Project Concluded: Final Report

Irrigation Stress and Early-Navel Fruit Maturity

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Mildly water-stressed Beck navel trees on October 15, 2008 located in a plot marked for experimental harvest.

OVERVIEW

The objective of this research was to measure effects of late-season irrigation stress on fruit yield, quality, and maturity of an early-maturing navel orange variety. This report concludes four years of research funded by the Citrus Research Board.

In the first year (2005), the project lost its first cooperating grower as a result of proprietary issues and had to abandon work in the orchard of a second as a result of a heavy clay soil that made soil-water measurements difficult. In the subsequent three years (2006-08), a suitable site and cooperator were found, and in the summer of 2006 three irrigation regimes were initiated in the experimental orchard. In 2007, late-season irrigation stress was intensified in two of the treatment regimes in the trial. In the final season, 2008, the trees in the treatment with the highest irrigation stress in 2006 and 2007 were fully irrigated to measure the recovery response of the tree in terms of fruit yield, quality and harvest maturity.

Generally, over the course of the three years, late-season irrigation stress decreased fruit yield, fruit numbers and grade, and increased total soluble solids (i.e. Brix), titratable acidity, the BrimA index, and color. Fruit juiciness and the soluble solids/acid ratio (i.e. sugar/acid ratio) were little affected. The intensity of the irrigation stress in 2007 decreased fruit yield by number and weight, decreased the percentage of large fruit and reduced fruit grade. When trees exposed to two years of late-season irrigation stress were fully irrigated the following year, fruit yield and quality was similar to trees that had been fully irrigated all three years.

INTRODUCTION

Early-maturing navel orange varieties such as ‘Beck’, ‘Newhall’, and ‘Fukumoto’ that are planted in the southern San Joaquin Valley produce the first navel orange fruit of the season in California. The price a grower receives for early fruit depends on several factors. The earliest of the early harvested oranges receive a price premium, but before harvest occurs the fruit must meet minimum regulatory standards for sweetness and color. Generally, the larger-sized oranges also receive a price premium, with sizes less than 113 too small for packing.

Table 1. Treatment descriptions based on the relative amount of water applied each year.

Treatment name	2006	2007	2008
T1	least	least	highest
T2	intermediate	intermediate	least
T3	highest	highest	highest

Many growers felt that irrigation was an important factor related to early fruit quality and yield, however very little scientific information was available to guide irrigation decisions. Some growers fully irrigated until harvest to maximize fruit yield and individual fruit size, while others reduced irrigation toward harvest for several reasons. First, since the oranges are picked green and require treatment with ethylene gas, overly turgid fruit are susceptible to green spotting as a result of damage to the oil glands during picking, transporting and other handling. Reducing orange cell turgidity can be accomplished in a period of a few days. Secondly, less water in the orange can temporarily increase fruit sugar on a weight basis, not by producing more sugar in the orange but through simple concentration of what is already present resulting in a drier orange. However rainfall or irrigation necessary to prevent excessive softness can reverse this affect. Thirdly, longer-term water stress has been shown in satsuma mandarin to increase the amount of sugars, more so than the level of acidity. Mandarins appear to adjust to prolonged stress by active osmoregulation, which involves an increase in the weight and the concentration of soluble solids, mostly sugars, within the fruit in response to water stress. Thus, osmotic adjustment may result in an orange with a higher sugar content and sugar acid ratio at harvest without sacrificing fruit juice content. Osmotic adjustment appears to be a longer lasting physiological development less sensitive to lower temperatures, irrigation or rainfall events occurring near harvest. If sweetness improves and color is not advanced, a

Table 2. Effect of the side of the tree (south or north) averaged across irrigation treatments on percent juice, soluble solids concentration, titratable acid, BrimA and color of Beck navel fruit in the southern San Joaquin Valley. Fruit harvested October 15, 2007.

