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LEMON EVAPOTRANSPIRATION AND YIELD UNDER WATER DEFICIT IN JORDAN VALLEY

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SUMMARY- In countries with limited water resources like Jordan; deficit irrigation (DI) could be used as a strategy to manage water more efficiently while maintaining good production with out significant yield reduction. This research was conducted in the Jordan Valley to test two DI levels against the standard practice of full irrigation by evaluating yield and actual evapotranspiration. The study was conducted for two consecutive years (2005 and 2006) on full-grown lemon trees (10-year old) using three irrigation treatments: T1 for full irrigation; T2 for 75% of T1; and T3 for only 50% of T1. The field was irrigated, from the beginning of April to the end of November, twice a week using a micro-irrigation system with pressure compensating emitters while the irrigation duration varied according to the irrigation depth applied for each treatment. The root zone depletion analysis showed that lemon trees in T3 were under water stress from early June to harvest and from mid of June to end of October for T2 in both years, whereas no water stress occurred in T1 for the two years. The yield in 2005 was 17.8, 28.6 and 13.3 ton/ha whereas the yield in 2006 dropped to 16.3, 17.8 and 12.8 ton/ha for T1, T2 and T3, respectively. Improved water use efficiency was observed for the 75% level of DI in the first year and slight differences were obtained in the second year. From these results, one may conclude that the implementation of the 75% DI instead of full irrigation would be recommended to save water while sustaining the yield.

Key words: Deficit irrigation, evapotranspiration, water stress, Jordan Valley, FAO-PM 56.

INTRODUCTION

Jordan is considered to be one of the ten poorest countries worldwide in water resources. Due to limited water resources and the relatively high population growth rate (2.5% in 2004), the annual per capita share is expected to decrease from 160 m^3 in recent years to less than 90 m^3 by 2025 (Shatanawi *et al*, 2007). The irrigation share of the total water uses demonstrates significant decrease during the period 1985-2005 (78% in 1985 to 62% in the year 2005). In absolute figures, irrigation water use has also been reduced from its peak in 1993 (726 MCM/a) to 511 MCM in the year 2003 (MWI-GTZ, 2004).

The scope for further irrigation development to meet food requirements in the future is severely constrained by the decreasing water resources and the growing competition among the different sectors for water. Therefore, reducing the irrigation water without affecting crop production will result in releasing resources for other uses or expanding the irrigated area. In the context of improving water productivity, there is a growing interest in deficit irrigation (DI), an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. The principles underlying DI can be viewed as an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (English, 1990). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop (FAO, 2002).

Deficit irrigation can be either sustained or regulated. The former is practiced during the whole season while the latter is carried out during the non-critical phonological crop stages. According to Castel and Buj (1990), the regular deficit irrigation (RDI) reduced the yield of orange trees by 5 to 15% and increased the total soluble solids and acid contents of the fruit juice. The differences in yield were mainly attributed to the effect of the RDI on average fruit weight. Germaná and Sardo (2004) indicated that the increased fruit weight and the incremental water savings could compensate the reduction in yield under deficit irrigation. Domingo *et al*. (1996) indicated that RDI could reduce leaf water potential of lemon trees and decrease the relative fruit growth rate. However, chemical characteristics of the lemon fruit were not significantly modified by the RDI treatment.

Water saving was seen as the big advantage of RDI with no significant effects on fruit quality and yield. González-Altozano and Castel (2000) concluded that the RDI during July and August could save between 6 to 22% of irrigation water without affecting yield components or fruit quality. However, continuous RDI during September and October resulted in significant reductions in fruit size and external peel disorders (creasing) in al large proportion of the fruits of clementina de nules. Mostert and Van Zyl (2000) obtained similar findings on citrus fruit quality under water stress and indicated that the total soluble solids (TSS) and the acidity of juice decreased with increased volume of water applied. Single regulated deficit irrigation regimes reduced irrigation by 13–24%, while combined regime reduced it by 23–35%.

