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CONTENTS

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BORON IN THE SOILS AND IRRIGATION WATERS OF SOUTHERN CALIFORNIA AND ITS RELATION TO CITRUS AND WALNUT CULTURE[1]

W. P. KELLEY[2] AND S. M. BROWN[3]

INTRODUCTION

In the latter part of 1925 and at various times subsequently, our attention has been called to certain citrus trees growing in the vicinity of several different citrus packing houses in southern California that have been injured severely. Usually the injury developed rather suddenly. In some instances only a few trees, in others several hundred, have been affected. In practically every case the trees were previously vigorous and thrifty.

The injury first became apparent by a yellowing of certain parts of the leaves, usually beginning with the tips and margins, and this was soon followed by a similar yellowing of the tissues between the veins. As the effect progressed the tips died back. Sometimes isolated areas along the margins of the leaves or small spots between the veins were killed. Many of the affected leaves fell prematurely and not infrequently the smaller twigs died. The more severely affected trees shed practically all of their leaves and in a few instances the entire tree died. The shedding of the leaves of the less severely affected trees was followed sooner or later by the development of new shoots

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whose leaves appeared normal for a few weeks save for a slight paleness and perhaps a reduction in size, but later the new shoots went the way of their predecessors.

The injury referred to above has been chiefly confined to orange trees. In a few instances lemon and walnut trees have also been affected. The walnut leaves turned brown around the margins and died back from the tips, the injury gradually extending into the mesophyll tissues toward the midrib. The margins of the affected tissues were usually irregular, and not infrequently brown spots of various sizes developed between the veins. Many of the walnut leaves fell prematurely, but usually the injurious effect was not apparent until after midsummer.

Soon after this problem came to our attention it was found that the injury in question was associated with a contamination of the irrigation water brought about by the accidental discharge of wash-water from nearby citrus packing houses. These wash-waters frequently contained dissolved boron compounds, either borax or boric acid.[4] Chemical analysis showed positive relationships between the injury to the trees and the water-soluble boron content of the soil, on the one hand, and the boron content of the leaves, on the other.

It was noted that the appearance of the less severely affected lemon and walnut trees of these groves was markedly similar to that of certain abnormal lemon and walnut groves of Ventura County which had been under investigation for several years, but the determination of the cause of which has baffled all previous study. Recently we have found that the abnormality of these, as well as of certain groves in several other localities, is related to the occurrence of soluble boron, which occurs either as a natural constituent of the irrigation supply or of the soil itself.

It is well known that several species of plants show marked response to the presence of soluble boron in the nutrient medium. On the one hand, the investigations of Agulhon,(1) Mazé,(11) Warington,(14) Brenchley and Thornton,(3) Brenchley and Warington,(4) and Sommer and Lipman(13) have clearly established the fact that boron is essential for the normal functioning of certain plants. Small amounts of this element now appear to be just as necessary for the complete development of these plants as nitrogen, phosphorus, potassium, or calcium,

[4] A concentrated solution of borax or boric acid is used as a fungicide in many of the citrus packing houses of California. After a given solution has been used for a certain length of time it was formerly discharged into a convenient drainage channel. However, after it became established that boron is extremely toxic, the packing house waste has been disposed of in such way as to avoid the contamination of irrigation supplies and the impregnation of orchard soils.

which elements have long been known to be essential. On the other hand, Hotter,[9] Agulhon,[1] Brenchley,[2] Warington,[14] Conner and Fergus,[6] Skinner *et al.*,[12] Collings,[5] and others have found that toxic effects appear if the concentration of boron exceeds a very low value. Some of these workers found that boron is extremely toxic, an application at the rate of only a few pounds per acre being sufficient to produce marked injury to certain plants.

In an address delivered before the Washington Academy of Sciences in 1920, Kellerman[10] suggested that toxic concentrations of boron are likely to be found here and there in the soils and irrigation waters of the southwestern part of America. He pointed out that large deposits of borax and other boron minerals occur in several places in southern California and that analysis has shown that small amounts of boron occur in various lakes and streams of this region. Dr. Kellerman also made the interesting suggestion that the high toxicity of certain alkali soils of the semi-arid region of America may be due in part at least to soluble boron.

