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CRITICAL HIGH ROOT-ZONE TEMPERATURES FOR CONTAINER-GROWN CITRUS

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Abstract. **Experiments using electrolyte leakage techniques with excised citrus seedling roots and experiments with the root system of whole plants exposed to high temperatures for several weeks were conducted to determine critical temperatures for citrus roots. Critical exposure times for Carrizo citrange exposed to 45 and 50° C were 158 and 45 min, respectively. Critical temperatures for a 20 min exposure were 51.6, 52.5, and 53.5° C for Carrizo citrange, sour orange and Swingle citrumelo roots, respectively. Carrizo citrange seedlings were grown for 9 weeks with root-zone treatments of 28, 34, and 40° C for 6 hr daily. Shoot to root ratio was significantly increased by the 40° C root-zone temperature.**

Production of citrus and other fruit trees in containers has increased in Florida in the last decade (1). Citrus trees produced in containers are marketed as resets in established groves, for new commercial plantings and for residential and commercial landscapes. Extension of the transplanting season and ease of transporting, marketing and transplanting are advantages of a container phase in citrus tree production. There are, however, disadvantages to container production. The small container volume relative to the exposed surface area subjects the root system to temperature extremes and rapid temperature fluctuations. Direct and reflected solar radiation on the sidewalls of containers have been shown to result in growth medium temperatures in excess of 50° C when the air temperature may be only 35° C (2, 4, 15). Container color (4), design (14), spacing and orientation (7) influence container medium temperatures.

Direct heat injury to plant tissues as described by Levitt (12) results from a short exposure to an extreme temperature and is detectable immediately at the cellular level. Electrolyte leakage (leakage of cellular materials from plant tissues) techniques have been used to determine direct injury to plant cell membranes (3, 13).

Indirect heat injury results from prolonged exposure to temperatures below those causing direct injury. Plant starvation, biochemical lesions or the accumulation of toxic byproducts have resulted from such exposures (12).

Direct Injury

Temperature treatment effects. Research was initiated in 1980 to determine temperatures causing immediate, irreversible injury to root cell membranes of woody plants, including selected citrus rootstocks. It was imperative to determine the critical maximum temperature for citrus rootstocks so modifications in cultural practices aimed at reducing container medium temperatures can be properly evaluated.

Sour orange (*Citrus aurantium* L.), Carrizo citrange [(*C. sinensis* L. (Osbeck.) X *Poncirus trifoliata* L. (Raf.)] and Swingle citrumelo [*C. paradisi* Macf. X *P. trifoliata* L. (Raf.)] seedlings were grown in 3 liter containers in 70% of full sun for 1 year before determination of relative heat tolerance of roots. Excised roots (1 g samples) were placed in test tubes and exposed to temperatures from 38 to 65° C in a thermostatically regulated water bath for 20 min. Injury was determined by electrolyte leakage procedures (6, 8). Electrolyte leakage of each sample was expressed as the ratio of incubation solution conductivity after treatment and incubation to the conductivity after being autoclaved at 120° C for 20 min and incubation.

A sigmoidal response curve was fitted to the data for each rootstock using the equation, $Le = z + [(100 - z)/(100 + e^{-k\,(T-T_m)})]$, where z was the baseline level of electrolyte leakage, T_m was the temperature at the midpoint on the curve, k was a function of the slope at T_m, and T was the treatment temperature. A least squares approach was used to determine the best equation for the data and calculate 95% confidence intervals for the predicted Tm values for each rootstock.

Percentage of electrolyte leakage (L_e) from heat-treated roots are presented in Figure 1, as previously presented in *HortScience* in 1984 (10). The predicted critical temperatures for excised roots of Carrizo citrange (51.6 ± 0.5° C) for a 20 min exposure was lower than roots of Swingle citrumelo (53.5 ± 0.5° C). Roots of sour orange displayed an intermediate response (52.5 ± 0.7° C) with more deviation from the fitted response curve. Roots of the citrus rootstocks appear more heat tolerant than *Juniperus chinensis* L. 'Parsonii' (48.5 ± 0.5 C) and *Ilex cornuta* L. 'Burfordii' (46.5 ± 0.5° C) (6). The predicted critical temperatures for each rootstock was further substantiated using microscopic examination of root cells and heat treatment of whole intact plants (8).

