The yield and fruit size distribution results in the Clementine trial were similar but much less marked or consistent. Possibly the young age of this block, third year of bearing, caused inconsistent results.

In both plots, counting the flowers and calculating the percent that set fruit, did not produce data that consistently supported our hypothesis that the gibberellin sprays produced less flowers.

The preliminary results are good enough that more complete trials should now be conducted on cultivars of interest. Based on the data from the three years of bearing in the younger Clementine block, complete investigation of gibberellin's potential as a thinner should be conducted on the following cultivars; W. Murcott Afourer, Clausellina and Kuno Wase satsumas and Clementine Oroval. These cultivars were selected based on their performance in a mixed block using the following criteria in this order; seediness > fruit size > and individual yield. Clementina Fina may also be a good candidate for further trials as it has good yields of small fruit.

In summary, this preliminary study demonstrated a 25 ppm gibberellin spray applied mid November through early January clearly decreased yield and increased fruit size in mature satsumas. The results are less clear with clementines and satsumas that have not reached full bearing. Attempts to count the flowers and calculate percent set failed to demonstrate specifically how the gibberellin spray affected flower production and fruit set. Further studies should focus on late fall gibberellin applications to promising mandarin cultivars.

PROJECT CONCLUDED/FINAL REPORT

Evaluation of Regulated Deficit Irrigation on Mature Orange Trees Grown Under High Evaporative Demand

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Regulated deficit irrigation is the practice using water management to impose plant water stress in a controlled manner. The primary objective of RDI with tree crops has been to control canopy size and limit applied water (Chalmers et al., 1981).

Recent work indicates that RDI can improve horticulturally important aspects of various tree crops. Goldhamer and Viveros (2000) showed that early season deficit irrigation can increase fruiting density in almond trees, and Teviotdale et al. (2001) reported that mid season RDI can significantly lower the incidence of almond hull rot. However, the practical utility of these beneficial aspects of RDI in production agriculture depends on whether they can be achieved without concomitant negative impacts on tree processes and other important fruit yield/quality components.

Water deficits in citrus usually result in smaller harvest fruit size (Levy et al., 1978; Heller et al. 1973, Castel and Buj, 1990, Sites et al., 1951). However, many of the early irrigation studies compared irrigated and dryland trees or fixed evaluated fixed irrigation schedules over the entire season rather than RDI. Domingo et al. (1996) reported that RDI did not significantly reduce fruit yield but delayed maturity in lemons. Hilgeman and Sharp (1970) suggested that periods of deficit irrigation followed by a return to full irrigation would not necessarily result in smaller harvest fruit size.

The peel disorder known as creasing and/or puff afflicts certain orange tree varieties in California. It is characterized by air spaces that develop in the white albedo of the peel and it usually is detectable only at maturity. While internal fruit quality is not affected by creasing, it reduces the packing quality of the fruit and thus reduces grower profit. Research results of irrigation effects on creasing have been contradictory; irrigation has been reported to increase creasing (Miller and Turnbull, 1948), decrease creasing (Kuriyama et al, 1981), and have no effect (Le Roux and Crous, 1938).

The study reported herein was undertaken to evaluate whether citrus RDI could reduce creasing on a particularly susceptible variety in California. Since creasing apparently depends on cell size and intercellular air spaces in the albedo, we theorized that water stresses would affect the growth rates of these cells that could influence the incidence of creasing.

MATERIALS AND METHODS

Experimental Site: This work was conducted from 1996-1999 in a commercial, 30-year old orange orchard of "Frost Nucellar" grafted on Troyer rootstock located in eastern Kern County. The soil is a shallow sandy loam with a root zone of about 3 ft. Tree spacing was 22 x 22 ft, and a clean, weed-free surface was maintained with herbicides.

Evaporative Demand: Reference crop water use (ETo) was calculated using the modified Penman technique (Snyder and Pruitt, 1989) and data collected by automated (CIMIS; California Irrigation Management Information System) weather stations. These stations were located within 12 miles of the experimental site.