Understanding the impact of RDI on crop production requires assessment for several years. This was emphasized by Girona *et al*. (2005 a, b) who indicated that fruit production of almonds had been affected by deficit irrigation after four years of the irrigation regime when fruit set decreased slightly and significantly reduced vegetative growth of the trees. During the first two experimental years, kernel dry matter accumulation did not decrease with drought in the RDI treatment. However, both cropping and kernel growth were reduced during the third and fourth years of the experiment. A possible explanation for this decrease was attributed to a hypothetical depletion of the carbohydrate reservoir in RDI trees and also to the negative soil water balance. Overall, the results indicated that regulated deficit irrigation could be used successfully on peach trees grown in deep soils. The response to deficit irrigation would be also affected by the soil wetting pattern and rooting depth (Girona *et al*. 2002).

Obviously, the effects of RDI on crop yield and the substantial water savings require further studies and research to evaluate the impacts and benefits of this irrigation practice. Therefore, a collaborative project "Deficit Irrigation for Mediterranean Agricultural Systems (DIMAS)" in the Mediterranean basin is carried out to evaluate the concept of deficit irrigation (DI) as a mean of reducing irrigation water use while maintaining or increasing farmers' profits. The ultimate goal of DIMAS is to develop a workable, comprehensive set of irrigation (DI) strategies that can be disseminated quickly among the various agricultural systems of the Mediterranean Region. This study is a part of the DIMAS project and aims to evaluate the effects of DI on yield and quality of lemon grown in the middle Jordan Valley. The objectives of the research are extended to determining the actual evapotranspiration of citrus under different levels of water stress and thus obtaining a set of data that can be further used for DI validation.

MATERIALS AND METHODS

Field experiment

The experiment was conducted at the Agricultural Research Station of the University of Jordan (ARS-UJ) in the central Jordan Valley. Jordan Valley is the main irrigated area in Jordan that has an altitude of 32^{o} and a longitude of 35^{o}: 30'with an elevation ranging from – 200 m (bmsl) in the north to about -400 m (bmsl) near the Dead Sea in the south. The valley is characterized by semi–arid climate with annual precipitation ranging from 150 mm in the south to more than 400 mm in the north. The valley exhibits a very favorite climate to grow vegetable and many sub- tropical fruits and citrus in the winter. The experiment site, which is located at 32˚10' N Latitude and 35˚37' E longitude and altitude of -230 m (below mean sea level), has been selected in the citrus orchard of the ARS-UJ where 108 lemon trees have been identified as a test plot. The area of the plot is 54m × 72m of about 3888 m^2. The soil is classified as ustochreptic and ustollic camborthid with some ustic torriorthent and torrifluvent units with hyperthermal temperature regime. Soil texture is mainly sandy loam with a bulk density of 1.62 g cm^{-3}. The study was conducted for two consecutive years (2005 and 2006) on full-grown citrus orchard (10-year old) using a plot of 3,888 m^2 with three treatments replicated three times in a completely randomized block design. The irrigation treatments are: T1 represents full irrigation calculated by multiplying FAO ET_o by 0.64 as a crop coefficient; T2 is 75% of full irrigation while T3 is only 50% of T1. Each treatment had 12 trees but measurements and readings were based on the two middle trees.

The yield, crop evapotranspiration, fruit quality and some phonological characteristics of the trees were evaluated. Four shoots were determined on the periphery of the selected trees using special tags, and length of these vegetative growths was carried out every two weeks. Percent of soil area covered by the canopies of the trees were determined and the diameter of the shaded area was measured. Fruit quality was assessed through some external and internal quality measurements made on 25 randomly selected fruits from each treatment. The parameters included average fruit diameter and weight, total soluble solid (TSS) and Titrable acidity (TA). Total yield for each treatment was estimated from the yield of the two middle trees of each replicate.

Estimation of irrigation water requirements

The field was irrigated twice a week using micro-irrigation system while the irrigation duration was varied according to the irrigation depth applied for each treatment. Two drip irrigation lines with inline compensating emitters were used for each row in each replicate at a distance of 0.5 m from the tree trunk. The irrigation took place from the beginning of April to the end of November. However, the implementation of the different deficit treatments began in early June and continued until harvest late November. Leaching fraction of 20% was applied for the different treatments. The daily crop evapotranspiration was obtained from the FAO-56 reference evapotranspiration (ET_o) approach and the actual evapotranspiration was estimated using the water balance technique. Observed crop evapotranspiration was estimated from the difference between the soil moisture readings assuming that the deep percolation was equally to the leaching fraction. Water use efficiency (WUE) was calculated by dividing crop yield by the crop evapotranspiration under each irrigation treatment.

