CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

FINAL REPORT

Project Title: Citrus Yield and Fruit Size Can Be Sustained for Trees Irrigated with 25% or 50% Less Water by Supplementing Tree Nutrition with Foliar Fertilization – *Comparison of Conventional Irrigation and Partial Root Zone Drying at the Same Reduced Irrigation Rates Supplemented with Equal Foliar Fertilization*

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PROJECT LEADER
Carol J. Lovatt
Professor of Plant Physiology
Dept. of Botany and Plant Sciences
University of California
Riverside, CA 92521-0124
Phone: (951) 827-4663
FAX: (951) 827-4437
E-mail: <carol.lovatt@ucr.edu>

PROJECT LEADER
Ben Faber
UC Farm Advisor
Coop. Ext. Ventura County
669 County Square Drive, #100
Ventura, CA 93003
Phone: (805) 645-1451
FAX: (805) 645-1474
E-mail: <bafaber@ucdavis.edu>

COOPERATOR
Stephen Cockerham
Superintendent of Agricultural Operations
Agricultural Operations
1060 Martin Luther King Blvd.
Riverside, CA 92521

COOPERATOR
Philip A. Roberts
Professor of Nematology and Nematologist
Chair, UCR Agricultural Operations Policy Committee
Dept. of Nematology
University of California
Riverside, CA 92521

CITRUS RESEARCH SITE
Riverside, CA
The Citrus Research Center and
Agricultural Experiment Station
University of California
1060 Martin Luther King Blvd.

STATEMENT OF OBJECTIVE:

The objective of this research was to determine the feasibility of using partial root zone drying (PRD), to reduce the amount of water and irrigation-applied fertilizer used to produce citrus, combined with foliar fertilization to sustain the yield of commercially valuable large-size fruit and, thus, increase grower net income. Specific objectives: (1) to reduce annual water use in a commercial navel orange orchard by alternately wetting and drying the root zone on two sides of the tree using irrigation rates that are 25% and 50% less than the well-watered control under conventional irrigation (CI); (2) to compare the PRD treatments with CI at the reduced rates (CI-

RR) of 25% and 50% less than the well-watered control; (3) to determine the effect of supplementing PRD and CI-RR treatments with foliar fertilization (especially N and K to ensure adequate nutrition to sustain yields of large-size fruit) on yield, fruit size and quality and on return bloom for two crop-years compared to the well-watered control trees receiving soil (irrigation-applied) fertilization; and (4) to provide a cost:benefit analysis of the results to the growers.

PROJECT OBJECTIVES:

1. To reduce annual water use in a commercial navel orange orchard by alternately wetting and drying the root zone on two sides of the tree using irrigation rates, which are 25% and 50% less than the well-watered control under conventional irrigation (CI).

2. To compare the PRD treatments with CI at the reduced rates (CI-RR) of 25% and 50% less than the well-watered control.

3. To determine the effect of supplementing PRD and CI-RR treatments with foliar fertilization (especially N and K to ensure adequate nutrition to sustain yields of large-size fruit) on yield, fruit size and quality and on return bloom for two crop-years compared to well-watered control trees receiving soil fertilization.

4. To provide a cost:benefit analysis of the results to the growers.

EXECUTIVE SUMMARY:

1. Problem: With San Joaquin Valley irrigation water nearing $200 per acre-foot and growers possibly having to produce their crops with 30% less water, our research goal was to meet the challenge of California's water shortage crisis by demonstrating that yield of commercially valuable large fruit can be sustained despite irrigating citrus trees with 25% or 50% less water. **2. Project objective.** The research presented herein tested the feasibility of using partial root zone drying (PRD), to reduce the amount of water and irrigation-applied fertilizer used to produce citrus, combined with foliar fertilization to sustain the yield of commercially valuable large-size fruit and, thus, increase grower net income. **a. Specific objectives:** (1) to reduce annual water use in a commercial navel orange orchard by alternately wetting and drying the root zone on two sides of the tree using irrigation rates that are 25% and 50% less than the well-watered control under conventional irrigation (CI); (2) to compare the PRD treatments with CI at the reduced rates (CI-RR) of 25% and 50% less than the well-watered control; (3) to determine the effect of supplementing PRD and CI-RR treatments with foliar fertilization (especially N and K to ensure adequate nutrition) on yield, fruit size and quality; and (4) to provide a cost:benefit analysis of the results to the growers. A prior Prosser Trust-funded project comparing PRD and CI-RR enabled us to install the irrigation system and purchase soil moisture meters, a significant savings to this proposal, and to collect 2 years of informative yield data, on which we based the CDFA project. We conducted 2 years of research with support from the CDFA to determine whether 'Washington' navel orange trees could be irrigated with 25% or 50% less water with no negative impact on yield of valuable large fruit and grower income when PRD and/or CI-RR was combined with foliar fertilization (Year 1) and also with an irrigation-applied cytokinin (Year 2). **b. Research approach.** The experiment, a randomized complete block with five irrigation treatments and five replications of each treatment, was carried out in a commercial navel orchard at UCR. Each treatment was applied to three parallel rows, with the internal three trees of five consecutive trees in the middle row of the three rows used for data collection. There are two buffer rows between data rows and two buffer trees between data trees within a row. Irrigation treatments were: (1) well-watered control (based on evaporative demand) – each side of the tree within the row had an emitter so that both sides of the tree were wet; (2) PRD at 25% and (3) 50% less water than the control – each side of the five trees in a row had an emitter, which alternated delivery to one side of the tree and then the other; (4) CI-RR at 25% and (5) 50% less water than the control – each side of the five trees within the row had an emitter so that both sides of the tree were irrigated. One Bermad flow meter per treatment controlled the irrigation rate. Pressure regulators ensured accurate delivery. The emitters were Bowsmith fan-jets. Soil moisture content was measured at depths of 30 and 60 cm on each side of a data tree in each treatment for all five replications using Watermark Soil Moisture meters. All trees were irrigated when soil moisture was at -30 cb at 30 cm for the well-watered control trees. Application amounts were based on campus-based CIMIS ET calculations. Fertilization rates were based on standard leaf and soil analyses. For the well-watered control, annual fertilizer amounts were divided into eight applications made March through October. Trees in PRD and CI-RR treatments received reduced soil (irrigation-applied) fertilizer proportional to reduced irrigation amount and foliar fertilizer as urea-N (50 lb low biuret urea/acre, 46% N, 0.25% biuret) in mid-January to increase floral intensity, potassium nitrate (25 lb KNO_3/acre) in February and again at 75% petal fall (end of April-early May) to increase fruit size and reduce crease, and urea-N (50 lb urea/acre) at maximum peel thickness (early to mid-July) to increase fruit size. Our treatments were designed to not only increase water-use efficiency, but also nutrient-use efficiency. In the second year of the research, trees in all reduced irrigation treatments received 75% less water than the well-watered control trees and two treatments, the Year 1 CI-RR-50% and PRD-50%, received the cytokinin 6-benzyladenine (6-BA) two times a week through the irrigation from 1 August to 31 October for a total of 4 g 6-BA/tree. **c. Results.** Results obtained in Year 1 provided clear evidence that fruit of the ‘Washington’ navel orange were very sensitive barometers of irrigation rate. Reductions in irrigation amount that never exceed 23% less than the well-watered control and resulted in only 16% less water for the entire year (Jan. to harvest in Nov.) reduced total yield as kilograms per tree and reduced the kilograms and number of fruit per tree in all marketable size categories, especially larger, more commercially valuable fruit of packing carton sizes 88, 72 and 56. Further reductions in irrigation rate exacerbated these problems. Foliar fertilization did not compensate for reduced irrigation rates during Year 1. Thus, in Year 2 to maintain the yield of commercially valuable large fruit (packing carton sizes 88, 72 and 56), treated trees were all irrigated at 75% of the well-watered control and received foliar-applied fertilizer, but half of the treatments also received a total 4 g of the cytokinin 6-benzyladenine per tree in small doses applied two times a week through the irrigation from 1 August until October 31. Reducing the irrigation rate as much as 24% to 48% from January to March with an average of 25% to 30% less water than the well-watered control with or without 6-benzyladenine did not reduce total yield in Year 2, but produced significantly fewer commercially valuable fruit (packing carton sizes 88, 72 and 56). The effect of reduced irrigation rate on fruit size was not mitigated by foliar fertilization alone or when combined with 6-benzyladenine. The cost:benefit analysis indicated that income lost due to the reduced yield of commercially valuable large fruit was not offset by the lower cost of the reduced amount of water applied per acre for any of the reduced irrigation treatments. **d. Criteria for success.** A net increase in grower income resulting from a PRD and/or CI-RR treatment plus foliar fertilization that saves 25% or 50% of the irrigation volume with an increase or no reduction in yield of commercially valuable large fruit would have indicated success. The research was not a success. Navel orange fruit growth (fruit size) proved highly sensitive to even minimal water deficit. **3. The target audience** is the navel orange growers of California (> 124,385 irrigated acres), who have seen their production costs (especially water and fertilizer) increase dramatically and their crop value decline. Producers of other crops will gain knowledge from the results of this research. The data from this project should be valuable to citrus growers for documenting the amount of water needed to sustain crop production and California's citrus industry should restrictions be proposed.

