WATER RELATIONS AND CITRUS FRUIT QUALITY

L. G. Albrigo[1]

Both water stress and excess available moisture have been implicated in fruit quality problems (both internal and external) of citrus. A basic understanding of tree-fruit water balance is important in considering the relationship of plant moisture to fruit quality.

FRUIT WATER BALANCE

Early workers (34) discovered that fruit volume growth responds to irrigation. Diurnal shrinkage of the fruit occurred with minimum size reached about 2:00 P.M. The fruit recovered its original size plus some gain each night until soil moisture was depleted. An irrigation at this time allowed the fruit to resume growth in this diurnal pattern. It was found subsequently that leaves draw water from the fruit through transpiration (32). Fruit moisture lost during this process comes primarily from the peel. Diurnal fruit shrinkage from daily leaf transpiration was accompanied by diurnal changes in osmotic and water potential of the peel (25). The juice vesicles are anatomically isolated from the vascular system in comparison with the peel and do not change water status as rapidly (25). Fruit water potential decreased daily during a drying period following an irrigation.

Leaf water potentials decreased with higher transpiration rates (10). The water potentials were even lower if the plants were pre-stressed by soil moisture drying cycles. Fruit water potential should be expected to behave in the same manner.

The fruit itself transpires moisture, besides the influence of leaf transpiration on fruit water content, and this contributes to drying of the fruit's peel. The rate of moisture loss per unit area of healthy fruit surface is less than 1/3 that of the leaf. This is primarily because the stomata are further apart on the fruit, do not occur over the oil glands and are not present next to the calyx (button) at the stem end (1). Some of the stomata present are nonfunctional due to plugging with wax (5). This same wax occurs as a platelet coating of the surface between the stomata (5) and can vary considerably in thickness and corresponding water loss resistance (1), depending upon the climate and general growing conditions in a given grove (3). Heavier coatings of wax could reduce water loss by increased plugging of stomata rather than as a direct barrier over the whole surface. It is not known if the number of wax-plugged stomata are proportional to the total wax.

ANTITRANSPIRANTS

Antitranspirants are a means of alleviating plant moisture stress and thereby of treating fruit disorders induced by moisture stress, hence the basic effects of these materials should be considered. Only film-forming materials will be discussed, since stomatal closing chemicals are not cleared for use.

Film-forming antitranspirants have been used on several fruit crops (4, 6, 8, 11, 12, 13, 14, 15, 16, 17, 29). These materials increase diffusion resistance of leaves to water vapor (11), reduce water transpiration (8, 12, 16, 17), and reduce internal tree and fruit water stress (11, 13, 15). Total yields have been increased (14, 15, 16) but total soluble solids were diluted (6, 14, 16) and sometimes total solids per fruit were reduced (14). Applications of antitranspirants at earlier stages of fruit growth were more likely to reduce total solids production than applications closer to harvest (14). Most of the yield increases have been the result of increased fruit size. Antitranspirants have not been adequately tested as means of increasing fruit set where water stress is believed to be causing excess fruit drop.

Film antitranspirants form discontinuous layers on leaves (2) and fruit (5) which block or partially block some of the stomata and coat the interstomatal areas (2, 5, 29). Considerable variation exists between antitranspirant materials in their ability to adhere to the epidermal surface and resist weathering. Some materials will persist for several months (2), while others lose effectiveness within 1 to 2 weeks (17).

Various plastic film materials (35) and film-forming materials (7, 8) have been evaluated for their permeability

[1] Associate Horticulturist, Agricultural Research and Education Center, IFAS, University of Florida, Lake Alfred.

to gases important in plants (carbon dioxide, oxygen) and to water vapor. Materials have always been shown to be more permeable to the smaller water molecule than to carbon dioxide or oxygen. This means that films will tend to inhibit photosynthesis more than water loss on a gas exchange basis, particularly if coatings are very thick (8). It has been found in practice with thinner film coatings that photosynthesis may not be reduced very much even though water loss is significantly reduced (11, 16). This comes about in at least 3 ways: 1) the amount of carbon dioxide required for photosynthesis by plants as compared to the water lost is small and part of this carbon dioxide may be supplied from respiration; 2) those stomata not covered by a film coating stay open longer with reduced water stress and have wider apertures (11) for carbon dioxide uptake; and 3) improved internal water balance may permit better enzymatic activity for photosynthetic metabolism. Humid air allowed photosynthesis to continue at higher temperatures when compared to a dry air stream (31).

