Effect of Sustained Deficit Irrigation on Evapotranspiration and Stem Water Potential of Navel Oranges in Jordan Valley

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ABSTRACT

This research was conducted to estimate actual average of evapotranspiration (\(ET_a\)) of mature navel orange trees, and to calculate crop coefficients (\(K_c\)) of navel oranges, and to find the effect of deficit irrigation treatments (DIT) on stems water potential. The study was conducted on 14 years old navel orange trees for growing season 2006/2007 in the Northern part of Jordan Valley on a silty clay soil (latitude: 32° 50’ N, longitude: 35° 34’ E, altitude: -254 m). Three levels of irrigation treatments (IT) were applied; namely 100%, 75% and 50% of reference evapotranspiration, representing over irrigation (OIT), full irrigation (FIT), and deficit irrigation (DIT), respectively. The amount of applied water during five months of irrigation season from mid May till the end October 2006 were 660.3, 502.8, and 345.3 mm for 100%, 75% and 50% IT, respectively. The maximum ten-day average actual crop evapotranspiration (\(ET_a\)) during the irrigation period were 3.61, 3.67 and 2.25 mm/day for 100%, 75%, and 50% ITs, respectively. Average crop coefficient (\(K_c\)) of navel oranges during the irrigation period at Tal el-Arbaeen for the 100% was 0.49 and this value is lower than \(K_c\) of FAO56 by about 25%. Stem water potential at 100% over irrigation treatment (OIT) of navel orange trees had less negative value during the irrigation season (-1.57 MPa), whereas the highest negative value (-2.17 MPa) occurred at 50% deficit irrigation treatment (DIT). Deficit irrigation is a useful method to improve water use efficiency of mature navel orange tree in Jordan Valley.

Keywords: Navel Orange, Deficit Irrigation, Actual Evapotranspiration, Crop Coefficient, Stems Water Potential.

INTRODUCTION

In semiarid and arid regions an adequate supply of irrigation water is a major limiting factor to agricultural production (Nadler et al., 2003). In Jordan high quantities of the available water resources are allocated to the irrigation districts (about 62%) (Shatanawi et. al., 2006). Water is the most important environmental constraint determining plant growth and fruit yield of citrus trees in the Jordan Valley which is considered as the main agricultural zone in Jordan (Lorite et al., 2004). In Jordan the availability of water for irrigation will decrease in the future due to increased demands of other sectors. It is possible to allocate part of the water used in irrigation to other alternative uses (Castiel et al., 2004) or increasing agricultural area by increasing water saving through using deficit irrigation strategy (Lorite et al., 2004).

Agricultural practices must be applied in order to minimize water losses and increase crop water productivity of citrus, i.e. improving plant growth with reduced evaporation from soil and transpiration from leaves (Centritto et al., 2005). It is important to assess the ability of citrus to make use of the residual soil water available from the winter season. In this way, irrigation water requirement for early spring could be substantially less than that indicated by evapotranspiration demand (Yang et al., 2003). Plants rely on water stored in the soil during the winter season without excessive water stress and applying irrigation during the period in which fruit cells grow actively is practical (Tognetti et al., 2006).

Sustained deficit irrigation, where irrigation is reduced during the whole irrigated season (Holtz, 2004).
Deficit irrigation can be profitable when irrigation costs are high or water supplies are limited. Farms practicing deficit irrigation achieved lower net incomes per ha but higher net incomes per unit of applied water than the fully irrigated farms (English et al., 1990).

Application of deficit irrigation on citrus orchards in Jordan Valley depends on recognizing the benefits of managed water stress by farmers and their concerns about potential long term problems of water shortage. Deficit irrigation demonstration on a large scale can be successful if profits are maintained or increased and that the higher level of irrigation management required is within the ability of on-farm personnel.

Actual crop evapotranspiration ($ET_c$) variation of citrus was related to irrigation management, plant physical and biological characteristics, meteorological factors and the distribution of intercepted light (Castel and Buj 1990). There is linear relationship between evapotranspiration (ET) of citrus and soil water potential (Plessis 1985). Actual evapotranspiration ($ET_a$) ranged from 750 to 660 mm and mean monthly maximum was 3.2 mm/day in July for Washington navel orchards (Castel et al., 1987). The value of soil water stress coefficient ($K_w$) decreased steadily from 1.0 at field capacity to approximately 0.5 at 50% available soil water depletion. Consoli et al. (2006) found that estimated $K_w$ values ranged from 0.45 to 0.93 for clean-cultivated navel oranges orchards canopy covers having ground shading between 3.5 and 70%, respectively.

