quired to cover the grove with irrigation water, however, in most situations it will be desirable to start applying water sometime before the trees show any wilting. Water applied as soon as the soil at a depth of 18 to 24 inches is near the wilting point will probably prevent severe water shortage in groves on soils similar to those examined in this study. If it can be avoided, trees should not be allowed to dry out to the point where they show definite wilting. The grower is well aware of the ill effects of prolonged wilting, but even before the trees wilt, fruit growth is gradually reduced as the tree is subjected to increasing water deficit.

To determine how effective an application of irrigation water has been in wetting the soil that was dried out by tree roots, it is necessary to examine the soil in such a manner that variations in distribution of water will be detected. Wherever all of the dry soil was not wetted the line of demarcation between wet and dry soil will be sharp. The soil that is wetted will be wet to field capacity and a few inches below the "wetting front" the soil will be as dry as it was before irrigating water was applied.

The labor and time of examining the soil is greatly reduced by the use of a convenient tool. Either the smallest size of post-hole auger obtainable (2 or 3 inches in diameter), or an auger made by welding a four-foot rod with a crosspiece at the top to a one inch carpenter's bit with the cutting flanges and threaded tip ground off, is a fairly convenient tool. In soils in which it can be used, a probe made of ½ inch rod is very convenient. It is easily thrust through very wet soil but the resistance to penetration increases sharply when the dry soil is encountered. In some soils the probe is useless, either because of too little difference in resistance offered by wet and dry soil or because of hard layers.

Determining the depth of wetting after an irrigation gives some idea of the uniformity of distribution with which the water was applied and serves as a basis for estimating the length of time that water should be applied to wet the soil to the desired depth. Without an occasional careful examination of the soil after irrigating, serious faults that might be corrected economically may pass unnoticed.

SEASONAL ABSORPTION OF NUTRIENT IONS BY ORANGE TREES IN SAND CULTURE

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INTRODUCTION

The growing of plants directly in nutrient solutions or in pure sand to which such solutions are added has long been a useful method in studying various phases of plant nutrition in which the information sought cannot be obtained from plants growing in soil under field conditions. In the present investigation sand cultures were employed to study the seasonal intake by young orange trees of nitrogen, phosphorus, potassium, magnesium, and calcium from solutions containing all of

[1] Acknowledgment is made to G. Hrnciar of the Station staff, and to erstwhile members, C. H. Brokaw, F. M. Cyst, and J. M. Harris, who at various times assisted with the analyses and care of the trees.

the nutrients in soluble form. The method also offered an opportunity to obtain an accurate record of the amount of water used by the trees throughout the year.

Because of the artificial nature of the root environment in a sand culture as compared with a complex soil system, and for other reasons that will be brought out later, the data which follow might well prove misleading as a direct basis for fertilizer practice. The experiment was designed simply to determine from month to month the extent to which the orange tree absorbs the various nutrient ions here studied.

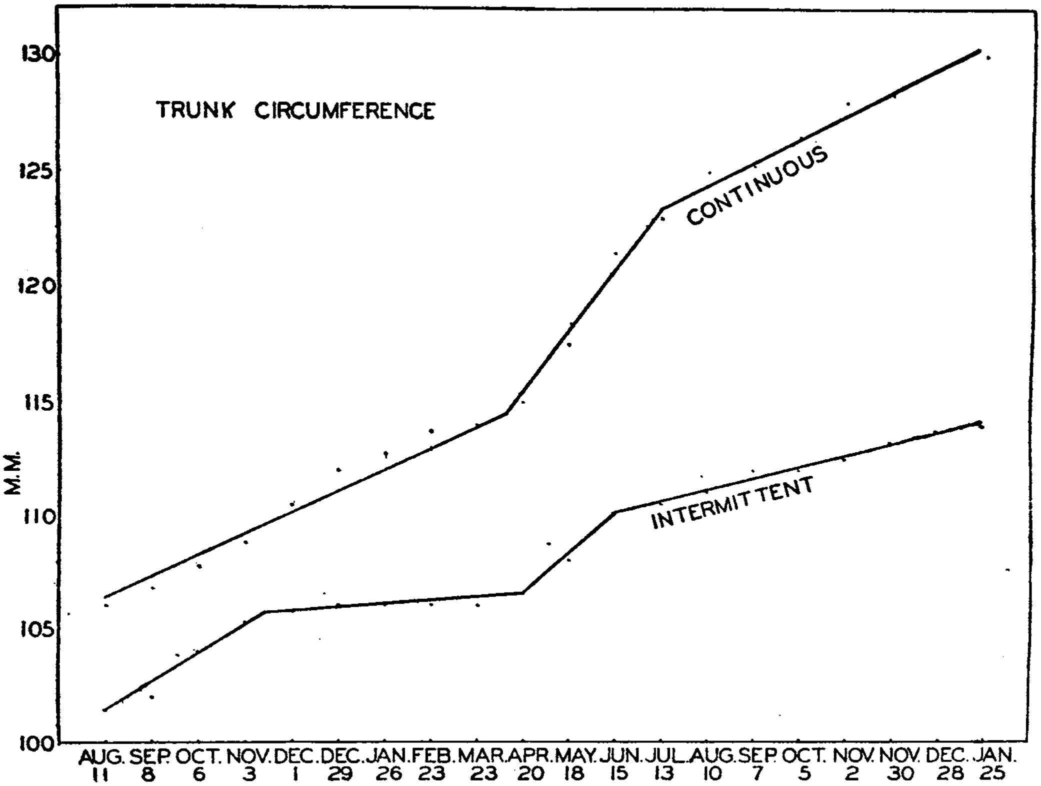

Fig. 2. Seasonal increase in trunk circumference of young orange trees grown in sand cultures supplied continuously and intermittently with complete nutrient solution.

