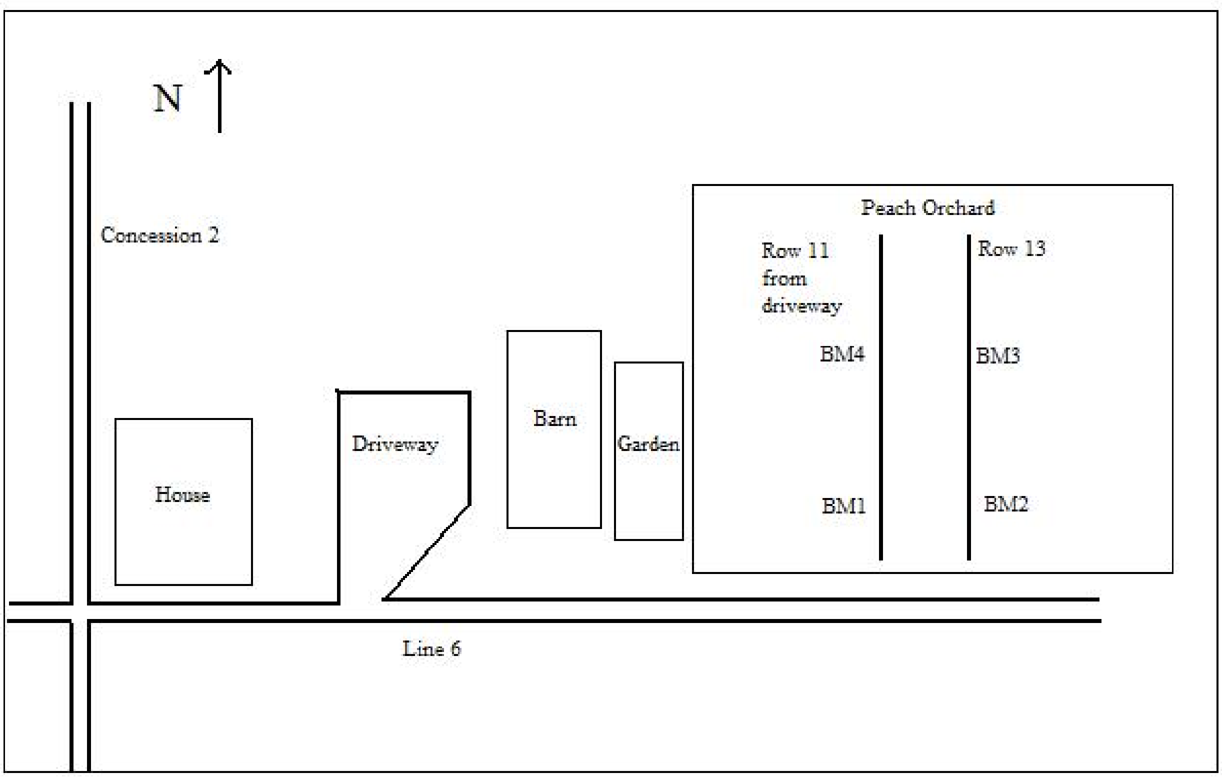
Tim Andrews (NS1)



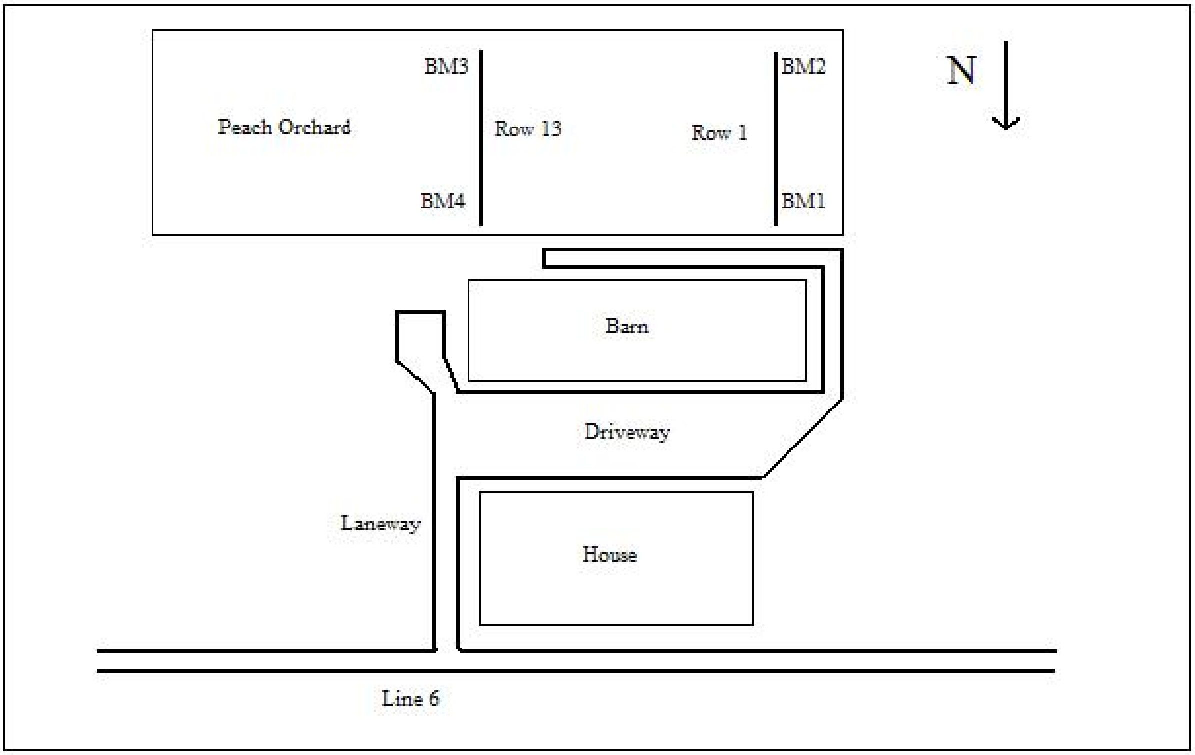
Kevin Buis (NS2)



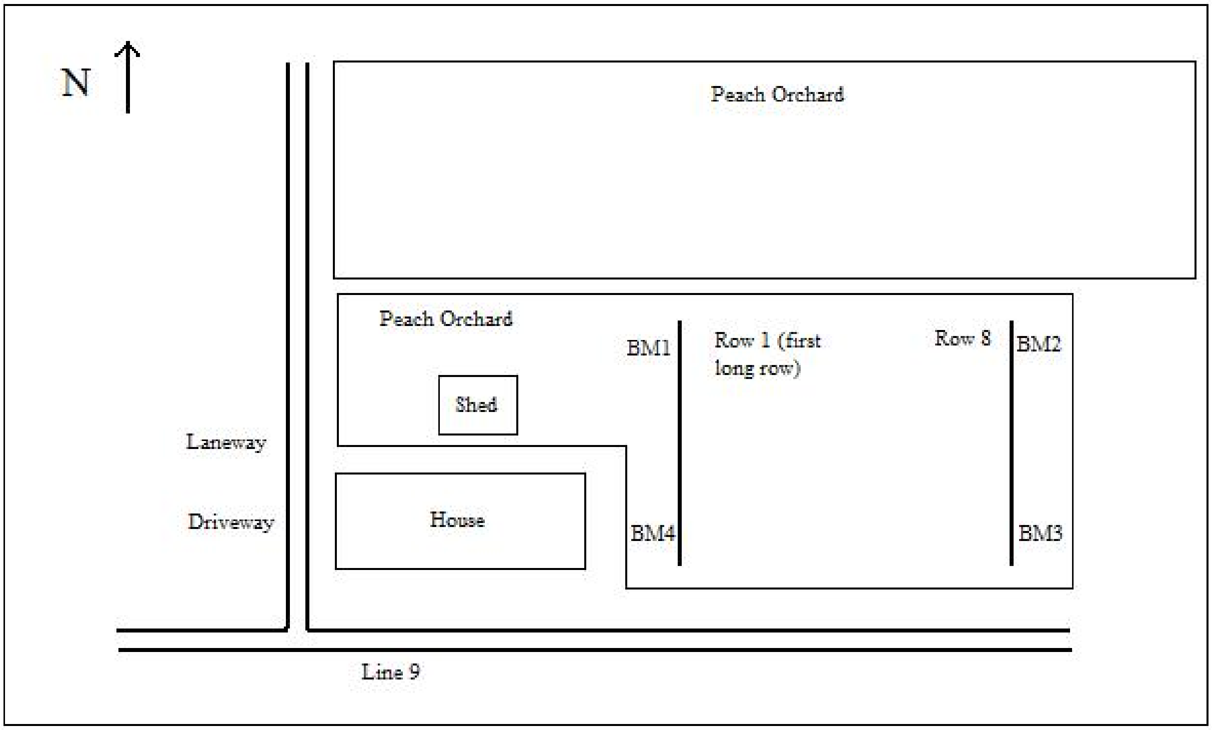
Anne Muir (NS3)



