Hebron University
College of Graduate Studies & Academic Research

Estimation of Crop Water Requirement for Cucumber (*Cucumis sativus*) Grown in Green Houses

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Symbols

#: Number.

ω : Water content based on weight.

$\theta_{critical}$: volumetric water content on critical point.

θ_f : Today's volumetric water content.

θ_{fc}: volumetric water content on field capacity.

θ_i : Yesterday's volumetric water content.

θm: gravimetric water content.

θ_{pwp}: volumetric water content on permanent wilting point.

θv: Volumetric water content .

μ : Standard Deviation.

As: Bulk density.

C: Control.

cm: centimeter.

cm^3: cubic centimeter.

c^o:Celsius.

Drz: Depths of root zoon.

ds : deciSiemens per meter.

ET: Evapotranspiration.

ETm: Evapotranspiration maximum.

FC: Field Capacity.

FDR: Frequency Domain Reflectromtry.

F^o: Fahrenheit

g : gravity.

gr: grams.

I : Irrigation depths.

Kg: Kilograms

KPa: kilo Pascal.

m: meter .

MAD : Maximum Allowable Depilation.

Max : Maximum.

Min : Minimum.

mm: millimeter.

MR : Meter Reading.

MS: Micro soft.

pH: Potential of Hydrogen is a measure of the acidity or alkalinity of a solution.

psi: Pounds or pound force per square inch.

PVC: Poly Vinyl Chloride.

pwp : permanent wilting point.

R: Replicate.

R^2: Coefficient of Determination.

RH: Relative Humidity.

s^2 : second square.

T: Temperature.

TDR: Time Domain Reflectromtry.

*V:*volume .

WC : Water content.

W_{dry} : weight of dry soil.

wt : Weight.

W_{wet} : weight of wet soil.

π: is the ratio of a circle's circumference.

ρ_b: apparent specific gravity.

Abstract

Scarcity of water for domestic use and for agricultural production has been hitting the Middle East in general and Palestine in particular. It is estimated that more than 60% of fresh water is used for agricultural purposes in Palestine. A reduction in this percentage is necessary due to the increase of the population.

Best irrigation management practices are not used in irrigated Palestinian agriculture. Irrigation scheduling using water budget techniques are not practiced to minimize the waste and the deep percolated water that seeps under the root zone and is not beneficially used by the plant.

In this research, evapotranspiration for cucumbers grown in a green house and weather parameters in the green house were measured during the growing season.Irrigation scheduling was practiced based on measured evapotranspiration in replicate plots; a control plot was managed by the farmer utilizing traditional irrigation practices. A model was developed that correlated simple weather data to evapotranspiration for cucumber under green house conditions. This model can be used to predict the evapotranspiration of cucumbers grown under green house conditions.

Even though less water was used in the experimental plots in comparison to the control plot, higher yield was measured. This can be attributed to the leaching of nutrients by the high amounts of water applied by the farmer to the control plot. Nutrients were leached below the root zone in the control plot which the plant was not able to absorb and utilize.

It is recommend that farmers utilize irrigation scheduling based on water budget techniques using the evapotranspiration model developed for growing cucumbers under green house conditions. This management practice would reduce irrigation water consumed and would increase yield.

1 Chapter One

Introduction

The reason why this research is so important is that water resource problems in the Middle East, especially in the West Bank and Gaza, have become the most urgent, complex, and intractable of any region in the world. In fact, fresh water supplies in the Middle East now are barely sufficient to maintain a quality standard of living. “As the population in this region continues to grow and economic development increases, these countries must work together to ensure that ecosystems are preserved and adequate water supplies sustained.” (White, 1999).

The Committee on Sustainable Water Supplies for the Middle East stated in 1999 that “Given the rate of population growth, water quality and quantity will not be sustainable unless suitable conservation methods are used in all three major sectors of water use—urban, agricultural, and industrial.

As water demand increases in the region, and as the cost of obtaining additional water supplies grows more expensive, the role of traditional agriculture has to be reevaluated.

The agricultural sector is the major consumer of water in Palestine. Scarcity of water for domestic use and for agricultural production has been hitting the Middle East in general and Palestine in particular. It is estimated that more than 60% of fresh water is used for agricultural purposes in Palestine. To provide sustainable water supplies for future generations a reduction in this percentage is necessary due to the increase of the population.

As the world’s population is increasing and the general standard of living is improving, the quantities of fresh water needed and used for domestic purposes have increased drastically, Population in Palestine and also in Hebron City has been increasing dramatically and is expected to reach more than 268,000 inhabitants by the year 2020 as shown in figure 1.1 (Palestinian Central Bureau of Statistics 2007).

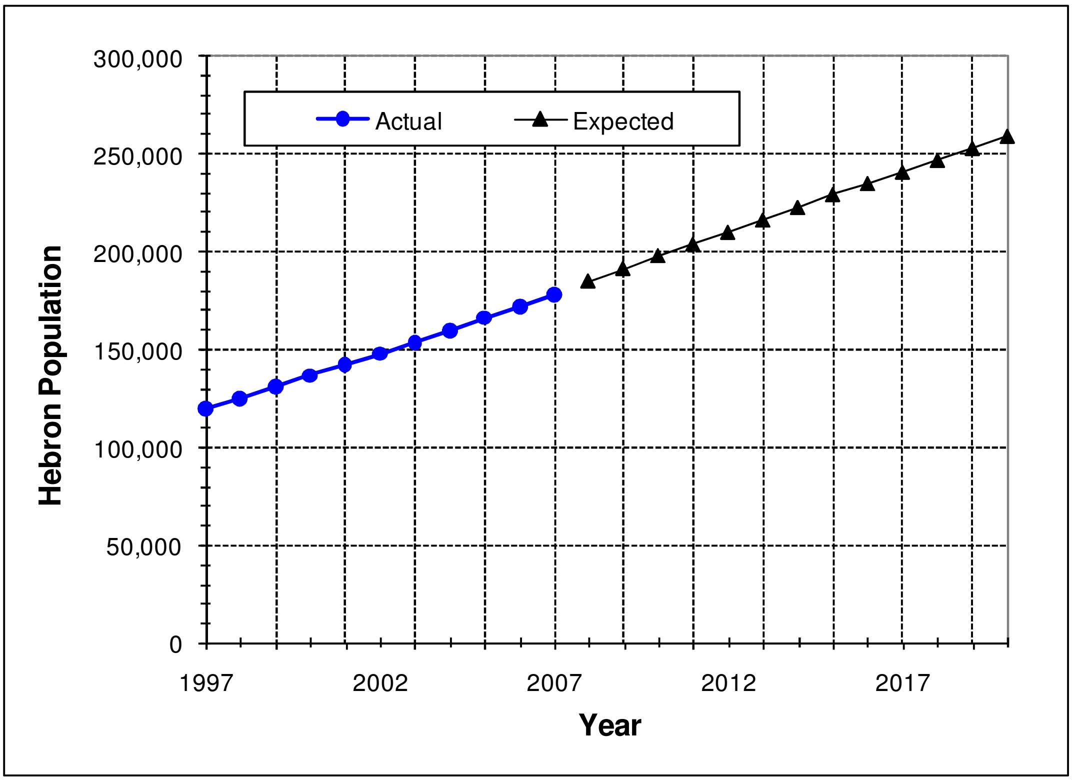

Figure 0.1: Population growth of Hebron City and expected Increase until 2020 (Palestinian Central Bureau of Statistics 2007).

At the same time the need for water for agricultural purposes has been also dramatically increasing. The main users nowadays of fresh water in agriculture are greenhouses where vegetables are grown around the year in the Hebron area to support the farmers and to maintain a steady flow of food products to the market. Scarcity of water is due to the high population and increasing of use in agriculture and industrial and illegal settlements strategically placed on top of water aquifers which supplies around 80% fresh water in West Bank (ARIJ, 2002).

Crop water requirement, consumptive use of water by plants, or Evapo-transpiration (ET) is one of the most basic components of the hydrologic cycle.

Evapotranspiration (ET) is the sum of evaporation and plant transpiration. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies.

Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata present in the leaves. Evapotranspiration plays an important role in the water cycle. Factors that affect evapotranspiration include the plant's growth stage or level of maturity, percentage of soil cover, solar radiation, humidity, temperature, and wind (James 1993).

If evapotranspiration amounts are known for certain localities, the farmers can be trained to schedule irrigation based on a water budget technique that determines when to irrigate and how much water to apply.

Evapotranspiration can be experimentally measured in the field or calculated from climatologically data. Evapotranspiration for local vegetables grown under green house conditions are not available and probably none have been measured in the Hebron area.

The main concept of this research is to grow cucumbers under green house conditions and measure evapotranspiration by the direct measurement techniques are based on the conservation of mass principal. In addition, a portable weather station will be installed in the same green house to monitor and record weather data to be used to correlate the directly measured evapotranspiration with the weather parameters in order to develop a model for future use by farmers. This model will enable farmers and agricultural engineers alike to use the water budget technique to determine when to irrigate and by how much.

This technique can save on the amounts of water and fertilizers that are applied in growing crops reducing the cost of production, conserving water resources, reducing salts leached to ground water and enhancing the quality and quantity of the produce. Irrigation practices under green house production of vegetables in Palestine are not based on best management practices forcing the irrigator to apply more than 3 to 4 times the required amount of water to reach maximum allowable yield (Sbeih2002).

Accordingly, the two classical questions of irrigation scheduling are: when to irrigate? How much water to apply? Waller and Tamimi, (2004) and from work done in Arizona and in Aqaba – Jordan reported water depths applied in irrigation in arid lands showed the water is deep percolated to a depth of more than 2.5 meters below plant root zone. These practices increase the amount of applied water and fertilizers which in turn increases the cost of agricultural production exploiting water resources and increasing salinity of soil and ground water. This lack of evapotranspiration and crop water requirement data does not allow the farmer to apply best management practices in green houses producing vegetables in Palestine causing random irrigation times and amounts.

Efficiencies of irrigation systems are very low causing high losses in deep percolation and run off. According to measurements made by (Whitcomb and *et al.*,1985) on irrigation systems in the arid area during which they measured the water content of drip irrigated fields grown with vegetables in the summer time; they found out that even though the ground water level in the fields in the middle of the summer was at a depth lower than one meter below soil level, moisture content reached field capacity at levels of 0.5m, 1.0m, 2.0m and down to a depth of 2.5 meters below the root zone due to over irrigation and the application of irrigation water without management tools.

The problem Statement and objectives of this research is the most farmers in Palestine in general and in Hebron area in particular do not use irrigation scheduling techniques due to the lack of measured ET data for vegetables grown in Palestine under green house conditions. And hence they irrigate the crops based on feel and observation. This causes over irrigation and the waste of plenty of water in irrigating agricultural crops in general and under green houses in particular. This is considered a waste in a vital natural resource that is scarce in Palestine and which life depend on it.

The objectives of this research study are four folds:

1. Measure crop water requirement for cucumber under green house conditions in Hebron.
2. Measure the environmental factors (weather parameters) that affect evapotranspiration to save on water being a scarce natural resource in Palestine.

3. Develop water budget technique based on the measured evapotranspiration to determine when to irrigate and how much to apply.

4. Based on the field measured data obtained in objective 1, develop a model based on weather data prevailing under green house conditions to predict crop-water requirement (Evapotranspiration).

2 . Chapter Two

Literature Review

2.1 Green Houses in Palestine

Greenhouse vegetable production has traditionally been located near population centers and in the leveled land. The Palestinian agricultural sector represents the yield base essential for the Palestinian economy. It forms 30% of Palestinian labor force (The Palestinian Central Bureau of Statistics/ Agricultural Statistics 1999/2001). Table 2.1 shows the number of farmed greenhouses is in different directorates of the West Bank (The Palestinian Central Bureau of Statistics/ Agricultural Statistics 2004/2005).

Table 0.1: Number of farmed greenhouses in the West Bank (The Palestinian Central Bureau of Statistics/ Agricultural Statistics 2004/2005).

Palestinian City in West Bank	Area in donums of greenhouse
Jerusalem	28
Ramallah	23
Hebron	590
Jenin	3162
Jericho	1214
Bethlehem	114
Nablus	860
Tulkarim	2478
Qalqilia	2496
Tobass	4118
Salfeit	89
Total	15172

The greenhouse production amount of vegetables in 1997 / 1998 reached about 9079 tons (about 1.8% of total vegetable production in the Palestinian lands, which was 481455 tons). The number of greenhouses in Hebron was estimated at 244 donums for 1998 (The Palestinian Central Bureau of Statistics/ Agricultural Statistics 1999/2001).

2.2 Water Usage in Irrigated Green Houses

Vegetables produced in greenhouses require ample amounts of water for optimum growth, yield, and fruit quality Growth processes will slow, and lower yield and quality will result if the plant is water stressed even for a very short period, especially during critical growing stages (Hochmuth, 1991). Drip irrigation can improve yields and earliness in cucumbers. On the average, cucumbers need 25 mm to 50 mm of water every week, with more needed in hot, dry weather. Fruit set and fruit quality are also highly dependent on water availability (Wittwer *et al.*, 1979).

Cucumbers have a high water requirement (Abou-Hadid *et al.*,1990). Periodically, heavy watering is desirable to ensure proper penetration to the root zone. Warm water (not below 65ºF (20ºc)) should be used in irrigation. Cold water chills the roots, and slows plant growth with a direct reduction in yield (Wittwer *et al.*, 1979).

2.3 *Cucumber Production*

Cucumber is one of the major crops grown under plastic greenhouses in Palestine. The production of greenhouse cucumbers in many parts of the world parallels that of greenhouse tomatoes, the cucumber is a semi-tropical vegetable, and grows best under conditions of high light, humidity, soil moisture, temperature, and fertilizer, the cucumber is almost always grown in rotation with lettuce and tomatoes, or in rotation with bedding or vegetable plants. It is possible to grow cucumbers after greenhouses become empty in the spring following bedding plant production (Wittwer *et al*, 1979).

Vegetables contribute with a production value of US$27 million which is about 46.1% of total agricultural production value in the Governorate of Hebron, The cucumber crop contributes US$15 Million to the Hebron Governorate economy which is about 55% of vegetable production, the tomato crop contributes with 10%, the eggplant crop contributes with 6.9 % and the kidney beans crop contributes with 5.6%, the total area of lands farmed with vegetables in Hebron Governorate reached about 13980 donums - about 4.4% of total area farmed in the governorate, which is estimated at 313116 donums (Palestinian Central Bureau of Statistics/ Agricultural Statistics 1999, 2000 and 2001).The production of the cucumber in the West bank was 89084 tons and in Hebron was 5373 tons ,the number of green houses planted with cucumber in 11088 (Table 24 in the report of Palestinian Central Bureau of Statistics/ Agricultural Statistics 2004 and 2005)donums and the yield for each donum is 9107Kg/Donum (Palestinian Central Bureau of Statistics/ Agricultural Statistics 2004 and 2005).

2.4 Evapotranspiration

Evapotranspiration (ET) is the total amount of water lost via transpiration and evaporation from plant surfaces and the soil in an area where a crop is growing.

Evaporation occurs from all open surfaces whenever there is sufficient energy for vaporization. Transpiration involves movement of water from a soil medium into plant to the atmosphere. Because it is difficult to determine transpiration and evaporation losses separately and precisely, and because larger plants lose water mostly by transpiration, evapotranspiration is used to group them together (Nokes, 1995) and (Keach, 1998).

Transpiration is generally favorable to plants since it aids in absorption and transport of mineral nutrients. It also cools the leaves during radiation periods due the removal of the latent heat for vaporization. Too much transpiration, however, can result in plant stress. Most plants have mechanisms for diminishing high transpiration stress through reducing leaf area by rolling of leaves, by reducing stomatal opening, or by changing leaf orientation as result of wilting to reduce intercepted solar irradiance (Nokes, 1995).

ET represents the water that the plant transpires and that which evaporates from the soil. Consumptive use data for different crops is particularly important in arid and semi-arid regions. Chrtzoulakis and Drosos (1995) worked in the greenhouse for the water use yield of greenhouse growing eggplant under drip irrigation. They determine the water use for the eggplant by the tensiometer and the maximum evapotranspiration (ET_m) when soil water potential was maintained at values higher than – 20 KPa. Evapotranspiration for eggplants ranged from 0.5 mm/day to 4.5 mm/day. The Evapotranspiration for the entire season was evaluated at 380mm.

Knowledge of ET is necessary in planning and operating water resources projects such as: surface and underground water; water management; water projects for irrigation; power; water transportation; flood control; agricultural, municipal and industrial water uses, and wastewater reuse systems. Evapotranspiration data are essential for estimating irrigation water requirements. They are useful in sizing wastewater reuse systems (Metcalf, E. I., 2003)

Prenger et al (2002) made a comparison of four evapotranspiration models in a greenhouse environment, and compared the measured ET with two empirical climatic factors: solar irradiance and vapor pressure deficit and with calculated ET based on four evapotranspiration models :(1) Penman, (2) Penman-Monteith, (3) Stanghellini, and (4) Fynn. They correlated each method with the measured evapotranspiration value and the coefficient of determination (R2) was found to be 0.872, 0.214, 0.481 and 0.848 for Penman, Penman-Monteith, Stanghellini and Fynn methods respectively. The lowest R2 found is the penman-Monteith method.