METHODS

Fourteen Parson Brown orange trees budded two years previously in the nursery on rough lemon rootstock were used for the experiment. The roots were washed completely free from adhering soil, after which the trees were replanted in January 1942 in pure quartz sand in 8-gallon vitrified tile crocks. To each tree was fastened a piece of tarpaper roofing, so fashioned as to exclude rain water from the sand in the crock. These covers were easily removed for the purpose of applying nutrient solution or water. The crocks were supported on racks at a height of 2 feet from the ground. The bottom of each crock was provided with a drainage hole, in which was inserted an 8-inch length of glass tubing, by means of a one-holed rubber stopper. The lower end of the glass tubing was inserted in a 5-gallon glass bottle, which was placed immediately under the crock and which served to collect the drainage (Fig. 1). A liberal amount of toluene was maintained in the drainage bottles to minimize bacterial action within the leached solutions until they were collected for analysis.

Two crocks, prepared in the same manner except that no trees were planted therein, were used as controls in a manner to be explained presently.

The first six months of feeding allowed the trees to establish new tops and roots and were also devoted to determining procedures to be followed during the ensuing experimental period. At the end of this initial experimentation, the potted trees were divided into two sets of seven trees each, and one crock containing sand only was assigned to each set of trees as a control. The first set of 7 trees was given nutrient solution daily, each tree receiving identical, carefully measured amounts of solution. The control crock, containing sand only, was given nutrient in the same amount. During periods of high transpiration enough water in measured amounts was also applied to keep the trees from wilting.

At the end of each 2-week period the crocks were flushed out thoroughly with 30 liters of water over an 8-hour period. This collected wash water was added to and thoroughly mixed with the original leachate and the total

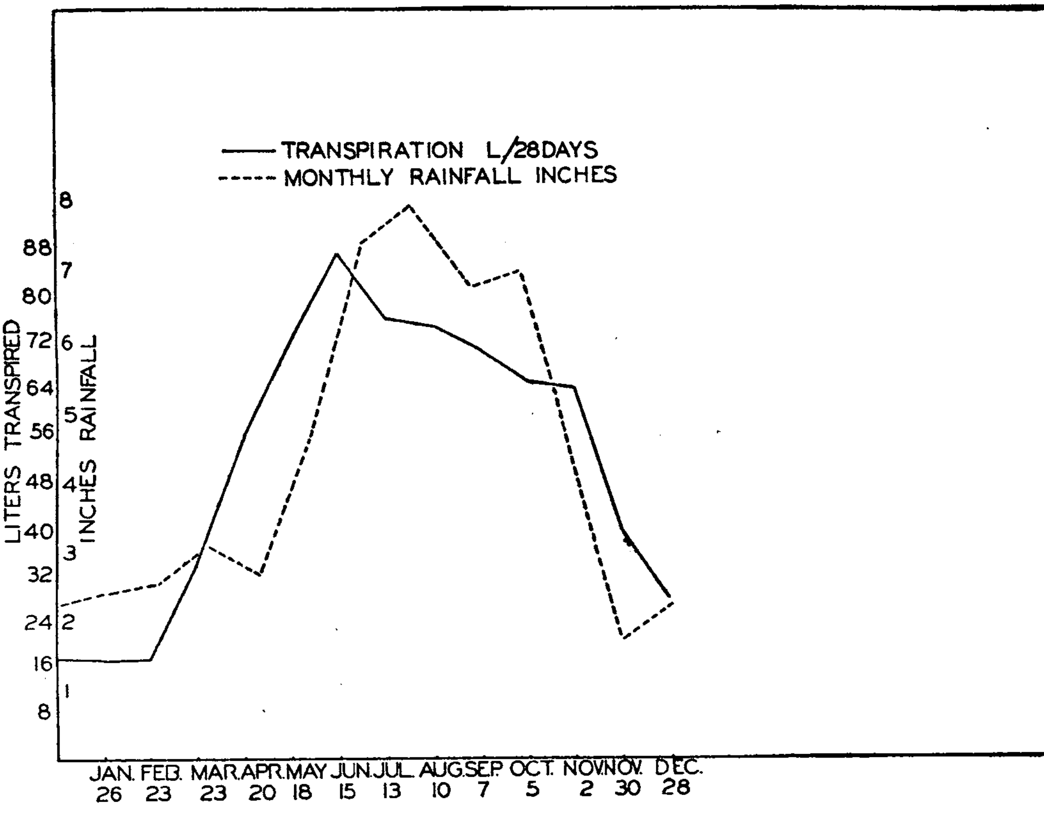

Fig. 3. Transpiration rate (liters per 28 days) of orange trees grown in sand culture, and mean monthly rainfall in Orlando area (40-year average, U. S. Weather Bureau.

volume carefully determined. Two-liter samples from each total leachate were used in determining N, P, K, Mg, and Ca, calculating the total amounts of each element leached from each crock. The differences between the amounts of each of these elements found in the leachings from the control crock containing sand only and the amounts in each tree leachate were calculated and represented that absorbed by the tree during the foregoing feeding period.

