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Leaf Water Relations in a Flood-Irrigated Young Grapefruit Orchard: Implications for Irrigation of Different Soil Volumes

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ABSTRACT

The effect of flood and trickle irrigation treatments on plant water status was compared on four-year-old grapefruit trees (*Citrus paradisi* Macf.) on sour orange (*C. aurantium* L.) rootstock. Trickle irrigation treatments (2 emitters/tree; 6% of the orchard floor wetted) were scheduled according to:1.) 0.5 Class A pan evaporation adjusted to the ground area covered by tree canopies (TPAN) or 2.) tensiometer readings of -0.02 MPa at 30 cm soil depth (TTEN). Flood irrigation (100% of the orchard floor wetted) was initiated whenever the soil reached 50% available water depletion (FLOOD) within the top 60 cm soil layer. After a six month dry period with only 82 mm of rain, values of morning and afternoon leaf water potential (Ψ_L) were less negative in FLOOD than TPAN and TTEN trees on four dates during the first four weeks after flood irrigation in May. During the same period, however, stomatal conductance (g_s) of FLOOD trees was higher than TPAN and TTEN trees on only one date. No differences in (Ψ_L) and in (g_s) occured during a similar period after the second flood irrigation in September which followed a six month period of average percipitation with a total of 300 mm of rain. The soil in FLOOD plots reached 33% water depletion in the first four weeks after each flood irrigation. However, as the soil in FLOOD plots approched 50% soil water depletion, flood-irrigated trees had (Ψ_L) from 0.2 to 0.4 MPa more negative than trickle-irrigated trees in the afternoon but no differences occurred in the morning. Only on one date were decreased Ψ_L's accompanied by reductions in g_s. No differences in g_s and Ψ_L occurred between TPAN and TTEN treatments. Wetting 6% of the orchard floor with four-year-old grapefruit trees was adequate under average local precipitation conditions but was less effective than complete soil wetting in minimizing plant water stress under conditions of drought.

RESUMEN

Se comparó el efecto de los tratamientos de irrigación por goteo y por inundación en el estado hídrico de la planta en toronjo *(Citrus paradisi* Macf.) sobre patrones de naranjo agrio *(C. aurantium* L.). Los tratamientos de irrigación por goteo (2 emisores por árbol; 6% del suelo de la huerta húmedo) fueron programados de acuerdo a:1.) 0.5 de evaporación en el evaporímetro clase A ajustado a el área del suelo cubierta por las canopias de los árboles (TEVAP = TPAN) o 2.) las lecturas del tensiómetro de −0.02 MPa a 30 cm de profundidad del suelo (TTEN) El tratamiento de irrigación por inundación (100% del suelo de la huerta húmedo) se inició cada vez que el suelo alcanzó una disminución del agua accesible en un 50% dentro de la capa de los 60 cm superiores del suelo (INUNDACION = FLOOD). Después de un período seco de 6 meses con solo 82 mm de lluvia, los valores diurnos y vespertinos del potencial hídrico (Ψ_L) fueron menos negativos en los árboles de INUNDACION que en TEVAP y TTEN en cuatro fechas durante las primeras cuatro semanas después de la irrigación por inundación en mayo. Sin embargo, durante el mismo período, la conductancia estomática (g_s) en los árboles del tratamiento INUNDACION fué más alta que en los de TEVAP y TTEN en solamente una fecha. No hubo diferencias en el Ψ_L y en el g_s durante un período similar después de la segunda irrigación en septiembre la cual fué seguida de un período de seis meses de precipitación promedio con un total de 300 mm de lluvia. El suelo en las parcelas de INUNDACION alcanzó una disminución del agua de un 33% en las primeras cuatro semanas después de cada riego por inundación. Sin embargo, a medida que el suelo en las parcelas de INUNDACION alcanzó el 50% de agotamiento del agua, los árboles irrigados por inundación tuvieron durante la tarde Ψ_L de 0.2 a 0.4 MPa más negativos que los árboles irrigados por goteo aunque no se presentaron diferencias en la mañana. Solamente en una fecha se presentaron potenciales hídricos disminuidos acompañados por reducciones en g_s. No hubo diferencias en los Ψ_L y g_s entre los tratamientos de TEVAP y TTEN. El humedecimiento del 6% del suelo de la huerta con árboles de toronja de cuatro años de edad fué adecuado bajo las condiciones de precipitación promedio locales pero fué menos efectivo que el humedecimiento completo del suelo para minimizar el estrés hídrico de la planta bajo condiciones de sequía.