WORK DESCRIPTION:

The design was a randomized complete block with five irrigation treatments and five replications of each treatment in a commercial navel orchard at the University of California-Riverside Citrus Research Center and Agricultural Experiment Station. Each treatment was applied to three parallel rows and the internal three trees of five consecutive trees in the middle row of the three rows were used for data collection. Thus, there were two buffer rows between data rows and two buffer trees within a row between data trees for different treatments. The irrigation treatments were: (1) well-watered control (based on evaporative demand) – trees had an emitter on each side of the five trees within the row so that both sides of the tree were watered; (2) 25% PRD – 25% less water than well-watered control – trees had an emitter on each side of the five trees within the row, which alternated in delivery of water to one side of the tree and then the other; (3) 50% PRD – 50% less water than well-watered control – trees had an emitter on each side of the five trees within the row that alternated in delivery to one side of the tree and then the other; (4) 25% CI-RR – 25% less water than well-watered control – trees had an emitter on each side of the fives trees within the row so that both sides of the tree were watered; and (5) 50% CI-RR – 50% less water than well-watered control – trees had an emitter on each side of the five trees within the row so that both sides of the tree were watered. One Bermad flow meter was used per treatment to control the rate of irrigation. Pressure regulators were used to maintain pressure to ensure an accurate rate of delivery. The emitters were Bowsmith Fan Jets. Evaporative demand based on CIMIS was used to set the amount of water to be applied to the well-watered control trees. PRD- and CI-RR-treated trees received that amount reduced as specified by the treatment. Soil moisture content was measured at depths of 30 and 60 cm on each side of a PRD data tree in each treatment and one in the middle for each CI data tree in each treatment for five replications using Watermark Soil Moisture meters. All treatments were irrigated when soil moisture content was –30 cb at a depth of 30 cm for the well-watered control trees. Irrigation amounts were based on UCR campus-based CIMIS ET calculations using current and historic weather data to project the irrigation needs for the well-watered control trees for the up-coming three or four days, respectively. This approach was an improvement over simply replacing the water the trees used in the past three or four days – an approach that only by coincidence meets the actual water needs of the trees. Since fruit growth was a sensitive indicator of tree water status and final fruit size was critical to the success of this research, we measured fruit transverse diameter monthly from 1 July through 1 October. Trees in PRD and CI-RR treatments received reduced soil (irrigation-applied) fertilizer proportional to reduced irrigation amount and foliar fertilizer as urea-N (50 lb low biuret urea/acre, 46% N, 0.25% biuret) in mid-January to increase floral intensity, potassium nitrate (25 lb KNO_3/acre) in February and again at 75% petal fall (end of April-early May) to increase fruit size and reduce crease, and urea-N (50 lb urea/acre) at maximum peel thickness (early to mid-July) to increase fruit size. Our treatments were designed to not only increase water-use efficiency, but also nutrient-use efficiency. In September, 40 spring flush leaves from non-fruiting terminals were collected from around each data tree at a height of 1.5 m. Samples were immediately stored on ice, taken to UCR, washed thoroughly, oven-dried at 60 ºC, ground to pass through a 40-mesh screen and sent to the UC-

DANR Laboratory at UC-Davis for analysis. Tissue was analyzed for N, S, P, K, Mg, Ca, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. At harvest, yield (kg and fruit number per tree) and fruit size distribution (pack out) were determined using an in-field fruit sizer. A subsample of 10 fruit per tree were used to determine fruit weight, juice weight, percent juice, juice volume, total soluble solids, percent acid and solids to acid ratio by the UC Lindcove REC Analytical Laboratory. Each year, treatment effects were determined by ANOVA ($P = 0.05$). A cost:benefit analysis was performed to determine the efficacy of reducing irrigation in general and by PRD in particular. Crop value was calculated using the kilograms per tree and the following prices per 40-lb carton: packing carton size 48 - US$ 20, 56 - US$20, 72 - US$16, 88 - US$13, 113 - US$ 11, 138 - US$9 and < 138 - US$0 (Redlands-Foothill Packinghouse, November 2011, used for Years 1 and 2). Water costs at US$200/acre-foot and US$129/acre-foot were calculated using the actual gallons applied per treatment adjusted to an acre. The cost of irrigation-applied fertilizer (80 lb UN32 @ US$37/acre)(http://coststudies.ucdavis.edu/files/orangevs2009.pdf) was reduced by the percent of the reduced irrigation rate. Well-watered control trees also received foliar-applied urea (30 lb low-biuret urea/acre, 46% N, 0.25% biuret) costing US$27/acre (http://coststudies.ucdavis.edu/files/orangevs2009.pdf). The cost of two applications foliar-applied urea (50 lb low biuret urea/acre, 46% N, 0.25% biuret) and potassium nitrate (25 lb KNO_3/acre), US$91/acre and US$35.20, respectively, was added to the expenses for trees in the reduced irrigation treatments. The cost of foliar-application was not included; the cost of the 6-benmzyladenine was not included. The cost of the extra-irrigation line for the PRD treatments was not included.