Sample Date	Juice weight/ fruit weight, %		Soluble solids content (SSC), %		Titratable acid, (TA), %		BrimA		Soluble solids/Titratable. acid ratio (SSC/TA)		Color chart [1]	
	south	north	south	north	south	north	south	north	south	north	south	north
9/25	26[2] a[3]	27 b	10.0 b	9.0 a	1.1 a	1.5 b	5.6 b	3.0 a	9.1 b	6.0 a	4.4 a	4.4 a
10/1	26 a	27 b	10.2 b	9.3 a	1.0 a	1.4 b	6.0 b	3.8 a	9.8 b	6.8 a	4.6 a	4.7 a
10/8	26 a	28 b	10.6 b	9.7 a	1.1 a	1.3 b	6.3 b	4.3 a	10.0 b	7.2 a	5.3 a	5.1 a

1 Color based on color chips with values representing colors from 1 to 13, 1 being greenest and 13 a reddish orange. For those familiar with the 'A' and 'B' color rating system, 'A' color is approximately equivalent to a '5' on the U.C. color chart system.
2 Each table value is averaged across treatments (10 oranges per replicate x 5 replicates x 3 treatments x 2 tree sides).
3 Values in the same cell followed by different letters are significantly different by Fisher's protected *lsd* test at $P \leq 0.05$.

sweeter orange may result, even if the harvest date remains the same.

The net effect of a longer-term water stress on reductions in fruit numbers and size may make a longer-term water stress less profitable. The objective of our study was to quantify the degree of late-season water stress applied to trees and the effects of this stress on yield and fruit quality of 'Beck' early- maturing navel orange.

Procedures

Experimental site: The study was conducted in a commercial orange grove planted in 1994 and located adjacent to the foothills in the southwestern corner of the San Joaquin Valley near the town of Mettler. The trees in the orchard were planted in rows 22 feet apart with 11 feet between trees. Tree rows are oriented in an east-west direction. The experimental location is ideal for water stress experiments in that rainfall from August through early November was minimal. The trees in the orchard were very uniform in appearance, healthy and were kept about 10 to 12 feet in height during the course of the experiment. The soil was a deep, well-drained coarse sandy clay loam.

Irrigation treatments: A treatment was identified by the record of relative water application rates that a group of trees received over the three-year period of this study. The experiment consisted of three treatments, identified as T1, T2 and T3. A description of the treatments is shown in Table 1. Each treatment was applied to the same trees for the duration of the experiment.

The target period for the late-season water stress was from late August through harvest in mid- to late October. Differential irrigation treatments were administered through the use of irrigation emitters with different flow rates and by opening and closing valves located on the irrigation hoses at intervals through the stress periods. The degree of stress produced in the tree was determined by mid-day measurements of shaded leaf-water potential made on leaves from two to three trees in each plot at weekly intervals through the stress period with a pressure chamber. Water meters and neutron probe access tubes were installed in replicated plots so that water application rates and soil-water status could be measured to assist in scheduling irrigations and maintaining desired tree stress levels. Neutron probe readings were made at weekly intervals. The deep soils in the experimental trial had a high soil-water storage capacity. To achieve the desired levels of stress by late August, initiation of decreased irrigation treatments began on August 7.

The standard ranch practice in the orchard was to irrigate each tree with a single black Bowsmith® Fanjet® microsprinkler attached to a 0.9-inch diameter drip hose. The lowest rate of applied water was achieved by removing each fanjet emitter and replacing it with a single plug-in manifold servicing three drip emitters. Each of the drip emitters was attached to the manifold with a two-foot long piece of spaghetti tubing. The intermediate and highest water application rates were applied with a single black and orange fanjet, respectively. The drip manifold and black fanjet applied approximately 38 and 71% of the water of the orange fanjet, respectively. Emitter flow rate was increased in Treatment 1 and decreased in Treatment 3 after harvest so that soil-water storage would be returned to near field capacity in the top three feet of soil profile by early spring. All nitrogen in this experiment was applied through the irrigation system in the spring and during this period all trees had emitters with the same flow rate to ensure equal nitrogen application rates.

