J. Amer. Soc. Hort. Sci. 107(5):767–770. 1982.

The Effects of Rainfall and Irrigation Management on Citrus Juice Quality in Texas[1]

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Additional index words. Vitamin C, L-ascorbic acid, Brix, citric acid, suspended solids, naringin, *Citrus senensis*, orange, *Citrus paradise*, grapefruit

Abstract. **Juice yield, degrees Brix (soluble solids), citric acid, suspended solids, L-ascorbic acid (Vitamin C), pH, and naringin content in grapefruit were measured from 1969–1975 on 2 sizes of 'Marrs' and 'Valencia' oranges, *Citrus sinensis* (L.) Osbeck, and 'Ruby Red' grapefruit, *C. paradisi* Macf., subjected to 4 irrigation management regimes in an area where rainfall contributes about half the annual water requirement. Irrigation main effects in individual years were influenced by variable annual amounts and seasonal distribution of rainfall. Vitamin C, juice yield, pH, and suspended solids were only occasionally affected by irrigation treatment. Citric acid content of 'Valencia' orange juice was consistently higher and the citric acid and Brix of grapefruit juice were usually higher in the 2 less frequently irrigated treatments, regardless of rainfall. Among-years analyses of variance showed significant reductions in Brix, citric acid, and suspended solids with increased frequency of irrigation for all cultivars.**

For citrus grown in the Rio Grande Valley of Texas, rainfall is supplemented with irrigation. In the course of a larger study of the water requirements of 'Marrs' and 'Valencia' oranges and 'Ruby Red' grapefruit (Wiegand and Swanson 12, 13, 14), chemical characteristics of juice indicative of quality and maturity were determined annually at harvest for seven crop seasons, 1969 through 1975. Four irrigation regimes were fixed by seasonal water depletion criteria, but rainfall varied in both amount and annual distribution among years. Thus, the data afforded the opportunity to examine how juice quality or fruit maturity was affected by irrigation management, and how rainfall amount and seasonal distribution modified or eliminated water stress (or water management) main effects. This report summarizes the juice quality from this point of view.

Goell and Levy (7), in the course of long-term irrigation trials in Israel, found that the effects of water-stress treatments were observable within one season and were reliably reproducible "within ranges dictated by climatic variation." Late-ripening oranges and grapefruit, picked after winter rains and low temperatures, were less responsive to some of the variables tested than fruit harvested in the fall. Bar-Akiva and Hamou (1) indicated that waterlogging decreased fruit size and that over-irrigation and accompanying shortages of oxygen decreased N, P, and K, and increased Mg in the tops of citrus seedlings. Levy et al. (8) showed that fruit physical characteristics, e.g., thickness of rind, fruit size and set, and juice yield, were affected by water stress but not by salinity and that these characteristics were useful diagnostic tools in quantifying different kinds of stress. Total soluble solids and titratable acidity were significantly higher in the juice of fruit from water-stressed trees.

Materials and Methods

The grove studied was planted in 1964 on the U.S. Dept. of Agriculture experimental farm near Weslaco, Tex. The grove incorporated a randomized block design of 4 treatments with 3 replications each for 'Marrs' and 'Valencia' oranges and 'Ruby Red' grapefruit on sour orange *C. aurantium* L. rootstock. Each replication contained 16 trees on a 4.6 × 6.7 m spacing. The 4 interior trees served as test trees and were harvested individually to determine fruit number, size,and weight (13), whereas the exterior guard trees were harvested commercially. Soil was Hidalgo sandy clay loam (Typic calciustoll). Diuron, bromacil + diuron, simazine, and MSMA + sodium cacodylate plus hoeing were used for weed control. Azinphosmethyl, carbaryl, carbophenothion, chlorobenzilate, dicofol, ethion, formetanate hydrochloride, phosalone, spray oil and zineb were used at various times for insect control, and cupric hydroxide was used for melanose control. There were 4 irrigation treatments: A) Irrigation when 80% of the plant available water (PAW) in the surface 90 cm of soil was depleted (WD-80); B) 60% PAW depletion in the 90-cm-deep root zone at irrigation (WD-60); C) 40% PAW depletion at irrigation (WD-40); and D) Irrigation at 60% PAW depletion in winter, spring, and fall, and at 80% depletion in summer (WD-60W/60SP/80S/60F) for the 'Valencia' oranges and irrigation at 80% PAW depletion in winter and summer, and at 60% PAW depletion in spring and fall (WD-80/60SP/80S/60F) for grapefruit and 'Marrs' oranges. These treatments range from wetter than to drier than recommended grower practice. Records of rainfall were obtained at a Class A weather station within 200 m of the grove. Irrigation (border flood) was carried out as shown in Table 1. Table 2 presents the net precipitation (rainfall minus drainage) recorded in winter, spring, summer, and fall quarters, and the annual total. Subsurface drain lines at a depth of 2 m provided a well-drained and aerated root zone. Soil water content for determining depletion was measured by neutron scattering.