Flood irrigation, which is commonly used to irrigate citrus trees in the subtropical lower Rio Grande Valley of Texas, typically supplies water to the entire orchard floor. However, long intervals between waterings could result in considerable soil drying. In contrast, trickle irrigation can maintain close to optimal soil water content most of the time but only in a limited soil volume. Trickle irrigation improved growth of young citrus trees compared to other irrigation methods in Arizona (Roth et al., 1974; Rodney et al., 1977) but studies conducted in Israel (Moreshet et al., 1983, 1989; Bielorai et al., 1985) and Florida (Koo, 1978, 1985; Smajstrala and Koo, 1984) showed trickle irrigation having a detrimental effect on citrus growth and/or yield when not enough ground area was irrigated.

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In a recent study, no differences occured in growth and fruiting of flood - and trickle-irrigated young grapefruit trees (Swietlik, 1992). The amount of water applied with tricle irrigation did not limit growth and yield, but no determination was made whether the area of soil irrigated was adequate. Such determination can best be made by comparing the water status of trickle-irrigated trees to flood-irrigated trees (100% ground irrigated) when the latter experience near optimal soil moisture conditions a few days after irrigation.

Local studies have not been conducted to compare the water status of citrus trees under different irrigation systems and only a few such studies have been reported from other citrus-growing regions. No differences were found in leaf osmotic potential, water potential (Ψ_L), and stomatal conductance (g_s) between flood - and trickle-irrigated mature orange trees in Spain (Castel et al., 1989). Under the deep, sandy soil conditions in Florida, Ψ_L and g_s in mature grapefruit trees were directly related to the ground area covered by irrigation, i.e., they were highest under overhead sprinklers, intermediate under microsprinklers, and lowest under trickle irrigation (Zekri and Parsons, 1988). These differences occurred only after a long dry period indicating that with occasional rains there was significant water contributed from outside the irrigated zones. With 600 mm annual rainfall and ample root growth outside the irrigated zones (Swietlik, 1992), such a contribution may be important in south Texas but not likely in dry, arid climates where root growth is largely confined to the irrigated zones (Bielorai, 1985; Levin et al., 1980; Morshet et al., 1989; Roth and Gardner, 1985).

The purpose of this study was to compare Ψ_L and g_s of flood - and surface trickle-irrigated young grapefruit trees at various times following irrigation.

MATERIALS AND METHODS

The complete experiment was described elsewhere (Swietlik, 1992). Briefly, trees of 'Ray Ruby' grapefruit on sour orange rootstock were planted at 8.5 x 4.6 m spacing in 1986 in Raymondville sandy clay soil (fine, mixed, hyperthermic Vertic Calciustolls). One flood and two trickle irrigation treatments were initiated in 1986, four years before Ψ_L and g_s measurements were begun in 1989. In 1989, trickle irrigation was based on: 1) 0.5 of Class A pan evaporation adjusted to the mean ground area covered by tree canopies (TPAN), or 2) an average tensiometer reading of less than −0.02 MPa within the irrigated zone at 30 cm soil depth (TTEN). The average soil water potential in TPAN treatment was −0.012 MPa measured with tensiometers. Irrigation intervals in the TPAN and TTEN treatments, during rainless periods, ranged from 1 to 3 days in the summer to 14 and 21 days in the winter, respectively. For the TPAN treatment, irrigation intervals were determined using a procedure described by Karmeli and Keller (1975).

There were two turbulent flow emitters (Olson Irrigation Systems, Santee, Calif.) per tree (each delivering 3.8 liters/h) wetting ≈ 6% of the orchard floor. Flood irrigations (FLOOD) of 15 cm water each were applied to the whole orchard floor whenever depletion of available soil water, averaged over the 30 and 60 cm depth, reached 50% as indicated by a neutron probe (Model 503 DR, Campbell Pacific Nuclear, Pacheco, Calif.).

All trees used for Ψ_L and g_s measurements received 160 g N $tree^{-1}$ $year^{-1}$. With the trickle system, liquid commercial N−32 fertilizer ($NH_4 : NO_3 = 1 : 1$) was injected into the lines at 200 mg N/liter concentration from January to August whereas in the flood system it was split into January and May applications and distributed in a circle beneath the trees 2.5 times larger than the tree canopy before irrigation. The irrigation treatments were applied to five-tree plots (experimental units) replicated four times. However, two and four trees in each experimental unit were used for Ψ_L and g_s measurements, respectively.