Temperature and exposure duration interactions. Exposure duration has been shown to be a critical factor in plant response to supraoptimal temperatures (5). For this reason, research was conducted to determine the interactions of temperature and exposure duration on citrus root cell thermostability.

Carrizo citranges were grown in 9 liter containers in a medium of pine bark, Canadian peat and builders' sand (3:2:1 v/v/v) amended with 3.0, 1.8, 1.2 and 6.0 kg/m³ of dolomitic limestone, superphosphate, Perk (micronutrient manufactured by Estech, Inc., Winter Haven, FL) and 18N-3P-10K (Osmocote 18-6-12, manufactured by Sierra Chemical Co., Milpitas, CA), respectively. Osmocote 18-6-12 was also surface applied every 120 days at 24 g per

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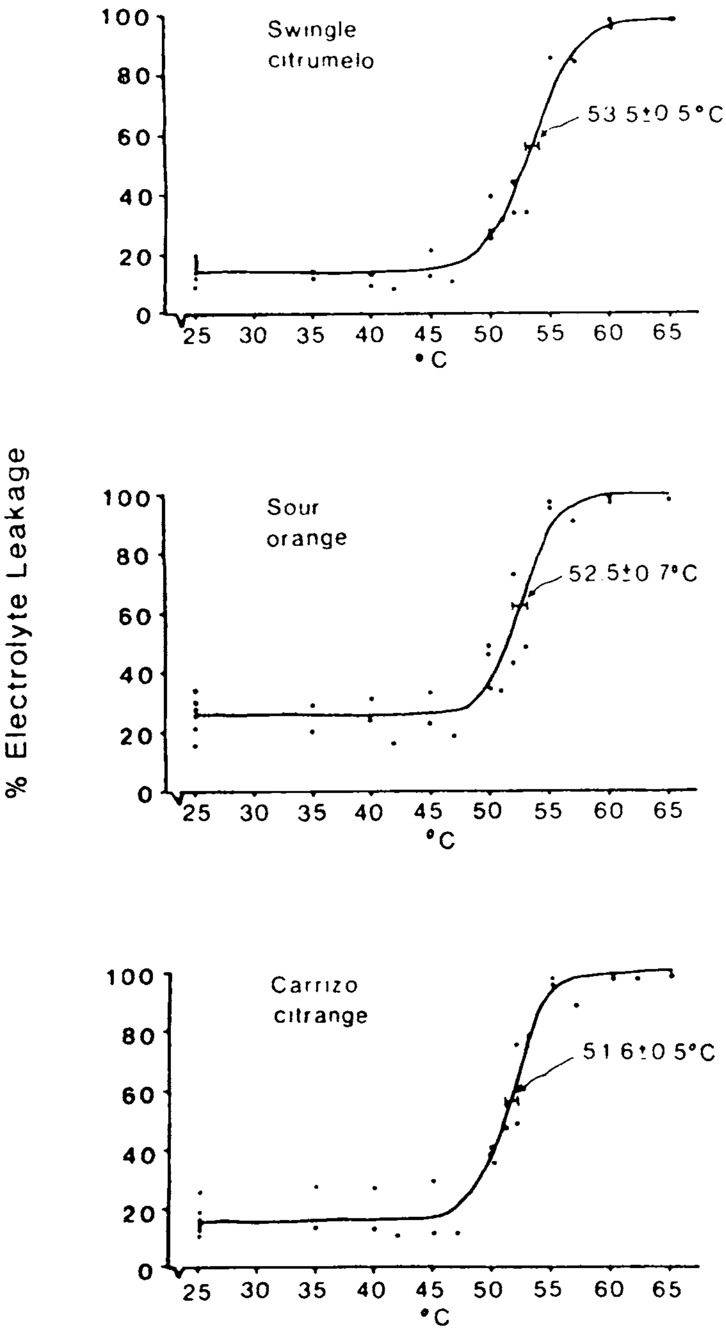

Fig. 1. Electrolyte leakage of roots from 3 citrus rootstocks exposed to treatment temperatues for 20 min. Sigmoidal curves were fitted through the data and midpoints with 95% confidence limits are indicated. (Adapted from Ingram, et. al. 1984, J. Amer. Soc. Hort. Sci. 109:189-193.)

container. Plants were grown in a glasshouse with 70 percent of full sun in Gainesville, FL for 5 months before determination of root cell thermostability in Aug. 1984.