Experimental design: The experimental site was established within an area 45 tree rows wide by 30 trees deep within a larger orchard of 'Beck' navel orange trees. A single treatment was applied to an experimental unit which consisted of a plot 3 rows wide by 10 trees long. Data were collected from the center row of each plot, with the two neighboring rows functioning as a border. The experiment was designed as a randomized, complete block providing five replications of each of the three treatments.

Fruit sampling and harvest: Three of the trees in the interior of the data row were dedicated to fruit quality sampling conducted at intervals during the season, whereas three of the trees were reserved for yield and fruit quality measurements at harvest. The first and tenth tree in each plot functioned as a border. In 2006, five oranges, and in 2007 and 2008, ten similar sized oranges were collected at weekly intervals from both the north and south sides of trees in each plot beginning in late September and continuing through harvest. Shaded fruit, without scars or sunburn, were removed from the canopy in a band from five to seven feet above ground level.

Table 3. Effect of irrigation treatment on juiciness, soluble solids concentration, titratable acid percentage, BrimA index and color of Beck navel fruit in the southern San Joaquin Valley, 2006, 2007 and 2008[1].

Sample Date	Juice weight fruit weight,%			Soluble solids content (SSC), %			Titratable acid content, (TA), %			BrimA			Soluble solids – Titratable acid ratio (SSC/TA)			Color chart [2]		
	T1[3]	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
2006																		
9/26	24 a[4]	26 a	25 a	9.3 c	8.7 b	8.4 a	1.4 b	1.3 a	1.2 a	3.5 a	3.7 a	3.6 a	8.5 a	7.8 a	7.8 a	4.0 a	4.0 a	4.0 a
10/3	26 a	27 a	25 a	9.5 c	8.9 b	8.5 a	1.2 a	1.1 a	1.1 a	4.8 a	4.5 a	4.3 a	8.5 a	8.3 a	8.2 a	4.0 a	4.0 a	4.0 a
10/10	28 a	28 a	28 a	9.5 c	9.0 b	8.7 a	1.2 a	1.1 a	1.1 a	4.7 b	4.6 b	4.1 a	8.0 a	8.3 a	7.7 a	4.0 a	4.0 a	4.0 a
10/17	27 a	29 a	29 a	10.1 c	9.5 b	9.0 a	1.1 a	1.1 a	1.0 a	5.6 b	5.2 a	4.9 a	9.2 a	8.9 a	8.9 a	4.0 a	4.0 a	4.0 a
10/24	28 a	32 a	28 a	10.1 c	9.5 b	9.2 a	1.1 a	1.0 a	1.0 a	5.8 b	5.6 b	5.1 a	9.5 a	9.9 a	9.1 a	5.5 a	5.4 a	5.2 a
10/30	25 a	27 a	27 a	10.8 c	9.8 b	9.3 a	1.1 a	1.0 a	1.0 a	6.6 b	5.8 b	5.4 a	10.4 a	10.1 a	9.4 a	6.0 b	5.8 b	5.2 a
2007																		
9/25	27 a	27 a	27 a	10.3 c	9.4 b	8.8 a	1.4 b	1.3 a	1.2 a	4.6 b	4.3 b	3.9 a	7.5 a	7.7 a	7.5 a	4.8 b	4.3 ab	4.1 a
10/1	26 a	27 a	27 a	10.5 c	9.7 b	8.9 a	1.3 b	1.2 a	1.1 a	5.3 c	4.9 b	4.5 a	8.4 a	8.3 a	8.2 a	4.9 c	4.6 b	4.3 a
10/8	27 a	27 a	28 a	11.1 c	10.0 b	9.2 a	1.3 c	1.2 b	1.1 a	5.9 c	5.2 b	4.8 a	8.7 a	8.6 a	8.5 a	5.3 a	5.2 a	5.0 a
10/15	26 a	26 a	28 a	11.9 c	10.2 b	9.5 a	1.4 b	1.1 a	1.1 a	6.5 b	5.9 b	5.2 a	8.9 a	9.7 a	9.0 a	6.0 b	5.2 a	5.2 a
2008																		
9/30	29 b	26 a	28 b	8.5 a	9.4 b	8.5 a	1.1 a	1.1 a	1.1 a	4.1 a	4.9 b	4.2 a	8.0 a	8.5 a	8.2 a	4.0 a	4.0 a	4.0 a
10/7	29 a	28 a	28 a	8.7 a	9.6 b	8.5 a	1.0 a	1.1 b	1.0 a	4.6 a	5.3 b	4.4 a	8.7 a	9.1 a	8.5 a	4.0 a	4.0 a	4.0 a
10/14	29 a	28 a	28 a	8.7 a	9.6 b	8.6 a	1.0 a	1.1 a	1.0 a	4.6 a	5.3 b	4.6 a	8.7 a	9.0 a	8.7 a	4.3 a	4.4 a	4.6 a
10/21	29 a	29 a	28 a	9.0 a	10.0 b	9.0 a	1.0 a	1.1 b	0.9 a	5.1 a	5.7 b	5.2 a	9.5 a	9.6 a	9.6 a	4.8 a	4.8 a	4.9 a
10/28	29 a	29 a	28 a	9.3 a	10.5 b	9.1 a	0.9 a	1.0 b	0.9 a	5.6 a	6.5 b	5.5 a	10.2 a	10.7 a	10.2 a	5.0 a	5.4 a	5.1 a

