THE NUTRITIONAL STATUS OF CITRUS TREES IN LEBANON

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AN ABSTRACT OF THE THESIS OF

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A survey was conducted on the nutritional status of a representative sample of Lebanese citrus orchards with regard to the leaf inorganic constituents of N, P, K, Mg, Ca, Na, Fe, B, Zn, Mn, and Cu, as compared to currently available conventional standards of citrus leaf analyses; to determine the relation of N and P to the other elements; and to study the interrelationships among K, Mg, Ca, and Na, noting particularly the interrelationship between K and Mg in light of their levels in the leaves and soils.

Leaf and soil analyses were carried out on 396 leaf samples and 396 soil samples collected between August 10 and September 16, 1966, from 66 citrus orchards located on the coastal area between Cheik Zendi in the Akkar plain in North Lebanon and Bayyada in South Lebanon. The majority of the samples (288 leaf samples and 288 soil samples) were from Shammouti and Valencia oranges, while the rest of the samples collected were from Mediterranean mandarines, Navel oranges, and Sa'asly lemons. Information on the cultural practices followed in the orchards between the years 1963 and 1966 was compiled. The leaves were analyzed for total N, P, K, Mg, Ca, Na, Fe, B, Zn, Mn, and Cu. The soils were analyzed for exchangeable K, NH_4OAc extractable Mg, $CaCO_3$ contents; and soil reaction (pH).

The soil $CaCO_3$ contents and the pH values indicated that all the orchards under study had calcareous soils.

There was much disagreement among the growers with respect to cultural operations and particularly in the case of fertilizer applications. However, ammonium sulfate, goat manure and ordinary superphosphate were found to be the most commonly used fertilizers.

On comparing the levels of leaf inorganic constituents found with those of conventional leaf standards, it was found that N and K contents of the leaves tended to be "low". A similar tendency, but to a lesser extent, was observed for leaf P. The majority of the trees studied were either "deficient" or "low" in leaf Mg, Zn, and Mn, and to a lesser extent in Cu, whereas leaf Ca and Na were either "high" or "in excess" in most of the cases. The trees seemed to have no problem with Fe or B.

Studies on the interrelationships among the elements revealed that leaf N contents correlated positively with Na, and negatively with P, K, Ca, B, Zn, and Cu contents of the leaves. Leaf P was found to correlate negatively with the N and Ca leaf contents and positively with leaf K. Leaf K was not related to the soil exchangeable K, but it was found to correlate negatively with leaf Ca. Leaf Mg was found to correlate negatively with the K/Mg ratio in the soil, but it was not related to leaf K, leaf Ca, or NH_4OAc extractable Mg in the soil. Leaf Na correlated negatively with leaf Ca, but it had no consistent relationship with leaf K or leaf Mg.

There was some evidence that the calcareous nature of the soils, coupled with the continuous use of superphosphate, the indiscriminate use of nitrogen fertilizers, particularly ammonium sulfate, and the prolonged irrigation intervals, had upset the nutritional balance in the citrus trees under study, especially affecting the levels of leaf K, Mg, Zn, Mn, and Cu.

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I. INTRODUCTION

Fruit nutrition is among the most challenging of the problems that are still facing plant physiologists, soil chemists, and horticulturists. Different methods and approaches have been attempted by many workers to determine the nutritional requirements of plants through the use of leaf and soil analyses. Some of the best reviews along this line are those that appear almost annually in the Annual Review of Plant Physiology Series, published by the Annual Review Inc. (U.S.A.). Citrus fruit trees are among those which have received substantial attention recently in many parts of the world, as judged by the tremendous amount of research reported about the different phases of citrus production (Smith, 1966, pp 199-207).

The Mediterranian basin is an important citrus belt. Among those Mediterranian countries growing citrus is Lebanon, where the area devoted to citrus trees has increased from 6,500 to 10,000 hectars within the past decade (Fuleihan et al., pp 9), indicating an increasing interest by Lebanese growers towards citrus production. This is especially of interest when considering the total area devoted to cultivated fruits and the relatively small area of Lebanon (10,500 Km^2).