Crops water status is based on plant responses to water stress. The predawn leaf water potential, assumed to represent the mean soil water potential next to the roots, is closely correlated to the relative transpiration rate (Ameglio et al., 1999). Stem water potential and midday leaf water potential values in control irrigation treatment for lemon trees were high and fairly, reaching mean values of $-1.32$ and $-1.82$ MPa, respectively (Ortuño et al., 2006 a). Stem water potential of lemon was correlated with changes in reference evapotranspiration ($ET_o$) ($r^2=0.79$) (Ortuño et al., 2006 b). Deficit irrigation induced a decrease in leaf turgor potential and leaf water potential of lemon (Ortuño et al., 2004a, Domingo et al. 1996). The relative leaf water potential of lime trees at predawn decreased sharply when available soil water was lower than 60% (Silva et al., 2005).

Research was conducted to provide decision maker with actual crop water requirement of navel orange through estimation actual evapotranspiration ($ET_o$) and crop coefficients ($K_w$) of navel oranges under condition of deficit irrigation treatments (DIT).

**BACKGROUND**

The available water resources in Jordan are highly dependent on the amount of precipitation. It is expected to have more than 430 MCM of water deficit by the year 2020 (MWI, 2004). Jordan Rift Valley (JRV) extends from the lake Tabarieh in the North to Red sea in the South passing through Dead Sea. The annual rainfall varies from 350 mm in northern part to 35 mm in southern part (Shatanawi et al., 2003, 2006). Jordan Valley is the most important cultivated area in Jordan where it is famous for the production of vegetable and citrus crop under irrigation (Shatanawi et al., 2003). Total agriculture area of Jordan Valley is about 33,000 ha (Shatanawi et al., 2003, 2006). Currently, the area is declining and about 75% of this area is cultivated due to water resources scarcity. Water allocation for farmers in Jordan Valley was reduced from 4 mm/day on the average during normal wet year to 2.0 mm/day and 1.7 mm/day for the drought years of 1999 and 2000, respectively (Shatanawi et al., 2003).

Total cultivated area in Jordan Valley is about 28.4 thousand ha (about 10.5% from total cultivated area in Jordan) distributed as follow: fruit trees 9.291 thousand ha, field crops 2.267 thousand ha and vegetables 16.934 thousand ha. Citrus trees area in Jordan Valley about 6.48 thousand ha (about 23% from the total area cultivated in the Jordan valley) and this form about 69.8% from the total fruit trees planted area in the Jordan Valley (DOS, 2006). Citrus tree irrigation is necessary to be commercially viable due to the semi-arid climate with its annual rainfall of about 300 mm and imbalance between water supply from rainfall and demand by citrus trees (Ortuño et al., 2004a).

**METHODOLOGY**

This research was conducted in a private farm (latitude: $32^\circ 50^\prime$ N, longitude: $35^\circ 34^\prime$ E, altitude: -254 m) on 14-years old navel orange trees on sour orange rootstock with planting space was $5$ m x $6$ m for 2006/2007 growing season in Tal al-Arbaeen area located in the northern part of the Jordan Valley. January is considered the coolest month in the year while August is the warmest month. Climate is Mediterranean, hot and dry summers and mild winters with average rainfall 300
mm (NCARE, 2000). Rainfall is erratic. In 2006/2007 the amount of rainfall was 259.3. The irrigation period extended from May to October because rainfall ceased in this period and navel oranges enters in the stage of fruit development and ripening.

All navel orange trees received the same amount of fertilizers: 0.75 kg N, 0.20 kg P₂O₅ and 0.40 kg K₂O per tree, which were supplied through the irrigation system. Also, iron chelate (Fe_EDDHA, 6% Fe) concentration was added to navel orange trees in the range of 150 to 200 gm per tree.

