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Winter Drought Stress Can Delay Flowering and Avoid Immature Fruit Loss during Late-season Mechanical Harvesting of 'Valencia' Oranges

Juan Carlos Melgar[1], Jill M. Dunlop, L. Gene Albrigo, and James P. Syvertsen

University of Florida, IFAS, Horticultural Sciences Department, Citrus Research and Education Center, 700 Experiment Station Road, Lake Alfred, FL 33880

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***Abstract*. We determined if winter drought stress could delay flowering and fruit development of immature 'Valencia' sweet oranges to avoid young fruit loss during late-season mechanical harvesting. Beginning in December over three consecutive seasons (2007–2009), Tyvek® water-resistive barrier material was used as a rain shield groundcover under 13- to 15-year-old trees. There were three treatments: 1) drought = no irrigation and covered soil; 2) rain only = no irrigation, no cover; and 3) normal irrigation with rain and no cover. Covers were removed in February or March and normal irrigation and fertilization were resumed. The drought stress did not affect fruit yield, size, percentage juice, or juice quality of the current crop harvested in May and June relative to continuously irrigated trees. Drought stress delayed flowering by 2 to 4 weeks so that the immature fruit for next season's crop were smaller than on continuously irrigated trees during June but fruit growth caught up by September. During mechanical harvesting, previously drought-stressed trees lost fewer young fruit than continuously irrigated trees. Thus, winter drought stress effectively delayed flowering and avoided young fruit loss during late-season mechanical harvesting without negative impacts on yield or fruit quality of 'Valencia' orange trees.**

Successful mechanical harvesting of perennial fruit crops requires efficient, economical harvesting systems that do not shorten a tree's productive life or diminish fruit quality relative to hand harvesting (Roka et al., 2000). Although most of the world's citrus is harvested manually, adoption of mechanical harvesting using trunk shakers or canopy shakers and catch frames is expected to increase in the next few years as a consequence of its higher efficiency and lower costs than conventional hand harvesting (Brown, 2005), especially in the large citrus plantations of processed fruit in Florida and Brazil (Roka, 2004). No negative physiological, growth, or yield responses of mechanically harvested trees have been reported in early or midseason orange cultivars (Li and Syvertsen, 2005). In addition, mechanical harvesting during peak bloom (approximately March) in late-season 'Valencia' orange trees does not remove any more flowers than manual harvesting so mechanical harvesting has little effect on subsequent fruit set (Li et al., 2005). In late-season cultivars like 'Valencia', which have immature green fruit for next year's crop and mature harvestable fruit on the tree at the same time, no yield losses have been reported if 'Valencia' trees are mechanically harvested until immature fruit reach ≈2.5 cm in diameter (Li and Syvertsen, 2004). However, demand from the citrus industry has increased pressure to extend the harvest season past June when next year's crop becomes large enough to be susceptible to mechanical harvesting. Several studies (Hedden et al., 1984; Roka et al., 2005; Whitney et al., 1975) have reported yield losses in the next year after trees had been mechanically harvested late in the season. Techniques for improving late-season harvesting so that little or no impact on the next year's yield occurs are needed.

Citrus flowering in Florida can occur after a low temperature (less than 20 °C) or drought induction period (Davenport, 1990; Valiente and Albrigo, 2004) during the winter rest period when vegetative growth is minimum (Moss, 1969; Reuther et al., 1973). In warm tropical citrus, flowering follows rain or irrigation after a dry period (Cassin et al., 1969) and summer drought stress also can regulate flowering in subtropical Mediterranean-like climates (Barbera et al., 1985). Florida has a subtropical humid climate with ≈70% of the average annual precipitation (1100 to 1300 mm) falling between June and September resulting in relatively dry winter seasons (Obreza and Pitts, 2002). Flowering occurs in spring when soil moisture is adequate, but the start of differentiation and budbreak begins as early as late December or the first week of January (Albrigo, 1997). Thus, drought stress could delay flowering in citrus.