Irrigation Regimes: There were 13 deficit irrigation regimes in addition to a fully irrigated treatment, hereafter referred to as the Control. The Control was managed by an independent consultant employed by the cooperating grower and scheduled based primarily on estimated ETc. The RDI regimes (T2-12) were designed to impose differing water stress levels during various time periods throughout the season (Table 1). Two additional deficit irrigation regimes (T13-14) applied water at set percentages of the Control for the entire season. The RDI saved from 9.0 to 26.4% of water applied with the Control.

Microsprinkler irrigation with single heads (11 gal/hr; Bowsmith, Inc., Exeter, CA) located midway between trees in the tree row was used. The system modified to apply the desired RDI treatments; a second lateral was installed in each tree row and equipped with a combination of sprinkler head and pressure regulator to apply target rates of 25 and 50% of the Control. Applied water was measured on each replication using in-line water meters.

Monitoring: There were six replications of the 14 irrigation treatments arranged in a split block design. Each replication consisted of three tree rows each containing ten trees. The interior eight trees of each replication were monitored. The experiment was designed to have four trees in each replication completely picked in both January and March. However, there was a freeze in December 1998 (third experimental year) that internally damaged enough fruit that the cooperating grower decided not to commercially harvest the fruit. We were only able to have a single harvest of four trees in March 1999. Additionally, heavy rains in January and February 2000, resulted in our first harvest of the final (fourth) season being delayed until early March.

Stem water potential (SWP) was measured every other week between 12:30-2:00 PM on single leaves on each of four trees per treatment in a single replication. These pressure chamber measurements (Model 3005, SoilMoisture Equipment Co., Santa Barbara, CA) were made using the technique suggested by Shackel et al. (1997).

Beginning in early June, fruit diameter was measured every week using portable electronic calipers on two fruit per tree in each replication (16 total fruit per replication).

At each harvest, four trees per replication were clean picked and gross yields measured. Fruit samples (300-400 fruit per replication) were randomly collected during each harvest and sized using an electronic sorting machine. This sample was also used to determine average fruit weight and quality. Samples of about 40 mid sized fruit was graded by professional evaluators and characterized as "Fancy," "Choice," or "Juice." The peel appearance problem that resulted in the characterization of the sample fruit as Choice and Juice was also documented, including those fruit with creasing.

Fruit load was determined based on gross yields and mean fruit weight. The electronic sizing and fruit grade data were used to calculate packable cartons ranging from 163 to 24 fruit/carton. Only fancy and choice fruit were considered as packable.

RESULTS AND DISCUSSION

Due to the unsatisfactory initial procedure used to characterize fruit quality, data from the first experimental year are excluded from the results. The means reported herein were determined from yearly averages of the two harvests in 1998 and 2000 and the single harvest in 1999.

Mean water applied to the Control was 31.6 inches compared with a mean estimated ETc of 34.4 inches (Table 1). Rainfall averaged 8.4 inches and although we did not attempt to quantify effective rainfall, it is likely that the Control treatment received full irrigation. The other irrigation treatments resulted in lower SWP at various times of the season relative to the Control (Table 1). These values ranged from -1.64 to -2.39 MPa.

The early season RDI regimes resulted in decreased fruit growth rates (Fig. 1b). However, there was a lag between the onset on tree water stress and initiation of the deficit irrigation period. For example, T3 irrigated at 25% of the Control from mid May-mid July but it wasn't until late June that consistent, significant SWP differences occurred between T3 and the Control. This was presumably due to the buffering effect of the soil moisture reservoir and the relatively low evaporative demand at the time.