Fifty test tubes containing 1-g samples of excised roots from 3 plants were placed in a temperature controlled circulating water bath for each of 12 temperature treatments (25 to 60° C) and 5 tubes were taken from the bath every 30 min for 5 hr and electrolyte leakage determined (6, 8, 13).

A sigmoidal response curve was fitted to electrolyte leakage data across temperature treatments for each of the 10 exposure times using a least-squares procedure as previously described with *Pittosporum tobira* (8). A mathematical model to describe temperature and exposure time interactions was derived by characterizing changes in each variable in the fitted sigmoidal equation in relation to exposure time and substituting these in the original equation (5).

The T_m of the 10 sigmoidal curves decreased exponentially as the exposure duration, E, increased, as was reported for *Pittosporum tobira* (5), *Ilex crenata* 'Helleri' and *Ilex vomitoria* 'Schellings' (9). Regression of T_m on ln E is presented in Figure 2. A model to describe interactions of temperature and exposure duration was derived and the fitted response surface is presented graphically in Figure 3. Predicted critical exposure times for selected temperatures were calculated and presented in Table 1. Carrizo citrange roots would be killed by less than 1.5 hr exposure to 48° C.

Critical temperatures and exposure times must be known for crop plants before cultural practice modifications to reduce temperatures can be meaningfully evaluated. If the temperatures were reduced by several degrees but were still high enough to cause injury, the cultural practice modifications may not be justified.

Indirect Injury

The objective of this portion of the research project was to study the influence of root-zone temperature on growth and physiological response of container-grown citrus. A portion of the results of this experimentation was published in *HortScience* in 1986 (10). Carrizo citrange seedlings were potted in 12 x 12.5 x 8.5 cm black plastic containers with a medium of pinebark, moss peat and sand (3:2:1 v/v/v) amended with 2.4 kg dolomitic limestone, 1.2 kg superphosphate (0-90-0), and 0.6 kg Perk/m^3 (micronutrient formulation by Estech Inc., Winter Haven, FL).

The containers were suspended in insulated boxes (1 m x 1 m x 20 cm) where the roots were exposed to 28, 34,

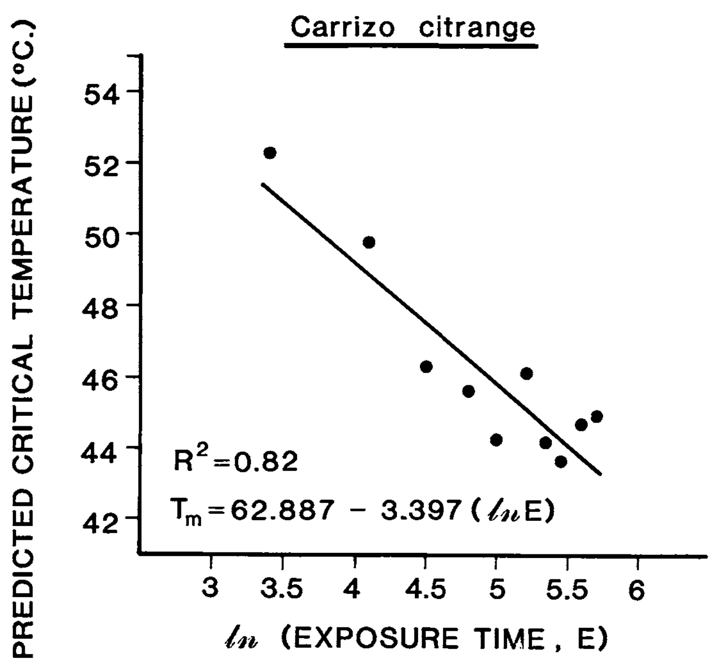

Fig. 2. Regression of predicted midpoint temperatures (T_m) on the ln of exposure time (E) for Carrizo citrange.