Field observations have pointed out the possible existance of nutritional disorders in Lebanese citrus orchards. However, studies on the nutritional aspects of citrus fruit production have been very limited, despite the fact that fertilization is among the most expensive cultural operations practiced by Lebanese citrus growers. Thus, before conducting detailed research upon citrus nutrition, it was deemed necessary to conduct a preliminary survey upon the present nutritional status of citrus orchards in Lebanon.

The purpose of this investigation was (1) to determine, in the light of currently available information and standards of leaf analyses, the present nutritional status of citrus orchards in Lebanon with regard to 11 inorganic elements, (2) to determine if there were any relationship between leaf nitrogen and phosphorous and any of the other inorganic elements, and (3) to investigate the interrelationship among the major leaf cations (potassium, magnesium, calcium, and sodium), noting particularly the interrelationship between potassium and magnesium in light of their levels in the leaves and soils.

II. REVIEW OF LITERATURE

Nutritional disorders in fruit trees are very common throughout the world, and they vary with climate, soil type, fertilization, spray programs, and many other factors. The importance of balanced nutrition in fruit trees has been recognized for a long time and a great amount of research has been conducted along this line within the past few decades. According to Shear et al. (1946), maximum growth and yield of plants are functions of the coexistance of the optimum intensity of the elements and a balance amongst them. They further stated that any shift in the level of one or more elements, not accompanied by suitable changes in the levels of all other elements, may result in an unbalanced nutrition expressed in various deficiency symptoms. Bahrt and Roy (1940) pointed out that there was a tendency for one element to increase to make up for the deficiency of another element in plant tissues. Shear et al. (1948) suggested that the uptake and accumulation of an ion were influenced by the absorption and accumulation of all other ions. Many recent studies have revealed the existance of reciprocative and synergistic effects among the nutritive elements in citrus, but only those reports which are pertinent to the present study are reviewed in the following paragraphs.

The Relation of Macro- and Some Microelements to the Status of Nitrogen and Phosphorous in Citrus

The Relation of Leaf Macro- and Some Microelements to Nitrogen

It has been suggested that the nitrogen status of citrus trees has a great influence on the absorption and accumulation of practically all other elements (Smith, 1962b, pp 86). This has been confirmed by the results of many workers, whereby nitrogen fertilizer applications to citrus trees were found to increase the concentration of leaf N (Reuther and Smith, 1950; Embleton et al., 1952; Labanauskas et al., 1958), leaf Mg (Boynton and Compton, 1945, pp 350; Labanauskas et al., 1958), and leaf Mn (Embleton and Jones, 1956; Labanauskas et. al., 1958); and to decrease the leaf contents of P (Chapman and Raymer, 1951, pp 341; Parker and Jones, 1951; Embleton et al., 1952; Reuther and Smith, 1950; Smith et al., 1953; Smith et al., 1954; Reitz and Koo, 1960), K (Boynton and Compton, 1945, pp 350; Reuther and Smith, 1950; Reitz and Koo, 1960), B and Cu (Smith et al., 1954; Labanauskas et al., 1959), and Zn (Camp, 1943; Reuther and Smith, 1950; Smith et al., 1954). However, contradictory results regarding the effect of N on other leaf elements are met frequently in the literature. According to Smith (1966, pp 224), Mg uptake by trees was more efficient with adequate supplies of N than with limited N. This was not in agreement with the findings of Wallace et al. (1952) who reported that N fertilizers had reduced Mg concentration in the leaves of Valencia oranges as compared to those receiving no fertilizers. However, the forementioned workers agreed with regard to the depressive effect of N fertilizers on P and K levels in the leaves. Labanauskas _et al_. (1962) found that limestone plus ammonium sulfate application had reduced the Mg concentration in Navel orange trees in comparison to the effect of ammonium sulfate alone. Moreover, Smith and Rasmussen (1961) reported that equal rates of calcium nitrate, ammonium nitrate, and ammonium sulfate applied to grapefruits had similar effects on the level of Mg in the leaves, but leaf Mg increased upon increasing the rate of N and by keeping the pH above 6.

