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EFFECTS OF NITROGEN AND POTASSIUM FERTILIZATION ON WINTER INJURY OF CITRUS TREES

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Abstract. **Tree damage was evaluated in several fertilizer experiments following the freezes of 1962, 1983 and 1985. Methods used in the evaluation included visual ratings of leaf damage, emergence of new leaves after freeze, fruit drop and wood damage. Leaf analysis was used as an expression of the nutritional status of the trees. Tree damage was more extensive when nitrogen (N) and potassium (K) levels were in the deficient ranges. In general, trees fertilized with high rates of N tended to be more resistant to freeze injury. Trees fertilized with high rates of K had a small but consistent tendency to be less cold resistant. The importance of using leaf analysis to maintain a balanced nutritional program from the standpoint of cold tolerance is discussed.**

While freeze damage to Florida citrus is well-documented, little information is available relating cultural practices to cold tolerance of citrus. The unpredictable occurrence of damaging freezes makes it difficult to conduct experiments primarily for the purpose of gathering information on cold resistance. The meager published information is based on damage observed in experimental plantings that happened to be in existence at the time of the freezes. Much of the general knowledge on cold-hazard is based on long-time grower experience. Krezdorn and Martsolf (7), in a review of the effects of cultural practices on cold tolerance, stated that the bulk of the evidence indicates freeze damage is not influenced by mineral nutrition as long as the trees are not deficient in any mineral element.

Certain nutritional effects on the amount of cold damage have been reported. Lawless (8) reported nutritional deficiencies, particularly those of magnesium and copper, markedly increased the susceptibility of the trees to cold (8). Late applications of nitrogen may cause excessive growth and delay the development of winter dormancy thereby reducing cold hardiness and should be avoided (2). Spencer (10) found that trees receiving large quantities of phosphate were more severely injured by cold temperatures than trees not receiving phosphate before a freeze. Smith and Rasmussen (9) observed some 4000 trees in several fertility experiments and concluded that the nutrient status of trees above deficiency levels had only a slight effect on cold tolerance. Their studies showed that high rates of N fertilization had a small but definite tendency to increase the resistance of the tree to freeze injury. High rates of potash (K) had a small but definite tendency to reduce the cold resistance of the tree.

This paper summarizes observations of tree damage from several N and K experiments following the freezes of 1962, 1983 and 1985.

Materials and Methods

Data were collected from 5 long-term N and K experiments following the freezes of 1962, 1983 and 1985. These experiments were conducted on Astatula fine sand at the Citrus Research and Education Center (CREC), and its Davenport grove near Lake Alfred in central Florida. The trees were 20 to 25 yr of age when the freezes occurred. Treatments, experimental design, cultivars and rootstocks of the 5 experiments are summarized in Table 1. Treatments in Expt. 1 to 4 involved not only N and K but other variables as well. Experiment 5 was a potash rate experiment. Details of the design and treatments of Expt. 1, 2 and 5 have been published and will not be repeated (1,3,6). Expt. 3 was a N source, rate and timing study on 'Valencia' orange. Expt. 4 was a N-P-K rate study on 'Temple' orange.

In Expt. 1 to 4, the trees were rated for leaf damage 3 and 12 weeks after the 1983 and 1985 freezes. A rating of 0 to 10 was used with 0 being no damage and 10 meaning 100% leaf damage. All the leaves were damaged after the 1985 freeze. Trees were rated on the basis of new leaf emergence and calculated as percentage of damaged leaves. Thus, if a tree had 20% new leaf emergence, it was considered as 80% leaf damage. Because of the large volume of data collected, only the main effects of the treatments are reported.

In Expt. 5, fruit was examined within 3 weeks after the 1962 freeze by cutting the fruit ¾ to 1 inch from the stem end. Damaged wood was pruned and the diameter of the cuts was measured 6 months after the freeze.

Nutrient content of four- to five-month-old spring flush leaves from non-fruiting twigs collected several months prior to the freezes were used to express the N and K status of the trees. Statistical interpretations were calculated from all measurements where appropriate.

Results and Discussion

Experiments 1 to 4 involve N treatments. The data showed N rates played a significant part in the level of tree damage sustained in both the Dec. 1983 and Jan. 1985 freezes with trees receiving high N rates showing less foliage damage (Table 2). The differences were significant in all 4 experiments where N rates were involved. In general, leaf damage was more extensive in the 1985 than the 1983 freeze, probably due to lower temperatures and longer durations. Leaf samples were collected from all experiments 4 to 5 months prior to the 1983 and 1985 freezes. Leaf N content gave a good indication of N treatments. Significant correlations were found between leaf N

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Table 1. Experimental design, treatments, cultivars and rootstocks of 5 N and K experiments.