Evapotranspiration for cucumber grown under greenhouse conditions in Palestine are not known and cannot be found in the published literature for Palestine only we know the evaporation as we see in the table 2.2 shows the estimated values of evaporation amounts for different locations in the West Bank.

Table 0.2: Annual Evaporation in some areas of the West Bank (The Palestinian Central Bureau of Statistics/ Agricultural Statistics 2004/2005).

Region	**Annual Evaporation (mm)**	**Region**	**Annual Evaporation (mm)**
Al Maleh	2298	Jerusalem	2095
Al Fare'a	2426	Bedyya	2000
Jericho	2243	Boreen	2038
Daraja	2394	Tulkarm	1917
Bani Na'em	2343	Methalon	1996
Al Zaheriyya	2034	Hebron	2025

2.5 Soil moisture content definition and meaning

Soil moisture is the water held in pores in the soil in liquid and vapour phases (Scott and Maitre, 1998). Soil moisture shows a great variability in space and time, the most important parameter influencing the amount of the moisture in the soil included seasonal rainfall or irrigation, soil texture, vegetation type, topography, and land use (Salve *et al*., 2001 and Fu *et al*., 2004).

Soil moisture is the most important component of the hydrological cycle, particularly in the arid and semi-arid areas where rainfall is infrequent and evaporation rate is high (Alsekh, 2006). The soil moisture is of great importance in the growing plant in green houses because of adding water by irrigation systems to the plant this water which added gives the soil moisture and the available water for the plant.

3 . Chapter Three

Methods and Materials

3.1 Land Preparation

A green house lot was located in the northern part of Hebron called Ras Al Jurah. The green house is privately owned and it has an area of approximately 600 m^2. The farmer has been growing vegetables for the past 15 years.

The green house land was plowed for a depth of about 25 cm. A drip irrigation system was installed for growing cucumbers in a 1.0 m by 0.5 m grid as shown in figure 3.1. Figure 3.1 also shows the layout of the experimental design; a water source placed at elevation 5 meters higher than the field supplied water to a 32 mm Poly-Vinyl Chloride (PVC) sub-main line and the pressure that was measured at the entry point in the sub-main was equal to 0.49 bars which is equivalent to 7.1 psi. Five 16 mm PVC laterals were connected to the sub-main line and each lateral had 20 – 4 liter/hour drippers. These drippers were calibrated under the available pressure of 7.1 psi and the flow rate was measured to average 3.0 liters/hour. The installed drippers outflow would have been 4.0 liters/hour if the pressure head was approximately 13 psi.

A portable wireless weather station was housed in a shaded open box which measured barometric pressure, air temperature and air humidity.

Six experimental plots were selected in a representative location within the green house and each plot had 20 irrigation drippers. The farmer utilized the remaining area of the green house was growing cucumbers. Two plots, C1 and C2(figure3.1), were designated as the control plots for which the farmer controlled irrigation, fertilization and all agricultural operations and practices in a manner similar to the practices performed throughout the green house.

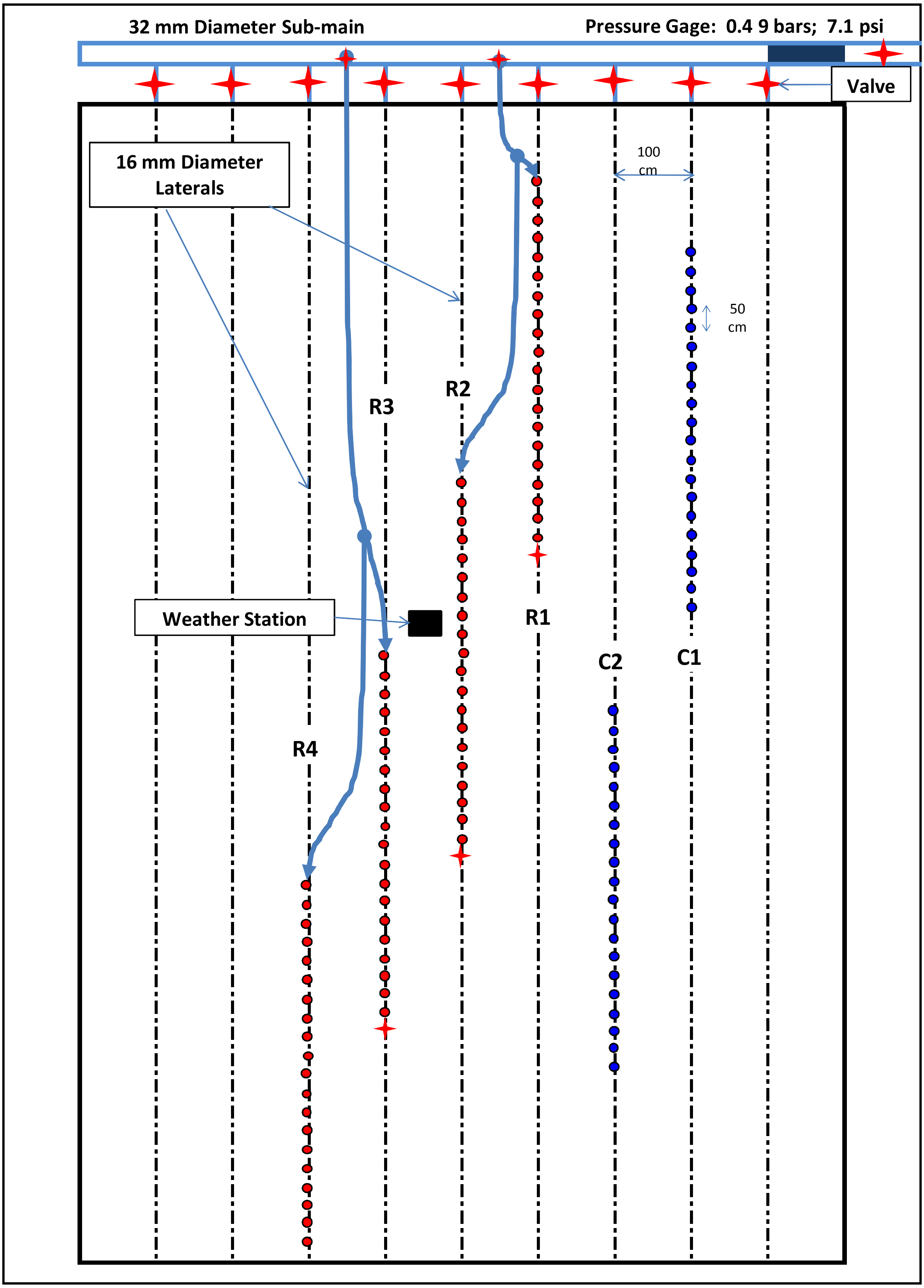

Figure 0.1: Experimental Layout in the Field

It should be mentioned here that there was a limitation from the farmer on the selection of the plots since the farmer agreed that the researcher uses only adjacent plots so as to be able to perform his agricultural practices without any limitations from the experiment and from the resistance blocks.

The other 4 plots were designated as replicates: R1, R2, R3 and R4 (Figure3.1)for which the planted cucumbers were irrigated based on a water budget technique derived from reading soil water content to determine when to irrigate and by how much. In the results and discussion chapter, this technique will be presented and discussed.

3.2 Soil Properties

Four composite samples were collected from different locations of the experimental plots in the green house and at different levels from the soil profile extending from soil surface to 50 cm depths using an auger. These soil samples were taken to the soil laboratory at the college of agriculture at Hebron University for which 7 different tests were performed as shown in Table 3.1

Table 0.1:Soil Properties for Green House

Parameter	**Unit**	**Average**	**Standard Deviation(μ)**
Field Capacity	%	32.59	3.756
Electrical Conductivity	dS/m	0.47	0.080
Organic Carbon	%	1.51	0.159
Organic Matter	%	2.64	0.309
Bulk Density	g/cm^3	1.09	0.033
Mineral Density	g/cm^3	2.83	0.119
pH		7.31	0.119

Table 3.2 shows the numbers used to designate the structure of the soil using the soil textural triangle and the samples gave a clay textural designation and hence the average structural designation was determined as clay soil.

Table 0.2: Soil Textural Tests and designation

Soil sample	Clay %	Silt %	Sand %	Soil Texture
Average	61.63	28.5	9.87	Clay
Standard Deviation(μ)	3.4569	2.467	4.7861	

3.3 Calibration Curve

Electrical Resistance Blocks that were used to measure soil moisture content for the soil are of EIJKELKAMP type. These blocks were calibrated for the experimental plots area within the green house. Ten random locations at different soil depths ranging from 5 cm to 40 cm were selected within the plots area and different electrical resistance blocks were installed and wetted regularly. After few days, when equilibrium between the soil and the blocks was reached, different irrigation water depths were applied at each location varying the water content of the soil from field capacity to low soil moisture content.

Readings were taken for each of the electrical resistance block using the EIJKELKAMP meter then ten soil samples from the same locations where the electrical resistance blocks were placed in the experimental plots area were collected and analyzed in the college of agriculture soil laboratory at Hebron University for water content based on gravimetric water content determination method.

The readings versus the soil water content on weight and volumetric basis were calculated and the laboratory results are as shown in Table 3.3.

Table 0.3: Soil Data for Determining Soil Properties for the Experimental Plots in the Green House

Sample	1	2	3	4	**Average**	
Bulk Density (As)	1.07	1.06	1.13	1.11	1.09	
FC (%)	37.9	30.1	32.5	29.8	32.6	
Sample #	Meter Reading	Wt. of Water (gms)	Wt. of Dry Soil (gms)	ω (Water Content Based on Wt.) (%)	θ Volumetric Water Content (%)	θ (%) Best Fit
0	98				32.6%	32.3%
1	96	9.1	38.9	23.4%	31.3%	31.4%
2	85	9.3	45.4	20.5%	27.1%	27.6%
3	78	7.0	35.7	19.6%	25.9%	26.0%
4	73	9.4	49.6	19.0%	25.1%	25.1%
5	68	6.8	36.2	18.8%	24.7%	24.5%
6	67	7.2	38.5	18.7%	24.6%	24.4%
7	55	7.3	40.0	18.3%	23.8%	23.7%
8	41	7.8	44.5	17.5%	23.2%	23.3%
9	40	6.8	38.9	17.5%	23.1%	23.3%
10	20	5.4	32.4	16.7%	22.0%	21.9%

The following procedure used to calculate water content has been adopted from (James, 1993). Water content based on weight, ω, is defined as the ratio, expressed as a percentage, of the weight of water in a given soil mass to the weight of solid particles.

The gravimetric sampling method was used in the laboratory to measure water content on weight basis. This method is a direct method of measuring the water content of soil samples taken from the experimental plots. The samples were weighed, dried, and re-weighed after drying.

The following equation was used to determine the water content on weight bases as shown in equation 1 in which *W* denotes weight and ω is water content based on weight.

$$\omega = \frac{W_{wet} - W_{dry}}{W_{dry}}$$ **Equation 0-1**

For research purposes in agricultural applications, water content is computed on volume basis using equation 2, in which *V* denotes volume and θ_v is water content based on volume.

$$\theta_v = \frac{V_{H_2O}}{V_{Total}}$$ **Equation 0-2**

To determine a relationship between ω and θ_v, equation 3 can be utilized

$$\theta_v = \omega(A_s)$$ **Equation 0-3**

in which,

$A_s = \frac{\rho_b}{g\left(\rho_{(H_2O)}\right)}$ is defined as bulk density;

$\rho_b = \frac{W_{dry}}{V_{Total}}$ is defined as the apparent specific gravity;

$\rho_{(H_2O)}$ is defined as the density of water at 4° C which is equal to 1000 kg/m$^{3;}$ and

g: is defined as gravity constant which is equal to 9.81 m/s^2.

Bulk density was measured for 4 samples and the average value used is 1.09 as shown in table 3.3.

Water content at field capacity was measured in the laboratory using 4 samples and the average value of the 4 samples is calculated at 32.6% based on volume as shown in table 3.3.

Four soil samples were taken from the experimental plots from different levels and were dried in the oven at 105° C for 24 hours. Soil was placed in a cylinder and compacted then a known volume of water was added to each cylinder and all cylinders were capped to prevent evaporation of water. The four cylinders were placed in the lab for 24 hours under room temperature. During this time soil reached field capacity and equation 3.2 shown above was used to calculate θ_v under field capacity conditions.

From the calibration curve provided by the manufacturer of the electrical resistance blocks and corresponding to a negative pressure (tension) of 15 bars representing the permanent wilting point, pwp, and using the same technique described for the calculation of field capacity, water content at permanent wilting point, pwp, was measured and evaluated at 19% on volume basis.

Resistance block meter readings were plotted against the measured volumetric water content shown in table 3.3. The curve resulting from the plotting represents the relationship between the resistance blocks meter readings and the volumetric water content as shown in figure 3.2. Therefore if one measures the resistance of the block in the field using the meter device, one can determine out the volumetric water content of the soil manually.

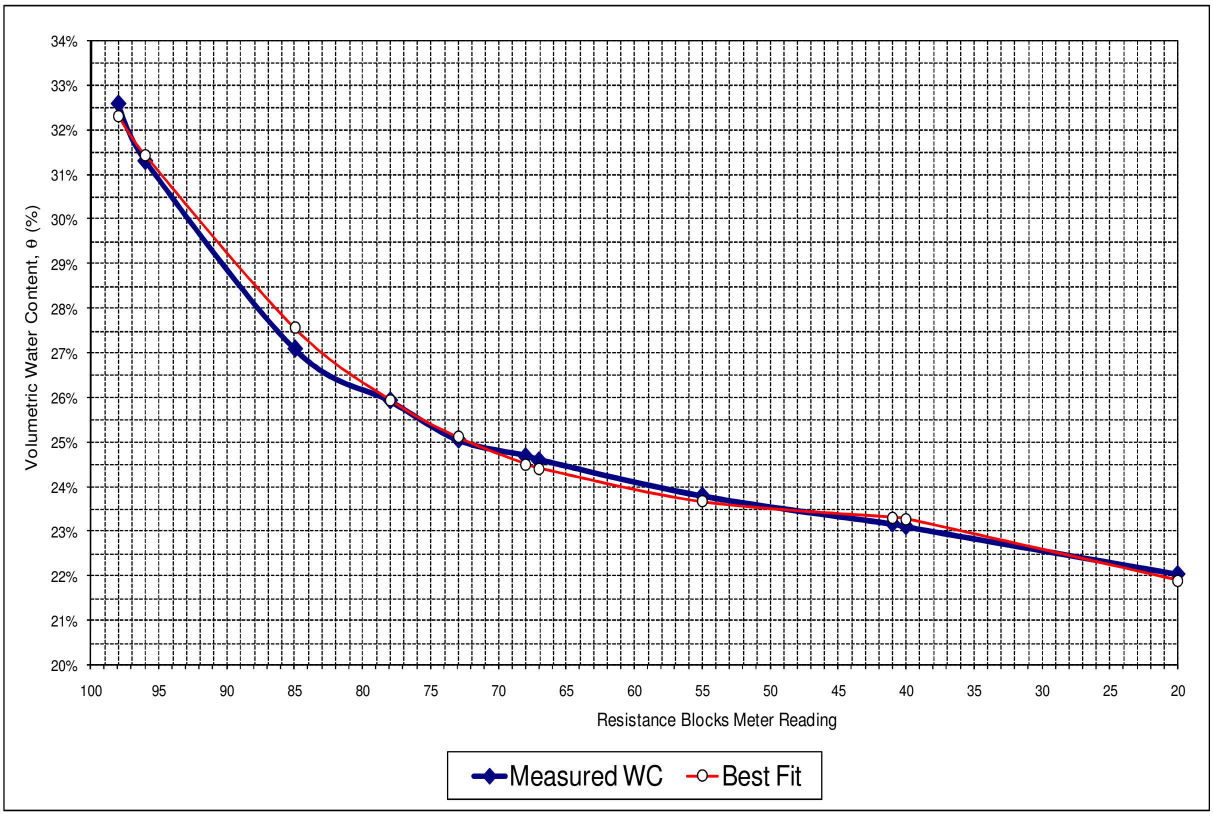

Figure 0.2: Measured and Calculated Water Content versus Resistance Blocks Meter Readings

To have an equation that can be used in calculating the volumetric water content in a computer program or a spreadsheet to automate irrigation scheduling as will be shown later , regression analysis was performed using the regression tool present in MS Excel and an equation was generated with an $R^2 = 0.9954$. The R^2 value is a term called the coefficient of determination which measures the proportion of the total variation about the arithmetic mean that can be explained by the regression (Lyman and Longnecker M.,2001). The regression equation that gives the best fit curve in figure 4 is shown as equation 3.4; in which *MR* is the Meter Reading.