The onset on tree water stress (significant differences in T3 SWP relative to the Control) occurred concomittantly with the slowing of fruit growth (Fig. 1b, 1c). In early July, T3 SWP declined to -1.7 MPa versus -1.1 MPa for the Control. This resulted in fruit growth rates of 0.23 and 0.66 mm/d for T3 and the Control, respectively. While the SWP of T3 continued to decline to mid July, reaching -2.0 MPa, there was no further decline in the T3 fruit growth rate. Upon reintroduction of full irrigation in mid July, SWP did not recover to Control values until early August. This was presumably due to the fact that the T3 soil profile was not immediately refilled even though irrigation levels returned to that of the Control in mid July. While we recognized that profile refilling was desirable following the deficit irrigation period, it was not possible with our experimental set up. Nevertheless, T3 fruit growth rates were higher than the Control immediately following the resumption of full irrigation (Fig. 1b). For example, T3 fruit growth was 0.60 mm/d in late July compared with 0.43 mm/d for the Control while T3 SWP was still significantly less than the Control (Fig. 1c). In fact, T3 fruit growth rates remained higher than the Control until mid August (Fig. 1b).

It's likely that the higher fruit growth rates following the reintroduction of full irrigation immediately after deficit irrigation is primarily due to rehydration of the fruit. However, the continued high fruit growth rates (three weeks in the case of T3) of the RDI fruit suggest that dry matter is at least partially responsible in that rehydration should be a short term phenomenon. Accelerated dry matter accumulation supports the concept of Chalmers et al. (1981) that photosynthate normally used in vegetative growth may be freed for subsequent fruit growth using RDI.

There were no significant differences in gross yields, fruit load, and packable cartons (Fancy and Choice fruit) between the Control and any of the irrigation treatments (Table 2). Individual fruit weight was lower than the Control in T6 and T9; regimes that withheld irrigation in July and irrigated at 25% of the Control from early July to mid August, respectively, and resulted in minimum SWP of -1.78 and -2.39 MPa, respectively. Thus, accelerated fruit growth in response to full irrigation following severe mid summer deficit irrigation is not sufficient to achieve Control fruit size at harvest. It is interesting to note that the minimum SWP achieved during the deficit irrigation period in T3 (-1.95 MPa) was within the range of T6 and T9 but did not have reduced fruit size. The difference was that the T3 deficit period occurred earlier in the season.

Creasing in the Control averaged 29.8% of all fruit. Creasing in the early season RDI regimes (T2 and T3) were significantly lower, averaging 18.3 and 9.7%, respectively. This resulted in significantly better fruit quality for these treatments, particularly T3. Fancy fruit accounted for 38.0% of the fruit in T3 compared with 22.1% for the Control while juice fruit was 12.0 and 20.0% for T3 and the Control, respectively. Indeed, most of the RDI regimes that imposed deficit irrigation though mid July had lower percentages of Juice fruit as did T12; no irrigation from mid October to mid December.

Holtzhausen (1981) suggested that any factor which limits the growth of the outer layers of the fruit while enhancing the enlargement of the inner layers would result in the breakage of the cell walls in the outer layer and subsequent creasing. Miller and Turbull (1948) also suggested that irrigation and creasing are related due to growth effects but suggested that it is the sudden stimulation of growth due to irrigation after a period of stress that results in creasing. Our data do not support this theory. However, the key word in relating irrigation to creasing is "growth." It is not a coincidence that the growth regulator gibberellin is commonly applied to orchards to control creasing. Tree water stress is also a growth regulator (Bradford and Hsiao, 1982). It is possible that there is a period early in the season where the rates of cell expansion in the endocarp (fruit edible parts or segments) and albedo favor the formation of weak sites (cracks) in the albedo. The endocarp and albedo cells expand at different rates early in the season (Monselise et al., 1976). It is likely that water stress during this critical, specific period of fruit development could change the relative rates of endocarp and albedo cell enlargement; slowing the endocarp without affecting the albedo. The fact that creasing is more severe in some years and early season temperature variations affect creasing (Jones et al., 1967) are consistent with our hypothesis that the magnitude of creasing depends on interactions between factors that influence the growth rates of different fruit tissues, including weather and water management.