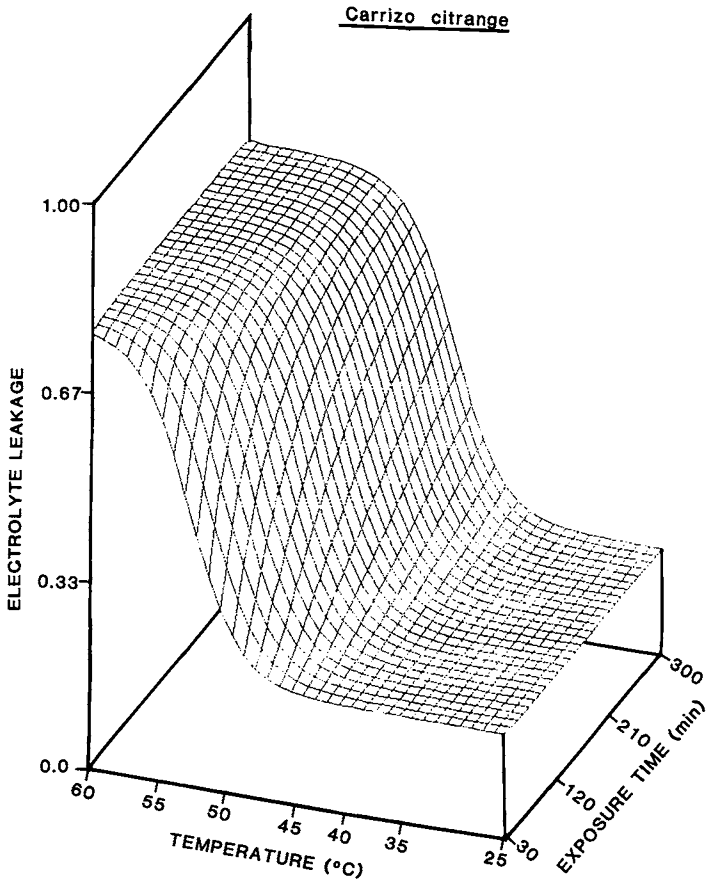

Fig. 3. Model of electrolyte leakage from Carrizo citrange excised roots in response to temperature and exposure time.

$$\text{Electrolyte leakage} = 0.1893 + \frac{0.592}{1 + e^{-0.4784(\text{temp} - 65.076 + 3.964 * \ln E)}}$$

or 40° C for 6 hr daily, 1200 to 1800 hr. Convective heat was supplied in each box by 4 100-W aluminum foil-covered incandescent light bulbs controlled by a thermostat. Small box fans circulated the heated air to aid in uniform distribution. The boxes were in a glasshouse with an average midday light intensity of 800 μmol s^{-1} m^{-2} and were allowed to equilibrate with ambient glasshouse temperatures (30° C day and 24° C night) for the 18 hr between heat cycles. There were 4 boxes at each temperature and 3 plants were placed in each box. Plants were irrigated daily with 300 ml and fertilized weekly with a solution of 20N-10P-17K at 150 ppm N.

The shoot to root ratio was greater for plants grown for 90 days with a 40° C root-zone temperature, but there were no statistical differences in shoot or root dry weights individually (Table 2). Increased shoot to root ratios due to supraoptimal temperatures have also been reported for *Pittosporum tobira* (11) and *Ixora coccinea* (12). Seedling variability may have influenced results, since seedlings were not screened initially for sexual or nucellar embryos.

Conclusions

Carrizo citrange is somewhat tolerant of root-zone temperatures between 28 and 40° C for 6 hrs daily for 90 days. However, there was a slight increase in shoot to root ratio by the 40° C treatment. Plants with relatively high shoot to root ratios are not ideal for transplanting to field conditions. Exposure of Carrizo citrange roots to 45° C for less than 1.5 hr per day would result in direct injury to root cells. Temperature regimes determined to cause injury to citrus roots have been shown to occur in container media exposed to direct solar radiation in Florida.

Table 1. Predicted critical exposure times for Carrizo citrange roots, at selected supraoptimal temperatures.

