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THE EFFECT OF CERTAIN MINERAL DEFICIENCIES ON THE GROWTH, LEAF APPEARANCE, AND MINERAL CONTENT OF YOUNG OLIVE TREES

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Various unusual leaf patterns appearing on olive trees, often associated with poor tree growth, may be due to a deficiency of one of the mineral-nutrient elements studied in this investigation—nitrogen, phosphorus, potassium, or magnesium.

Results of a two-year sand-culture experiment are here presented by a series of leaf analyses, growth measurements of the trees, and color photographs of the leaf symptoms obtained.

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THE EFFECT OF CERTAIN MINERAL DEFICIENCIES ON THE GROWTH, LEAF APPEARANCE, AND MINERAL CONTENT OF YOUNG OLIVE TREES[1]

H. T. HARTMANN[2] and J. G. BROWN[3]

THE FERTILIZATION PROGRAM for olives (*Olea europaea* L.) is confined in California to annual applications of nitrogen. Experimental tests by Johnston and Moore (1941) and Merrill (1941) about ten years ago definitely showed that increased yields were obtained with nitrogen fertilization. Since that time the annual application of ½ to 1 pound of actual nitrogen per tree is an accepted practice with California olive growers.

It was shown by Scott, Thomas, and Thomas (1943) that in the Wyandotte area of Butte County a deficiency of boron in olives existed. Olive growers in that area have subsequently treated their orchards with borax so that at present it is difficult to find olive trees showing characteristic boron-deficiency symptoms.

An extensive leaf-analysis survey by Lilleland[4] of the nutrient status of olive trees in various parts of California from 1944 through 1947 showed that the potassium content of olive leaves in the Wyandotte area of Butte County was considerably lower than elsewhere. In 1947 at the Graves orchard in this region olive trees were noted that produced leaves affected with a characteristic necrotic tip area and a pale green color. Chemical analysis of the leaves showed their potassium content to be very low (0.11 per cent of the dry weight). Soil applications of potassium sulfate corrected the tree condition and increased the potassium content of the leaves to normal values (0.4 to 1.0 per cent), indicating that the cause of the trouble was potassium deficiency.

SAND-CULTURE EXPERIMENTS

To obtain more information on the mineral-nutrient requirements of olives, a sand-culture experiment was conducted in the greenhouse at Davis, where olives were grown under various mineral-element deficiency conditions. An attempt has been made to establish nutrient-deficiency symptoms of some

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[4] Lilleland, O. Unpublished data.

of the mineral elements and to determine the normal range for these elements as found in the olive according to leaf analysis.

Since boron deficiency was not studied in the present work, the boron-deficient leaves, as shown in figure 5, were obtained from orchard trees in Butte County, as were also the potassium-deficient leaves included for comparison.

These experiments were started on July 20, 1948, and continued until July 25, 1950. One-year-old Mission olive trees propagated from cuttings were used. Five trees per treatment were grown in 3-gallon cans in a fine-particle white quartz sand, which chemical analysis showed to be free of the elements under study. The cans were given a thick inside coating of hot grafting wax containing resin, linseed oil, beeswax, and lampblack.

Five nutrient solutions recommended by Hoagland and Arnon (1938) were used: (1) a full nutrient solution, (2) one lacking nitrogen, (3) one lacking phosphorus, (4) one lacking potassium, and (5) one lacking magnesium. They were completely renewed every 4 weeks, and distilled water was added once each week to replenish that lost by transpiration and evaporation. The solutions were maintained at a pH of approximately 5.5 by the addition of sulfuric acid. Enough 0.5 per cent iron citrate solution was added each week to prevent the development of iron-deficiency chlorosis.

Leaf Analyses

One of the major objectives of this work was to attempt to correlate the leaf symptoms associated with the various nutrient deficiencies with the mineral-nutrient levels in the leaves. Consequently, samples of mature leaves were collected from the various treatments at intervals during the two-year period. After washing, drying, and grinding, the samples were analyzed for potassium, calcium, and magnesium, using flame photometric techniques (Brown, Lilleland, and Jackson, 1950). Phosphorus was determined on a solution of the ashed material by a phosphomolybdate colorimetric procedure (Fisk and Subbarow, 1925). Total nitrogen was determined by means of the Gunning method modified to include nitrate nitrogen (Association of Official Agricultural Chemists, 1945). Selenium oxychloride was added as a catalyst.

