Potential Water Saving in Avocado During the Summer Period

Levin, Adolfo Gabriel[1], Oshri Rinot[1] and Michael Noy[2]

[1]Northern R&D-Israel; [2]Israeli Extensions Office-Ministry of Agriculture.

Key words: avocado, deficit irrigation, yield, stem water potential

The effect of four different irrigation rates (100% [control], 125%, 75% and 50%) was tested during the summer period of 2010 on the avocado trees cv. Pinkerton in the north-east avocado cultivation area of Israel. The different water application rates were applied during the months of July and August. The standard water quantity was calculated according to the pan evaporation and crop factor agreed for the area. The water quantities applied during the experimental period were 5219 (100%), 6580 (125%), 3940 (75%) and 2740 (50%) m^3/ha. The treatments were tested in four replications in randomized blocks. Forty eight hours after the beginning of the experiment, the 50% treatment already showed significantly higher daily trunk shrinkage and a week later also significantly higher water trunk pressure, respective to the rest of the treatments. Results obtained in additional physiological tested parameters e.g. photosynthesis activity and stomata conductivity were similar for all 4 treatments. No significant differences in number of fruit per tree and total yield were observed among the treatments but the average fruit size and the fruit size distribution were significantly reduced in the most reduced irrigation treatment (50%). However, under mild irrigation stress (75% treatment), similar results were observed in all the tested parameters compared to the control and over-irrigated treatments. We conclude that potentially, 25% of the irrigation water can be saved during the period of maximum atmospheric water demand without negatively affecting the performance of the trees in the short and medium term.

Ahorro potencial de agua en Aguacate durante los meses de verano

El efecto de cuatro diferente cantidades de agua (100% [control], 125%, 75% y 50%) durante los meses de verano fue testeada en árboles de aguacate de la variedad Pinquerton durante el año 2010 en la zona de cultivo Nor-este de Israel. La aplicación de las diferentes cantidades de agua se concentró durante los meses de Julio y Agosto. La cantidad de riego básico (control) fue establecida en base a la evapotranspiración del lugar y el coeficiente de cultivo aceptado para la zona. Las cantidades de agua aplicadas durante el período del experimento fueron las siguientes: 5,219 (100%), 6580 (125%), 3940 (75%) y 2740 (50%) m^3 por hectárea. El diseño experimental fue de 4 replicas distribuidas al azar en 4 bloques. Cuarenta y ocho horas después del comienzo del experimento los valores de contracción diaria en el tronco ya eran significativamente más altos en el tratamiento deficitario máximo (50%) respecto al resto de los tratamientos; una semana más tarde la misma tendencia fue observada para la presión de agua en el tronco. Resultados similares fueron obtenidos en el resto de los parámetros fisiológicos medidos durante el período del experimento. En cuanto a los parámetros de producción, no se observo diferencia significativa en la producción ni tampoco en la cantidad de frutos por árbol. Sin embargo, el tamaño promedio del fruto y la distribución de los tamaños fueron significativamente reducidos en el tratamiento más deficitario. Ninguna diferencia en los parámetros medidos durante el experimento fue observado entre el tratamiento parcialmente deficitario (75%) y los tratamiento control y sobre irrigado (100 y 125% respectivamente). Nosotros concluimos que existe la posibilidad de ahorrar 25% de agua durante el periodo de máxima demanda de agua en el riego, sin afectar negativamente la producción de los árboles en el corto y mediano plazo.

Introduction

Forecast of water withdrawals on a global scale predict sharp increases in future demand to meet the needs of urban, industrial, and environmental sectors (Fereres and Soriano, 2007, p.147). Given that the single biggest water problem worldwide is scarcity (Jury and Vaux, 2005, p.15715), the amount of fresh water available for agricultural use is decreasing. Climatic changes, irregular rain seasons, human population increase, and fresh water contamination are among the main factors responsible for decreasing of available water for agriculture use. Irrigated agriculture is the primary user of diverted water globally, reaching a proportion that exceeds 70-80% of the total in the arid and semi-arid zone (Fereres and Soriano, 2007, p.147).