Three irrigation treatments (ITs) were conducted as following:
- **T-1 (OIT):** received irrigation amount equivalent to 100% of seasonal crop evapotranspiration.
- **T-2 (75% FIT):** received irrigation amount equivalent to 75% of OIT during the irrigation season.
- **T-3 (50% DIT):** received irrigation amount equivalent to 50% of OIT during the irrigation season.

The experiment was conducted in randomized complete block design with three replications.

The FAO Penman-Monteith equation was used in Wadi el-Yabis metrological station to calculate reference evapotranspiration (Allen et al., 1998). Irrigation season extended from beginning of May to end of October. The irrigation frequency was the same for all treatments. Irrigation amount for citrus (ETᵣ) was obtained by multiplying a crop coefficient (Kᵣ) of approximately 0.65 (for citrus) according to FAO 56 by reference evapotranspiration (ET₀) obtained from weekly climatic data of Wadi el-Yabis metrological station (Allen et al., 1998). The amount of irrigation calculated was divided by 0.9 to compensate for unavoidable losses.

Rainfall and daily climatic data (wind velocity, relative humidity and solar radiation) from Wadi el-Yabis metrological station near the experimental site was used to calculate the reference grass evapotranspiration automatically by NCARE website using FAO Penman-Monteith equation (Allen et al., 1998).

A drip irrigation system was used to deliver water to navel orange tree. One drip irrigation line with ten emitters for each tree was used at distance of 0.5 m from the tree trunk. Inline pressure compensating emitters spaced 0.5 meter and having flow rate of approximately 2.3 litters per hour at pressure 1.5 bar was used. The fraction of wetted area in relation to the total area of experimental site at 0.30 m soil depth after completing irrigation period was around 25%. García et al., (2004) found that wetted soil volume was 20% by using one drip irrigation line for irrigated citrus trees with 100% of estimated evapotranspiration, whereas 35% was wetted by using two drip lines one meter apart. High quality irrigation water with salinity less than 0.70 dS m⁻¹ was used.

### Soil Characteristics

Table 1 shows the chemical and physical properties of upper and lower composite soil samples according to standard method of soil analysis (Page et al., 1996). Soil texture is silty clay with adequate potassium and phosphorus, while nitrogen content is moderate (Ryan et al., 2001).

<table>
<thead>
<tr>
<th>Properties</th>
<th>Soil depth (cm)</th>
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<tbody>
<tr>
<td></td>
<td>Unit</td>
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<tr>
<td>pH</td>
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<tr>
<td>EC</td>
<td>dS/m</td>
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<tr>
<td>P</td>
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<td>K</td>
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<td>N</td>
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<td>OM</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>Silty Clay</td>
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</tbody>
</table>
Soil Moisture Measurement

A neutron probe was used with 36 aluminum access tubes, each 1.8 m deep. The maximum root depth of citrus is 1.5 m (Allen et al., 1998). Soil moisture changes were monitored using neutron scattering probe by installation of four aluminum access tubes distributed within the shaded area of tree canopy. Reading was taken for 8 depths (15, 30, 45, 60, 90, 120, 150 and 180 cm) for each access tube using a Campbell Pacific Nuclear Model 503DR neutron moisture gage (Evett et al., 2003, Kriedemann and Goodwin, 2003). Field capacity and permanent wilting point were measured in the laboratory for each soil depth on undisturbed soil samples using ceramic plate apparatus at 0.3 and 15 bars, respectively.

Dry and wet soil profile was used for neutron probe calibration (Evett et al., 2003, Evett and Steiner, 1998) to get one simple linear correlation equation \( \theta_v = -8.767 + 25.653 \) with \( r^2 = 0.94 \). Gaze et al. (2002) found that there was a closer correlation between changes in soil moisture deficit (SMD) measured by the NP and those predicted by a modified Penman-Monteith equation. Volumetric soil water content of the experimental site at saturation was ranged from 51.6% to 43.7%, volumetric soil water content at field capacity measured by ceramic plate at 0.3 bar was ranged from 35.5 to 33.2, whereas volumetric soil water content at permanent wilting point measured at 15 bars was ranged from 16.1% to 22.1% for surface and deepest soil layer, respectively.

