Grapefruit Leaf and Fruit Growth in Response to Drip, Microsprinkler, and Overhead Sprinkler Irrigation

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Abstract. Fruit and vegetative growth of 21-year-old grapefruit (Citrus paradisi Macf.) trees on well-drained sandy soil was studied in central Florida. Drip, microsprinkler, and overhead sprinkler irrigation was compared at two levels of irrigation (150 and 450 mm-year⁻¹). Significant differences in leaf area, fruit size, fruit growth, new flush growth, and canopy area were found with different irrigation systems applying similar amounts of water. Growth was improved by irrigation even in a year of high rainfall (1410 mm). With mature trees, drip systems promoted the least growth, while overhead sprinkler systems promoted the most. Leaf fresh and dry weights and individual leaf areas in the overhead sprinkler treatments were 40% to 50% greater than in the drip or nonirrigated treatments, while specific leaf weight and leaf water content per unit dry weight were similar for all treatments. Final fruit size and tree canopy area were 9% to 20% greater in the overhead sprinkler treatments than in the corresponding drip or nonirrigated treatments. Responses to microsprinklers were generally intermediate between the overhead sprinkler and the drip treatments. Because of the low soil area coverage, applying water at the higher rate with the drip system did not improve growth as well as the overhead system at the lower rate. With mature grapefruit trees under central Florida conditions, systems providing greater soil area coverage gave better leaf and fruit growth than systems providing less soil coverage.

Materials and Methods

This study was carried out from Feb. 1982 to Mar. 1983 on ‘Marsh’ grapefruit on rough lemon [C. jambhiri (Lush.)] rootstock. Trees were planted in 1961 on Astatula fine sand (field capacity = 6.5%) at a 7.5 × 7.5 m spacing.

The experiment compared drip, microsprinkler, and overhead sprinkler irrigation at two water application levels (150 and 450 mm-year⁻¹). The experimental design consisted of seven treatments, including a nonirrigated control. Treatments were randomized in four blocks with four trees in each block. Treatments are abbreviated D, M, and O for drip, microsprinkler, and overhead sprinkler, respectively, 150 or 450 for the lower and higher application rates, and NI for the non-irrigated control. Timing of irrigation was determined by neutron probe readings and depended on both rainfall and type of irrigation system. The 150- and 450-mm treatments were irrigated at about 35% and 65% of field capacity, respectively. Because of the smaller emitters and area covered, the microsprinkler and drip systems were operated more frequently than the overhead irrigation system. The D450 and M450 systems were operated almost daily, while the D150 and M150 systems were operated about every 3 to 5 days. Depending on rainfall, the O150 and O450 systems were operated every 7 to 20 days. Actual amounts of water applied and estimated percolation are described by Koo (1985).

Undertree irrigation was managed by four drippers or two microsprinklers per tree that partially wetted the soil area under the trees. The overhead sprinklers wetted the entire orchard floor area. Percent coverage of the total ground area was 8%, 37%, and 100% for the D, M, and O irrigation systems, respectively. Deliveries for each dripper, microsprinkler, and overhead sprinkler were 4.5, 50, and 125 liters-h⁻¹, respectively. Area wetted by each dripper or microsprinkler was 1.2 m² and 10.7 m², respectively.

A sample of 80 mature, fully expanded leaves per treatment was taken for analysis three times during the year (Mar., Aug., and Dec. 1982). Leaves were collected in the early morning, measured with a LI-COR leaf area meter, and dried. Leaf dry weight was determined after oven-drying for 24 hr at 80°C. Water content and specific leaf weight (SLW = dry weight per unit leaf area) were calculated.
Fruit size and growth were determined by measuring fruit circumference with a graduated steel tape and converting circumference values to volume. A conversion equation was computed after collecting a sample of 25 fruit of varying size and measuring fruit circumference. Volume was measured by water displacement and the best-fitting relationship between circumference (C) and volume (V) was determined using regression analysis (Fig. 1). In June, 16 fruit per treatment (one fruit from each tree quadrant) were tagged and fruit growth measurements were taken in the morning every 3 to 4 weeks. The fruit were selected from the outside of the canopy at a height between 1 and 2 m from the soil. Monthly fruit growth rate and cumulative fruit growth were determined. In December, an additional 16 fruit per treatment were sampled and final fruit size was determined using a total of 32 fruit per treatment from eight trees.

The trees were hedged in two directions and topped in June 1980 and hedged in the north-south direction in Apr. 1982. Sixteen trees per treatment were measured and means of canopy area was determined. In Mar. 1983, tree canopy surface area was determined by measuring the height of the tree and its width in two directions. The following formula for a parabolic cone was used: 
\[ S = 2\pi W^2/3h^2 \left[ (W/16 + h^2/2) - (W/4)^3 \right], \]
where \( S \) = surface area, \( W \) = average width, and \( h \) = height of the tree (Koo, 1967).