THE EFFECT OF BORON ON CITRUS AND WALNUT TREES

We have found that boron is widely distributed in the soils of southern California.[5] As shown in table 1, the highest concentration of water-soluble boron was found in the soil from those orchards where certain fruit trees show definite injury. Moreover, the results obtained by analyzing the leaves of citrus and walnut trees have shown a striking relationship between their boron content and their general state of health. The boron content of the normal leaf of these species was found to vary from only a few parts per million to approximately 100 p.p.m. (table 2). The leaves of the injured trees, on the other hand, contain much more boron, the amount found ranging from 266 to 1,679 p.p.m. (table 3).

[5] Boron was determined by the well-known method of distillation with methyl alcohol, followed by double titration of the distillate with standard alkali, using paranitrophenol and phenolphthalein as indicators and mannitol as catalyzer. The entire process was carried out in boron-free apparatus and with the use of boron-free reagents. With soil the determination was usually made by leaching a kilogram with 2000 cc distilled water, evaporating the leachate to dryness in silica dishes, transferring the residue to a boron-free flask and distilling with methyl alcohol in the presence of phosphoric acid. With irrigation water 4 liters was evaporated to dryness and the residue was then subjected to the same process of distillation. With plant material 10 to 20 grams of the dry substance was ignited in a platinum dish in the presence of an excess of lime. The char was leached with dilute hydrochloric acid, the leachate made alkaline, and the determination was then completed as in the case of the soil extracts. Duplicate determinations were always made.

TABLE 1

WATER-SOLUBLE BORON CONTENT OF SOILS. BASED ON THE DRY WEIGHT

Locality	Evidence of injury	Source of boron	Boron content (p. p. m.)
Riverside	None		Trace
Riverside	None		Trace
La Habra	None		Trace
Tustin	None		0.3
North Pomona	Positive	Packing house wash-water	5.2
Sespe Canyon	Positive	Irrigation supply	7.7
Sespe	Positive	Irrigation supply	3.0
Bardsdale	Positive	Irrigation supply	3.6
Tustin	Positive	Irrigation supply	2.3
San Fernando Valley near Tujunga Canyon	Positive	Irrigation supply	5.1
Santa Paula	Positive	Native to soil	3.1
Chula Vista	Positive	Native to soil	4.0
Oasis	Positive	Native to soil	21.0

TABLE 2

BORON CONTENT OF NORMAL CITRUS AND WALNUT LEAVES. BASED ON THE DRY WEIGHT

Kind of leaf	Locality	Boron content (p. p. m.)
Orange	Arlington	46
Orange	Villa Park	87
Orange	Anaheim	81
Orange	Arlington	30
Orange	Cucamonga	30
Orange	Redlands	44
Orange	Redlands	25
Orange	Upland	24
Orange	Ontario	21
Lemon	Arlington	27
Lemon	Bloomington	19
Lemon	Upland	27
Lemon	Tustin	54
Lemon	Ontario	25
Walnut	Whittier	93
Walnut	Whittier	103
Walnut	Santa Ana	51
Walnut	Anaheim	112
Walnut	Puente	16
Walnut	Hemet	38
Walnut	Corona	26
Walnut	La Habra	61
Walnut	Olive	54

Experiments with Artificial Applications of Boron.—The relationship found between the injury to the citrus and walnut trees and the boron content of the soil and of the leaves indicated strongly that the observed injury was produced by boron. This view has been strengthened by the results of tests made by applying known amounts

TABLE 3

BORON CONTENT OF CITRUS AND WALNUT LEAVES THAT WERE INJURED BY WASTE WATERS FROM PACKING HOUSES. BASED ON THE DRY WEIGHT

Kind of leaf	Locality	Boron content (p. p. m.)
Lemon	North Pomona	407
Lemon	North Pomona	266
Lemon	Glendora	839
Orange	Glendora	1,679
Orange	Glendora	1,385
Orange	Azusa	1,281
Orange	Azusa	756
Orange	Covina	900
Walnut	North Pomona	456
Walnut	Ontario	683

of boron to the soil or to the water used in irrigating healthy trees. In one experiment, lemon trees about twenty years of age were irrigated at monthly intervals with water containing approximately 5, 25, and 50 p.p.m. of boron respectively, applied as ordinary borax. The experiment was begun in March, 1926, at the Citrus Experiment Station on soil of a sandy loam type.