In many areas of Israel drought and scarce fresh water resources endanger the sustainability of irrigated agriculture. Among irrigated crops, fruit trees are of high economic value and can suffer the most from poor water management because of the carry-over effects into subsequent years. As a consequence, the future of the agriculture in many of the fruit cropping areas of the country depends on the effective use of fresh irrigation water for the commercial production of high quality crops. Efficient water use has become an important issue, on the one hand because the lack of available water resources, which in some areas is becoming more and more of a serious problem, and on the other ,because of the high price of fresh water for agricultural use (1.6 NIS per m^3=$ 0.46 US) . Since shortages and further price increases of fresh water are to be expected, there is a need to increase water use efficiency, either by improving genetic performance and horticultural practice, or by improving irrigation scheduling (Naor, 2006, p.339). Irrigation is a major horticultural practice in fruit crops in Israel, and is the most intensively practiced operation throughout the season. For this reason, in these areas, the optimization of water use and the efficiency of irrigation by means of deficit irrigation strategies that allow maximum yields whilst reducing water application are of great importance. In this sense, regulated deficit irrigation (RDI) may offer an approach to saving water in some fruit crops with minimal or no impact on yield and/or crop revenue (Chalmers, Mitchell and Van Heek., 1981, p.307; Domingo, Ruiz-Sánchez, Sánchez-Blanco and Torrecillas, 1996, p.115; Goldhamer, 1997, p. 14; Kang and Zhang, 2004, p. 2437) as well as improving water use efficiency (WUE).

The avocado (*Persea americana*) production area in Israel is mainly concentrated in the central-northern area of the country, from the coastal plane in the west to the Galilee Mountains and internal valleys (Jordan and Beit Shean) in the north-east. Of 6,500 hectares planted in Israel, around 1,500 are almost exclusively irrigated with fresh water. Israel produces between 80,000-90,000 tons of fruit per year with a revenue value estimated at 212,250,000 new Israeli shekels (NIS)=$ 60,642,857 US).

Over the past 10-15 years the water application rate in the main avocado growing areas of Israel has been between 800 and 1,200 mm per year, depending on the growing region, as well as the cultivar, with an average production between 12 to 15 tons per hectares, achieving in some cases even 40 tons per hectare (e.g. in cv. Pinkerton, Arad and Ettinger). Previously, the water application rates were aproximately600mm per year with an average yearly production of less than 10 ton per hectare. Not only has the increase in the water application rate had an important impact on the yield increment observed in the last 10 years, but also the water application technique has changed, e.g. from the weekly or even fortnightly water application previously practiced, to the daily application used today that has played an important role in this yield improvement.

Very little research worldwide in general, and in Israel, in particular, has been carried out regarding to water deficit irrigation in avocado trees and its consequence from the fruit quantity and quality point of view. To the best of our knowledge, this will be the first research study in avocado to evaluate the impact of deficit irrigation at the highest atmosphere water demand period (summer) on tree physiology, and fruit quantity and quality in the short, medium and long terms.

The aim of our research was to evaluate the effect of reduced/deficit drip irrigation at the most intensive irrigation period of the year (summer time) on fruit quality and fruit production in cv. Pinkerton. The development of a curve response to different irrigation levels during the summer season will provide the growers with a powerful decision tool for the development of irrigation strategies under conditions of water shortage.

Materials and Methods

Plant material and experimental design

The experiment was carried out during the summer of 2010 at the avocado grove of Kibbutz Maayan Baruch. The experimental plot designated 60/3 east, consisted of 34 rows, 7 m apart by 5.5 m between trees. In the plot, five rows of cv. Pinkerton alternated with one of cv. Ettinger as a pollenizer. The first and the last trees of the Pinkerton rows contained Ettinger cv.. The rootstock in the plot was a Mexican type, the trees were 30 years old and the agricultural practices in the plot were of high standard, recommended by the Israeli Agriculture Extension Office for Avocado Growers.

Four different water quantities were applied between the 24th of June and the11th of September 2010 and their effect on tree physiology, fruit quantity and fruit quality was evaluated. The evaluated treatments were as follows: 1) Control or 100% water application based on crop coefficient of evaporation pan, recommended by the Israeli Extension Service); 2) 50% of the recommended water application; 3) 75% of the recommended water application; and 4) 25% more than the recommended water application (125%). The experimental design was a randomized block with four replications. Each section consisted of 15-16 trees. The center 3 or 4 trees were used for experimental measurement and the others served as a buffer.

Water was supplied every day in two equal irrigation pulses. All the agricultural practices including the use of fertilizers, pruning, insect, disease and weeds management were carried out according to the recommendations of the Israeli Extension Office.

