It is especially important in a time of labor shortage to increase the efficiency of harvesting operations through a more orderly movement of the crop. Growers may achieve this by applying 2,4-D as recommended (1). It is suggested that half of the 'Pineapple' orange groves be sprayed each year and the untreated groves be picked first. This should prevent the normal gap between the 'Pineapple' and 'Valencia' crops and delay heavy fruit drop in the event of a freeze. 2,4,5-TP should not be used until it has been cleared for this purpose; otherwise, the crop could be condemned. 2,4,5-TP is currently being used on apples and apricots and its used on citrus is expected.

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EFFECT OF AIR-BORNE FLUORIDES ON 'VALENCIA' ORANGE YIELDS[1]

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ABSTRACT

A field experiment with bearing 'Valencia' orange trees on rough lemon rootstock was carried out to study the effects of different levels of air-borne fluorides on yield, fruit quality, and leaf growth. The experimental trees were in a grove exposed to relatively high levels of air-borne fluorides. Six trees were enclosed in individual plastic greenhouses. Fluorides were removed from the air entering 3 greenhouses by dry calcium carbonate filters, while unfiltered ambient air was moved through the other 3 greenhouses. Three additional trees were not enclosed and were used as outdoor checks.

The leaves of trees in the unfiltered greenhouses absorbed much less fluorine than those of the outdoor checks, even though there was little difference in the fluorine content of the air. This appears to be due to the fact that the leaves were kept dry inside the greenhouses. Greenhouse trees receiving unfiltered air produced significantly less fruit in 1965-66 than those receiving filtered air, and the outdoor check trees yielded significantly less fruit than the unfiltered greenhouse trees.

Leaf size decreased as leaf fluorine increased. There was a trend toward higher acid and lower Brix/acid ratio of the juice with increasing fluorine in the leaves, but these differences were not significant.

INTRODUCTION

Fluorine is found in green plants throughout the world, usually at levels too low to cause injury. Although many soils contain several hundred parts per million of fluorine, relatively little of this is in available form and much of that which is absorbed by the roots tends to remain in the root system. During the past 15 years, gaseous fluorides have become a serious problem as air pollutants in areas adjacent to certain types of manufacturing plants. These include phosphate manufacturing plants, aluminum plants, steel plants, and ceramic plants. All of these plants employ processes that release varying amounts of gaseous fluorides into the air, the amounts depending on the materials

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used in manufacture and the extent to which waste gases are scrubbed to remove fluorides.

Green plants vary widely in their sensitivity to gaseous fluorides, but many species are injured by prolonged exposure to less than 1 part per billion (ppb) fluorine in the air. Gladiolus is one of the most sensitive plants. Mature leaves of citrus are relatively tolerant of gaseous fluorides, but young citrus leaves in Florida may show fluorine chlorosis when they contain as little as 20 or 30 parts per million (ppm) fluorine.

The work reported here was carried out to study the effect of air-borne fluorides on yield and quality of fruit and on leaf growth of 'Valencia' orange trees.

Literature Review

In 1950, a new pattern of leaf chlorosis was reported in the Bartow area of Polk County, Florida in citrus groves near phosphate manufacturing plants (6). Application of several 0.1 N hydrofluoric acid and fluosilicic acid foliar sprays to grapefruit trees 19 miles from the nearest phosphate plant produced the same chlorotic pattern. This suggested that the chlorotic pattern found near Bartow was caused by gaseous fluorides released into the air by the phosphate manufacturing plants.

In California, orange trees grown in deep soil beds in a greenhouse and exposed to 1 to 5 ppb fluorine as HF gas for about 26 months were much smaller after 13 months of fumigation than controls grown in clean air (2). There were significant reductions in trunk diameter, height of tree, crown volume, and average leaf size in the fumigated trees as compared with trees grown in clean air. These differences remained relatively constant during the second year of treatment. There was also a detrimental effect on yield and quality of fruit. Fluorine chlorosis and necrosis symptoms were found in leaves containing 75 or more ppm fluorine.