Experiment	Cultivar/ rootstock	Treatment N	Treatment K_2O	Other treatments		Experimental design	Replication	Trees/ plot
		lb./acre/yr						
1	Pineapple/[z] Rough lemon	90	120	Spacings:	20 × 25 ft	Split plot	3	4
		180	240		15 × 20 ft	spacing main plot		
		270			10 × 15 ft	N and K subplots		
		360						
2	Valencia/ Rough lemon	90	120	Irrigation:	0 inches/yr	Factorial	4	4
		180	240		6 inches/yr	randomized		
		270			12 inches/yr	block		
3	Valencia/ Rough lemon	90	180	N Source:	Ammonium nitrate	Factorial	4	4
		180	180		Sulfur coated urea	randomized		
		270	180		Isobutylidene diurea	block		
4	Temple/[y] Cleopatra mandarin	90	120	Phosphate:	100 lb./acre/yr	Factorial	3	3
		180	240		200 lb./acre/yr	randomized		
		270			300 lb./acre/yr	block		
5	Hamlin/ Rough lemon	210	0	None		Randomized	2	8
		210	50			block		
		210	130					
		210	210					
		210	260					
		210	310					
		210	400					

[z]*Citrus sinensis* (L.) Osb./*C. jambhiri* Lush.
[y]*C. temple* Hort. ex Y. Tanaka/*C. reticulata* Blanco.

Table 2. Effects of N rates on leaf N concentrations, fruit yield and freeze damage.[z]

Experiment	N rates lb./acre/yr	Leaf N(%) 1983	Leaf N(%) 1984	Leaf damage[z](%) 1983	Leaf damage[z](%) 1985	Fruit yield (box/tree) 1983	Fruit yield (box/tree) 1984
1	90	2.13	2.40	70	89	3.3	0.8
	180	2.50	2.62	50	71	3.6	1.6
	270	2.65	2.72	43	63	3.7	2.3
	360	2.64	2.69	23	61	3.4	3.0
		**[w]	**	**	**	n.s.	**
2	90	2.37	2.37	86	72	4.6	–
	180	2.76	2.56	60	63	6.8	–
	270	2.80	2.62	50	60	6.7	–
		**	**	**	**	**	–
3	90	2.37	2.50	69	60	3.6	2.2
	180	2.54	2.75	56	52	4.8	3.9
	270	2.73	2.81	47	48	4.8	4.1
		**	**	**	**	**	**
4	90	2.59	2.34	37	77	4.0	2.1
	180	2.68	2.46	26	67	5.1	3.0
	270	2.68	2.47	18	68	4.4	3.4
		**	**	**	**	**	**

[z]Freezes: 25-27 Dec. 1983. Minimum temp. 22°F, 17 hr below 30°F, and 21-23 Jan. 1985. Minimum temp. 19°F, 22 hr below 30°F.
[w]n.s.—no significance; *—significant at 5% level; **—significant at 1% level.

Table 3. Effects of K_2O rates on leaf K concentration fruit yield, and freeze damage.[z]

Experiment	K rates lb./acre/yr	Leaf K(%) 1983	Leaf K(%) 1984	Leaf damage[z](%) 1983	Leaf damage[z](%) 1985	Fruit yield (box/tree) 1983	Fruit yield (box/tree) 1984
1	120	1.35	1.58	37	64	3.3	2.1
	240	1.82	2.17	54	78	3.7	1.8
		**[w]	**	**	**	*	n.s.
2	120	1.62	1.77	61	61	6.3	–
	240	1.85	2.09	71	68	5.7	–
		**	**	**	**	**	–
4	120	1.31	1.52	28	71	4.6	2.4
	240	1.49	1.73	26	70	4.4	3.2
		**	**	n.s.	n.s.	n.s.	**

[z]Freezes: 25-27 Dec. 1983. Minimum temp. 22°F, 17 hr below 30°F, and 21-23 Jan. 1985. Minimum temp. 19°F, 22 hr below 30°F.
[w]n.s.—no significance; *—significant at 5% level; **—significant at 1% level.

content and the percentage of leaves killed by the freezes. Negative correlation coefficients of r = –0.61 and –0.80 were found for 1983 and 1985 respectively. Thus, to a certain extent, leaf N can be used to predict freeze damage, and therefore should be further investigated.