YEAR 1 – TASK 1:

Month of initiation: 1/10   Month of completion 1/11

Subtask 1.1: Laid out experiment, selected trees of similar size, crop load and health, and labeled data trees.

Subtask 1.1 initiated and completed in February 2010

Subtask 1.2: Monitored soil moisture content, at -30 cb at 30 cm soil depth, determined evaporative demand based on CIMIS and calculated the amount of water to be applied to the well-watered control or reduced irrigation treatments, and irrigated the trees.

Subtask 1.2 initiated in January 2010 and completed in December 2010

Subtask 1.3: Monitored tree phenology, applied foliar fertilizer treatments at proper stage of tree phenology, measured fruit diameter and peel thickness, collected leaf samples. Washed, dried, ground leaf samples and sent them to the UC-DANR Laboratory for analysis.

Subtask 1.3 initiated in January 2010 and completed in September 2010; mid-year report sent July 2010

Subtask 1.4: Harvested mature crop and obtained all yield data, including fruit quality data (samples taken to the Lindcove REC Analytical Lab).

Subtask 1.4 initiated in January 2011 and completed in January 2011

Subtask 1.5: Statistically analyzed data.

Subtask 1.5 initiated in October 2010 and completed in January 2011

Subtask 1.6: Prepared and sent annual report to FREP.

Subtask 1.6 initiated in December 2010 and completed in January 2011

YEAR 2 – TASK 2:

Month of initiation: 1/11 Month of completion 1/12

Subtask 2.1: Monitored soil moisture content, at -30 cb at 30 cm soil depth, determined evaporative demand based on CIMIS and calculated the amount of water to be applied to the well-watered control or reduced irrigation treatments, and irrigated the trees.

Subtask 2.1 initiated in January 2011 and completed in December 2011

Subtask 2.2: Monitored soil moisture content, at -30 cb at 30 cm soil depth for a treatment, determined evaporative demand based on CIMIS and calculated the amount of water to be applied to the well-watered control or reduced irrigation treatments, and irrigated the trees.

Subtask 2.2 initiated in January 2011 and completed in December 2011

Subtask 2.3: Monitored tree phenology, applied foliar fertilizer treatments at proper stage of tree phenology, measured fruit diameter, collected leaf samples. Washed, dried, ground leaf samples and sent to the UC-DANR l Laboratory for analysis.

Subtask 2.3 initiated in January 2011 and completed in September 2011; mid-year report was submitted in July 2011

Subtask 2.4: Harvested mature crop and obtained all yield data, including fruit quality data (samples taken to the Lindcove REC Analytical Laboratory).

Subtask 2.4 initiated in December 2011 and completed in January 2012

Subtask 2.5: Statistically analyzed all data.

Subtask 2.5 initiated in October 2011 and completed in January 2012

Subtask 2.6: Prepared and sent annual report to FREP.

Subtask 2.6 initiated in December 2011 and completed in January 2012

RESULTS, DISCUSSION AND CONCLUSIONS:

RESULTS

Irrigation was twice a week on Tuesday and Friday in Year 1 and Monday and Thursday in Year 2. Irrigation amounts were based on UCR campus-based CIMIS ET calculations using current and historic weather data to project the irrigation needs for the well-watered control trees for the up-coming three or four days, respectively. This approach was an improvement over simply replacing the water the trees used in the past three or four days – an approach that only by coincidence meets the actual water needs of the trees. All treatments were irrigated when soil moisture content of the well-watered control trees was –30 cb at a depth of 30 cm. The gallons of water applied per treatment per quarter from January to harvest in November are given in Table 1. Note that January to March is the period of inflorescence development and bud break; April to June is the period of flower opening and fruit set; July to September is the period of exponential fruit growth and marked increase in fruit size; and October to harvest in November is the period of fruit maturation.

Year 1. From January to March trees in all reduced irrigation treatments received at most only 20% less water than the well-watered control trees (Table1). Only limited amounts of water were applied in January and trees were not irrigated in February due significant rainfall during these months. From April through June, trees in the CI-RR-50% and PRD-50% treatments received 27% and 20% less water than the well-watered control trees, respectively. Significant reductions in the amount of irrigation water applied occurred from July to September when trees in the CI-RR-50% and PRD-50% received 49% and 44% less water than the well-watered control trees, respectively. These differences were maintained through harvest on 30 November 2010.

By the end of August, the diameters of fruit (measured on the tree) for trees in all reduced irrigation treatments were significantly smaller than that of the fruit of well-watered control trees ($P < 0.0001$) (Table 2). Fruit diameters for trees in the CI-RR-50% treatment were significantly smaller than fruit in all other treatments, even the PRD-50% treatment. Interestingly, the CI-RR-50% trees received only 7.2% less water from April to June and 5.5% less water from July to September than trees in the PRD-50% treatment. These results demonstrate the high sensitivity of navel orange fruit growth to water-deficit. Reduced fruit size was not due to thinner peels. There were no significant differences in peel thickness among the five treatments.

From 1 January through harvest on 30 November, well-watered control trees received 100% of ET. Trees scheduled to receive 75% of this rate (i.e., 25% less water) by conventional irrigation (CI-RR-75%) or by partial root zone drying (PRD-75%) actually received only 16% less water for the year than the well-watered control trees (Note that the difference in the amount of irrigation water applied to trees in the CI-RR-75% and PRD-75% treatments was 0.8% for the year)(Table 1). The greatest reduction in irrigation water applied was 22% from July through harvest for CI-RR-75% and PRD-75% trees. This level of stress and its timing significantly reduced total yield as kilograms per tree, but not as the number of fruit per tree, indicating that the effect was on fruit growth not fruit retention from July to harvest and that the 10% reduction in irrigation from January through June also had no effect on fruit set (Tables 3 and 4). The CI-RR-75% and PRD-75% trees produced significantly fewer fruit in all size categories than the well-watered control trees, with the exception of producing significantly more fruit smaller than packing carton size 138 (< 6.0 cm in diameter) as both kilograms and number per tree. Thus, the major effect of the 22% reduction in irrigation rate from June through harvest in November by either conventional irrigation or PRD was an effect on fruit growth as both size and weight. The 22% reduction in irrigation translated into a significant reduction in kilograms and number of fruit in all commercially marketable fruit size categories and especially in commercially valuable large size fruit of packing carton sizes 88, 72, and 56 compared to well-watered control trees (Tables 3 and 4). Six months of 22% less water significantly reduced the average weight of individual fruit and both juice weight and juice volume per fruit (Table 5). The reduced juice content of the fruit significantly increased both the total soluble solids (TSS, ºbrix) and percent acidity of the fruit (Table 5). Since both these quality parameters increased, there was no significant effect of irrigation rate on the solids to acid ratio (TSS:Acid) of individual fruit. The ratio of solids to acid was low due to the fact that November was early for the harvest of 'Washington' navel oranges in Year 1. However, all fruit were at legal maturity. The November harvest was necessary to prevent differences in crop load that occurred in response to differences in irrigation rates in Year 1 from impacting floral intensity and thus crop load in Year 2. For trees receiving 22% less irrigation water, there were no significant differences in yield, fruit size or fruit quality related to conventional irrigation or partial root zone drying.