Where the water containing 50 p.p.m. was used, practically every leaf fell from the trees within a few days after the second application was made. The trees that were irrigated with the solution containing 25 p.p.m. began to show symptoms of leaf injury within about three months. The leaves turned yellow around the margins and between the veins. The tips gradually died back and many of the leaves fell. The water which contained only 5 p.p.m. of boron produced no apparent effect until after the fifth application. At that time, however, the leaves became markedly affected. The appearance of these leaves was indistinguishable from that of the trees that had been injured by boron waste water from the various packing houses.

An experiment conducted at our request by Mr. C. A. Jensen with mature lemon trees growing on a comparatively heavy type of soil at the Limoneira Ranch, Santa Paula, California, yielded similar results. Where he made the smaller applications of boron, injury set in only after a greater number of applications than was the case on the lighter type of soil at Riverside. The appearance of the leaves was essentially the same, however. The general nature of the effect was identical with that produced at Riverside.

As is shown in table 4, the injury to lemon and orange trees, produced by the application of known amounts of boron, was accompanied

by the absorption and deposition in the leaves of abnormal quantities of boron, just as was found to be the case with the groves referred to above.[6]

TABLE 4

BORON CONTENT OF CITRUS LEAVES AS AFFECTED BY ARTIFICIAL APPLICATIONS OF BORAX. BASED ON THE DRY WEIGHT

Kind of leaf	Locality	Condition	Boron content (p. p. m.)
Orange	Riverside	Normal*	43
Orange	Riverside	Injured	463
Lemon	Riverside	Normal*	76
Lemon	Riverside	Injured	308
Lemon	Riverside	Severely injured	1,083
Lemon	Limoneira	Injured	545
Lemon	Limoneira	Severely injured	1,400

* Samples taken from untreated trees.

The Natural Occurrence of Boron.—As has been pointed out already, our attention was drawn to the fact that there is a marked similarity between the appearance of the lemon trees injured by waste waters from packing houses and certain lemon groves located in Ventura County, California. Investigation has shown a definite relationship between the occurrence of these symptoms and the use of certain irrigation supplies. One of these supplies of irrigation water is drawn from the Sespe Creek and another from wells located near Fillmore. Several citrus orchards near Piru, whose irrigation supply is drawn in part from the Piru Creek, present a similar appearance, especially in the case of lemon trees. Certain citrus and walnut groves located on the south side of the Santa Clara River between points approximately opposite Santa Paula and Fillmore, and a few relatively small areas on the north side of the Santa Clara River, both east and west of Santa Paula, also show evidence of boron injury. Minor indications of boron toxicity are also found in the various lemon and walnut groves of other parts of Ventura County. For example, several walnut groves found between Saticoy and Ventura have shown slight boron injury during the latter part of each summer for several years. Similar conditions exist in certain walnut groves of the Santa Susana Valley.

Samples of leaves taken from the above-named localities were found to contain excessive amounts of boron (see table 5). As suggested already, the chief source of the boron in these localities appears

[6] A more detailed discussion of the toxic effect of boron, based on culture experiments with citrus and walnut trees, will be presented in a separate paper by A. R. C. Hass.

to be the irrigation supply. As shown in table 6, several irrigation waters of this general section contain appreciable amounts of boron. This is especially true of the Sespe and Piru creeks. Analysis of the water from various wells indicates that a considerable portion of the

TABLE 5

BORON CONTENT OF INJURED CITRUS AND WALNUT LEAVES FROM VENTURA COUNTY. BASED ON THE DRY WEIGHT

Kind of leaf	Locality	Boron content (p. p. m.)
Lemon	Sespe	378
Lemon	Sespe	651
Lemon	Sespe Canyon	796
Lemon	Sespe Canyon	927
Lemon	Santa Paula	495
Lemon	Piru	760
Orange	Piru	1,111
Orange	Sespe Canyon	812
Walnut	Sespe Canyon	1,018
Walnut	Ventura	365
Walnut	Ventura	360
Walnut	Santa Susana	469
Walnut	Moorpark	570