Stem Water Potential Measurement

Several indicators can be used to estimate plant response to water stress, the most widely available of which is leaf water potential as measured with a pressure chamber. Midday stem water potential determinations were carried out (between 12:00 and 13:00 hr on monthly basis) in mature leaves from the south and east quadrant close to the trunk. Midday stem water potential values for one tree in each plot were measured. Two shoots per tree were selected from the tree canopy, each shoot has 3-5 mature, intact and fully expanded leaves close to the trunk located on the interior of the tree canopy at a 1.5 to 2.0 m height (Fulton et al., 2001, Ortuño et al., 2004b, and Girona et al., 2002). Shoots were selected randomly from the middle third of the trees. Shoots were covered with plastic bags enclosed with aluminum foil, while the shoot still attached to the tree. The shoots remained covered in the bags for at least 90-120 min to allow equilibration with the water potential of the tree (Nortes et al., 2005 and Girona et al., 2002). Then, shoots were detached from the main branch with sharp razor blade to provide a smooth cut surface, while still covered with plastic bag for measuring water potential in a pressure chamber (Naor and Cohen, 2003, Fulton et al., 2001).

Stem water potential was determined immediately in the field with a pressure chamber. The measurement was taken within 30 second from shoot detachment. Stem water potential was also measured on bare shoot without cover at midday to compare between covered and bare shoot for different irrigation. Stem water potential was measured every three months on uncovered shoots from early morning (8:00 AM) till afternoon (16:00pm) every two hours for different ITs to show the change in stem water potential for navel orange trees through the day and time of the year. Midday shoot water potentials using pressure chamber were measured every four weeks.

Stem water potential (SWP) was monitored according to the pressure chamber technique and using a plant water status console (Model 3005, Soil Moisture Equipment Co., Santa Barbara, CA, US). Midday stem water potential was measured with a pressure chamber, following procedures described by Turner (1988).

Calculations

Soil water content (SWC) was calculated for the soil depth based on neutron probe readings by using the following equation (equation 1):

\[
SWC = \sum_{i=1}^{n} (\theta_v \cdot d_i), \quad \ldots 1
\]

Where:

- SWC: Soil water content (mm)
- \( \theta_v \): Volumetric water content (cm\(^3\) cm\(^{-3}\) soil)
dz: Soil layer thickness (mm)
i = Soil layer (1 to 8)

The difference in water storage within the root zone depth between two consecutive readings when no water input occurred was attributed to evapotranspiration and/or deep percolation. However, variations in water storage in the soil profile below the root zone were attributed to drainage only (Fares and Alva, 2000).

Actual evapotranspiration ($\text{ET}_a$) was calculated by water balance equation through neutron probe readings (equation 2).

$$\text{ET}_a = I + P - \Delta S - DP - R \quad \text{....2}$$

Where:
- $\text{ET}_a$: Actual crop evapotranspiration (mm)
- $I$: Irrigation (mm)
- $P$: Rainfall (mm)
- $\Delta S$: The change in soil water storage (mm)
- $DP$: Deep percolation from the lower boundary (>1.50 m) of root zone (mm)
- $R$: Runoff (mm)

In this study, surface runoff was assumed negligible. Deep percolation was considered as the amount of irrigation water that move below the lower limit of root zone (>1.5 m) due to surplus of irrigation water above the volumetric water content above the field capacity. Also, rainfall intensity was low during winter, no runoff occurs, in such a case actual evapotranspiration $\text{ET}_a$ was the sum of rainfall, irrigation, deep percolation and change in soil water storage.

Deep percolation (DP) was calculated by divided irrigation quantity on wetted area percentage (25%) and refills the soil layers up to 1.5 m to the field capacity ($d_i$) based on neutron probe measurement of moisture depth ($d_i$) (mm) before irrigation for each layer and excess quantity of water move lower than root zone >1.5 m was considered as deep percolation after multiplied by wetted area percentage (equation 3).

$$\text{DP} = \frac{(I / Pw) - \sum_{i=1}^{7} (d_{i} - d_{zi}) \times Pw}{dz} \quad \text{....3}$$

Where:
- $I = \text{Irrigation water applied (mm)}$
- $Pw = \text{Wetted area percentage from the total area occupied by tree.}$
- $d_{zi} = \Theta_v$ (mm) at field capacity for certain layer ($d_{zi} < d_{zi}$)
- $i = \text{Soil layer (1 to 7)}$