1 Fruit harvested, Oct. 30 in 2006, Oct.15 in 2007, and Oct. 29 in 2008.
2 Color based on color chips with values representing colors from 1 to 13, 1 being greenest and 13 the most orange.
3 T1, T2 and T3 refer to the three irrigation treatments conducted over the three years of the experiment.
4 Values in a row by treatment on a given date for each characteristic that are followed by different letters are significantly different by Fisher's protected *lsd* test at $P \leq 0.05$.

Fruit samples were transported to the laboratory at the U.C. Lindcove Research and Extension Center (LREC) for determination of fruit quality characteristics such as percent juice soluble solids concentration (aka Brix), juice titratable acid, peel roughness, color, and percentage of juice weight and volume to fruit weight. The final fruit sample collected in 2006 and 2007 for the evaluation of fruit quality characteristics occurred as the harvested fruit was passing over the automated packline and consisted of 10 fruit sized 56 and represented an average of fruit from the north and south side of the tree. In 2008, the final fruit sample was picked in the field, separately from the south and north side of the trees, on Oct. 28. The timing of the harvest each year was made by commercial packing house representatives and tended to coincide with the first development of legal maturity of the fruit. Fruit were harvested Oct. 30 in 2006, Oct. 15 in 2007 and Oct. 29 in 2008. At harvest, the fruit from three trees in each plot were completely picked and transported to LREC for determination of yield, fruit size, grade, color and the other quality characteristics described above.

Sensory evaluation: To determine if laboratory-measured differences in percentages of soluble solids, titratable acid and juiciness would be sufficient to correlate with human sensory perception, fruit where compared from trees under the lowest and highest irrigation treatments in both 2007 and 2008 using the sensory panel established at the U.C. Kearney Ag Center (UCKAC). One of us, Dr. Arpaia, has been evaluating BrimA as a possible better measure of fruit sensory acceptability than the ratio of soluble solids/acid ratio. BrimA was calculated from measured juice soluble solids concentration and titratable acid using the formula as follows: *Brim A = % soluble solids – (4.0 * % titratable acid).*

BrimA results were compared against results from human sensory perception by following an established protocol. Fruit from four replicates of the two treatments were tested. Fruit was picked for testing on October 15, 2007 and October 21, 2008. Bagged fruit was stored at 41°F and 90% R.H. until testing at UC-KAC. On the day of sampling, samples were taken from storage and allowed to adjust to ambient room temperature (approximately 68ºF). The fruit were washed and dried for sanitation purposes. The top and bottom one-third of each fruit was cut away and discarded. The middle one- third was kept in its coded, disposable bowl and placed on trays and covered until time for cutting into bite-sized pieces. The samples were cut at the last possible minute to keep the time between cutting and eating as short as possible to reduce changes that may occur due exposing the fruit to air. The peel was cut away and discarded. Each fruit was cut into eight equal segments and placed back into the coded bowls. The bowls were placed on large trays and stacked or covered by other trays to keep the fruit segments from drying out and being exposed to contaminants.