RESULTS

Plant Growth

Figure 1 shows the appearance of representative trees at the conclusion of the test, and the dry weight per plant for the leaves, stems, and roots is given in table 1 and figure 2. In general, the full-nutrient plants made the greatest total growth, followed in order by those deficient in potassium, nitrogen, phosphorus, and finally magnesium.

There were certain exceptions to this order, however. The magnesium-deficient trees were slightly larger in top growth than the nitrogen-deficient trees, but the reverse was true concerning their roots and leaves. The minus-N, minus-P, and minus-Mg trees had dropped many of their leaves, principally the terminal ones, at the conclusion of the experiment. This was not true for the minus-K trees, however, which showed no symptoms of distress.

Throughout the 24 months this experiment was in operation, considerable attention had to be given to the control of black scale, *Saissetia oleae* Bern. It was interesting to note that the insects attacked only the full-nutrient and minus-potassium trees.

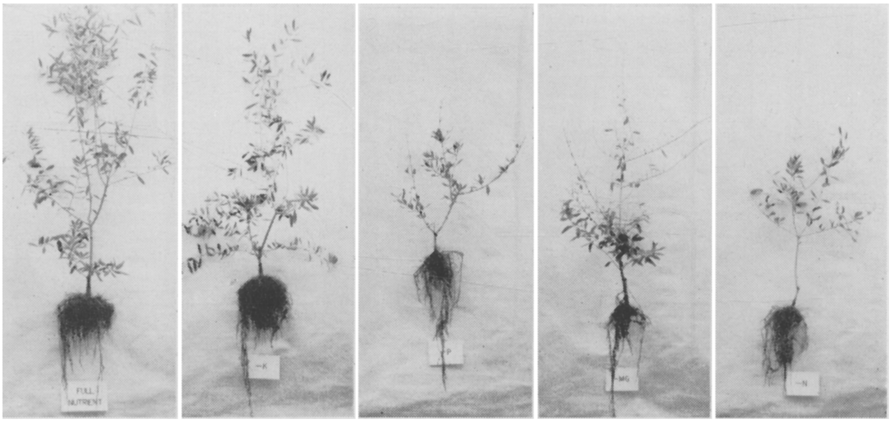

Fig. 1. Appearance of typical trees after 24 months at the indicated conditions. Left to right: Full nutrient; –K; –P; –Mg; –N.

TABLE 1

COMPOSITION PER PLANT OF OLIVE TREES GROWN IN NUTRIENT-SAND CULTURE FROM JULY 30, 1948, TO JULY 25, 1950

Average of Five Plants.

Treatment	Total dry weight, grams				Total content of N, P, K, Mg, Na, and Ca, grams			
	Leaves	Stems	Roots	Entire plant	Leaves	Stems	Roots	Entire plant
Full nutrient	96.0	133.0	1,475.0	1,704.0	3.70	3.98	60.33	68.01
Minus potassium	72.0	97.0	177.0	346.0	2.53	3.06	7.01	12.60
Minus nitrogen	13.0	22.0	154.0	189.0	0.46	0.35	5.94	6.75
Minus magnesium	5.0	25.0	77.0	107.0	0.18	1.28	5.01	6.47
Minus phosphorus	6.0	15.0	91.0	112.0	0.22	0.33	3.52	4.07

Leaf Symptoms

The results of the leaf, stem, and root analyses are given in tables 2, 3, and 4 and figure 3. Figures 4, 5, and 6 show in color the characteristic leaf symptoms which have been found associated with the deficiencies of phosphorus, boron, potassium, magnesium, and nitrogen in the olive. While the potassium leaf content of the young minus-potassium trees in the sand-culture tests was reduced to 0.12 per cent of the dry weight, the characteristic necrotic leaf area found in the potassium-deficient mature trees in Butte County, which had a potassium leaf content in the neighborhood of 0.11 per cent, was not obtained.

