Million fluorine was found in certain leaf samples, no clear correlation between fluorine content and degree of chlorosis was apparent. Normal leaves taken outside the affected area showed from 12 to 30 p.p.m. fluorine. It has been reported by Kaudy, et al. (3) that citrus leaves in California, obtained near an industrial plant, showed up to 211 p.p.m. fluorine. However, no chlorosis was reported in that area.

Since analysis of citrus leaves were erratic, samples of an air plant, Spanish Moss (Tillandsia Usneoides), were collected at varying distances from one of the triple-superphosphate plants and analyzed for fluorine. The results, shown in Table 1, indicate that fluorine was being released in the manufacturing operation, since the amount in the Spanish Moss decreased as the distance from the plant site increased. The deviation from the general trend noted for the 3.5 mile sample can be ascribed to the topography of the area. The chlorosis tends to be more pronounced in low spots.

In the spring of 1955, sprays of aqueous hydrofluoric acid, fluosilicic acid, and phosphoric acid were applied at a concentration of 0.1 Normal to the foliage of four year old Ruby Red grapefruit trees. These trees were located north of Lake Alfred, nineteen air miles from the nearest triple-superphosphate plant. Approximately one liter of solution was applied per tree per spray application. After seven applications over a period of two months, a chlorotic pattern—identical to that found in the Lakeland-Highlands area — appeared on the foliage. This pattern occurred on the trees which had received the hydrofluoric and fluosilicic acid sprays, but not on those which had received the phosphoric acid sprays. The pattern was confined to the growth produced during the period of spraying and was most pronounced on leaves which were about three-fourths matured. In addition to the chlorotic pattern, a marked reduction in leaf size was also frequently observed.

Although, in some cases, the application of nutritional sprays and chelated iron to affected groves has resulted in an improvement in general appearance, the chlorotic leaves have not re-greened and the pattern persists. Observations to date indicate that once the pattern appears on the leaf, it remains until the leaf drops.

**LITERATURE CITED**


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**WATER TABLE FLUCTUATION AND DEPTH OF ROOTING OF CITRUS TREES IN THE INDIAN RIVER AREA**

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There is a divergence in opinion as to the adequacy of the drainage system now in use in the Indian River Area. Some feel that the citrus areas are inadequately drained, pointing to the following facts: (1) Nearly all groves contain areas of slightly lower eleva-
tion than the average grove surface and such areas commonly contain poor trees. Some of these poor areas may be due to coarse texture soils or low fertility. (2) Practically all citrus trees in the Indian River Area are very shallow-rooted, a fact readily verified when trees are pulled. (3) Most Indian River trees are very susceptible to drought, presumably a result of the shallow root system. (4) Tree loss is higher in Indian River groves than in groves where drainage has never been a problem; this is a general characteristic of tree crops grown in poorly drained sites. On the other hand, there are those who believe that the area is generally overdrained, that the water table has been undesirably lowered, and that the result has been the increased necessity for irrigation in these areas.

The objectives of this paper are to present data on the fluctuation of the water table in Indian River citrus grove soils, on the depth of rooting of citrus trees growing in soils drained to various depths, and on the yield of citrus trees in relation to various drainage situations. These factors are discussed in relation to drainage and irrigation practices in the Indian River Area.

The available experimental evidence bearing on this problem has largely been obtained by Young (2,3,4) who supports the view that drainage is more often inadequate than excessive. The evidence to be presented below also supports this view, and employs an approach to the problem different from that used in other investigations.

METHODS

This investigation was conducted in the grove of the Indian River Field Laboratory 5 miles west of Ft. Pierce, Florida. The grove is bounded on the north, east, and south by lateral ditches of the North St. Lucie River Drainage District, and on the west by an interior water collection ditch. The collection ditch is filled with artesian water in dry periods, and drained during wet weather. The grove is equipped with three drainage pumps which are operated whenever necessary to remove standing water not quickly removed by gravity flow into the drainage laterals. This system has worked very well for removal of surface water with the exception of one dyke break in October 1950. In most areas of the grove, drainage is considered adequate. Complete irrigation of the grove has been necessary only one time in the past five years.

The following soil types arranged approximately in order of decreasing acreage, are included in the 35-acre grove area: Felda fine sand, Parkwood loamy fine sand, Sunniland fine sand, Manatee fine sandy loam, Leon fine sand, and Pompano fine sand. Except where specifically noted, no differentiation was made among soil types in handling the data.

Three groups of trees were used in these studies: Marsh grapefruit trees planted in 1930, Valencia orange trees planted in 1930, and Valencia orange trees planted in 1940. All trees are on sour orange rootstock, and were sufficiently old to have rooted lower than the depths reported below in the absence of unfavorable environmental condition. Individual-tree yield records were obtained over a four-year period.

Fluctuation of the water table was observed by measurements of the depth to free water surface in 27 open wells distributed throughout the 35 acres. The wells consisted of five-inch diameter galvanized-iron irrigation pipe, perforated on the sides, and sunk into the soil to a depth of about eight feet. Measurements of the depth to free water were made by weighted tape from the top of the pipe to the free water surface in the well, and corrected to the depth below the soil surface. Wells were located on the crowns of the beds, an important fact in the interpretation of the data.