The change in soil water storage ($\Delta S$) for 1.50 m soil depth by taking the difference between soil moisture content measured by neutron probe before (May/2006) and after (November/2006) irrigation season multiply by wetted area percentage, and the difference between soil moisture content after the end irrigation season (November/2006) and/or after the end of rainy season or before next irrigation season (at the end of April/2007) using equation 4, due to long irrigation period the change in soil moisture storage was roughly considered as part of water consumption and hence assumed negligible.

$$\Delta S = \sum_{i=1}^{7} (\Theta_v i - \Theta_f) \times d_{zi} \quad \text{....4}$$

Where:
- $\Theta_v$: Initial volumetric soil moisture content after irrigation or rainfall (cm$^3$ cm$^{-3}$ soil).
- $\Theta_f$: Final volumetric soil moisture content before irrigation or rainfall (cm$^3$ cm$^{-3}$ soil).
- $dz$: Soil layer thickness (mm)
- $i = \text{Soil layer (1 to 7)}$

Crop coefficient ($K_c$) was calculated using equation 5.

$$K_c = \frac{\text{ET}_a}{\text{ET}_o} \quad \text{....5}$$

Where:
- $\text{ET}_o$: Reference evapotranspiration calculated from Penman-Monteith equation 1.
- $\text{ET}_a$: Actual evapotranspiration calculated from equation 5.

Data of grass reference evapotranspiration ($\text{ET}_o$) from el-Yabis meteorological weather station was used to estimate crop coefficient ($K_c$).

RESULT AND DISCUSSION

Irrigation Water Control and Management

Irrigation amount in production season 2006/2007 was 660.3, 502.8, and 345.3 mm for 100% OIT, 75% FIT, and 50% DIT, respectively. The volumetric soil water content for 100% OIT after irrigation approached volumetric soil water content at field capacity, whereas the volumetric soil water content for 50% DIT existed in the mid distance between volumetric water content of field capacity and permanent wilting point (Figure 1).
Figure 1: Volumetric soil water contents (10 July/2006) before and after irrigation (13 July/2006) calculated from neutron probe readings for all ITs (A-100%, B-75% and C-50% IT) compared with saturated volumetric soil water content at Tal el-Arbaeen.
Actual Crop Evapotranspiration (ET<sub>c</sub>)

The actual evapotranspiration of navel oranges estimated from neutron probe measurements from Mid of May till the end of October 2006 (harvest date) by taking into consideration only applied water from irrigation and rain fall was 537.2, 499.1 and 294.3 mm for 100%, 75% and 50% ITs, respectively. All curves for cumulative applied water during irrigation season and cumulative actual evapotranspiration have the same trend for all ITs of navel oranges (Figure 2). Also, Figure 2 shows that during irrigation season lower actual evapotranspiration for 50% DIT as compared to 75% FITs and 100% OIT in 45.2% and 30.3%, respectively. Whereas, 75% FIT has less actual evapotranspiration than 100% OIT with 21.3%. Deep percolation of water below the root zone can be part of the water balance; it was found that under deficit irrigation treatment only small portion of irrigation water (10.3 mm) move below the lower limit of root zone as deep percolation for 50% DIT (Table 2). This deep percolation was attributed to simultaneously applied irrigation water with rain fall during irrigation season. Actual navel orange evapotranspiration was less than potential evapotranspiration (Goldhamer and Fereres, 2004). Moreover, irrigation immediately follows the deficit irrigation periods into a relatively dry soil profile eliminating potential deep percolation.

Irrigation treatment of 100% was considered as over irrigation treatment (OIT) because higher deep percolation (about 180 mm) was estimated from neutron probe readings (Table 2), and this was confirmed through estimated actual navel orange evapotranspiration (ET<sub>c</sub>) for 100% and 75% ITs that shows there was no difference in ET<sub>c</sub> for these ITs. So that, 75% irrigation treatment was considered as full irrigation treatment (FIT), and 50% irrigation treatment was considered as deficit irrigation treatment (DIT).