Trees in the CI-RR-50% and PRD-50% treatments scheduled to receive half as much water as the well-watered control trees actually received 20% less water than the well-watered control trees from January through March. From April through June, the CI-RR-50% trees received 27% less water than the well-watered control trees, but the PRD-50% trees received only 20% less. From July through harvest in November, the CI-RR-50% and PRD-50% trees received 49% and 44% less water than the well-watered control trees, respectively. The reduced amount of irrigation water applied to trees in these treatments increased fruit abscission and decreased fruit size. Both the total kilograms and number of fruit per tree were significantly less for trees in the CI-RR-50% and PRD-50% treatments than for trees in the CI-RR-75% and PRD-75% treatments and the well-watered control trees (Tables 3 and 4). All trees receiving less irrigation water than the well-watered control trees produced less kilograms and number of fruit of packing carton size 56, 72 and 88, but there were no significant differences among trees irrigated with 22% (CI-RR-75% and PRD-75%), 49% (CI-RR-50%) or 44% (PRD-50%) less water than the well-watered control trees. These differences irrigation rates, however, had an impact on the kilograms and number of fruit per tree of packing carton size 113 and 138, demonstrating the negative effect of the greater reduction in irrigation rate on fruit retention and fruit size (Tables 3 and 4). There was also an obvious negative correlation between irrigation rate and the juice weight and juice volume of individual fruit, i.e., as irrigation rate decreased, juice weight and volume per fruit decreased (Table 5). Interestingly, fruit with lower juice volume had higher total soluble solids and percent acidity. Because both total soluble solids and acidity changed in parallel, there was no effect of irrigation rate on total soluble solids to acid ratio. Note that the 5% lower rate in irrigation for trees in the CI-RR-50% versus PRD-50% treatment resulted in a significant difference in fruit quality. There was a poor correlation between soil moisture content and yield and fruit quality parameters.

Foliar-application of urea-N (50 lb low biuret urea/acre, 46% N, 0.25% biuret) in mid-January to increase floral intensity, potassium nitrate (25 lb KNO_3/acre) in February and again at 75% petal fall (end of April-early May) to increase fruit size and reduce crease, and urea-N (50 lb urea/acre) at maximum peel thickness (early to mid-July) to increase fruit size did not offset the negative effects of reduced irrigation on fruit size.

The significant reduction in yield (kilograms and number) of fruit in all commercially marketable fruit size categories, especially highly valuable large fruit of packing carton sizes 88, 72, 56 and 48, due to reduced irrigation dramatically reduced grower income, even when the irrigation rate was reduced only 22% (CI-RR-75% and PRD-75%)(Table 6). Much of the savings in water costs was reduced by the added expense of foliar fertilizers (US$126.20) (Table 7). The results of this research dramatically illustrate how strongly citrus grower income is tied to providing adequate irrigation.

Year 2. From January through March, the CI-RR75%, PRD-75%, CI-RR-50% and PRD-50% received 24%, 22.5%, 48%, and 45% less water than the well-watered control trees (Table 1). Given the failure of the foliar fertilizer treatments to mitigate the effects of even a 22% reduction in irrigation (CI-RR-75% and PRD-75%) on fruit size in Year 1, in Year 2 (the final year of a 5-year study, which thus far had always resulted in reduced fruit size), we decided to test the efficacy of applying a cytokinin through the irrigation in combination with the foliar fertilizer treatments. To do this, we decided to irrigate all trees in the reduced irrigation treatments at 75% of the well-watered control starting in April and apply the cytokinin 6-benzyladenine during the period of exponential fruit growth to increase fruit size. 6-Benzyladenine was applied with the two irrigation events per week from 1 August through the end of October (harvest was 8 Nov.), for a total of 4 g 6-BA per tree. From April through June, the CI-RR 75%, CI-RR-75% + 6-BA, PRD-75% and PRD-75% + 6-BA trees received 26%, 28%, 22% and 3.5% (faulty flow meter) less water than the well-watered control, respectively (Table 1). On-tree measurement of fruit diameter indicated no significant differences in fruit size through 8 July for trees in any reduced irrigation treatment and the well-watered control trees (Table 8). From July through September, the CI-RR 75%, CI-RR-75% + 6-BA, PRD-75% and PRD-75% + 6-BA trees received 26%, 27%, 22% and 19% less water than the well-watered control, respectively (Table 1). By 1 August, there were still no significant differences in fruit diameter among treatments (Table 9). The 6-BA application was initiated on 1 August. By 1 September, there were significant differences in fruit size, especially in the south and west quadrants of the trees, the warmer quadrants of trees within rows running East-West. Fruit diameter was reduced the greatest for trees in the CI-RR-75% + 6-BA, which from April through September received the least irrigation (Table 10). Similar results were obtained when fruit diameter was measured on 1 October (Table 11). From 1 October through harvest on 8 November, the CI-RR 75%, CI-RR-75% + 6-BA, PRD-75% and PRD-75% + 6-BA trees received 22%, 22%, 23% and 19% less water than the well-watered control, respectively, and the differences for the entire year were 25%, 30%, 22% and 17% less water than the well-watered control trees (Table 1). These differences in irrigation rates had no significant effect on total yield as kilograms or number per tree compared to the yield of the well-watered control trees (Tables 12 and 13). Trees treated with 6-BA tended to have higher total yields (kilograms and number of fruit per tree) compared to trees in the same irrigation treatment not receiving 6-BA. However, all trees in the reduced irrigation treatments (with or without 6-BA) yielded significantly fewer commercially valuable large fruit (packing carton sizes 88, 72, 56 and 48) and significantly more fruit smaller than packing carton size 138 as both kilograms and number of fruit per tree compared to the well-watered control trees (Tables 12 and 13). However, unlike Year 1, the reduced irrigation treatments did not cause a significant reduction in the yield of packing carton size 113 and 138 fruit as kilograms or number per tree. The reduction in irrigation rate had negative effects on the weight of individual fruit, juice weight and juice volume, but no significant effects on total soluble solids, percent acidity or the ratio of total soluble solids to acid (TSS:acid) (Table 14). TSS:acid was low due to the early November harvest, but all fruit were legally mature. In Year 2, as in Year 1, there was a correlation between soil moisture content and yield and fruit quality parameters.