TABLE 2

LEAF ANALYSES OF MISSION OLIVE TREES GROWN IN NUTRIENT-SAND CULTURES

Chemical Elements Expressed as Percentage of Dry Weight. Differential Treatments Started July 30, 1948.*

Date of collection	Treatment																								
	Minus potassium					Minus magnesium					Minus phosphorus					Minus nitrogen					Full nutrient				
	K	Ca	Mg	P	N	K	Ca	Mg	P	N	K	Ca	Mg	P	N	K	Ca	Mg	P	N	K	Ca	Mg	P	N
Feb. 3, 1949	0.76	0.77	0.29	0.19	2.34	1.95	0.26	0.08	0.16	2.14	1.43	0.29	0.13	0.08	1.78	0.93	0.32	0.17	0.10	0.96	1.83	0.46	0.16	0.15	2.49
June 18, 1949	0.83	0.92	0.26	0.16	1.69	2.44	0.30	0.11	0.15	1.96	1.30	0.33	0.15	0.06	1.57	1.85	0.49	0.15	0.11	1.40	2.05	0.66	0.19	0.15	1.96
Oct. 5, 1949	0.58	0.93	0.24	0.17	1.69	2.52	0.33	0.07	0.14	1.86	1.53	0.30	0.12	0.05	1.41	1.67	0.37	0.14	0.13	1.02	2.01	0.41	0.15	0.15	1.84
Jan. 14, 1950	0.12	1.88	0.40	0.13	2.00	2.56	0.70	0.14	0.14	2.40	1.21	0.61	0.17	0.04	1.74	1.29	0.66	0.15	0.24	0.99	1.61	0.83	0.22	0.16	2.00
June 2, 1950	0.12	1.42	0.35	0.14	...	2.34	0.26	0.06	0.15	2.04	1.21	0.39	0.21	0.04	1.79	1.38	0.36	0.11	0.19	0.98	1.65	0.75	0.15	0.14	2.12
July 25, 1950	0.17	1.10	0.41	0.15	1.66	1.96	0.43	0.10	0.10	1.06	1.23	0.51	0.37	0.03	1.50	1.61	0.56	0.14	0.29	0.95	1.78	0.46	0.16	0.13	1.29

* Composite leaf analysis of all the trees at the beginning of treatments.—K .0.81; Ca, 0.34; Mg, 0.17; P, 0.18; N, 1.92.

TABLE 3

COMPARISON OF LEAF ANALYSES OF YOUNG LEAVES AND OLD LEAVES, ALSO LEAVES, STEMS, AND ROOTS OF MISSION OLIVES GROWN IN NUTRIENT-SAND CULTURES

Chemical Elements Expressed as Percentage Dry Weight. Differential Treatments Started July 30, 1948.

Date of collection and age of leaves	Treatment																								
	Minus potassium					Minus magnesium					Minus phosphorus					Minus nitrogen					Full nutrient				
	K	Ca	Mg	P	N	K	Ca	Mg	P	N	K	Ca	Mg	P	N	K	Ca	Mg	P	N	K	Ca	Mg	P	N
Jan. 14, 1950																									
Young leaves	0.32	0.89	0.25	0.15	1.55	2.01	0.33	0.07	0.14	1.92	1.37	0.34	0.13	0.05	1.48	1.31	0.37	0.09	0.11	0.90	1.53	0.54	0.13	0.13	1.94
Old leaves	0.11	1.88	0.40	0.13	2.00	2.56	0.70	0.14	0.15	2.40	1.21	0.61	0.17	0.04	1.74	1.29	0.66	0.15	0.24	0.99	1.61	0.83	0.22	0.16	2.00
June 2, 1950																									
Young leaves	0.46	0.66	0.21	0.18	1.87	- - -	- -	- - -	- -	- -N	o yo	ung l	eave	s ava	ilabl	e - -	- -	- - -	- -	- - -	1.78	0.36	0.15	0.15	1.97
Old leaves	0.12	1.42	0.35	0.14	...	2.34	0.26	0.06	0.15	2.04	1.21	0.39	0.21	0.04	1.79	1.38	0.36	0.11	0.19	0.98	1.65	0.75	0.15	0.14	2.12
July 25, 1950																									
Leaves	0.17	1.10	0.41	0.15	1.66	1.96	0.43	0.10	0.10	1.06	1.23	0.51	0.37	0.05	1.50	1.61	0.56	0.14	0.29	0.95	1.78	0.46	0.16	0.13	1.29
Stems	0.18	1.75	0.22	0.13	0.85	2.58	0.35	0.11	0.11	1.95	0.88	0.34	0.08	0.02	0.82	0.71	0.33	0.08	0.13	0.33	1.25	0.60	0.14	0.11	0.86
Roots	0.13	1.22	0.78	0.29	1.33	1.74	2.11	0.37	0.62	1.61	1.53	0.36	0.12	0.25	1.58	1.50	0.59	0.37	0.51	0.84	1.80	1.25	0.41	0.24	1.32

