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NONHARDENING TEMPERATURES—MAJOR FACTOR IN FREEZE DAMAGE TO CITRUS TREES IN DECEMBER 1983[1]

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Abstract. **Citrus plantings that survived the 1977, 1981, and 1982 freezes in Florida did not survive the December 24, 25, 26, 1983 freeze. Plantings that were lost included 8-yr-old 'Valencia' orange [Citrus sinensis (L.) Osb.] and 'Marsh' grapefruit (C. paradisi Macf. on 12 different rootstocks as well as 6-yr-old 'Star Ruby' grapefruit on 8 different rootstocks. Citrus selections that were noted for exceptional freeze tolerance after the 8°F minimum temperatures in 1981 were injured during 19°F in 1983. Cultural practices, tree health, age of trees, minimum temperatures, and freeze duration could not account for the extensive damage. It was concluded that noncold-hardening conditions that led into the Christmas freeze were largely responsible for excessive freeze damage to the trees. Cold-hardening temperatures were 6 times greater in 1977 and 1981, and 4 times greater in 1982 than in 1983 based on total number of hr of 50°F or less that occurred during the 11 weeks immediately preceding the freeze. During the last 4 weeks, cold hardening in 1977, 1981, and 1982 exceeded that in 1983 by 9, 12, and 3 times, respectively.**

The Christmas freeze of 1983 in Florida was one of the most unexpected and totally damaging freezes of the century in major citrus-growing areas in the upper interior and west coast counties. Conditions were highly favorable for devastating losses. Trees were in a freeze-vulnerable, active-growing stage, and many had been injured and weakened during the freezes in 1977, 1981, and 1982. Most of the fruit was still on the trees and a shipping holiday was in effect. Freeze forecasts were delayed because of unusual atmospheric conditions and hurried freeze protection efforts were hindered by holiday activities. All of these factors reinforced concerns of devastating losses after 2 nights of freezing temperatures as low as 19°F for 1 or more hr. Citrus plantings were virtually destroyed, fruit processing plants were closed, thousands of people lost jobs, financial drains were placed on local and state assistance programs, citrus imports increased, total crop yield was reduced by one-third or more, and consumers paid higher prices. Grove rehabilitation may take as long as 6 yr in new replant situations and 3 to 4 yr where trees were buckhorned (pruned to major scaffold limbs). In some instances, citrus plantings will be abandoned and targeted for nonagriculture uses.

This report summarizes comparative observations of prefreeze weather conditions, freeze profiles, tree injury, and cold-hardy citrus types during the 1983 freeze with that of 1977, 1981, and 1982. Data are part of the USDA research program on freeze problems in Florida.

Materials and Methods

Freeze injury observations in this report were limited to research plantings on the USDA A. H. Whitmore Foundation Farm near Leesburg, Florida. Plantings surveyed were equal-aged plantings of 'Valencia' orange and 'Marsh' grapefruit, on 12 different rootstocks, 'Star Ruby' grapefruit trees on 8 different rootstocks, trees that expressed exceptional cold hardiness in the 1981 freeze (5), and a new planting of cold-hardy citrus hybrids. Except for the new planting, all of the trees surveyed were survivors of the 1977, 1981, and 1982 freezes.

Ratings of freeze injury were started 5 months after the 1983 Christmas freeze and were completed in 4 weeks. Wood dieback had stopped and new growth indexed the extent of tree damage. Trees were visually rated and coded numerically on severity of leaf and wood kill. Categories of injury ratings remained the same as in 1977 (4) and 1981 (5).

Temperatures and rainfall were measured on site as in previous freeze situations. Air temperatures were recorded on hygrothermographs calibrated to the nearest 1°F and located in standard weather shelters 4½ ft above ground level. Rainfall was obtained in a standard rain gauge. Temperatures and rainfall data were used to comparatively index prefreeze conditions 11 weeks before freezes and freeze profiles were obtained from hygrothermograph charts.

Results and Discussion

The 1983 Christmas freeze was devastating in citrus plantings on the USDA A. H. Whitmore Foundation Farm. Many of the trees that survived the 1977, 1981, and 1982 freezes did not survive the 1983 freeze. Trees which were not totally lost (killed to the rootstock) were severely injured to the extent that the plantings were abandoned in favor of new plantings in 1985.

Devastating effects were especially evident in 8-yr-old sister plantings of 'Valencia' orange and 'Marsh' grapefruit on 12 different rootstocks. Forty-five of 165 'Valencia' trees which survived past freezes were killed (Table 1). This was a 27% tree loss in 1983 and represented 60% of the total trees lost prior to the 1983 freeze. The combined loss (including 1983) of 120 trees or 50% of the original planting,

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plus a 5 rating (76 to 100% kill) in 3-inch diameter wood kill was too severe to consider rehabilitation efforts.