The second set of 7 trees and the second crock containing sand only were given water only in the same manner as described above. At intervals of approximately three months they were fed for a period of two weeks, and the leachates collected and analyzed at the termination of the feeding period. This intermittent feeding was adopted to determine if trees which were "hungry," as it is assumed that grove trees sometimes become between applications of fertilizer, would have an appreciably different demand for the various elements from trees fed continuously.

The nutrient solution used was of the following composition:

Nitrogen—112 p.p.m. from $Ca(N0_3)_2.4H_20$
56 " " $KN0_3$
174 " " $NaN0_3$
Total N 342 "
Potassium—143 p.p.m. from $KN0_3$
94 " " KH_2P0_4
Total K 237 "
Phosphorus—75 p.p.m. from KH_2P0_4
Magnesium—54 p.p.m. from MgS04. 7H20
Calcium—160 p.p.m. from Ca (N03)2. 4H20

In addition, minor elements were added to bring their concentrations in p.p.m. to 1 of iron, 0.4 of manganese, 0.4 of zinc, 0.4 of copper, and 0.4 of boron.

Sufficient quantity of the above nutrient solution was used to insure an excess of all elements over that which the trees absorbed, as evidenced by the appreciable amounts of the elements determined in the leachate. The pH of the leachate disclosed a marked tendency of the nutrient solution to shift to the alkaline side due to a greater absorption of the acidic ions than of the basic ions. To prevent this shift toward alkalinity from progressing to the point where certain ions might be precipitated, the pH of the nutrient solution, and of the tap water used in watering, was adjusted to 4.5.

Records were kept as to time and amount of bloom and of flushes of growth, as well as bi-weekly measurements of trunk circumference measurements.

The trees were grown out of doors in full sunlight. At times when danger of freezing was imminent, all crocks were removed to a greenhouse until the danger of cold damage was past. Nicotine sulfate and oil sprays were used from time to time as required for insect control.

Temperature records in the root zone were kept by means of a continuously recording thermograph, the thermobulb being buried in the sand of one of the crocks.

Results

Tree behavior. The trees receiving continuous feeding grew normally, exhibiting healthy, dense foliage and a good bloom during January-February of the second season. This bloom was several weeks earlier than on grove trees nearby, due probably to the continuous availability to the potted trees of ample water and nitrogen. No symptoms of deficiency appeared except for leaf patterns indicating a minor manganese deficiency in the spring, which soon disappeared. The leaves of the trees on intermittent feeding, as might be expected, developed typical symptoms of increasing nitrogen deficiency during the intervals without nutrients but these promptly disappeared after each feeding period. They were approximately 2 weeks later in blooming than the trees fed continuously.

In the second season in the crocks the continuously-fed trees produced a heavy crop of fruit, considering tree size, amounting to an average of 10.3 pounds of fruit per tree. The intermittently-fed trees produced an average of 6 pounds of fruit. The fruit from the two sets of trees were approximately equal in size, and no apparent difference existed in rind thickness or texture.

The continuously-fed trees gradually out-grew those intermittently fed in amount of top growth. Fig. 2 shows the seasonal increase in trunk circumference of the two sets of trees. Although the most rapid rate of increase in trunk growth occured between March 1 and August 10, a steady rate of increase continued throughout the balance of the year in the continuously-fed trees. It is clear that orange trees can and do increase in trunk caliper even during the so-called winter dormant period if they are well fed. Very little trunk growth occurred in the winter months in the case of the intermittently-fed trees.

Water usage. The difference between the amount of water applied and that which percolated through the pots to the collecting bottle represents an accurate measure of the transpiration rate when the relatively small loss due to evaporation from the sand surface under the paper cover of the crocks was corrected for by the results with the treeless control crocks. The seasonal transpiration rate for the continuously-fed trees is shown graphically in Fig. 3, together with the seasonal rainfall distribution (40-year average for Orlando, from U. S. Weather Bureau reports). The similarity in shape between the transpiration and the precipitation curves is very striking and is no small factor in the success and economy of production in Florida's citrus areas.