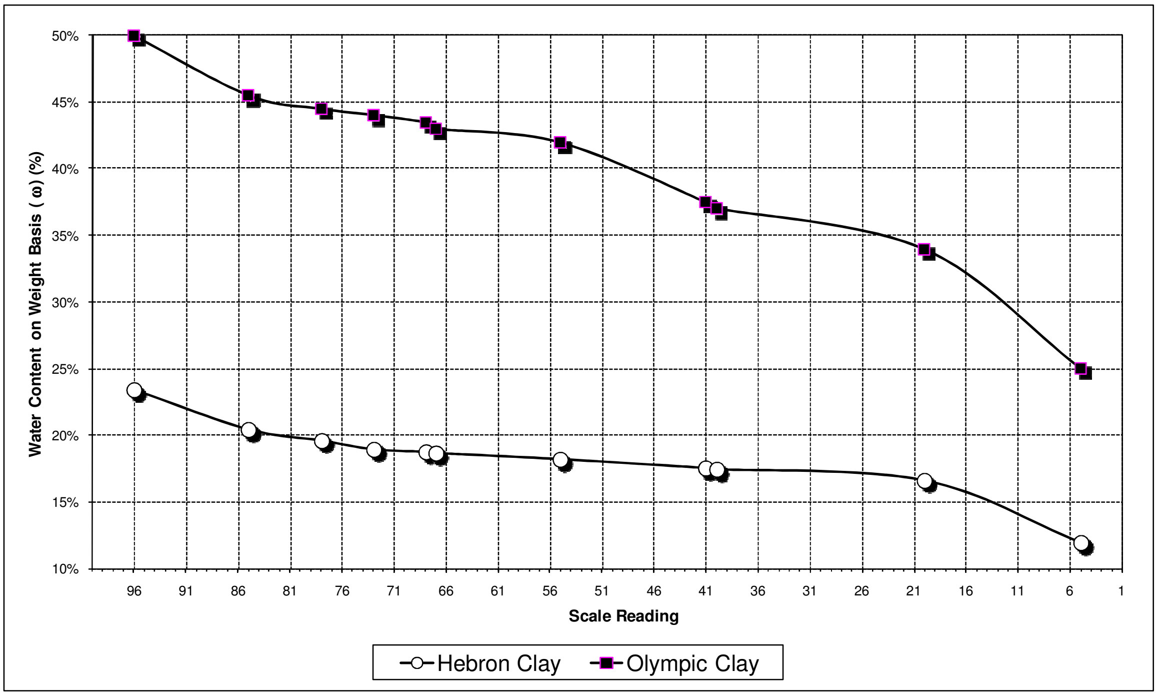

Figure 0.3: Hebron Clay versus Manufacturer Calibration Curve for Olympic Clay as Used to Determine Permanent Wilting Point, PWP

$$\boldsymbol{Water\ Content\ (\theta_v) = 17.19 + (0.364292)\ MR - (0.00747352)\ MR^2 + (5.44049 \times 10^{-5})\ MR^3}$$

(Equation 0-4)

The results from the equation are plotted in figure 3.2 and designated as "best fit". This equation was used in the overall spreadsheet described later to convert the readings from the electrical resistance blocks reader to actual volumetric water content.

3.4 Installing Electrical Resistance Blocks

From previous experiences and manufacturer recommendations a maximum depth of root zone was given as 35 cm for growing cucumbers under drip irrigation systems. (James 1993) showed a maximum root zone depth of 50 cm for cucumbers grown under surface irrigation system in open fields. (Waller and Tamimi 2004) indicated that the maximum root zone depth for cucumbers grown under drip irrigation system never reached more than 30 cm in the Hebron area. At the end of the experiment, the roots of the plants were measured and it was concluded that the root depths never exceed the 30 cm depth as indicated by (James, 1993).

For each experimental plot including the control plots, three electrical resistance blocks of type EIJKELKAMP were installed at three levels: 15 cm, 30 cm and 40 cm. It was assumed that the root zone will concentrate mainly in the depth between 5 cm and 30 cm. At the end of the season, all plants roots were measured and the assumption proved to be true since the roots were concentrated and meshed between 5 and 30 cm.

The purpose for the 40 cm level electrical resistance blocks was to observe if any deep percolation takes place during irrigation and deep percolation was never observed since the electric resistance block reading at 40 cm stayed constant. The electrical resistance of the resistance blocks was measured using this type (1422 Soil Moisture Meter) manufactured by the same company who produced the EIJKELKAMP resistance blocks. The layout of one of the electrical resistance blocks is shown in figure 3.4.

To install each electrical resistance block a hole was dug by an auger to different depths as needed. A resistance block was inserted in the dug hole and the electrical wire was guided outside the hole. Pre-prepared soil slurry was poured inside the hole to increase the water content of the soil surrounding the electrical block to around field capacity. The electrical resistance blocks were left in the ground for about 3 days until equilibrium status between the blocks and the soil was reached. During the equilibrium waiting time, water was added as needed to make sure that the experiment starts at field capacity when the cucumber was planted.

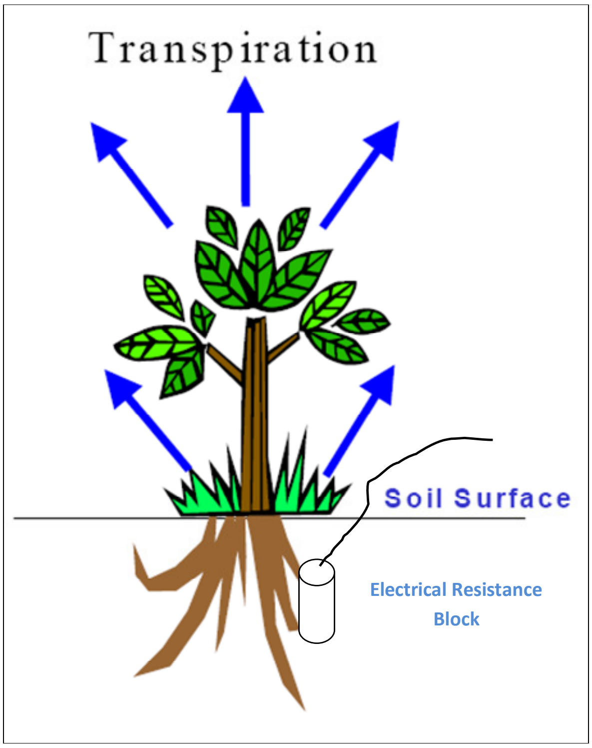

Figure 0.4: Layout of Electrical Resistance Block placement in the soil

3.5 Planting Cucumbers

On June 1, 2006 cucumber seedlings were planted in rows for each of the plots shown in figure 3.1. Irrigation water was turned on for 20 minutes before planting and 10 minutes after planting using the installed drip system. Soil, water and plant parameters were recorded starting on the morning of June 4, 2006 when the plants started growing and their roots got strong and dug into the soil.

3.6 Measured Parameters

Only maximum and minimum daily temperature and relative humidity were measured for this research. If the capacity of instrumentation is improved at the college laboratories, more parameters can be measured and a direct comparison can be made between the sited study and this research.

Yuan and Kang (2001) developed a drip irrigation scheduling system for tomatoes in unheated greenhouses. They found that after using water – balance methods for the tomatoes consumption of water in the greenhouse there was no

significant water flux or movement of water upwards at 75 cm depth when soil water is kept higher than a water content equivalent to 20kPa at 15cm depth.
The most important atmospheric factors affecting transpiration are the humidity of the air surrounding the plant, the temperature and humidity of the air carried to the plant by wind, and the net radiation available to the plant (James, 1993). Fynn et al (1993) measured the evapotranspiration for the chrysanthemums grown in greenhouses. Their measurements were made of evapotranspiration (ET), air velocity, air temperature, air dew point temperature carbon dioxide concentrate, leaf temperature, leaf area index, and photo-synthetical activity and global solar radiation. Comparisons were made between the evapotranspiration of the crop and the predicted water use from a computer model that used temperature, relative humidity and solar irradiance levels as inputs. The evapotranspiration was studied as a function of vapour pressure deficit and solar irradiance levels both separately and together. A relationship between stomatal resistance and solar irradiance levels for chrysanthemums was established. Soil moisture content using the electrical resistance blocks meter was measured every day at 6:30am for all plots. Each plot had 3 resistance blocks located at 15cm, 30cm and 40cm depths and the control plots had 3 sets of resistance blocks at each soil depths of 15cm, 30cm and 40cm.Water content reading was converted to volumetric water content using the regression equation presented earlier as equation 3.4. In addition, daily maximum and daily minimum air temperature, daily maximum and daily minimum relative humidity were also measured every day at 6:30am throughout the growing season that started on June 4, 2006 and ended on August 30, 2006.

3.6.1 Water Content

As water is the most limiting factor for agricultural production in Palestine, soil moisture determination is of major significance. Soil moisture influences crop growth not only by affecting nutrient availability, but also nutrient transformation and soil biological behavior (Hesse, 1971). Surface soil moisture can also be used to parameterize soil water simulation models that estimate soil moisture content with depth in the plant rooting zone (Hymer et al., 2000). There are many methods that are usually used to measure soil water content. The following are just some of these methods that can be found detailed in the literature and books related to measuring soil-water content such as James (1993).

The gravimetric method measures mass water content (θ_m) by taking field samples that are weighed oven dried and then weighted again to measure the mass of water in the sample and related to the solids found in the sample. This method has many advantages such as accuracy and the ability to measure representative sample from multiple locations. However, some of the disadvantages of this method include the labor that is needed for this method and the length of time that is required to get results. The feel and appearance method requires that the operator takes field samples and feel them by hand which cost very little and takes little time to do and representative samples can be taken from multiple locations in the field. However, one of the short comings for this method is the fact that results obtained by this method have low accuracy and an experienced operator need to evaluate the measurement.

The Neutron scattering (attenuation) method to measure volumetric water content (θ_v) sends attenuation of high-energy neutrons by hydrogen nucleus to extrapolate the results into water content readings. Some of the advantages are that the samples a relatively large soil sphere and soils can be repeatedly sampled at the same site for several depths. It is an accurate method but the neutron probes have a high cost, requires a radioactive licensing and safety procedures and their readings are not reliable for shallow measurements near the soil surface.

Other methods that can be use for measuring soil-water content are: Dielectric constant which uses Time Domain Reflectrometry (TDR) and Frequency domain Reflectromtry (FDR), Mastrorilli et al (1998) they measured the daily actual evapotranspiration measured with TDR (Time domain Reflectrometry) technique in Mediterranean conditions out of the greenhouse, the results showed that in soils without vertical cracks daily ET can be estimated in the field using the TDR technique over a wide range of soil water contents.

Tensiometers which measure soil water potential (tension); electrical resistance blocks which measures soil water electrical conductivity which is the reciprocal of the soil water electrical resistance are other methods that can be used to correlate soil water content using calibration curves.

These techniques when used to measure soil-water content can save on the amounts of water and fertilizers that are applied in growing crops reducing the cost of production, conserving water resources, reducing salts leached to ground water and enhancing the quality and quantity of the produce.

Since this research is utilizing electrical resistance blocks to measure water content in the field, the following section will discuss this procedure in more details. The advantages of the using electrical resistance blocks are that they are inexpensive allowing many replicates. (Assuming the cost of the meter or multiplexer system and labor is constant or similar to other systems). This sort of sensor can be left in field to automatically monitor soil-water content continuously. Some of the disadvantages of electrical resistance blocks are the fact that all such types of blocks suffer from hysteretic (more resistance to wetting up or drying out (or vice versa) at a set water tension). The sensitivity in the dry range is usually very flat (a large change in dryness reflects small changes in measured resistance). The gypsum was an attempt to buffer soil salinity changes which does work to some extent. The result is, however, that the block will degrade over time, and eventually dissolves completely into the soil solution. The time this takes may be in the order of a year depending on conditions. The more extreme the water content - the quicker this occurs. James (1993) and Hymer *et al* (2000)

The results of water content that were measured in the field were measured every day at 6:30am which is considered the beginning of the day. Based on work done by (James, 1993) it was decided to use the water content reading of the electrical resistance blocks installed at 15 cm in the soil due to the fact that the reading represents the average water content in the 30 cm soil level taken at the middle point between the soil surface and the depth of the root zone since the root zone that is used and measured during the experiment is equal to 30 cm. The single point of water content used to estimate evapotranspiration for the cucumber on daily basis is represented by the average water content of the four readings in the different experimental replicate plots labeled R1, R2, R3 and R4 as shown in appendix I. Appendix I shows the daily measured water content at soil depths of 15 cm. In the same table, the average value of water content that was utilized in the calculations.

Table 3.4 shows a sample of the measured data that was stored in a spreadsheet.

Table 0.4Sample of daily measured data at the experimental plots

Date	Days Since Planting	C1			C2			R1			R2			R3			R4			Weather Station			
		Meter Reading			Meter Reading			Meter Reading			Meter Reading			Meter Reading			Meter Reading			Relative Humidity		Air Temperature	
		15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	Max (%)	Min (%)	Min (°C)	Max (°C)
4-Jun-06	1	92	86	31	94	20	31	91	91	91	93	85	91	89	84	91	91	89	93	43	20	18	47
5-Jun-06	2	93	90	30	94	47	39	92	76	92	92	87	91	89	82	89	90	88	93	48	20	18	44
6-Jun-06	3	90	87	29	93	51	42	85	40	91	57	86	92	81	77	86	76	85	92	48	20	17	40
7-Jun-06	4	83	84	28	91	48	40	54	27	89	39	83	91	52	66	77	54	82	91	52	20	15	39
8-Jun-06	5	91	87	26	92	47	57	76	21	84	77	80	89	65	65	68	72	79	91	63	20	12	44
9-Jun-06	6	88	84	26	90	45	54	40	18	73	40	77	87	45	45	58	42	74	91	66	20	12	42
10-Jun-06	7	86	81	25	89	42	50	86	15	62	69	91	83	75	45	54	73	76	91	70	20	12	41
11-Jun-06	8	93	84	24	90	42	63	90	13	52	82	79	88	73	36	46	81	77	81	74	20	12	40
12-Jun-06	9	91	83	23	89	43	62	79	11	42	62	79	87	54	30	39	57	75	89	74	20	12	39
13-Jun-06	10	92	86	22	90	45	74	88	9	34	83	82	85	62	26	36	65	81	91	74	20	12	37
14-Jun-06	11	88	83	21	88	42	69	91	63	31	96	89	87	71	32	48	85	87	91	74	20	12	39
15-Jun-06	12	90	81	21	88	42	68	51	18	27	83	84	84	29	30	41	29	84	91	74	20	14	39
16-Jun-06	13	92	80	20	88	49	66	85	71	23	93	81	77	30	31	36	41	84	91	77	20	14	37

Table 3.5 shows the conversion of the meter readings to volumetric water content for all experimental plots.

Table 0.5: Sample of Daily Converted Meter Readings to Volumetric Water Content (%) at the Experimental Plots

		C1			C2			R1			R2			R3			R4		
		Water Content			Water Content			Water Content			Water Content			Water Content			Water Content		
Date	Days Since Planting	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm
4-Jun-06	1	29.8	27.8	22.9	30.6	21.9	22.9	29.5	29.5	29.5	30.2	27.6	29.5	28.8	27.3	29.5	29.5	28.8	30.2
5-Jun-06	2	30.2	29.1	22.9	30.6	23.5	23.3	29.8	25.6	29.8	29.8	28.1	29.5	28.8	26.8	28.8	29.1	28.4	30.2
6-Jun-06	3	29.1	28.1	22.8	30.2	23.5	23.3	27.6	23.3	29.5	23.7	27.8	29.8	26.6	25.8	27.8	25.6	27.6	29.8
7-Jun-06	4	27.0	27.3	22.7	29.5	23.5	23.3	23.6	22.6	28.8	23.3	27.0	29.5	23.6	24.3	25.8	23.6	26.8	29.5
8-Jun-06	5	29.5	28.1	22.6	29.8	23.5	23.7	25.6	22.0	27.3	25.8	26.4	28.8	24.2	24.2	24.5	25.0	26.2	29.5
9-Jun-06	6	28.4	27.3	22.6	29.1	23.4	23.6	23.3	21.6	25.1	23.3	25.8	28.1	23.4	23.4	23.8	23.3	25.3	29.5
10-Jun-06	7	27.8	26.6	22.5	28.8	23.3	23.5	27.8	21.2	24.0	24.6	29.5	27.0	25.4	23.4	23.6	25.1	25.6	29.5
11-Jun-06	8	30.2	27.3	22.4	29.1	23.3	24.1	29.1	20.8	23.6	26.8	26.2	28.4	25.1	23.2	23.4	26.6	25.8	26.6
12-Jun-06	9	29.5	27.0	22.3	28.8	23.4	24.0	26.2	20.4	23.3	24.0	26.2	28.1	23.6	22.9	23.3	23.7	25.4	28.8
13-Jun-06	10	29.8	27.8	22.2	29.1	23.4	25.3	28.4	19.9	23.1	27.0	26.8	27.6	24.0	22.6	23.2	24.2	26.6	29.5
14-Jun-06	11	28.4	27.0	22.0	28.4	23.3	24.6	29.5	24.1	22.9	31.4	28.8	28.1	24.9	23.0	23.5	27.6	28.1	29.5
15-Jun-06	12	29.1	26.6	22.0	28.4	23.3	24.5	23.5	21.6	22.6	27.0	27.3	27.3	22.8	22.9	23.3	22.8	27.3	29.5
16-Jun-06	13	29.8	26.4	21.9	28.4	23.5	24.3	27.6	24.9	22.3	30.2	26.6	25.8	22.9	22.9	23.2	23.3	27.3	29.5
17-Jun-06	14	29.1	24.7	22.0	28.1	23.5	23.9	28.1	25.8	21.9	29.5	26.0	25.3	23.0	23.3	22.8	23.3	27.8	29.5
18-Jun-06	15	29.1	23.9	22.2	27.8	23.4	23.5	29.1	26.0	23.6	29.8	27.0	25.1	23.3	24.3	22.8	24.0	28.4	29.8
19-Jun-06	16	23.9	23.2	22.2	24.4	23.3	23.2	20.8	26.0	22.3	26.8	24.6	24.2	24.7	23.6	21.8	20.8	27.3	30.2

3.6.2 Wetted Radius

When surface drip irrigation is used to irrigate crops a wetted circle is formed on top of the soil. The center of this wetted circle is approximately the dripper of the irrigation system. The water infiltrates into the soil to the root zone area as a bell shape that tappers of at the bottom. The shape and height of this wetted shape depends fully on the type of soil, soil water content and the root system.