Depth of rooting was determined by a modification of the method of Ford (1). Measurements were made beneath each of the 27 trees nearest the 27 water table wells. Four locations around each tree were selected on the shoulders of the beds, and a hole was dug with a 10 inch well driller's auger at each location. Soil was removed in three inch increments of depth, and washed on a screen so that the roots were separated from the soil. Roots smaller in diameter than 1.5 mm. were dried and weighed. Root concentration was calculated to grams of roots per cubic foot of soil, representing a three-inch layer of soil over an area two feet square. The depth-of-rooting measurements were made in November and December of 1958.
RESULTS

Water table fluctuation. — Measurements were made at monthly intervals during the first four years of observations of water table level. In the last 1½ years, the observations were made at weekly intervals. Study of the data obtained showed that the water level rose and fell in all the wells in unison, so that average levels could be used to show the trends. Average water table levels below the tops of the beds are shown in Figures 1 and 2. The level of the curve at any time can be accounted for by the amount of rainfall. The September 1949 peak (Fig. 1) followed the August 28 hurricane. The 1950 season was very dry until after July, with only 2.2 inches of rain falling that month, followed by 11.46 inches of rain in August and a hurricane in September. In 1951 the April rainfall was 11.35 inches with a corresponding peak in water table, followed by only 2.18 inches in September with a corresponding fall in water table. Other fluctuations can be accounted for in similar fashion.

The records of water table depth taken at weekly intervals (Fig. 2) enables making a closer approximation of the time the water table exists at a high level.

In August, September, and October 1953, a total of 30 inches of rain fell in a persistent series of moderate to heavy storms. Under these conditions the water table stood less than three feet from the tops of the beds for 85 consecutive days. Citrus roots cannot survive continuous flooding and were probably killed to a level several inches above the water table. By contrast, on April 10, 1954, a five foot water table had developed in the grove after which 5.94 inches of rain fell April 21-23. On April 24 the water table had risen to 1.9 feet. Since rains did not persist, the water table fell by May 8 to a level of 4.7 feet. This example shows that the drainage system is quite adequate for occasional heavy rains, but inadequate to prevent rise in water table to undesirably high levels in case of prolonged heavy rainfall.

The extreme fluctuation of the water table possible under the present system is also shown in Figures 1 and 2. The range recorded was from 1.4 to 5.8 feet below the surface of the soil. The high extremes doubtless cause loss of roots through flooding and the low extremes are so low as to be no factor in water supply during drought periods. The water table is far from being stabilized at any level in this grove.
Depth of Rooting—The average root concentration in the soil by depths and by varieties is given in Figure 3. The shaded area represents the concentration and distribution of roots of Valencia trees, while the unshaded bars represent roots of Marsh grapefruit trees. In more favorable locations both Marsh and Valencia had roots to a maximum of 39 inches although in negligible concentration at that depth. Throughout the entire grove, 75 percent of all small roots found were within 16 inches of the tops of the beds. Valencia trees had considerably fewer roots at all depths than did Marsh trees.

A comparison of depth of rooting between Indian River trees and Ridge trees is presented in Figure 4. The data for Indian River are the average of all locations at the Indian River Field Laboratory grove, while the Ridge data are for Marsh grapefruit, adapted from Ford (1). All trees were on sour orange rootstock.

![Graph of Root Distribution](image)

The root distribution at well location No. 8 in Parkwood soil is shown in Figure 5. The roots occupy the upper 18 inches of the soil in good concentration, and extend down to a depth of 33 inches. The summer-fall water table stood at 29 inches average in August 1953 to October 1953, and 75 percent of the roots were found above a level of 28 inches. In this location, the trees are generally of good appearance and the yield of 2.5 boxes per tree is about the average of the block over the past four years. Fruit size is generally satisfactory, averaging about 71 mm diameter for the crops of 1951-52 and 1952-53, with an average Brix of 12 degrees in the same period. In short, these are satisfactory trees.

By contrast, the root distribution at well location No. 7 is shown in Fig. 6. This well is on Manatee soil and the soil surface is 1.65 feet lower than at location No. 8. In this location, the roots are strongly concentrated in the surface three inches of soil where they compete for moisture with the cover crop and evaporation, and would be very vulnerable to the effects of cultivation. In this location, the summer-fall water table in 1953 stood at an average of 12 inches and 75 percent of the roots were found above the 12 inch level.
These trees are extremely susceptible to drought, and the area in which they are located is generally irrigated several times each year by sprinkling. Yield per tree averaged 1.5 boxes per tree over a four-year period, while fruit diameter in 1951-52 and 1952-53 averaged only 65 mm. Brix of 14 degrees in the fruit juice was high compared with the well-drained location. In summary, these trees are very unsatisfactory from most standpoint, and are marginal producers. Their unsatisfactory condition must obviously be charged to inadequate drainage.