Sensory difference testing was conducted on fruit from each treatment and replication. Panelists received randomized pairs of samples and were asked to identify whether the

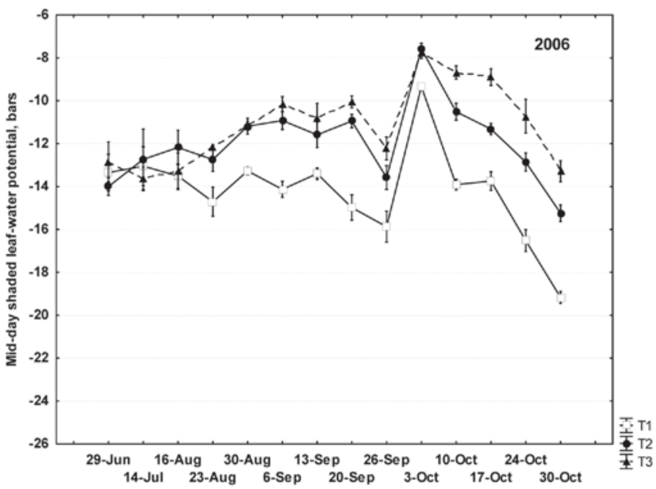

Figure 1. Mid-day shaded leaf water potential over time for three irrigation treatments in 2006.

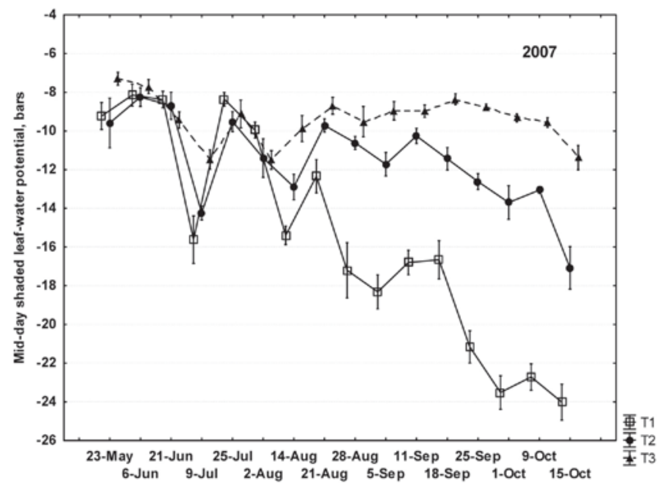

Figure 2, Mid-day shaded leaf water potential over time for three irrigation treatments in 2007

samples were “Same” or “Different”. Panelists were instructed to rinse the palate well with distilled water between pairs. Panelists could receive any combination of the pairs: 1 vs.1, 1 vs. 3, 3 vs. 3 or 3 vs. 1. The results of the tests were analyzed using statistical tables generated for paired-comparison tests. Sensory testing was performed over a two-consecutive day period. Panelists were solicited from the employees available at the University of California Kearney Agricultural Center. Some panelists had previous experience on sensory evaluation panels; others had no prior experience. Usually, several panelists are gone on any given day, so average attendance is usually 12-15 panelists for each test. A brief training session outlining procedures to be followed was provided to all panelists. The test procedures were described in detail as well as being presented in written form.