The soil type is clay which has a high percent of gravels is 27.4% this number was calculate in the laboratory from taking a four composite soil sample and analyze them.

It was assumed that the water infiltrates as a cylinder to calculate the volume of water applied during each irrigation event knowing the flow rate of each dripper and the time of irrigation as will be discussed later in this chapter. This assumption is valid since the irrigation water stops at 40cm from the soil surface. As indicated earlier an electrical resistance block has been placed at the 40 cm depth and was reading the same water content value indicating that water did not go below that point which means that the bell shape of the wetted water ended before the 40 cm depth of the soil.

The drippers' wetted perimeter was measured every time irrigation took place and the length of irrigation time was also recorded. A sample of such data collected during this research is shown in table 3.6.

Table 0.6: Sample Data Sheet for Radius of Wetted Perimeter and Irrigation Time

Date	Days Since Planting	C1			C2			R1			R2			R3			R4			Time	
		Radius (cm)			Radius (cm)			Radius (cm)			Radius (cm)			Radius (cm)			Radius (cm)			C	R
		15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	15cm	30cm	40cm	Min	Min
4-Jun-06	1	14	13	11	14	11	12														
5-Jun-06	2	14	13	11	14	11	12	14	15	12	12	15	9	15	12	14	12	15	13	10.0	5.0
6-Jun-06	3																				
7-Jun-06	4	12	9	10	9	10	11													10.0	
8-Jun-06	5	15	12	13	10	14	12	8	9	9	11	9	10	10	10	11	10	9	10	10.0	5.0
9-Jun-06	6	15	11	13	9	12	11													10.0	
10-Jun-06	7	15	15	15	13	15	15	8	11	12	10	11	11	11	10	10	9	11	9	10.0	10.0
11-Jun-06	8	15	16	15	14	16	15	15	14	15	14	15	15	15	14	14	13	15	13	10.0	12.0
12-Jun-06	9																				
13-Jun-06	10	18	19	18	19	18	17	14	13	13	11	12	15	15	13	15	13	15	15	25.0	12.0
14-Jun-06	11							16	12	16	15	15	13	15	12	14	15	14	15		12.0
15-Jun-06	12	16	17	16	17	15	17													18.0	
16-Jun-06	13	16	17	16	17	16	15	14	13	13	11	15	13	15	13	15	15	13	15	20.0	15.0
17-Jun-06	14	17	18	16	17	17	15	15	13	14	15	14	13	15	13	15	15	15	15	10.0	10.0
18-Jun-06	15	15	12	15	15	14	15	12	11	12	15	13	15	12	13	15	12	11	15	15.0	15.0
19-Jun-06	16																				
20-Jun-06	17	15	15	16	14	15	14	14	15	13	15	13	14	15	14	15	13	14	13	20.0	15.0

3.6.3 Maximum Allowable Depletion (MAD) and Critical Water Content

The value of maximum allowable depletion, MAD, used for cucumbers in the calculations has been determined to be 0.5 (James, 1993). Which means that 50% of soil moisture available to the plant was allowed to be depleted before irrigation was required.

MAD is just a management tool that is used to calculate the water content after which the plant reaches critical stage in regard to water utilization and the stomata of the plant starts to partially to shut down. This critical water content can be calculated from the equation 3.5.

$$\theta_{critical} = \theta_{fc} - \left(MAD\ (\theta_{fc} - \theta_{pwp})\right) \qquad \textbf{(Equation 0-5)}$$

in which *fc* represents field capacity, *pwp* represents permanent wilting point, θ represents volumetric water content.

Utilizing equation 3.5 the critical water content at which irrigation should take place was calculated to be equal to 25.8% as shown in equation 3.6.

$$\theta_{critical} = 32.6\% - (0.5\ (32.6\% - 19\%)) = 25.8\% \qquad \textbf{(Equation 0-6)}$$

Hence, whenever the average measured water content at depth 15 cm reached 25.8% or lower as measured using the electrical resistance blocks, irrigation water was applied. The resistance block reading that corresponds to this water content can be determined as 77 from figure 3.2 presented earlier in chapter 3.

3.6.4 Plants heights and fruits yield

Plants heights were measured weekly and recorded in the data sheets while the fruits yield was measured and recorded for each plot on the day they were picked. A sample of this data is shown in table 3.7.

Table 0.7: Sample Data Sheet for Plants Height and Fruit Yield

Date	Days Since Planting	Yield (# of Fruits)						Yield (kg) per Plot						Height (cm)					
		C1	C2	R1	R2	R3	R4	C1	C2	R1	R2	R3	R4	C1	C2	R1	R2	R3	R4
4-Jun-06	1																		
5-Jun-06	2																		
6-Jun-06	3																		
7-Jun-06	4																		
8-Jun-06	5																		
9-Jun-06	6													12	10	12	13	12	11
10-Jun-06	7																		
11-Jun-06	8																		
12-Jun-06	9																		
13-Jun-06	10																		
14-Jun-06	11																		
15-Jun-06	12																		
16-Jun-06	13													32	15	16	14	24	14
17-Jun-06	14																		
18-Jun-06	15																		
19-Jun-06	16																		
20-Jun-06	17																		
21-Jun-06	18																		
22-Jun-06	19																		
23-Jun-06	20													45	49	64	40	47	55
24-Jun-06	21																		
25-Jun-06	22																		
26-Jun-06	23	7	7	10	9	5	5	0.3	0.302	0.335	0.325	0.15	0.145						
27-Jun-06	24																		
28-Jun-06	25	5	5	7	7	8	6	0.28	0.28	0.103	0.29	0.32	0.279						
29-Jun-06	26	12	13	18	19	25	14	0.375	0.5	0.62	0.63	0.825	0.38						
30-Jun-06	27													130	95	70	85	90	92
1-Jul-06	28	46	76	52	48	36	27	2.11	3.525	2.65	1.82	1.83	1.35						
2-Jul-06	29																		
3-Jul-06	30	31	34	29	34	37	34	1.625	1.5	1.15	1.35	1.625	1.63						
4-Jul-06	31																		
5-Jul-06	32	36	31	26	28	25	29	1.7	1.375	1.4	1.42	1.325	1.4						
6-Jul-06	33																		
7-Jul-06	34	32	30	42	43	54	54	1.825	1.7	2.825	2.1	3.325	3.025	130	115	135	137	135	136
8-Jul-06	35																		
9-Jul-06	36	24	32	23	25	23	15	1.45	1.55	1.2	1.2	1.48	0.75						
10-Jul-06	37																		

3.6.5 When to Irrigate

The water that is delivered to the root zone can be determined from the measured wetted radius, the shape of the wetted area, and the depth of the root zone. These are all known factors and are measured values and hence the water delivered to the root zone is known. All these factors are part of the spreadsheet that is presented in Appendix II.

The total of the water that evaporates from the soil surface and the water that transpires from the plant leaves is known as evapotranspiration as was discussed earlier in chapter one. This value is the ET value that is unknown and this research is trying to figure it out.

The water that percolates below the root zone is controlled by reading the water content under the root zone and making sure that it does not change; meaning that no deep percolation is taking place.

Water budget techniques to determine when to irrigate are dependent on known evapotranspiration and can be utilized after reporting the results of this research to the farmers.

It was decided to irrigate whenever the average water content measured by the electrical resistance blocks read water content of less than the critical water content equivalent to 25.8% on volume basis and the reading of the meter had a reading less than 77of Meter Raiding.

Almost during the entire growing season, irrigation of water to the plants took place as can be seen in the spreadsheet shown in Appendix II. There are only 4 days that irrigation did not occur due the decision of the researcher of not to irrigate based on the wetness of the wetted circle.

3.6.6 Irrigation Time and Irrigation Depth

The researcher turned on the irrigation system and watched for the wetted circle to be as big as the day before and then turned off the irrigation system when run off of water started on the soil surface. Irrigation time period in minutes for each irrigation event is shown in the spreadsheet presented Appendix II.

Irrigation depth was calculated based on the following equations:

$$\boldsymbol{Irrigation\ Depth} = \frac{\boldsymbol{Volume\ of\ Applied\ Water}}{\boldsymbol{Area\ of\ Wetted\ Circle}}$$ **(Equation 0-7)**

$$Irrigation\ Depth = \frac{Dripper\ Flow\ Rate \times Irrigation\ Time}{(Wetted\ Radius)^{2} \times \pi}$$

$$Irrigation\ Depth\ [mm] = \frac{3\left[\frac{ltr\left[\frac{1.0\ m^3}{1000.0\ ltr}\right]}{hour}\right] \times Irrigation\ Time\left[minute\left[\frac{1.0\ hour}{60.0\ minute}\right]\right]}{(Wetted\ Radius)^{2} \times \pi \quad \left[\frac{cm\ [1.0\ m]}{100\ cm}\right]^2} \times 1000\ \left[\frac{mm}{m}\right]$$

These equations with their unit conversion factors were used in the spreadsheet presented in Appendix II and applied irrigation depth was determined for each irrigation event.

4 . Chapter Four

Results and Discussions

In this chapter, the results and measurements obtained from measuring water content, critical water content at which irrigation should take place, the wetted radius, the time at which irrigation should occur, irrigation time which is the time duration during which irrigation is turned on, irrigation depth applied, measured evapotranspiration, measured yield, water use efficiency and the model developed to predict evapotranspiration will be presented.

4.1 Measured Evapotranspiration

Evapotranspiration was calculated from measured data for each day based on the irrigation depth applied in the previous 24 hours, depth of roots in the root zone, and the difference between today's water content and yesterday's water content as shown in the following equation:

$$Evapotranspiraton = Irrigation\ Depth - Root\ Depth\ \times \frac{(Today's\ \theta - Yesterday's\ \theta)}{100\%}$$

$$ET\ \left[\frac{mm}{day}\right] = I\ [mm] - D_{rz}\ [mm] \times \frac{\left(\theta_f - \theta_i\right)[\%]}{100\%}$$

The irrigation depth used in the previous equation is the value calculated earlier in section 5. The root depth, D_{rz}, was increased linearly from 100 mm on the planting date corresponding to June 1, 2006 to 300 mm on the date of first fruit picking which corresponded with the end of day on June 25, 2006. The root depth was assumed to stay constant at 300 mm from June 26, 2006 until the end of the growing season corresponding to August 29, 2006 and that what was observed at the end of the season when the plants were uprooted and the root depths were measured.

For this study the cucumber evapotranspiration ranged between 4 mm/day and 9.5 mm/day with a total evapotranspiration for the entire season of 693mm.

Final water content corresponding to today's water content, θ_f , is the value measured on the specific day using the electrical resistance blocks meter and initial water content corresponding to yesterday's water content, θ_i, is what was measured the day before. As indicated earlier, water content values used in the calculations are the averages of the 4 water content readings at the 15 cm soil depths as measured in the 4 experimental (replicate) plots.

Evapotranspiration is usually reported on weekly or monthly basis. For this research daily evapotranspiration values are shown in Appendix II and are being reported here as weekly values. Figure 4.1 shows a graphical representation of the weekly measured evapotranspiration values for cucumbers grown under green house conditions in the Hebron Area. The ET value in the graph has the units of mm/day which means that the evapotranspiration value for each day of the specific week is that amount in units of mm/day. For example, the ET value that corresponds to week 3 is about 8.5 mm/day as can be seen in figure4.1. That means that for each day of the third weeks, ET is estimated at 8.5 mm/day. If one wants to be more accurate, the different values shown for each day of the third week are the interpolation values for the different days.

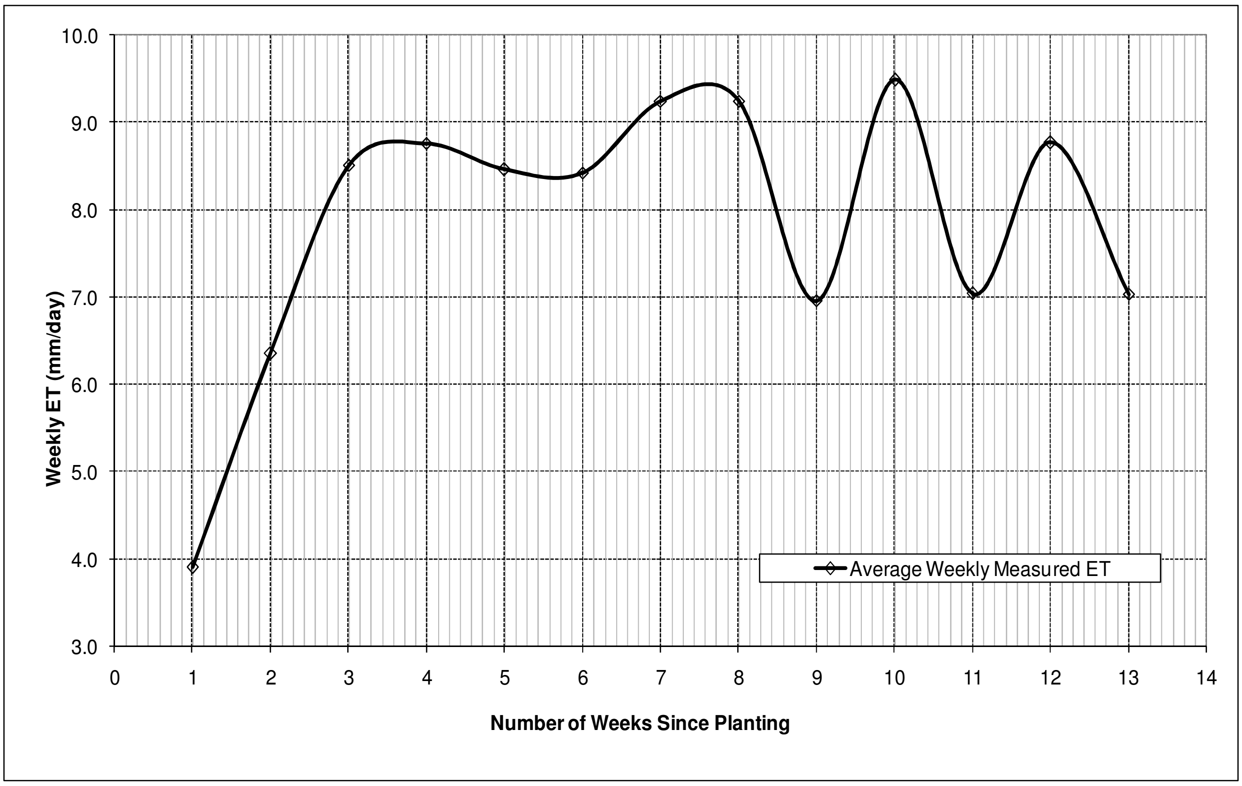

Figure 0.1: Measured Average Weekly Evapotranspiration for Cucumber Grown under Green House in Hebron Area

Figure 4.1shows a rapid increase in the value of evapotranspiration from the start of the growing season until the end of the third week when evapotranspiration levels out and becomes constant. This date, the end of the third week since planting, corresponds closely with the first harvesting of cucumbers as will be shown in the section about measured yield. The fluctuation after the third week is believed to happen due to the frequent and rapid harvesting and picking of the cucumber fruits. The plant sucks out water to build and mature the fruits and when the fruits are picked the evapotranspiration reduces due to diminishing need of the plant to mature the cucumber fruits since they were no longer part of the plant. It should be mentioned that the fruit cucumber's weight consist of about 75% water (Hochmuth, 1991).

It should be mentioned here that the ET values shown in figure 4.1 are the values of ET that represent the entire green house where the experiment was conducted. This is assumed because the factors that influence evapotranspiration are similar in the green house for the plots managed by the farmer, the controls, and the replicate plots managed by the researcher.

4.2 Measured Yield

Fruit harvesting of cucumbers in all experimental plots and control plots started on June 26, 2006 corresponding to day 23 since planting. Each plot is 1 m by 11 m^2 resulting in an area of 11 m^2 for each plot. The total picked fruit for the entire season are shown in Appendix III shows the total picked cucumbers for the entire growing season in kg/plot which corresponds to Kg/11 m^2. By doing some mathematical formulation the yield per dunum for each plot can be calculated and is shown in Appendix III and is represented graphically as shown in figure 4.2. Figure 4.2 shows that the yield in each one of the replicate plots is slightly higher than the control plots. Water use efficiency will be presented in the next section to determine the amount of water that has been used to produce this yield for each plot.