The effects of K rates on leaf damage from the 1983 and 1985 freezes in Expt. 1, 2, and 4 are summarized in Table 3. Trees receiving high rates of K in both Experiments 1 and 2 showed more leaf damage than the low rate which was opposite to the effects of N. No difference in leaf damage was found between the two K rates in Expt. 4. Leaf K appears to reflect K treatments and may in part be used to predict leaf damage by freeze as in the case of leaf N. The correlation coefficients between leaf K and percentage damaged leaves were 0.84 and 0.70, respectively, for the 1983 and 1985 freezes.

Experiment 5 was a K rate study (1) where tree and fruit damage measured after the 1962 freeze (Table 4). Fruit damage was greater in the no potash plot, but there was no difference in fruit from trees receiving from 50 to 310 lb. of K_20 per acre per year. Wood pruning measurements showed increasing potash rates reduced the size of wood killed up to 210 lb. of K_2O per acre per year, with rates above 210 lb. showing no difference in the diameter of wood killed. Higher rates of K up to 260 lb. of K_2O per acre also reduced the number of branches killed on the tree when compared to the lower rates. A leaf K range between 1.50 and 1.80% was associated with the least wood damage compared to lower or higher leaf K values.

The influence of treatments other than N and K rates in Experiments 1 to 4 varied from no to some effects (Table 5). Different tree spacings in Expt. 1 showed wide spacing trees had more leaf damage than closely spaced trees. The data were significant in 1983 but not in 1985. There was no interaction between leaf N and tree spacing.

Irrigation in Expt. 2 showed high irrigation treatments resulted in more leaves damaged by freeze than the low or no irrigation in 1983 (Table 5). This trend may be related to the N content in leaves since the no irrigation treatment had the highest leaf N and the high irrigation treatment had the lowest leaf N. The inverse relationship found here between leaf N and leaf damage is similar to that found in the N rate experiments (Tables 1 and 2).

Nitrogen source and time treatments in Experiment 3 did not have much effect (Table 5). Trees receiving IBDU had higher leaf N content and had less damaged leaves when compared to NH_4NO_3 and SCU treated trees. The data, however, were not consistent.

Table 4. Effect of potassium rates on freeze injury of Hamlin orange.[z]

K rate lb./acre/yr	Leaf K (%)	Damaged fruit[y] (%)	Wood damage: Diameter (cm)	Wood damage: Area/tree[x] (cm^2)	Fruit yield (box/tree)
0	0.56	85	4.2	761	7.5
50	1.06	55	2.9	721	7.9
130	1.41	52	2.4	524	9.9
210	1.53	59	1.9	448	9.8
260	1.81	63	1.9	342	9.7
310	1.65	55	1.8	365	8.8
400	1.91	38	1.9	416	11.1

[z]11-13 Dec. 1962. Minimum temperature 16°F, 16 hr below 30°F.
[y]Fruit were cut ½-inch from stem end.
[x]Area of the wood pruned from each tree was calculated from the diameter of cuts and the number of branches pruned. Area was calculated with the formula $A = \frac{1}{4} \pi D^2$.

Table 5. Effects of other treatments in the N and K experiments on leaf damage.

Experiment	Treatments	Leaf N (%) 1983	Leaf N (%) 1985	Leaf damage (%) 1983	Leaf damage (%) 1985	Fruit yield (box/tree) 1983	Fruit yield (box/tree) 1984
1	Spacing (ft)						
	20 × 25	2.53	2.62	55	76	5.3	3.0
	15 × 20	2.46	2.56	41	69	3.4	1.8
	10 × 15	2.46	2.63	40	68	1.7	1.0
		n.s.[z]	n.s.	**	n.s.	**	n.s.
2	Irrigation (inches/yr)						
	0	2.79	2.55	62	65	4.6	–
	6	2.63	2.49	64	63	6.5	–
	12	2.52	2.50	72	67	7.0	–
		**	n.s.	**	n.s.	**	–
3	N source[y]						
	NH_4NO_3	2.47	2.70	58	56	4.2	3.3
	SCU	2.48	2.66	61	48	4.3	3.4
	IBDU	2.69	2.70	54	47	4.8	3.4
		**	n.s.	n.s.	*	*	*
	N timing						
	once/yr	2.56	2.68	58	49	4.6	3.0
	twice/yr	2.54	2.69	57	51	4.2	3.7
		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
4	P_2O_5 rates (lb./acre)						
	90	2.70	2.44	62	76	4.6	2.5
	180	2.64	2.42	59	69	4.3	2.8
	270	2.60	2.42	57	66	4.6	3.2
		**	n.s.	n.s.	**	n.s.	n.s.