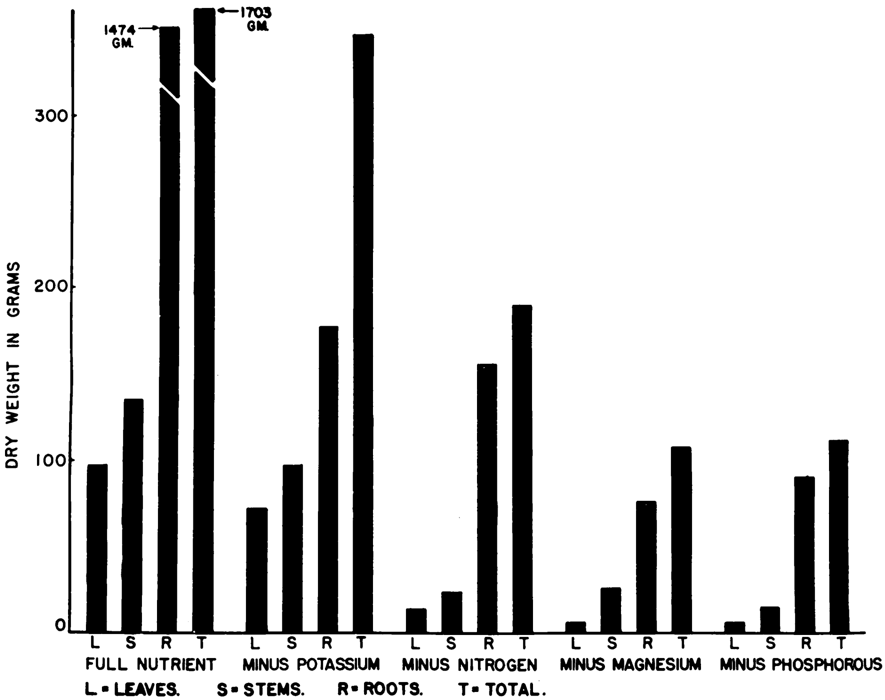

Fig. 2. The average dry weight per plant in the various treatments at the conclusion of the experiment.

TABLE 4

RANGE* OF CHEMICAL ELEMENTS IN OLIVE LEAVES

Expressed as Percentage of Dry Weight Except Boron, which is in P.P.M.

	Maximum	Average	Minimum
Nitrogen, per cent	2.5	1.3	0.9
Phosphorus, per cent	0.30†	0.15	0.03
Potassium, per cent	2.5‡	0.8	0.1
Magnesium, per cent	0.40§	0.15	0.06
Boron,¶ p.p.m.	268‖	20 to 30	7 to 13

* "Maximum" is the highest amount obtained; "average" is the approximate amount found in most orchards; "minimum" is the amount present when the trees show deficiency symptoms and would be expected to respond to fertilizer. The maximum and minimum values given were obtained from the pot-culture tests.
† Found in trees low in nitrogen.
‡ Found in trees low in magnesium.
§ Found in trees low in potassium.
¶ Hansen (1946). See Literature Cited.
‖ In plants irrigated with water containing 10 p.p.m. boron.