In a greenhouse experiment in California, the apparent order of decreasing sensitivity to hydrogen fluoride fumigation, based on gross growth, leaf size, and chlorosis was: navel orange, 'Lisbon' lemon, 'Valencia' orange, 'Eureka' lemon, red grapefruit, 'Marsh' grapefruit, and 'Temple' orange (1). Exposure to fluoride gas decreased the average size of leaves in all 7 varieties, decreased the top weight of all varieties except 'Temple' orange, and increased the extent of chlorosis on all varieties. The 2 lemon varieties showed the most severe chlorosis, but navel and 'Valencia' oranges showed greatest reduction in gross growth (linear growth, trunk diameter, and weight of tops). In this test, concentration of HF in the air started at 12 ppb, but later was reduced to 7 ppb and then to 3 to 5 ppb.

Under California grove conditions, more fluorine was absorbed by leaves of navel orange trees sprayed with NaF and HF than by those sprayed with NH_4F and H_2SiF_6, at each of 4 concentrations, except the lowest concentration used (3).

A survey of 'Valencia' orange groves in Polk and Hillsborough Counties, Florida, near the phosphate manufacturing area, was conducted in 1961-62 (4). Spring flush leaves were sampled each month for 12 months. In one grove located about 1 mile from the nearest phosphate plant, 310 ppm fluorine was accumulated in 1961 spring flush leaves by April 1, 1962. Similar leaves in 5 other groves absorbed from 115 to 169 ppm fluorine in the same period. Three of these groves were 4 to 8 miles north, northwest, or west of the group of phosphate plants in the Bartow-Mulberry-Brewster area, and 2 were within 1 mile of an isolated phosphate plant. Groves east of the group of phosphate plants, or more than 10 miles from them in other directions, absorbed only low to moderate amounts of fluorine. Wind direction evidently played an important role in determining the amount of air-borne fluorides reaching the various groves in this survey.

The removal of fluorides from the atmosphere around 'Valenica' orange trees in plastic greenhouses in the field resulted in greater rates of photosynthesis, increased chlorophyll contents and lower rates of respiration by the leaves than were shown by trees exposed to air-borne fluorides (8). Fluorine-chlorotic leaves of citrus were regreened by application of foliar sprays consisting of 20 to 30 pounds hydrated lime, 15 pounds manganese sulfate, and 10 pounds urea per 100 gallons when limited rainfall permitted most of the heavy spray residue to remain on the leaves for 2 or 3 months (5). It was concluded, however, that the application of such sprays was impractical as a primary means of reducing injury to citrus from air-borne fluorides because abundant rainfall in Florida, particularly during the summer months, washes away much of the spray residue within a few weeks.

Methods

Control of Atmospheric Fluorides.—Nine medium-sized bearing 'Valencia' orange trees on rough lemon rootstock in a grove growing on Rutlege fine sand south of Bartow, Florida, were used in this experiment. The grove was located in an area exposed to relatively high fluorine air pollution from nearby phosphate manufacturing plants. Six of the trees were covered by individual plastic greenhouses 15 feet square, 12 feet high at the eaves, and 15 feet high at the ridge. Electrically operated blowers and louvered outlets provided a change of air about every 35 seconds. Dry calcium carbonate filters on the blowers supplying air to 3 greenhouses were used to remove fluorides from the air. The 3 filters were replaced with new ones after about 18 months of operation to maintain filtering efficiency. Blowers for the other 3 greenhouses forced in unfiltered ambient air. The 3 trees not enclosed received the same fertilizer and spray program as the greenhouse trees and were used as outdoor checks. All trees were irrigated as required. The blowers were operated continuously from May 6, 1963 to May 2, 1966, except for brief shutdowns for minor greenhouse repairs, spraying, and heating on cold nights.

Air samples were taken in 2 filtered greenhouses, in 2 unfiltered greenhouses and beside 2 outdoor check trees continuously in 24-hour increments from March 11 to May 2, 1966. These were taken with sequential air samplers and analyzed by the Regional Environmental Office of the Florida State Board of Health in Winter Haven.