Reitz and Long (1953) found that an inverse relationship existed between N and Ca in the leaves of citrus trees grown on the calcareous soils of the Indian River area of Florida. This was contradictory to the findings of Reuther and Smith (1950) who found a positive relationship between N and Ca while working with young bearing Valencia oranges grown on an acid deep sandy soil in Florida. A positive relationship between N and Ca was also found by Wallace _et al_. (1952) working with Valencia oranges on the calcareous soils of southern California.

Labanauskas _et al_. (1959) found that the Mn concentration in the leaves of Valencia oranges was significantly increased by heavy applications of ammonium sulfate and ammonium nitrate, but not by similar amounts of calcium nitrate. The same differential treatments had no effect on the levels of Zn, Cu, or Fe. These workers attributed the unexpected response of Zn to the annual maintenance sprays of Zn applied in their experimental plots. In another experiment, Labanauskas _et al_. (1962) found that limestone plus ammonium sulfate reduced the Mn concentration in the leaves of Navel oranges as compared to that in leaves of trees treated with ammonium sulfate alone. According to Smith and Rasmussen (1959b) high lime strongly depressed the absorption of Mn and Zn by citrus trees.

The Relation of Leaf Macro- and Some Microelements to Phosphorous

The interaction of P with other elements has been reported by many workers (Reuther et al., 1949, pp 82; Embleton et al., 1952; Bingham and Martin, 1955; Labanauskas et al., 1959). However, contradictions concerning these interactions are found frequently in the literature.

Investigations by Smith et al., (1963) showed that increasing the rate of superphosphate applied to pineapple oranges was associated with an increase in leaf Ca and a decrease in K and Mg, but leaf N was unaffected at any time during the investigation between the years 1947 and 1962. This was in agreement with the results reported by Reuther et al., (1949, pp 82) on the effect of P on leaf Ca and Mg. The latter workers, however, found no significant effect of P fertilizers on leaf K. On the other hand, Reitz and Long (1953) found a negative correlation between P and Ca in citrus leaves when Ca was above 6 percent, and they concluded that more attention must be paid to P fertilizers in calcareous soils than under acid soil conditions. This last finding paralleled the suggestions of Chapman and Vanselow (1956) that P deficiency in many calcareous soils was due to excess lime in the soil.

Bingham et al. (1958) found that the availability of B, Cu, and Zn to oranges was reduced by excessive applications of $Ca(H_2PO_4)_2$. Spencer et al. (1960) found a similar response for Cu, B, and Fe when superphosphate and limestone were applied to grapefruits, but that Mn absorption was increased. Bingham and Martin (1955) found that the Mn and Fe contents of lemon leaves were unaffected by phosphate fertilizers, but that Zn and Cu deficiencies were induced by high rates of phosphate applications; similar effects of phosphate fertilizers on Zn and Cu were reported by Labanauskas et al. (1960). Zinc deficiency was also reported by Reuther and Crawford (1946, pp 487) to be induced by heavy applications of phosphate fertilizers applied to citrus trees grown on calcareous soils. Chapman and Rayner (1951, pp 340-347) suggested that indiscriminate use of P fertilizers would aggravate Zn, Mn, and Fe deficiencies, and that N fertilizers would be less effective. To the contrary, Labanauskas et al. (1959) found that heavy phosphate fertilization significantly increased the Mn and Fe concentrations in the leaves of Valencia oranges, but Zn concentrations in the leaves depended on the interaction of potassium and phosphate applications. The Zn level was reduced in the leaves when potassium alone was applied, but it was increased following the application of combined P and K fertilizers.