Foliar-application of urea-N (50 lb low biuret urea/acre, 46% N, 0.25% biuret) in mid-January to increase floral intensity, potassium nitrate (25 lb KNO_3/acre) in February and again at 75% petal fall (end of April-early May) to increase fruit size and reduce crease, and urea-N (50 lb urea/acre) at maximum peel thickness (early to mid-July) to increase fruit size did not offset the negative effects of reduced irrigation on fruit size. Supplying 4 g of 6-BA through the irrigation two times a week during the period of exponential fruit growth (1 August to 31 October) had no significant beneficial effects on fruit size and crop value. The ultimate determining factor was the amount of water the trees received. Crop value was directly related to the yield of commercially valuable large fruit (packing carton sizes 88, 72, 56, and 48), which was adversely affected by reductions in the amount water trees received. The Year 2 results confirm the sensitivity of citrus fruit size and grower income to the provision of adequate irrigation water to the trees.

All reduced irrigation treatments significantly reduced grower income compared to the well-watered control (Table 15). Attempting to irrigate the trees in all the reduced irrigation treatments at 75% of the well-watered control from April through harvest reduced the yield of highly valuable fruit (packing carton sizes 88, 72, 56, and 48), but not that of the commercially marketable fruit of packing carton sizes 113 and 138. However, much of the savings in water costs was reduced by the added expense of foliar fertilizers (US$126.20) (Table 16). Even if the cost of foliar fertilizer is subtracted, the savings in reduced irrigation do not offset the losses in crop value.

DISCUSSION

One of the more dramatic results of this research was the documentation of how extremely sensitive ‘Washington’ navel orange fruit growth is to small differences in irrigation rate during the period of exponential fruit growth. In Year 1, differences of only 20% to 22% from July to harvest (30 November) impacted total yield as kilograms per tree and affected fruit size, reducing both the kilograms and number of fruit per tree in all marketable size categories, especially the larger, more commercially valuable fruit of packing carton sizes 88, 72, 56 and 48. Further reductions in irrigation rate exacerbated these problems. All reduced irrigation treatments increased the kilograms and number of fruit less than 6.0 cm in diameter (fruit smaller than packing carton size 138), which have little to no economic value. Yields for the well-watered control trees in Years 1 and 2 were similar as kilograms per tree (6% greater in Year 1), but the number of fruit per tree in Year 1 was 40% greater than in Year 2, with well-watered control trees producing 2335 fruit per tree in Year 1 compared to 1662 fruit per tree in Year 2. The additional 670 fruit might have been a factor contributing to the overall smaller size of the fruit and greater reduction in yield of commercially marketable size fruit compared to the well-watered control trees in Year 1 than in Year 2. In Year 2, trees in the CI-RR-50% and PRD-50% treatments received 50% less water from January through March with no negative effect on fruit retention. Trees in these treatments had total yield as kilograms and number of fruit per tree equal to that of the well-watered control trees. Starting in April an attempt was made to irrigate all trees with 25% less water than the well-watered control trees. Trees in the PRD-75% + 6-BA treatments, however, received only 3.5% and 19% less water than the well-watered control trees (due to a faulty flow meter) from April through June and July through September, respectively. In contrast, trees in the CI-RR-75% + 6-BA treatment experienced the greatest decrease in irrigation rate, 28% and 27% during these periods, respectively. Although the reductions in irrigation rate were modest, they were imposed during the periods of fruit set and exponential fruit growth. As a consequence, yield of commercially valuable large fruit (packing carton sizes 88, 72, 56 and 48) as both kilograms and number of fruit per tree was significantly lower for all reduced irrigation treatments. Taken together the results of our research indicate that a 20%, or even 40%, reduction in irrigation rate (80% or 60% ET) can be tolerated by trees from January through March, but reducing irrigation 20% or less during the period of exponential fruit growth has a negative effect on fruit growth, final fruit size, and yield of commercially valuable large fruit (packing carton sizes 88, 72, 56 and 48). Yield reductions in these fruit size categories significantly reduced grower income. Savings achieved through reducing the irrigation rate did not offset the revenue loss accompanying the reduced yield of large size fruit. Treating trees in reduced irrigation treatments with foliar-applied fertilizer or 6-benzyladenine through the irrigation did not offset the negative effect of water deficit on fruit size and added to the cost of fruit production.

Regulated-deficit irrigation (RDI) and partial root zone drying (PRD) were developed to reduce water use and expense in the production of tree fruit and grapes (Kriedemann and Goodwin 2003). Both methods limit the vigor of vegetative shoot growth in favor of crop development with the goal that neither the current nor return yield is negatively affected. Reduced flushing of vegetative shoots is considered an important factor in controlling Asian Citrus Psyllid populations and the spread of Huanglongbing in citrus. With RDI, water deficit is applied in an orchard in a carefully controlled manner during a specific period in the phenology of the tree. When using RDI, timing is critical. RDI was shown to have limited utility in navel orange production in California (Goldhamer 2003). In contrast, PRD is the practice of alternately wetting and drying the root zone on two sides of the tree. With PRD, timing is flexible, and PRD is employed year-round.

Partial root zone drying ahs been used rather than RDI in commercial sweet orange production in Australia. Partial root zone drying (PRD) was developed in Australia and has been used extensively in the commercial production of grapes, cereal, field vegetables, olives and citrus (Dry et al. 2000a,b, Loveys et al. 1999, 2000). However, since the initiation of our research, PRD has been abandoned as an irrigation technique for citrus production in Australia, where the idea and data supporting water savings of 40% with no negative effects on citrus yield or fruit quality originated (Loveys et al. 1999; Personal Communication from Donald Irving, Research Scientist, New South Wales Department of Primary Industries). Use of irrigation rates in excess of 100% ET for the well-watered control were believed to be the basis for the original positive results. It is clear from our results that the irrigation rate (100% ET) used in the present research for the well-watered control trees provided little to no surplus water. Negative effects on yield were obtained when the irrigation rate was reduced as little as 20% from July through September. Results of a study on grape suggested that the effects of reduced irrigation rates were independent of whether irrigation was by PRD or CI (Gu et al. 2004). Our results were consistent with those of Gu et al. (2004). No differences in yield or fruit quality for a given irrigation rate were related to irrigation method. Our results provide strong evidence that yield parameters, especially fruit size, are more sensitive to reduced rates of irrigation during some stages tree phenology than others, suggesting that modest savings in irrigation water could be better achieved through RDI than either PRD or CI-RR.

CONCLUSION

The California citrus industry produces “picture perfect” navel orange fruit for the fresh fruit market on 124,385 irrigated acres. The cost of irrigation water is a major expense associated with citrus production. The results of our research provide clear evidence of the negative consequences of reducing irrigation rates for navel orange production below 100% ET on yield, fruit size and grower income. Even modest reductions of only 20% imposed during the critical period of exponential fruit growth reduced the yield of commercially valuable fruit (packing carton sizes 88, 72, 56 and 48) and grower income. Careful irrigation management will be required to reduce production costs by reducing irrigation rate. The results of our research also illustrate the significant financial consequences to which growers could be subject if, at some point, they are required to produce their crops with 30% less water (http://www.latimes. com/news/local/la-me-water21nov21,1,1338299.story, Http://www.Fresnobee.com/business /story/222 120.html). The data from this project should be helpful to citrus growers for building the case that such a restriction should not be imposed.