The experiment was terminated on May 2, 1966, at the request of Consumers' Cooperative Association, an organization that purchased the grove early in 1966 shortly after building a phosphate plant nearby.

Fluorine Determination.—Leaves and other plant tissue used for analysis were washed to remove surface fluoride contamination and dried at 70° C. Fluorine was determined by a modification of the distillation method of Willard and Winter (7).

Results

The experimental trees were defoliated with some loss of small twigs by the December 1962 freeze. New leaves that started growing soon after the freeze (December flush) contained more than 200 ppm fluorine, and the 1963 spring flush contained slightly more than 40 ppm fluorine when the greenhouses were enclosed on May 6, 1963.

Fluorine Content of the Air.—The average fluorine contents of air samples representing the 3 treatments in this experiment were as follows for the 2 periods March 11 through March 31, 1966, and April 1 through May 1, 1966, respectively: outdoor checks, 3.9 and 6.3 ppb; unfiltered greenhouses, 3.2 and 5.65 ppb; filtered greenhouses, 1.5 and 1.95 ppb. The values for the filtered greenhouses were relatively high because the limestone filters were operating at reduced efficiency and were due for replacement. Spot checks of fluorine in the air in filtered greenhouses when the filters were relatively new showed average values well below 1 ppb fluorine. Because of changes in wind direction, there was considerable daily variation in fluorine levels in the air. The highest average value adjacent to the outdoor check trees for a 24-hour period was 14.2 ppb fluorine, and the lowest value was 0.6 ppb.

Leaf Fluorine Content.—The fluorine level in the 1962 December flush leaves on trees receiving filtered air decreased from more than 200 ppm to less than 100 ppm fluorine within a few months after the greenhouses were enclosed, whereas the fluorine increased in the leaves of the same flush on outdoor check trees. The effect of treatment on fluorine content of leaves of later flushes sampled at various times is shown in Table 1.

The limestone filters did not remove all of the fluorine from the air entering the filtered greenhouses, but they did reduce fluorides to a relatively low level. The leaves of trees in greenhouses receiving unfiltered air contained considerably less fluorine than those of the outdoor check trees. While theoretically the fluorine content of the air should have been the same outdoors as in the unfiltered greenhouses, average air fluorine analyses reported above for March and April, 1966, showed slightly lower fluorine in the air in the unfiltered greenhouses than outdoors. It is believed that the considerably lower fluorine content of the leaves on the greenhouse trees receiving unfiltered air as compared with those on the outdoor check trees was due primarily to the fact that the leaves *in the*

Table 1. Effect of air-borne fluorides on mean fluorine content of 'Valencia' orange leaves.

Date sampled	Flush	Filtered air ppm	Unfiltered air ppm	Outdoor checks ppm
June 6, 1963	1963 summer[1]	7	15	23
January 10, 1964	1963 summer	13	60	151
	1963 fall	3	19	51
April 16, 1964	1963 fall	27	47	92
	1964 spring	1	7	22
May 28, 1965	1964 spring	6	32	60
August 3, 1964	1964 spring	7	55	64
July 2, 1965	Old leaves	34	196	307
August 20, 1965	1965 spring	5	43	86
January 5, 1966	1965 spring	10	71	197

[1]These leaves developed after the greenhouses were enclosed on May 6, 1963.

greenhouses remained dry, whereas those outdoors were moist from rain or dew much of the time. Citrus leaves appear to take up more fluorine from the air when they are moist than when they are dry. Hydrofluoric acid is highly soluble in water.

On April 12, 1966, a sample of young 1966 spring flush leaves was taken from each of the 9 trees in the experiment. On May 2, when the experiment was terminated, a similar set of samples was taken. The increase in leaf fluorine for the 3 treatments and the average fluorine contents of the air during that 20-day period are shown in Table 2. It will be noted that the fluorine in the leaves increased more than 100% on the outdoor check trees during this period. Even though the fluorine content of the air in the unfiltered greenhouses was nearly as high as that outdoors, much less fluorine was absorbed by the leaves in the unfiltered greenhouses.