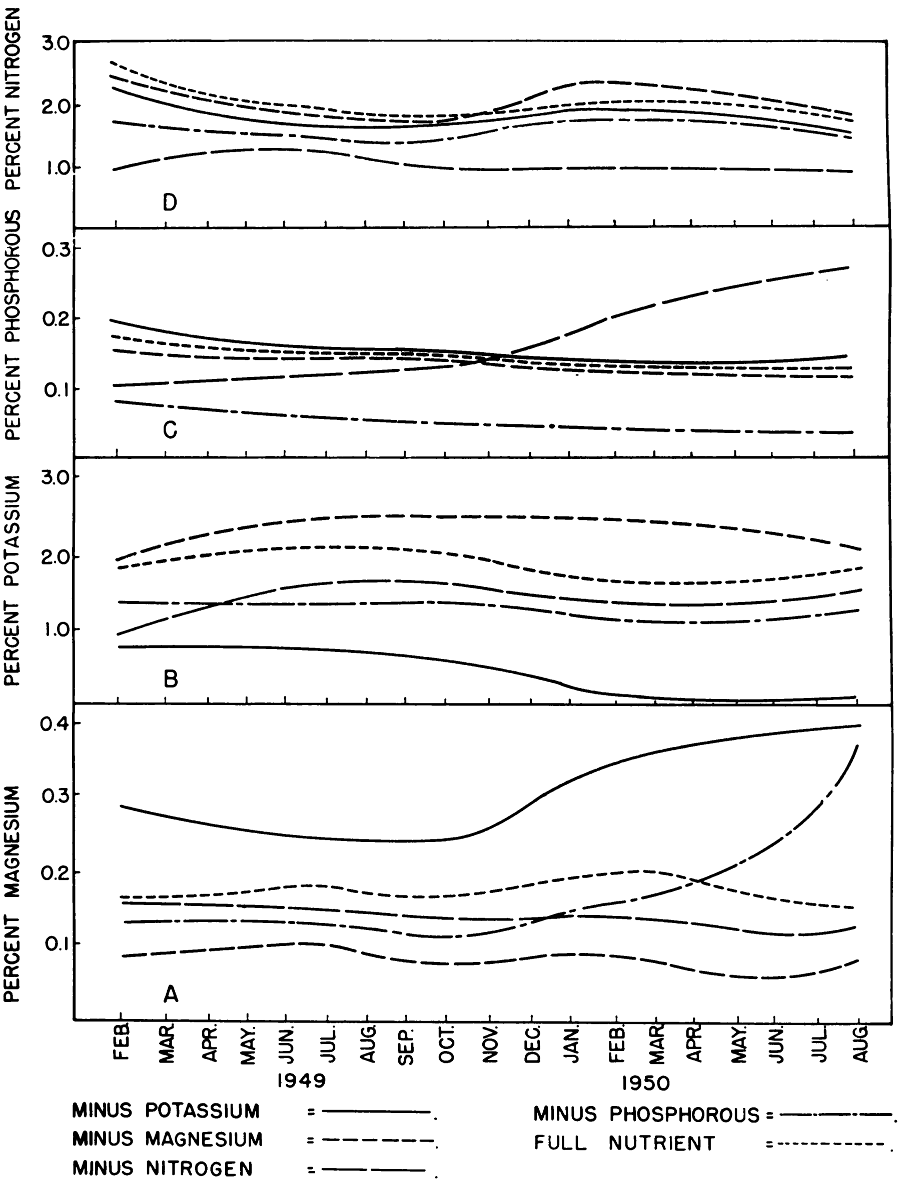

Fig. 3. The nitrogen, phosphorous, potassium, and magnesium contents of the leaves in the various treatments throughout the course of the experiment.

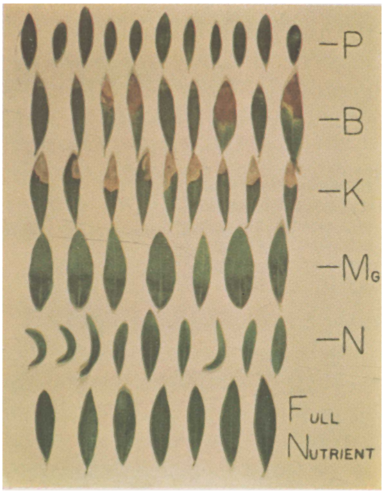

Fig. 4. Olive leaves showing the symptoms of various mineral nutrient deficiencies in comparison with leaves from full-nutrient trees.

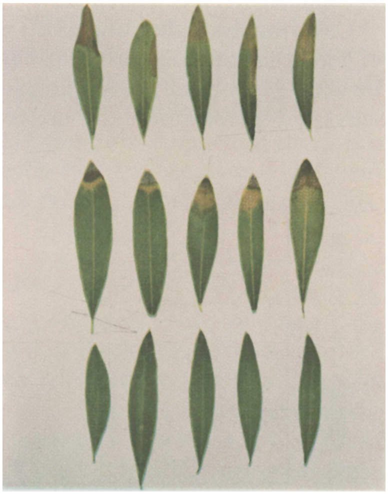

Fig. 5. A comparison of leaves from olive trees deficient in potassium and boron with leaves from full-nutrient trees. *Top.* Minus potassium. *Center.* Minus boron. *Lower.* Full nutrient.