The least number of 'Valencia' trees lost during the past 8 yr that had 4 major freezes were on the more cold-hardy type rootstocks (6). These were sour orange No. 2 (*C. aurantium* L.), Swingle citrumelo (*C. paradisi* X *Poncirus trifoliata* (L.) Raf.), diploid Rubidoux trifoliate orange (*P. trifoliata*) and an experimental citrangor (*C. sinensis* X *P. trifoliata*) X *C. sinensis*). Two of the rootstocks, tetraploid Rubidoux trifoliate orange and diploid Carrizo citrange, had 40 to 50% tree loss. Each of the remaining 6 rootstocks had more than a 50%-tree loss.

Rootstock differences were not evident based on injury up to and including 3-inch diameter wood (Table 1). Trees were uniformly rated a 5 (76 to 100% kill) regardless of rootstock. Trees which survived 8°F in 1981 with little or no kill in 3-inch wood lost more than 75% of that wood during the 19°F freeze in December 1983.

Extensive damage found in the 'Valencia' planting was also evident in the adjacent sister planting of 'Marsh' grapefruit (Table 2). Sixty-four grapefruit trees were killed which was 1.18 times greater than all of the trees lost prior to the 1983 freeze and represented 34% of the 186 trees going into the 1983 freeze. These losses are somewhat greater than those in the 'Valencia' planting, but similar in a combined loss of about 50% for the entire planting of 240 trees.

The least number of grapefruit trees lost was on the same rootstocks as in the 'Valencia' planting. Only 1 tree was lost on Swingle citrumelo, 2 on diploid Rubidoux trifoliate orange, 3 on sour orange No. 2, and 5 on citrangor (CPB-43732). Two rootstocks had 30 and 40% tree loss, and 6 rootstocks had 50% or greater. As with 'Valencia', rootstocks were similar in amount of damage up to and including 3-inch diameter wood of 'Marsh' grapefruit.

Another grapefruit planting that was abandoned be-

Table 1. Tree loss and damage in an 8-yr-old planting of 'Valencia' orange on 12 different rootstocks on USDA A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1983 December freeze.[z]

Rootstocks	Trees planted (no.)	Trees lost: Prior to 1983	Trees lost: 1983 freeze (no.)	Trees lost: Total	Leaf kill 1981 (%)	Leaf kill 1983 (%)	Fruit loss 1981 (%)	Fruit loss 1983 (%)	Amount of 3-inch diam wood killed 1981 (rating[y])	Amount of 3-inch diam wood killed 1983 (rating[y])
Sour orange No. 2	20	1	0	1	100	100	100	100	1.1	5
Swingle citrumelo	20	3	0	3	100	100	100	100	1.0	5
Diploid Rubidoux trifoliate	20	4	0	4	100	100	100	100	1.0	5
Citrangor (CPB-43732)	20	2	2	4	100	100	100	100	1.1	5
Tetraploid Rubidoux trifoliate	20	3	5	8	100	100	100	100	1.0	5
Diploid Carrizo citrange	20	4	5	9	100	100	100	100	1.3	5
Cleo X Carrizo (C61-182)	20	1	10	11	100	100	100	100	1.7	5
Tetraploid Carrizo citrange	20	6	9	15	100	100	100	100	1.1	5
Rangpur lime	20	9	8	17	100	100	100	100	2.1	5
Severinia buxifolia	20	8	3	11	100	100	100	100	1.9	5
Chase rough lemon	20	14	3	17	100	100	100	100	2.5	5
Pee Wee (Rangpur X Troyer (77-44))	20	20	—	20	100	100	100	100	—	5
All rootstocks	240	75	45	120	100	100	100	100	1.4	5

[z]19°F min temp, 1-hr duration.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, and 5 = 76 to 100%.