Total yearly amount of actual evapotranspiration of navel oranges in 2006/2007 growing season was 737.3, 650.7 and 594.1 mm/year for 100%, 75% and 50% ITs, respectively (Table 2). The amount of actual evapotranspiration during irrigation season was less than total annual actual evapotranspiration by navel orange trees for all ITs. The actual evapotranspiration during the irrigation periods from 22.9%, 76.7% and 49.5% from the total annual actual evapotranspiration of navel orange trees for 100%, 75%, and 50% ITs, respectively. That mean 50% DIT compensates most of water shortage during irrigation period by abstraction water from soil moisture storage (Table 2). The low difference in actual evapotranspiration of navel oranges between annual and through irrigation season for all ITs could be attributed to lower water requirement of navel orange trees during the winter season because navel orange trees are less actively growing (Figure 2). The source of water consumed by navel oranges in the non-irrigation period is rainfall. Plessis (1985) found a linear relationship between ET<sub>c</sub> of citrus and soil water potential. About 25.1% of applied irrigation water for 100% FIT was lost as deep percolation (Table 2). Moreshet et al. (1983) found that water depletion by Shamouti trees from the partially irrigated plot was 66% of that of the fully irrigated one.

Water consumptive use reductions require lower amounts of applied irrigation water and this decrease irrigation costs, the fact of the matter is that water costs in Jordan Valley are generally low and savings of 200-300 mm are not normally considered as major reductions in operational expenses. Moreover, most farmers consider purposely imposing stress with deficit irrigation a risk and the compensations must balance this risk. Also, water costs savings are not generally enough to compensate adopting deficit irrigation because water price is very low in Jordan Valley. These tariffs are still very low and seem inefficient to reduce farmers’ demand (Petitiguyt et al., 2003). If growers recognize that irrigation water can be saved using deficit irrigation and this water can be added to their profit by being used elsewhere, deficit irrigation strategy adoption is likely. English et al. (1990) concluded that deficit irrigation can be profitable when irrigation costs are high or water supplies are limited.

The actual water consumptive use of navel oranges was calculated from neutron probe reading by taking in consideration deep percolation, irrigation amount and rainfall. The maximum actual crop evapotranspiration (ET<sub>c</sub>) from ten-daily average occurred in the mid of June for 100% FIT and at mid of July for 75% and 50% DITs as follow: 3.61, 3.67 and 2.55 mm/day for 100%, 75% and 50% ITs, respectively (Figure 3). The actual evapotranspiration of navel orange of 75% IT was not differing from 100% IT and that was attributed to deep percolation of 100% IT due to over irrigation. Castel et al. (1987) found that actual evapotranspiration (ET<sub>c</sub>) of Washington navel orange measured by neutron meter at 7 to 10 day intervals was 660 mm. Also, Yang et al. (2003) through their study on eight-year-old orange trees found that there was a significant seasonal variation of crop evapotranspiration (ET<sub>c</sub>) and they concluded that an
average ETₐ exceeded 4.40 mm/day in summer and dropped to 0.6 mm/day in winter. The actual crop evapotranspiration became far from each other in summer season, which could be attributed to differences in the irrigation amount applied (Figure 1).

Table 2: Actual annual evapotranspiration (ETₐ) of navel oranges and deep percolation (DP) determine from neutron probe readings for different ITs, and rain fall (P) at the experiment site (Tal el-Arbaeen) in 2006/2007 growing season extended from 15/May/2006 till 28/April/2007.

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Irrigation Amount (I)</th>
<th>Deep percolation (DP)</th>
<th>Rain fall (P)</th>
<th>ETₐ</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>660.3</td>
<td>182.3</td>
<td>259.3</td>
<td>737.3</td>
</tr>
<tr>
<td>75%</td>
<td>502.8</td>
<td>111.4</td>
<td>259.3</td>
<td>650.7</td>
</tr>
<tr>
<td>50%</td>
<td>345.0</td>
<td>10.2</td>
<td>259.3</td>
<td>594.1</td>
</tr>
</tbody>
</table>

Figure 2: Actual evapotranspiration (ETₐ) of navel orange total yearly and during irrigation season for all ITs in 2006/2007 at Tel el-Arbaeen.