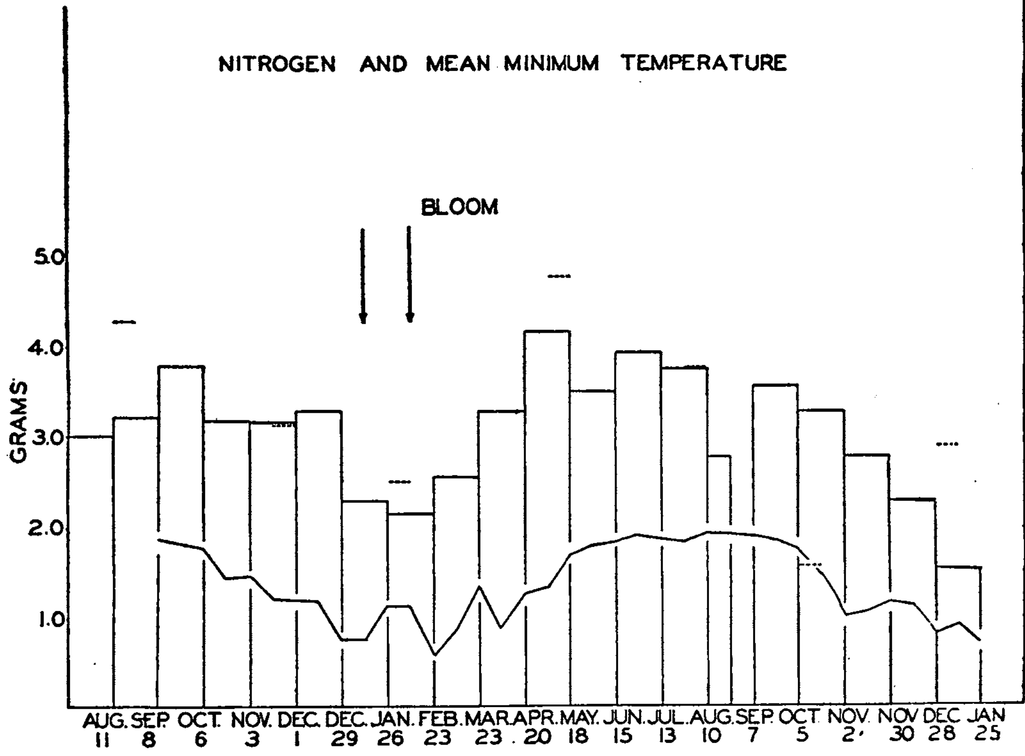

Fig. 4. Seasonal absorption of nitrogen by young orange trees grown in sand cultures with a complete nutrient solution supplied continuously (solid blocks) and intermittently (dotted line). Mean minimum temperatures of the culture medium are also shown.

Nitrogen. The absorption of nitrogen and of each of the other elements under study was determined independently for each tree for each 2-week period. In order to smooth out individual variations which naturally occur and to simplify presentation, the absorption figures have been calculated as means of each group of seven trees by 4-week intervals and graphs made to show the seasonal intake over an 18-month period of development. The two arrows on each chart point to the dates of start of spring shoot growth and of full bloom, respectively.

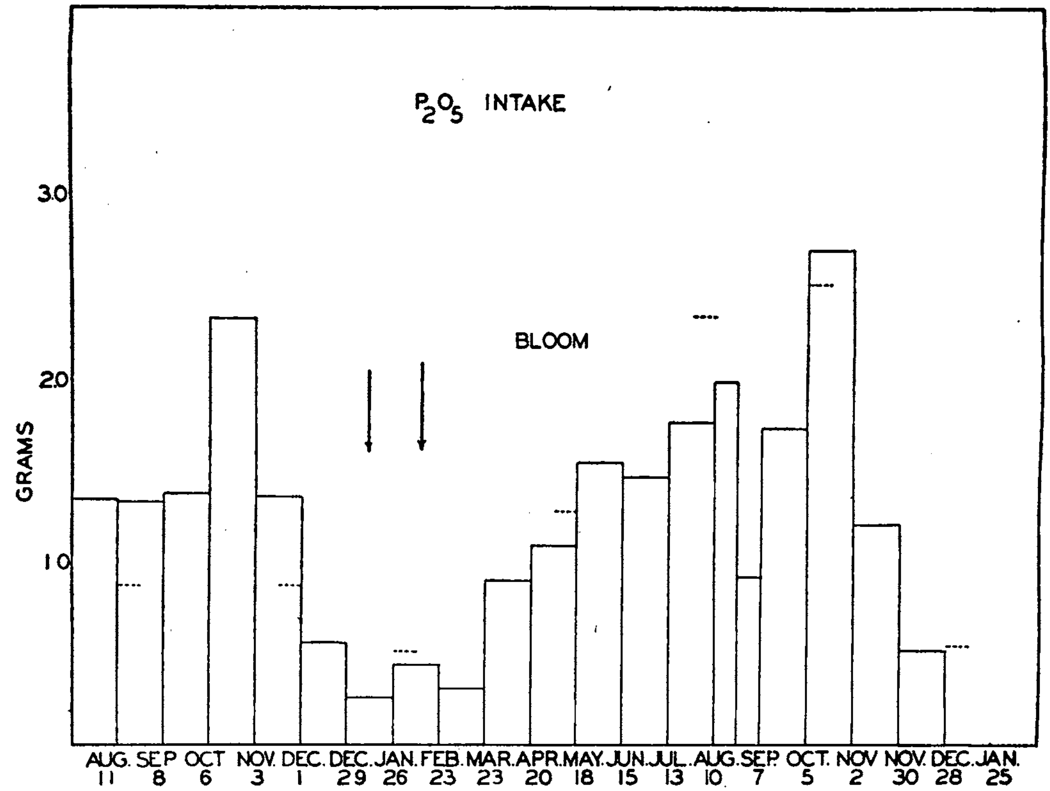

Fig. 5. Seasonal absorption of phosphorus (as P2O5.)

Nitrogen was absorbed in appreciable amounts at all seasons of the year, although the rate of absorption was lowest during the months of January and February. A rapid increase in absorption is shown beginning in March, reaching a peak in April and May, at which time the rate was approximately double that during the January-February low (Fig. 4). It is worthy of note that the increase in rate of nitrogen absorption, as was true of the other ions also, did not begin until sometime after bloom.