Fluorine Content of Fruit.—Mature fruit sampled on March 11, 1965, was analyzed for fluorine (Table 3). The highest levels of fluorine in the fruit were found in the peel. There was slightly more fluorine in the juice than in the pulp. The U. S. Food and Drug Administration allows a maximum of 7 ppm fluorine in the whole fruit based on fresh weight. While this concentration was approached in the peel of

Table 2. Increase in fluorine content of young 1966 spring flush 'Valencia' orange leaves as related to mean fluorine content of the air during a 20-day period.

Treatment	Fluorine in leaves ppm 4-12-66	Fluorine in leaves ppm 5-2-66	Mean increase in leaf fluorine in 20 days ppm	Mean fluorine in air ppb[1]
Filtered air	10.2	11.3	1.1	2.1
Unfiltered air	22.3	37.5	15.2	6.3
Outdoor checks	55.3	113.6	58.3	6.9

[1]Parts per billion fluorine in the air, average of 2 air samples each 24-hour period for each treatment for the 20 days from April 12 to May 2, 1966. Air sampling performed by Regional Environmental Office of the Florida State Board of Health, Winter Haven, Florida.

fruit from the outdoor check trees, the values for the whole fruit were well below the tolerance.

Leaf Size.—In May 1964 and in July 1965, width and length of 200 current spring flush leaves were measured on each tree. Average leaf areas were calculated and are shown in Table 4. There was a 20% reduction in average leaf size on the greenhouse trees receiving unfiltered air and a reduction of about 50% on the outdoor check trees, as compared with the trees receiving filtered air.

Fruit Quality.—Fruit was sampled for internal quality determination on March 11, 1965, February 9, 1966, and March 28, 1966. Quality analyses for the sampling of March 28, 1966 are shown in Table 5. These data show a trend toward higher acid content and resulting lower Brix/acid ratio of the juice with increasing levels of fluorine in the leaves, but the results are not statistically significant. A similar trend was found in the sampling of February 9, 1966. The fruit on the trees in all the greenhouses showed a good orange color early in January, 1966, whereas most of the fruit on the outdoor check trees were still green at that time.

Yield.—None of the trees produced any fruit in 1963-64 because of freeze damage. Yields for both 1964-65 and 1965-66 are shown in Table 6. In the spring of 1964, a mealybug infestation

Table 3. Effect of air-borne fluorides on fluorine content of peel, pulp, and juice of 'Valencia' orange fruit. Fruit sampled March 11, 1965.

Treatment	Fluorine content: Juice ppm	Pulp ppm	Peel ppm	Whole fruit ppm[1]
Filtered air	.63	.40	.87	.52
Unfiltered air	.52	.39	2.31	.85
Outdoor checks	.69	.54	6.22	1.78

[1]Weighted mean of average ppm F in pulp and peel, based on relative weights of pulp and peel.

Table 4. Effect of air-borne fluorides on size of spring flush leaves of 'Valencia' orange trees.

Treatment	Mean leaf area cm^2 1964	Mean leaf area cm^2 1965	2-year average cm^2	Relative area 2 years %
Filtered air	42.70	32.00	37.35	100.0
Unfiltered air	33.49	26.18	29.84	79.9
Outdoor checks	17.18	19.89	18.54	49.6

Table 5. Effect of air-borne fluorides on internal quality of 'Valencia' oranges.

Treatment	Juice by weight %	Brix %	Acid %	Ratio Brix/acid
Filtered air	61.0	11.75	0.83	14.26
Unfiltered air	58.5	12.17	0.91	13.59
Outdoor checks	59.2	11.52	0.97	12.10

occurred on 4 of the greenhouse trees and caused excessive dropping of small fruit. Two of these trees received filtered air, and 2 received unfiltered air. The infestation was light with little or no effect on yields on the remaining 2 greenhouse trees. There was no mealybug infestation on the outdoor check trees. The most severe mealybug injury occurred on tree C receiving filtered air. This tree produced only 30 pounds of fruit, most of it late bloom. Because of the mealybug infestation on the greenhouse trees, statistical analysis of the 1964-65 yields is not reported. However, the mean fruit production of trees in the greenhouses, both filtered and unfiltered, was 2½ times greater than the yield of the outdoor check trees, even though there was no mealybug infestation on the outdoor check trees.