Earle Muir (NS4)

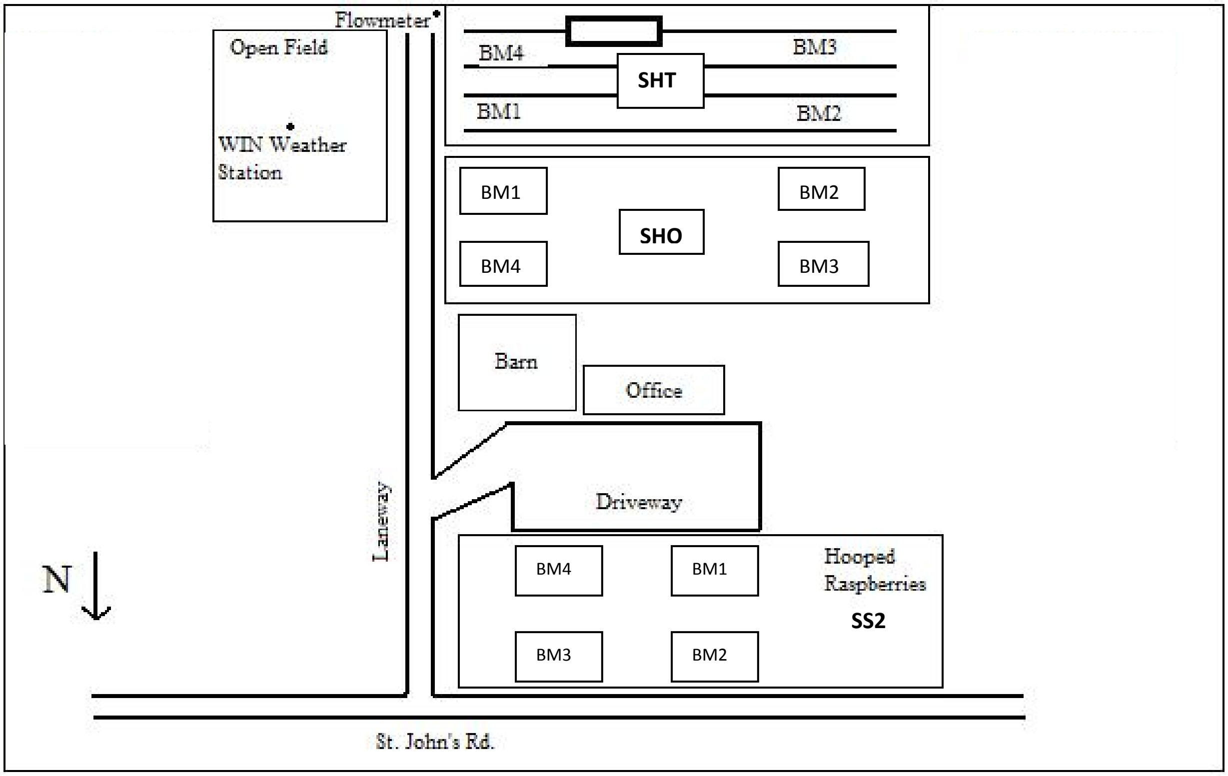


Erwin Wiens (NS5)