The two examples cited above serve to point out the relation between depth of rooting and position of the water table, but the entire group of well locations can be used to calculate a general relation between these two factors. To do this, the average water table level was calculated for each well for the period August 8 to October 24, 1953, and the level in the soil above which 75 percent of the roots were found was calculated for each location. These pairs of values show a definite relationship. The situation at Well 27 constitutes the only exception of any note, and may readily be explained as the only location on the Leon series of soil, where the roots were not limited by the water table, but rather by the well-formed organic hardpan at this location. Omitting the data for Well 27, the correlation coefficient for these data is 0.777, significant beyond the 1 percent level, with a regression equation of $E = 0.604 x + 0.05.$ These data further confirm the view that the primary factor limiting penetration of roots into the soil is presence of the water table.

An attempt was made to relate the depth to the water table with the yield of the trees. For an estimate of the water table level, the same August 8 to October 24, 1953, average figures were used as above. For estimates of yield, the average yield per year during the crops from blooms of 1951 to 1954 were calculated for the 12 trees in immediate proximity to the individual wells. In order to use the data for the grapefruit and the two blocks of oranges as a unit, the yields were calculated as percentages of the average of the respective blocks. A yield value of 100 percent thus represents the average yield of all trees in the particular block. No general relationship was apparent in these data, except that in the case of location No. 7 the water table depth was at about 1 foot below the surface in the specified period. The yield was only 55 percent of average. Omitting location No. 7, the correlation coefficient ($r$) was a nonsignificant 0.212. The probable explanation of these data is that yield is not depressed if the rainy season water table peak can be held below 1.5 feet from the surface. This was accomplished in all but one of the locations in this grove. Observations in the grove support this interpretation, since the bulk of the grove seldom has needed irrigation and appears unaffected by excessive periods of wet weather.

**Discussion**

The situation in the experimental grove is thought to be similar to that in many groves on the East Coast. For the most part, commercial groves are fairly well drained, but in nearly all groves one to several areas of poor trees are found. In the case described, the area of poor trees had a high water table, and the trees had little depth of rooting and low yields. In areas where the water did not rise above a certain level (of about 1.5 feet in this case) even in extremely wet periods, the trees were vigorous in appearance and yielded well, had deeper penetration of roots into the soil, and were drought resistant.

In commercial groves, the poorly drained areas may constitute any proportion of the grove. The economically advisable practice depends on the proportion of the grove affected and the expense of correcting the situation. Cases have been observed where practically entire groves suffer from poor drainage,
while in other groves only a small area is affected. In the latter case it may be more economical to abandon the marginal area, but when an entire block is affected there is no way to increase yield except by improving drainage.

The data presented on water table fluctuation suggest that maintenance of a water table at any constant level would be accomplished with difficulty. The level was very responsive to drought and rainfall conditions, varying over a wide range.

Practical application of the information obtained must be made for each individual case. Doubtless a 1.5 foot peak water table would not be adequate on coarse sands as it appears to be for the fine sands in the experimental grove. Before making practical decisions, the installation of simple water table wells as described above would be extremely helpful. The information they give can be used to determine whether water damage is responsible for the poor tree condition in problem areas, and will reflect the success of measures taken to improve drainage problems.

Summary
Fluctuations in water table level were followed over a five-year period by means of open wells in a single mature citrus grove near Ft. Pierce, Florida. The extreme fluctuation found during the period was from 1.4 feet to 5.8 feet below the surface of the soil. The drainage system provided for rapid lowering of the water table after short periods of heavy rain, but was inadequate to carry off the excess water resulting from prolonged rainy periods.

Depth of rooting was shallow. In the entire grove, 75 percent of the roots were within 16 inches of the crown of the beds. Depth of rooting was dependent on the depth of the water table. The correlation coefficient between depth of water table from August 8 to October 24, 1953, and depth to include 75 percent of all roots found was 0.777, a value significant above the 1 percent level. Yield of trees did not appear to be affected if the peak water table was lower than 1.5 feet below the surface of the soil.

LITERATURE CITED

SUB-SOIL DRAINAGE AS A FACTOR IN THE SPREAD OF THE BURROWING NEMATODE

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A characteristic of spreading decline of citrus caused by the burrowing nematode, Radopholus similis (Cobb) Thorne, is the spread of this disease in all directions from a center of infestation. The average annual spread of the margin of infested areas has been calculated to be approximately 1.6 trees per year, (Suit, 2). The rate of spread of infested areas varied from grove to grove and from year to year in the same grove.

As the reason for these differences in the rate of spread was not known, work was started to study this problem. Of the possible factors considered, the movement of water in the soil seemed to be pertinent to the problem. It is the purpose of this paper to present observations on water movement through the soil as a factor in the spread of burrowing nematodes.

Observations on the expansion of spreading decline areas were made by plotting detailed maps of affected groves to indicate the area of declining trees. These groves were remapped annually to record the changes in the size and shape of the disease areas. A comparison of the maps showed that spread-