The 1969 crop was the first harvest studied. 'Marrs' oranges were usually harvested the second week in November; grapefruit the first week in January; and 'Valencia' oranges the second or third week in March. As in other crop years,the grapefruit and Valencia oranges harvested in calendar year 1970 were paired

[1]Received for publication June 30, 1981. Trade and company names are given for information only, and do not infer endorsement or preference by the U.S. Dept. of Agriculture over others which may be available.

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Table 1. Irrigation treatments used in this study.

Treatment	Water applied per irrigation (cm)	Depletion of plant-available water in surface 90 cm of soil (%)	Time of year (period)[z]	Cultivars
A	12	80	Throughout	All
B	9	60	Throughout	All
C	6	40	Throughout	All
D	12	80	Summer	Marrs & Ruby Red
	9	60	Fall, Winter, Spring	do
	12	80	Winter, Summer	Valencia
	9	60	Spring, Fall	do

[z]Winter (W) is from Nov. 15 to Feb. 14; Spring (SP) is from Feb. 15 to May 14; Summer (S) is from May 15 to August 14; and, Fall (F) is from Aug. 15 to Nov. 14.

with the 'Marrs' oranges harvested in 1969, because juice quality was primarily influenced by the 1969 growing season. All fruit from test trees were passed through a mechanical sizer that also counted the fruit. Size ranges for oranges were 252 (<7.0-cm diameter), 252–200 (7.0–7.8 cm), 200–125 (7.8–9.0 cm), and >125 (>9.0 cm). Grapefruit were split into 5 sizes: <112 (<9.2-cm diameter), 112–96 (9.2–9.8 cm), 96–70 (9.8–11.0 cm), 70–54 (11.0–12.1 cm), and >54 (>12.1 cm). Sixty oranges in the 252–200 and 200–125 size ranges from each replication of each treatment were randomly chosen for analysis; 60 grapefruit were collected in each of the 96–70 and 70–54 size ranges. Some 15–20 fruit of each variety were taken separately for priming the extractor. Two sizes were taken for analyses because a) these 2 sizes represented the bulk of the harvest and b) the opportunity to study differences between fruit sizes was available with little extra effort.

The fruit were processed and analyzed as described by Cruse and Lime (3), including degrees Brix, percent acid, and Brix/acid ratio. Juice yield was measured from weight ratio of juice to whole fruit. The pH and pulp (suspended solids) were determined by standard industry methods (11). The colorimetric procedure of Nelson and Sommers (10) was used for vitamin C in 1970 and subsequent seasons and reported as milligrams of L-ascorbic acid per 100 milliliters of juice. Naringin determined by the Davis test (6) was reported as parts per million (ppm).

Results and Discussion

Annual (Within-Year) Effects. In 'Marrs' oranges, the only juice characteristic affected with any consistency was soluble solids (degrees Brix); Brix decreased with increasing water availability to trees. Vitamin C content was significantly higher in the wettest treatment in 1973, which was also a year of high rainfall. However, Cohen (2) found that citrus Vitamin C content

Table 2. Quarterly and annual irrigation and rainfall minus drainage amounts by water management treatments and years.