Crop evapotranspiration and crop coefficients

Soil parameters that were used in the FAO-56 procedure to calculate crop evapotranspiration and crop and stress coefficients are presented in *Table 1*. A nearby weather station monitored air temperature, relative humidity, precipitation, wind speed, wind direction, solar radiation, soil temperature at 5, 10 and 20 cm depths, and barometric pressure. The station and sensors are installed based on the guidelines of the World Meteorological Organization (WMO, 1981). All sensors are scanned at a one-second frequency and summarized every 15 minutes. At midnight, the daily extremes and totals are determined. The Central Jordan Valley has a warm climate in winter with a minimum temperature of 8.5 ^oC in January and a hot summer with a maximum temperature of 40.4 ^oC in July. The yearly average maximum and minimum temperatures are 30.9 and 18.5 ^oC, respectively, while the yearly mean temperature is 24.7 ^oC.

Table 1. Soil parameters used in the FAO56-PM crop coefficient determination.

Parameter	Value
Field capacity, θ_{FC}	0.22 m^3 $m\text{-}^3$
Permanent wilting point, θ_{pwp}	0.12 m^3 $m\text{-}^3$
Effective rooting depth, Z_r	1.5 m
Total available water, TAW	150 mm
Readily available water, RAW	75 mm
The ratio of RAW to TAW, *P*	0.5 (fraction)

Root zone depletion (D_r), which is the water storage relative to field capacity, was calculated to assess the water stress conditions. Quantifying the soil water deficit (SWD) and its relation to canopy or leaf conductance is essential for application of the Penman–Monteith equation to water-stressed plants (Li *et al*., 2004). Root zone depletion is a good indication of soil water stress, because it helps in determining the water stress dates, severity, duration and reoccurrence. In addition, it can provide a practical mean to monitor plant response to water stress, as the direct measurement of soil water content requires a priori unknowns of many soil and plant parameters that are difficult to measure (Nadler *et al*., 2003). Therefore, to evaluate the level of water stress under RDI with FAO 56-PM equation, a stress coefficient (K_s) was calculated as follows (Allen, 2000):

$$K_s = \frac{TAW - D_r}{TAW - RAW} \quad (1)$$

where K_s is a dimensionless transpiration reduction factor and ranges from 0 to 1, D_r is root zone depletion in mm, TAW is total available soil water in the root zone in mm, and RAW is readily available soil water in the root zone in mm. When D_r < RAW, K_s = 1.

RESULTS AND DISCUSSION

Results showed differences in yield among the different treatments and between the first and the second year of the experiment. The RDI of T2 and the full irrigation (T1) treatments resulted in significantly higher yield than the T3 treatment (T3). For 2005, the total yield of T2 reached 28.6 ton/ha compared to 17.8 and 13.3 ton/ha for T1 and T3, respectively (*Table 2*). The average fruit weight for T1 was significantly higher than that of T3 while the TA was significantly higher for T3 than for the other two treatments. In 2006, similar tend of productivity was observed with lesser productivity for T2 in this year than in 2005. The average fruit weight and the other quality parameters did not differ significantly among the treatments. However, a slight increase in average fruit diameter and an obvious increase in average fruit weight were observed in 2006 (*Table 3*).

A slight decrease in average fruit weight was observed under T3 treatment. This indicates the impact of deficit irrigation on quality parameters of lemon. According to previous research (Davenport 1990; Goldschmidt and Samach, 2004), water stress triggers flower formation and induced flowering in citrus and therefore results in increasing the number of fruits per tree. This, however, resulted in reduced fruit weight and the total yield. In addition, fruits under deficit irrigation of T3 (50% of full irrigation) had higher TA than T1 and T2. The impacts of RDI on fruit quality go with findings of previous research (e.g. Castel and Buj, 1990; Domingo *et al*., 1996; Kanber *et al*., 1999; González-Altozano and Castel, 2000) who indicated that the impacts of deficit irrigation and water stress on citrus would vary according to the level of DI and its continuity.

Table 2. Average fruit weight, fruit diameter, TSS, TA and yield for 2005.