Of interest, also, is the observation that during the feeding period the nitrogen intake of the trees fed intermittently, represented by the dotted lines on the graph, was in the same order of magnitude as was the intake of the trees receiving continuous nutrient, suggesting that rate of nitrogen intake at any given period was not materially influenced by previous nitrogen consumption.

The mean minimum temperatures of the sand plotted with nitrogen intake make apparent that a fair correlation exists in which nitrogen absorption decreases with a lowering of the temperature. Chapman and Parker (2) report a similar relationship in their studies of nitrogen absorption by orange trees from water cultures. It is very doubtful that temperature per se is the only factor involved in this corrolation, for if it were, the relative rate of absorption of the other ions might be expected to follow closely that of nitrogen. It will be seen that there were points of marked dissimilarity in the behavior of the other nutrients even though the absorption of all ions decreased during the cooler months.

intake of phosphorus occurred during December, January, February, and March, followed by relatively high intake during the period April through November. (Fig. 5). During the month of October in both years, phosphorus intake was greatly increased for some unaccountable reason. During the period of nitrogen omission (August 24-September 7 of the second season) the phosphorus rate of intake was approximately half that of the preceding

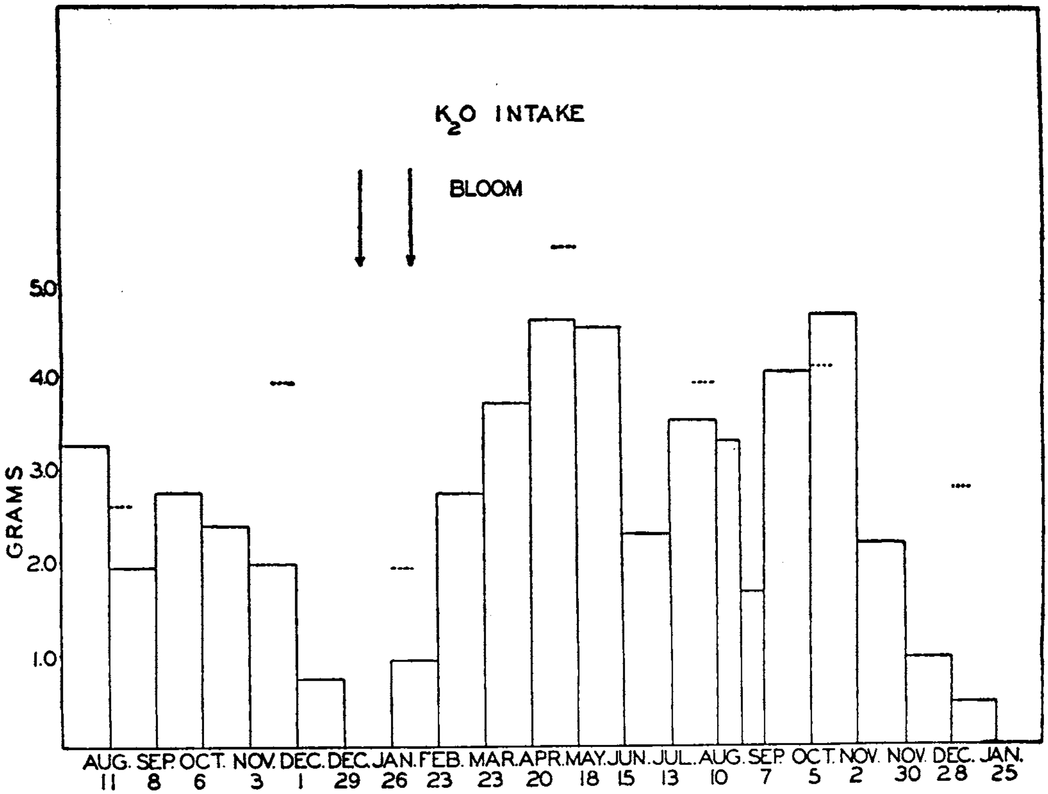

Fig. 6. Seasonal absorption of potassium (as K2O.)

At one period during the experiment (August 24-September 7) nitrogen was purposely omitted from the nutrient solution. It is interesting to note that following this exclusion, the intake of nitrogen was not accelerated to any appreciable degree with a return of this element to the solution.

Phosphorus. A period of greatly decreased

period, increasing in the period immediately following to a rate similar to that before withholding of the nitrogen. The sudden increased phosphorus intake occurred 4 weeks following nitrogen abstinence; however, such an increase also occurred at the same time of the previous year when nitrogen was supplied continuously.

Phosphorus intake of trees fed intermittently was generally of the same order of magnitude of those fed continuously, with some fluctuations.

Potassium. The seasonal absorption of potassium showed a greater magnitude of fluctuation than nitrogen intake, being very low during the period December-February, and increasing rapidly following bloom (Fig. 6). During the first January studied, intake of this element ceased completely, there being some indication during this time that potassium was actually being returned to the solution from the roots; the amount, however, was of a very small order of magnitude and not consistent for all the trees in the crocks under continuous feeding.

