spectacle of an industry being tried by three judges, two lawyers and a star witness who didn't understand what the fighting was all about. The industry survived! An erudite columnist wrote that all that saved Argentina from destruction by the politicians and the generals was that the cows kept to the old fashioned ways and went on doing what comes naturally—the citrus industry is saved perennially by the trees that do the same.

All good things must come to an end—and, too late, all bad discourses must do likewise. To conclude I want to point out that the title of this paper is listed in the menu as "The Past and Present in the Citrus Industry—Question Mark." That question mark is a stroke of genius —it delineates the past, the present and the future better than a million words—it's concise, descriptive and very educational. I wish I'd have thought of it myself, but Irv must get the credit. It still is the master stroke that makes the title.

Finally, and in a very serious mood, I want to make a wish for the citrus industry—may the breeding program for cold resistance you so ardently supported after the 1957 freeze be so successful that we can extend the limits of the industry to Washington D.C., and make Tallapoosa, Georgia the citrus capital of the world.

A CASE OF SODIUM TOXICITY IN CITRUS

PAUL F. SMITH[1]

U. S. Horticultural Field Station

Orlando

In 1957 a large experiment on nitrogen rates and sources was started in a 35-year-old Valencia grove near Windermere, Florida. The trees have Rough lemon roots and are growing on deep Lakeland fine sand. After several years of rather uniform behavior, the trees that received fairly high rates of nitrate of soda as a sole source of nitrogen became unthrifty looking and began to decline. In about one year a number of apparently normal trees degenerated to an almost leafless state and assumed the appearance of hardness resembling that of trees severely affected with spreading decline. There is no spreading margin, however, as the trouble is sharply confined to plots receiving the high rates of nitrate of soda. Trees on lower rates of nitrate of soda and those on all rates of ammonium nitrate continue to appear normal and bear heavy crops of fruit. The present report is concerned with the studies made on the cause of this decline. The experiment is not completed insofar as the effects on yield and fruit quality are concerned, and no data on these aspects will be reported here.

[1]The author gratefully acknowledges the cooperation of the personnel of Chase Groves Inc. on whose property the experiment is being conducted. Especial thanks is due Dr. Ivan Stewart for comparative samples from a similar experiment on Pineapple oranges being conducted at the Lake Alfred Station and to Dr. Julius Feldmesser for nematode identifications.

EXPERIMENTAL BACKGROUND

This grove was close planted (15 X 30 ft.) and has been well cared for except that, like most groves of this age, it had received excessive copper before 1952. A few trees show scaly-bark symptoms of psorosis and the attending weakness from that virus disease. The majority of the trees, however, appear normal and have a very high production history. Except for two years (1952, 1953) when copper toxicity was at its zenith, the yield has averaged about 600 boxes of fruit per acre for the past 20 years. Production in 1952 dropped to less than 500 boxes per acre and in 1953 to less than 400 boxes. Full production was resumed in 1954 after heavy liming and the curtailment of the use of copper in 1953. The grove is irrigated when necessary.

Spot sampling of soil and roots in 1957 showed that the citrus nematode (*Tylenchulus semipenetrans*) was present in goodly numbers throughout the grove, but no areas of tree weakness were evident.

Nitrogen rates of 0.25, 0.32, 0.40, 0.47, and 0.55 lb. N per box were chosen and applied twice yearly beginning in April 1957. For a 600-box capacity, these rates equal 150, 195, 240, 285, and 330 lb. N per acre per year. These are provided separately in the form of anhydrous ammonia, ammonium nitrate, and nitrate of soda and each treatment is applied in 4 randomized blocks.

OBSERVATIONS, TESTS, AND DISCUSSION

General observations.—For the first 4 years

(1957-1960) all trees performed satisfactorily and no large difference was noted among nitrogen sources insofar as growth and tree appearance were concerned. During the winter of 1960-61 a number of trees on the 285- and 330-pound rates of nitrate of soda shed leaves excessively, especially in one end of the grove where the soil is a lighter grade of Lakeland fine sand. Following irrigation, however, a heavy new flush of leaves accompanied the bloom in early March and the trees again looked reasonably good in spite of thin foliage density as a result of the undue loss of older leaves.