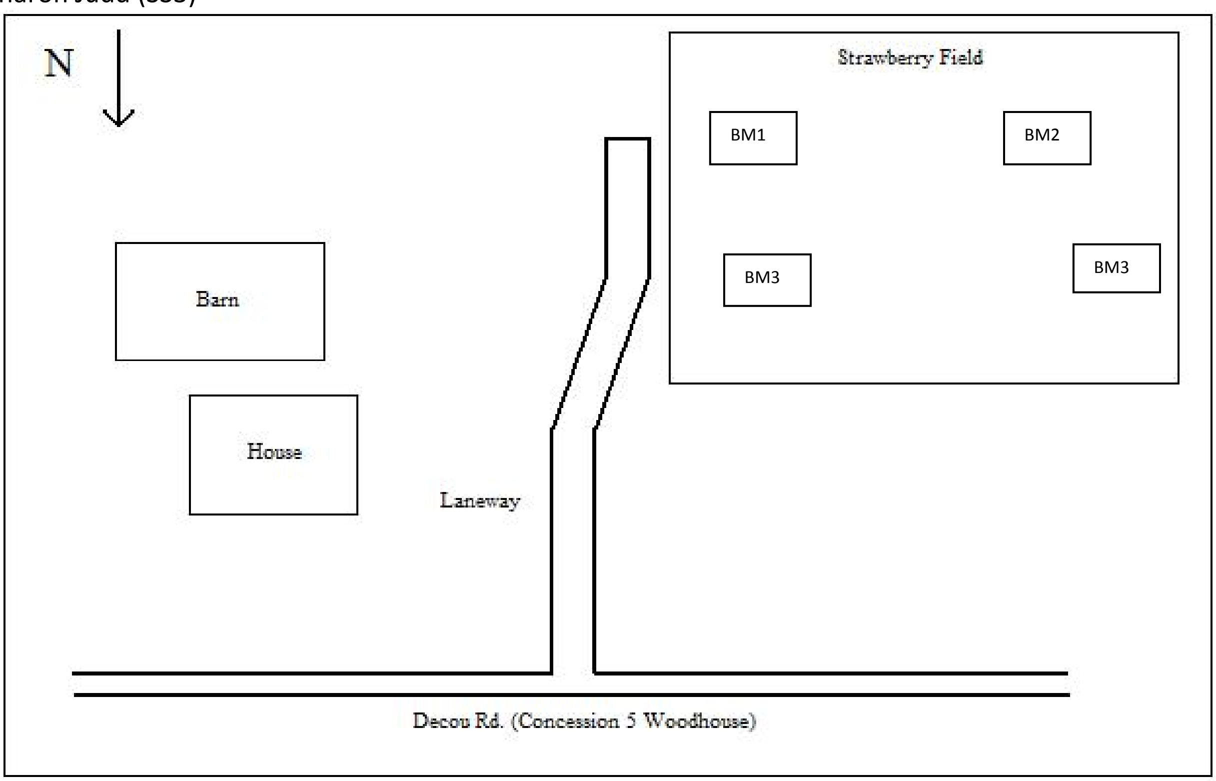


Simcoe hub and satellite sites

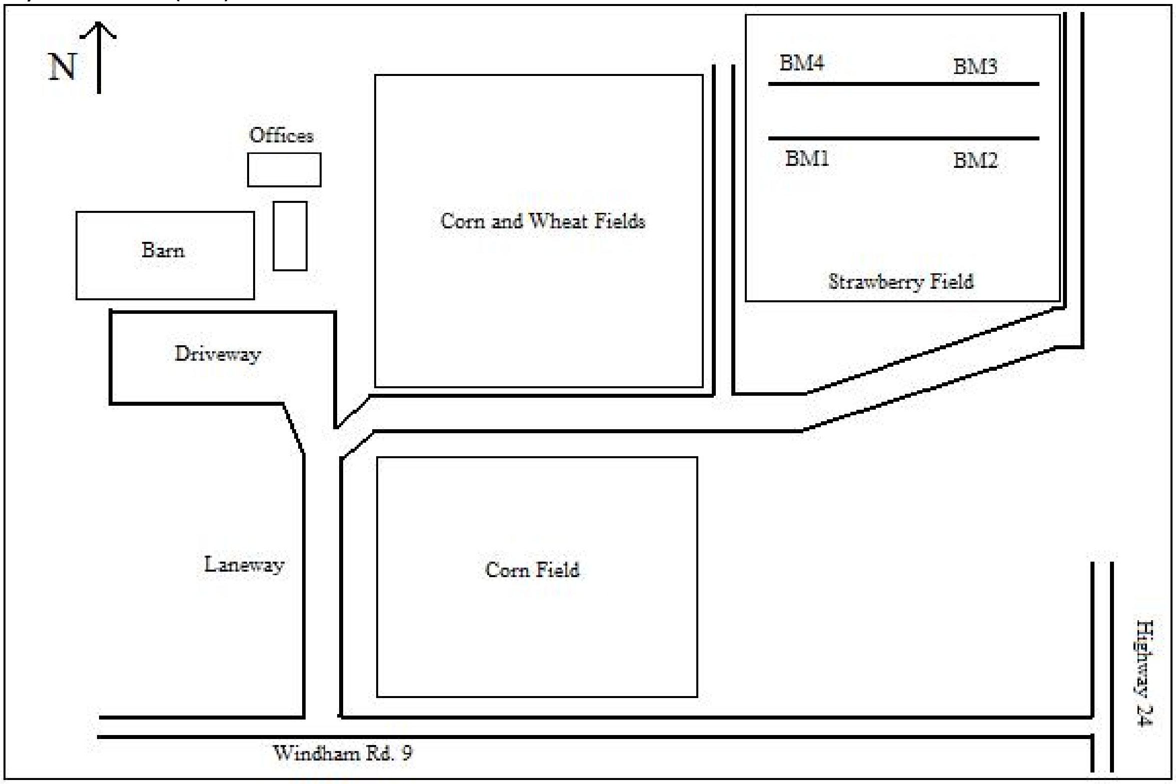
John Cooper (SHT, SHO, SS2)



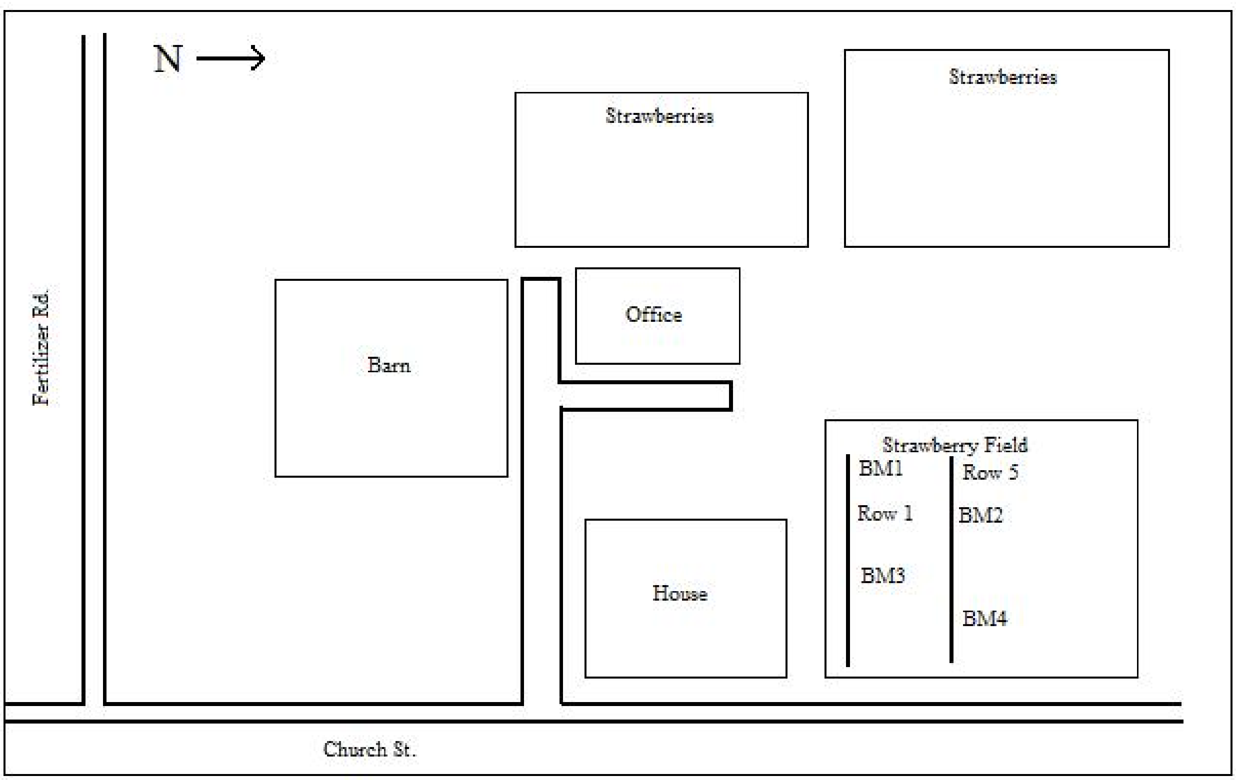
Sharon Judd (SS3)



Mary Shabatura (SS4)



Dave Vandevelde (SS5)



APPENDIX B

Grower Survey Part I on Current Irrigation Water Use

Growers' Irrigation Survey (Part I) on Current Water Use

BRACE CENTER/MCGILL UNIVERSITY PROJECT
CANADA – ONTARIO WATER SUPPLY EXPANSION PROGRAM
JULY 2007

General Information

- Name of grower ______________________________
- Age ______________________________
- Educational level ______________________________
- Are you owner or operator? ______________________
- Is it an intergenerational farm? If yes, which generation? ________
- For how many years are you farming? ________________
- Is the farm the primary income source? ________________

Field, Crop and Soil Information

- How long is the growing season? (days) __________
  - -Planting date __________
  - -Harvesting date __________

Irrigated Acreage: Zone Specifications

No.	Area (acres)	Crop	Soil Type	No. Rows	Plant Spacing (ft. × ft.)	Row Width (ft)	Row Length (ft)	No. Plants per Row
1								
2								

Irrigation System Information

Drip Irrigation								
No.	No. Emitters	Flow Rate per Emitter (or Total Flow Rate)	Pressure Setting (psi)	Drip Line Spacing (in.)	Size of Emitter (in.)	Emitter Brand	Depth (in.)	Max. System Operating time (hr/day)
1								
2								

Sprinkler Irrigation									
No.	Traveling (T), Stationary (S) or Power Take Off (PTO)	Lateral Spacing (ft)	Sprinkler Spacing Along Lateral (in.)	No. of Sprinklers Heads	Number of Nozzles	Nozzle Size (in.)	Sprinkler Flow Rate	Nozzle Flow Rate	Max. System Operating time (hr/day)
1									
2									

Daily Irrigation System Operating Time

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Time (hrs)																															
June																															
Time (hrs)																															
July																															
Time (hrs)																															
August																															
Time (hrs)																															
September																															
Time (hrs)																															

Pump Specifications

- ◎ Brand _____________
- ◎ Model number _____________
- ◎ Horsepower _____________
- ◎ Impellor size _____________
- ◎ Revolution per minute (rpm) _____________
- ◎ Flow rate _____________
- ◎ Energy consumption (KWh/year, Hydro Bill or gallons of Fuel) _____________

Irrigation Scheduling

- ◎ When do you irrigate (moment during the day)? _____________
- ◎ How much water is used for each irrigation water application? (mm/day & mm/acre) _____________
- ◎ For how many years are you irrigating? _____________

- ◎ Based on which information do you determine the amount of water that should be applied and when to irrigate?