The trees were sprayed with parathion and Guthion several times during 1964 to eliminate the mealybug infestation on the trees in the greenhouses. The outdoor check trees were given the same sprays even though they had no mealybug infestation. Pesticidal sprays applied to the experimental trees about once a month during 1965 prevented any damage to the 1965-66 crop.

Comparison of the 1965-66 mean yields by the Duncan multiple range test showed that the trees receiving filtered air produced significantly more fruit than the trees receiving unfiltered air. The mean yields from both of these treatments were significantly greater than that produced by the outdoor check trees. There was a significant negative correlation, $r = -.685^*$, between yield of fruit and fluorine content of 1965 spring flush leaves sampled in August 1965.

Table 6. Effect of air-borne fluorides on yield of 'Valencia' orange trees.

	Yield of fruit pounds					Mean leaf fluorine, ppm		
						1965 spring flush		Old leaves
Treatment	A	B	C	Mean[1]	Yield %	8-20-65	1-5-66	7-2-65
			1964-65 Crop Picked March 11, 1965					
Filtered air	413[2]	301[3]	30[4]	248	100.0			
Unfiltered air	427[2]	102[4]	170[3]	233	94.0			
Outdoor checks	29[5]	80[5]	166[5]	92	37.1			
			1965-66 Crop Picked March 28, 1966					
Filtered air	397	372	363	377[c]	100.0	5	10	34
Unfiltered air	302	273	316	297[b]	78.7	43	71	196
Outdoor checks	140	59	116	105[a]	27.8	86	197	307

[1]Mean yields followed by different letters are significantly different at $P = 0.05$.

[2]Slight damage by mealybugs.

[3]Moderate damage by mealybugs.

[4]Severe damage by mealybugs.

[5]No mealybug damage.

The linear regression formula is $Y = 345.61 - 1.912X$, where X = ppm F in the leaves and the regression coefficient Y is expressed as pounds of fruit per tree. This shows a 95-pound (27%) decrease in average yield of fruit per tree for each increase of 50 ppm F in 5½ month-old spring flush leaves. There was a highly significant negative correlation, $r = -.907^{**}$, between yield of fruit and fluorine content of 1965 spring flush leaves sampled in January 1966. This linear regression formula is $Y = 381.91 - 1.3132X$, and shows a 65-pound decrease in mean yield of fruit for each increase of 50 ppm F in 10-month-old spring flush leaves. There was also a highly significant correlation, $r = -.869^{**}$, between yield of fruit and fluorine content of old leaves sampled in July 1965. This linear regression formula is $Y = 417.25 - 0.8797X$.

Discussion

The mechanisms by which air-borne fluorides produce leaf chlorosis and leaf burn (necrosis), reduce leaf size, retard tree growth, and lower fruit production (2) are not fully understood. Exposure of citrus trees to relatively high levels of air-borne fluorides during the spring bloom period is believed to cause the greatest losses in fruit production. The spring bloom accompanies the growth of new spring flush leaves. Extensive leaf chlorosis, leaf burn, and dropping of young leaves and excessive dropping of bloom and small fruit have been observed in several central Florida citrus groves during and immediately following their exposure to high levels of air-borne fluorides. This, of course, is an easily understood mechanism resulting in large reductons in yield of fruit. Young, soft citrus leaves are much more susceptible to injury from air-borne fluorides than are older leaves. Heavy drop of young leaves, bloom, and small fruit as a result of exposure to high levels of air-borne fluorides, however, occurs in relatively few Florida citrus groves. It did not occur on the trees included in this experiment. Hence, other less obvious mechanisms would appear to be largely responsible for the yield reductions found.