By October some leaves of the spring flush had started to drop and summer flush of growth on the affected trees was negligible. Although shedding of 7- to 8-month-old leaves is unusual, the number of newly dropped leaves was not great and no symptom that indicated a distress pattern was noticeable. The newly fallen leaves, however, had brown tips while the remainder of the leaf was green and virtually unwilted.

By January 1962 the affected trees were almost completely defoliated. They were carrying a large crop of fruit and the few remaining leaves were inconspicuous among the fruit. The ground under the trees was covered with a thick layer of dead leaves, whereas healthy trees in adjoining plots had dropped virtually no leaves. Leaf shedding was still going on. Nearly all freshly fallen leaves had brown tips and many had brown circular or semi-circular spots along the side, but such patterns were difficult to find on attached leaves, indicating that abscission takes place rapidly after the spots develop. Possibly some leaves develop scorch symptoms in the early stages of drying immediately after abscission. This is considered a likelihood since patterned leaves were rarely found attached to the tree at times when nearly every freshly-dropped leaf showed scorch symptoms.

In March 1962 a light bloom and vegetative flush developed on the defoliated trees in contrast with a heavy bloom and growth on healthy trees. By July much of the fruit had dropped and the trees were in a severe state of decline.

Leaf-sodium status.—Samples of freshly dropped leaves (about one-year-old) were collected in March 1962 and analyzed for sodium (Na) and chloride (Cl). They contained over 8,000 p.p.m. Na and only 600 p.p.m. Cl. These values are over three times the level required for Na toxicity according to work in California (2, 7) and only about one-twentieth the amount required for Cl toxicity. Other samples confirmed the low Cl content of the foliage in this grove even though all the potash has been supplied as KCl.

Since excess sodium seemed to be causing the decline of the trees, samples which had been collected each July for the past 6 years were analyzed for Na (fig. 1). The first samples in 1957 were taken less than 3 months after the first application of the nitrogen sources and showed no relation of Na content to treatment. Each year thereafter there has been an increase in the Na concentration in the 4- to 5-month-old leaves sampled. In 1960 the trees on the highest rate of nitrate of soda had reached 2,500 p.p.m. level, about the suggested threshold level for toxicity in California. By 1962 the 285-lb. rate also produced values well above the toxic level for Na. None of the leaves sampled in July showed any toxicity pattern. Leaves of the same flush, however, later showed tip or side burning almost simultaneous with shedding which started when the leaves were 8 to 10 months old. The curves

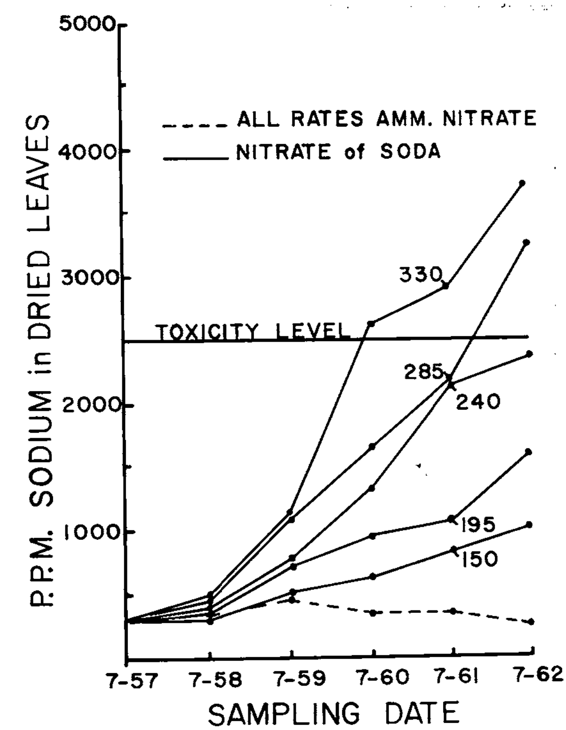

Figure 1.—Sodium concentration in 4- to 5-month-old Valencia orange leaves sampled in July of each year since the start of differential nitrogen rates. The numbers indicate the annual rates of N from nitrate of soda. The Na content of the leaf is strongly influenced by the rate of supply and the duration of the treatment. Leaves from ammonium nitrate plots show a low and fairly constant amount of Na.

are all continuing upward, but it remains to be seen whether any of the 3 lower rates become detrimental to the leaves. By contrast the sodium in the trees on ammonium nitrate has been low in amount and fairly constant over the 6 years.