New flush growth refers to the enlargement of new leaf and stem tissue. New flush growth was estimated by the method of J.C. Allen (personal communication) by measuring the length of new stem growth and adding that to the lengths of individual leaves on that stem. A total of 23 new summer flushes per treatment were sampled and tagged when they were \( \approx 20 \) mm long. Flush and total leaf lengths were measured after 1 week and 2 weeks of growth between 23 June to 29 July.

Analysis of variance (F test) was used to determine significant differences and Duncan’s multiple range test was employed for mean comparison at \( P < 0.05 \).

**Results**

*Leaf size.* Leaf fresh weight, dry weight, and area were significantly larger in the overhead sprinkler treatments than in the remaining treatments (Table 1). No significant differences in specific leaf weight or water content per unit of dry weight were found among treatments. Leaves of the NI treatment had the smallest area and the lowest fresh and dry weights. Trees irrigated with overhead sprinklers produced leaves that averaged 50% greater in fresh and dry weights and area than trees receiving no irrigation.

*Fruit growth.* In both June and December, the M450, O150, and O450 treatments produced significantly larger fruit than NI or D150 (Table 2). The overall monthly fruit growth rate was at its maximum in June and July, declined from September to October, and slowed greatly by December (Fig. 2). Fruit size was measured every month and there was no significant difference in fruit growth rate among treatments from June through December.

*New leaf flush and tree canopy growth.* Flush growth was measured over a 2-week period. NI trees produced significantly fewer leaves per flush and shorter stem and total leaf lengths than trees in M450 and O450 plots (Table 3). No flush length increase was detected between the first and the second week in the NI treatment. Flush measurements of trees in D150 did not differ significantly from those in NI. All treatments, except D150, produced significantly higher total leaf and stem lengths than the NI treatment.

Both overhead sprinkler treatments (O150 and O450) produced significantly larger tree canopy areas than NI, D150, D450, or M150. The canopy area for M450 was intermediate (Table 2).

**Discussion**

This study shows that irrigation is beneficial to grapefruit even in a high rainfall year (1410 mm). Overhead sprinklers gave better results than either microsprinkler or drip systems. M450 results were closer to overhead sprinkler results than were the drip treatments. The microsprinkler system was found to be much better than the drip system when applying similar amounts of water. Results from O150 were usually similar to O450. Growth response in D150 was usually not significantly different from the non-irrigated treatment.

One likely reason for the improved growth in the overhead sprinkler treatments is root distribution in relation to area wetted by the different irrigation systems. In arid regions, roots adapt to the relatively small soil volume wetted by the drippers (Levin et al., 1979). However, in Florida, where the rainfall normally is abundant, roots of mature trees are not confined to areas under the drippers or jets but are spread out near the surface of much of the orchard soil area; 60% to 90% of the roots are in the top 1 to 1.5 m of soil (Ford, 1952; W.S. Castle, personal communication). Thus, the amount of irrigated ground coverage is important in this rainy region. In another study, reduced yield under a drip system was attributed to temporary stresses developed in the main root system (Bielorai, 1977). Moreshet et al. (1983) obtained more and larger orange fruit with irrigation over the entire ground area as compared with its restriction to 40% of the surface area. The poorer results in the partially irrigated plots were attributed to water stress caused by dessication of new roots developed in the nonirrigated soil volume after wetting by rain.

During some non-rainy periods, leaf water potentials in the D150 and NI treatments were significantly lower than in the O150 or O450 treatments (Zekri and Parsons, 1988). This greater stress is the most likely cause of the lower growth in the drip treatments.

Vegetative growth is particularly sensitive to water deficit. There is a close relationship between moisture status and shoot growth, leaf expansion, and organ enlargement (Leopold and Kriedemann, 1975). Leaf extension is particularly sensitive to
than those under drip or microsprinkler irrigation (R.C.J. Koo, 1985). Our results with citrus are similar to those on pear. Stress between March and July has been shown to reduce early fruit growth of oranges and grapefruit (Hilgeman, 1977). In our study, the rainfall in the April–May period was below average, and irrigation significantly affected fruit size by June. On the other hand, the rainfall from June through September was above average and irrigation effects were reduced. The NI treatments by December.

Increased citrus fruit size in response to higher irrigation levels has been observed by many workers (Erickson and Richards, 1955; Koo et al., 1974; Yagev, 1977). Reduction in soil moisture decreased fruit growth rate (Hilgeman, 1977; Lombard et al., 1965). The daily volume increase in oranges is affected by soil water tension (Hales et al., 1968; Halma, 1934). Hence, several workers have suggested the use of fruit growth rate as an index for irrigation needs in citrus and apple (Assaf et al., 1982; Furr and Taylor, 1939).