RESULTS

Applied water: Differences in applied water among the treatments were large. From Aug. 7 when the differential irrigation treatments began until harvest Oct. 30, 2006, the equivalent of 0.35, 0.64 and 0.88 acre feet of water per acre were applied to T1, T2 and T3, respectively. Neutron probe measurements also demonstrated that trees differentially depleted available water stored in the soil as the season progressed (data not shown). In Year 2007, including the increased quantity of water applied to refill the soil profile in the winter, 2.11, 2.58, and 3.55 acre feet were applied to T1, T2 and T3, respectively from the day after harvest Oct. 31, 2006 until the subsequent harvest Oct. 15, 2007. From October 16, 2007 until harvest October 29, 2008, 3.52, 2.83 and 3.45 acre feet were applied in T1, T2 and T3, respectively. Excess water was applied to the fully irrigated treatment, T3, especially in 2007 and 2008, to ensure the trees were fully irrigated. Water applied for the purpose of frost protection is minimal as fruit harvest occurs before the advent of significant frost hazard.

Tree stress as measured by leaf water potential: The degree of stress achieved in the trees was quantified by mid- day, shaded-leaf water potential measurements. The more negative the water potential value, the greater the degree of tree water stress. Generally, in the southern San Joaquin Valley during clear, dry and hot summer days, well-watered mid-day leaf water potential was in the range of -7 to -9 bars. Generally, in the three years of this study, targeted differential stress levels in the trees were not reached until late August or early September, as the trees depleted stored soil water.

In 2006, in June and July before differential irrigation treatments began, the trees in all treatments were under some stress as a result of grower irrigation scheduling with water potential in the range of -13 to -14 (Figure 1). With the onset of the differential irrigations in early Aug. 2006, water potential in the three treatments began to diverge. In 2006, differences in leaf-water potential between T1 and T2 were minimal whereas T3 was lower (Figure 1). In May 2007 and February 2008, we installed emitters with higher flow rates in all treatments to ensure the trees would be more fully irrigated prior to the imposition of stress in T1 and T2 in early August. In 2007, aside from a dip in early July, water potential values in all three treatments reflect trees that were sufficiently irrigated to prevent stress prior to the onset of the differential irrigation treatments beginning in early August (Figure 2). In 2007, good separation between the treatments, the best of the three years, was achieved, especially between the well watered treatment, T3, and the least irrigated, T1. In 2008, T1 and T3 were irrigated similarly, and T2 received the mildest stress imposed on it for the three year duration of this project (Figure 3).

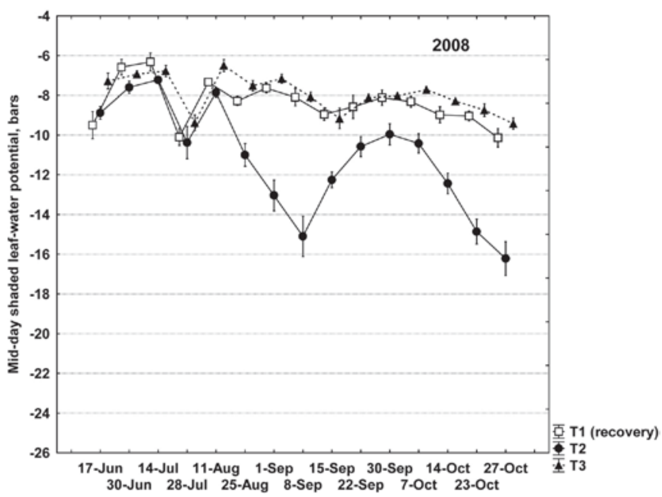

Figure 3. Mid-day shaded leaf water potential over time for three irrigation treatments in 2008.

Table 4. Effect of irrigation treatment on yield, fruit size and grade of Beck navel orange fruit in the southern San Joaquin Valley in 2006, 2007 and 2008.