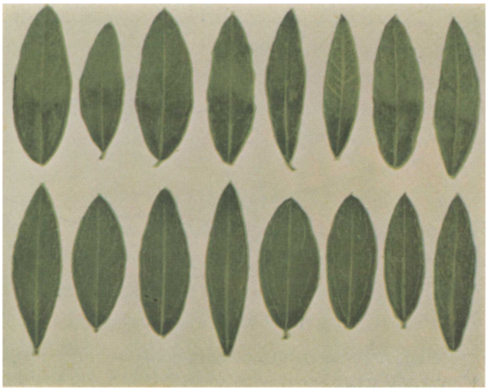

Fig. 6. *Top.* Typical leaves from olive trees grown under magnesium-deficient conditions. *Lower.* Leaves from full-nutrient trees.

Potassium Deficiency

Continued withholding of all potassium in the nutrient solution for a period of two years finally brought the potassium content of the leaves down to a level (0.12 per cent) comparable with the amount (0.11 per cent) found in leaves of potassium-deficient trees in Butte County. Perhaps if the sand-

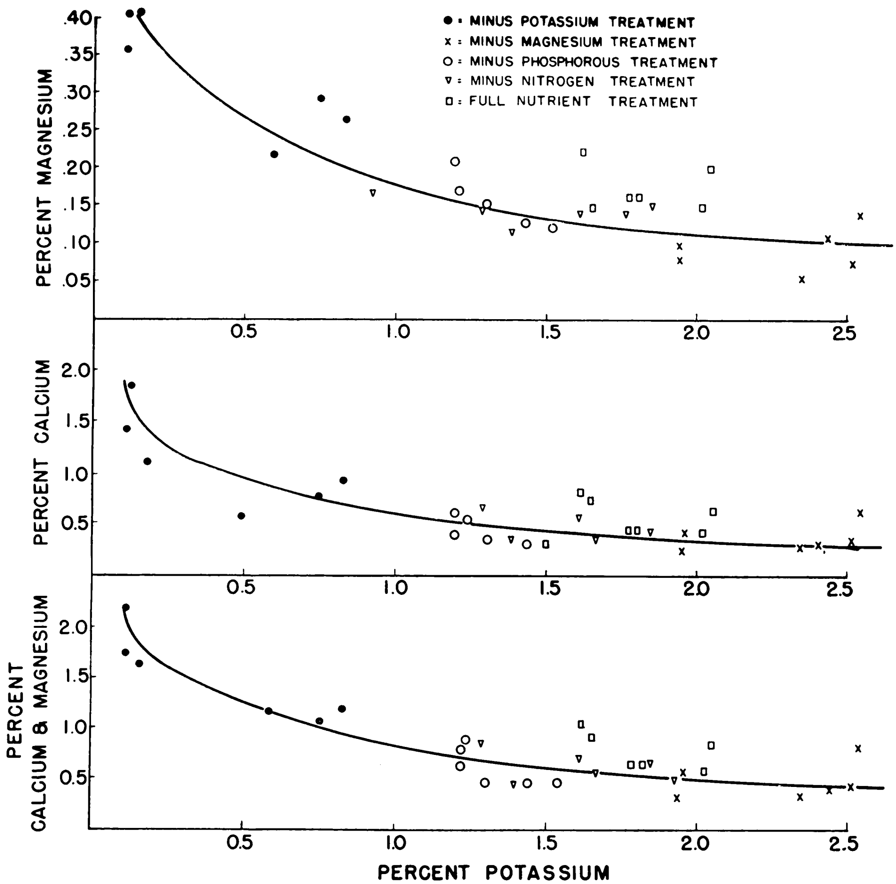

Fig. 7. Relation between the potassium content and the magnesium content, calcium content, and magnesium plus calcium content of leaves in the various treatments.

culture tests had been continued further, leaf symptoms would have appeared. The only reaction to a lack of potassium shown by the trees in the sand-culture tests was a general reduction in growth. This effect was not so striking as that obtained with the trees deficient in nitrogen, phosphorus, and magnesium. The reciprocal effect of the potassium status upon the magnesium and calcium leaf content is shown in figure 7 and tables 2 and 3.

In Butte County orchard trees, the leaf symptoms of potassium deficiency are very definite, consisting first of the development of a general light-green color, similar to that caused by a lack of nitrogen, followed by the occurrence of necrotic areas either at the tips or along the sides. The latter symptoms are most evident during February and March.