TABLE 6

BORON CONTENT OF IRRIGATION WATERS

Source	Date	Boron content (p. p. m.)
Sespe Creek	June, 1926	3.3
Sespe Creek	April, 1927	1.7
Sespe Creek	Sept., 1927	1.9
Piru Creek	Nov., 1926	1.3
Santa Clara River near Santa Paula	June, 1926	0.4
Santa Paula Creek	June, 1926	0.2
Well No. 1, Santa Clara Valley	Nov., 1926	3.6
Well No. 1, Santa Clara Valley	May, 1927	1.2
Well No. 1, Santa Clara Valley	Sept., 1927	1.7
Well No. 2, Santa Clara Valley	June, 1927	0.9
Well No. 3, Santa Clara Valley	June, 1927	0.5
Well No. 4, Santa Clara Valley	June, 1927	0.6
Well No. 5, Santa Clara Valley	June, 1927	0.9
Well No. 6, Santa Clara Valley	Aug., 1927	1.0

underground water supply of the Santa Clara Valley contains somewhat more than 0.5 p.p.m. of boron. In a few comparatively small areas of this valley abnormal amounts of soluble boron occur, probably as a natural constituent of the soil. Samples of soil from one of these spots showed 6 p.p.m. and from another 5 p.p.m. of water-soluble boron.

The fact that small amounts of soluble boron occur in the soil and water of this section is not surprising in view of the geological conditions. Deposits of colemanite, a calcium borate, outcrop at certain places in the watershed north of the Santa Clara Valley. One of these deposits was formerly drawn upon as a commercial source of borax. It is reasonable to expect that the water draining from such a watershed, and the soil that has been derived in part from formations which contain colemanite, would contain appreciable quantities of boron.

For the past two years certain lemon and walnut groves growing on the lighter types of soil in various parts of the San Fernando Valley have shown typical symptoms of boron injury. The appearance of the leaves is indistinguishable from that produced by artificial

TABLE 7

BORON CONTENT OF LEMON AND WALNUT LEAVES FROM SAN FERNANDO VALLEY. BASED ON THE DRY WEIGHT

Kind of leaf	Locality	Boron content (p. p. m.)
Lemon	Tujunga	417
Lemon	San Fernando	550
Lemon	San Fernando Heights	441
Lemon	Pocoima	381
Walnut	San Fernando	380
Walnut	Owensmouth	397
Walnut	Zelzah	278

applications of boron. Analyses of leaves from these trees, reported in table 7, showed a relatively high content of boron. It is probable that the source of boron in this instance is the Owens River, from which the irrigation supply is drawn. Samples of this water taken near the San Fernando reservoir on October 1, December 1, and December 22, 1926, showed 1.9, 1.2, and 1.0 p.p.m. of boron, respectively. It is probable that samples taken at other times will show still greater variation in boron content, since wide variation in the content of other soluble constituents is known to characterize the water of various streams of the semi-arid region.

It has been found that boron toxicity also occurs in certain grapefruit orchards near Oasis in the Coachella Valley. In this locality the injury to grapefruit trees becomes most apparent in the late fall and winter months. The affected leaves practically all fall off during the winter and a profuse new growth of normal appearance develops the following spring. In this instance the boron is probably a native

constituent of the soil. Mild boron injury is also shown by grapefruit trees growing in certain parts of the Imperial Valley.

A relatively large citrus orchard composed of both lemon and orange trees, located about five miles southwest of Tustin, has been injuriously affected by boron. The source of the boron in this case appears to be the well from which the irrigation supply is drawn. This water contains about 1 p.p.m. of boron. There is also slight indication of boron injury in a few lemon groves near Chula Vista in San Diego County and in certain walnut groves located near Goleta in Santa Barbara County.

GENERAL DISCUSSION

Normally a given leaf of the lemon or orange remains attached for thirty to forty months, and the natural abscission incident to senility occurs at the base of the petiole. On the other hand, when severely injured by boron the leaves may fall at the age of six to ten months, and in this case the abscission sometimes occurs at the upper end of the petiole.

Although injurious amounts of boron may be present in the nutrient medium, the new growth may not show any indication of injury for several weeks. A little later, however, the leaves of this growth will manifest typical symptoms of boron injury. Many of these leaves fall the following winter; consequently the foliage in the interior of the tree becomes thin.

The lemon tree shows the toxic effect of boron in a characteristic way; experience will enable anyone to recognize the symptoms readily. Frequently the symptoms are shown on the foliage of the interior as well as of the exterior of the tree. The walnut may not show the toxic effect until past midsummer, but by August or September the leaves turn brown around the margins, gradually die back, and fall off prematurely.