Figure 3: Ten-daily average actual evapotranspiration (ETₐ) of navel oranges at Tal el-Arbaeen during irrigation season in 2006.
Navel Oranges Crop Coefficient (Kc)

Ten-daily average crop coefficient (Kc) values of navel oranges ranged from 0.36 to 0.73 through irrigation season which extend from mid of May to the end of October 2006 (Figure 4). The maximum monthly crop coefficients (Kc) of navel oranges for 100% and/or 75% ITs occurred in October 2006 during the irrigation periods and values was 0.63 and this value is relatively approached from value reported by the FAO 56 (Table 3). The same trend was observed by Germana and Sardo (2004) for mature orange grove in Sicily and Consoli et al. (2006) for clean-cultivated navel orange orchards.

Applied water by drip irrigation led to soil water stress and influence Kc because only a small portion of the root system is wetted as the drying between irrigations might influence basal crop coefficient Kcb (Allen et al., 1998). Loveys et al. (1999) showed that no water stress symptoms appears when only one drip irrigation line per tree was used, even when water input was reduced by up to 80% compared with the fully irrigated flood irrigation.

The average navel orange crop coefficient (Kc) through irrigation season (May to October) for 75% FIT was 0.49 and this value relatively lower than value of crop coefficient (0.65) computed from FAO 56 (Allen et al., 1998) (Table 3). The yearly average values of crop coefficients for 100%, 75% and 50% ITs were 0.62, 0.57 and 0.38, respectively (Table 3).

Stem Water Potential (SWP) of Navel Oranges

Midday stem water potential (SWP) of covered shoot was measured monthly on navel orange trees in 2006/2007. It shows a more negative SWP value in summer and this negative value reach maximum in July for all ITs (Figure 5). SWP of 100% OIT for navel orange trees had less negative value in July during the irrigation period (-1.57 MPa) which mean that navel orange trees were in favorable soil moisture condition. Whereas the 50% DIT had highest negative SWP value (-2.17 MPa) which mean that navel orange trees were under soil moisture stress condition (Figure 5). SWP for all ITs in winter was less negative than that of summer in spite of irrigation in summer and that was attributed to rainfall and lower air temperature in winter that kept leaf cells turgid (Figure 5). SWP value of navel orange trees in traditional farm was ranged between 50% and 75% ITs. The values of navel oranges SWP for all ITs over the entire period of the growing season ranged from -0.5 to -2.2 MPa (Figure 5). The highest negative SWP value for navel oranges occurred in summer (-2.2 MPa) whereas the lowest value of occurred in winter (-0.5 MPa). The same trend for lemon trees was found by Ortuño et al. (2006 a).

Figure 4: Ten-daily average crop coefficient (Kc) of navel oranges in 2006 irrigation season at Tal el-Arbaeen using three ITs (100%, 75% and 50%).
Table 3: Monthly average crop coefficient ($K_c$) of navel oranges for 2006/2007 at Tal el-Arbaeen using three ITs (100%, 75% and 50%).

<table>
<thead>
<tr>
<th>Month</th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>May/2006</td>
<td>0.47</td>
<td>0.39</td>
<td>0.22</td>
</tr>
<tr>
<td>June/2006</td>
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<tr>
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<td>February/2007</td>
<td>0.70</td>
<td>0.74</td>
<td>0.67</td>
</tr>
<tr>
<td>March/2007</td>
<td>0.74</td>
<td>0.66</td>
<td>0.61</td>
</tr>
<tr>
<td>April/2007</td>
<td>0.46</td>
<td>0.59</td>
<td>0.48</td>
</tr>
<tr>
<td>Average</td>
<td>0.62</td>
<td>0.57</td>
<td>0.38</td>
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</table>

SWP values of 100% and 75% ITs approach from each other over entire growing season especially in winter, whereas SWP value of 50% DIT was far away from other ITs over entire growing season even in the winter where the irrigation is stopped and only rainfall was available. The soil moisture stress in the irrigation season effects negatively on SWP value of navel orange trees during the winter season (Figure 5). Figure 5 shows that SWP had less negative value in the October 2006 and that could be attributed to rainfall (33.1 mm). SWP for navel oranges had higher negative value in summer (during irrigation periods) than those of winter for all ITs (Figure 5).