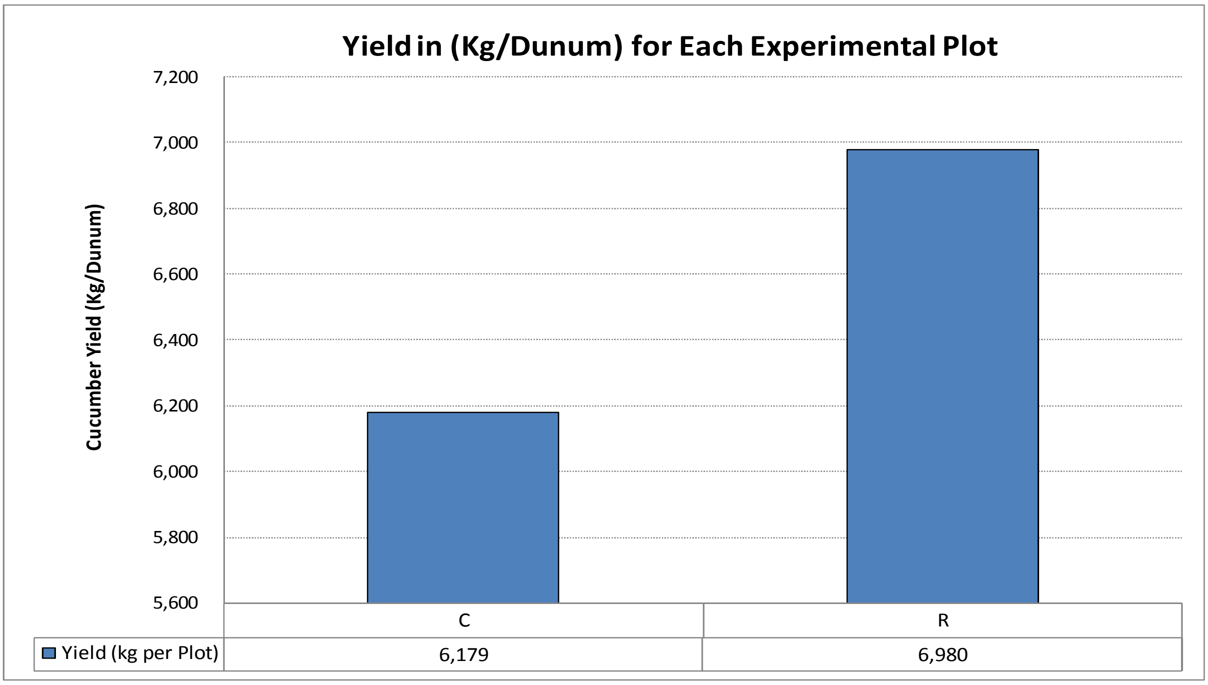

Figure 0.2: Cucumber Yield for each Plot in Kg / Dunum

4.3 Water Use Efficiency

Water use efficiency is defined as the ratio between crop yield and the amount of water applied to grow that yield. It is a measure to show the efficient use of water especially in areas where water is scarce as the case is in Palestine. So the measure is per cubic meter and not per dunum. The Water Use Efficiency then can be mathematically defined (James, 1993) as shown in the following equation:

$$Water\ Use\ Efficiency = \frac{Crop\ Yield}{Water\ \ Applied}$$ **Equation 0-1**

The average water applied to the control plots has been calculated based on dripper flow rate of 3 liters/hour; time of irrigation has been measured as shown in Appendix II .Then, multiplying the flow rate by the water application time converted to hours and multiplying all that by 20 drippers for the control plots, gives a total volume of 2080 liters of water on the average for the control plot with the area of 11 m^2. Using the same technique for the experimental plot R yields a total volume of 1526 liters of irrigation water for the R plot with the same area of 11 m^2.

Therefore, if one converts these numbers to m^3 / dunum then the total volume of irrigation water consumed by the control plot planted with cucumber for the entire season one would get about 189 m^3 / dunum. Doing the same calculations for the treatment results in a total volume of 138.7 m^3 / dunum.

Calculating water use efficiency for the control plot can be demonstrated as shown below:

$$Water\ Use\ Efficiency_{\ [Control]} = \frac{6180[\frac{Kg}{Dunum}]}{189[\frac{m^3}{Dunum}]} = 32.7\ \frac{Kg\ Cucumber}{m^3\ of\ Water}$$

$$Water\ Use\ Efficiency_{\ (Tretment)} = \frac{6980[\frac{Kg}{Dunum}]}{138.7[\frac{m^3}{Dunum}]} = 50.3\ \frac{Kg\ Cucumber}{m^3\ of\ Water}$$

Water Use Efficiency is high for the replicates because of the difference in irrigation water applied that caused the nutrients to leach from the control plots resulting in fewer nutrients for the plant to utilize. Also, most of the water applied in the replicates was beneficially used while a portion of the water that was applied in the control plots was deep percolated and was not beneficially used.

4.4 Modeling of Evapotranspiration

Factors that greatly affect evapotranspiration are air temperature, air relative humidity, solar radiation, wind speed and direction, leaf area index. Fynn et al(1993) measured the evapotranspiration for the chrysanthemums grown in greenhouses measuring air velocity, air temperature, air dew point temperature carbon dioxide concentration, leaf temperature, leaf area index, and photo-synthetical activity and global solar radiation. The determined evapotranspiration was a function of vapor pressure deficit and solar irradiance levels. However, Yang et al(1995) studded the effect of aerial condition on heat and mass exchange between plant and air in the greenhouses, they measured aerodynamic resistance calibrated from the sensible heat flux and the temperature difference between leaves and above-canopy. Differentiation between the aerial condition within a canopy and those above the canopy was strongly recommended for future studies on a greenhouse microclimate and transport processes utilizing the generated model.

Due to limited research monetary budget a simple weather station was purchased and used to read minimum and maximum average daily air temperature and minimum and maximum average relative humidity inside the greenhouse about 1.5 meters above the grown cucumbers. These data were measured during the growing season and tabulated in a spreadsheet to find a relationship between the measured evapotranspiration values and the weather parameters at the end of the growing season for developing the model to predict evapotranspiration.
Table4-1 shows a sample of the measured data for the first few weeks of the growing season.

Table 0.1: Weather data for few weeks of the growing season

	Days	Weather Station					Days	Weather Station			
	Since	Relative Humidity		Air Temperature			Since	Relative Humidity		Air Temperature	
Date	Planting	Max (%)	Min (%)	Min (°C)	Max (°C)	Date	Planting	Max (%)	Min (%)	Min (°C)	Max (°C)
4-Jun-06	1	43	20	18	47	19-Jun-06	16	74	20	14	41
5-Jun-06	2	48	20	18	44	20-Jun-06	17	66	20	13	42
6-Jun-06	3	48	20	17	40	21-Jun-06	18	71	20	15	44
7-Jun-06	4	52	20	15	39	22-Jun-06	19	72	20	15	39
8-Jun-06	5	63	20	12	44	23-Jun-06	20	79	21	16	40
9-Jun-06	6	66	20	12	42	24-Jun-06	21	67	20	14	44
10-Jun-06	7	70	20	12	41	25-Jun-06	22	76	20	14	42
11-Jun-06	8	74	20	12	40	26-Jun-06	23	75	20	13	43
12-Jun-06	9	74	20	12	39	27-Jun-06	24	76	20	14	38
13-Jun-06	10	74	20	12	37	28-Jun-06	25	64	21	14	40
14-Jun-06	11	74	20	12	39	29-Jun-06	26	74	21	15	40
15-Jun-06	12	74	20	14	39	30-Jun-06	27	70	22	14	38
16-Jun-06	13	77	20	14	37	1-Jul-06	28	60	23	16	38
17-Jun-06	14	74	20	10	39	2-Jul-06	29	61	22	16	37
18-Jun-06	15	72	20	13	40	3-Jul-06	30	63	20	16	39

To develop a model to predict the value of ET based on the measured weather data, the average daily temperature and the average daily relative humidity were calculated based on the minimum and maximum readings as shown in the following 2 equations:

$$T_{av} = \frac{T_{min}+T_{max}}{2}$$ **Equation 0-2**

$$Rh_{av} = \frac{Rh_{min}+Rh_{max}}{2}$$ **Equation 0-3**

In which *Rh* is relative humidity, *T* is temperature, *min* stands for minimum and *max* stands for maximum. The generated average daily data was averaged for each week of the growing season and the result is shown in Table 4.2as the weekly average temperature and relative humidity measured values.

Table 0.2: Weekly Average Temperature and Relative Humidity

	Weekly Averages	
Week	**Measured T [Degr. C]**	**Measured RH (%)**
1	29.8	33.9
2	26.1	45.4
3	26.8	46.3
4	27.6	46.5
5	27.1	45.4
6	25.8	48.2
7	26.2	49.0
8	26.8	46.1
9	26.0	42.7
10	27.1	44.6
11	25.9	46.4
12	27.5	47.2
13	27.3	41.0

There is a relationship that relates the weekly evapotranspiration to the three variables present in Table 4.2. The first variable is the specific week or week number since planting(X_1), the second is the weekly average temperature (X_2|) and the third is the weekly average relative humidity(X_3). If the relationship between *ET* and the 3 variables is assumed to be a linear relationship then the relationship has the form that is shown in the following equation:

$$ET = i + a\,X_1 + b\,X_2 + \;c\,X_3$$ **Equation 0-4**

This equation has to fulfill or partially fulfill the data shown in table 4.3.

Table 0.3: Input data into the linear regression to define ET model

Weekly Averages			
Measured ET (mm/day)	Week (X1)	Measured Temp. [C] (X2)	Measured RH (%) (X3)
3.91	1	29.8	33.9
6.35	2	26.1	45.4
8.51	3	26.8	46.3
8.76	4	27.6	46.5
8.46	5	27.1	45.4
8.43	6	25.8	48.2
9.24	7	26.2	49.0
9.25	8	26.8	46.1
6.96	9	26.0	42.7
9.49	10	27.1	44.6
7.04	11	25.9	46.4
8.77	12	27.5	47.2
7.04	13	27.3	41.0

To determine the values of *i*, *a*, *b* and *c* in which *i* the intercept of the equation one can obtain and equation which is called here the *ET* model to predict the value of *ET* for cucumbers grown under a green house for each week of the growing season if the average weekly temperature and the average weekly relative humidity are known or measured.

This relationship can be determined utilizing the linear regression statistical tools that are part of the Microsoft Excel computer program. Doing so and using the data present in table 4.3 as the input data to the regression, the output of the regression is shown in table 4.4.

The data in Table 4.4 shows that the intercept in the regression equation, i = -30.0518, a = 0.0937, b = 0.6510 and c=0 .4403.

Table 0.4: Regression Output for the ET Model

SUMMARY OUTPUT		
Regression Statistics		
Multiple R	0.8867	
R Square	0.7863	
Adjusted R Square	0.7150	
Standard Error	0.8338	
Observations	13.0000	
Variables	*Coefficients*	
Intercept	-30.0518	
X Variable 1	0.0937	
X Variable 2	0.6510	
X Variable 3	0.4403	

Plugging these constants into the predicted equation presented earlier results in the following regression model that can predict the value of *ET* for a specific week of the growing season based on that week average temperature and average relative humidity as shown in the following equation:

$$\boldsymbol{ET = -30.0518 + 0.0937\,W + 0.6510\,T + 0.4403\,Rh}$$ **Equation 0-5**

In which;

ET: is the weekly average evapotranspiration in mm/day

W: is the week number since planting cucumbers in the green house

T: is the weekly average temperature in °C

Rh: is the weekly average relative humidity in %.

In the evapotranspiration model developed in this research study, if the measured *W*, *T* and *Rh* are plugged into the *ET* equation shown above for the cucumber 13 week growing season then the ET values can be predicted as shown in Table 4.5.

Table 0.5: Predicted ET Values using the ET model

Weekly Averages				
Measured ET (mm/day)	**Week (W)**	**Measured Temp. [C] (T)**	**Measured RH (%) (Rh)**	**Predicted ET (mm/day)**
3.9	1	29.8	33.9	4.3
6.4	2	26.1	45.4	7.1
8.5	3	26.8	46.3	8.0
8.8	4	27.6	46.5	8.7
8.5	5	27.1	45.4	8.1
8.4	6	25.8	48.2	8.5
9.2	7	26.2	49.0	9.2
9.2	8	26.8	46.1	8.5
7.0	9	26.0	42.7	6.5
9.5	10	27.1	44.6	8.1
7.0	11	25.9	46.4	8.3
8.8	12	27.5	47.2	9.8
7.0	13	27.3	41.0	7.0

Taking these predicted values and plotting them with the measured values against the number of week since planting results in figure 4.3.

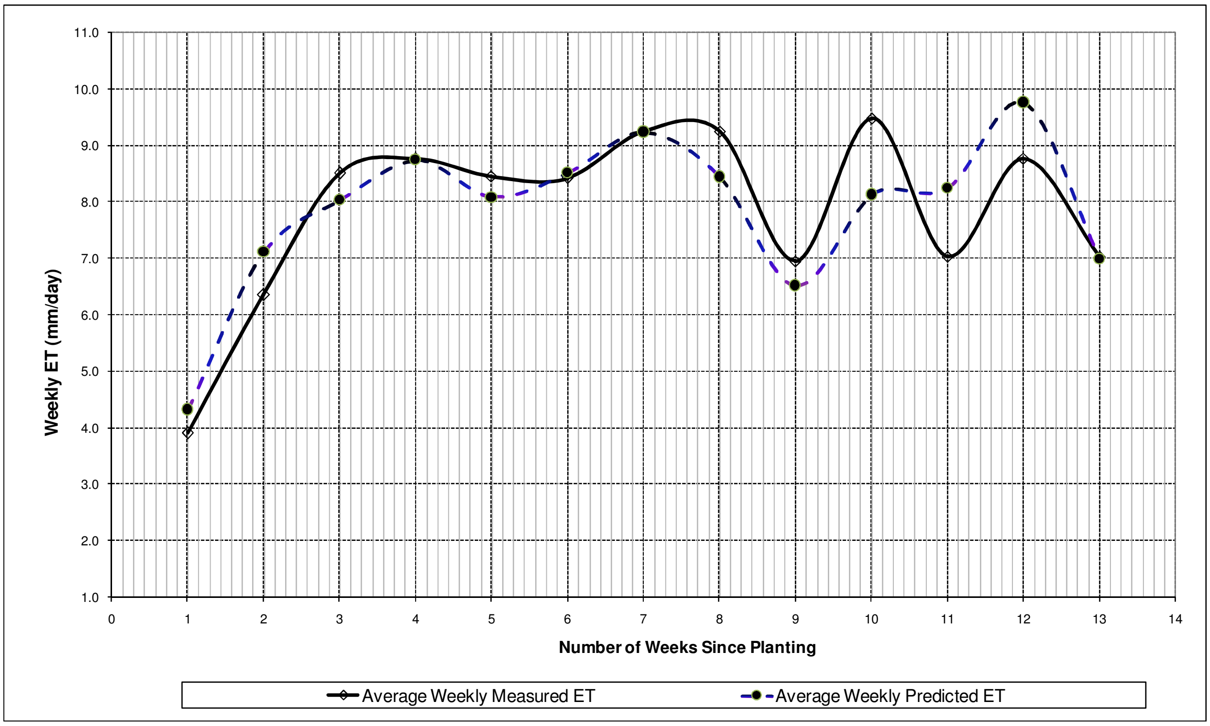

Figure 0.3:Model Predicted versus Measured Green House Cucumber Evapotranspiration

The difference between the measured and the predicted weekly evapotranspiration for cucumber grown under green house conditions is due to the goodness of fit of the regression model R^2 = 0.7863. Prenger et al (2002) made a comparison of four evapotranspiration models in a greenhouse environment, and compared the measured ET with two empirical climatic factors: solar irradiance and vapor pressure deficit and with calculated ET based on four evapotranspiration models :(1) Penman, (2) Penman-Monteith, (3) Stanghellini, and (4) Fynn. They correlated each method with the measured evapotranspiration value and the coefficient of determination (R^2) was found to be 0.872, 0.214, 0.481 and 0.848 for Penman, Penman-Monteith, Stanghellini and Fynn methods respectively. The lowest R^2 found is the penman-Monteith method and Ciolkosz and Albright (2000) found that in greenhouses the relationship between crop evapotranspiration and dish evaporation was linear, with an adjusted coefficient of multiple determination (R^2) of 0.57,in this research only maximum and minimum daily air temperature and relative humidity were used to develop the model and an R^2 of 0.7863 was determined.

For a simple model that requires only two measured parameters being the average weekly temperature and the average weekly relative humidity a goodness of fit of 0.7863 is good enough for the developed model.

5 . Chapter Five

Conclusion and Recommendations

Irrigation of crops in the fields and in green house is based on no management resulting in low efficiencies and uniformities. The use of old methods such as feel and appearance methods in determining when to irrigate and how much to apply is resulting in the over irrigating crops. Best irrigation management practices are not used in irrigated agriculture. Irrigation scheduling using water budget techniques is not practiced to minimize deep percolated water that seeps under the root zone and is not beneficially used by the plant for production.