Table 2. Tree loss and damage in an 8-yr-old planting of 'Marsh' grapefruit on 12 different rootstocks on USDA A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1983 December freeze.[z]

Rootstocks	Trees planted (no.)	Trees lost: Prior to 1983	Trees lost: 1983 freeze (no.)	Trees lost: Total	Leaf kill 1981 (%)	Leaf kill 1983 (%)	Fruit loss 1981 (%)	Fruit loss 1983 (%)	Amount of 3-inch diam wood killed 1981 (rating[y])	Amount of 3-inch diam wood killed 1983 (rating[y])
Swingle citrumelo	20	0	1	1	100	100	100	100	1.0	5
Diploid Rubidoux trifoliate	20	1	1	2	100	100	100	100	1.1	5
Sour orange No. 2	20	0	3	3	100	100	100	100	1.2	5
Citrangor (CPB-43732)	20	2	3	5	100	100	100	100	1.1	5
Cleo X Carrizo (C61-182)	20	1	5	6	100	100	100	100	1.6	5
Tetraploid Rubidoux trifoliate	20	3	5	8	100	100	100	100	1.0	5
Severinia buxifolia	20	6	4	10	100	100	100	100	1.5	5
Diploid Carrizo citrange	20	6	6	12	100	100	100	100	1.4	5
Tetraploid Carrizo citrange	20	3	9	12	100	100	100	100	1.5	5
Chase rough lemon	20	6	6	12	100	100	100	100	2.0	5
Rangpur lime	20	12	5	17	100	100	100	100	2.1	5
Pee Wee (Rangpur X Troyer (77-44))	20	14	6	20	100	100	100	100	3.3	5
All rootstocks	240	54	64	118	100	100	100	100	1.6	5

[z]19°F min temp, 1-hr duration.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, and 5 = 76 to 100%.

cause of excessive freeze damage was 6-yr-old 'Star Ruby' on 8 different rootstocks. Forty-seven trees were killed in the 1983 freeze (Table 3). This was 2.9 times greater than all the trees lost prior to the freeze. The combined loss of trees amounted to 76% of the original planting with no hope of rehabilitation. Rootstock differences were not evident other than the least number of trees were lost on sour orange No. 2 and Rangpur X Troyer rootstocks (*C. reticulata* var. *austera* Swing. X (*C. sinensis* X *P. trifoliata*)).

The greater damage in 1983 compared to 1981 cannot be attributed to lower temperatures nor longer durations of freezing temperatures (Fig. 1). The effect of relatively windy and low humidity conditions on severity of freeze injury in 1983 is not known but none of the past freezes, 1977, 1981, and 1982, were as windy and dry. This is illustrated in the hygrothermograph tracings which characterize the 1983 freeze as a classical advective type indicating continuous movement of cold air into the Florida peninsula. The other 3 freeze profiles largely reflect radiation cooling (loss of heat to an open sky under calm conditions) with discontinuities and unpredictable trends in temperature profiles. According to nomenclature presented by J. C. Georg at the 1978 Florida State Horticultural Society meetings, the 1977, 1981, and 1982 freezes were a combination of "radiation," "break," and "unmentionable" name freezes that cause considerable anxiety in people attempting to interpret freeze warning forecasts.

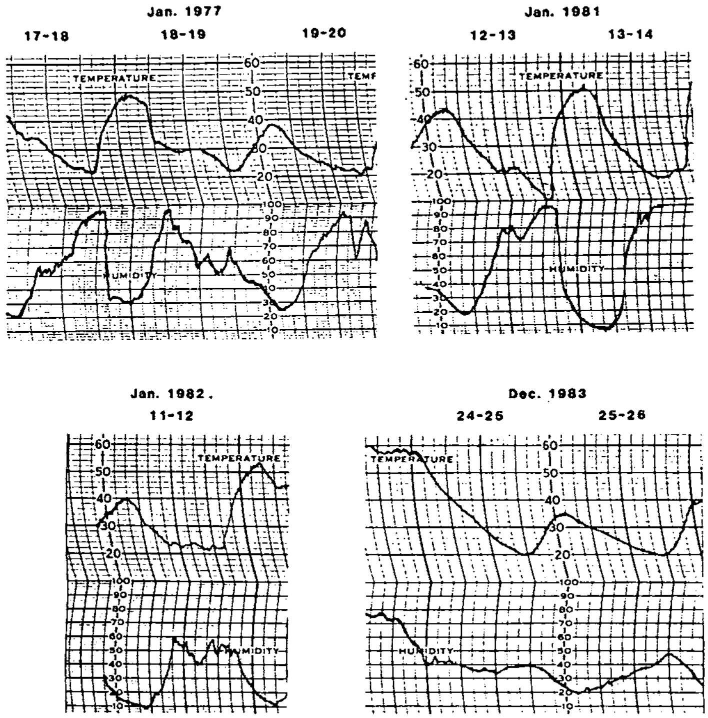

Fig. 1. Hygrothermograph tracings of freezes on the USDA A. H. Whitmore Foundation Farm near Leesburg, Florida.