Data on pear fruit growth (Aldrich et al., 1940) have shown that trees subjected to moisture stress early in the fruiting season had abnormally low rates of fruit enlargement. Even though fruit growth rates approached the maximum rate following an irrigation or rainfall, the loss of cumulative size was never regained. Our results with citrus are similar to those on pear.

Trees under overhead sprinklers produced more fruit per tree than those under drip or microsprinkler irrigation (R.C.J. Koo, personal communication) and had higher yields (Koo, 1985). The overhead treatment also produced larger fruit. It has been shown that citrus yield and weight per fruit were more consistently affected by irrigation than the number of fruit per tree (Wiegand and Swanson, 1982a).

In an arid region, trickle-irrigated apple trees produced less vegetative growth, as indicated by trunk area, than sprinkler-irrigated trees (Proebsting et al., 1984). Several studies with citrus have shown that irrigation can significantly increase tree size (Hilgeman and Sharp, 1970; Koo, 1979; Levy et al., 1978; Weigand and Swanson, 1982b). Increase in tree canopy area is important because greater tree size usually results in greater fruit yield (Koo, 1979; Levy et al., 1978).

Growth with micro-irrigation presumably was not as great as with the other treatments because not all of the water applied through the drip and microsprinkler systems was captured by the trees. In Florida’s sandy soils, each dripper wets an area about 1.2 m across and there is little lateral movement of water. Applying more water to a small area causes greater percolation loss. With D450, percolation was about twice as great as with the other treatments because not all of the water applied through the drip system (D450) could not promote growth as well as the overhead system at the lower rate (O150). Because of the greater coverage, trees used water more effectively from the overhead system.

Yield was not taken in this particular study, but yield was averaged over all irrigation systems and rates in a related study.
Table 3. Summer flush growth of grapefruit foliage in response to drip (D), microsprinkler (M), and overhead sprinkler (O) irrigation (average of 23 flushes per treatment).

<table>
<thead>
<tr>
<th>Growth measurements</th>
<th>NI</th>
<th>D150</th>
<th>D450</th>
<th>M150</th>
<th>M450</th>
<th>O150</th>
<th>O450</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf number per flush</td>
<td>6.5</td>
<td>7.3</td>
<td>8.6</td>
<td>8.3</td>
<td>10.2</td>
<td>8.8</td>
<td>9.2</td>
</tr>
<tr>
<td>New stem length (mm)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At end of first week</td>
<td>72</td>
<td>85</td>
<td>106</td>
<td>100</td>
<td>134</td>
<td>105</td>
<td>117</td>
</tr>
<tr>
<td>At end of second week</td>
<td>72</td>
<td>86</td>
<td>110</td>
<td>103</td>
<td>140</td>
<td>108</td>
<td>118</td>
</tr>
<tr>
<td>Total leaf length (mm)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At end of first week</td>
<td>400</td>
<td>482</td>
<td>536</td>
<td>554</td>
<td>730</td>
<td>566</td>
<td>629</td>
</tr>
<tr>
<td>At end of second week</td>
<td>523</td>
<td>644</td>
<td>714</td>
<td>734</td>
<td>922</td>
<td>755</td>
<td>847</td>
</tr>
<tr>
<td>Total leaf + stem length (mm)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At end of first week</td>
<td>472</td>
<td>567</td>
<td>642</td>
<td>654</td>
<td>864</td>
<td>671</td>
<td>746</td>
</tr>
<tr>
<td>At end of second week</td>
<td>595</td>
<td>730</td>
<td>824</td>
<td>837</td>
<td>1062</td>
<td>863</td>
<td>965</td>
</tr>
</tbody>
</table>

*Mean separation within rows by Duncan's multiple range test, 5% level.

NI is the nonirrigated treatment and 150 and 450 are the two levels of irrigation expressed in mm-year⁻¹.

Both results and those of Koo (1985) emphasize the importance of the area wetted by irrigation in a region with sandy soil. Greater area coverage by different spray jet emitters gave higher citrus production than drippers in sandy soils (Koo and Smaistrla, 1984; Koo, 1985). Poor results were also obtained with drip irrigation in comparison with sprinklers on lighter soils due to the limited horizontal distribution of water (Rawitz and Hillel, 1974). Drip irrigation was found to be satisfactory in young orchards, but not always successful in mature citrus plantations (Bielorai, 1978).

In summary, with mature trees in sandy soils, overhead sprinkler irrigation, which covered 100% of the orchard floor, promoted more leaf, fruit, flush, and tree canopy growth than drip or microsprinkler irrigation. Reduced growth in the drip treatments was probably due to the fact that a large proportion of the root system located outside the wetted zone had inadequate soil water during non-rainy periods. The overhead system supplied water to essentially all the roots, while the micro-irrigation systems (D and M) supplied water to fewer roots.

**Literature Cited**