Unless otherwise indicated, Ψ_L and g_s measurements were taken at one-week intervals from 1 June to 26 Oct., 1989. Leaf water potential and g_s were measured on fully expanded leaves, positioned in the middle of the latest flush of growth on the northwest side of the tree which was exposed to sun in the afternoon hours. Morning (0630-0930 HR) and afternoon (1330-1600 HR) measurements were taken on the same days with a pressure chamber (Scholander et al., 1965; Soil Moisture Equipment, Santa Barbara, Calif.) Each leaf was placed in a plastic bag lined with aluminum foil prior to detachment from a shoot (Turner, 1981). Measurements were replicated four times with the two trees per replication and one leaf per tree.

Measurements of g_s were conducted between 1330 and 1600 HR on the abaxial side of leaves with a LI-COR Steady State Porometer (Model LI 1600C, LI-COR, Lincoln, Nebr.). There were four replications with four trees per replication and one leaf per tree. Water vapor pressure deficit of air (VPD) was determined at the midpoint of each measurement period using a sling psychromenter and a psychrometric table.

A split-plot analysis of variance was used to evaluate the data. Irrigation treatments consituted main plots and repeated measurements over time (dates) constituted sub-plots. Irrigation method means on a given date were separated using single degree of freedom contrasts.

RESULTS AND DISCUSSION

The irrigation method x date interaction was significant for afternoon Ψ_L ($P=0.0001$). Leaf water potential was less negative in FLOOD than TPAN and TTEN trees during the first four weeks after the flood irrigation in May but the differences ceased to exist for the next two weeks (29 June - 6 July) (Fig. 1A). Leaf water potential was less negative in trickle - than flood-irrigated trees between 13 July and 5 Sept. except 3 and 17 Aug. when the differences were nullified by 85 mm rainfall on 25 - 27 July (Fig. 2A) and exceptionally low VPD of 1.2 kPa on 17 Aug., respectively. The rainfall re-wetted the top 60 cm of soil which had by then attained 50% water depletion (Fig. 2B).

The irrigation method x date interaction was significant for morning Ψ_L ($P=0.0001$). Leaf water potential was less negative in FLOOD than TTEN and TPAN trees during the first four weeks of the first flood irrigation cycle but no differences existed on the later measurement dates except 20 July when Ψ_L was more negative in FLOOD compared to TPAN and TTEN trees (Fig. 1B).

During the second flood irrigation cycle, afternoon Ψ_L was more negative in TPAN and TTEN trees compared to FLOOD trees on 28 September but the reverse was true on 21 and 26