Antitranspirants can be used to avoid extreme plant moisture stress and water use, if they are applied at the proper time and at low rates if fruit are on the trees (4, 6, 14, 15). Higher rates can be used on transplants successfully but heavy coatings (5% or more of actual film-formers by volume) will reduce photosynthesis and may physically restrict growth (29).

FRUIT QUALITY PROBLEMS RELATED TO WATER STRESS

Creasing

Creasing is characterized by separation of the tissue in the albedo to leave depressed lines in the peel. These cleavages have been reported to occur as early as 2 months after full bloom in 'Washington Navel' oranges (21). Tree nutrition has been shown to play a role in the incidence of creasing (23). Potassium nitrate sprays and thicker fruit peel have been associated with reduced creasing. Some workers have reported creasing increased with irrigation, while others have found no relationship (see 23). Jones *et al.* (23) found that fruit on the south side of the tree (greatest heat load) developed creasing earlier and more severely, and the inside of each fruit was more likely to be damaged. They suggested that radial temperature gradients might create a differential water stress across the fruit leading to albedo stress and subsequent creasing. It has been reported that high water stress can lead to breakdown of loosely packed mesophyll-type cell structures (18). It appears that late spring would be the time to expect initiation of creasing (21) and the best time to assess the role, if any, of temperature and water stress on creasing.

'Valencia' Segment Dehydration

'Valencia' oranges, particularly those on rough lemon rootstock, often develop a desiccated condition of the stem end of the segments in southern Florida groves. This condition develops in nearly mature fruit in the spring. The drying has been observed to extend halfway down the juice segments of some fruit. This has resulted in juice content reductions of up to 20%. The cause of this disorder may be related to the higher evapotranspiration in the southern parts of the state in the fall to spring period. Monthly mean temperatures are usually 4 to 6^{o} F higher in southern than in central Florida. Adequate irrigation is often not provided during this time period. Flatwood soils of this area are usually shallow and have low water-holding capacity.

Average leaf-water potentials in 1975 (Table 1) showed that lows of −25 bars were present in January and were raised to −10 to −15 bars after irrigation was started. Daily temperatures and humidities for the test periods indicate that greater transpiration, and therefore lower water potentials, would have been expected later in the spring if soil moisture levels had been comparable.

The exact role of water stress is not known but 3 possible effects could be involved in the drying out of the juice vesicles: 1) high water stress can lead to tissue breakdown (18); 2) the relatively slow movement of water into the juice vesicles as compared to the peel (28) might

Table 1. Leaf water potential at 2:00 p.m. of 'Valencia' orange trees in south Florida on flatwood soil (1975) before and after irrigation started.

Rootstock	Date 1/29[x]	2/18[y]	3/17[y]	4/29[y]
	Bars	Bars	Bars	Bars
Carrizo	−21	−13	−13.5	−14
Sour orange	−25	−18	−13	−13.5
Rough lemon	−17	−15.5	−11.5	−10.5
2% AT—% Reduction[z]		23%	10%	10%
2:00 p.m. temperature ^{o}F	82	86	89	90
2:00 p.m. relative humidity (%)	82	77		61

[x]Before irrigation system in operation.

[y]After drip irrigation system operating.

[z]Antitranspirant (AT) spray applied February 17, 1975. Average water potential reduction for 3 rootstocks.

be reduced further under continued water stress to the point where even slow movement to the peel for transpirational loss is not replenished, and 3) translocation to the fruit is greatly curtailed under high water stress (31). The ramifications of greatly reduced carbohydrate movement to the nearly mature fruit for an extended period of time are not known. Mineral movement also might be curtailed.