Treatment	Fruit wt (g)	Fruit diameter	TSS (%)	TA	TSS/TA	Yield (kg/tree)	Yield (Ton/ha)
T1	109.4a*	5.3	9.5	0.87b	10.9	64.2ab	17.8ab
T2	91. 7ab	5.6	9.8	0.77b	12.7	102.8a	28.6a
T3	77.4b	5.3	10.6	1.05a	10.1	48.0b	13.3b

* Means within column followed by different letters were significantly different at P < 0.05 using Fisher's LSD procedure (MINITAB Inc., 2004).

Table 3. Average fruit weight, fruit diameter, TSS, TA and yield for 2006.

Treatment	Fruit wt (g)	Fruit diameter	TSS (%)	TA	TSS/TA	Yield (kg/tree)	Yield (Ton/ha)
T1	141.0	6.0	7.8	0.64	12.2	58.5ab*	16.3ab
T2	145.3	6.0	8.4	0.64	13.2	64.0a	17.8a
T3	134.0	5.9	9.0	0.71	12.7	46.3b	12.8b

* Means within column followed by different letters were significantly different at P < 0.05 using Fisher's LSD procedure (MINITAB Inc., 2004).

Annual reference evapotranspiration was 1215 mm in 2005 and 1264 mm in 2006. The total irrigation and precipitation amounts were 864, 747 and 629 mm in 2005; and 813, 689, and 565 mm in 2006 for T1, T2 and T3, respectively (*Table 4*). Actual evapotranspiration (ET_C) was 777, 690 and 562 mm in 2005 and 798, 684 and 548 mm in 2006 for the T1, T2 and T3, respectively. Therefore, application of RDI resulted in saving of 18 % and 19 % in the irrigation water amounts for T2 in 2005 and 2006, respectively (*Table 4*). For T3, irrigation water saving was 37 % in both years. This suggests that the RDI of 75% full irrigation allowed water savings up to 19% without affecting yield or its components, nor fruit quality. Subsequently, water use efficiency (WUE) was obviously improved under T2 treatment, particularly in the first year. The T1 treatment had the lowest WUE while T2 had the highest WUE in both years.

The irrigation and ET_c were essentially the same for T1 throughout the irrigation period (from April 1st to the end of November) in 2005 and 2006 (Fig. 1a, 1b). For T2 and T3 in both years, ET_C and the irrigation were quite close in April and May, ET_C was higher than the irrigation from the beginning of June to mid of August, they were almost identical from mid of August until the end of October when rainfall took place, and ETC was higher than the irrigation in November. During the deficit irrigation period, (From beginning of April to end of November) ET_C was higher for T1 than for T2 and T3 and ET_C was higher for T2 than for T3 in both years. Minimum and maximum ten-day ET_C were 5.1 and 34.1 mm in 2005 and 5.2 and 37.2 mm in 2006, respectively.

Table 4. Crop evapotranspiration, applied water (irrigation + rainfall), crop yield, water use efficiency (WUE) and water saving for the different treatments in 2005 and 2006.

Treatment	ET_C (mm)	Applied water (mm)	Yield ton/ha	WUE kg/m^3	Water saving (%)
			2005		
T1	770	864	17.8	2.3	0
T2	682	747	28.6	4.2	18
T3	555	629	13.3	2.4	37
			2006		
T1	793	813	16.3	2.0	0
T2	680	689	17.8	2.6	19
T3	545	565	12.8	2.4	37

Water stress would result in a deviation between the actual and potential ET_c due to shortage in the available water in the root zone. During the first three months of the year (before irrigation), the root zone depletion analysis showed that water stress did not take place in T1 in 2005 while in 2006 it occurred in the first two weeks of January and during most of March (Fig. 2a, 2b). The water stress for T2 happened in the first two weeks in January of 2005 while in 2006 it happened in the first two weeks of January and during most of March. The water stress for T3 took place in the first two weeks of January in 2005 while in 2006 it happened throughout the three months. During the full irrigation period (April and May), there was no water stress for T1 and T2 in both years while for T3 water stress took place in April of 2005 and April and May in 2006. During the deficit irrigation period, lemon trees in T3 were under water stress from early June to harvest. This resulted in lower shoot growth during summer, particularly in august (hottest month). For T2, the RDI resulted in a water stress from mid of June to the end of October in both years. The level of water stress and its periodicity under T2 treatment were less than those of T3.