Year	Irrigation treatment	Yield lbs/tree	Fruit/tree number	Percent of fruit per tree in various size categories							Fruit grade, % in category		
				< 40[1]	48	56	72	88	113	>113	Fancy	Choice	Juice
2006	T1[2]	164 a	312 a	8.5 a	20.6 a	17.1 a	24.7 a	16.0 a	6.7 a	6.4 a	96.4 a	2.7 a	0.9 a
	T2	160 a	267 a	15.5 b	25.4 a	17.9 a	24.4 a	10.6 a	3.7 a	2.4 a	96.5 a	3.0 a	0.5 a
	T3	143 a	244 a	16.0 b	23.9 a	18.8 a	23.2 a	11.4 a	4.5 a	2.2 a	96.6 a	2.6 a	0.8 a
2007	T1	261 a	566 a	4.5[3] a	9.0 a	22.9 a	31.0 b	25.9 c	6.0 b	0.7 b	53.4 a	41.6 c	5.0 b
	T2	297 b	584 a	10.3 b	18.0 b	30.2 b	25.3 a	13.9 b	1.8 a	0.1 a	61.9 b	33.9 b	4.2 ab
	T3	358 c	646 b	16.3 c	20.0 b	31.2 b	21.9 a	9.5 a	1.0 a	0.1 a	67.9 c	28.8 a	3.3 b
2008	T1	253 a	419 a	21.9 a	19.3 a	34.8 a	13.8 a	6.6 a	2.4 a	1.3 a	59.9 b	29.2 a	10.8 a
	T2	219 a	382 a	17.7 a	17.4 a	36.1 a	15.6 a	7.5 a	3.6 a	2.1 a	51.7 a	32.9 a	15.3 b
	T3	251 a	404 a	26.5 a	19.2 a	31.9 a	13.1 a	5.5 a	2.4 a	1.4 a	55.6 ab	32.1 a	12.2 a

1 Number of fruit required to fill a standard California 38 lb carton.
2 See Methods section for an explanation of irrigation treatment codes.
3 Values in the same column for a given year followed by different letters are significantly different by Fisher's protected *lsd* test at $P \leq 0.05$

Water stress and changes in fruit quality characteristics during the season: Irrespective of treatment, differences were found in some fruit quality characters between the north and south side of the trees all years. Differences between sides of the tree for juice percentage, soluble solids, titratable acid, the BrimA, and the soluble solids/ titratable acid ratio are shown for 2007 (Table 2). Some of the differences in soluble solid concentration between the south and north side of the trees appears to be result in differences in juice percentage (Table 2). In no year were differences found between sides of the tree across irrigation treatments in color development as evaluated by the human eye against standardized color pictures.

Irrigation treatment also affected fruit quality characteristics as the fruit matured. Juice soluble solids were higher in stressed trees, especially in trees in T1 in 2007 that experienced the highest stress levels (Table 3). However, even the relatively mild stresses imposed in T2 in 2006, 2007 and 2008 increased soluble solids concentration. Titratable acid was also affected by stress but not to the degree of soluble solids (Table 3). The soluble solids/titratable acid ratios were not different among irrigation treatments since both soluble solids and titratable acids increased (Table 3). Differences in BrimA were found among irrigation treatments all years and this calculated index was nearly as sensitive to water stress as the soluble solids concentration. Differences in color between T1 and T3 appeared early in 2007 as a result of the higher levels of stress in the trees of T1. The percentage of juice weight to fruit weight, generally was not affected by irrigation treatment (Table 3), nor was the ratio of juice volume to fruit weight (data not shown), suggesting that the increase in soluble solids concentration and titratable acidity was not the result of fruit dehydration but probably tree osmotic adjustment. In 2008, where T1 and T3 were irrigated similarly, fruit quality and yield were very similar between the two treatments (Tables 3 and 4), suggesting that the negative effects of water stress seen in 2006 and 2007 did not carry over into 2008 once full irrigation returned.

Table 5. Effect of irrigation treatment on fruit color at harvest as evaluated by the automated color sensor in the experimental packline at the U.C. Lindcove Research and Extension, 2006, 2007 and 2008.