PROJECT EVALUATION:

We have completed two full years of irrigation and foliar fertilizer treatment applications, harvested the crop for both years and completed the statistical analysis of the yield data, including fruit size distribution (pack out), and fruit quality parameters. As a last resort to achieve reduced irrigation rates without reducing fruit size and grower income, we tested the efficacy of supplying the cytokinin 6-benzyladenine (4 g/tree) during exponential fruit growth to trees receiving 25% less water during this period compared to the well-watered control trees. We are still waiting for the results of the leaf analyses from the DANR Laboratory at UC-Davis to determine whether there were differences in the nutritional status of the trees in the different irrigation treatments that might be a factor influencing final fruit size. The results of our research are valuable to citrus growers. First, they demonstrate the high degree of sensitivity of navel orange fruit to water availability at different stages of fruit development, especially the exponential stage of fruit growth, and the relationship between fruit size and grower income. These results should motivate growers to carefully manage their irrigation. Second, the results of our research document the water needed for the sustainability citrus production. These data should be valuable to citrus growers in negotiating essential water allocations when restrictions are proposed.

OUTREACH ACTIVITIES SUMMARY:

During the 2-years of this project the PI gave presentations, which included information related to this project to growers, industry people and other researchers at the following venues: (1) "Phenology and Physiology of Citrus Productivity" to the Friends of Citrus at the USDA Citrus and Date Germplasm Repository, UCR, February 17, 2010; (2) "Impact of Climate Change on Citrus and Avocado Flowering and Yield in California and Mexico", an invited seminar presented to research at INIFAP-Campo Experimental Santiago Ixcuintla, Santiago Ixcuintla, Nayarit, MÉXICO, March 12, 2010; (3) "Phenology and Physiology of Citrus and Avocado Productivity", an invited Seminar presented to graduate students and faculty at the University of Arizona, Tuscon, AZ, April 27, 2010; (4) "Phenology and Physiology of Citrus Productivity", an invited seminar presented at citrus grower education meeting sponsored by Citrus Research Board, Auburn, CA, October 29, 2010; (5) "Phenology and Physiology of Citrus Productivity", a second invited seminar sponsored by Citrus Research Board, Pala, CA, February, 2011; (6) with the help of Co-PI Ben Faber and Emily Thacher Ayala of the Ojai Valley 'Pixie' Growers Association, a seminar to discuss alternate bearing in mandarins and available strategies for mitigating it, which included a discussion of foliar fertilization and adequate irrigation to maintain fruit size; the Co-PI was invited to present (7) "Citrus Management Practices" the Growers Association of Cukurova, Turkey, April 6, 2011; and (8) "Citrus Irrigation Practices" to the Horticulture Department, Cukurova University, June 3, 2011.

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Table 1. Gallons of water applied per treatment from 1 January to harvest 30 November 2010 and 1 January to harvest 8 November 2011.

	Year 1					Year 2				
Month	Control	CI-RR-75%	CI-RR-50%	PRD-75%	PRD-50%	Control	CI-RR-75%	CI-RR-75% + 6-BA	PRD-75%	PRD-75% + 6-BA
Jan	3830	2970	2350	3090	1840	14460	11260	7450	11640	7750
Feb	0	0	0	0	0	6060	4270	2570	4630	2720
Mar	13210	12070	11170	12890	11700	9820	7500	5750	7560	6190
Jan-Mar	17040	15040	13520	15980	13540	30340	23030	15770	23830	16660
% control	**--**	**88.3**	**79.3**	**93.8**	**79.5**	**--**	**75.91**	**51.98**	**78.54**	**54.91**
Apr	11600	12290	11600	11710	12330	18970	13900	12970	13980	14570
May	24170	23220	19280	23020	21030	27430	19460	19100	21680	21450
Jun	22270	17740	11370	17590	13050	27100	21270	20950	21430	34920
Apr-Jun	58040	53250	42250	52320	46410	73500	54630	53020	57090	70940
% control	**--**	**91.7**	**72.8**	**90.1**	**80.0**	**--**	**74.33**	**72.14**	**77.67**	**96.52**
Jul	24840	19250	12210	19670	14190	23980	16770	17560	18990	20170
Aug	24820	19610	12380	20430	13440	26640	21420	19810	21250	21540
Sep	23520	18080	12490	17840	13490	22250	15780	15600	16300	17630
Jul-Sep	73180	56940	37080	57940	41120	72870.0	53970.0	52970.0	56540.0	59340.0
% control	**--**	**77.8**	**50.7**	**79.2**	**56.2**	**--**	**74.06**	**72.69**	**77.59**	**81.43**
Oct to Harvest	17140	13330	8550	13430	9520	18180	14150	14150	14080	14740
% control	**--**	**78.9**	**51.2**	**80.1**	**53.7**	**--**	**77.83**	**77.83**	**77.45**	**81.08**
Total	160370	134790	99050	135940	107570	194890	145780	135910	151540	161680
% control	**--**	**84.0**	**61.8**	**84.8**	**67.1**	**--**	**74.80**	**69.74**	**77.76**	**82.96**

Table 2. Effect of reducing irrigation 25% or 50% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 January through 30 August 2010 on fruit size (mm transverse diameter) of 'Washington navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Whole tree	Tree quadrant			
		North	East	South	West
	------------------ *fruit diameter (mm)* ------------------				
Control	49.97 a[z]	50.76 a	51.29 a	49.15 a	48.69 a
CI-RR-75%	46.47 b	46.41 b	45.94 b	47.40 ab	46.14 ab
CI-RR-50%	39.96 c	40.90 c	40.05 c	40.16 d	38.71 c
PRD-75%	45.34 b	45.54 b	46.28 b	45.65 bc	43.98 b
PRD-50%	43.81 b	43.58 bc	44.22 bc	42.83 cd	44.62 b
P-value	<0.0001	<0.0001	0.0002	<0.0001	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher's Protected LSD Test.

Table 3. Effect of reducing irrigation 25% or 50% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 January through harvest 30 November 2010 on yield and fruit size (kg/tree) of 'Washington navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Total	Packing carton size						
		56 8.1-8.8 cm	72 7.5-8.0 cm	88 6.9-7.49 cm	113 6.35-6.89 cm	138 6.00-6.34 cm	<138 <6.00 cm	56+72+88 6.9-8.8 cm
	------------------ *kg per tree* ------------------							
Control	259.2 a[z]	2.8 a	5.9 a	33.4 a	71.7 a	86.1 a	58.55 b	42.1 a
CI-RR-75%	220.0 b	0.1 b	0.7 b	3.2 b	14.8 bc	58.0 b	143.28 a	4.0 b
CI-RR-50%	135.3 c	0.0 b	0.0 b	0.0 b	1.0 c	7.9 c	126.34 a	0.0 b
PRD-75%	200.2 b	0.1 b	0.4 b	5.6 b	23.5 b	46.2 b	124.36 a	6.1 b
PRD-50%	154.4 c	0.1 b	0.5 b	2.9 b	6.7 bc	23.5 c	121.40 a	2.7 b
P-value	<0.0001	0.0811	<0.0001	<0.0001	<00001	<0.0001	<0.0001	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher's Protected LSD Test.