Treatment temperature (°C)	Predicted critical exposure time, E_c (min)[z]
45	158 ± 25[y]
48	74 ± 18
50	45 ± 10
52	27 ± 8
55	13 ± 5

[z]Calculated values derived from a model describing temperature and exposure time interactions on membrane thermostability measured by electrolyte leakage. $E_c = e^{(65.073 - T)/3.964}$

[y]Confidence intervals calculated as $Ec \pm t_{0.05} \sqrt{\text{variance (Ec)}}$.

Table 2. Response of Carrizo citrange to 3 root zone temperatures. (Adapted from Ingram, et. al., 1986. HortScience 2:254-255.)

Treatment temperature (°C)	Shoot dry wt (g)	Root dry wt (g)	Shoot/ root wt ratio
28	2.4	2.6	1.0
34	3.0	3.3	0.9
40	3.2	2.6	1.3
Linear[z]	NS	NS	0.05
Quadratic	NS	NS	NS

[z]Regression analyses were used to test for significant linear and quadratic responses. NS = not significant.

Literature Cited

1. Castle, W. S., and J. J. Ferguson. 1982. Current status of greenhouse and container production of citrus nursery trees in Florida. Proc. Fla. State Hort. Soc. 95:42-46
2. Fretz, T. A. 1971. Influence of physical conditions on summer temperatures in nursery containers. HortScience 6:400-401.
3. Furmanski, R. J., and R. W. Buesher. 1979. Influence of chilling on electrolyte leakage and internal conductivity of peach fruits. HortScience 14:167-168.
4. Ingram, D. L. 1981. Characterization of temperature fluctuations and woody plant growth in white poly bags and conventional black containers. HortScience 16:762-763.
5. Ingram, D. L. 1985. Modeling high temperature and exposure time interactions on *Pittosporum tobira* Thunb. root cell membrane thermostability. J. Amer. Soc. Hort. Sci. 110:470-473.
6. Ingram, D. L., and D. Buchanan. 1981. Measurement of direct heat injury of roots of three woody plants. HortScience 16:769-771.
7. Ingram, D. L., and C. R. Johnson. 1981. Influence of orientation, spacing and placement pattern of production containers on 'Formosa' azalea growth. Proc. Sou. Nurs. Ass. Res. Conf. 26:25-27.
8. Ingram, D. L., and D. W. Buchanan. 1984. Lethal high temperatures for roots of three citrus rootstocks. J. Amer. Soc. Hort. Sci. 109:189-193.
9. Ingram, D. L. 1985. Root cell membrane heat tolerance of two dwarf hollies. J. Amer. Soc. Hort. Sci. 111:270-272.
10. Ingram, D. L., C. Ramcharan, and T. A. Nell. 1986. Response of container-grown banana, ixora, citrus and dracaena to elevated temperatures. HortScience 21:254-255.
11. Johnson, C. R., and D. L. Ingram. 1984. *Pittosporum tobira* response to container medium temperature. HortScience 19:524-525.
12. Levitt, J. 1980. Response of plants to environmental stresses. 497 pp. Vol. I. Chilling, freezing and high temperature stresses. Academic Press, New York.

13. Sullivan, C. Y. 1972. Mechanisms of heat and drought resistance in grain sorghum and methods of measurement. pp. 247-264. In: N. G. P. Rao and L. R. House (eds.). Sorghum in the seventies. Oxford & I. B. H. Publishing Co. New Delhi, India.

14. Verma, B. P. 1979. Container design for reducing root zone temperature. Proc. Sou. Nurs. Ass. Res. Conf. 24:179-182.

15. Young, K., and D. R. Q. Hammet. 1980. Temperature patterns in exposed black polyethylene plant containers. Agr. *Meterol. 21:165-172.*