  -Please rank the importance of each of the following (scale from 1: least to 5:most) when deciding how much to irrigate:

  Crop growth stage _____________
  Weather _____________
  Energy cost _____________
  Data from moisture sensors _____________
  Outcome of other moisture tests _____________

  Other (specify) ____________________________

Irrigation Water

- ◎ Where is the source of irrigation water (i.e. municipal drainage system, well, stream, …)? _____________
- ◎ What is the capacity of your on farm pond/reservoirs? _____________
- ◎ On what type of irrigation water delivery system are you relying on to access water from the municipal drainage system/well/stream to the field (i.e. natural stream, pipes, man-made canals, …)? _____________
- ◎ What are the dimensions of the natural stream/pipe/man-made canal delivering water? _____________
- ◎ Does the irrigation water quantity/flow rate are measured by any device? _____________

  If yes, indicate
  -Metered flow rate _____________
  -Meter reading at start of year _____________
  -Meter reading at end of year _____________

- ◎ When (what year) did you install (1) and upgrade the equipment (2)? (1) _____________
  (2) _____________

- Do you have a Permit To Take Water (PTTW)? _____________

  -What is the annual water withdrawal stated on water license? _____________
  -What is the peak flow rate allowed by the water license? _____________

- Does water availability constrain your irrigation? When? How?

  Details:

- Do you anticipate any water shortages? When? How?

  Details:

- Do you have a tile drainage system installation? What kind? _____________
- Do you recapture and reuse runoff? Volume? _____________
- Are you aware or participating in water conservation programs?

  Details:

Projected Expansion of Irrigated Acreage

- How many additional acres are you planning to irrigate? (acres) _____________
- What kind of crops do you plan to grow in the future? _____________
- In what time frame? (i.e. in 2 years from now, 5 years?) _____________
- From which source the extra irrigation water required will be withdrawn? _____________
- What would be the additional irrigation water quantity required? _____________
- Approximately how much will you invest? ($/acre) _____________
- What is the expected income? ($/acre) _____________
- Will this expansion require a PTTW? _____________
- If yes, what is the amount of water licensed? _____________

Cost

- How much did you invest for the technical equipment (irrigation system, water meter, men-made canals, pumps …)?

  Details:

- What is the cost of maintenance of the irrigation equipment? ($) _____________
- What is the cost associated with additional labor requirement? ($) _____________
- What is the cost associated with irrigation water use (municipal tax)? ($/irrigated acre) _____________

- Did you have to pay a "catch-up" payment? (Any new participant in the system has to pay a cumulative capital contribution made over the years by the original participants)? If Yes, how much? ($) _____________
- What is the energy cost associated to irrigation (Hydro bill)? ($) _____________
- Is there a cost for the permit and how much is it? _____________
- Do you have any annual permit or license fees? _____________

- Energy prices have risen considerably recently. If energy prices were to rise at rates as suggested below, would you anticipate reducing your irrigation water use and, if so, by how much (as a percentage)?

  10 percent _____________
  20 percent _____________
  30 percent _____________
  More than 30 percent _____________

- Please consider the price you have received for your principal crops in the last 2-3 years. What would the minimum increase in price be necessary to convince you to **improve** your existing irrigation equipment?

  10% increase
  20%increase
  30% increase
  >30% increase (specify)

- Please consider the price you have received for your principal crops in the last 2-3 years. What would the minimum increase in price would be necessary to convince you to **replace** your existing irrigation equipment?

  10% increase
  20%increase
  30% increase
  >30% increase (specify)

APPENDIX C

Grower Survey Part II on Soil Moisture Sensors

Growers' Irrigation Survey (Part II) on Soil Moisture Sensors

BRACE CENTER/MCGILL UNIVERSITY PROJECT
CANADA – ONTARIO WATER SUPPLY EXPANSION PROGRAM
OCTOBER 2007

Cooperator's satisfaction

Questions that are preceded by this flag only apply to hub sites cooperators.

1. Please rate from 1 (poor) to 5 (great) your satisfaction with the irrigation scheduling information you received.

- Usefulness of data
- Clarity of data
- User friendliness of data
- Time required to assimilate and understand the data
- Frequency of data delivery
- Not applicable, the irrigation scheduling information was not received

2. Would you say that the soil moisture information has helped you to irrigate more efficiently?

Yes ❑ No ❑ Not Applicable ❑

If yes, please give some examples?

3. How has the information modified your current irrigation scheduling practices? Has it facilitated your irrigation scheduling?

4. Has your understanding of soil moisture and irrigation scheduling improved as a result of this project?

Yes ❑ No ❑

If yes, please give some examples?

5. Do you know what your field capacity value is? If yes, what is it?

6. Do you know what your trigger point for irrigation is? If yes, what is it?

7. Was the data provided by the soil moisture monitoring equipment useful? If so, in what way? Please give some examples.

8. How were your yields in the experimental area this year, compared to other years?

- Excellent (much better than expected)
- Good (above average)
- Average (normal)
- Poor (below average)
- Very low (much below what was expected)

9. What would your yields have been without irrigation?

- Excellent (much better than expected)
- Good (above average)
- Average (normal)
- Poor (below average)
- Very low (much below what was expected)

10. How was your irrigation need this year, compared to other years? Please explain how the irrigation frequency and the amount of water applied were different from other years (if different).

11. Approximately how much water have you saved or spent as a result of using the soil moisture data equipment?

<u>Future irrigation scheduling techniques</u>

1. Please rate the usefulness from 1(poor) to 5(great) for each of the equipment installed on your farm.

- Manual Tensiometer
- Manual Portable FieldScout TDR
- Echo Probe
- C-Probe
- Gro-Point TDR
- Watermark (Watchdogs)
- Campbell Water Content Reflectometer TDR
- Hortau
- Flow Meter

2. By which means would you like to access soil moisture monitoring data? What would be most convenient for you (i.e. directly in the field, fax, internet, consultant, e-mail, …)?

3. How do you intend to use the soil moisture information?

4. Which irrigation scheduling techniques have you decided to adopt for future years (if any)? Please explain why.

5. Do you consider the quantity of water saved (or augmented) during the growing season worth the investment into future soil moisture monitoring equipment?

6. How much extra time would you be willing to spend on irrigation scheduling?

7. If funding is available to continue the project in the future, do you have any recommendations to improve it?

8. Do you have any other comments?

APPENDIX D

Irrigation and Flow Meter Records

This information is based on grower personal irrigation records from their log books. The information presented is based on their estimated daily values, except for the three farms where flow meters were installed (these are indicated as such) which are more accurate.

__Grower #1__ Leamington (Surface & Subsurface Zones) - Flow meter

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																					6.2	11.9			6.1	3.4	3.9		3.4	4.1		39.0
A (mm)																					10.2	15.8			8.6	5.1	5.5		5.1	6.1		56.4
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)		4.1	4.1	4.1	4	4	4		4.1	4.1	4.1	3.3	4.1	2.6		3.2	3.3	2.4	2.1	2.2	2.1		3.3	3	4.1	4.1		3.3	3.9	2.1	1.9	87.6
A (mm)		5.6	5.8	5.7	1.6	1.5	4.4		5.9	5.9	6	4.8	6	3.9		4.6	4.9	3.2	3	3.3	2.9		4.9	4.4	6.5	6.3		0.9	1	3.3	2.8	109.1
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	4.1	2.5	2.1	2.9											0.2	4.1	2.3															18.2
A (mm)	6.2	3.5	2.9	4.1											0.2	5.9	3.1															25.9

__Grower #1__ Leamington (Surface & Subsurface Zones) - Irrigation Records

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																		4	4	4	4	4	4		4	4	4	4	4	4		48.0
A (mm)																		4.5	4.5	4.5	4.5	4.5	4.5		4.5	4.5	4.5	4.5	4.5	4.5		54.0
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	2.5	2.5	2.5	2.5	106.0
A (mm)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	2.8	2.8	2.8	2.8	119.5
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5																							22.5
A (mm)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8																							25.2

Grower #2 Leamington (1st Zone) - Irrigation Records

July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)			3							3	3	3	3	3	3	3			3		3	3	3	3	3			3	3	3	3	54.0
A (mm)			1.7							1.7	1.7	1.7	1.7	1.7	1.7	1.7			1.7		1.7	1.7	1.7	1.7	1.7			1.7				25.5
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	3	3	3	3																												12.0
A (mm)	1.7	1.7	1.7	1.7																												6.8