'Pineapple' Pitting

Pineapple' orange pitting develops on the tree just after color break in the Indian River Citrus Area. Most of the flavedo cell collapse occurs from the equator to the stylar end of the fruit. Affected areas are first noticeable as shrunken areas that subsequently turn a dark brown. Additional injury areas often become evident after packing and shipping the fruit, but all the predisposed injury areas will develop on the tree if the fruit is harvested late enough. Addition of a film antitranspirant before the dry fall period began reduced the amount and severity of this disorder (6) (Table 2). Both fungicides and antitranspirants reduced the incidence of 'Pineapple' pitting in another experiment. More surface wax was present where fungicides were applied when compared to the untreated fruit (Table 3). Surface microorganisms may be involved in this disorder through their action on the epidermal cells or the surface wax layer. It appears that reduction fruit water loss and subsequent water stress are important factors in reducing the incidence and severity of 'Pineapple' pitting.

Stem End Rind Breakdown

Stem end rind breakdown (SERB) occurs in oranges after harvest, particularly if they are held for 2 to 3 days at low relative humidity before washing and waxing (19, 22) (Table 4). A zone of flavedo tissue starting 3 to 5 mm from the button and extending 10 to 20 mm toward the equator is susceptible. The area becomes sunken and eventually brown if SERB develops. This susceptible area next to the button has no stomata and a thicker wax coating (1). The vascular system does not branch extensively into the thicker albedo tissue in the area around the button, which may result in slow water replenishment. Field treatments with antitranspirants 1 to 2 months before harvest to reduce water stress have reduced the incidence of SERB in the packed fruit (Table 5). It appears from the slight reduction that preventing fruit water loss after harvest is much more important than preharvest conditions. (Tables 4, 5).

'Valencia' Aging

'Valencia' orange aging often occurs when the fruit is stored for 2 or more months at low temperatures (0 to 4.4° C). The peel around the button becomes wrinkled and can take on a grayish cast. There is no visible evidence of necrosis. More of this disorder occurs when the fruit is

Table 2. 'Pineapple' pitting reduction by a preharvest antitranspirant (AT) spray (Indian River, flatwoods soil).

Treatment	Date 12/11/69	2/18/70
	Rating[z]	
Control	1.7 a	2.0 a
AT 0.5%	1.5 b	2.0 a
AT 1.0%	1.2 b	1.8 b

[z]Final value is a weighted average based on this scale: 1 = no pitting, 2 = slight pitting, and 3 = severe pitting. Values followed by unlike letters in a column are significantly different at the 5% level.

Table 3. Surface wax material on 'Pineapple' oranges 2 months after field treatments with fungicide sprays.

Treatment	Total wax[z]	20-Day weight loss[z]
		(%)
Control	75.3 a	8.6 b
Benomyl	91.0 b	6.6 a
Difolatan	98.4 b	6.6 a
Benomyl + Difolatan	100.3 b	5.4 a

[z]Values followed by unlike letters in a column are significantly different at the 1% level.

Table 4. Effect of delayed handling and low humidity on stem end rind breakdown (SERB) of 'Valencia' oranges.

Treatment	Avg temp (°F)	Avg RH (%)	SERB 1 week (%)
Washed and waxed at once	70	–	1.6
Delayed handling	77	69	16.6
Degreened—high humidity	85	94	0.6
Degreened—low humidity	83	74	77.5

Source: Hopkins and McCornack (21).

harvested in early May. Antitranspirant sprays 1 to 2 months before harvest greatly reduced this disorder (6) (Table 6). It was also found that high humidity storage, over 95% relative humidity, and use of wax-impregnated cartons were very effective in reducing 'Valencia' aging.

FRUIT QUALITY PROBLEMS RELATED TO EXCESS WATER

Diluted Total Soluble Solids

Excess irrigation or rainfall can lead to undesirably low total soluble solids, although sufficient irrigation is needed for adequate fruit set and development (28, 33). Irrigation was shown to result in diluted total soluble solids of both grapefruit (33) and oranges (28, 33) (Table 7). A simulated drought period from July through September (normal rainy season) resulted in higher total soluble solids than simulated droughts at any other time of year (33).