We hypothesized that if the Florida 'Valencia' bloom period could be delayed by a few weeks using winter drought stress without negative effects on the quality of the current season's crop, the fruitlets from delayed flowering would be too small to be affected by mechanical harvesting late in the current harvest season and thus safely extend the mechanical harvesting period. This would require a winter drought of ≈3 months duration to perhaps delay flowering ≈3 to 4 weeks. To be successful, mature fruit yield and juice quality would have to be maintained and subsequent fruit growth of the delayed crop would have to catch up to that of well-irrigated trees so as not to impact the yield or fruit quality of next year's crop. Because 'Valencia' trees commonly display alternate bearing cycles of high and low annual yields, investigations of drought treatment effects on the timing of flowering and yield require 3 consecutive years to conclusively separate treatment effects from year–to-year variations.

Materials and Methods

Tree growth conditions. The study was conducted at the University of Florida/IFAS, Citrus Research and Education Center, Lake Alfred, FL (long. 28.09° N, lat. 81.73° W; elevation 51 m). A well-managed grove with uniform, 13-year-old 'Valencia' sweet orange [*Citrus sinensis* (L.) Osb.] trees budded on 'Swingle' citrumelo [*Citrus paradisi* Macfad. × *Poncirus trifoliata* (L.) Raf.] was used. The soil was well-drained Candler fine sand with less than 1% organic matter (Li et al., 2006). The tree rows were north- to south-oriented and spaced 7 m apart. Trees were planted in pairs such that spacing between adjacent trees was 2 m with 5 m between pairs of trees in the row. Beginning in Dec. 2006, three irrigation treatments were arranged in a randomized block design with three replicate blocks of 10 trees each (five sets of two trees). Thus, the experimental design was three irrigation treatments × three blocks with 30 replicate trees in each treatment. Irrigation treatments were 1) drought stress, no irrigation with covered soil to shed rainfall; 2) rain only; and 3) well-irrigated controls, normal rainfall plus supplemental microsprinkler irrigation (rain + irrigation). Supplemental microsprinkler irrigation was applied during winter as needed up to two times per week for up to 1.5 to 4 h duration as recommended (Morgan et al., 2006) to maintain trees in a well-irrigated condition. For the rain-excluding soil covers, continuous sheets of Tyvek® home wrap (Dupont™, Wilmington, DE) were used to cover the entire soil surface under the canopies. The treatments were maintained from 4 Dec. 2006 to 15 Mar. 2007 (100 d) when the covers were removed and previously droughted trees were well irrigated.

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[1]To whom reprint requests should be addressed; e-mail jcmelgar@crec.ifas.ufl.edu.

To determine any possible treatment carryover effects into 2007–2008 from the 2006–2007 winter treatments, both previous control (rain + irrigation) and drought treatments were split in two in Dec. 2007 with half of the trees becoming well watered without soil cover (control) and the other half covered beneath canopies and subjected to drought stress (drought). Treatments were maintained from 13 Dec. 2007 to 21 Mar. 2008 (100 d) after which the Tyvek® covers were removed and all trees were well irrigated. On Dec. 2008, treatments were switched again back to the initial distribution in 2007 except for removing all covers at the same time on Mar. 2009. Consequently, some trees (n = 15) were under the same winter treatments for 3 years (e.g., drought:drought:drought), whereas other trees were under alternate treatments of drought:rain + irrigation:drought or rain + irrigation:drought:rain + irrigation, as can be seen in Table 1. The intermediate rain-only treatment was maintained during the winter season in the same trees throughout the 3 years.

Stem water potential. To evaluate tree water status, midday stem water potential (SWP; McCutchan and Shackel, 1992) was measured near 1200 HR in three previously covered mature leaves on one tree in each treatment in each of the three blocks (n = 27). All leaves were from the previous summer flushes that were located in the west side of the canopy. Leaves to be measured were first placed in aluminum foil-covered plastic bags for at least 1 h before measurement. SWP was measured periodically during the winter treatments using a Scholander-type pressure chamber (PMS Instrument, Corvallis, OR; Scholander et al., 1965) until 2 weeks after irrigation was resumed, but data are only reported for approximately minimum SWP in Mar. 2007–2009 just before resuming normal irrigation.