[z]n.s.—no significance; *—significant at 5% level; **—significant at 1% level.
[y]NH_4NO_3—ammonium nitrate; SCU—sulfur coated urea; IBDU—isobutylidene diurea.

Freeze damage data from the irrigation treatments in the current study are contrary to that reported from the 1977 and 1981 freezes (4). Irrigation treatments resulted in less leaf, fruit and wood damage than the no irrigation control from the 1977 and 1981 freezes. These differences perhaps could be partially explained by the climatic conditions prior to the freezes. The annual rainfall for 1976, 1980 and 1983 was 51, 42 and 63 inches, respectively. The 1983 rainfall was 11 and 19 inches more than the 1976 and 1980 rainfall, which may have depleted the nutrient supplies in the soil. This was evidenced by a wider leaf N range in the 1983 irrigation treatments (2.52 to 2.79%) than in other years. The 1983 fruit production was 4.6 boxes per tree for the no irrigation control and 6.5 and 7.0 boxes per tree for the 2 irrigation treatments. It is possible that the irrigated trees treatments were in a N-stressed condition, compared to the non-irrigated control trees due to the depleted nutrient supply and heavy fruit load.

Phosphorus (P) treatments in Expt. 4 resulted in a lower percentage of damaged leaves with the data being significant in 1985 but not 1983. These trends do not appear to be related to leaf N or leaf P content (data not shown).

Data show that N and K fertilizer practices influenced the ability of citrus trees to withstand cold with a clearcut tendency for high N to reduce cold damage of foliage. The trend was consistent in all 4 experiments for both freezes. High K, on the other hand, tended to increase the cold susceptibility of foliage. These findings are in contrast to the long-established belief that K has a hardening effect on citrus trees making them less susceptible to cold injury, while high N increases the susceptibility to cold injury (2). Our findings for the 1983 and 1985 freezes are in agreement with results reported by Smith and Rasmussen (9).

It should be emphasized that tree damage evaluation after each freeze is influenced by the accumulated effects of climatic and other environmental conditions including cultural practices prior to the onset of weather condition. This may explain the inconsistencies in results observed following different freezes. Yelenosky et al. (12) attributed the nonhardening temperatures prior to the freeze as a major factor determining freeze damage in 1983. That year was also one of higher than normal rainfall (64.14 inches) which may have depleted the nutrient supply in the soil. This was reflected in the relatively low leaf N content that year and it may partially explain the positive response of the trees to high rates of N application.

Stress from fruit crop on the tree could be one of the leading factors in influencing the cold resistance of the tree (11). This was demonstrated in tree spacing treatments in Expt. 1 (Table 5) and the irrigation treatments in Expt. 2 (Table 5). In both experiments, trees with higher fruit production had more leaf damage from the 1983 freeze than trees with lower fruit production. However, the size of the fruit crop did not seem to be a factor in the cold resistance of the tree from N and K treatments, at least not within the confines of these experiments (Tables 2 and 3). In general, higher N and K treatments resulted in higher fruit production and less leaf damage than trees from lower N treatments. This would indicate the importance of maintaining a healthy tree with a balanced fertilizer program.

Leaf analysis, notably N and K levels, are useful indices of the health and vigor of citrus trees. The present recommendations of maintaining optimum ranges of leaf N (2.5 to 2.7%) and K (1.2 to 1.7%) are based on those for tree health and fruit production (5). The present study shows these levels can also be used for maximizing freeze tolerance. There was more foliage damage when leaf N content was below 2.5% and less damage between 2.5 to 2.8%. Potassium levels below 1.2% resulted in more wood damage and levels above 1.7% showed more leaf damage than the optimum range of 1.2 to 1.7%. Leaf analysis is a useful tool in reflecting the mineral nutritional status and the health of the tree. A healthy tree will tolerate cold better than a less healthy tree. Annual leaf samplings for mineral analysis are usually collected in the summer which would provide sufficient time for corrective nutritional measures to be taken if needed.

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