Fruit Splitting

Fruit splitting occurs primarily during the fall when the fruits are fairly high in total soluble solids and the peel has thinned. Fruits are under internal turgor pressure (25) and this pressure is greater with increased soil moisture after irrigation (24) or rainfall. Most of the structural strength to resist splitting occurs in the outer peel (26) and probably is specifically in the outer cuticle-epidermal wall complex. It has not been determined if reduced structural strength or increased turgor pressures from one year to another causes the high fruit splitting years.

Water Spot

Water spot of 'Navel' oranges is caused by absorption of moisture through the peel when winter rains extend over several days in the January-April time period in California (27). Absorption takes place through sites in the surface, weak either because of continued cell division or surface injuries as from wind damage. Peel oils are released under the excessive cell turgor pressure and accelerate tissue destruction. Fungal invasion often follows the initial damage.

Oleocellosis

Oleocellosis occurs during harvesting operations when oil is released by damage to the surface oil glands (9, 30). The damaged ares will remain green subsequent to ethylene degreening. Injured areas eventually become slightly sunken and then turn brown (9, 30). The oil glands are most easily ruptured if the fruit has a high turgor pressure such as that which occurs early in the morning (9, 20, 30) when fruit water potential is highest (25) or shortly after irrigation (9) or rainfall.

Table 5. Preharvest antitranspirant (AT) effect on postharvest stem end rind breakdown (SERB).

Treatment	% SERB	
	'Pineapple'	'Valencia'
Control	84.1	22.2
AT 1%	66.6	–
AT 3%	–	8.3

Table 6. Influence of a preharvest antitranspirant (AT) spray on stem end aging of stored 'Valencia' oranges.

Treatment	% Aging[z]		
	1970	1971	1972
Control	34.1 c	33.9 b	10.7 b
AT 1%	24.5 bc	36.1 b	5.7 a
AT 3%	7.2 a	7.5 a	4.4 a

[z]Values followed by unlike letters in a column differ significantly at the 1% level.

Table 7. Influence of irrigation (I) on Brix (total soluble solids) and acidity of orange and grapefruit.

Treatment		Brix (°)	Acidity (%)	Ratio
Oranges, 7-yr average[y]				
Hamlin	I	9.9	0.93	10.6
	NI	10.3	1.00	10.3
Pineapple	I	10.9	1.02	10.7
	NI	11.3	1.09	10.4
Valencia		11.2	0.96	11.7
	NI	11.8	1.02	11.6
Grapefruit, 3-yr average[z]				
Duncan		8.8	1.37	6.4
	NI	9.1	1.50	6.1
Marsh	I	8.0	1.28	6.3
	NI	8.8	1.39	6.3

[y]Source: Koo and Sites (27).

[z]Source: Sites et al. (32)

Stylar End Breakdown

Stylar end breakdown of 'Persian' limes is associated with harvesting the fruit while wet or turgid (20). The pointed stylar tip is easily damaged by rough handling, especially if the fruit is harvested early in the day when it is most likely to be firm due to a higher moisture content.

Zebra Skin

Zebra skin of tangerines is most likely to occur when harvesting occurs 2 to 4 days after a rainfall that was preceded by a dry period (19). The damage occurs as longitudinal dark areas over each segment, giving a striped appearance. The damage appears to be a bruising of the turgid peel lying over each segment. This is the only peel in contact with and rigidly backed by the juice segments. Some internal oil release may be involved in the damage.

SUMMARY

There is ample evidence that both water stress and water excess situations at times can cause fruit disorders and lower fruit quality. A rapid change from dry to wet conditions can be particularly detrimental. All the implications of tree and fruit water balance in fruit quality and specific disorders are not fully understood. Methodology for detailed studies of plant water balance now exist and make it possible to define more clearly the role of plant moisture in fruit growth and development and ultimate fruit quality. This area of research should receive considerable attention in the future.

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QUESTIONS

Q: Are any of these materials available for use yet?

Albrigo: Almost all of the films and antitranspirants are cleared. Actually, what it amounts to is that all of the testing is waived, as long as it is demonstrated to be a film-former, with no absorption by the plant. There are 5 or 6 materials that are available on the market. I think the economics of the application of antitranspirants are such that it is not an economical process at this time. It has some real promise in the nursery trade and in transplanting, but as far as spraying entire trees, with the cost of the material and the information we have on the benefits, it is questionable. We have done some studies that have indicated to us that on our deep soils in the Ridge, it would be possible to substitute a single application for irrigation.