The question of a chill factor operating during advective freezes in Florida has not been fully addressed. Based largely on speculation, it is generally thought that: 1) windy freezes do promote more uniform and faster cooling of the tree making it more vulnerable to lethal air temperatures and whole tree freezing; 2) moving tree parts in a windy freeze are less likely to supercool and thus are vulnerable to greater durations of ice in the tissues; 3) frozen tree part movement increases the likelihood of greater tissue rupture due to ice lesions; and 4) lethal dehydration stresses are increased due to the drying action of the wind.

What also remains unknown is the effect of past freezes on the condition of the trees at the time of the 1983 freeze. Whether the trees were in a weakened condition is speculative but past freeze injuries may have contributed to extensive tree loss and wood kill in 1983. This has been suggested in other freeze situations (1), but it is subjective based on association and surface appearance of trees prior to damaging freezes.

Somewhat more meaningful was the growing stage and cold hardiness of the trees immediately before the 1983 freeze. Trees were in an unhardened stage based on recent shoot flushes, warm temperatures, and adequate rainfall. Air temperatures and rainfall 11 weeks before the freeze indicated warmer and wetter conditions than those that preceded freezes in 1977, 1981, and 1982 (Table 4). Warm and wet conditions do not promote cold hardiness in citrus trees. Trees were probably in a very unhardened stage based on the amount of cold hardening temperatures (50°F and less) 11 and 4 weeks before the freeze (Table 4). The 105 total hr of cold hardening that preceded the 1983 freeze were 5.6 times less than the hr in 1977, 6 times less than in 1981, and 4.4 times less than in 1982. The large differences in amount of cold hardening temperatures are even more evident during the last 4 weeks immediately preceding the 1983 freeze. During the severe 8°F freeze in 1981 when cold hardening was considered primary in tree survival (5), amount of cold hardening temperatures exceeded that in 1983 by 11.9 times, or 406 hr compared to 34 hr.

The lack of cold hardiness was also very evident in trees that showed exceptional cold-hardy traits in 1981 (5). Se-

Table 3. Tree loss and damage in a 6-yr-old planting of 'Star Ruby' grapefruit on 8 different rootstocks on the USDA A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1983 December freeze.[z]

		Trees lost			Leaf kill		Fruit loss		Amount of 3-inch diam wood killed	
Rootstocks	Trees planted (no.)	Prior to 1983	1983 freeze (no.)	Total	1981 (%)	1983 (%)	1981 (%)	1983 (%)	1981 (rating[y])	1983 (rating[y])
Sour orange No. 2	10	0	4	4	100	100	100	100	1.8	5
Rangpur X Troyer (HRS-803)	10	0	4	4	100	100	100	100	1.8	5
Swingle citrumelo	9	0	7	7	100	100	100	100	2.2	5
Volkamer lemon	10	1	7	8	100	100	100	100	2.3	5
Citremon 1449	10	2	6	8	100	100	100	100	1.0	5
Chase rough lemon	9	6	3	9	100	100	100	100	1.3	5
Cleopatra mandarin	10	4	6	10	100	100	100	100	1.3	5
Carrizo citrange	12	3	8	11	100	100	100	100	1.1	5
All rootstocks	80	16	47	61	100	100	100	100	1.5	5

[z]19°F min temp, 1-hr duration.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, and 5 = 76 to 100%.

Table 4. Prefreeze temperature durations and rainfall on the USDA A. H. Whitmore Foundation Farm near Leesburg, Florida.

Before the freeze	70°F and greater				Lower than 70°F but greater than 50°F				50°F and lower				Rainfall			
(wk)	(hr)				(hr)				(hr)				(inches)			
	1977	1981	1982	1983	1977	1981	1982	1983	1977	1981	1982	1983	1977	1981	1982	1983
11	6	57	88	158	122	105	94	10	40	6	54	0	0.20	1.02	0.57	4.29
10	20	55	58	166	120	84	116	2	28	29	6	0	0.00	0.00	1.23	0.60
9	27	58	28	99	131	110	115	69	10	0	12	0	0.00	1.00	0.39	0.00
8	26	31	34	99	89	105	76	69	53	32	80	0	2.05	0.67	0.00	0.00
7	0	14	41	31	78	98	59	125	90	56	100	12	1.23	1.81	0.00	0.29
6	30	30	22	25	116	100	95	98	22	38	51	45	0.65	0.00	0.30	0.15
5	28	28	9	45	100	80	79	109	40	60	48	14	1.49	0.00	0.14	1.67
4	5	4	12	27	66	84	77	134	97	80	57	7	0.78	0.00	0.34	0.51
3	3	0	41	86	97	67	108	62	68	101	32	20	0.69	0.22	4.40	0.22
2	5	0	46	9	101	57	91	152	62	111	19	7	1.06	0.00	0.00	3.86
1	7	2	20	19	82	53	80	149	79	113	0	0	1.22	0.00	0.00	0.00
Total	157	279	399	764	1,102	943	990	979	589	626	459	105	9.37	4.72	7.37	11.59
Last 4 wk	20	6	119	141	346	261	80	497	306	406	108	34	3.75	0.22	4.74	4.59