Year	Irrigation treatment	Percent of fruit per tree in three color categories		
		Green	Yellow-Green	Orange
2006	T1[2]	83.8[1] a[3]	11.9 b	4.3 b
	T2	90.2 ab	7.6 ab	2.2 a
	T3	95.4 b	3.8 a	0.7 a
2007	T1	58.02 a3	42.0 c	0.0 a
	T2	78.8 b	21.2 b	0.0 a
	T3	92.2 c	7.8 a	0.0 a
2008	T1	0.0 a	100.0 a	0.0 a
	T2	0.0 a	100.0 a	0.0 a
	T3	0.0 a	100.0 a	0.0 a

1 Each value is the average percentage of fruit in each color category. Each fruit was evaluated automatically by instrument as it passed through the packline at the UC Lindcove Research and Extension Center. Each value is based on all of the fruit harvested from three trees in each of 5 plots of each treatment.
2 See Procedures for explanation of irrigation treatments.
3 Values in the same column for a given year followed by different letters are significantly different by Fisher's protected *lsd* test at $P \leq 0.05$.

Water stress and differences in yield, fruit numbers and size, grade and color at harvest: Only in 2007 was yield by weight, and total number of fruit per tree affected by irrigation treatment (Table 4). Whether this finding was the result of the second year of stress to the trees, or simply that the applied stresses were more severe compared to the well-watered trees of T3 is not clear. In 2007, fruit weight per tree in T1 and T2 were 72% and 83%, respectively, of that of the fully-irrigated trees. Differences in the distribution of fruit sizes among treatments were also most pronounced in 2007. The most common fruit size was 72 in T1 and Size 56 in T2 and T3. Fruit grade suffered as a result of the late- season irrigation stress in 2007. In T1, only 53.4 % of the fruit was packable as fancy compared to 67.9 % in T3. Even the relatively mild stress of 2008 (Figure 3) resulted in a reduction of 7.3% in the amount of total fruit that was packable as fancy in T2 compared to T3 (Table 4). The loss of grade in T1 and T2 in 2007 appeared to be associated with the development of a more tangelo-shaped fruit. Treatment 1 in 2006 and 2007, and T2 in 2007 demonstrated earlier color development, as measured by automated color sensor in the packline, at harvest than T3 (Table 5). Treatment 1, the most heavily stressed treatment of the experiment in 2006 and 2007, produced yield, fruit numbers, fruit grade, and fruit quality comparable to T3 when irrigated similarly to T3 in 2008 (Tables 3, 4 and 5).

Sensory perception: Sensory panelists were not able to differentiate between fruit from T1 and T3 in 2007 or from T2 and T3 in 2008. Table 3 shows that for both the 2007 and 2008 tests, a significant difference in BrimA between the composite juice samples for the treatments presented to the panelists. However since the panelists were presented individual fruit, the fruit to fruit variability may have masked the difference detected in BrimA and soluble solids content. The juice soluble solids/acid ratios were not different among fruit from different irrigation treatments (Table 3).

CONCLUSIONS

Three years of late-season irrigation stresses initiated in August in the southern San Joaquin Valley of California resulted in decreasing shaded, mid-day leaf water potential ranging from -14 bars in early September to a maximum of -25 bars at harvest in an early-maturing Beck navel orange variety. Compared to fully irrigated navel orange trees, increasing degrees of late-season water stress increased juice soluble solid concentration and titratable acidity, hastened development of orange color, and when severe, decreased fruit yield by weight, fruit numbers, fruit size and grade. The juiciness of the fruit either expressed as a ratio of juice weight or volume to fruit weight was not affected by late-season irrigation stress. Consumers were not able to differentiate between the taste and other sensory parameters of fruit from trees that were fully irrigated versus water-stressed at harvests in mid to late October despite measured differences in soluble solids, acidity, BrimA and color.

Our results indicate that growers that have insufficient water midsummer to fully irrigate an orchard could reduce irrigation significantly to the levels of tree stress reported in this study without severely impacting yield, size or grade. Results also demonstrate after two years of late-season irrigation stress, with trees that were fully irrigated in the spring and early summer during the stressed years, that yield and fruit quality returned the following year to that of fully-irrigated trees once full irrigation was restored.