Relation of leaf age to sodium content.—To see what effect time of sampling had on the sodium content, the 1961 spring flush of growth was sampled 4 times at about 3-month intervals (fig. 2). Again, none of the leaves sampled showed any symptom of toxicity. There is an unavoidable bias in the final sampling date since nearly all the leaves of this age had already developed scorch pattern and dropped. They had no doubt had a greater Na content than leaves that remained on the tree. However, the general tendency seems to be clearly indicated. The Na concentration increases with leaf age. Previous study indicated that Na is never withdrawn from a citrus leaf (11).

Under the conditions of this test the greatest influx of Na into the leaves seems to follow the application of a new supply of Na to the soil.

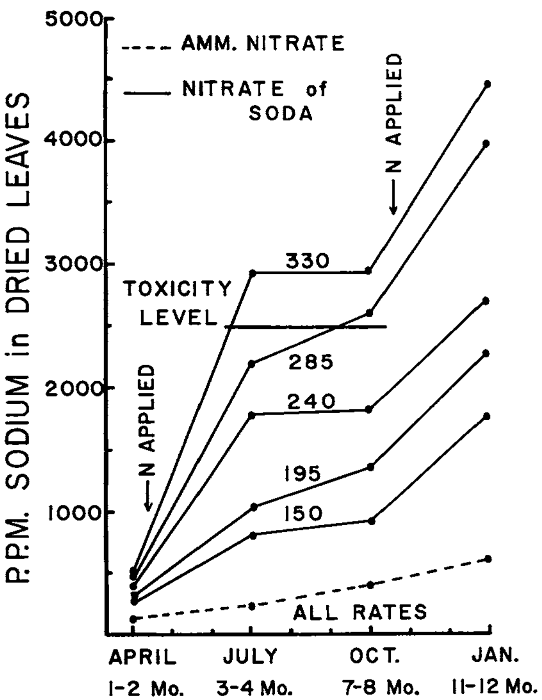

Figure 2.—Sodium concentration in 1961 spring flush Valencia orange leaves collected at different times of the year. The leaves ranged from 1 to 2 months of age in the first collection up to 11 to 12 months in the last. The curves are affected by both the rate of nitrate of soda and the time of application. All show gradual increase in Na accumulation as the leaf increases in age.

Sodium entry into the leaf almost stopped between July and October but increased again after the October application of nitrate of soda (fig. 2). The pattern of increase seems to indicate a strong relation to the wet and dry seasons and the leaching of Na. This light soil has virtually no retentive capacity for Na or K and the summer rains no doubt remove much of the Na from the root zone. Without leaching, the leaf increase would probably be rather steady as is indicated by the curve for the ammonium nitrate trees. In this case the supply of Na is very limited and probably represents a recycling of absorbed Na through decay of vegetation so that the release to the soil would be more or less continuous. There no doubt are small additions of Na in irrigation water and in the potash applied and these seem to maintain a low but constant supply of sodium to the system year after year (fig. 1).

Relation of nematodes to sodium uptake.—Healthy citrus roots have a strong tendency to exclude Na ions while absorbing essential nutrients. In this process the roots themselves acquire Na but do not allow much of it to pass on up the leaves (3,4,5,7,8). In the present case, 330 lb. of N from nitrate of soda is accompanied by 540 lb. of Na which far exceeds the 200 lb. of K applied per acre each year. The leaf Na, however, is only about one-fifth the leaf K. This illustrates the strong tendency of the tree to exclude Na.

Recent studies in California show that the presence of the citrus nematode markedly reduces the ability of citrus roots to exclude Na (9, 13). Almost anything that injures roots causes greater entrance of Na into the plant. It was even shown 20 years ago that a root can injure itself by accumulating too much Na and thus lose its ability to exclude the upward transport of Na (1).