Figure 5: Stem water potential changes (MPa) of navel oranges for the growing season from May 2006 till April 2007 for three ITs (100%, 75%, 50% and traditional farm) at Tal el-Arbaeen.
CONCLUSIONS
The actual crop evapotranspiration of navel orange of 75% FIT and 100% OIT increased linearly as compared with 50% DIT. According to obtain results of the study and statistical analysis using standard method of analysis found that no significant difference between 75% and 100% ITs in actual crop evapotranspiration even though higher deep percolation was occurred at 100% OIT as compared with other ITs. Stem water Potential values of 100% and 75% ITs approach from each other over entire growing season especially in winter, whereas SWP value of 50% DIT was far away from other ITs over entire growing season even in the winter where the irrigation is stopped and only rainfall was available. The soil moisture stress in the irrigation season effects negatively on SWP value of navel orange trees during the winter season.

Deficit irrigation is a very useful method to improve water use efficiency of citrus (navel orange) in the Jordan Valley. Although there is some threat of water stress to the plant, with careful soil water monitoring these threats can be reduced. Deficit irrigation can be profitable when irrigation costs are high or water supplies are limited. It is recommended when conducting deficit irrigation strategies in hot and dry agricultural land (areas with high levels of water evaporation) to have responsive watering systems and soils with good infiltration rates.

ACKNOWLEDGMENT
Special appreciation is extended to National Center for Agricultural research and Extension (NCARE) for technical and logistical support provided. Also, I would like to thank Eng. Suleiman Al Ghzawi the owner of local farm where the research was conducted for providing all facilities to success this study.

REFERENCES


تأثير نقص مياه الري الدائم على بخر- نتج، والجهد المائي للأغصان برتقال (أبو صرة) في وادي الأردن 

نبيل محمد باني هاني، محمد رشيد شطناوي *

ملخص

تم تنفيذ البحث لتحديد القيمة الفعلية لأغصان الحمضيات من خلال قياس البخر- نتج الفعلي وعوامل المحصول عند مستويات مختلفة من كميات الري، ودراسة تأثير عجز الري على الإجهاد الوظيفي لأشجار برتقال أبو صرة. أجريت الدراسة على أغصان برتقال أبو صرة والبالغة من العمر 14 سنة وتم وضع سطح الحضافة على أصل نباتي من أربع شجرة في منطقة تل الأربين في وادي الأردن (38°34′58″ شمالاً، 20°21′12″ شرقاً، وارتفاع 35 متراً فوق سطح البحر في الخريف عام 2007). أجريت الدراسة على أربعة مستويات رفديه من الري بنسبة 100%، 70%، 50% و0% من كمية الري الكاملة. وقد تم استخدام نظام عرض وشريعتي عبارة عن شرائط ونقطة مجوفة لقياس البخار الفعلي. الري تم أنقشة بواسطة نظام عبارة عن شرائط ونقطة مجوفة بفاحشة 0.04 لتر/ساعة في حالة الضغط 4.0 بار. تم إضافة مياه الري تحت الغطاء الريفي للأشجار. كانت كمية الري المضافة خلال أشهر الري الخمسة الممتدة من منتصف شهر أيار ولغاية نهاية شهر تموز للمواضيع 6002 كم³ لكل شجرة (220.2، 206.0، 210.2 ملم لكل من معاملات الري 100، 70، 50% على التوالي). كان أعلى استهلاك من البخار الفعلي (ETa) خلال فترة الري محسوبة من المتوسط لكل عشرة أيام كالميLINCA 2.25 بROMEUM 100% و50% على التوالي. على الرغم من أن نسبة محلية الماء في النباتات المزروعة كانت أقل بحوالي 15% من الري الكامل، إلا أن النتائج تشير إلى أن الري المرن والموسع يمكن أن يساعد في تقليل الخسائر المائية. يشير الجهد المائي من ağصان برتقال إلى أن النقص في الري يمكن أن يؤدي إلى تقليل الجهد المائي. الأغصان تتحمل نقص الري بشكل أكبر من الأغصان المرتبطة بري الزائد. 

الكلمات الدالة: برتقال أبو صرة، تأثير نقص بخر- نتج، معامل المحصول، الجهد المائي.

* المركز الوطني للبحوث الزراعية، البقعة، الأردن؛ وقسم الأراضي والمياه والبيئة، كلية الزراعة، الجامعة الأردنية. تاريخ استلام البحث 05/12/2010، وتاريخ قبوله 22/11/2012.