Potassium-deficient leaves are somewhat similar to those showing boron deficiency. However, the necrotic areas in potassium-deficient leaves may occur on the lateral margins of the leaves, while with boron deficiency these areas are always found at the tip. Also with potassium deficiency there is a fairly sharp break between normal and necrotic leaf tissues. Boron-deficient leaves show a transition zone, from green to yellow to brown areas. These differences are shown in figure 5.

Nitrogen Deficiency

One characteristic of the leaves in the minus-nitrogen group of plants was a shortening and curling along the midrib, giving the leaves a "boat-shaped" appearance as shown in figure 4. This may or may not be due to a nitrogen deficiency since it has not appeared in nitrogen-deficient olive trees in the field with a nitrogen leaf content as low as 0.90 per cent. Other evidences of nitrogen deficiency shown by the leaves were a general light color of green and a reduced leaf size. No particular chlorotic leaf pattern was seen, nor did any necrotic areas develop in the leaves. As with the phosphorus- and magnesium-deficient trees, a marked dropping of the younger leaves occurred (fig. 1). There was a definite inhibition in growth of the entire plant of about the same magnitude as found in the phosphorus- and magnesium-deficient trees. Root growth was not, however, inhibited to the same degree.

On the basis of the results of these sand-culture tests, nitrogen deficiency in olives would be shown by a reduction in leaf size, the presence of a light-green leaf color, and a general inhibition of growth. With such a nitrogen deficiency the nitrogen content of the leaves would be about 0.9 to 1.0 per cent of the dry weight as compared with 1.2 to 2.0 per cent for trees having an adequate nitrogen supply. As with other fruit-tree species, examples of nitrogen deficiency in olives are widespread throughout California in almost all soil types.

Phosphorus Deficiency

Figure 4 shows that leaves from the minus-phosphorus trees are considerably smaller than those from trees with complete nutrients. No leaf pattern was apparent, the color of the leaves being a very dark green. There was a pronounced dropping of the younger leaves, especially after about 18 months. After about 12 months there was an almost complete cessation of new terminal-shoot growth. Phosphorus deficiency occasioned a greater inhibition of growth than did a deficiency of any other element tested except magnesium.

Under field conditions the symptoms for phosphorus deficiency in olives would, therefore, be expected to include a reduction in leaf size, no chlorosis or mottling but rather a darkening of the green color, lack of new shoot growth, and a dropping of the terminal leaves. A later stage would probably include the death of these terminal twigs. Associated with such phosphorus-deficiency symptoms would be a leaf analysis for phosphorus of about 0.03 to 0.05 per cent in comparison with a phosphorus content of about 0.15 per cent for trees with adequate phosphorus.

At present no olive trees in California are known to exhibit a deficiency of phosphorus. Even in the low-phosphate soils around Paradise, in Butte County, olives apparently obtain sufficient phosphorus, with leaf analyses* showing that trees in this area have leaf-phosphorus contents of 0.07 per cent or more of the dry weight, in comparison with 0.03 per cent obtained at the conclusion of the present sand-culture tests.

Magnesium Deficiency

In figures 4 and 6 magnesium-deficient olive leaves are shown. Such symptoms started appearing about 10 weeks after magnesium was withheld from the plants. There was a progressive development of a light-green, chlorotic area from tip to base of the leaf. Usually the leaves dropped before more severe symptoms appeared, the most affected being the younger ones, so that the trees appeared defoliated (fig. 1). Unlike on the phosphorus-deficient trees there was for some time a continued shoot growth with the production of new leaves. Finally, however, at about 20 months, new growth ceased, and a general dropping of leaves occurred. Lack of magnesium caused a marked inhibition of growth.

Under field conditions magnesium deficiency in the olive would be expected to cause chlorotic leaves, with the light-green area advancing from the tip toward the base. A general defoliation of the younger shoots would occur, followed by the death of the terminal twigs. A general reduction in total plant growth would accompany the other symptoms. Leaves on trees exhibiting such symptoms would be expected to have a magnesium content of about 0.06 to 0.10 per cent, in comparison with about 0.15 to 0.20 per cent for trees with an adequate magnesium supply.