Flowering intensity and fruit set. Flowering intensity was estimated each year at the estimated peak of flowering time (March to April) by counting the number of open flowers within a 0.3 × 0.6-m frame placed against the branches in two canopy positions, east and west, ≈1.5 m from the ground (Ribeiro et al., 2008) in six replicate trees in each treatment, two trees per treatment in each of three blocks. Counts were made on 30 shoots per tree, 15 shoots on the east side, and 15 on the west side of the canopy within the limits of the frame. In July after May–June physiological drop, frame counts were used to estimate fruit set in each treatment as described previously. The total number of flowers (at full bloom) and green fruit (in July) per tree were estimated by extrapolating the organs counted within the area of frame to the whole canopy surface area (m^2). Canopy surface areas were estimated from a dimension analysis as a prolate spheroid surface with a flat bottom (Albrigo et al., 1975).

Juice analysis. Fifty mature fruit were annually collected in April just before harvest from six trees in each treatment, two trees from each block. These fruit were weighed and values added to the yield per tree at harvest. Samples were juiced in a processing pilot plant using a commercial extractor and percentage juice content (%), total soluble solids (°Brix), acidity (%), and brix:acidity ratio were determined using standard methods for Florida orange juice (Kimball, 1999; Wardowski et al., 1995).

Harvesting. The efficiencies of fruit removal from mechanical and hand harvesting (percent of total fruit) were compared at the end of May and at the middle of June 2007. A trunk shaker with a frequency of 4 Hz and amplitude of 0.1 m was used for mechanical harvesting (Futch and Roka, 2005a). In 2008 and 2009, mechanical and hand harvesting were compared at the beginning of June. An Oxbo 3210 pull-behind canopy shaker (Oxbo International Corp., Clear Lake, WI) at 242 cpm and 0.5 mph was used for mechanical harvesting (Futch and Roka, 2005b) in these 2 years. After mechanical harvesting, fruit left in trees were removed (gleaned) and total yield (kg) per tree was calculated. Number of fruit was estimated using the weight per fruit obtained from the samples for juice analysis. Shaking efficiency (percentage of fruit removal) was estimated every year as: mechanically harvested fruit (kg) × 100: total fruit (kg), in which total fruit weight was the sum of mechanically harvested plus gleaned fruit.

Fruitlet abscission and green fruit growth measurements. The green fruitlets that dropped on the ground at mechanical harvesting were collected and weighed. Fruitlet size (diameter) and fresh weight were immediately measured on a random subsample of 50 green fruit. In the field, the size of 60 fruitlets per tree on nine trees per treatment (three trees per treatment in each of three blocks) were measured biweekly from May to January to compare the growth of next year's crop on previously drought-stressed trees and well-irrigated trees.

Statistical analysis. Treatment effects were tested using analysis of variance and means were separated by Duncan's multiple range test ($P < 0.05$) from the SAS statistical package (SAS Institute, Cary, NC). To test for any year-to-year carryover effects from irrigation treatments, additional analyses of variance of juice quality parameters were run using only trees that received the same treatment in consecutive years.

Results

Stem water potential. Trees under drought stress had lower midday SWP values than rain-only or well-watered trees throughout the three winters with the greatest difference in March, just before resuming irrigation (Table 2). Overall, values in 2008 were higher (only 0.5 MPa different from irrigated) than in 2007 and 2009 (≈2 MPa lower than the irrigated treatment) because 2008 received the highest December through March rainfall, whereas the evaporative demand was similar (190, 168, and 172 mm in that period in 2007, 2008, and 2009, respectively). The rain-only treatment generally received an intermediate amount of water during the treatment period and at least in 2009, the SWP of the rain-only treatment was intermediate between the well-irrigated (rain + irrigation) and the drought treatments. Because uniform irrigation was resumed immediately after SWP measurements, SWP in previously stressed trees consistently recovered to values of well-watered trees within 2 weeks (data not shown).

Flowering intensity. We successfully delayed bloom for 2 to 4 weeks in mature 'Valencia' trees using winter drought stress in all 3 years (Table 3). On 1 Mar. 2007, vegetative buds and flowers were visible on the irrigated control trees, whereas no new growth was visible on previously drought-stressed trees. Drought stress was relieved on 15 Mar. and peak bloom occurred on 12 Apr. Peak bloom in the drought stress treatment was delayed almost 1 month in 2008 and for 2 weeks in 2009. The number of open flowers in previously drought-stressed trees was lower than in previously well-irrigated or rain-only trees in 2007 and 2009 but not in 2008. The drought treatment had the fewest accumulated number of flowers over the 3 years, whereas the well-watered control trees produced the greatest number of flowers. The previously drought-stressed trees, however, set a larger percentage of fruit such that there

Table 1. Description of the treatments carried out every winter with number of trees used (in parentheses).