Evapotranspiration of cucumbers grown in a green house has been measured in the field using electrical blocks that reflect soil water content at different depths. Weather factors in the green house were measured during the growing season and were recorded to develop a model based on simple weather data. During the experiment irrigation scheduling was practiced based on measured evapotranspiration in replicate plots; a control plot was managed by the farmer utilizing traditional irrigation practices when deciding when to irrigate and how much to apply. A model was developed that correlated the measured weather data and the measured evapotranspiration for cucumber under green house conditions. This model can be used to predict the evapotranspiration of cucumbers grown under green house conditions.

During the growing season it was observed that less water is being applied in the experimental plots in comparison to the control plot, but higher yield was measured. This can be attributed to the leaching of nutrients by the high amounts of water applied by the farmer to the control plot. Nutrients were leached below the root zone in the control plot which the plant was not able to absorb and utilize. For cucumbers grown under green house conditions, it is recommend that farmers utilize irrigation scheduling based on water budget techniques using the evapotranspiration model developed for growing cucumbers. This management practice would reduce irrigation water consumed and would increase yield.

The researcher believes that more work needs to be done in relation to modeling evapotranspiration under green house conditions. More weather parameters can be used to predict evapotranspiration. And it is believed that if solar radiation and hourly temperature and hourly relative humidity are measured that will enhance the model and increase its R^2 to a value higher than the 0.78 determined by this research.

Evapotranspiration models for other vegetables grown under green house conditions can be modeled using the same technique used in this research and water budget techniques can be used by farmers and agricultural engineers to use water more efficiently and to produce more yields per cubic meter of irrigation water.

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Appendix I

		R1	R2	R3	R4	
		Water Content	Water Content	Water Content	Water Content	Average Water Content
Date	Days Since Planting	@ 15cm Level	@ 15cm Level	@ 15cm Level	@ 15cm Level	(%) @15cm
4-Jun-06	1	29.5	30.2	28.8	29.5	29.5
5-Jun-06	2	29.8	29.8	28.8	29.1	29.4
6-Jun-06	3	27.6	23.7	26.6	25.6	25.9
7-Jun-06	4	23.6	23.3	23.6	23.6	23.5
8-Jun-06	5	25.6	25.8	24.2	25.0	25.1
9-Jun-06	6	23.3	23.3	23.4	23.3	23.3
10-Jun-06	7	27.8	24.6	25.4	25.1	25.8
11-Jun-06	8	29.1	26.8	25.1	26.6	26.9
12-Jun-06	9	26.2	24.0	23.6	23.7	24.4
13-Jun-06	10	28.4	27.0	24.0	24.2	25.9
14-Jun-06	11	29.5	31.4	24.9	27.6	28.3
15-Jun-06	12	23.5	27.0	22.8	22.8	24.0
16-Jun-06	13	27.6	30.2	22.9	23.3	26.0
17-Jun-06	14	28.1	29.5	23.0	23.3	26.0
18-Jun-06	15	29.1	29.8	23.3	24.0	26.5
19-Jun-06	16	20.8	26.8	24.7	20.8	23.3
20-Jun-06	17	25.6	29.8	26.0	21.8	25.8
21-Jun-06	18	26.8	30.2	25.8	26.6	27.3
22-Jun-06	19	29.1	30.6	26.4	28.8	28.7
23-Jun-06	20	29.5	30.6	27.3	29.1	29.1
24-Jun-06	21	28.1	27.6	27.6	23.7	26.7
25-Jun-06	22	29.1	28.4	26.8	27.6	28.0
26-Jun-06	23	30.6	31.4	25.8	26.2	28.5
27-Jun-06	24	30.2	31.4	29.5	26.4	29.4
28-Jun-06	25	28.8	31.0	29.1	30.6	29.9
29-Jun-06	26	30.6	30.6	27.6	29.1	29.5
30-Jun-06	27	29.8	25.6	26.2	28.8	27.6
1-Jul-06	28	25.4	25.4	23.1	25.3	24.8
2-Jul-06	29	31.4	23.4	22.8	23.9	25.4
3-Jul-06	30	22.9	24.7	22.0	23.3	23.2
4-Jul-06	31	23.5	23.9	23.3	22.4	23.3
5-Jul-06	32	30.2	23.5	29.1	27.8	27.7
6-Jul-06	33	31.9	30.6	28.8	29.1	30.1
7-Jul-06	34	28.8	28.4	27.8	28.4	28.4
8-Jul-06	35	31.9	24.3	30.2	30.2	29.1

9-Jul-06	36	24.9	24.6	24.0	24.1	24.4
10-Jul-06	37	21.9	23.4	24.0	22.9	23.1
11-Jul-06	38	20.4	23.5	23.5	21.3	22.2
12-Jul-06	39	26.8	30.2	23.3	25.4	26.4
13-Jul-06	40	29.5	31.4	25.4	29.8	29.0
14-Jul-06	41	23.5	30.6	29.1	22.2	26.3
15-Jul-06	42	23.0	29.1	23.1	19.7	23.7
16-Jul-06	43	29.8	31.0	28.4	28.4	29.4
17-Jul-06	44	22.3	23.2	22.4	21.2	22.3
18-Jul-06	45	24.9	28.4	24.7	24.1	25.5
19-Jul-06	46	26.4	29.1	26.4	25.4	26.8
20-Jul-06	47	30.2	29.5	28.8	29.5	29.5
21-Jul-06	48	27.3	24.4	28.8	23.3	25.9
22-Jul-06	49	23.3	28.1	27.3	21.8	25.1
23-Jul-06	50	24.3	23.4	22.6	21.6	23.0
24-Jul-06	51	25.3	23.3	23.7	23.4	23.9
25-Jul-06	52	26.6	27.6	24.0	22.9	25.2
26-Jul-06	53	31.4	23.1	22.6	26.4	25.9
27-Jul-06	54	30.2	30.6	23.3	23.5	26.9
28-Jul-06	55	29.8	29.8	30.6	29.8	30.0
29-Jul-06	56	30.6	30.2	28.8	29.8	29.8
30-Jul-06	57	30.6	29.1	27.3	28.4	28.9
31-Jul-06	58	27.3	29.1	27.3	29.1	28.2
1-Aug-06	59	29.1	29.1	27.8	28.1	28.5
2-Aug-06	60	31.9	31.4	31.9	31.4	31.6
3-Aug-06	61	29.8	31.0	29.5	30.2	30.1
4-Aug-06	62	25.3	22.9	24.4	23.3	24.0
5-Aug-06	63	26.4	31.4	30.2	30.6	29.6
6-Aug-06	64	28.4	26.4	26.8	27.8	27.4
7-Aug-06	65	29.8	28.4	28.8	29.1	29.0
8-Aug-06	66	30.2	31.0	27.6	28.8	29.4
9-Aug-06	67	31.4	30.6	24.9	27.8	28.7
10-Aug-06	68	29.1	25.0	27.6	26.6	27.1
11-Aug-06	69	32.3	32.3	31.4	31.9	32.0
12-Aug-06	70	29.8	29.8	29.5	29.8	29.7
13-Aug-06	71	30.6	31.0	29.8	30.6	30.5
14-Aug-06	72	29.1	30.6	29.5	29.8	29.7
15-Aug-06	73	31.0	30.2	30.6	31.0	30.7
16-Aug-06	74	31.0	31.0	30.6	31.0	30.9
17-Aug-06	75	29.1	30.2	29.1	30.2	29.6
18-Aug-06	76	28.4	29.5	28.8	29.8	29.1
19-Aug-06	77	29.5	31.0	29.5	30.6	30.1

20-Aug-06	78	25.4	25.6	26.6	25.4	25.8
21-Aug-06	79	26.8	29.1	27.8	28.4	28.1
22-Aug-06	80	27.3	27.6	27.3	27.8	27.5
23-Aug-06	81	29.1	30.2	28.8	29.8	29.5
24-Aug-06	82	26.2	24.9	26.8	27.3	26.3
25-Aug-06	83	27.6	27.8	27.6	27.6	27.6
26-Aug-06	84	29.1	31.4	28.4	29.5	29.6
27-Aug-06	85	26.0	25.0	27.3	27.6	26.5
28-Aug-06	86	29.8	29.8	29.5	29.8	29.7
29-Aug-06	87	31.0	31.0	30.6	31.0	30.9