Gross revenue was calculated assuming $6.75 per Choice carton and $9.50 per Fancy carton. These were the average industry prices during 1998-2000. There were no statistically significant differences between the Control and any of the deficit irrigation treatments. However, it is notable that the highest gross revenues of all 14 irrigation treatments were the two early season stress regimes (T2 and T3); $8710/ac and $8728/ac, respectively, versus $8085/ac for the Control.

There was a fairly strong linear relationship (correlation coefficient=0.559) between gross yields and applied water (Fig. 2a). Linear production functions are typical for most crops; certainly field and row crops. With the latter, the relationship is usually one-to-one, i.e. reductions in applied water result in an equivalent reduction in yield. This was not the case in the current study.

Production functions in tree crops are less important than with agronomic crops in that fruit quality can be a critical element in determining crop value, rather than just gross yield. This is clearly illustrated by the complete lack of any relationship between gross revenue and applied water (Fig. 2b).

CONCLUSIONS

Early season RDI can be implemented without decreasing the harvest fruit size due, in part, to accelerated fruit growth that occurs following the reintroduction of full irrigation. Regulated deficit irrigation regimes that imposed similar mid season tree water stress as the early season RDI treatments were more likely to result in smaller fruit. Creasing can be significantly reduced in navel orange using RDI regimes that impose early season water stress. Our early season RDI data suggest that applied water can be reduced by 25% relative to fully irrigated trees without reducing gross revenue. With high water costs and in areas where creasing in prevalent, it is likely that this practice can significantly increase grower profit.

Successful implementation of this technique depends on the timely imposition of tree water stress. The approach used in this experiment is not directly transferable to areas with different soils, profiles, and evaporative demands. We believe that measurements of tree water status, such as SWP, may be useful to improve the precision of RDI management.

IRRIGATION TREATMENT	1998-2000 MEAN APPLIED WATER[1] (INCHES)	DEFICIT IRRIGATION PERIOD	DEFICIT IRRIGATION RATE (% CONTROL)	1998, 2000 MINIMUM STEM WATER POTENTIAL[2] (MPA)
Control	31.6		-	-
2	25.4	thru May 31	0	-1.56
3	23.7	May 16-Jul 15	25	-1.95
4	27.9	May 16-Jun 30	50	-1.30
5	26.3	May 16-Jul 15	50	-1.40
6	23.3	Jul 1-Jul 31	0	-1.78
7	27.0	Jul 1-Jul 31	25	-1.71
8	27.8	Jul 1-Jul 31	50	-1.25
9	23.2	Jul 1-Aug 15	25	-2.39
10	26.5	Jul 1-Aug 15	50	-1.77
11	26.1	Jul 1-Aug 30	50	-1.54
12	27.0	Oct 16-Dec 15	0	-1.64
13	24.7	Season	75	-
14	28.7	Season	85	-
Rain (inches)[3]	8.3			
ETo (inches)[4]	52.9			
ETc (inches)[5]	34.4			

[1] From last irrigation in previous calendar year to harvest in subsequent year. [2] During deficit irrigation period. MPa x 10 equals measurements in bar units. [3] Mean from after harvest of period year to just harvest of subsequent year. [4] Mean for calendar years. [5] Assuming crop coefficient (Kc) of 0.65.

Table 1. Applied water, regulated deficit irrigation (RDI) periods and rates, and minimum stem water potential (SWP) achieved during RDI period.