Physiological parameters

Leaf gas exchange and leaf temperature:
Net CO_2 assimilation rate (A_{net}), leaf stomatal conductance to water vapor (g_s) and leaf temperature (T_l) were measured twice a day, at morning and afternoon on a clear day, just before the end of the differential irrigation period. Measurements were conducted using a portable open-path gas exchange system (CIRAS-2, PP Systems USA). Mature leaves facing the sun at the time of the measurement were enclosed in the clear top leaf chamber. Care was taken not to affect the photosynthetic photon flux density (PPFD) reaching the leaf. The leaf chamber was supplied with air at ambient temperature and humidity containing 380 ppm of CO_2. After reaching stable readings of A_n g_s and T_l (usually about 1 minute in the chamber) the values were recorded.

Midday stem water potential:
Three leaves per replicate were selected from the inner part of the canopy, and were enclosed, while still attached, in plastic bags covered with aluminum foil. After a 90 minute equilibration period, the leaves were detached from the tree and their stem water potentials were determined immediately in the field with a pressure chamber (Ari-Mad, Kfar Charuv, Israel). The two measurements were averaged before statistical analysis.

Maximum daily shrinkage (MDS):
Trunk diameter fluctuations were measured throughout the experimental period in four trees per treatment (one per replicate), using a set of linear variable displacement transducers (LVDT) (model DE-1M, measurement linear range (LVDT stroke): 10 mm; Sensitivity: 0.2 V/mm, PhyTech Ltd, Rehovot, Israel) attached to the trunk. Sensors were placed 20-40cm aboveground, below the first branch. All external parts are manufactured using stainless steel, titanium and engineering polymers. Measurements were continuously taken and sent to a repeater by radio signal. The readings were downloaded daily to a central computer by connecting to a mobile modem. The repeater was programmed to auto-saved data every 60 minutes. Maximum daily trunk shrinkage was calculated as the difference between maximum and minimum daily trunk diameter.

Crop yield:
In 2010, the crop was picked from each experimental tree and each fruit individually weighed, and the yield per tree, average fruit size, number of fruit per tree and fruit size distribution was subjected to statistical analysis.

Flowering intensity:

In 2011, flowering intensity at full bloom was ranked between 0 for no flowers to 4 for the best flowering trees, i.e. those with all 1 year old branches carrying inflorescences.

Statistical analysis:
Effects were evaluated by analysis of variance (ANOVA) fololloweed by Multiple Comparison of Means, Tukey or Tukey-Kramer HSD (honestly significant difference) test (JMP-7, SAS Institute, Cary, NC, USA). Results are expressed as means ± standard errors (SE). Differences were assessed as significant at $P<0.05$.

Results

The cumulative irrigation applied in the control treatment during the experimental period was 523mm (Figure 1). The water quantities applied in the rest of the treatments were similar to the intended original values (Figure 1), designation of the treatments as below (Figure 1).

Figure 1. Cumulative irrigation applied to the four treatments during the experimental period. The water quantities are based on the water-meter dial installed in each treatment before the beginning of the experiment.

Effect of different water application rate on fruit development

The studied cultivar manifested a typical seasonal pattern of avocado fruit growth (sigmoid curve) with the highest growing ratio between fruit set and hardiness of the stone (Figure 2) reaching almost a plateau toward harvesting. The fruit growth curve was similar to the control in all stress and over irrigated treatments (Figure 2).

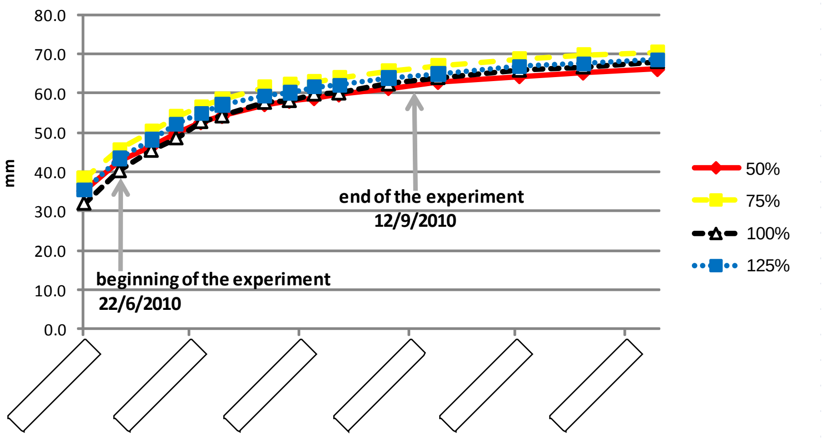

Figure 2. Avocado fruit growth, represented by fruit maximum diameter (mm). Each point is the average of 20 measurements.