Appendix II

		C1				C2				R1				R2				R3				R4					Theta FC =	32.6		Q(ltr/hr)=	3.0	MAD =	0.5		Critical Theta =		25.8
		Water Content				Water Content				Water Content				Water Content				Water Content				Water Content				Rh	Temp	Average Water Content	Average Water Content		Irrigation Time (Mints)		Average Wetted Radius (cm)		Irrigation Depth (mm)		ET (mm)
Date	Days Since Planting	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	Avrg (%)	Avrg (°C)	(%) @40cm	(%) @15cm	Drz (mm)	C	R	C	R	C	R	R
4-Jun-06	1	29.8	27.8	**28.8**	22.9	30.6	21.9	**26.3**	22.9	29.5	29.5	**29.5**	29.5	30.2	27.6	**28.9**	29.5	28.8	27.3	**28.0**	29.5	29.5	28.8	**29.1**	30.2	31.5	32.5	29.6	29.5	100.0			12.5			0.0	
5-Jun-06	2	30.2	29.1	**29.6**	22.9	30.6	23.5	**27.0**	23.3	29.8	25.6	**27.7**	29.8	29.8	28.1	**29.0**	29.5	28.8	26.8	**27.8**	28.8	29.1	28.4	**28.8**	30.2	34.0	31.0	29.6	29.4	108.5	10.0	5.0	12.5	13.2	10.2	4.6	4.7
6-Jun-06	3	29.1	28.1	**28.6**	22.8	30.2	23.5	**26.9**	23.3	27.6	23.3	**25.4**	29.5	23.7	27.8	**25.8**	29.8	26.6	25.8	**26.2**	27.8	25.6	27.6	**26.6**	29.8	34.0	28.5	29.2	25.9	117.0					0.0	0.0	4.1
7-Jun-06	4	27.0	27.3	**27.2**	22.7	29.5	23.5	**26.5**	23.3	23.6	22.6	**23.1**	28.8	23.3	27.0	**25.2**	29.5	23.6	24.3	**23.9**	25.8	23.6	26.8	**25.2**	29.5	36.0	27.0	28.4	23.5	125.5	10.0		10.2		15.4	0.0	2.9
8-Jun-06	5	29.5	28.1	**28.8**	22.6	29.8	23.5	**26.6**	23.7	25.6	22.0	**23.8**	27.3	25.8	26.4	**26.1**	28.8	24.2	24.2	**24.2**	24.5	25.0	26.2	**25.6**	29.5	41.5	28.0	27.5	25.1	134.0	10.0	5.0	12.7	9.7	9.9	8.5	6.3
9-Jun-06	6	28.4	27.3	**27.9**	22.6	29.1	23.4	**26.3**	23.6	23.3	21.6	**22.5**	25.1	23.3	25.8	**24.5**	28.1	23.4	23.4	**23.4**	23.8	23.3	25.3	**24.3**	29.5	43.0	27.0	26.6	23.3	142.5	10.0		11.8		11.4	0.0	2.6
10-Jun-06	7	27.8	26.6	**27.2**	22.5	28.8	23.3	**26.1**	23.5	27.8	21.2	**24.5**	24.0	24.6	29.5	**27.0**	27.0	25.4	23.4	**24.4**	23.6	25.1	25.6	**25.4**	29.5	45.0	26.5	26.0	25.8	151.0	10.0	10.0	14.7	10.3	7.4	15.1	11.5
11-Jun-06	8	30.2	27.3	**28.7**	22.4	29.1	23.3	**26.2**	24.1	29.1	20.8	**24.9**	23.6	26.8	26.2	**26.5**	28.4	25.1	23.2	**24.1**	23.4	26.6	25.8	**26.2**	26.6	47.0	26.0	25.5	26.9	159.5	10.0	12.0	15.2	14.3	6.9	9.3	7.5
12-Jun-06	9	29.5	27.0	**28.2**	22.3	28.8	23.4	**26.1**	24.0	26.2	20.4	**23.3**	23.3	24.0	26.2	**25.1**	28.1	23.6	22.9	**23.2**	23.3	23.7	25.4	**24.6**	28.8	47.0	25.5	25.9	24.4	168.0					0.0	0.0	4.2
13-Jun-06	10	29.8	27.8	**28.8**	22.2	29.1	23.4	**26.3**	25.3	28.4	19.9	**24.2**	23.1	27.0	26.8	**26.9**	27.6	24.0	22.6	**23.3**	23.2	24.2	26.6	**25.4**	29.5	47.0	24.5	25.8	25.9	176.5	25.0	12.0	18.2	13.7	12.1	10.2	7.5
14-Jun-06	11	28.4	27.0	**27.7**	22.0	28.4	23.3	**25.9**	24.6	29.5	24.1	**26.8**	22.9	31.4	28.8	**30.1**	28.1	24.9	23.0	**23.9**	23.5	27.6	28.1	**27.9**	29.5	47.0	25.5	26.0	28.3	185.0		12.0		14.3		9.3	4.9
15-Jun-06	12	29.1	26.6	**27.8**	22.0	28.4	23.3	**25.9**	24.5	23.5	21.6	**22.6**	22.6	27.0	27.3	**27.2**	27.3	22.8	22.9	**22.8**	23.3	22.8	27.3	**25.0**	29.5	47.0	26.5	25.7	24.0	193.5	18.0		16.3		10.7	0.0	8.3
16-Jun-06	13	29.8	26.4	**28.1**	21.9	28.4	23.5	**26.0**	24.3	27.6	24.9	**26.2**	22.3	30.2	26.6	**28.4**	25.8	22.9	22.9	**22.9**	23.2	23.3	27.3	**25.3**	29.5	48.5	25.5	25.2	26.0	202.0	20.0	15.0	16.2	13.8	12.2	12.6	8.7
17-Jun-06	14	29.1	24.7	**26.9**	22.0	28.1	23.5	**25.8**	23.9	28.1	25.8	**27.0**	21.9	29.5	26.0	**27.7**	25.3	23.0	23.3	**23.2**	22.8	23.3	27.8	**25.6**	29.5	47.0	24.5	24.9	26.0	210.5	10.0	10.0	16.7	14.3	5.7	7.7	7.8
18-Jun-06	15	29.1	23.9	**26.5**	22.2	27.8	23.4	**25.6**	23.5	29.1	26.0	**27.5**	23.6	29.8	27.0	**28.4**	25.1	23.3	24.3	**23.8**	22.8	24.0	28.4	**26.2**	29.8	46.0	26.5	25.3	26.5	219.0	15.0	15.0	14.3	13.0	11.6	14.1	12.9
19-Jun-06	16	23.9	23.2	**23.5**	22.2	24.4	23.3	**23.9**	23.2	20.8	26.0	**23.4**	22.3	26.8	24.6	**25.7**	24.2	24.7	23.6	**24.2**	21.8	20.8	27.3	**24.0**	30.2	47.0	27.5	24.6	23.3	227.5						0.0	7.4
20-Jun-06	17	23.5	21.9	**22.7**	22.0	24.1	23.1	**23.6**	22.5	25.6	25.3	**25.4**	21.3	29.8	23.7	**26.8**	23.5	26.0	23.5	**24.7**	20.6	21.8	27.0	**24.4**	27.3	43.0	27.5	23.2	25.8	236.0	20.0	15.0	14.8	14.0	14.5	12.2	6.3
21-Jun-06	18	23.0	20.6	**21.8**	21.9	23.5	22.6	**23.0**	21.6	26.8	24.1	**25.4**	20.4	30.2	23.7	**26.9**	23.3	25.8	23.5	**24.7**	19.7	26.6	27.6	**27.1**	29.5	45.5	29.5	23.2	27.3	244.5	10.0	15.0	14.3	14.1	7.7	12.0	8.2
22-Jun-06	19	22.6	19.7	**21.1**	21.8	23.1	21.8	**22.5**	21.0	29.1	26.0	**27.5**	26.8	30.6	27.0	**28.8**	23.3	26.4	24.9	**25.6**	19.9	28.8	28.4	**28.6**	30.2	46.0	27.0	25.0	28.7	253.0	20.0	15.0	14.8	13.6	14.5	12.9	9.5
23-Jun-06	20	23.4	19.4	**21.4**	21.5	23.1	21.2	**22.1**	20.4	29.5	23.2	**26.3**	22.8	30.6	27.3	**28.9**	23.3	27.3	24.1	**25.7**	19.7	29.1	28.1	**28.6**	30.6	50.0	28.0	24.1	29.1	261.5	20.0	15.0	14.5	14.1	15.1	12.0	11.0
24-Jun-06	21	19.4	18.5	**19.0**	21.3	20.1	20.6	**20.4**	19.9	28.1	21.5	**24.8**	20.8	27.6	23.4	**25.5**	23.0	27.6	20.8	**24.2**	18.8	23.7	26.2	**24.9**	30.6	43.5	29.0	23.3	26.7	270.0						0.0	6.4
25-Jun-06	22	18.2	18.2	**18.2**	21.2	18.8	20.1	**19.5**	19.7	29.1	19.4	**24.2**	19.9	28.4	20.6	**24.5**	22.2	26.8	21.2	**24.0**	18.2	27.6	23.6	**25.6**	29.8	48.0	28.0	22.5	28.0	278.5		5.0		8.8		10.4	6.9
26-Jun-06	23	19.4	22.3	**20.8**	21.0	20.6	19.7	**20.1**	22.6	30.6	22.5	**26.5**	22.6	31.4	19.4	**25.4**	21.3	25.8	22.7	**24.2**	22.7	26.2	22.8	**24.5**	26.4	47.5	28.0	23.3	28.5	287.0	30.0	15.0	15.3	14.3	20.3	11.6	10.2
27-Jun-06	24	23.2	22.4	**22.8**	20.6	23.6	21.8	**22.7**	22.6	30.2	22.6	**26.4**	22.7	31.4	25.6	**28.5**	20.6	29.5	22.8	**26.1**	22.8	26.4	22.4	**24.4**	26.6	48.0	26.0	23.2	29.4	295.5	30.0	15.0	14.5	14.1	22.7	12.0	9.5
28-Jun-06	25	23.4	23.3	**23.3**	22.0	23.7	21.8	**22.8**	22.6	28.8	22.6	**25.7**	22.5	31.0	18.8	**24.9**	22.8	29.1	22.7	**25.9**	22.6	30.6	22.8	**26.7**	27.3	42.5	27.0	23.8	29.9	300.0	10.0	10.0	12.7	13.0	9.9	9.4	7.9
29-Jun-06	26	23.6	23.9	**23.7**	21.9	23.5	22.2	**22.8**	22.6	30.6	23.1	**26.8**	25.4	30.6	22.3	**26.4**	22.8	27.6	22.8	**25.2**	22.6	29.1	24.2	**26.7**	30.6	47.5	27.5	25.3	29.5	300.0	10.0	10.0	13.7	14.3	8.5	7.7	9.0
30-Jun-06	27	23.0	23.9	**23.4**	21.9	22.0	21.5	**21.8**	22.6	29.8	23.0	**26.4**	24.7	25.6	25.4	**25.5**	22.8	26.2	23.3	**24.7**	23.4	28.8	24.9	**26.8**	30.6	46.0	26.0	25.4	27.6	300.0	15.0	10.0	13.7	14.4	12.8	7.7	13.3
1-Jul-06	28	22.4	23.9	**23.1**	21.8	27.3	22.3	**24.8**	22.6	25.4	26.4	**25.9**	24.7	25.4	22.7	**24.1**	22.8	23.1	23.3	**23.2**	22.8	25.3	23.9	**24.6**	27.3	41.5	27.0	24.4	24.8	300.0	20.0	10.0	12.7	12.8	19.8	9.8	18.1
2-Jul-06	29	22.6	23.5	**23.1**	21.5	27.8	22.0	**24.9**	22.6	31.4	24.3	**27.9**	23.7	23.4	26.6	**25.0**	22.6	22.8	23.3	**23.0**	22.8	23.9	23.6	**23.7**	27.3	41.5	26.5	24.1	25.4	300.0	25.0	10.0	16.5	15.8	14.6	6.3	4.6
3-Jul-06	30	23.7	23.3	**23.5**	21.5	27.3	21.8	**24.5**	22.5	22.9	20.6	**21.7**	23.3	24.7	26.6	**25.7**	22.6	22.0	22.0	**22.0**	21.8	23.3	21.3	**22.3**	25.3	41.5	27.5	23.2	23.2	300.0	30.0	10.0	17.0	16.8	16.5	5.6	12.1
4-Jul-06	31	23.4	23.1	**23.3**	21.5	26.4	21.6	**24.0**	22.5	23.5	20.6	**22.1**	22.9	23.9	24.6	**24.3**	22.5	23.3	21.5	**22.4**	21.6	22.4	21.6	**22.0**	25.3	50.5	27.5	23.1	23.3	300.0	15.0	10.0	14.3	14.3	11.6	7.8	7.7
5-Jul-06	32	23.8	23.3	**23.5**	21.5	28.1	21.9	**25.0**	22.5	30.2	22.3	**26.2**	22.9	23.5	23.5	**23.5**	22.8	29.1	21.3	**25.2**	21.2	27.8	21.5	**24.7**	23.9	49.5	28.0	22.7	27.7	300.0	15.0	10.0	15.0	14.4	10.6	7.7	5.5
6-Jul-06	33	31.0	29.5	**30.2**	26.2	27.8	29.1	**28.5**	30.6	31.9	21.5	**26.7**	21.5	30.6	31.0	**30.8**	24.6	28.8	26.0	**27.4**	23.1	29.1	27.3	**28.2**	29.5	56.0	25.5	24.7	30.1	300.0	30.0	10.0	16.8	14.6	16.9	7.5	0.2
7-Jul-06	34	31.0	29.8	**30.4**	26.6	27.6	29.1	**28.3**	30.2	28.8	31.0	**29.9**	23.0	28.4	28.1	**28.3**	26.6	27.8	25.6	**26.7**	23.4	28.4	28.4	**28.4**	29.1	56.0	25.0	25.5	28.4	300.0	45.0	30.0	20.3	19.3	17.3	12.8	17.9
8-Jul-06	35	29.1	29.1	**29.1**	24.4	24.4	28.1	**26.3**	28.4	31.9	26.4	**29.1**	22.2	24.3	23.8	**24.1**	25.8	30.2	24.1	**27.1**	23.0	30.2	25.6	**27.9**	23.5	53.0	25.5	23.6	29.1	300.0						0.0	2.3
9-Jul-06	36	30.2	29.1	**29.6**	23.4	22.7	23.4	**23.1**	23.5	24.9	21.3	**23.1**	24.3	24.6	23.0	**23.8**	21.3	24.0	23.5	**23.8**	21.3	24.1	23.7	**23.9**	21.8	41.5	26.0	22.2	24.4	300.0	30.0	20.0	17.0	16.5	16.5	11.7	25.9
10-Jul-06	37	29.8	26.4	**28.1**	22.4	24.6	25.1	**24.9**	23.8	21.9	22.7	**22.3**	21.5	23.4	22.5	**22.9**	21.3	24.0	21.8	**22.9**	21.6	22.9	23.0	**22.9**	21.8	43.5	25.5	21.6	23.1	300.0	20.0	10.0	17.0	16.3	11.0	6.0	10.0
11-Jul-06	38	29.5	23.5	**26.5**	21.0	23.8	23.5	**23.7**	23.2	20.4	22.0	**21.2**	20.1	23.5	20.8	**22.1**	23.5	23.5	21.5	**22.5**	21.0	21.3	21.6	**21.5**	21.8	38.5	25.0	21.6	22.2	300.0	20.0	10.0	17.2	16.0	10.8	6.2	8.9
12-Jul-06	39	31.4	22.6	**27.0**	20.4	29.5	22.8	**26.1**	22.5	26.8	21.6	**24.2**	20.1	30.2	21.0	**25.6**	22.2	23.3	21.2	**22.2**	21.0	25.4	20.6	**23.0**	22.5	49.0	28.0	21.4	26.4	300.0	40.0	30.0	20.5	20.7	15.1	11.2	1.7
13-Jul-06	40	31.4	31.9	**31.6**	20.4	28.8	25.3	**27.0**	23.4	29.5	23.8	**26.6**	20.1	31.4	29.5	**30.4**	21.6	25.4	22.4	**23.9**	21.9	29.8	21.5	**25.7**	29.1	57.0	25.0	23.2	29.0	300.0	30.0	20.0	17.7	16.3	15.3	12.1	4.3
14-Jul-06	41	31.0	31.9	**31.4**	22.2	27.8	26.2	**27.0**	23.9	23.5	25.0	**24.2**	20.1	30.6	28.8	**29.7**	20.8	29.1	22.4	**25.7**	21.0	22.2	22.7	**22.4**	23.5	55.5	26.0	21.3	26.3	300.0	20.0	10.0	15.0	13.2	14.1	9.2	17.3
15-Jul-06	42	32.3	31.9	**32.1**	22.3	25.4	25.4	**25.4**	23.9	23.0	23.9	**23.5**	20.1	29.1	28.1	**28.6**	20.8	23.1	21.0	**22.0**	21.0	19.7	22.5	**21.1**	21.3	53.5	25.5	20.8	23.7	300.0	30.0	15.0	21.5	17.5	10.3	7.8	15.6
16-Jul-06	43	31.4	33.3	**32.4**	21.5	27.8	24.2	**26.0**	23.4	29.8	23.4	**26.6**	20.1	31.0	29.8	**30.4**	20.1	28.4	21.0	**24.7**	21.3	28.4	21.6	**25.0**	21.3	48.5	27.0	20.7	29.4	300.0	30.0	15.0	20.8	18.2	11.0	7.2	9.9
17-Jul-06	44	28.8	27.0	**27.9**	20.6	22.2	23.2	**22.7**	23.1	22.3	23.0	**22.6**	20.1	23.2	24.9	**24.0**	20.1	22.4	21.0	**21.7**	21.3	21.2	20.6	**20.9**	20.8	42.0	27.5	20.6	22.3	300.0	30.0	15.0	16.7	14.2	17.2	11.9	33.4