Grower #2 Leamington (2nd Zone) - Irrigation Records

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																		3						3	3	3	3	3	3	3		24.0
A (mm)																		1.4						1.4	1.4	1.4	1.4	1.4	1.4	1.4		11.2
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)		3	3		3		3	3	3	3		3	3	3		3		3	3	3	3	3	3	3	3	3		3		3	3	69.0
A (mm)		1.4	1.4		1.4		1.4	1.4	1.4	1.4		1.4	1.4	1.4		1.4		1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4		1.4		1.4	1.4	32.2
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	3	3	3	3											3	3	3															21.0
A (mm)	1.4		1.4	1.4											1.4	1.4	1.4															8.4

Grower #3 Leamington - Irrigation Records

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																					3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5		35.0
A (mm)																					4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1		41
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)		3.5	3.5		3.5		3.5	3.5	3.5	3.5		3.5	3.5	3.5		3.5		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5		3.5		3.5	3.5	80.5
A (mm)		4.1	4.1		4.1		4.1	4.1	4.1	4.1		4.1	4.1	4.1		4.1		4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1		4.1		4.1	4.1	94.3
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	3.5	3.5	3.5	3.5											3.5	3.5	3.5															24.5
A (mm)	4.1	4.1	4.1	4.1											4.1	4.1	4.1															28.7

Grower #4 *Leamington - Irrigation Records*

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		Total
T (hrs)																												2	3	3		8.0
A (mm)																												2.9	4.3	4.3		11.5
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	3	3	3		3		3	3	3	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	6	3.5	3.5	3.5	99.0
A (mm)	4.3	4.3	4.3		4.3		4.3	4.3	4.3	4.3	4.3	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	1.9	5.0	5.0	134.9
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	3.5	3.5	3.5	3.5	1.5											3.5	3.5	3.5												0.5		26.5
A (mm)	5.0	5.0	5.0	5.0	2.2											5.0	5.0	5.0												0.7		37.9

Grower #5 *Dresden - Flow Meter*

July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
T (hrs)						12								9																		21.0
A (mm)						8.0								6.0																		14.0
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	7																															7.0
A (mm)	4.7																															4.7
Sept.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)							7																7									14.0
A (mm)							4.7																4.7									9.4

<u>Grower #6</u>   Dresden - Irrigation Records

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)													6								12											18.0
A (mm)													38.5								77.1											115.6
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)		8						8								6			6													28.0
A (mm)		51.4						51.4								38.5			38.5													179.8
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)			8														8												12			28.0
A (mm)			51.4														51.4												77.1			179.9
Sept.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																8																8.0
A (mm)																51.4																51.4
October	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)				8											8																	16.0
A (mm)				51.4											51.4																	102.8

<u>Grower #7</u>   Dresden - Irrigation Records

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																							16									16.0
A (mm)																							25.2									25.2
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)													20												20							40.0
A (mm)													31.5												31.5							63.0

Grower #8 *Simcoe (Strawberries Outside) - Irrigation Records*

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)												3			3			3			2			2			
A (mm)												17.3			17.3			17.3			11.5			11.5			
June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)				2			2		2		2		2		2			2		2					1.5		1.5
A (mm)				11.5			11.5		11.5		11.5		11.5		11.5			11.5		11.5					8.7		8.7
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	2		2		2		2		2		2		2		2			2		2		2		2		2	
A (mm)	11.5		11.5		11.5		11.5		11.5		11.5		11.5		11.5			11.5		11.5		11.5		11.5		11.5	
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	2		2		2		2		2			2		2		2	2	2				2		2		2	
A (mm)	11.5		11.5		11.5		11.5		11.5			11.5		11.5		11.5	11.5	11.5				11.5		11.5		11.5	
Sept.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	2		2		2		2			2		2		2			2		2		2					2	
A (mm)	11.5		11.5		11.5		11.5			11.5		11.5		11.5			11.5		11.5		11.5					11.5	

May	28	29	30	31	
T (hrs)	2			2	17.0
A (mm)	11.5			11.5	97.9
June	28	29	30		
T (hrs)		1.5			20.5
A (mm)		8.7			118.1
July	28	29	30	31	
T (hrs)	2		2		30.0
A (mm)	11.5		11.5		172.5
August	28	29	30	31	
T (hrs)	2		2	2	32.0
A (mm)	11.5		11.5	11.5	184
Sept.	28	29	30		
T (hrs)					22.0
A (mm)					126.5

Grower #8   *Simcoe (Strawberries Tunnel) - Irrigation Records*

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)												3			3			3			2			2				2			2	17.0
A (mm)												17.5			17.5			17.5			11.7			11.7				11.7			11.7	99.3
June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)				2			2		2		2		2		2			2		2					1.5		1.5		1.5			20.5
A (mm)				11.7			11.7		11.7		11.7		11.7		11.7			11.7		11.7					8.8		8.8		8.8			120.0
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	2		2		2		2		2		2		2		2			2		2		2		2		2		2		2		30.0
A (mm)	11.7		11.7		11.7		11.7		11.7		11.7		11.7		11.7			11.7		11.7		11.7		11.7		11.7		11.7		11.7		175.5
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	2		2		2		2		2			2		2		2	2	2				2		2		2		2		2	2	32.0
A (mm)	11.7		11.7		11.7		11.7		11.7			11.7		11.7		11.7	11.7	11.7				11.7		11.7		11.7		11.7		11.7	11.7	187.2
Sept.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)	2		2		2		2			2		2		2			2		2		2					2						22.0
A (mm)	11.7		11.7		11.7		11.7			11.7		11.7		11.7			11.7		11.7		11.7					11.7						128.7

Grower #8   *Simcoe (Strawberries Tunnel) - Flow Meter*

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)													0.9	1.9	2.1	1.6		3.6	1.5	2.6	1.6	2.8	2.9		0.4		2.6
A (mm)													4.0	11.6	14.5	10.0		21.6	8.0	13.5	10.3	14.7	18.9		9.8		15.4
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	2.8		1.9		2.1		2.2		2.4		2.7		3.5		1.7			1.2		1.9		1.9		2.3		2.1	
A (mm)	12.7		8.7		11.1		14.2		11.9		13.4		19.1		7.8			5.3		8.4		11.7		11.1		11.5	
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	2.1		2.3		1.5		1.9		1.9			1.1		1.8		1.4		1.1				1.8		1.9		1.6	
A (mm)	11.4		14.1		8.9		12.2		7.2			5.2		12.0		7.8		5.8				8.6		7.7		7.4	
Sept.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	1.8		2.1		2.3		2.2			2.1		1.9		2.3			2.3		1.3		1.9			1.8			
A (mm)	10.5		12.2		12.1		12.8			10.6		10.1		15.1			13.3		7.0		10.5			9.4			
Oct.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T (hrs)	1.4																						2.1				
A (mm)	8.9																						10.0				

June	28	29	30		
T (hrs)		3.1			27.7
A (mm)		16.5			168.6
July	28	29	30	31	
T (hrs)	2.8		1.9		33.5
A (mm)	14.2		11.5		172.6
August	28	29	30	31	
T (hrs)	1.8		1.8		24.1
A (mm)	8.2		7.6		124.1
Sept.	28	29	30		
T (hrs)		1.5			23.7
A (mm)		9.1			132.7
Oct.	28	29	30	31	
T (hrs)					3.5
A (mm)					18.9