Table 4. Effect of reducing irrigation 25% or 50% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 January through harvest 30 November 2010 on yield and fruit size (number of fruit/tree) of 'Washington navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Total	Packing carton size						
		56 8.1-8.8 cm	72 7.5-8.0 cm	88 6.9-7.49 cm	113 6.35-6.89 cm	138 6.00-6.34 cm	<138 <6.00 cm	56+72+88 6.9-8.8 cm
	-- *no. of fruit per tree* ---							
Control	2335 a[z]	10 a	26 a	192 a	497 a	809 a	799 b	228 a
CI-RR-75%	2624 a	0 b	3 b	18 b	103 bc	545 b	1955 a	22 b
CI-RR-50%	1805 b	0 b	0 b	0 b	7 c	74 c	1724 a	0 b
PRD-75%	2328 a	0 b	2 b	32 b	163 b	434 b	1697 a	34 b
PRD-50%	1939 b	0 b	2 b	13 b	46 bc	221 c	1656 a	15 b
P-value	<0.0001	0.0811	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at *P*-value specified by Fisher's Protected LSD Test.

Table 5. Effect of reducing irrigation 25% or 50% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 January through harvest 30 November 2010 on quality of harvested fruit of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Fruit wt. (g)	Juice wt. (g)	Juice wt. (%)	Juice vol. (ml)	TSS (ºbrix)	Acid (%)	TSS:acid
Control	123.9 a[z]	42.8 a	34.4 a	14.9 a	12.9 d	1.4 c	9.2 a
CI-RR-75%	89.6 b	28.4 b	31.6 ab	9.1 b	14.6 c	1.7 b	8.8 a
CI-RR-50%	70.8 c	16.7 d	23.0 d	4.1 d	16.9 a	2.1 a	8.4 a
PRD-75%	95.7 b	28.6 b	29.7 bc	8.7 bc	14.9 c	1.7 b	8.8 a
PRD-50%	84.1 b	23.1 c	27.1 c	6.5 c	16.0 b	1.8 b	9.2 a
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1332

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher's Protected LSD Test.

Table 6. Effect of reducing irrigation 25% or 50% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 January through harvest 30 November 2010 on the crop value of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Total	48 ≥8.81 cm	56 8.1-8.8 cm	72 7.5-8.0 cm	88 6.9-7.49 cm	113 6.35-6.89 cm	138 6.00-6.34 cm
	-- *crop value (US$) per 96 trees/acre* --						
Control	5191.10 a[z]	36.38 a	134.94 a	227.07 a	1041.60 a	1891.60 a	1859.50 a
CI-RR-75%	1772.90 b	0.00 a	3.42 b	27.88 b	98.30 b	390.60 bc	1252.70 b
CI-RR-50%	198.40 c	0.00 a	0.00 b	0.00 b	0.70 b	26.90 c	170.70 c
PRD-75%	1812.50 b	0.00 a	2.59 b	15.85 b	175.50 b	620.20 b	998.40 b
PRD-50%	776.00 bc	2.08 a	2.43 b	19.02 b	68.00 b	176.70 bc	507.80 c
P-value	<0.0001	0.4301	0.0811	<0.0001	<0.0001	<0.0001	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at *P*-value specified by Fisher's Protected LSD Test.

Table 7. Relative effect of reducing irrigation 25% or 50% by conventional irrigation (CI-RR) or partial root zone drying (PRD) from 1 January through harvest 30 November 2010 when irrigation water is priced at $200/acre-foot[z] or 129/acre-foot, but also supplying foliar-applied fertilizer, on the production costs for 'Washington' navel orange trees at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	$200/acre-ft.	$129/acre-ft.
Control	457.73	317.95
CI-RR-75%	484.87	367.40
CI-RR-50%	387.88	301.55
PRD-75%	487.70	369.22
PRD-50%	408.80	315.04

[z] 1 acre-foot is 325,851 gallons.

Table 8. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through 8 July 2011 on fruit size (mm transverse diameter) of ‘Washington’ navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Whole tree	Tree quadrant			
		North	East	South	West
	fruit diameter (mm)				
Control	39.9 a[z]	38.7 a	38.4 a	43.4 a	39.3 a
CI-RR-75%	41.3 a	38.7 a	40.8 a	44.8 a	40.8 a
CI-RR-75% + 6-BA[y]	38.3 a	35.7 a	38.8 a	41.9 a	37.8 a
PRD-75%	39.9 a	36.9 a	40.3 a	42.8 a	39.7 a
PRD-75% + 6-BA[y]	39.7 a	36.8 a	38.9 a	43.3 a	39.7 a
P-value	0.2739	0.1428	0.2511	0.3291	0.3773

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher’s Protected LSD Test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 9. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through 3 August 2011 on fruit size (mm transverse diameter) of ‘Washington’ navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Whole tree	Tree quadrant			
		North	East	South	West
	fruit diameter (mm)				
Control	48.6 a[z]	47.6 a	48.4 a	50.2 a	48.4 a
CI-RR-75%	48.5 a	47.4 a	48.9 a	49.9 a	48.0 a
CI-RR-75% + 6-BA[y]	46.0 a	44.1 a	45.7 a	48.2 a	46.1 a
PRD-75%	47.6 a	46.2 a	47.4 a	49.2 a	47.6 a
PRD-75% + 6-BA[y]	48.1 a	46.5 a	48.3 a	49.6 a	48.0 a
P-value	0.2614	0.1363	0.1625	0.6620	0.5292

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher’s Protected LSD Test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 10. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through 1 September 2011 on fruit size (mm transverse diameter) of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Whole tree	Tree quadrant			
		North	East	South	West
	-- *fruit diameter (mm)* --				
Control	57.1 a[z]	55.9 a	55.4 a	59.3 a	57.9 a
CI-RR-75%	56.9 a	55.5 a	56.9 a	58.2 ab	56.9 ab
CI-RR-75% + 6-BA[y]	52.8 b	51.8 b	52.1 b	54.0 c	53.2 c
PRD-75%	54.7 ab	54.3 ab	54.0 ab	56.1 bc	54.5 bc
PRD-75% + 6-BA[y]	54.8 ab	53.6 ab	54.4 ab	56.8 abc	54.5 bc
P-value	0.0203	0.0690	0.0593	0.0078	0.0298