2006–2007	2007–2008	2008–2009
Drought (30)	Well irrigated (15)	Drought (15)
	Drought (15)	Drought (15)
Rain only (30)	Rain only (30)	Rain only (30)
Well irrigated (30)	Well irrigated (15)	Well irrigated (15)
	Drought (15)	Well irrigated (15)

Table 2. Effect of winter irrigation treatment on average (n = 27) stem water potential (MPa) just before resuming irrigation on 15, 17, and 20 Mar. in 2007, 2008, and 2009, respectively, and total water applied from December to March (mm) from rainfall and irrigation.

	Winter irrigation treatment	2007	2008	2009
Stem water potential	Drought	–3.15 b[z]	–1.51 b	–3.26 c
	Rain only	–1.22 a	–1.01 a	–2.35 b
	Well irrigated	–1.21 a	–1.02 a	–1.22 a
Water applied	Drought	0	0	0
	Rain only	146	184	53
	Well irrigated	224	253	174

[z]Within each column at the top, different letters indicate significant differences at $P \leq 0.05$.

were no differences in the estimated total number of fruitlets per tree by July 2007 and 2009. Droughted trees also had fewer young green fruit than well-irrigated trees in 2008, the year with the highest fruit set in well-irrigated trees. Differences were not significant in the average total number of fruitlets accumulated over the 3 years.

Fruit growth, yield, and premature fruit loss. The winter drought stress did not significantly decrease yield of the current mature fruit crop relative to well-irrigated trees in any year of the experiment (Table 4). The average accumulated yield over the 3 years or the average number of fruit per tree was unaffected by irrigation treatment. The intermediate drought-stressed trees (the rain only trees), however, had lower yields than the well-irrigated trees in 2007 and 2009. Although there were no carryover effects on yields in 2008 or 2009 after similar consecutive treatments in previous years (data not shown), overall, yield decreased significantly for all the treatments in 2008 and 2009 compared with 2007.

During mechanical harvesting, previously drought-stressed trees consistently lost fewer young immature fruit than the well-irrigated trees every year (Table 5), although not significantly so in 2009. Immature fruitlets were smaller in diameter on previously drought-stressed, bloom-delayed trees in May and June than on well-watered trees in all 3 years. However, the development rate of the previously smaller fruit from the drought stress treatment caught up with fruit on well-watered trees by September in 2007 (Fig. 1) and fruit growth data were similar during 2008–2009 (data not shown). In addition, there was no carryover effects on fruitlet loss or diameter from similar irrigation treatments in consecutive years in 2008 or 2009 (data not shown).

The efficiency of fruit removal by mechanical harvesting was similar for all the treatments in all 3 years, although a trunk shaker was used in 2007 and a canopy shaker was used in June 2008 and 2009 (Table 6). Previously drought-stressed trees had the highest percentage fruit removal only in 2007. This was supported by the significantly greater efficiency of fruit removal from previously drought-stressed trees than in continuously well-watered trees in the earlier harvests that year (Fig. 2).

Juice analysis. The previous winter drought stress treatment did not affect average fruit size, percentage of juice, or juice quality as estimated by Brix:acid ratio of mature fruit in April in any year (Table 7) because there were no treatment effects on juice Brix or acid (data not shown). In addition, there were no carryover effects from similar irrigation treatments in consecutive years on fruit size or juice quality parameters in 2008 or 2009 (data not shown).

Effect of harvesting method. There were no differences in total fruit yield from mechanically harvested and hand-harvested trees in 2008 and 2009, although mechanically harvested trees had greater yield than hand-harvested trees in 2007 (Table 8). In this analysis, only those trees that were harvested by the same method for at least 2 consecutive years were considered.

Discussion

Although winter drought-stressed trees had consistently lower stem water potential values than well-irrigated trees, tree water status recovered very rapidly in the stressed trees after rewatering. Similar rapid responses to drought relief have been reported by Fereres et al. (1979) and Pérez-Pérez et al. (2008) in which recovery occurred in sweet orange trees in less than 1 week after resuming irrigation.