		C1				C2				R1				R2				R3				R4					Theta FC =	32.6		Q(ltr/hr)=	3.0	MAD =	0.5		Critical Theta =		25.8
		Water Content				Water Content				Water Content				Water Content				Water Content				Water Content				Rh	Temp	Average Water Content	Average Water Content		Irrigation Time (Mints)		Average Wetted Radius (cm)		Irrigation Depth (mm)		ET (mm)
Date	Days Since Planting	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	15cm	30cm	Avrg	40cm	Avrg (%)	Avrg (°C)	(%) @40cm	(%) @15cm	Drz (mm)	C	R	C	R	C	R	R
18-Jul-06	45	29.8	30.2	**30.0**	29.8	26.2	28.1	**27.1**	29.1	24.9	31.0	**27.9**	27.8	28.4	28.4	**28.4**	30.6	24.7	26.8	**25.8**	30.6	24.1	26.8	**25.4**	28.8	41.5	26.5	29.4	25.5	300.0	20.0	10.0	16.2	14.7	12.2	7.4	2.4
19-Jul-06	46	29.8	28.8	**29.3**	30.6	28.8	30.2	**29.5**	31.0	26.4	26.4	**26.4**	28.4	29.1	29.1	**29.1**	30.2	26.4	27.6	**27.0**	29.1	25.4	27.6	**26.5**	28.8	45.0	26.0	29.1	26.8	300.0	20.0	15.0	16.7	15.3	11.5	10.3	6.4
20-Jul-06	47	31.0	29.8	**30.4**	23.5	28.1	24.5	**26.3**	23.7	30.2	24.0	**27.1**	22.5	29.5	27.0	**28.2**	24.4	28.8	22.7	**25.7**	23.2	29.5	23.3	**26.4**	23.5	49.5	26.0	23.4	29.5	300.0	30.0	20.0	22.8	19.9	9.2	8.0	0.1
21-Jul-06	48	31.4	31.0	**31.2**	22.0	28.1	22.6	**25.4**	22.9	27.3	23.0	**25.1**	21.2	24.4	24.6	**24.5**	23.1	28.8	20.4	**24.6**	20.4	23.3	21.2	**22.2**	20.4	50.5	26.5	21.2	25.9	300.0	20.0	10.0	17.7	16.3	10.2	6.0	16.6
22-Jul-06	49	29.1	25.4	**27.3**	21.8	23.1	22.4	**22.7**	22.7	23.3	22.6	**22.9**	21.0	28.1	21.8	**25.0**	21.5	27.3	20.8	**24.0**	20.8	21.8	22.6	**22.2**	21.2	49.5	26.5	21.1	25.1	300.0	30.0	15.0	15.0	13.2	21.2	13.8	16.2
23-Jul-06	50	28.4	22.8	**25.6**	21.6	23.5	22.3	**22.9**	22.6	24.3	22.0	**23.2**	20.8	23.4	21.8	**22.6**	21.0	22.6	20.6	**21.6**	20.6	21.6	22.5	**22.1**	21.0	47.5	28.0	20.8	23.0	300.0	30.0	15.0	21.5	17.5	10.3	7.8	14.2
24-Jul-06	51	23.8	21.0	**22.4**	21.3	24.1	22.2	**23.1**	22.5	25.3	21.5	**23.4**	20.8	23.3	21.9	**22.6**	20.8	23.7	20.8	**22.3**	20.8	23.4	22.4	**22.9**	20.8	44.0	27.0	20.8	23.9	300.0	30.0	15.0	20.8	18.2	11.0	7.2	4.4
25-Jul-06	52	23.9	22.4	**23.1**	21.3	22.5	22.3	**22.4**	22.4	26.6	22.0	**24.3**	20.8	27.6	22.6	**25.1**	20.8	24.0	20.6	**22.3**	20.6	22.9	22.4	**22.6**	20.8	40.5	26.5	20.7	25.2	300.0	20.0	10.0	16.7	14.2	11.5	7.9	4.0
26-Jul-06	53	29.8	24.1	**26.9**	21.3	27.0	22.2	**24.6**	22.4	31.4	22.6	**27.0**	20.6	23.1	25.3	**24.2**	20.8	22.6	20.4	**21.5**	20.4	26.4	22.3	**24.3**	20.8	41.5	27.0	20.6	25.9	300.0	20.0	15.0	16.2	14.7	12.2	11.1	9.3
27-Jul-06	54	29.8	24.7	**27.3**	21.9	24.1	22.3	**23.2**	22.5	30.2	22.5	**26.3**	20.8	30.6	26.4	**28.5**	21.0	23.3	20.4	**21.8**	20.4	23.5	22.4	**23.0**	21.2	43.5	25.0	20.8	26.9	300.0	30.0	20.0	16.7	15.3	17.2	13.7	10.6
28-Jul-06	55	29.8	24.1	**26.9**	21.6	27.0	22.5	**24.8**	22.6	29.8	22.6	**26.2**	20.8	29.8	28.8	**29.3**	20.8	30.6	20.4	**25.5**	20.4	29.8	22.5	**26.1**	20.8	50.5	26.0	20.7	30.0	300.0	30.0	15.0	22.8	19.9	9.2	6.0	3.3
29-Jul-06	56	29.8	31.0	**30.4**	21.2	27.0	20.6	**23.8**	23.3	30.6	29.5	**30.0**	20.6	30.2	28.8	**29.5**	21.8	28.8	28.1	**28.5**	20.4	29.8	23.3	**26.5**	30.6	43.5	27.5	23.3	29.8	300.0	25.0	20.0	17.5	16.8	13.0	11.3	11.8
30-Jul-06	57	28.8	30.6	**29.7**	22.5	23.7	21.6	**22.7**	23.5	30.6	28.4	**29.5**	20.6	29.1	28.4	**28.8**	22.9	27.3	26.2	**26.7**	20.4	28.4	23.4	**25.9**	29.5	43.0	25.5	23.3	28.9	300.0	25.0	20.0	18.5	15.8	11.6	12.7	15.6
31-Jul-06	58	29.5	29.5	**29.5**	30.2	30.2	30.2	**30.2**	30.2	27.3	28.1	**27.7**	31.0	29.1	27.8	**28.5**	31.4	27.3	27.8	**27.6**	30.2	29.1	29.1	**29.1**	29.5	39.5	26.5	30.5	28.2	300.0	60.0	50.0	33.8	29.2	8.3	9.4	11.3
1-Aug-06	59	27.3	29.8	**28.6**	30.6	24.7	28.1	**26.4**	29.8	29.1	29.5	**29.3**	31.0	29.1	28.4	**28.8**	31.0	27.8	27.3	**27.6**	31.0	28.1	29.1	**28.6**	29.5	40.0	25.0	30.6	28.5	300.0	30.0	20.0	30.2	24.7	5.2	5.2	4.2
2-Aug-06	60	27.3	26.8	**27.1**	29.8	29.1	27.3	**28.2**	27.0	31.9	28.1	**30.0**	28.1	31.4	28.4	**29.9**	30.2	31.9	24.7	**28.3**	28.4	31.4	28.8	**30.1**	29.5	39.0	26.5	29.1	31.6	300.0	40.0	35.0	31.3	26.8	6.5	7.7	1.5
3-Aug-06	61	29.8	27.0	**28.4**	29.5	23.5	27.0	**25.3**	24.6	29.8	29.8	**29.8**	23.8	31.0	28.4	**29.7**	29.5	29.5	24.6	**27.0**	27.6	30.2	28.1	**29.2**	29.5	38.5	27.0	27.6	30.1	300.0	30.0	25.0	24.7	23.6	7.8	7.2	11.7
4-Aug-06	62	22.6	21.6	**22.1**	24.2	19.7	24.7	**22.2**	23.4	25.3	24.2	**24.7**	21.3	22.9	25.1	**24.0**	27.0	24.4	23.3	**23.8**	24.0	23.3	26.8	**25.0**	25.4	35.5	28.5	24.5	24.0	300.0	20.0	15.0	23.7	18.8	5.7	6.7	25.2
5-Aug-06	63	31.4	27.8	**29.6**	23.3	23.7	22.5	**23.1**	31.0	26.4	26.4	**26.4**	19.9	31.4	28.4	**29.9**	24.3	30.2	24.0	**27.1**	23.2	30.6	27.0	**28.8**	30.6	37.5	28.0	24.5	29.6	300.0	45.0	40.0	27.8	26.7	9.2	9.0	8.1
6-Aug-06	64	29.1	23.9	**26.5**	22.9	24.2	23.7	**24.0**	22.3	28.4	29.5	**28.9**	19.1	26.4	27.6	**27.0**	23.3	26.8	23.6	**25.2**	23.1	27.8	26.4	**27.1**	28.1	38.0	27.0	23.4	27.4	300.0	45.0	40.0	29.3	26.7	8.3	9.0	15.8
7-Aug-06	65	30.6	30.2	**30.4**	30.2	27.0	28.4	**27.7**	30.6	29.8	31.0	**30.4**	24.3	28.4	28.8	**28.6**	31.0	28.8	27.8	**28.3**	31.9	29.1	29.5	**29.3**	30.2	51.0	27.5	29.3	29.0	300.0	35.0	30.0	24.7	22.7	9.2	9.3	4.3
8-Aug-06	66	30.2	29.5	**29.8**	29.1	26.6	28.1	**27.4**	27.6	30.2	30.6	**30.4**	23.9	31.0	26.8	**28.9**	29.5	27.6	29.1	**28.3**	31.0	28.8	29.8	**29.3**	30.2	55.0	26.0	28.6	29.4	300.0	37.0	30.0	29.3	25.0	6.8	7.6	6.6
9-Aug-06	67	30.6	29.8	**30.2**	29.8	26.8	27.8	**27.3**	26.2	31.4	31.0	**31.2**	23.5	30.6	28.8	**29.7**	29.8	24.9	29.8	**27.3**	31.0	27.8	29.5	**28.6**	30.2	56.5	25.5	28.6	28.7	300.0	25.0	20.0	21.8	19.0	8.3	8.8	10.9
10-Aug-06	68	25.1	24.6	**24.9**	27.3	28.8	25.3	**27.0**	23.5	29.1	27.3	**28.2**	21.8	25.0	26.6	**25.8**	29.1	27.6	23.1	**25.3**	26.6	26.6	24.4	**25.5**	23.6	52.5	25.5	25.3	27.1	300.0	30.0	30.0	27.2	26.5	6.5	6.8	11.7
11-Aug-06	69	29.5	20.6	**25.0**	23.5	28.1	23.5	**25.8**	21.6	32.3	29.5	**30.9**	20.1	32.3	28.4	**30.4**	26.4	31.4	20.4	**25.9**	23.4	31.9	23.3	**27.6**	22.3	39.5	27.0	23.0	32.0	300.0	37.0	30.0	29.3	25.0	6.8	7.6	7.1
12-Aug-06	70	27.6	20.1	**23.9**	23.4	26.4	23.4	**24.9**	21.2	29.8	27.6	**28.7**	20.1	29.8	27.3	**28.6**	25.4	29.5	20.1	**24.8**	23.3	29.8	23.2	**26.5**	21.5	43.5	25.5	22.6	29.7	300.0	25.0	20.0	21.8	19.0	8.3	8.8	15.6
13-Aug-06	71	31.4	31.4	**31.4**	29.8	28.8	29.5	**29.1**	25.8	30.6	32.3	**31.5**	19.9	31.0	29.1	**30.0**	29.1	29.8	28.4	**29.1**	27.6	30.6	28.4	**29.5**	30.2	52.5	26.5	26.7	30.5	300.0	30.0	30.0	27.2	26.5	6.5	6.8	4.5
14-Aug-06	72	27.6	28.8	**28.2**	27.6	25.1	26.8	**26.0**	24.2	29.1	30.2	**29.6**	19.7	30.6	25.6	**28.1**	28.1	29.5	24.7	**27.1**	25.6	29.8	26.2	**28.0**	25.6	52.5	24.0	24.7	29.7	300.0	45.0	40.0	29.3	26.7	8.3	9.0	11.2
15-Aug-06	73	30.6	28.8	**29.7**	25.4	27.6	25.8	**26.7**	23.8	31.0	32.8	**31.9**	19.4	30.2	28.8	**29.5**	31.4	30.6	28.8	**29.7**	32.3	31.0	28.8	**29.9**	31.0	40.0	26.5	28.5	30.7	300.0	35.0	30.0	24.7	22.7	9.2	9.3	6.4
16-Aug-06	74	31.4	31.0	**31.2**	30.6	27.8	29.1	**28.5**	30.2	31.0	32.3	**31.7**	22.5	31.0	28.8	**29.9**	31.9	30.6	28.1	**29.4**	32.3	31.0	28.8	**29.9**	30.6	44.5	26.0	29.3	30.9	300.0	37.0	30.0	29.3	25.0	6.8	7.6	7.0
17-Aug-06	75	29.1	30.2	**29.6**	29.1	25.4	27.6	**26.5**	27.8	29.1	31.0	**30.0**	21.6	30.2	27.6	**28.9**	31.0	29.1	25.4	**27.3**	31.0	30.2	27.6	**28.9**	29.8	47.5	27.0	28.4	29.6	300.0	25.0	20.0	21.8	19.0	8.3	8.8	12.6
18-Aug-06	76	27.6	28.8	**28.2**	28.1	23.5	24.9	**24.2**	26.0	28.4	30.6	**29.5**	20.8	29.5	25.6	**27.5**	30.2	28.8	23.8	**26.3**	29.8	29.8	27.6	**28.7**	29.8	49.5	28.0	27.7	29.1	300.0	30.0	30.0	27.2	26.5	6.5	6.8	8.4
19-Aug-06	77	29.1	31.0	**30.0**	30.6	27.8	28.8	**28.3**	28.4	29.5	31.9	**30.7**	21.0	31.0	28.8	**29.9**	31.4	29.5	27.8	**28.6**	31.9	30.6	28.4	**29.5**	30.2	57.5	27.0	28.6	30.1	300.0	37.0	30.0	29.3	25.0	6.8	7.6	4.6
20-Aug-06	78	23.5	25.3	**24.4**	28.4	22.3	25.6	**23.9**	26.0	25.4	29.8	**27.6**	20.4	25.6	24.4	**25.0**	31.0	26.6	24.5	**25.5**	29.8	25.4	27.3	**26.4**	29.1	56.5	26.5	27.6	25.8	300.0	25.0	20.0	21.8	19.0	8.3	8.8	21.9
21-Aug-06	79	26.4	29.1	**27.7**	31.4	23.4	29.1	**26.3**	31.0	26.8	31.0	**28.9**	31.0	29.1	27.0	**28.1**	31.0	27.8	29.1	**28.5**	30.2	28.4	29.1	**28.8**	29.8	43.0	27.5	30.5	28.1	300.0	30.0	30.0	27.2	26.5	6.5	6.8	0.1
22-Aug-06	80	25.4	28.4	**26.9**	31.0	23.1	27.6	**25.3**	29.5	27.3	30.2	**28.7**	29.8	27.6	26.2	**26.9**	31.9	27.3	26.6	**26.9**	29.8	27.8	28.1	**28.0**	29.5	45.5	28.5	30.2	27.5	300.0	45.0	40.0	29.3	26.7	8.3	9.0	10.6
23-Aug-06	81	30.6	30.6	**30.6**	29.5	27.3	26.6	**26.9**	25.3	29.1	31.9	**30.5**	25.8	30.2	27.0	**28.6**	30.6	28.8	26.0	**27.4**	29.5	29.8	27.8	**28.8**	29.8	31.0	28.0	28.9	29.5	300.0	35.0	30.0	24.7	22.7	9.2	9.3	3.4
24-Aug-06	82	29.5	23.2	**26.3**	25.0	23.5	24.0	**23.8**	23.6	26.2	29.1	**27.6**	23.0	24.9	23.5	**24.2**	28.4	26.8	24.0	**25.4**	26.6	27.3	27.3	**27.3**	29.1	34.5	27.5	26.8	26.3	300.0	37.0	30.0	29.3	25.0	6.8	7.6	17.2
25-Aug-06	83	25.4	28.4	**26.9**	31.0	23.7	27.6	**25.6**	29.5	27.6	30.6	**29.1**	30.2	27.8	26.4	**27.1**	31.9	27.6	26.8	**27.2**	29.5	27.6	27.8	**27.7**	29.8	45.5		30.3	27.6	300.0	25.0	20.0	21.8	19.0	8.3	8.8	4.7
26-Aug-06	84	30.6	30.2	**30.4**	29.8	27.3	26.6	**26.9**	25.4	29.1	31.0	**30.0**	26.0	31.4	27.3	**29.4**	30.2	28.4	26.0	**27.2**	29.5	29.5	27.8	**28.6**	29.8	37.0	27.0	28.9	29.6	300.0	30.0	30.0	27.2	26.5	6.5	6.8	0.9
27-Aug-06	85	29.5	23.2	**26.3**	24.9	23.4	24.1	**23.7**	23.6	26.0	29.5	**27.7**	23.1	25.0	23.6	**24.3**	28.8	27.3	24.0	**25.7**	26.8	27.6	27.6	**27.6**	29.5	45.5	28.0	27.0	26.5	300.0	37.0	30.0	29.3	25.0	6.8	7.6	17.1
28-Aug-06	86	27.6	20.1	**23.9**	23.4	26.4	23.4	**24.9**	21.2	29.8	27.6	**28.7**	20.1	29.8	27.3	**28.6**	25.4	29.5	20.1	**24.8**	23.3	29.8	23.2	**26.5**	21.5	43.5	25.5	22.6	29.7	300.0	25.0	20.0	21.8	19.0	8.3	8.8	1.0
29-Aug-06	87	31.4	31.0	**31.2**	30.6	27.8	29.1	**28.5**	30.2	31.0	32.3	**31.7**	25.8	31.0	28.8	**29.9**	31.4	30.6	28.8	**29.7**	32.3	31.0	28.8	**29.9**	31.0	40.0	28.5	30.1	30.9	300.0	30.0	30.0	27.2	26.5	6.5	6.8	3.3

Appendix III

		Yield (kg per Plot)					
Date	Days Since Planting	C1	C2	R1	R2	R3	R4
25-Jun-06	22						
26-Jun-06	23	0.3	0.302	0.335	0.325	0.15	0.145
27-Jun-06	24						
28-Jun-06	25	0.28	0.28	0.103	0.29	0.32	0.279
29-Jun-06	26	0.375	0.5	0.62	0.63	0.825	0.38
30-Jun-06	27						
1-Jul-06	28	2.11	3.525	2.65	1.82	1.83	1.35
2-Jul-06	29						
3-Jul-06	30	1.625	1.5	1.15	1.35	1.625	1.63
4-Jul-06	31						
5-Jul-06	32	1.7	1.375	1.4	1.42	1.325	1.4
6-Jul-06	33						
7-Jul-06	34	1.825	1.7	2.825	2.1	3.325	3.025
8-Jul-06	35						
9-Jul-06	36	1.45	1.55	1.2	1.2	1.48	0.75
10-Jul-06	37						
11-Jul-06	38	1.625	1.625	2.05	1.325	1.5	1.905
12-Jul-06	39						
13-Jul-06	40	3.15	2.65	2.05	2.2	2.325	2.65
14-Jul-06	41						
15-Jul-06	42	1.825	1.325	1.82	1.725	1.75	1.875
16-Jul-06	43						
17-Jul-06	44	2.895	2.825	3.45	3.09	3.15	3.07
18-Jul-06	45						
19-Jul-06	46	3.15	3.675	4.85	4.8	4.15	4.55
20-Jul-06	47						
21-Jul-06	48	1.3	1.5	2.32	2.05	2.15	2.125
22-Jul-06	49						
23-Jul-06	50	2.1	1.8	1.2	2.5	1.5	1.9
24-Jul-06	51						
25-Jul-06	52	3.15	3.675	4.85	4.8	4.15	4.55
26-Jul-06	53						
27-Jul-06	54	2.895	2.825	3.45	3.09	3.15	3.07
28-Jul-06	55						
29-Jul-06	56	3.15	2.65	2.05	2.2	2.325	2.65
30-Jul-06	57	1.6	1.65	1.5	2.325	2.33	2.34
31-Jul-06	58	1.58	1.65	1.6	2.35	2.34	2.35
1-Aug-06	59	1.4	1.66	1.61	2.1	2.2	2.2
2-Aug-06	60	1.3	1.33	1.55	2	1.9	1.8

3-Aug-06	61						
4-Aug-06	62	2.5	1.8	1.2	1	1.8	1.2
5-Aug-06	63	1.575	1.33	1.61	2.125	1.925	1.825
6-Aug-06	64	1.58	1.66	1.6	2.35	2.34	2.3
7-Aug-06	65	1.31	1.22	1.54	2.05	1.92	1.82
8-Aug-06	66						
9-Aug-06	67	2.5	1.82	1.2	1.1	1	1.8
10-Aug-06	68	0.125	0.2	1.05	0.25	0.25	1
11-Aug-06	69	1.2	2.05	2.5	2.4	2.65	2.55
12-Aug-06	70						
13-Aug-06	71	1.8	1.3	2.7	1.4	2.05	2.7
14-Aug-06	72						
15-Aug-06	73	1.2	2	2.52	2.42	2.64	2.5
16-Aug-06	74						
17-Aug-06	75	3.55	2.95	2.7	3.2	2.9	3.1
18-Aug-06	76						
19-Aug-06	77	1.7	1.5	1.4	1.85	1.75	1.8
20-Aug-06	78						
21-Aug-06	79						
22-Aug-06	80	0.915	0.97	1.5	1.75	1.65	2.2
23-Aug-06	81						
24-Aug-06	82	0.915	0.97	1.5	1.75	1.65	2.2
25-Aug-06	83						
26-Aug-06	84	1.7	1.5	1.4	1.85	1.75	1.8
27-Aug-06	85						
28-Aug-06	86	3.55	2.95	2.7	3.2	1.65	3.1
29-Aug-06	87						
30-Aug-06	88	1.2	2.05	2.5	2.4	1.65	2.8
31-Aug-06	Totals	68	68	74	77	75	81
	Total Yield (kg/Dunum)	6,191	6,167	6,750	6,980	6,852	7,335

الملخص

تقدير متطلبات المياه لمحصول الخيار المزروع داخل البيوت البلاستيكية

إن شح المياه الذي هو أهم مورد طبيعي في منطقة الشرق الأوسط عامة وفي فلسطين خاصة له تأثير على الإنتاج الزراعي والاستهلاك الآدمي للمياه، استهلاك المياه النقية في الإنتاج الزراعي يقدر ب ٦٠ %منها، وهنا يجب العمل على التقليل من هذه النسبة أمام الزيادة المطردة في عدد السكان .

ان كمية مياه الري المستعملة في داخل البيوت البلاستكية والحقول تكون غير متماثلة في الكمية والكفاءة وذلك بسبب العمليات الزراعية المختلفة واستخدام الطرق الزراعية القديمة غير المحوسبة في تحديد موعد الري وكمية المياه للري الأمثل.

جدولة الري باستخدام تقنية ميزانية الماء لم تزاول بعد لتقليل الفقدان ورشح الماء الذي يرشح تحت طبقة الجذور للنبات وهذا الماء الذي يرشح لا يمتص من قبل المجموع الجذري للنبات و بالتالي لا يستفيد النبات منه، في هذا البحث تم إيقاف رشح الماء تحت منطقة المجموع الجذري من خلال استخدم تقنية ميزانية الماء.

تم قياس التبخرنتح لنبات الخيار وعناصر المناخ في داخل البيت البلاستيكي خلال الموسم الزراعي وتم اعتماد جدولة ري لمنطقة البحث ،واعتمدت هذه الجدولة على حساب التبخرنتح في منطقة الدراسة . اما في الجزء القريب من موقع التجربة ،فلقد تحكم المزارع بادارة الري باستعمال الطريقة التقليدية.

خلال هذا البحث طور تصميم مرتبط بقراءات الجو البسيطة لإيجاد التبخرنتح لنبات الخيار في ظروف البيت البلاستيكي وهذا التصميم يمكن أن يستخدم لتوقع التبخرنتح لنبات الخيار في ظروف البيت البلاستيكي.

الدراسة بينت بأن كمية المياه التي تم استخدامها في التجربة كانت اقل في منطقة التجربة بالمقارنة مع منطقة المزارع وبالإضافة إلى المياه القليلة التي استخدمت فكان الإنتاج أكثر في منطقة التجربة، ويعزى ذلك إلى الغسيل الذي حصل للعناصر بواسطة كمية المياه الكبيرة التي أضافها المزارع وهذه العناصر غسلت تحت منطقة الجذور لذلك لا يمكن للنبات أن يمتصها ويستخدمها.

توصي الدراسة المزارعين أن يستخدموا الجدولة المائية للري وذلك بالاعتماد على الميزانية التقنية للري باستخدام التصميم للتبخرنتح لنبات الخيار في ظروف البيوت البلاستيكية، وهذه الطريقة الإدارية للري سوف تقلل استهلاك أهم الموارد الطبيعية وهو المياه وتزيد الإنتاج.