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TROPICAL FRUIT CROPS IN FLORIDA—A RAPIDLY CHANGING SITUATION

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Abstract. **During the past few years there has been a remarkable increase of interest in tropical fruit production in Florida. While production of established crops like avocado, banana, Barbados cherry, lime, mango, papaya and plantain has remained nearly static, plantings of many other crops have increased. The greatest production increase has been in atemoya, carambola, guava, longan, lychee, mamey sapote, passion fruit, pineapple and sugar apple. Other fruits being propagated for planting are black sapote, canistel, jackfruit and white sapote. Fruits with potential for the future include akee, ambarella, jaboticaba, Indian jujube, monstera, pitaya, purple mombin, Spanish lime, star apple, tamarind and wampee. Information on cultivars, production practices and marketing is needed for most of these crops. The high interest in new crops has led to consideration of some fruits which are not likely to succeed in Florida because of poor adaptation to the climate. These include babaco, feijoa, kiwi, naranjilla, pepino dulce and tree tomato. The reasons for their poor adaptation are discussed.**

Southern Florida is well known for its diversity of tropical fruits, the result of an active program of plant introduction and research over a long time (1, 2, 3, 4, 5, 6). Changes in importance of the various fruits have occurred gradually through the years as they were affected by changing consumer tastes, foreign competition and climatic events such as freezes.

Remarkably rapid changes have occurred during recent years, however, resulting in the establishment of commercial plantations of many fruits which had previously been cultivated only as home garden plants in Florida. The most important reasons for these changes appear to be an influx of ethnic groups from the American and Asian tropics, an increased demand from affluent consumers in developed countries for new, unusual fruits and the increasing desire and ability of producers in tropical regions to satisfy that demand.

Commercial fruits are defined here as those which are grown in Florida and sold locally or in distant markets. Many of these crops have been growing in the state as dooryard plants for a long time, but they are not well known to the North American public. In that sense they are "new crops". The tropical fruits grown commercially or having potential for commercial production in Florida are listed in Tables 1 and 2, with their common and scientific names and the estimated area of production.

The objective of this paper is to describe the present status of tropical fruit production in Florida and to discuss possibilities for the near future.

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Well-Known Fruits with Static Production

Avocado, lime and mango have been the most important tropical fruits in Florida for a long time, but almost

Table 1. Tropical fruits produced commercially in Florida.

Common name	Scientific name	Origin	Estimated acres of production
Atemoya	*Annona* hybrids	USA, Israel, etc.	30
Avocado	*Persea americana*	Trop. America	12,500
Banana, plantain	*Musa* hybrids	Trop. Asia	350
Barbados cherry	*Malpighia glabra*	Trop. America	25
Carambola	*Averrhoa carambola*	SE Asia	150
Guava	*Psidium guajava*	Trop. America	50
Lime	*Citrus* x 'Tahiti'	USA	7,000
Longan	*Euphoria longana*	SE Asia	60
Lychee	*Litchi chinensis*	China	200
Mamey sapote	*Calocarpum sapota*	Trop. America	300
Mango	*Mangifera indica*	Trop. Asia	2,900
Papaya	*Carica papaya*	Trop. America	350
Passion Fruit	*Passiflora edulis*	S. America	35
Pineapple	*Ananas comosus*	S. America	250
Sapodilla	*Manilkara zapota*	Trop. America	30
Sugar apple	*Annona squamosa*	Trop. America	60

Table 2. New tropical fruit crops with potential for commercial production in Florida[z].

Common name	Scientific name	Origin
Akee	*Blighia sapida*	Africa
Ambarella	*Spondias cytherea*	So. Pacific
Black sapote	*Diospyros digyna*	Trop. America
Canistel	*Pouteria campechiana*	Trop. America
Indian jujube	*Zizyphus mauritiana*	Trop. Asia
Jaboticaba	*Myrciaria cauliflora*	S. America
Jackfruit	*Artocarpus heterophyllus*	Trop. Asia
Monstera (ceriman)	*Monstera deliciosa*	Mexico
Pitaya	*Cereus* spp.	Trop. America
Purple mombin	*Spondias purpurea*	Trop. America
Spanish lime (mamoncillo)	*Melicoccus bijugatus*	Trop. America
Star apple (caimito)	*Chrysophyllum cainito*	Trop. America
Tamarind	*Tamarindus indica*	Africa
Wampee	*Clausena lansium*	China
White sapote	*Casimiroa edulis*	Trop. America

[z]Currently produced in home gardens.