Results from this study showed that the full irrigation practice with FAO56-PM equation resulted in no water stress for the two years. In December and after the cease of irrigation, no water stress took place for T1 in both years. This could be attributed to the residual water stored in the soil after the full irrigation practice. For the same period, water stress was evident on several days in 2005 and on all the days in 2006 for T2 and T3. The severity of the water stress was significantly higher for T3 than T2 in 2005 and 2006. The level of water stress (K_s > 0.75) under T2 during the different periods of 2005 did not affect the yield of that year. In 2006, the K_s value reached 0.45 for T2 during March and early April. This level of water stress could contribute to the lower productivity of T2 in 2006 compared to 2005, as this growth period was considered as the first growth period for citrus (Davenport 1990; Domingo et al., 1996; Goldschmidt and Samach, 2004). These findings suggest that the application of T2 will improve WUE, providing that water stress is avoided during early spring and a K_s value of 0.75 is not surpassed during summer.

The trend of water stress during the 2005 and 2006 would indicate that water stress coefficient (K_s) showed good response to RDI and performed well under water scheduling with FAO56-PM equation. This confirms the findings of Li *et al*. (2004) who indicated that a climate-based soil water balance would provide a better means of quantifying soil water deficit, under the application of Penman–Monteith equation, than a solely soil-based measurement. Therefore, this coefficient could be implemented in addition to soil water monitoring under RDI practice.