According to our observations, lemon, grapefruit, and walnut trees are especially sensitive to boron. The orange is somewhat less sensitive. At present it is not possible to say just what is the minimum concentration of boron that will produce injury to these species. It seems certain, however, that an irrigation water which contains 1 p.p.m. of boron will ultimately produce more or less injury.

If the concentration of boron is not too high and yet sufficient to produce injury, most of the older leaves of citrus trees fall off during

the latter part of the winter and early spring months. This as stated above is often followed by the development of numerous new shoots which for a few weeks seem to be approximately normal, and the new growth is likely to give the impression that the cause of the injury has been removed and that the trees are on the way to recovery. However, with the approach of the following fall typical symptoms of boron injury again appear and by winter practically every leaf will show pronounced discoloration. These leaves fall a few months later and again new shoots appear the next spring. Lemon and orange trees may continue this sort of an existence for several years. However, the fruit that is produced is inferior in quality and the crop is small.

Although certain irrigation waters which contain approximately 1 p.p.m. of boron have produced marked toxicity, the injury did not become apparent until after these waters had been in use for several years. In these cases two sets of factors are probably involved: first, the absorptive power of the soil, and second, concentration due to evaporation. The former tends to delay the development of injury, the latter operates to accentuate it. As stated already, with the same concentration of boron in the irrigation water, toxic effects develop sooner on light than on heavy soil, but it is not safe to conclude from this fact that an irrigation water that contains a small amount of boron can be used indefinitely on a heavy type of soil. Sooner or later the soil will become saturated with boron and the concentration resulting from evaporation may then be expected to bring about injury.

Laboratory studies have shown that soluble boron can be leached out of the soil. In an experiment with soil samples taken from a badly affected lemon orchard of the San Fernando Valley it was found that practically all of the soluble boron was removed in the early stages of the leaching. This experiment helps to explain the fact that the boron-affected orchards commonly show the most pronounced injury in the fall and winter months. The boron which has accumulated during the previous irrigation season is probably leached out to some extent by the relatively heavy winter rains which occur in this section. In this way the accumulation of boron is automatically held in check.

It is possible, therefore, that an occasional heavy irrigation applied by the flooding method might leach out the boron which accumulates as a result of evaporation and thus prove to be distinctly helpful as a means of reducing the injury. In this connection it is important to bear in mind that the soil moisture inevitably becomes more concen-

trated with respect to boron as well as other salts than the irrigation water itself, owing to evaporation. The results of a simple experiment will serve to illustrate this point. Samples of soil were taken from two lemon groves of the San Fernando Valley which showed definite boron injury. The soil solution removed from these samples by the displacement method was found to contain 6.0 p.p.m. in one case and 6.5 p.p.m. in the other. However, analysis of the irrigation water used regularly on these groves revealed only 1 p.p.m. of boron.

The results of this investigation strongly indicate that boron is readily absorbed by citrus and walnut trees and that this element tends to accumulate in the leaves of these species. Because of this fact a determination of the boron content of the leaves affords a valuable indication as to the boron conditions in the soil. As stated already the boron content of the dry matter of normal citrus and walnut leaves, when grown in southern California, ordinarily does not exceed 100 p.p.m. Frequently it is less than 50 p.p.m. On the other hand, leaves that show definite boron injury are likely to contain several hundred parts per million of boron. We have taken advantage of this fact in deciding whether boron is causally related to a given abnormality of these trees.

In this connection it is important to state that the age and stage of development of the leaf has an important bearing on its content of boron. Apparently the absorption of boron is a very gradual process, and it is not until the concentration within the cells of the leaf exceeds a certain point that toxic effects become manifest. Relatively mature leaves should therefore be chosen for analysis. Whether other species of fruit trees absorb boron in a similar way has not yet been determined.

On the basis of our analyses small amounts of boron appear to be widely distributed in southern California and the citrus and walnut trees of this section always contain appreciable amounts of this element. Whether a small amount of boron is essential for these plants,[7] as is the case with several other species, cannot now be definitely stated. At any rate it is safe to say that boron is toxic if present in more than a very low concentration. In certain places there appears to be an association between boron and a type of abnormality of citrus trees closely resembling, if not identical with, the well-known condition usually designated as 'mottle leaf.' It is possible that by careful study of the effect of boron, important light may be thrown on the mottle-leaf question.