Recent examination showed that large populations of the citrus nematode are still present throughout the grove. Whether sodium toxicity would be present if the nematodes were not present is a question, which cannot be answered definitely from the available information. There seems to be no doubt, however, that the nematodes are a factor in the degree of injury sustained. Some indication that the nematodes cause greater sodium uptake may be found by comparing the leaf contents of these trees with those of similar-aged trees on the same soil type and rootstock in another experiment conducted by Stewart and Leonard (12) at Lake Alfred. These two experiments were started about the same time. The Lake Alfred experiment is on Pineapple oranges. The difference in variety is probably a small factor when considering leaf composition. No parasitic nematodes were found in several soil samples taken in this block of trees. Leaf Na was determined in samples collected in September 1961 and provided by Dr. Stewart. The values for these are shown in table 1 along with values from the Valencia experiment on October 4, 1961.

In the two cases where the rates of applied nitrate of soda were almost identical, substantially less Na existed in the Pineapple foliage. This is consistent with the evidence from California that parasitic nematodes do increase the uptake of sodium. However, the differences in sampling techniques, in varieties, in methods of timing of the applications (three applications per year in the Pineapple experiment vs. two in the Valencia), and the difference in sites all make it impossible to make close comparisons. The Pineapple trees receiving 350 lb. of N from nitrate of soda have not reached a toxic level of leaf Na, although they are close to it (table 1). These trees have been the best producers in that experiment (12).

The Pineapple trees receiving 550 lb. of N from nitrate of soda are described as being thin in foliage and produce weak flushes of growth (12). Their Na content is well up into the toxic range. Observations in June 1962 showed some scorch pattern identical with that on the Valencia trees, but affected leaves were not numerous. Apparently affected leaves are quickly shed from the tree just as observed for the Valencias. Yields have been relatively poor but the reduction may be attributable at least in part to the very high rate of N fertilization or to other factors.

TABLE 1

Leaf sodium in 40-year-old trees from two similar experiments with different rates of nitrate of soda and in which the Valencias were heavily infested with citrus nematodes while the Pineapples were not.[1/]

Lb. N per acre per year	Ppm Na in leaf dry matter: Valencias (+ nematodes)	Ppm Na in leaf dry matter: Pineapples (- nematodes)
50	-	380
100	-	660
150	1100	-
195-200	1430	1170
240	2350	-
285	2790	-
330-350	3410	2380
550	-	5800

1/ Leaves about 7 to 8 months old when collected in September and October. The Pineapple leaves were from the experiment of Stewart and Leonard (12).

Discussion.—While the preponderance of evidence indicates that citrus has a wide tolerance for various nitrogen sources, the present instance indicates an exception when some unfavorable condition exists. Secondary factors that cause root injury appear to require consideration in the choice of a nitrogen source. In addition to nematode feeding, water damage, insect damage, and copper toxicity are all known to injure or kill small citrus roots in Florida, and seemingly any of these factors could augment the absorption of Na. Nitrate of soda is seldom used as the sole source of N in the commercial production of citrus and it is unlikely that its moderate use as a supplementary source of nitrogen is causing any damage to citrus trees even in the presence of nematodes. A few cases of serious decline of trees along the East Coast have been called to the writer's attention in recent years, where the growers have used large amounts of nitrate of soda on poorly drained soils with the thought that weak root systems would benefit from nitrate nitrogen. As least some of these groves are known to have citrus nematodes. While no attempt has been made to associate the Na status of the foliage with the decline, it seems evident now that use of nitrate of soda on such groves is unwise.

The present toxicity of Na is of interest to mineral nutritionists because of the rare natural separation of sodium injury from that of chloride injury. Salinity causes problems with many crops throughout the world, but the chloride that generally accompanies the excess sodium seems to cause more damage than the sodium, or the combination of the two ions causes a toxic condition referred to as "salt-damage" (5, 10). When excess chloride is absorbed it causes a yellowing of the leaf tissue in a margin ahead of the "burn" or dead tissue (3, 10). In the present case no yellowing of tissue was seen and there was an abrupt margin between dead and green tissues. This was true of both tip burn and lateral edge spots. Virtually identical symptoms have been recently encountered in California following the use of nitrate of soda on an acid soil and where the chloride content of the irrigation water was very low (6).