During the period August 24-September 7, when nitrogen was withheld from the nutrient solution, intake of potassium decreased sharply to 50% of the absorption during the preceding 2-week period. When nitrogen was restored to the nutrient solution, the intake of potassium for the ensuing 4-week period increased sharply to a level 17% greater than during the 4-week period prior to withholding the nitrogen and the following month it was 38% greater. Based on behavior the preceding year, the rate of potassium intake during this period would be decreasing. It would therefore appear that the rate of potassium intake is influenced both by (a) concurrent nitrogen absorption and (b) potassium hunger. The latter supposition is further substantiated by the intakes of potassium during the feeding periods of the intermittenly-fed trees which, at each period (with one exception) were

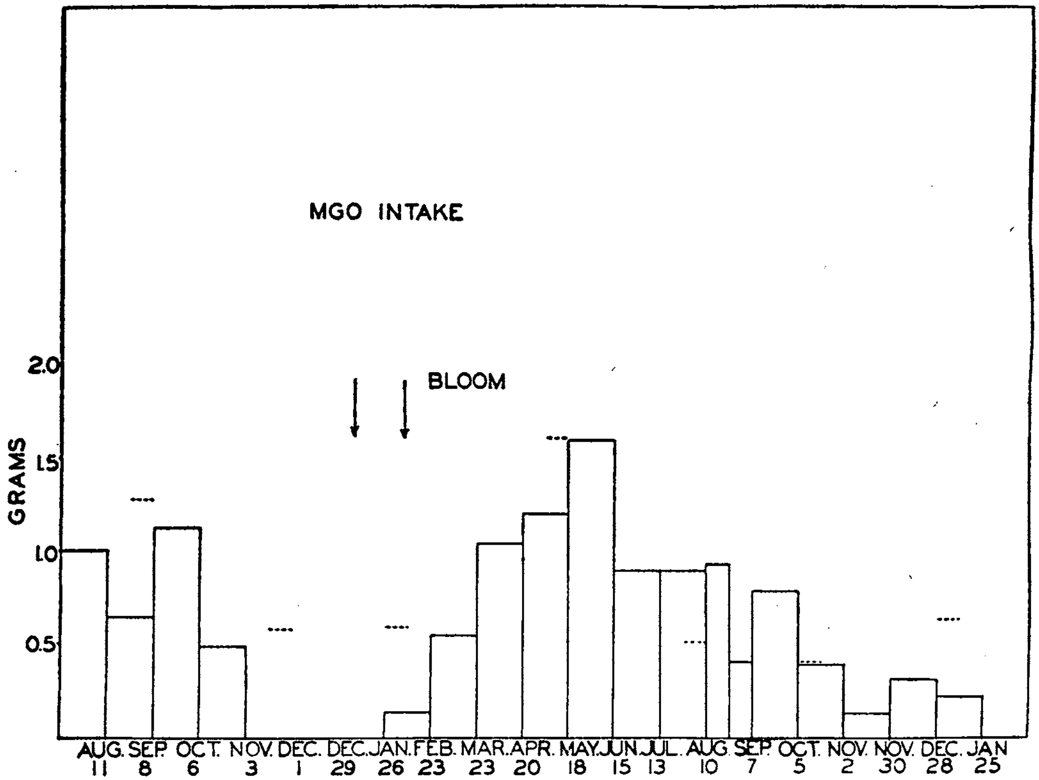

Fig. 7. Seasonal absorption of magnesium (as MgO.)

greater than the potassium intake of continuously-fed trees during the same periods. The exception noted occurred during the time when potassium intake of the continuously-fed trees was stimulated by previously withholding nitrogen. Breazeale (1) has pointed out that the absorption of phosphorus and potash, but not of calcium, is accelerated by the presence of nitrogen, in a study of seedling wheat plants grown in water cultures.

nesium was absorbed, and like potassium, there was some evidence of a return to the sand of slight amounts of this element. This apparent excretion of magnesium and potassium can possibly be accounted for by the normal dying of some root tissues which then lost their powers of ion retention and therefore diffuse small amounts of these elements continuously, the amount becoming recordable only when the young, live roots were absorb-