Winter drought stress effectively delayed flowering between 2 and 4 weeks and decreased young fruit loss during late-season mechanical harvesting of ‘Valencia’ oranges. Because there were no significant differences in young fruit number across treatments, the lowest number of flowers in previously drought-stressed trees in 2007 and 2009 was compensated for by the highest fruit set. In addition, although previously drought-stressed trees set a lower number of fruitlets in 2008, there were no differences in yield in 2009. This implies that there was less subsequent fruit drop in previously drought-stressed trees than in well-watered trees. There are many well-known compensating relationships among flowering, fruit set, and yield in citrus (Albrigo and Galán-Saúco, 2004; Guardiola, 1997).

Mechanically harvesting up to mid-May in citrus has been reported not to reduce yield in the next year compared with hand harvesting (Li and Syvertsen, 2004) and similar yield results have been obtained by commercial growers who have now accumulated as much as 10 years of mechanical versus hand-harvesting data (Buker et al., 2004). However, late-season harvesting of ‘Valencia’ oranges has always been a problematic issue for the wider adoption of mechanical harvesting because yields the next year had been reported to be reduced between 30% and 40% as a consequence of removal of small, immature fruit (Coppock et al., 1981; Hedden and Coppock, 1971). In our experiment, there was no effect of type of harvesting on yield of trees consecutively harvested by either method for 2 or 3 years in a row.

Across all treatments, we did have significant decreases in yield, however, in the last 2 years of the experiment. Alternate bearing by individual blocks is more severe for ‘Valencia’ than for early-season cultivars (Wheaton, 1997). In some years, alternate bearing over the entire State may be initiated by an adverse environmental event that causes severe crop reduction in a particular year as happened after the three hurricanes that struck Florida in 2004. Historically, Statewide average

Table 3. Effect of winter irrigation treatment on the maximum number of open flowers per tree on the date of full bloom (in parentheses) and the number of young green fruit per tree in July.[z]

	Winter irrigation treatment	2007	2008	2009	Cumulative 2007–2009
	Drought	906.0 b (12 Apr.)	2,383.0 (4 Apr.)	1,596.0 b (15Apr.)	4,885.0 b
Flowers	Rain only	3,109.0 a[y] (28 Mar.)	2,866.0 (3 Mar.)	3,971.0 ab (31 Mar.)	9,946.0 ab
	Well irrigated	2,704.0 a (28 Mar.)	1,831.0 (3 Mar.)	7,629.0 a (31 Mar.)	12,164.0 a
	CV (%)	67.0	72.6	92.9	57.2
	Drought	982.0	680.0 b	680.0	2,136.0
Green fruit	Rain only	1,293.0	1,077.0 ab	666.0	3,201.0
	Well irrigated	1,237.0	1,439.0 a	993.0	3,415.0
	CV (%)	34.2	44.8	80.8	35.8

[z]There were n = 6 trees × 30 shoots per treatment.
[y]Within each column in the top and bottom, different letters indicate significant differences at $P \leq 0.05$.

Table 4. Effect of winter irrigation treatment on total annual yield (kg/tree), accumulated yield over the 3 years and estimated fruit number per tree (n = number of trees, in parentheses) was the same for yield and estimated fruit number.

Winter irrigation	Yield			Accumulated yield	Fruit number		
treatment	2007	2008	2009	2007–2009	2007	2008	2009
Drought	90.8 ab[z] (16)	57.9 (15)	81.9 a (19)	191.3 ab	479	349	329
Rain only	80.0 b (8)	56.0 (10)	48.2 b (6)	165.7 b	402	282	291
Well irrigated	102.2 a (16)	66.4 (15)	72.5 a (17)	243.2 a	533	323	369
CV (%)	18.8	38.3	37.8	15.3	—	41.8	37.5
Grand mean	93.2 a	61.6 b	70.0 ab	—	—	—	—

[z]Within each column (except grand mean) and within the grand mean row, different letters indicate significant differences at $P \leq 0.05$.