If that were done. and we had that in Dr. Niles' variables to consider the cost of that versus irrigation, and we had some production figures, that might be interesting to look at. We might be at about a breakeven point in terms of irrigation cost (including installation) versus using this, because these materials might cost as much as $100 per spray per acre. They are pretty expensive. When you spray small trees, you can control the volume. When you can dip the plant, or you don't have to spray as much area, it can be done economically. However, these have to be put on as dilute spray, and the volume per acre makes these sprays pretty expensive when they cost $10 to $20 per gallon and you have to apply them at rates of about 1%.

Q: What is you assessment of the price of these products and the possibility of the prices coming down in the future?

Albrigo: It would seem to me that many of them are overpriced, based on 2 things. One is that there are basically 3 types of antitranspirants: 1) the artificial ones that are made basically like latex acrylic paint, the base for which doesn't cost anything like $10 per gallon, so I think the manufacturer could bring the price down. 2) A type that I think is a fairly good antitranspirant is the fraction of natural hydrocarbon waxes that comes from oil distillation. This is a fraction that comes from the refinery—they have to find uses for it. I have talked to a couple of people who used to be in the business and they don't think it costs more than $0.50 per gallon; yet, they're selling around $10 per gallon. 3) Finally, for the polymer polyterpene antitranspirant, there's no way I can judge what it costs to produce, but I suspect that maybe it doesn't cost $20 per gallon.

However, the manufacturers all have problems in that they are dealing in relatively low volumes of sales. Obviously, a lot of their cost is in labor and management. If we got to the point where we really saw some benefits from using large volumes of antitranspirants, there's a good chance that the price will come down, particularly if we can get some data comparing different ones and showing that there are 2 or 3 that are equally good to use. If we could do that, then we could create competition, which would help lower prices.

Q: Have you done work with 'Nova', in particular on rough lemon, as to fruit drying out?

Albrigo: No, I have not. Relative to the drying condition in mandarins and mandarin-types, I'm not sure that it is a water-stress problem as much as it is our having to realize that there is a very short period of time when most of the mandarin varieties are truly suitable for harvest. They go from immature to mature in a short period of time, and 2 weeks later, they are overmature. As soon as they are overmature they start to dry out.

Most of the problems that people run into in drying out of mandarin-types, tangerines and hybrids, is more a problem of not realizing this maturity relationship than it is a truly unusual situation of drying out. I have heard occasional reports of some of these hybrids that may be more of a problem and there may be something we could do with them. However, it's hard to find any to work with, and that's one reason we've not looked at them as much. Even so, you have to be very careful about watching maturity and harvest the mandarin-types when they're ready. They are not an orange. We get away with a lot of things in terms of harvesting all of our citrus, even though we think we can store them on the tree. This is really not a good practice from the standpoint of fruit quality.

Q: Have you ever tried any of these on the oleocellosis problem in fresh lemons?

Albrigo: No, but I would expect that it would accentuate the problem by increasing the water potential within the fruit. We have used the antitranspirants where we felt we had a water-stress problem, and we've applied these in the field, we have generally reduced the amount of the disorder. We usually don't completely eliminate it, but we do reduce it. So I think we're on fairly sound ground there, but I have felt that the antitranspirants would accentuate the problems involving excesses of water.

Q: Are you at the position where you might give us something definite on the use of these materials with young trees?

Albrigo: Not completely, but I can say that we have evidence from some studies last year, which are supported by work in citrus in other places and on other crops. In container plants, where the plants will dry out relatively rapidly, the films can cut down on how often you have to irrigate. Of course, under a sprinkler system, this may not matter too much. However, when you move the plant out, there may still be a benefit.

In transplanting, I think there can be some real benefits if the material is put on at least a week before transplanting, so that the film has a chance to stabilize. There is at least one nursery using the material. There are some materials that are sold that don't work, however, but I don't want to get into that at this stage, due to limited evidence and the fact that there are still an awful lot of materials that we haven't tested.

Q: In the nursery, are you using more than 1%, and are there any phytotoxic effects at higher concentrations?