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher's Protected LSD Test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 11. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through 1 October 2011 on fruit size (mm transverse diameter) of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Whole tree	Tree quadrant			
		North	East	South	West
	-- *fruit diameter (mm)* --				
Control	61.2 a[z]	62.1 a	59.7 a	63.3 a	59.8 a
CI-RR-75%	60.8 a	60.5 ab	60.2 a	62.6 a	59.9 a
CI-RR-75% + 6-BA[y]	56.3 b	55.4 c	55.5 b	58.1 b	56.3 a
PRD-75%	58.1 ab	57.7 bc	57.5 ab	58.6 b	58.7 a
PRD-75% + 6-BA[y]	58.4 ab	58.2 bc	57.7 ab	60.2 ab	57.7 a
P-value	0.0317	0.0066	0.1014	0.0101	0.3522

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher's Protected LSD Test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 12. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through harvest 8 November 2011, with and without irrigation-applied 6-benzyladenine (6-BA) from 1 August to harvest (8 Nov.), on yield and fruit size (kg/tree) of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Total	Packing carton size						
		56 8.1-8.8 cm	72 7.5-8.0 cm	88 6.9-7.49 cm	113 6.35-6.89 cm	138 6.00-6.34 cm	<138 <6.00 cm	56+72+88 6.9-8.8 cm
	--- *kg per tree* --							
Control	239.7 a[z]	14.4 a	45.7 a	34.3 a	65.2 a	45.6 a	33.2 c	94.3 a
CI-RR-75%	218.1 a	8.4 ab	13.8 b	17.0 bc	51.9 a	56.5 a	67.4 ab	39.1 b
CI-RR-75% + 6-BA	224.0 a	2.7 b	7.8 b	9.6 c	39.8 a	70.1 a	93.6 a	20.1 b
PRD-75%	216.2 a	1.5 b	10.0 b	16.6 bc	48.4 a	61.8 a	77.8 ab	28.2 b
PRD-75% + 6-BA	237.2 a	2.1 b	19.0 b	26.9 ab	66.1 a	60.0 a	63.1 b	48.0 b
P-value	0.7057	0.0128	<0.0001	0.0006	0.1555	0.2878	0.0004	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at the *P*-value specified by Fisher's Protected LSD Test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 13. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through harvest 8 November 2011, with and without irrigation-applied 6-benzyladenine (6-BA) from 1 August to harvest (8 Nov.), on yield and fruit size (number of fruit/tree) of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Total	Packing carton size						
		56 8.1-8.8 cm	72 7.5-8.0 cm	88 6.9-7.49 cm	113 6.35-6.89 cm	138 6.00-6.34 cm	<138 <6.00 cm	56+72+88 6.9-8.8 cm
	------------------ *no. of fruit per tree* ------------------							
Control	1662 a[z]	51 a	216 a	198 a	440 a	371 a	382 c	466 a
CI-RR-75%	1785 a	30 ab	65 b	98 bc	351 a	459 a	775 ab	193 bc
CI-RR-75% + 6-BA	2019 a	10 b	37 b	56 c	269 a	570 a	1077 a	102 c
PRD-75%	1874 a	5 b	48 b	96 bc	327 a	503 a	895 ab	149 bc
PRD-75% + 6-BA	1914 a	7 b	90 b	155 ab	447 a	488 a	727 b	253 b
P-value	0.3683	0.0128	<0.0001	0.0006	0.1555	0.2878	0.0004	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at *P*-value specified by Fisher's Protected LSD Test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 14. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through harvest 8 November 2011, with and without irrigation-applied 6-benzyladenine (6-BA) from 1 August to harvest (8 Nov.), on 'Washington' navel orange fruit quality located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Fruit wt. (g)	Juice wt. (g)	Juice wt. (%)	Juice vol. (ml)	TSS (ºbrix)	Acid (%)	TSS:acid
Control	157.0 a[z]	56.2 a	36.5 ab	20.9 a	11.8 b	1.3 b	9.3 a
CI-RR-75%	137.0 b	48.5 bc	35.0 ab	17.3 bc	12.8 a	1.4 a	9.1 a
CI-RR-75% + 6-BA[y]	117.0 c	41.2 d	35.1 ab	14.5 c	12.3 ab	1.4 ab	9.1 a
PRD-75%	125.3 bc	42.5 cd	33.7 b	14.6 c	12.9 a	1.5 a	8.9 a
PRD-75% + 6-BA[y]	135.2 bc	50.8 ab	37.6 a	19.1 ab	12.4 a	1.4 a	8.7 a
P-value	0.0006	0.0002	0.0768	0.0003	0.0021	0.0139	0.6619

[z] Values in a vertical column followed by different letters are significantly different at *P*-value specified by Fisher's Protected LSD test.
[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 15. Effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) and supplying foliar-applied fertilizer from 1 April through harvest 8 November 2011, with and without irrigation-applied 6-benzyladenine (6-BA) from 1 August to harvest (8 Nov.), on the crop value of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	Total	48 ≥8.81 cm	56 8.1-8.8 cm	72 7.5-8.0 cm	88 6.9-7.49 cm	113 6.35-6.89 cm	138 6.00-6.34 cm
	-- *crop value (US$) per 96 trees/acre* --						
Control	6286.80 a[z]	67.75 a	689.00 a	1753.00 a	1071.30 a	1720.10 a	985.60 a
CI-RR-75%	4206.80 bc	155.81 a	403.60 ab	528.30 b	529.20 bc	1370.50 a	1219.20 a
CI-RR-75% + 6-BA	3313.30 c	20.16 a	128.40 b	300.30 b	300.00 c	1050.60 a	1513.80 a
PRD-75%	3590.90 bc	2.11 a	72.90 b	385.60 b	518.30 bc	1276.60 a	1335.30 a
PRD-75% + 6-BA	4709.90 b	0.96 a	99.60 b	729.40 b	839.60 ab	1744.60 a	1295.70 a
P-value	0.0003	0.1498	0.0128	<0.0001	0.0006	0.1555	0.2878

[z] Values in a vertical column followed by different letters are significantly different at *P*-value specified by Fisher's Protected LSD Test.

[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively.

Table 16. Relative effect of reducing irrigation 25% by conventional irrigation (CI-RR) or partial root zone drying (PRD) from 1 April through harvest 8 November 2011 when irrigation water is priced at \$200/acre-foot[z] or \$129/acre-foot, but also supplying foliar-applied fertilizer, with and without irrigation-applied 6-benzyladenine (6-BA) from 1 August to harvest (8 Nov.), on the production costs of 'Washington' navel orange trees located at the Citrus Research Center and Agricultural Experiment Station of the University of California-Riverside.

Treatment	\$200/acre-ft.	\$129/acre-ft.
Control	542.48	372.62
CI-RR-75%	511.86	384.80
CI-RR-75% + 6-BA[y]	487.62	369.17
PRD-75%	526.00	393.92
PRD-75% + 6-BA[y]	550.89	409.98

[z] 1 acre-foot is 325,851 gallons.

[y] 6-Benzyladenine (6-BA) was not applied until 1 August 2011; CI-RR-75% + 6-BA and PRD-75% + 6-BA received 48% and 45% less water than the well-watered control trees from January through March, respectively. The cost of the 6-BA was not included in the calculation.