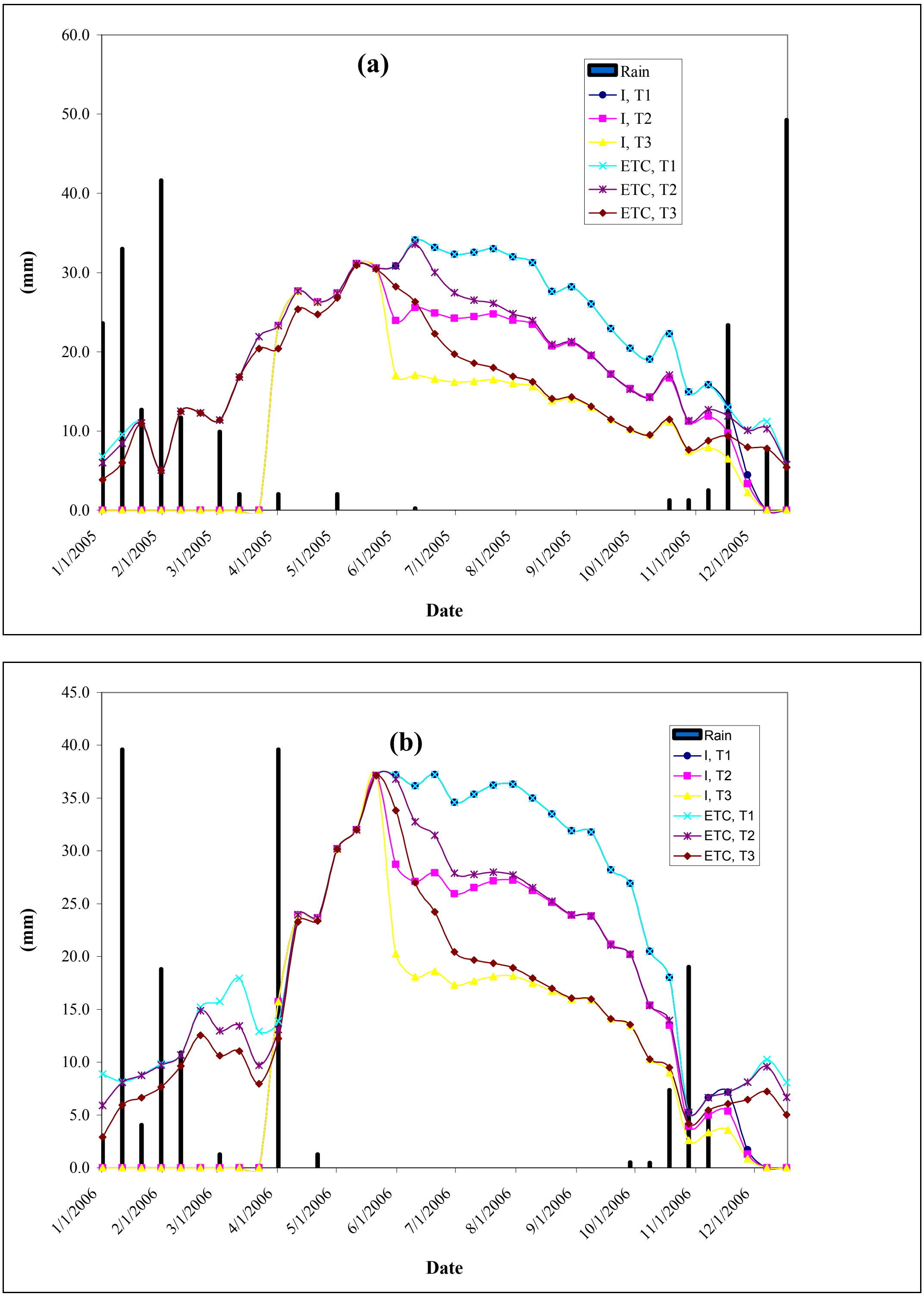

Fig. 1. Ten-day rainfall, irrigation and crop evapotranspiration for the different treatments in 2005 (a) and 2006 (b).

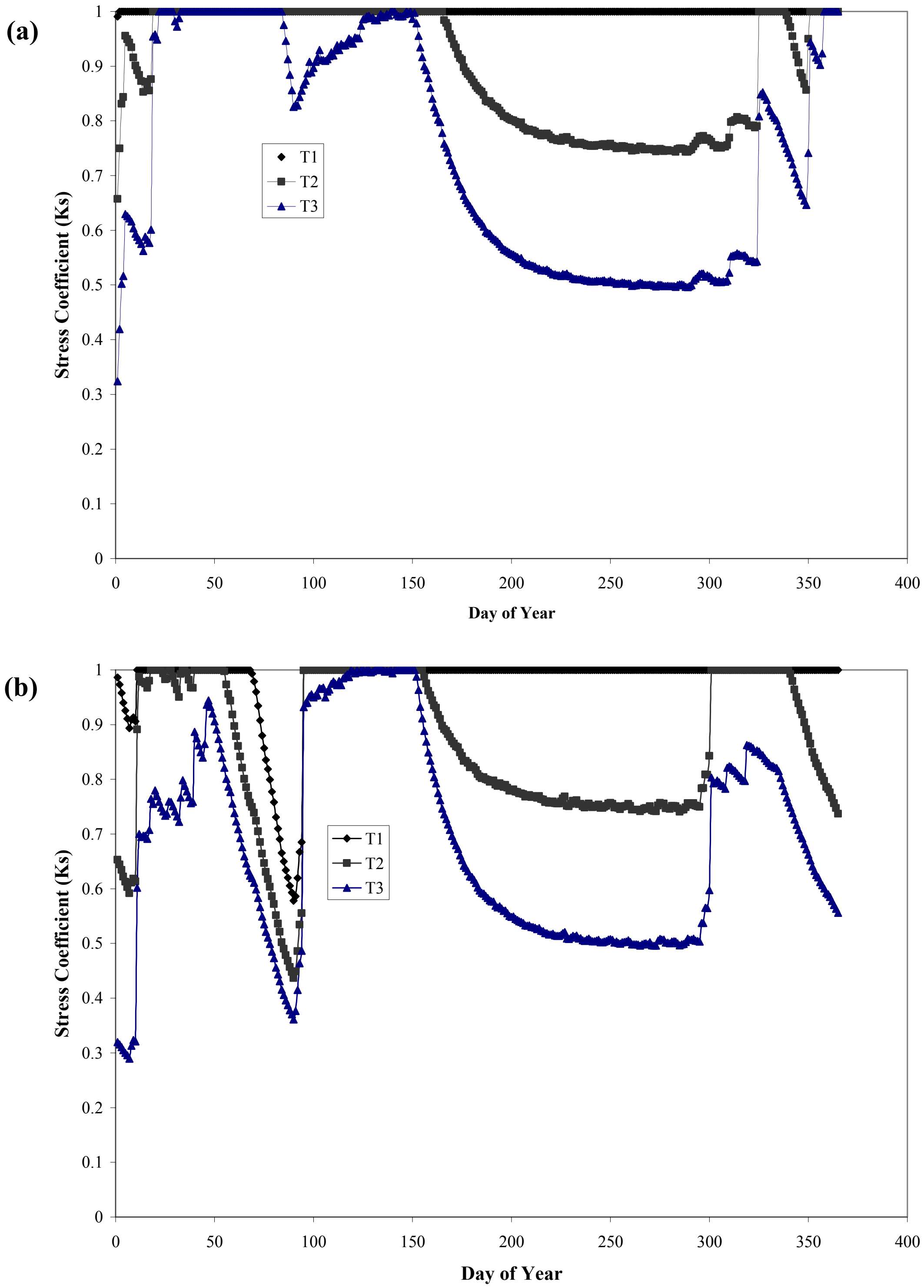

Fig. 2. The stress coefficient for the different treatments in 2005 (a) and 2006 (b)