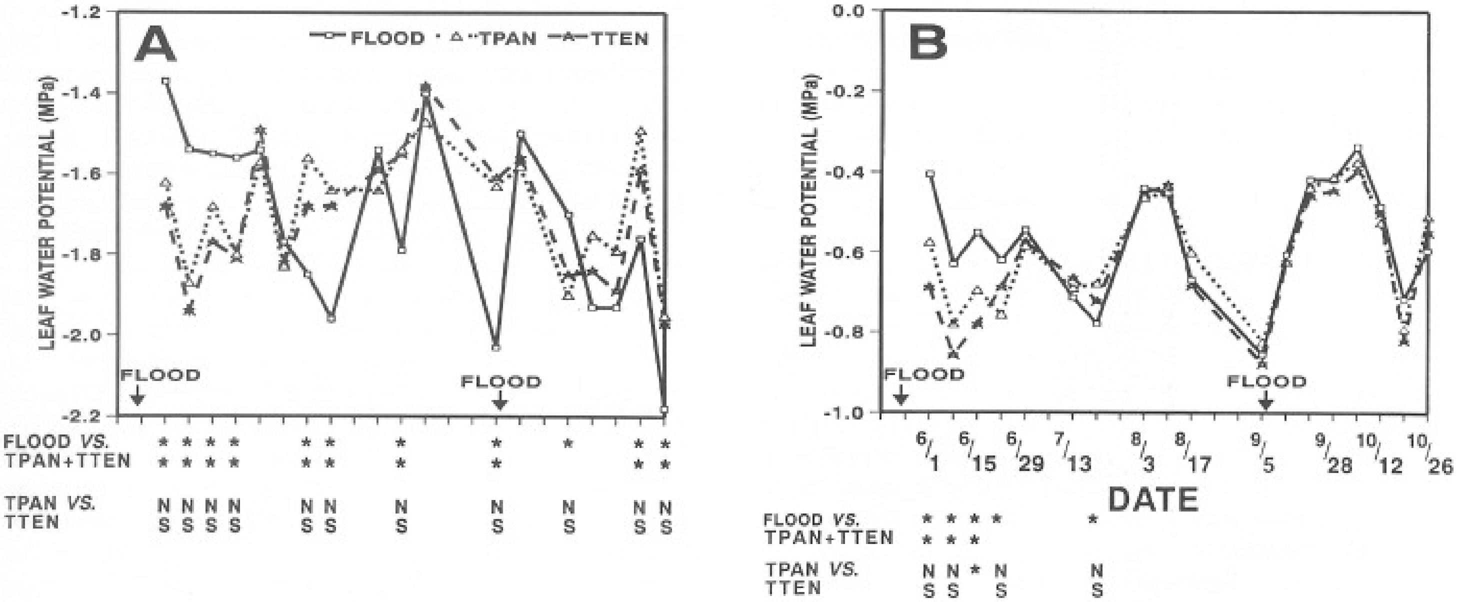

Fig. 1. (A) Afternoon and (B) morning leaf water potential of flood - and trickle-irrigated young 'Ray Ruby' grapefruit trees. The two irrigation contrasts given under each figure are for mean separations by dates (NS,**,* = not significant; 1%; or 5% significance respectively). The absence of statistical designations mark the dates when both contrasts were not significant. FLOOD = flood irrigation; TPAN = trickle irrigation according to 0.5 Class A pan; TTEN = trickle irrigation at soil water potential of −0.02 MPa at 30 cm depth.

October (Fig. 1A). No differences were found between the irrigation treatments in terms of morning Ψ_L during the second flood cycle (Fig. 1B).

Following the first irrigation, stomatal conductance was higher in FLOOD than TPAN and TTEN trees on 8 and 15 June but the opposite was true by the end of the first flood irrigation cycle on 5 Sept. (Table 1). No differences occurred on any of the remaining 14 dates of measurement (data not shown); the range of g_s values was 0.15 - 0.45 cm•s^{-1}.

The Ψ_L data for the initial four weeks of the first flood irrigation cycle indicated that 6% irrigation coverage under a trickle system was too small to maintain plant water status similar to that observed with 100% of the orchard floor wetted under a flood system (Fig. 1 A, B). Such was not the case, however, at the beginning of the second irrigation cycle. The different responses were most likely due to various amounts of soil water available outside the trickle irrigation zones. Only 82 mm of rain fell in six months prior to the first irrigation cycle but as much as 303 mm occurred during a similar period before the second irrigation cycle. Afternoon VPD and potential evapotranspiration (calculated as 0.8 Class A pan evaporation) were similar at the beginning of both irrigation cycles, i.e. on the average, 2.6 vs. 2.7 kPa and 0.71 vs. 0.63 cm/day, respectively.