No range of leaf Na concentration is well established as a threshold for toxicity. When normal 4- to 7-month-old leaves contain more than 2,000 to 2,500 p.p.m. Na, the tree usually is less thrifty than normal and may be thin in foliage. This range, however, is below the level of actual toxicity in the leaf sampled. Since Na continues to accumulate with leaf age, this range indicates impending leaf scorch or premature dropping of older leaves from the same tree, which would make the canopy thin. Also, when the leaf content reaches this range it most likely indicates serious root damage from excess accumulation of Na in the roots.

SUMMARY

A decline of Valencia orange trees has been associated with the accumulation of excess sodium following the sustained use of fairly high rates of nitrate of soda.

A steady increase in leaf sodium over a 6-year period was accompanied by severe defoliation and loss of vigor during the last two years, coinciding with leaf levels of Na above 2,500 p.p.m. in 4- to 5-month-old leaves.

No chlorosis was associated with the toxicity. Immediately prior to defoliation, brown tips or brown lateral spots along the leaf margin developed. These were especially prominent on freshly fallen leaves.

There is some indication that the citrus nematode may be a contributory factor in the excessive accumulation of sodium.

LITERATURE CITED

1. Broyer, T. C. and D. R. Hoagland. 1943. Metabolic activities of roots and their bearing on the upward movement of salts and water in plants. Amer. Jour. Bot. 43: 261-273.
2. Chapman, H. D. 1960. Leaf and soil analysis in citrus orchards. Calif. Agr. Expt. Sta. Manual 25. 53 pp.
3. Cooper, W. C. and A. V. Shull. 1953. Salt tolerance and accumulation of sodium and chloride ions in grapefruit on various rootstocks grown in a naturally saline soil. Proc. Rio Grande Valley Hort. Inst. 7:107-117.
4. Haas, A. R. C. and J. N. Brusca. 1954. Sodium effects in citrus seedlings. Calif. Citrog. 39:373, 375.
5. Harding, R. B., M. P. Miller, and M. Fireman. 1958. Absorption of salts by citrus leaves during sprinkling with water suitable for surface irrigation. Proc. Amer. Soc. Hort. Sci. 71:248-256.
6. Jones, W. W. Personal correspondence of March 19, 1962.
7. Jones, W. W., H. E. Pearson, E. R. Parker, and M. R. Huberty. 1952. Effect of sodium in fertilizer and in irrigation water on concentration in leaf and root tissues of citrus trees Proc. Amer. Soc. Hort. Sci. 60:65-70.
8. Martin, J. P.; J. O. Ervin, and R. A. Shepherd. 1961. Influence of exchangeable Na and K at different saturation levels on growth and composition of citrus plants Soil Sci. 91:273-279.
9. Martin, J. P., R. B. Harding, and M. J. Garber. 1961. Relation of soil properties and plant composition to growth of citrus seedlings in 100 nonfumigated and fumigated old citrus soils. Soil Sci. 91:317-323.
10. Pearson, G. A., J. A. Goss, and H. E. Hayward. 1957. The influence of salinity and water table on the growth and mineral composition of young grapefruit trees. Proc. Amer. Soc. Hort. Sci. 69:197-203.
11. Smith, P. F., W. Reuther, and A. W. Specht. 1952. Seasonal changes in Valencia orange trees. II. Changes in microelements, sodium, and carbohydrates in leaves. Proc. Amer. Soc. Hort. Sci. 59:31-35.
12. Stewart, Ivan and C. D. Leonard. 1961. Comparison of nitrogen rates and sources for Pineapple oranges. Proc. Fla. State Hort. Soc. 74:75-79.
13. Van Gundy, S. D. and J. P. Martin. 1961. Influence of **Tylenchulus semipenetrans** on the growth and chemical composition of sweet orange seedlings in soils of various exchangeable cation ratios. Phytopath. 51:146-151.