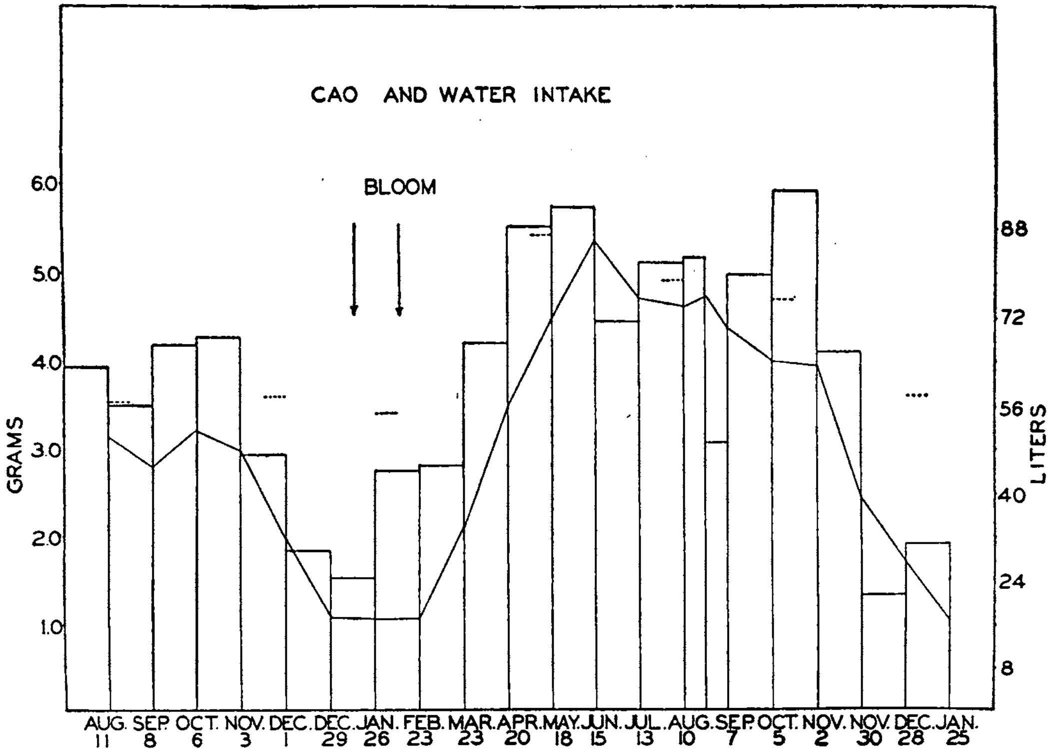

Fig. 8. Seasonal absorption of Calcium (as CaO.) The continuous line showing the water intake suggests a relationship between calcium intake and transpiration.

Magnesium. The intake of magnesium was very low during the period November through February, increasingly rapidly through the spring to a peak in late May and early June, and then decreasing to November (Fig. 7). During three of the 4-week periods (November through January, the first year) no magnesium was absorbed ing none of the elements in question. Haas and Reed (3) mention excretion of potassium into nutrient solution by citrus seedlings when the potassium becomes very low.

During the period August 24-September 7 when nitrogen was withheld, the intake of magnesium was suppressed to half of its magnitude before and after. After resumption of nitrogen feeding, there was a normal intake of magnesium again.

Intake of magnesium by the intermittently-fed trees during the feeding periods is of interest. During warm weather, when this element was being absorbed readily by the continuously-fed group of trees, the rate of magnesium intake by the intermittently-fed group was about the same. However, during the colder weather when magnesium intake was at a very low level by the continuously-fed group, it was still being absorbed in appreciable amounts by the trees which were intermittently fed. This would suggest that some absorption of magnesium may occur at any period of the year when an actual tree hunger for this element exists, although during the summer it is much more readily absorbed.

Calcium. The absorption of calcium in comparison with the other ions studied was relatively high, the period of greatest intake occurring from April through November. As in the case of nitrogen, appreciable although reduced amounts of calcium were absorbed throughout the winter months. A good degree of correlation was noted between calcium intake and transpiration as shown in Fig. 8, where the two are plotted together.

Analytical data (3) have revealed that calcium tends to increase in the leaves of citrus trees throughout their entire lives, and that such accumulation is more pronounced in Florida during the summer months, which is the period of greatest rate of transpiration.

Absorption ratios. The proportions of N, P205, K20, Mgo, and CaO absorbed in each 4-week interval during the experiment are presented in table 1. Nitrogen is placed at unity, and all other fertilizer ingredients are calculated on this basis. From the table it can be seen that with nitrogen equal to 1 the P205 absorption varied between the limits of 0.73 to 0; K20 varied between the limits of 1.29 to 0; MgO and CaO, respectively, were 0.46 and 1.78 as maxima and 0 and 0.56, respectively, as minima. In general, higher ratios of the other nutrient elements to nitrogen absorbed occurred during the warm months and low ratios

TABLE 1. Seasonal ratios of nutrient absorption (with nitrogen given a value of 1)

4 weeks ending	N	P_2O_5	K_2O	MgO	CaO
Aug. 11	1	0.45	1.08	0.33	1.31
Sept. 8	1	0.41	0.61	0.20	1.08
Oct. 6	1	0.37	0.73	0.30	1.11
Nov. 3	1	0.73	0.75	0.15	1.35
Dec. 1	1	0.43	0.63	0.00	0.93
Dec. 29	1	0.17	0.22	0.00	0.56
Jan. 26	1	0.11	0.00	0.00	0.67
Feb. 23	1	0.20	0.43	0.06	1.27
Mar. 23	1	0.12	1.08	0.21	1.11
Apr. 20	1	0.28	1.13	0.32	1.29
May 18	1	0.26	1.11	0.29	1.33
June 15	1	0.44	1.29	0.46	1.63
July 13	1	0.43	0.68	0.26	1.30
Aug. 10	1	0.54	1.08	0.28	1.57
Sept. 7	N omitted	---	---	---	---
Oct. 5	1	0.49	1.16	0.22	1.40
Nov. 2	1	0.83	1.48	0.11	1.79
Nov. 30	1	0.44	0.79	0.05	1.48
Dec. 28	1	0.23	0.43	0.14	0.58
Jan. 25	1	0.00	0.31	0.14	1.26
Ratio of total for entire period	1	0.41	0.88	0.21	1.30
Ration of total for fruiting year	1	0.38	0.98	0.23	1.36

during the colder months. Absorption ratios for the entire period of the experiment, calculated from the total absorption of each in the order indicated above, were found to be 1-0.41-0.88-0.21-1.30 for the trees fed continuously, and 1-0.35-1.07-0.24-1.26 for the trees fed intermittently. The ratios for the totals of the last 12 months of the experiment, from January 26, 1943, through January 25, 1944, in which period the trees bloomed and matured a crop of fruit, were 1-.38-0.98-0.23-1.36 for N, P205, K20, MgO and CaO, respectively. In considering the absorption ratios for any given period the actual amount of nitrogen absorbed during that period should also be kept in mind since the other elements are only relative to the amount of nitrogen.