IRRIGATION TREATMENT	GROSS YIELD (tons/ac)	FRUIT LOAD (#/tree)	FRUIT WEIGHT (g/fruit)	PUFF AND CREASE (% of fruit load)	FANCY FRUIT (% of fruit load)	JIUCE FRUIT (% of fruit load)	PACKABLE CARTONS (#/ac)	GROSS REVENUE ($/ac)
Control	20.7	1003 ab[1]	209 def	29.8 c	22.1 abc	20.0 cdef	1090 abc	8085 abc
T2	20.2	984 a	207 def	18.3 b	27.3 c	12.8 ab	1160 c	8710 c
T3	19.4	984 a	199 bcde	9.7 a	38.0 d	12.0 ab	1111 abc	8728 c
T4	21.0	978 a	218 f	29.8 c	21.4 abc	16.8 abcd	1145 bc	8502 bc
T5	20.6	996 a	209 ef	26.9 c	25.0 bc	15.5 abc	1157 c	8692 c
T6	19.5	1062 ab	187 abc	26.9 c	26.4 bc	13.8 ab	1111 abc	8367 abc
T7	20.2	1013 ab	202 cdef	30.6 cd	24.8 bc	14.8 abc	1130 abc	8466 bc
T8	20.5	983 a	213 ef	31.9 cde	20.7 ab	17.9 bcde	1126 abc	8329 abc
T9	19.8	1115 b	182 ab	30.3 c	23.7 abc	16.8 abcd	1125 abc	8360 bc
T10	20.5	1034 ab	203 cdef	38.5 def	17.7 a	22.1 def	1049 abc	7688 ab
T11	20.2	995 a	207 def	40.4 f	22.0 abc	24.4 f	1026 ab	7669 ab
T12	19.9	962 a	211 ef	26.3 bc	25.8 bc	11.7 a	1103 abc	8285 abc
T13	20.0	1030 ab	192 bcd	42.9 f	23.9 abc	24.3 f	1019 a	7686 ab
T14	20.8	1045 ab	203 cdef	31.9 cde	17.9 a	25.9 f	1012 a	7451 a
	NSD[2]							

[1] Values in each column not followed by the same letter are significantly different according to the Fisher's Protected Least Significant Difference method at the 5% confidence level.

[2] NSD indicates no significant difference.

Table 2. Mean (1998-2000) yield, quality, and revenue components.