Effect of different water application rate on trunk daily shrinkage

During all the experimental period, the most water stressed treatment (50%) showed higher MDS values with respect to the control and rest of the treatments (75 and 125%), but soon after the end of the experimental period, similar values were observed (Figure 3). The differences in MDS values between the 50% treatment and the rest were almost constant for the experimental period (23/6 to

11/9/2011), except for the day when 47ºC was recorded, where all four treatments, including the overwatered one (125%) clearly showed stress symptoms in their MDS values (Figure 3). However, the recovery was quicker for the better irrigated ones. The control treatment showed the highest daily trunk growth (Figure 4).

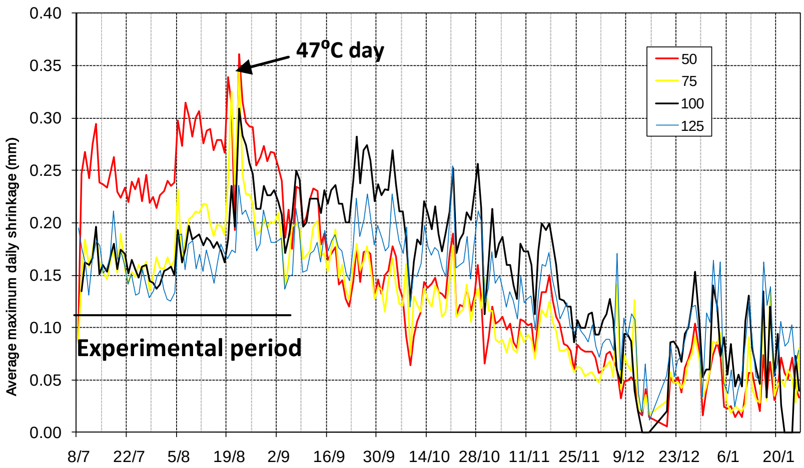

Figure 3. Average daily shrinkage during and after the experimental period of the four irrigation treatments. Each point is the average of four measurements.

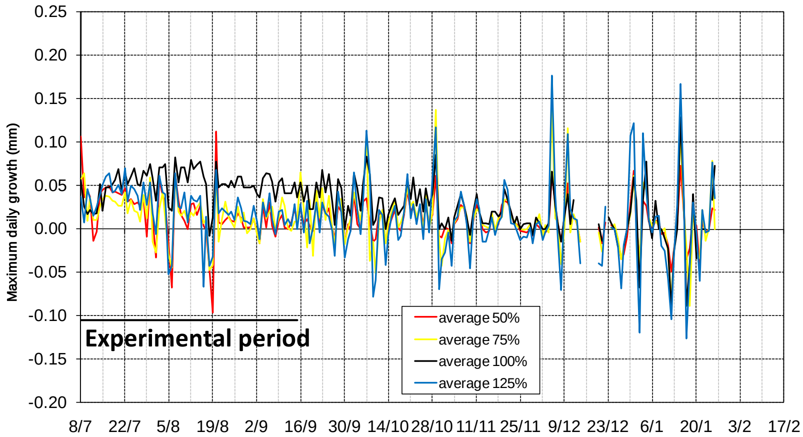

Figure 4. Maximum daily trunk growth of the four treatments. Each point is the mean of 4 measurements.

The net photosynthetic assimilation, *A*net, leaf diffusive conductance to water vapor, *g*s and leaf temperature (T_l) values at the end of the different irrigation withholding periods are shown in Figure 5. The overall results indicated that the water stressed irrigated treatment (50%) produced significant lower values on *A*net and *g*s (p<0.05), but produced similar values on T_l. However, such differences were observed only during the morning hours, but not during the afternoon, where the four treatments showed similar values in all the evaluated parameters. When the *g*s values obtained during the morning were compared with those obtained during the afternoon hours, the former were significantly higher in all the treatments. A similar but opposite tendency was observed for the T_l values (Figure5).The effect produced by the day time on the gs values, was also observed for the *A*net ones. However, no effect of day time on A_{net} values, on the most water stressed irrigation treatment was observed (Figure 5). The differences in Anet values among the treatments were paralleled by differences in gs of similar magnitude. Stomatal conductance was found to be closely correlated to Anet, independently of the irrigation treatment (Figure 5).