<u>Grower #8</u>   Simcoe (Raspberries Tunnels) – Irrigation Records

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)												3			3			3			2			2				2			2	17.0
A (mm)												4.2			4.2			4.2			2.8			2.8				2.8			2.8	23.8
June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)				2			2		2		2		2		2			2		2					1.5		1.5		2			21.0
A (mm)				2.8			2.8		2.8		2.8		2.8		2.8			2.8		2.8					2.1		2.1		2.8			29.4
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	1.5		2		2		2		2		2	2	2		2		2	2		2		2		2		2		2	2	2		35.5
A (mm)	2.1		2.8		2.8		2.8		2.8		2.8	2.8	2.8		2.8		2.8	2.8		2.8		2.8		2.8		2.8		2.8	2.8	2.8		49.7
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2		2			2	2	2	2	2	2	2	2	2	2	54.0
A (mm)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8		2.8	2.8	2.8	2.8	2.8	2.8		2.8			2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	75.6
Sept.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)	2		2	2	2	2	2	2		2	2	2	2	2	2		2															28.0
A (mm)	2.8		2.8	2.8	2.8	2.8	2.8	2.8		2.8	2.8	2.8	2.8	2.8	2.8		2.8															39.2

Grower #9 *Simcoe - Irrigation Records*

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)																												3				3.0
A (mm)																												13.9				13.9
June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)		2												2										2								6.0
A (mm)		9.3												9.3										9.3								27.9
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)		2																														2.0
A (mm)		9.3																														9.3
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)																			2.5													2.5
A (mm)																			11.6													11.6

Grower #10 *Simcoe - Irrigation Records*

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)																													1.7			1.7
A (mm)																													12.7			12.7
June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)	1.7						1.7		1.7				1.7			2.5							1,7									11.0
A (mm)	12.7						12.7		12.7				12.7			19.1							12.7									82.6
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)								2.0								5.1								2.5								9.6
A (mm)								15.2								38.1								19.1								72.4

Grower #11 *NOTL - Irrigation Records*

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																				8.5												8.5
A (mm)																				38.1												38.1
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)										8.5																	8.5					17.0
A (mm)										38.1																	38.1					76.2

Grower #12   *NOTL - Irrigation Records*

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)															5																	5.0
A (mm)															18.0																	18.0
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)			5																		5											10.0
A (mm)			18.0																		18.0											36.0

Grower #13   *NOTL - Irrigation Records*

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																									2							2.0
A (mm)																									50.8							50.8
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)																2																2.0
A (mm)																50.8																50.8

Grower #14   *NOTL - Irrigation Records*

July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)																				1.25												1.25
A (mm)																				50.8												50.8

Grower #15   *NOTL - Irrigation Records*

June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
T (hrs)																					20		3			7	12		20	16		78.0
A (mm)																					33.7		5			11.8	20.2		33.7	26.9		131.3
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)									24																							24.0
A (mm)									40.4																							40.4
August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
T (hrs)			12	12																												24.0
A (mm)			20.2	20.2																												40.4

APPENDIX E

Grower Responses to Survey Part II on Soil Moisture Sensors

1st Part

🏳 **1. Please rate from 1 (poor) to 5 (great) your satisfaction with the irrigation scheduling information you received.**

Answers:

#	Usefulness	Clarity	User friendliness	Time	Frequency of data delivery
1	5	4	4	3	5
2	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA
4	4	4	3	4	2
5	4	3	4	4	3
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	5	5	5	4	5
9	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA
11	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA
13	4	4	4	4	2
14	NA	NA	NA	NA	NA
15	NA	NA	NA	NA	NA
	4,4	4	4	3,8	3,4

***** Not Applicable => they did not receive the irrigation scheduling information

2. Would you say that the soil moisture information has helped you to irrigate more efficiently?

#	**Yes**	**No**	**NA**
1	X		
2			X
3			X
4			X
5	X		
6			X
7			X
8	X		
9			X
10			X
11	X		
12			X
13			X
14			X
15		X	
	27% (4/15)	7% (1/15)	67% (10/15)

Answers:

***** Not Applicable => they did not receive the irrigation scheduling information

1: Yes, he was able to know the exact amount of moisture in the soil profile. He further was able to see if he was applying water too quickly or on-time to the full fill the crop water needs.
5: Yes, because he has a limited amount of water, he has to be more efficient, to use water wisely. It helped him to make sure plants were having enough water. It is nice to have a guide that helps you to know when to irrigate, it is very helpful for the irrigation timing.
8: Yes, he watered more than he would have normally done.
11: Yes, because it proved him he started to irrigate too late and that he did not applied enough the first time.
15: No, his irrigation system is not allowing him to be very flexible as water is delivered by the municipality. Sometimes he has to water when there is water in the ditch and stop even if the crops need it because there is no available water. He tries his best to irrigate when the crops need it but sometimes he irrigates only when he can.

3. How has the information modified your current irrigation scheduling practices? Has it facilitated your irrigation scheduling?

#	Yes	No	NA
1	X		
2			X
3			X
4			X
5	X		
6			X
7			X
8	X		
9			X
10			X
11	X		
12			X
13			X
14			X
15	X		
	33% (5/15)	0	67% (10/15)

Answers:

***** Not Applicable => they did not receive the irrigation scheduling information

1: Yes, he has irrigated less per time and it was more efficient. He hopes he will apply what he learned and more changes to his irrigation scheduling practice for the future years.
5: Yes, it helped to irrigate more timely, more accurately.
8: Yes, he was more informed to take decisions.
11: Yes, now he knows he needs more water. He would apply more water next year.
15: Yes, he was meeting frequently the summer students when they were taking samples, he used the readings from the portable FieldScout TDR to be guided for his irrigation timings.

4. Has your understanding of soil moisture and irrigation scheduling improved as a result of this project?

#	Yes	No
1	X	
2	X	
3	X	
4	X	
5	X	
6	X	
7	X	
8	X	
9	X	
10	X	
11	X	
12	X	
13	X	
14	X	
15		X
	93% (14/15)	7% (1/15)

Answers:

1: Yes, it was great to see the saturation point, the field capacity, how much water there is the soil profile depending on the soil textures.
2: Yes, he better understands what the soil water holding capacity for the soil types are and where the wilting point and trigger points are.
3: Yes, it helped better knowing how the soil profile dries out, and where the wilting point is.
4: Yes, he now has a better appreciation for the variability in water holding capacity of his soil types.
5: Yes, he now knows better when to apply irrigation water.
6: Yes, it helped to determine when irrigation was beneficial.
7: Yes, he wants a probe to be more accurate.
8: Yes, he now knows what is going on in the soil profile while before he was guessing.
9: Yes, it has shown them how to benchmark the indicators, to validate and calibrate them (i.e. visual plants condition, soil feeling and appearance).
10: Yes, he learned more on the timing when he should water and on the quantity; if he did not apply enough or too much water by looking at the trends on the C- Probe graphs.
11: Yes, he had a good knowledge of what is field capacity and stuff like that (he took courses on that), but still it helped a little bit.
12: Yes, it showed her the benchmarks, the field capacity and so on. It helped to better understand how to irrigate.
13: Yes, now, he knows he has to water earlier and apply an inch every week.
14: Yes, he knows more about how to irrigate, timing and amount. He learned that there was not enough water in his root zone.
15: No, it doesn't.

5. Do you know what your field capacity value is? If yes, what is it?

#	Yes	No	Value	Correct Answer
1		X		
2		X		
3		X		
4		X		
5		X		
6		X		
7	X		32	
8	X		17	X
9	X		35	
10		X		
11		X		
12		X		
13		X		
14		X		
15		X		
	20% (3/15)	80% (12/15)		

Answers:

1: No, he doesn't know it on the top of his head, it is written somewhere in the documents we gave him.
3: No, he has it written down somewhere but he knows that his wilting point is 12%.
7: Yes, his field capacity value is 32 & the wilting point value is 15.
8: Yes, it is around 17.
9: Yes, it is 35.
11: Not specifically, he doesn't know it but Bano told him.
14: No. They have explained it at the last meeting; he understand the principle of soil moisture levels, field capacity and wilting point but he doesn't know the exact number.
2, 4, 5, 6, 12, 13 and 15: No, they don't.