lections of *Eremocitrus glauca* and its hybrids were injured as well as hybrids of trifoliate orange, mandarin (*C. reticulata*) hybrids, and the off-type seedling tree of Citrumelo (CPB-4481). The least injured of the above were individual trees of mandarin hybrids. A hybrid of ((*C. paradisi* X *P. trifoliata*) X *C. sinensis*) budded on *P. trifoliata* orange cvs. Large Flower and Flying Dragon was the least injured in a planting of 2-yr-old trees where 85 out of 96 trees or 88% were killed. This planting was also terminated.

The lack of cold hardening temperatures immediately preceding the 1983 freeze is considered the major factor in the extensive injury to citrus trees at the USDA A. H. Whitmore Foundation Farm. Under such circumstances, some relief may be had in costly freeze protection systems. The amount of protection may be minimal during advective-type freezes of 19°F.

Methods of determining cold hardiness in citrus trees apparently would help to assess the risk of freeze injury. Freezing point determinations (2) are available but may not be well suited for individual situations. Other laboratory type determinations (3) are also impractical in most instances. An index accumulation of cold hardening temperatures may be somewhat better. This is illustrated in Fig. 2 where accumulation temperature rates of 50°F or less would have to average about 60 hr per week for 11 weeks to have excellent cold hardening as exemplified in 1981. Less than 200 hr would suggest highly freeze-vulnerable, nonhardening tree conditions. Such data are adaptable to weather communication systems and may help to assess freeze-risk situations in Florida.

The 1983 freeze will probably enter the log of historic freezes in Florida as the most damaging freeze of the century in major citrus-growing areas of the upper interior and west coast counties. Lack of cold hardening temperatures, unharvested fruit, previous freeze injury to trees, holiday activities, unusual atmospheric conditions, and delayed freeze forecasts all contributed to the total devastating loss incurred during the 1983 windy-dry freeze. Of these, the lack of cold hardening temperatures is rated the most important factor.

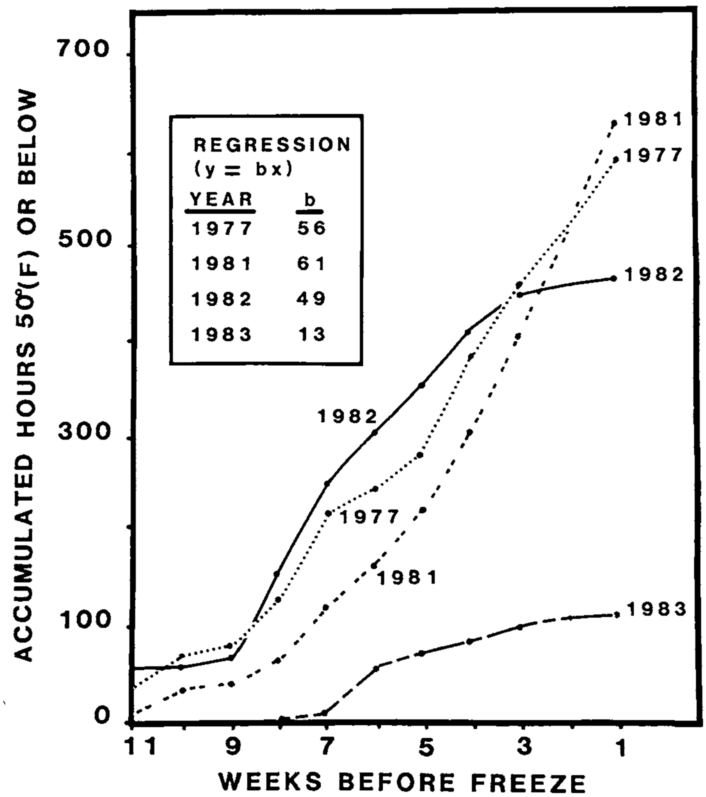

Fig. 2. Accumulated number of hr of 50°F and cooler temperatures prior to major freezes at the USDA A. H. Whitmore Foundation Farm near Leesburg, Florida.

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