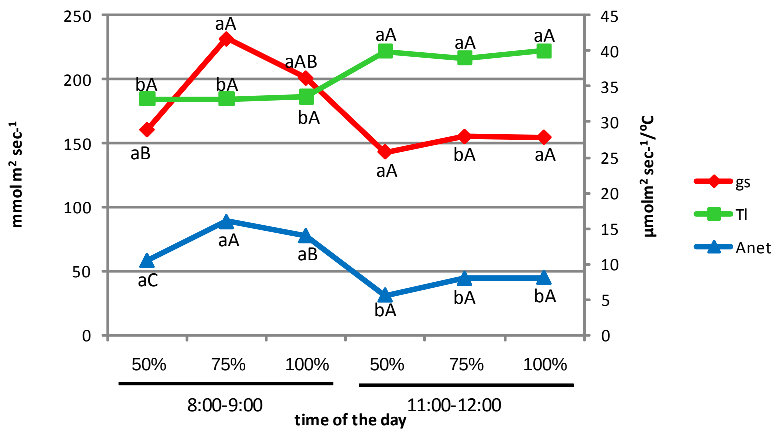

Figure 5. Effect of the different irrigation treatments on photosynthetic activity, stomata conductivity and leaf temperature during the early morning and midday. Each point is the mean of 3 measurements. For each treatment, values with different uppercase letters differ significantly at P< 0.05. For each time of the day, values with different lowercase letters differ significantly at P< 0.05.

Effect of different water application rates on stem water potential

When water stress was first implemented at the end of June, only the most severe irrigation treatment showed a marked decrease in water stem values, which became noticeable 15 days after water restriction. A minimum value of -1.0 MPa was recorded in this treatment just after the hottest day of the season (47ºC). No differences among the rest of the treatments were found. Following application of the different water rates, the recovery period for the most water-stressed treatments lasted almost two weeks (Figure 6).

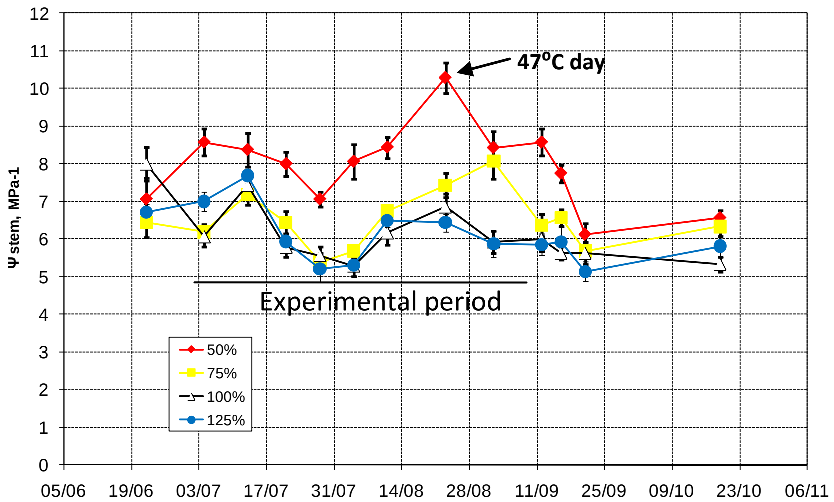

Figure 6. Midday stem water potential corresponding to the different irrigation treatments before, during and after the experimental period. Each symbol represents the mean of 4 measurements. Error bars indicate ± standard error.

Effect of different water application rate on crop yield

Crop yield and number of fruit per tree were not affected by the different irrigation level (Figure 7), however, the average fruit size and fruit size distribution were negatively affected by the most water stressed treatment. Interestingly, the mild water stressed irrigation treatment (75%) resulted in the highest average fruit size and the best fruit size distribution (Figs. 7 and 8).