Although the toxic effect produced by boron is characteristic and ordinarily it can be easily recognized, Haas and Thomas[8] have pointed out that boron symptoms may be confused with those produced by an excess of sulfate. The fact that sulfate is a predominant constituent of the irrigation water of certain localities should therefore be taken into consideration.

It seems desirable to emphasize the fact that our knowledge regarding the rôle of boron in the nutrition of plants, as well as that of various other elements, is inadequate. During recent years various workers have shown that small amounts of boron, and of several other elements which are not commonly considered to be essential to plant growth, play an important part in the development of various species. Usually these elements are required in very small amounts and some of them ordinarily occur in the soil in mere traces. It is a curious fact that, although small amounts of such elements as boron, manganese, copper, zinc, etc., are required for the full development of various plants, every investigator who has studied this question has noted that toxicity results when the concentration exceeds a very low level. In this respect these elements differ greatly from such elements as nitrogen and calcium. It is certain that a knowledge of the function of the above-named elements will be helpful in the study of the nutritional processes of various fruit trees. Such knowledge may prove to be of aid in the practical solution of some of the nutritional difficulties that are encountered in many places in California.

SUMMARY

1. Concentrations of boron occur in certain irrigation waters of southern California that are toxic to citrus and walnut trees. In a few relatively small areas the soil contains an injurious quantity of soluble boron, which has probably accumulated as a result of purely natural causes.

2. Citrus trees show the toxic effect of boron by a yellowing of the older leaves around the margins and between the veins and a dying back of the tips and margins. The new growth may not show the injury until it is several months old. Many of the affected leaves fall off in the winter and early spring months. When walnut trees are injured by boron, the leaves turn brown around the margins and between the veins during August and September. Earlier in the year the leaves may not show any evidence of boron injury. Boron-affected walnut leaves tend to fall prematurely.

3. Citrus and walnut trees absorb boron readily and this element tends to accumulate in the leaves. The determination of the boron content of the leaves of citrus and walnut trees gives valuable indication as to whether this element is the cause of abnormal leaf conditions.

4. When introduced into the soil as a constituent of the irrigation water, boron gradually accumulates in the upper layers of the soil as a result of evaporation. Heavy rains probably carry down some of the boron from time to time and thus retard the accumulation of soluble boron in the region of tree roots.

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The titles of the Technical Papers of the California Agricultural Experiment Station, Nos. 1 to 20, which HILGARDIA replaces, and copies of which may be had on application to the Publication Secretary, Agricultural Experiment Station, Berkeley, are as follows:

1. The Removal of Sodium Carbonate from Soils, by Walter P. Kelley and Edward E. Thomas. January, 1923.
3. The Formation of Sodium Carbonate in Soils, by Arthur B. Cummins and Walter P. Kelley. March, 1923.
4. Effect of Sodium Chlorid and Calcium Chlorid upon the Growth and Composition of Young Orange Trees, by H. S. Reed and A. R. C. Haas. April, 1923.
5. Citrus Blast and Black Pit, by H. S. Fawcett, W. T. Horne, and A. F. Camp. May, 1923.
6. A Study of Deciduous Fruit Tree Rootstocks with Special Reference to Their Identification, by Myer J. Heppner. June, 1923.
7. A Study of the Darkening of Apple Tissue, by E. L. Overholser and W. V. Cruess. June, 1923.
8. Effect of Salts on the Intake of Inorganic Elements and on the Buffer System of the Plant, by D. R. Hoagland and J. C. Martin. July, 1923.
9. Experiments on the Reclamation of Alkali Soils by Leaching with Water and Gypsum, by P. L. Hibbard. August, 1923.
10. The Seasonal Variation of the Soil Moisture in a Walnut Grove in Relation to Hygroscopic Coefficient, by L. D. Batchelor and H. S. Reed. September, 1923.
11. Studies on the Effects of Sodium, Potassium, and Calcium on Young Orange Trees, by H. S. Reed and A. R. C. Haas. October, 1923.
12. The Effect of the Plant on the Reaction of the Culture Solution, by D. R. Hoagland. November, 1923.
13. Some Mutual Effects on Soil and Plant Induced by Added Solutes, by John S. Burd and J. C. Martin. December, 1923.
14. The Respiration of Potato Tubers in Relation to the Occurrence of Blackheart, by J. P. Bennett and E. T. Bartholomew. January, 1924.
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