		Nov. 15–Feb. 14 (Winter)		Feb. 15–May 14 (Spring)		May 15–Aug. 14 (Summer)		Aug. 15–Nov. 14 (Fall)			Total water	
Year	Treatment	Irrig. (mm)	Precip. (mm)	Irrig. (mm)	Precip. (mm)	Irrig. (mm)	Precip. (mm)	Irrig. (mm)	Precip. (mm)	No. of Irrig.	Irrig. (mm)	Precip. (mm)
1969	A	0	66	0	86	120	73	0	213	1	120	438
	B	87	66	0	86	183	73	86	213	4	356	438
	C	186	66	64	86	256	62	63	208	9	569	422
	D	0	66	96	86	120	73	87	213	3	303	438
1970	A	0	117	0	85	0	206	0	251	0	0	659
	B	0	117	87	85	87	206	0	300	2	174	708
	C	59	117	123	85	131	201	69	286	6	382	689
	D	0	117	99	85	92	206	86	261	3	277	669
1971	A	0	8	0	101	0	269	0	243	0	0	621
	B	89	8	91	38	89	231	197	180	5	466	457
	C	196	8	133	88	149	264	151	187	9	629	547
	D	0	8	97	101	0	269	189	171	3	286	549
1972	A	0	76	0	211	0	267	0	149	0	0	703
	B	0	76	77	182	85	240	176	149	4	338	647
	C	132	76	161	172	162	171	183	149	11	638	568
	D	0	76	80	210	0	290	161	149	3	241	725
1973	A	0	160	0	196	0	283	0	301	0	0	940
	B	0	153	0	189	0	280	0	272	0	0	894
	C	0	160	120	116	69	241	64	205	4	253	722
	D	0	160	0	196	86	202	0	252	1	86	810
1974	A	0	30	0	56	0	66	114	242	1	114	394
	B	0	30	184	56	261	66	0	260	5	445	412
	C	126	30	128	56	335	66	136	190	11	725	342
	D	0	30	84	56	177	66	86	204	4	347	356
1975	A	0	68	124	11	124	237	0	142	2	248	458
	B	0	68	196	11	95	223	100	142	4	391	444
	C	63	68	138	11	136	223	80	142	6	417	444
	D	0	68	94	11	124	271	100	142	3	318	492

was a function of sunlight, and this finding was confirmed by Nagy (9). Cruse and Lime (4, 5) reported wide seasonal variation in Vitamin C during the same period as this study. Our results indicate circumstantially that soil water conditions are not a major factor influencing Vitamin C in any of the cultivars studied. New government nutritional regulations permit a 20% variation from a season's mean content of Vitamin C (4, 5). The industry continues to determine Vitamin C and has set, on its own, a "desirable minimum" content of 30 mg/100ml of juice. This standard was met by the juice of all treatments and cultivars except treatment A grapefruit (Table 3).

In grapefruit, pH, Vitamin C, juice yield, and suspended solids were only infrequently affected by combined irrigation and rainfall. Brix and citric acid values were similar within size; the larger fruit tended to yield less juice under the same conditions of extraction. Vitamin C content was variable in both fruit sizes. Naringin content was significantly different in both fruit sizes only in 1972; in the driest treatment (A), naringin averaged 40 ppm higher than in the other 3 treatments. Evidently factors other than irrigation frequency and rainfall influence the naringin content of grapefruit juice. In contrast, degrees Brix and citric acid content of grapefruit juice were each significantly affected by irrigation treatment in 7 of the 12 analyses run for the 2 fruit sizes. Generally the acid and soluble solids were higher in the 2 drier treatments (A and D).

In 'Valencia' oranges, the juice yield of size 125 was affected by irrigation treatments in 4 of the 6 years, whereas the juice yield of size 200 was affected in only 2 of 7 test years. The citric acid response to water conditions was significant across the 2 fruit sizes in 11 of 13 data years. Increasing water availability consistently decreased citric acid content. Differences in soluble solids were significant at the 0.01 level among irrigation treatments in 3 of 7 years. Vitamin C, pH, and suspended solids did not respond to water conditions.

Long Term (Among-Year) Effects on Juice Quality. Table 3 summarizes the among-year (long-term) treatment means for juice quality characteristics. The most consistent effects of irrigation treatments occurred in the 'Marrs' orange, where in all cases of significance, the juice attributes decreased in value in the order of increasing frequency of irrigation. Fruit of this cultivar increased in size and matured rapidly in the warm August to November period, when evaporative demand is high. Hence it is logical to expect 'Marrs' oranges to respond to available soil moisture more consistently than grapefruit which was not harvested until January, and 'Valencia' orange which was not harvested until March of the year following bloom. Water is withheld beginning in November to promote cold tolerance and to prevent growth flushes.

Brix, citric acid, and suspended solids of 'Valencia' orange and 'Ruby Red' grapefruit responded in the same order as the 'Marrs' orange. These, therefore, are the chemical characteristics most responsive to soil water conditions. The among-year analyses were less affected by the amount and distribution of rainfall than were the intra-year analyses because the irrigation treatments were rigorously adhered to for the duration of the study, whereas rainfall each year was unique and unpredictable. Thus one could argue that rainfall and environmental factors not considered in the analyses were more important than soil water conditions in influencing juice yield and Vitamin C content.