Albrigo: Generally, phytotoxic effects don't occur until concentrations reach 5% or higher. We are generally recommending 2 to 3% concentration for someone who wants to try it on transplants. Because it doesn't matter about diluting solids or anything like that, you can use these higher rates to obtain greater reduction in water use. If you are applying it either by dipping the plant or by controlled spraying on a nursery row, where you have almost continuous canopy, I think you can put on a fairly low rate per acre and perhaps afford to do it.

Q: Have you found anything regarding differences in root generation of transplants by using the antitranspirants?

Albrigo: We haven't checked root generation as yet.

Q: Is it economical to use the antitranspirants for cold storage of 'Valencia' after harvest?

Albrigo: My feeling is that in some years, it could be. However, we have a subsequent study using very good storage conditions of very high humidity and one of the better wax-impregnated cartons, so that the carton won't absorb a lot of moisture. When we've done this, and been very careful about the time of harvesting 'Valencia', being that we harvested them as early as they were mature so that they did not go through dry periods on the tree, we can end up with a very good product, even though we might have to hold it a month longer in storage. 'Valencia' will keep better in storage than on the tree, and will have a higher acid level by virtue of having had a higher acid level due to the earlier harvest.

So, from the point of view of the benefits in storage, I'm sure that it would not be economically profitable. However, if you had a grove without irrigation and substituted antitranspirants annually for irrigation in the spring, there are some real possibilities, particularly as water becomes expensive to us. It is something we will have to look at for the future and we will continue to do some work on it.

Q: In using the antitranspirant films, wouldn't there be adverse effects on photosynthesis and translocation of photosynthates in the developing new shoots due to coverage of the film? Also, when should the material be applied in relation to growth flushes, inasmuch as application before the expansion of a growth flush would leave the growth flush unprotected, whereas later application would not provide benefits for the development of the respective growth flush?

Albrigo: In some respects, this is true. However, there are some things going on in the tree that help out. One of the important things is that photosynthesis and translocation of photosynthates do not occur if the plant is under water-stress conditions. So, it is a compensating effect in that we reduce the ability for photosynthesis, but we can increase the general photosynthesis during the daytime by alleviating the water-stress conditions. So the detrimental effect that you might expect usually doesn't show up as anything more than a slightly measurable effect.

The other important thing is the question of when the material should be applied. Actual water-stress conditions start before the new flush has fully developed and expanded, when you could get optimum coverage. Obviously, you would like to apply the material before that time, but to obtain maximum effect of the spray over all the foliage that will be on the tree through most of the year after it develops, you would like to spray later. A split application where half of the material was applied at the beginning of water-stress, and half after the foliage developed wouldn't cost any more for the material itself, but it would cost for 2 runs through the grove. Again, it is a question of economics—how much added benefit would result from 2 applications as compared to the cost for those applications?

Q: What has been the effect on fruit size and solids as compared to irrigation?

Albrigo: We got increased fruit size on non-irrigated blocks as compared to controls. We also got far better fruit conditions—peel conditions—in our non-irrigated, antitranspirant-treated blocks than we did in adjacent irrigated blocks. However, the irrigation system did not operate quite as it was supposed to, so we did not get the maximum and most uniform irrigation that we would have liked. But we could definitely see the effect of water-stress on these trees, even though they were under irrigation.

I suspect that if we had had a good control of irrigation, that the increase in fruit size and dilution of solids due to irrigation might have been comparable to what we got with the antitranspirant. Our feeling now is that the cost situation is not such that we should go back and set up another long-term experiment to directly compare them. It might be helpful if we knew which irrigation system we should be comparing with the antitranspirants.

I don't think that we're in a position now to know all of the ramifications of going to this system, but we did carry it on long enough that, when it began to look promising, we at least knew it would work and we could produce citrus without using any supplemental irrigation. One reason I was interested in this was that we may actually come to the situation in Florida, like last year when we had to cut down on the amount of water we could use for a period of time, that we would have to consider alternatives to irrigation. One nice thing about these treatments is that if somebody tells you that you can't irrigate, tomorrow you can spray the antitranspirant and it begins to have its effects immediately. So, we are looking at them from many different aspects.