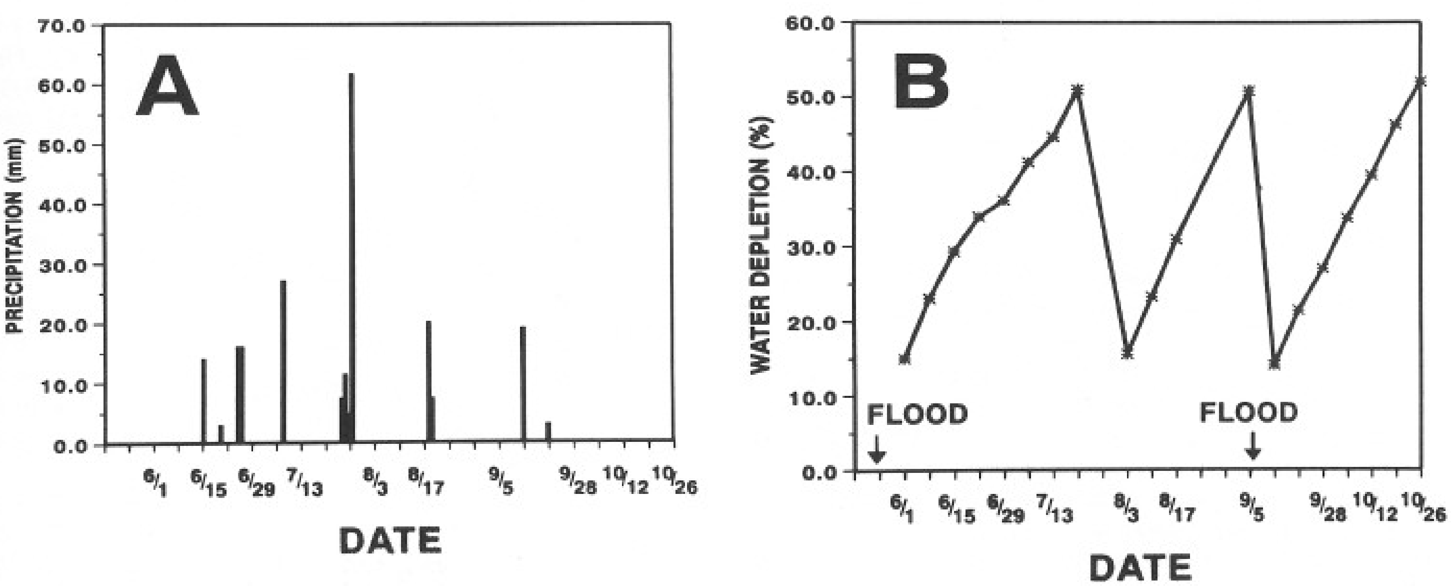

Fig. 2. (A) Precipitation, (B) soil water depletion in flood-irrigated plots averaged for the 30 and 60 cm soil depth.

Under local climatic conditions, roots of trickle-irrigated citrus trees occupied soil zones 2.3 m deep and 2.1 m away from the trunk four years after planting (Swietlik, 1992), and apparently trees were able to extract water stored well beyond the trickle-irrigated zones. Examination of the local precipitation data for the last 10 years revealed that droughts such as the one experienced prior to the first flood irrigation are rather uncommon, hence two emitters per four-year-old tree or younger should be adequate in most years. However, where long rainless periods are common, as in arid climates of California and Arizona, or in areas of course-textured soils with low water holding capacity as in Florida, additional trickle emitters or micro-jet sprayers may be needed. The importance of wetting a large enough soil volume has been emphasized by several studies conducted in mature fruit tree orchards (Bielorai, 1985; Koo, 1978, 1985; Moreshet, et al., 1983; Smajstrla and Koo, 1984; Zekri and Parsons, 1988).

This study shows that wetting 6% of the soil surface in a four-year-old grapefruit orchard is adequate under average local precipitation conditions. Under prolonged drought or in drier climates more emitters will likely be needed.

ACKNOWLEDGEMENT

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Table 1. Stomatal conductance in young 'Ray Ruby' grapefruit trees as affected by flood and trickle irrigation.

Treatment	Stomatal conductance ($cm \bullet s^{-1}$)	
	June 15	Sept. 5
FLOOD[z]	0.38	0.23
TPAN	0.29	0.34
TTEN	0.25	0.36
Contrasts:		
FLOOD vs TPAN and TTEN	**y	**
TPAN vs TTEN	NS	NS

[z]FLOOD = flood irrigation; TPAN = trickle irrigation based on 0.5 Class A pan; TTEN = trickle irrigation at soil water potential of −0.02 MPa at 30 cm depth. [y]NS; **; = not significant; significant at 1% level.

The advantage of trickle over flood irrigation in maintaining high was evident as the soil in FLOOD plots became drier, i.e., near the end of the interval between irrigations at 45% soil water depletion. The higher VPD in July-August (2.6-3.5 kPa, 17 Aug. excluded) than in October (1.6-2.7 kPa) explains why the difference in Ψ_L was more pronounced in the first vs. the second irrigation cycle. Only on one date (5 Sept.) was the decreased Ψ_L in FLOOD trees reflected in lowered g_s which corroborates an earlier report (Swietlik, 1992) showing no growth and yield differences between trickle - and flood-irrigated young grapefruit trees. Apparently stomata were not affected by Ψ_L of −2.1 MPa. Similarly, Zekri and Parsons (1988) and Syvertsen (1982) reported that g_s did not change much when Ψ_L was −2 MPa.

Under local conditions, water saving is the main benefit of trickle over flood irrigation (Leyden 1975; Swietlik, 1992). Further water savings may be realized through improved trickle irrigation scheduling as determined by TTEN treatment. About 419 kiloliters of water per hectare were applied in 1989 for TTEN vs. 995 for TPAN treatment without reducing g_s and afternoon Ψ_L and only occasionally reducing morning Ψ_L . As reported before, growth and yield of these trees did not differ (Swietlik, 1992).

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