The often-lacking response of juice yield and Vitamin C content to water management implies that fruit from groves that differ widely in water management will differ little in juice yield

Table 3. Average juice quality characteristics of 2 sizes of 'Marrs' and 'Valencia' orange and 'Ruby Red' grapefruit, 1969–1975.[z]

Cultivar	Size	No. of seasons	Treatment	Brix (°)	Citric acid (%)	Suspended solids	Juice yield (%)	Vit. C (mg/100ml)	pH	Naringin (ppm)
Marrs	200	7	A	10.6a	0.565a	18.2a	57.3	32.2	4.26A	
			B	10.2b	0.549ab	17.0ab	56.2	31.6	4.19B	
			C	10.0b	0.541b	16.6b	56.7	33.4	4.17B	
			D	10.2a	0.565a	17.9a	56.7	33.3	4.22AB	
Marrs	125	7	A	10.2a	0.54	18.1a	57.0a	32.0	4.30a	
			B	9.9bc	0.54	17.4ab	55.8ab	31.9	4.22b	
			C	9.7c	0.53	16.5b	54.6b	32.7	4.20b	
			D	10.0ab	0.53	17.8a	55.8ab	31.5	4.24ab	
Valencia	200	7	A	11.4a	0.89a	16.4	57.9	36.1	3.85b	
			B	11.4a	0.79b	15.7	56.5	35.1	3.87b	
			C	11.0b	0.79b	16.1	57.3	34.2	3.99a	
			D	11.2ab	0.82b	16.2	56.9	35.2	3.94a	
Valencia	125	6	A	10.7	0.87a	15.9	57.1	33.5	3.85b	
			B	10.8	0.78c	15.4	56.0	34.3	3.89b	
			C	10.6	0.78c	15.5	56.5	33.1	4.00a	
			D	10.7	0.83b	15.8	57.5	33.2	3.96a	
Ruby Red	96	5	A	9.7a	1.28a	13.9a	54.6	29.2	3.21B	177A
			B	9.6a	1.22b	13.5a	55.2	31.6	3.22AB	169AB
			C	9.3b	1.18c	12.4b	55.0	30.4	3.27A	147A
			D	9.8a	1.24ab	13.9a	55.1	32.0	3.26A	154B
Ruby Red	70	7	A	9.7a	1.24a	12.6	53.7	29.3	3.32	168A
			B	9.3b	1.18bc	12.5	53.7	31.2	3.34	155B
			C	9.0c	1.15c	12.0	53.0	30.8	3.38	143C
			D	9.5a	1.20b	12.6	53.7	31.0	3.34	152BC

[z]Mean separation within quality characteristic within cultivar and size groups by Duncan's multiple range test, 5% level (lower case) or 1% level (upper case).

and L-ascorbic acid, and that irrigation water shortage will have little effect on these components. Vitamin C content in orange juice over the duration of this study exceeded industry standards; Vitamin C in grapefruit juice from the driest treatment was sometimes lower than the industry standard.

On the other hand, high soil moisture levels strongly lower soluble solids and citric acid levels and unusually wet years can cause problems in meeting industry standards. The 7-year average of the Brix/acid ratio was about 18 for 'Marrs' orange, 7 + for 'Ruby Red' grapefruit and 12–13 for 'Valencia' orange (mid-season harvest). Consideration of the timing and amount of rainfall can provide the industry with a tool to anticipate the Brix, citric acid, and soluble solids of the upcoming harvest.

We could only consider annual and long-term effects of irrigation treatments and interactions, because juice was sampled only once a year. Elsewhere (15) we used regression procedures to examine juice quality response to quarterly water use, defined as water applied + rainfall − drainage − (90 cm deep) root zone depletion. We found that water conditions during the fall quarter preceding harvest influenced citric acid, Brix, and pH of 'Valencia' oranges and 'Ruby Red' grapefruit more than at other times of the year. In 'Marrs' orange, harvested in November, water conditions in the summer quarter (May 15 to August 14) affected Brix the most; water conditions in the winter quarter as well as in the summer and fall quarters affected citric acid content and soluble solids, respectively. Because 'Valencia' and 'Ruby Red' grapefruit size rapidly in the fall, and 'Marrs' orange sizes rapidly in summer and early fall, the data indicate that juice characteristics which respond to soil moisture are most affected during the period of rapid increase in fruit size that precedes maturation. Thus, our results could be extrapolated to other production areas even though seasonal rainfall amount and distribution differ from that of Texas.

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