6. Do you know what your trigger point for irrigation is? If yes, what is it?

#	Yes	No	Value	Correct Answer
1		X		
2	X		8 to 15	X
3		X		
4	X		7 to 18	X
5	X		15	X
6		X		
7	X		20 to 25	
8	X		12 to 13	X
9		X		
10	X		50% of FC	
11		X		
12		X		
13	X		15 to 18	X
14		X		
15		X		
	47% (7/15)	53% (8/15)		

Answers:

2: Yes, his irrigation trigger point is 8-15% VWC.
4: Yes, according to Brace data, the trigger point for irrigation was somewhere between 7 and 18 % VWC.
5: Yes, 15% of VWC.
7: Yes, his irrigation trigger point is 20-25.
8: Yes, it is around 12-13.
10: Yes, it is 50% of capacity.
13: Yes, it is around 15-18.

#6, 12, 14 and 15: No, they do not.

1: No, he doesn't know it on the top of his head, it is written somewhere in the documents we gave him.
3: No, he has it written down somewhere
9: No, they don't use a technical trigger point to irrigate.
11: Not specifically, he doesn't know it but Bano told him.

7. Was the data provided by the soil moisture monitoring equipment useful? If yes, in what way? Please give some examples.

#	Yes	No	NA
1	X		
2			X
3			X
4			X
5	X		
6			X
7			X
8	X		
9			X
10			X
11		X	
12			X
13			X
14			X
15			X
	20% (3/15)	7% (1/15)	73% (11/15)

Answers:

1: Yes, he learned that he has to irrigate shorter times. It helped to take less guess in terms of when to irrigate.
5: Yes, he particularly appreciated the manual tensiometer as it was easy to read, not complex. The other instruments haven't been very useful to him, they were too complex. He is not used to computers so he had trouble to access the probes data. He would have needed more time to understand how it works, time that was unfortunately unavailable during the growing season.
8: Yes, it provided readings to go by that without them, you're guessing.
11: No, too complicated, too detailed. It needs to be more userfriendly.

8. How were your yields in the experimental area this year, compared to other years?

- **Excellent (much better than expected)**
- **Good (above average)**
- **Average (normal)**
- **Poor (below average)**
- **Very low (much below what was expected)**

#	Excellent	Good	Average	Poor	Very Low
1		X			
		X			
2		X			
		X			
3			X		
4				X	
5	X				
6		X			
7	X				
8					X
					X
				X	
9	X				
10		X			
11		X			
12		X			
13			X		
14			X		
15			X		
	16% (3/19)	42% (8/19)	21% (4/19)	11% (2/19)	11% (2/19)

Answers:

4: He roughly had 43 ton/acre versus 50 ton/acre average.

9. What would your yields have been without irrigation?

- **Excellent (much better than expected)**
- **Good (above average)**
- **Average (normal)**
- **Poor (below average)**
- **Very low (much below what was expected)**

#	Excellent	Good	Average	Poor	Very Low
1				X	
				X	
2					X
					X
3				X	
4					X
5			X		
6			X		
7			X		
8					X
					X
					X
9				X	
10				X	
11				X	
12			X		
13				X	
14				X	
15				X	
	0	0	21% (4/19)	47% (9/19)	32% (6/19)

Answers:

3: The yields would have been around 15-20% less without irrigation.

5: He never would have grown strawberries without irrigating.

7: He got 30-35% extra yield compared to his neighbours who do not irrigate.

10. How was your irrigation need this year, compared to other years? Please explain how the irrigation frequency and the amount of water applied were different from other years (if different).

#	Frequency	Amount
1	Higher	Higher
	Higher	Higher
2	Higher	Same
3	Much above average	Much above average
4	Highest since he started irrigating	Highest since he started irrigating
5	Same	Same
6	A bit more	A bit more
7	Much higher	Much higher
8	Up 30%	Up 30%
	Up 30%	Up 30%
	Up 30%	Up 30%
9	Higher	Higher
10	Higher	Same
11	Doubled	Doubled
12	Higher	Higher
13	A lot more	A lot more
14	Higher	Higher
15	Higher	Higher

Answers:

1: He irrigated longer with a greater amount of water due to the below average precipitations.
2: This year was very dry, he had to irrigate daily over a longer period of time. As there were no big rain events, he didn't stop to irrigate.
3: The irrigation need was much above average in terms of frequency and amount this year.
4: Irrigation need was one of the highest it has ever been since we started irrigating.
5: His irrigation need was about the same than other years. He had enough water to irrigate this year, probably because they had more rain in August.
6: Crops water requirements under plastic beds are similar from year to year. However, this year was very hot and dry so he had to irrigate a bit more.
7: Much higher, much more frequent and heavier irrigations.
8: Up 30% more than it normally is.
9: He irrigated more to compensate for the lack of moisture due to the hot and dry growing season but he also irrigated less at the start of the growing season to protect the crops from frost. The crops were less prone to frost this year. He has however irrigated more this year than other years; the crop water requirements were higher than the frost protection water needs.
10: He irrigated more frequently but with the same amount of water.
11: High needs due to climate, it was a dry year. Frequency and amount have doubled this year.
12: More frequent and more water because it was so dry this year compared to other years.
13: He had to water a lot more this year.
14: Higher frequency and bigger volume was applied.
15: It was higher this year.

11. Approximately how much water have you saved or spent as a result of using the soil moisture data equipment?

#	Save	Spent	NA
1	Shorter runs		
2			X
3			X
4			X
5	25 to 30%		
6			X
7			X
8		30% *	
9			X
10			X
11		30 to 50%	
12			X
13			X
14			X
15			X

Answers:

1: It is hard to say, but he would say that he has saved water since he was irrigating with shorter runs.

5: He saved 25-30% of water by using the manual tensiometers. From the results he was doing a good a job; he never reached or went below the wilting point.

8: It is hard to know if the extra 30% water spent was due to the extremely hot growing season or to the use of the soil moisture data.

11: He used more water because he realized he wasn't going deep enough in the soil profile. He would have used 30-50% more water than usually if the equipments were in place earlier. He would have irrigated 4 times instead of 3 and much heavier.

2nd Part

1. Please rate the usefulness from 1(poor) to 5(great) for each of the equipment installed on your farm.

- Manual Tensiometer
- Manual Portable FieldScout TDR
- Echo Probe
- C-Probe
- Gro-Point TDR
- Watermark (Watchdogs)
- Campbell Water Content Reflectometer TDR
- Hortau
- Flow Meter

8: He cannot tell what the data the instruments out there were giving exactly. He was looking on internet to some data (he doesn't know from which equipment it was). The data he was looking on internet were very useful to him but he cannot rate the usefulness of any other equipment.

#	Manual Tensiometer	Manual Portable FieldScout TDR	Echo Probe	C-Probe	Gro-Point TDR	Watermark (Watchdogs)	Campbell Water Content Reflectometer TDR	Hortau	Flow Meter
1	3	3 - 4	4	4	4	3	3	4	4
2	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	5	4	4	4	4	4	4	NA	4
6	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	5	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	2	1 - 2	1 - 2	4	1 - 2	1 - 2	1 - 2	NA	NA
12	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	NA	NA	NA	NA	NA	NA	NA	NA	NA
14	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	NA	NA	NA	NA	NA	NA	NA	NA	NA
	3,3	2,5	3,2	4,3	3,2	2,8	2,8	3,3	4

2. By which means would you like to access soil moisture monitoring data? What would be most convenient for you (i.e. directly in the field, fax, internet, consultant, e-mail, …)?

#	Directly in the field	Fax	Internet	Consultant	E-mail
1			X		
2	X				X
3			X		
4			X		
5	X				
6					X
7			X		
8			X		
9	X				
10	X				
11			X		X
12	X				
13			X		
14	X				
15		X			X

Answers:

5: He doesn't mind to walk his field daily; he already makes it to look at the plants for diseases.

2: He would like to access the data directly in the field or by e-mail.

11: Personal e-mails would be great but he doesn't mind to look at a web page to access the data. He doesn't need to be specific to each farm; as long as he knows his type of soil he can adjust the data to his farm.

15: He would like by fax or e-mail.