Discussion and Summary

A record of monthly absorption of water, N, P, K, Mg, and Ca by two groups of Parson Brown orange trees grown in sand cultures is presented. One group was fed continuously with a nutrient solution containing all of the elements known to be essential to citrus, and the other group fed intermittently with a similar nutrient solution, with water only supplied in the intervals between feedings.

The rate of absorption of the various ions fluctuated greatly with the season of the year. In general, absorption of water and of nutrients was low in the colder months, reflecting, perhaps, the relatively quiescent period of tree activity. Following the resumption of new growth and bloom in the spring a rapid increase in the rate of intake of all ions occurred. In spite of similar seasonal trends the absorption of the various ions differed greatly in the extent of their fluctuations and in the time of cessation and resumption of their main absorption periods.

It is worthy of note that the increased rate of absorption of all ions in the spring did not begin until sometime after bloom. Because of the very low rate of absorption of all ions, or complete absence of some for a considerable period prior to bloom, it is apparent that blossom production and initial fruit set on these trees could have been influenced by these ions only through absorption several months previously.

It is well known that trees absorb elements which are non-essential for their development and that they may also absorb amounts of essential elements in excess of their requirements if such large amounts of the elements are available. There is some evidence that the orange trees on continuous feeding in this experiment may have taken in more nutrients than they could advantageously use. It was mentioned earlier that the continuously-fed trees produced an average of 10.3 pounds of fruit per tree, whereas the intermittently-fed trees averaged 6 pounds. The total absorption of all ions by the intermittently-fed trees was approximately only one-fifth that of the trees constantly suppplied with nutrients. This difference in absorption was out of all proportion to the difference in yield or in tree growth between the two sets.

From the viewpoint of practical application of the findings in this report it should be borne in mind that important inherent differences exist between a soil system and the sand cultures used herein. Even the light Norfolk soils exhibit a degree of ion fixation and base exchange which influence nutrient availability, whereas these factors are absent in pure sand cultures. In this connection, it is recognized that the concentration of individual ions in a nutrient solution may influence to some extent the degree of absorption of other ions and that therefore the picture of seasonal ion absorption presented here may not conform entirely with the absorption from a soil mass, or from a nutrient solution of different composition. It is recognized also that the fluctuations of temperature in the root zone of the sand cultures in this experiment were more extreme than would occur in the soil. Because of such differences, judgment and caution must be exercised in any attempts to interpret these findings in terms of grove fertilizer procedures. However, the striking behavior of the trees with respect to seasonal nutrient uptake raises the question as to whether most fertilization programs could not be made more efficient by varying the formula to comply more nearly with the seasonal ability of the trees to absorb the various ions and also thereby to avoid excessive loss by leaching of soluble nutrients during periods of iow intake.

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SOME OBSERVATIONS ON THE CITRUS INDUSTRY OF AUSTRALIA

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The observations presented in this paper are those which I was able to make while serving with the Armed Forces of the U. S. in Australia from 1942-45. The nature of my duties was such that they carried me into some of the citrus producing areas and also gave me contact with some of the research workers who were very helpful and generous in giving me information and showing me around. Especially helpful were: Mr. R. Benton and other members of the New South Wales Department of Agriculture, Sydney; Mr. E. West and his staff at the Griffith Laboratories of the Council for Scientific and Industrial Research, a Commonwealth Agency; and many growers, governmental and private representatives. Observations are not complete nor could all phases be followed through because the army had priority on my time and my personal desires were not considered. This paper is presented with the view that these observations will give the Florida citrus grower some knowledge of the citrus industry of Australia.

Citrus is produced in all of the states of the Commonwealth of Australia, with the exception of the island of Tasmania. This area, which is only a few thousand square miles less than that of the U. S. A., extends from a latitude of 5 degrees to 40 degrees south of the equator and from a longitude 110 degrees east to 150 degrees east. This includes the entire island mainland of Australia, from Townsville on the Coral Sea to Perth on the Indian Ocean, and from Melbourne on the South Pacific to Darwin on the Straits between the mainland and Java. The introduction of citrus dates back to the early settlements and prison colonies in the 1700's with the subsequent acreage and production steadily increasing until at the present time approximately 6,000,000 bushels of fruit are produced on 40,000 acres. Production is limited to several widely separated areas in each state, New South Wales leading with about 26,000 acres, Victoria following with 7,000 acres, Queensland with 3,000 acres and South and West Australia with some 4,000 acres each. Most of these areas are in the proximity of marketing centers such as Sydney, New South Wales; Melbourne, Victoria; Brisbane and Townsville, Queensland; Adelaide, South Australia; and Perth, West Australia. In general each producing area can be classified as an individual project, with each orchard an individual problem. One is impressed with the individuality