Table 5. Effect of winter irrigation treatment on fruitlet loss (kg) per tree (n = number of harvested trees, Table 4) and their mean (n = 50) fruitlet diameter (cm) from harvesting.[z]

Winter irrigation treatment	Fruitlet loss			Fruitlet diam		
	2007	2008	2009	2007	2008	2009
Drought	0.6 b[y]	1.2 b	1.9	2.1 b	2.6 b	1.5 b
Rain only	1.4 ab	5.5 a	1.8	2.8 ab	3.2 a	1.9 b
Well irrigated	3.8 a	6.9 a	3.9	3.7 a	3.2 a	2.6 a
CV (%)	60.7	84.6	60.7	14.9	10.9	27.4

[z]Values for 2007 are the average of harvesting on 31 May and 14 June. Harvesting dates in 2008 and 2009 were 5 June and 1 June, respectively.

[y]Within each column, different letters indicate significant differences at $P \leq 0.05$.

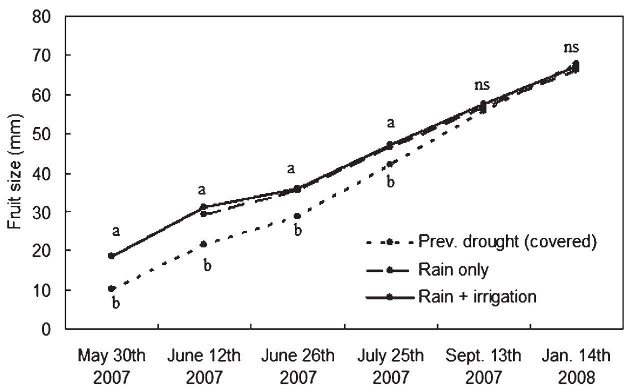

Fig. 1. Fruit size (diameter; n = 60) from harvesting time in late May 2007 until January 2008 after the three previous irrigation treatments: drought, rain only, or rain + irrigation (well-irrigated control). Measurements were done in nine trees per treatment.

Table 6. Effect of winter irrigation treatment on efficiency of annual fruit removal (%; n = number of harvested trees, Table 4) using a trunk shaker in May/June 2007 and a canopy shaker in June 2008 and 2009.

Winter irrigation treatment	Efficiency of fruit removal		
	May–June 2007	June 2008	June 2009
Drought	89.5 a	84.6	92.3
Rain only	89.5 ab	90.3	88.2
Well irrigated	78.2 b	86.4	90.8
CV (%)	9.5[z]	5.6	5.7

[z]No letters within each column indicates no significant differences.

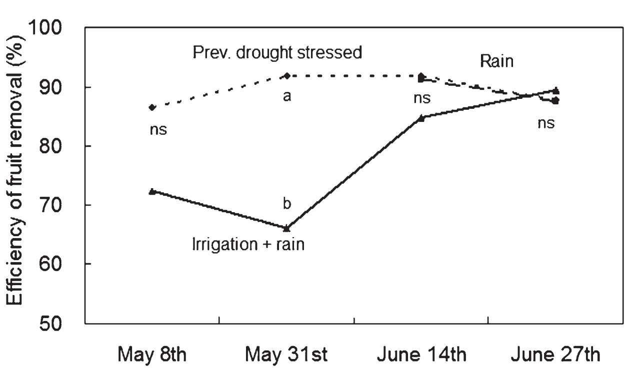

Fig. 2. Efficiency of fruit removal from mechanical harvesting trees (n = 20) on four dates in 2007 after the three previous irrigation treatments: drought, rain only, or rain + irrigation (well-irrigated control).

yields/ha of mature 'Valencia' trees tended to alternate because high-yielding years were followed by low years (Florida Agricultural Statistics Service, 2009). Yields were below the long-term average in 2007 (the 2006–2007 season) but increased back to average in 2008. Thus, the overall decline in yield in our data from 2007 to 2008 was not supported by the statewide average yields. We think this was an overall effect of the late-season harvesting, a practice known to decrease yield (Albrigo, 2006). Late harvest has been reported to increase yield in 'Valencia' in the first year of late-season harvesting, but it results in a decline of yields during the second and following years (Hilgeman et al., 1967; Jones and Cree, 1954; Ramirez et al., 1977). In 2008, we harvested some other trees from the same orchard 2 months earlier (early May) than our trees and the next year, they were late-season harvested in June 2009 as our trees and they had numerically greater yield than previously drought-stressed or well-irrigated trees (data not shown). In our experiment, the first year (2007) was an "on" year and, consequently, may have increased the negative effects of late harvests on 2008 and 2009 yields.