3. How do you intend to use the soil moisture information?

#	Answer
1	He hopes to be able to adjust more his irrigation frequency.
2	He would use it to make better decisions regarding irrigation; to decide when to start irrigation and then to maintain the soil moisture at the right level.
3	He would use it to irrigate more efficiently.
4	As discussed previously, the data boosted his confidence in his current practices. If he had continuous data, he could have used it to schedule the start of the irrigation events and adjust the length of irrigation times (i.e. to monitor soil moisture so that enough (not too much) water was being applied.
5	To do irrigation scheduling in the future.
6	He has been very involved in the project, he does not know much about the kind of information he can get with the equipments that were installed.
7	To do irrigation scheduling in the future.
8	To tune irrigation scheduling, to make it more detailed.
9	Again, they would use it to calibrate and validate the indicators.
10	To better determine when to apply water and avoiding over/under watering.
11	Look at the trends to see, how deep the water in the soil profile is (30 cm range). He knows when he has to irrigate which is to say when are the critical developments stages for peaches which need a boost of water (cell division + fruit sizing before harvest). And the problem is that he is not flexible to change dates, he cannot irrigate the whole field all at once even if it is the perfect timing and that the crop needs it, it takes 7-10 days to irrigate the whole field with the overhead gun (too expensive to by another one). It would therefore be more useful to look at the amount to be applied than at the timing.
12	The results showed her that she was doing a good job to maintain soil moisture in between FC & WP. She would therefore use the data to keep going, to show her that she is still putting on the correct amount of water.
13	He'll use it to decide when to water.
14	He would look at the data directly in the field and adjust his irrigation timing/amount consequently.
15	He would use it to look at the trends in the soil profile to see if water reach the rootzone enough deep and to see if the crops need water sooner than what he expects from his observations of the plants state and the soil feeling and appearance.

4. Which irrigation scheduling techniques have you decided to adopt for future years (if any)? Please explain why.

#	Yes	No	Undecided	Not Fixed Yet	Equipment	Explication
1	X				C-Probe	He found that the C-Probes were handier. To him, it is very important to be able to access the soil moistures levels at anytime. As he his very busy, he prefers to look at the data during lunch times and evenings. Probes data on internet were allowing him to do so.
2				X	Hortau or Portable FieldScout TDR	He is not fixed yet, he was interested by the manual portable FieldScout TDR or the Hortau tensiometer but he has to evaluate if it will be cost effective to install them.
3				X	C-Probe or Hortau	He was interested by the C-Probe and the Hortau tensiometer because they seem fairly easy to use, they have low maintenance, they are not intrusive and the data can be downloaded easily on a computer.
4		X			None	He will continue using the ET model, adjusting irrigation to weather and crop stage with in-field monitoring to make sure that the water being applied is sufficient and not excessive. Soil moisture monitoring would facilitate this.
5	X				Manual Tensiometer	Tensiometer, easy to read, very simple and cost effective.
6	X				Flow Meter	He would install a flow meter to know exactly how much water he applies.
7	X				Portable FieldScout TDR	It has to be cost effective; since he has too many stations to irrigate, the portable TDR might be better than the c*probe. However, he would prefer to install a c*probe than to use the portable TDR. Money is definitively an issue.
8				X	C-Probe	He was looking on internet to some very useful data to him (he doesn't from which equipment it was, (i.e. C-Probe) but no decisions was taken yet concerning the adoption on an irrigation scheduling technique.
9		X			None	They do not think they need to adopt any of these equipments.

10				X	Manual Tensiometer or C-Probe	He preferred the Manual Tensiometer because it is portable and relatively inexpensive. However depending on the budget (i.e. acres/cost) he would invest in a C-Probe.
11	X				C-Probe	The C-Probe is the more userfriendly tool.
12		X			None	They all have to seem to have their specific problems with them all. The C-Probe seems to be the best choice, but it is too expensive, especially since she knows she is doing a good job without it.
13	X				C-Probe	He is interested by the C-Probe because it seems easy to access the data and it worked better than the other equipments.
14			X		Not Sure Which	He would possibly adopt one of them, but he is not sure which one.
15	X				C-Probe Network	He is not interested to install any of the equipments for itself on his field but he would be interested in a C-Probe network where he could access by internet the moisture trends of the soil profile.
	47% (7/15)	20% (3/15)	14% (2/15)	20% (3/15)		

5. Do you consider the quantity of water saved (or augmented) during the growing season worth the investment into future soil moisture monitoring equipment?

#	Yes	No	NA	Explication
1	X			For sure it would be an advantage for future years to save water with these equipments.
2			X	
3			X	
4		X		This year he did not adjust his irrigation. However, the monitoring would be very useful because in a "typical" year, the dry period is lasting for a long period.
5	X			Yes, especially because he has a limited water supply.
6			X	
7			X	
8	X			Yes, it worth it.
9			X	
10			X	
11	X			Yes, it worth it.
12			X	
13			X	
14			X	
15			X	
	27% (4/15)	7% (1/15)	67% (10/15)	

6. How much extra time would you be willing to spend on irrigation scheduling?

#	Extra Time	Explication
1	Whatever	The time it needs to be spend but at the same time less than possible.
2	Some daily	He considers it worth to spend some extra time daily on irrigation scheduling.
3	10 mins/day	He feels it is important but he doesn't have extra time; the quicker is the better. He would be willing to spend 10 minutes per day on irrigation scheduling.
4	A bit more	He would invest a bit more time.
5	Whatever	For him, these equipments are a management tool which helps to get better crops. He doesn't mind to spend extra time on it due to the benefits he gets.
6	20 mins/day	None
7	Whatever	Whatever, he has to do it. He considers irrigation scheduling as being part of his job. He would hire someone to do it.
8	10 mins/day	None
9	50% More	They would be willing to increase the time spend on irrigation scheduling by 50%. At some point, they may switch for trigger irrigation which is more time consuming than sprinkler irrigation. However they want to be able to better target their irrigation not because they are concerned about water supplies but rather by the yields.
10	10-15 mins/day	None
11	1-1h30/week	None
12	NA	NA
13	Whatever	He doesn't have extra time but still he would spend as much as he needs to get the job done. He consider irrigation scheduling has being very important.
14	1hr/week	None
15	10 mins/day	None

7. If funding is available to continue the project in the future, do you have any recommendations to improve it?

#	Recommendations
1	Instead of having all these equipments installed we should select the preferred one by the growers (2-3) and retry the whole experiment.
2	He would have liked to get the data every few weeks during the growing season.
3	He would like to see the data during the growing season.
4	Benchmark sites might have been put on a map so they could remember which was which. Supply data on a frequent basis so that it can be used in season.
5	Good job, well undertaken. To get data more timely would be great. Having explained earlier how to access the data, works so on and how the equipment would perhaps have given better results.
6	None
7	No, it was well done.
8	None
9	They would have liked the data gaps (equipments failure or technical errors) to be bugged out to get the whole data set.
10	Nome
11	Find pieces of equipment that are cost effective and user friendly. A tool that gives directly on-site the data, something more practical that would tell here is your benchmark and you are above/below it. A compromise between researchers' needs and growers' needs would be appreciated.
12	Just to give the data on-time.
13	Getting the info sooner would be important.
14	Give the info more timely.
15	It could be interesting to install a c-probe network and involve the growers so that they can access by themselves the data on a daily basis and see what happen. It would also have been more useful for them if they would have got the data more timely

8. Do you have any other comments?

#	Comments
1	It has been a great experience to have these equipments, it shows how much guessing is involved in irrigation scheduling at the moment and how crucial the probes are to help reducing the guesses.
2	It was a very interesting work and he would be glad to be part of it again, to cooperate again on a similar project.
3	None
4	None
5	He is very concerned about water; this was very helpful for him.
6	None
7	Thank you for teaching us!
8	None
9	It was a really good comprehensive project.
10	The whole process was runned well and well organised.
11	Run it one more year! The field day would be much more useful next year. Now know people are very interested by the project, the data they can get and everything. We could take the bugs out, and re-try next year. The results would be far more concluding and the experiment far more useful for the growers that could access on-time the data.
12	The project was very interesting, to see the results and to learn about irrigation scheduling.
13	He was glad to be part of the project; it very helped him to manage irrigation for future years.
14	None
15	He would be interested in participating in the c-probe network.