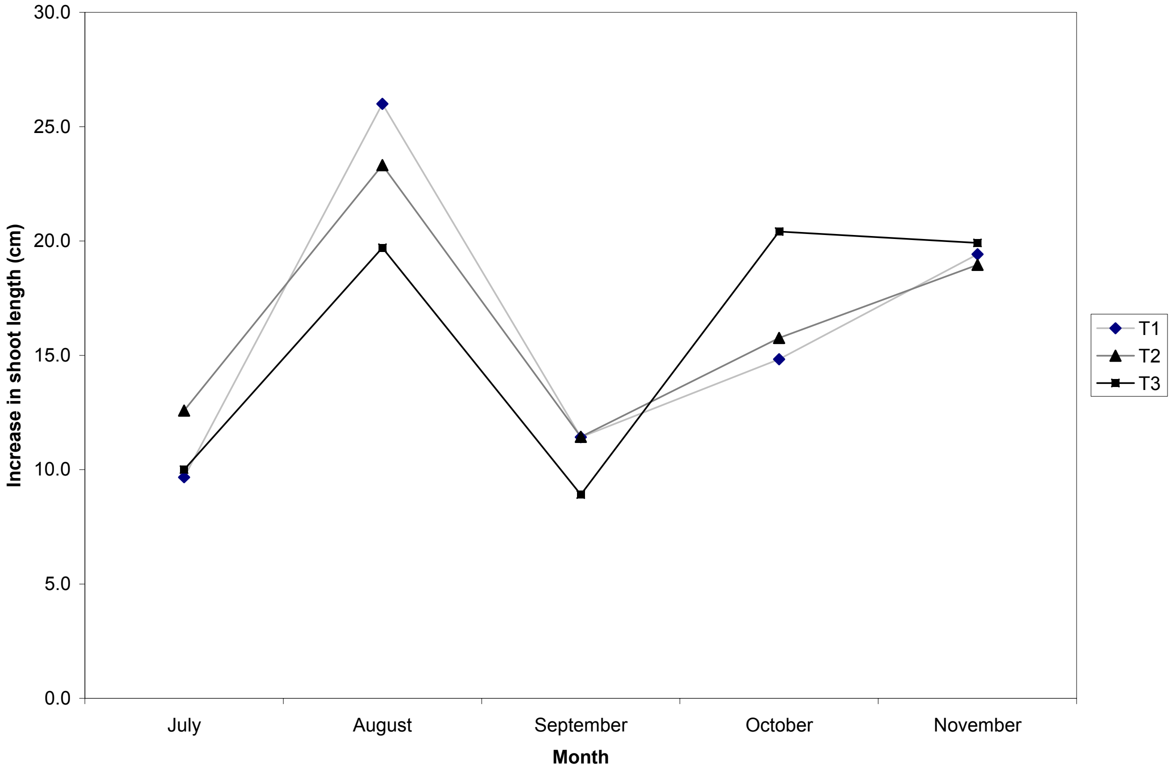

Fig. 3. Monthly increase in shoot length for the different treatments in 2005.

CONCLUSIONS

The results revealed that the effects of the RDI on the yield of citrus varied according to the level of deficit irrigation and the subsequent water stress. The use of 75% of crop evapotranspiration calculated from the FAO56-PM resulted in significantly higher crop yield than the 50% level with some increase in yield and water use efficiency than the full irrigation practice. Therefore, the use of this level of RDI early June to late November would maintain the total yield and save up to 19% of irrigation water amounts under the same experimental conditions. In this treatment, neither physical nor chemical lemon characteristics were significantly modified. In consequence, this treatment appears to be a promising irrigation strategy in areas with scarce water resources and similar to our study area, providing that a water stress coefficient of more than 0.75 is maintained.

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