No cases of magnesium-deficient olive trees grown under field conditions have as yet been reported in California. While the magnesium content of olive leaves in various areas of the state ranges from about 0.15 to 0.48 per cent of the dry weight, one orchard in the Fair Oaks area had a leaf analysis showing 0.10 to 0.12 per cent magnesium. Although no leaf symptoms were apparent this would be fairly close to the point where a deficiency might be expected to occur. Only a very narrow margin (about 0.01 per cent) exists between the magnesium-deficient range and the adequate magnesium range.

SUMMARY AND DISCUSSION

Young Mission olive trees were grown in sand cultures in the greenhouse for 24 months under five conditions—full nutrient, minus potassium, minus magnesium, minus phosphorus, and minus nitrogen.

At intervals during this period, leaf samples were obtained from the trees in each plot and analyses made for potassium, calcium, magnesium, phosphorus, and nitrogen. The general level of these nutrients to be found in the leaves of trees deficient in the four above-mentioned elements was obtained, as well as for trees receiving full nutrients.

Growth measurements of the trees were taken at the conclusion of this experiment. Color photographs of the leaves were made to correlate the appearance of the leaf with the leaf content of the mineral nutrients studied.

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* Lilleland, O. Unpublished data.

The behavior of the potassium-deficient trees during this test shows that trees can be markedly inhibited in growth by the deficiency of an essential element, without exhibiting any definite symptom. During the entire period of the test, these trees appeared normal and healthy in every respect. Without the full-nutrient trees for comparison, no abnormality would have been suspected. As determined by leaf analyses, the potassium content of the plants was steadily lowered throughout the duration of the test, and if continued further the characteristic leaf symptoms of potassium deficiency, as noted in Butte County olive trees, would probably have appeared. These

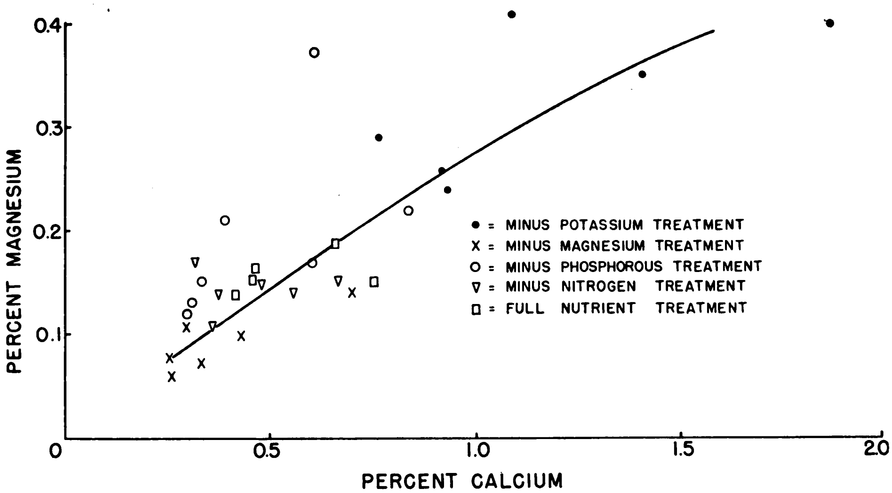

Fig. 8. Relation between the calcium and magnesium contents of the leaves in the various treatments.

leaf symptoms in Butte County orchards were not observed on a wide scale until about 1947. It is very probable that for some years preceding the appearance of these symptoms the trees were retarded in their growth because of a lack of potassium. The appearance of potassium-deficiency symptoms may have been accelerated after growers began widespread fertilization with nitrogen and corrected the boron deficiency previously observed.

As shown in figure 7 a definite inverse relation was found in these trees between the leaf content of potassium and the leaf content of both calcium and magnesium. Including all the leaf analyses made during the course of this experiment, a low potassium value was noted when either a high magnesium or calcium analysis was obtained. Conversely, when high potassium values were found, both the calcium and magnesium contents were relatively low. It should be pointed out also that a direct linear relation thus existed between the magnesium and calcium contents of the leaf. A low magnesium level was associated with a low calcium level. The same held true for high magnesium and calcium contents (fig. 8).

Although withholding nitrogen in the nutrient tests (fig. 3*C*) caused a definite increase in the phosphorus content of the plants, withholding phosphorus did not cause a corresponding rise in the nitrogen level of the trees (fig. 3*D*).

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. O. Lilleland for his suggestions in setting up and conducting these tests and to Mr. Edward Crosby, Research Assistant, and Mr. John Whisler, Laboratory Technician, who assisted to a large extent in carrying out the experiments.

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