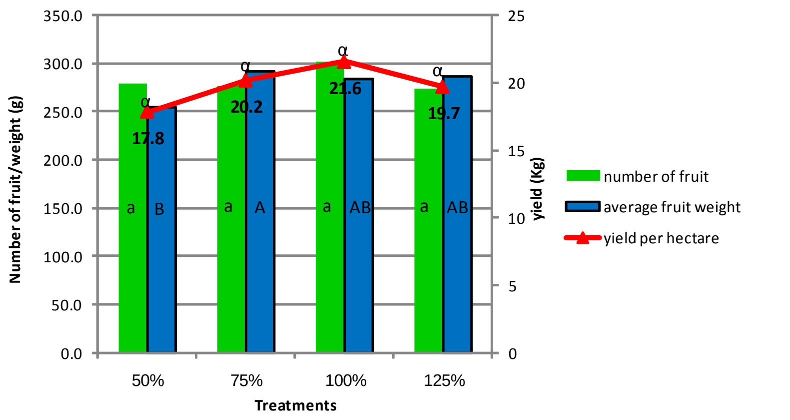

Figure 7. Fruit yield (kg per hectare), average fruit number per tree, and average fruit weight for the four irrigation treatments during the experimental period. Each point is the mean of 3 measurements. For average fruit weight, values with different uppercase letters differ significantly at $P < 0.05$. For average number of fruit, values with different lowercase letters differ significantly at $P < 0.05$. For yield per hectare, values with different Greek letters differ significantly at $P < 0.05$.

Figure 8. Effect of the different irrigation treatments on fruit size distribution at harvesting time. The fruit size classification is according to the factory standards. Each point is the mean of 4 measurements. Values with different uppercase letters differ significantly at $P < 0.05$.

Effect of different water application rates on bloom return in the following year

Bloom return, in the following season, was unaffected by the different water treatments (Figure 9). Similar flower intensity was observed not just at the treatment levels but also at an individual tree level.

Figure 9. Effect of the different irrigation treatments on flower intensity in the following season. Each point is the mean of 4 measurements. Values with different letters differ significantly at $P < 0.05$.

Discussion

To the best of our knowledge, the effect of restricting irrigation at the maximum atmospheric water demand period (summer) has not been previously reported for avocado trees. In this study, there was a significant difference in fruit average weight and fruit size distribution, but no significant difference in the number of fruit per plant or in yield per tree, observed between the different irrigation treatments. Flowering after the first year of the treatment was not affected even by the most deficit irrigation treatment. However, it is important to emphasize that by the end of the withholding irrigation period, the trees from the most reduced/water-stressed irrigation treatment (50%), showed clear symptoms of salinity damage of the old leaves with brownish edges and tip-burn, while vegetative development appeared to be retarded (data not shown). All the evaluated physiological parameters (photosynthesis, leaf stomatal conductance, midday stem water potential and trunk diameter fluctuations) were shown to be negatively affected by the most reduced irrigation treatment. However, the mild water-stressed irrigation treatment (75%) did not significantly affect any of the evaluated productive or physiological parameters. Interestingly, after the first year of the experiment, the over-irrigated treatment (125%) also did not show any advantage in any of the evaluated parameters compared to the control or even to the mild water-stressed (75%) treatment. When the economic value of each treatment was compared (data not shown), taking into account the cost of the saved water and the economic return of the fruit production (yield and fruit size distribution), the most economical treatment was that of 75%, resulting in a 5% more net value. Even though this is the first year of the experiment, and as a consequence it is too early to draw a management conclusion, there is no doubt that the results are encouraging, mainly for the potential use of the extra water rather than the economic value of the saved water itself.

Acknowledgements

The authors are grateful to the staff of Kibbutz Maayan Baruch for their invaluable assistance and to Menashe Levy for his technical support. This research was supported by the Northen R&D and the Israeli Avocado Fruit board.

References

1. Chalmers, D.J., Mitchell, P.D., and Van Heek L., 1981. Control of peach tree growth and productivity by regulated supply, tree density, and summer pruning. J. Amer. Soc. Hort. Sci. 106: 307-312.

2. Domingo, R., Ruiz-Sánchez, M.C., Sánchez-Blanco, M.J., and Torrecillas, A., 1996. Water relations, growth and yield of Fino lemon trees under regulated deficit irrigation. Irrig. Sci. 16: 115-123.

3. Fereres, E., and Soriano, A., 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 58 (2): 147-159.

4. Goldhamer, D.A., 1997. Regulated deficit irrigation of fruit and nut trees. Int. Water Irrig. Rev. 17: 14-19.

5. Jury, W.A., and Vaux Jr, H., 2005. The role of science in solving the world's emerging water problems. Proceedings of the National Academy of Sciences, USA. 102: 15715-15720.

6. Kang, S., and Zhang, J., 2004. Controlled alternate partial root-zone irrigation: its physiological consequence and impact on water use efficiency. J. Exp. Bot. Vol. 55, 407: 2437-2446.

7. Naor, A., 2006. Irrigation Scheduling of peach- Deficit irrigation at different phonological stages and water stress assessment. Acta Hort. 713: 339-349.