Fluoride will inhibit the activity of certain enzymes that occur in plants. Development of fluorine chlorosis on previously green leaves is evidence of chlorophyll destruction. *In addition*, fluorides may inhibit the synthesis of chlorophyll. In either case, the amount of photosynthesis per unit of leaf area is reduced since chlorophyll is required for photosynthesis. The reduction in chlorophyll and subsequently in photosynthesis occurs primarily in the tips and along the edges of citrus leaves where absorbed fluorine tends to accumulate. In addition, air-borne fluorides reduce total photosynthesis by decreasing the average size of the leaves. This directly reduces the area of photosynthetic activity. Therefore, because air-borne fluorides reduce net photosynthetic efficiency of the leaves per unit of leaf area (8), and because they reduce the area of photosynthetic activity by reducing average leaf size, reduced production of food by the trees for support of their growth and fruit production inevitably follows. This probably accounts for much of the reduction in yield found in this experiment.

Citrus groves in Polk and Hillsborough Counties near phosphate plants are not exposed to uniform levels of air-borne fluorides because of changes in wind direction and variation in amounts of gaseous fluorides emitted by the different phosphate manufacturing plants. Nevertheless, groves near phosphate plants in central Florida tend to show a gradual and relatively consistent buildup in leaf fluorine during their growth and development in spite of considerable daily variation in the concentration of air-borne fluorides.

The greenhouse trees receiving unfiltered air produced 21% less fruit in 1965-66 than did the trees receiving filtered air, although the 1965 spring flush leaves exposed to unfiltered air contained only 43 ppm fluorine on August 20, 1965, and only 71 ppm fluorine on January 5, 1966. This indicates that even relatively low levels of fluorine in the current year's spring flush leaves are associated with significant reductions in yield of fruit. It is not known how much of the yield reduction was caused by exposure of the trees during the bloom period to air-borne fluorides. Additional work is needed to determine the effect of various levels of air-borne fluorides during the bloom period on fruit production. Such studies should include fluoride levels too low to cause excessive drop of young leaves, bloom, and small fruit, as well as fluoride levels high enough to cause such drop.

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APHYTIS HOWARD (HYMENOPTERA: EULOPHIDAE) ON FLORIDA CITRUS[1]

MARTIN H. MUMA[2] AND ALLEN G. SELHIME[3]

This study of *Aphytis* Howard in Florida citrus groves covers our knowledge of these parasites of armored scale. The first species recorded from Florida citrus, Muma (1959), was *Aphytis chrysomphali* (Mercet). This undoubtedly is a species of the *chrysomphali* complex, but minor morphological and biological differences exist between our specimens and those described and discussed by Compere (1955) and DeBach and Sisojević (1960). *Aphytis lepidosaphes* Compere was recorded by Muma and Clancy (1959). Other species were recorded 2 years later in a list that included all species, Muma et *al.* (1961). Two species listed, *Aphytis mytilaspidis* (LeBaron) and *Aphytis proclia* (Walker), are now believed to be misidentifications.

Compere's (1955) systematic study of the genus has been used as a guide to species identity. DeBach's (1959 and 1960) and Quednau's (1964) descriptive papers have been used extensively to identify pupae and recently described species.

Evaluations of the economic potential of various species have been reported by Compere (1955), DeBach (1958), Muma (1959), DeBach (1960), DeBach and Sisojević (1960), Muma and Clancy (1961), and Clancy *et al.* (1963). Parasitism rates and control information appended to species descriptions and discussions in this paper complement or supplement favorable published evaluations except in the case of *Aphytis lingnanensis* Compere. Failure of this species to control an armored scale on Florida citrus is an enigma.

This paper is not a systematic study so complete synonymies, detailed descriptions, or diagnostic morphologic illustrations have not been included. Further, the cited species have not been biologically verified by breeding experiments as is frequently done, DeBach (1960). We recognized the forms as morphologic and biologic entities in their association with armored scale insects on Florida citrus trees. To facilitate identification of the several species, keys to the adults and pupae and a table of diagnostic characters are included.

KEY TO ADULTS ON FLORIDA CITRUS

1. Propodeal crenulae large and overlapping 2
   Propodeal crenulae minute or large but not overlapping 3

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[1] Florida Agricultural Experiment Stations Journal Series No. 2510.

[2] University of Florida, Citrus Experiment Station, Lake Alfred.

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