In previous mechanical harvesting studies, the number of immature fruit removed with a trunk shaker increased with increasing fruitlet diameter (Whitney, 1975). Here, as long as the diameter of young green 'Valencia' fruit was less than ≈2.5 cm, fewer fruitlets were dropped during late-season mechanical harvesting and consequently the next year's yield was not reduced. Although fruitlet size on well-irrigated trees at harvest was greater than on previously drought-stressed trees, the diameter of fruitlets remaining on the tree at harvest was lower (Fig. 1) than the diameter of those fruitlets that had dropped (Table 5). Thus, previously drought-stressed trees dropped fewer smaller fruitlets than well-irrigated trees and, as a consequence, there were no carryover effects from previous drought and late-season harvest treatments on yields the next year.

We found that fruit development from the drought stress–delayed bloom fruitlets caught up with the fruit size of those fruit of the earlier well-watered treatment. Other drought stress studies have reported that after normal irrigation resumes, fruit growth can proceed more rapidly than in previously well-watered trees so fruit size catches up with the well-watered trees (Furr and Taylor, 1939).

Although no differences were found in efficiency of fruit removal by mechanical harvesting in June, the previously drought-stressed trees apparently had a lower fruit detachment force than those trees that were well watered until the end of May 2007. There is a timing issue that needs to be resolved, however, because no differences were found in fruit removal efficiency between harvests in June 2008 and 2009.

Fruit growth and quality can be sensitive to drought stress (Cohen and Goell, 1988; Hilgeman and Sharp, 1970), but variations in timing and cultivar appear to be important factors. Winter drought stress did not change any measured fruit or juice quality parameters in the current crop. Because all trees in these studies were well watered beginning in March, if there were any drought-induced changes in fruit quality, such changes apparently disappeared by April. Some authors have also reported no changes in juice quality (Barry et al., 2004) when drought stress was applied late in fruit development (Stage III, as defined by Bain, 1958) or even small increases in sugar:acid ratios (Hutton et al., 2007), although other authors have reported the opposite (Sites et al., 1951) depending on the degree of drought stress.

Table 7. Effect of winter irrigation treatment on average (n = 50) fruit weight (g), percentage of juice and Brix:acidity ratio.[z]

Winter irrigation treatment	Fruit wt			Percent juice			Brix/acidity		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Drought	199[y]	181	176	60.9	60.9	53.3	19.8	17.7	15.3
Rain only	200	202	164	62.1	63.2	55.7	20.2	17.5	16.3
Well irrigated	199	202	201	60.5	60.2	57.3	20.5	17.9	16.5
CV (%)	9.7	10.6	12.0	4.9	4.7	5.9	11.2	7.2	11.1

[z]Samples were collected from six trees per treatment.
[y]No letters within each column indicates no significant differences.

Table 8. Effect of harvesting method on annual yield (kg) per tree.[z]

	Yield		
	2007	2008	2009
Hand harvested	78.9 b[y] (20)	67.7 (10)	82.9 (13)
Mechanically harvested	105.1 a (20)	61.5 (30)	63.6 (29)
CV (%)	13.9	37.8	50.9

[z]Only trees consecutively harvested at least during 2 years were considered (n = number of trees, in parentheses).
[y]Within each column, different letters indicate significant differences at $P \leq 0.05$.

Conclusion

Although late-season harvesting during several consecutive years can cause decreases in yield, winter drought stress is an effective practice to delay flowering and avoid young fruit loss during late-season mechanical harvesting of 'Valencia' oranges. Fewer flowers after winter drought can be compensated for by enhanced fruit set resulting in no decrease in yield. There were no fruit quality changes attributable to previous drought stress treatments. Late-season harvesting in 'Valencia', however, can be detrimental to next year's crop regardless of harvesting method. We used rain-excluding covers as an experimental tool, but such covers may not be a viable commercial option for growers. In addition to stopping irrigation, natural cover crops may help in inducing drought stress but are yet to be tested as a management tool.

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