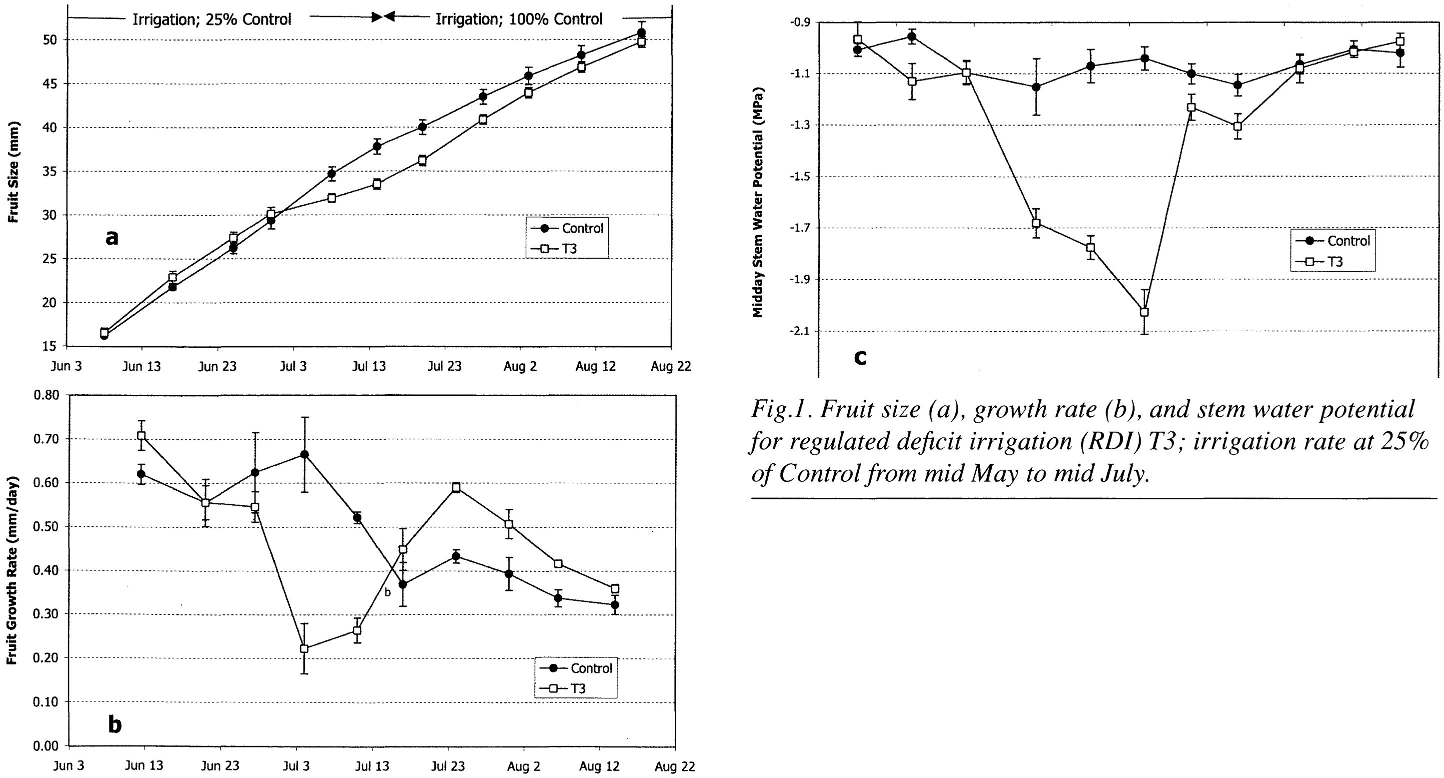

Fig.1. Fruit size (a), growth rate (b), and stem water potential for regulated deficit irrigation (RDI) T3; irrigation rate at 25% of Control from mid May to mid July.

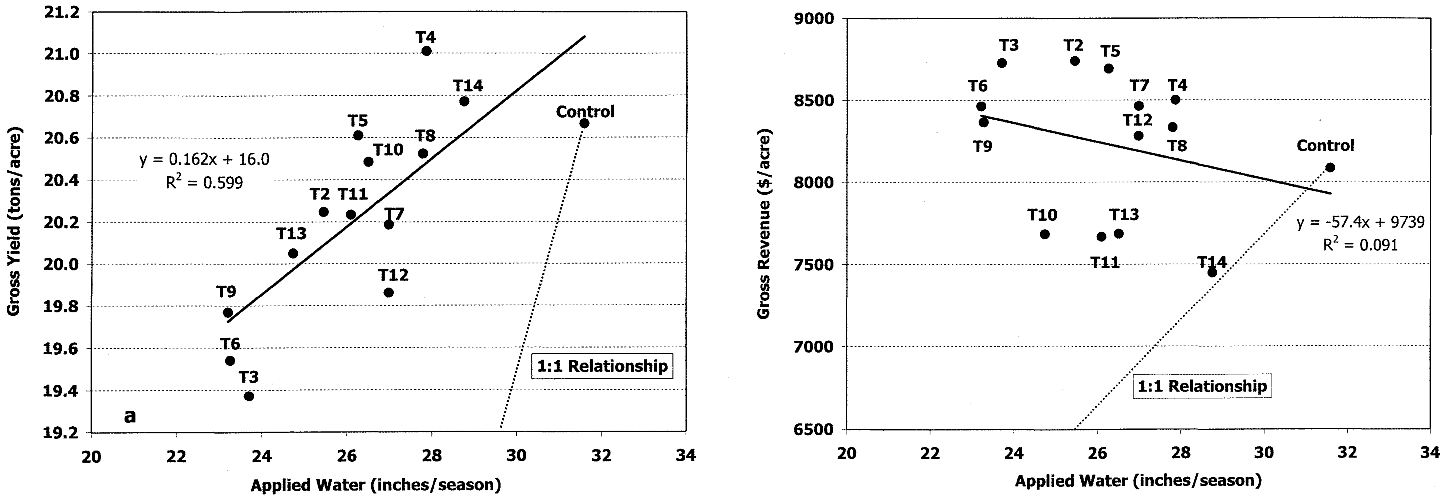

Fig. 2. Production (a) and revenue (b) for applied water using mean 1998-2000 data.