The Interrelationships Among the Major Cations

The Interrelationship of Potassium, Magnesium, and Calcium

The reciprocative effects between K, Ca, and Mg are well known (Fudge, 1946; Smith et al., 1954; Smith and Rasmussen, 1959b). It has been found that heavy soil applications of potassium fertilizers to citrus trees increase K and decrease Ca and Mg levels in the leaves, (Reuther and Smith, 1950; Embleton et al., 1956; Pratt and Harding, 1957). Reitz and Long (1953), in surveying 60 groves of grapefruit and 43 groves of Valencia oranges, found that response to K soil applications was not a problem in central Florida, but that K absorption was more difficult in the calcareous soils of the coastal regions. Pierre and Bower (1943, pp 30-33) emphasized the importance of the role of soil pH in cationic relationships by finding that K absorption by plants was depressed by Ca more at high than at low pH. Similarly, Jacobson et al. (1960) found that above pH 6.5, Ca depressed K absorption and that the depressing effect increased with the pH. In a 6 year experiment with Valencia oranges grown on calcareous soils at Riverside, McColloch et al. (1957) found that with yearly applications of potassium sulfate at rates ranging between 60 and 120 pounds per tree, Mg deficiency was induced by the higher levels.

Pratt et al., (1957) reported that K in the leaves correlated positively with the amount of exchangeable K in the soil in the 0-6", 6-12", 12-24", and 24-36" depths. This was not in agreement with the results reported by Harding (1954) and Nearpass and Drosdoff (1952) who found that leaf K was correlated with the percent saturation of K in the soil but not with the exchangeable soil K expressed in milli-equivalents. The relation between leaf and soil Mg showed a trend similar to that of K.

Pratt et al. (1957) found that a strong negative relationship existed between the Mg content of orange leaves and the exchangeable K/Mg in the 12-24", 6-18", 18-30", and 24-36", but not in the 0-6" or 6-12" depths of soil. A strong negative correlation between Mg in orange leaves and the exchangeable K/Mg ratio in the 18-30" was also reported by Bingham et al. (1956) and McColloch et al. (1957). According to Smith (1966, pp 192), the level of Mg in the leaves of sweet orange trees was a function of its availability associated with the relative availability of Ca and K. In investigations on young sweet orange seedlings grown in sand cultures it was shown that when Mg and Ca were increased simultaneously, Ca absorption was favored over that of Mg. When K and Mg were low in the nutrient solution, both elements were absorbed equally. However, K became antagonistic to Mg when both were high in the nutrient solution (Smith, 1966 pp 188 and 192). Similar studies with young Valencia oranges by Smith et al. (1954) showed that leaf K was slightly reduced while the Ca level was not affected by increasing the Mg concentration in the nutrient solution. It was concluded that Mg was the weakest antagonist among the 3 cations, while K was the strongest.

The Relation of Sodium to Other Cations

Sodium does not seem to be essential to plant growth, yet, it influences cation-interrelationships in the plants (Pierre and Bower, 1943, pp 23; Shear et al., 1946). Jacobson et al. (1960) found that Ca exerted a marked depressing effect on Na absorption over most of the pH range between 2 and 11. Conversely, Shear et al. (1946) suggested that Na had a greater depressing effect on Ca and Mg than on K in citrus leaves. This was in harmony with the suggestion of Chapman and Brown (1943, pp 98-99) that a high concentration of Na seemed to delay the onset of K deficiency by antagonizing the aggravating effects of Ca and Mg on K. The forementioned findings were contradictory to those of Reitz and Long (1953) who failed to find any relation between Na and Ca in the leaves, and who felt that leaf Na appeared to be more related to the location of citrus groves with respect to the sea coast than to soil characteristics or fertilization practices. Smith et al. (1954) found a reciprocation between Na and K but reported that it depended on the N status in citrus leaves, whereby K depressed Na more at intermediate levels than at low or high levels of N. The latter workers also found that Na concentration was not affected by Mg status, even when the citrus trees were suffering a severe Mg deficiency.

From the foregoing survey of literature, it can be seen that the reciprocative and synergistic relations amongst the macro- and microelements in the plant leaves, and the influence of fertilizers on these relations are the core of studies in the field of plant nutrition.

The contradictory results reported by many workers dealing with the same nutritional aspects of citrus reveal the complexity of soil-plant relationship. Those contradictions emphasize the importance of using both soil and tissue analyses as coworking tools in studying nutritional problems in plants as there are many of these problems yet to be solved.

III. MATERIALS AND METHODS

The present investigation was carried out on 66 commercial orchards located on the narrow (2 Km wide or less) coastal strip of land between Cheikh Zendi in the north and Bayyada in the south of Lebanon. The majority of the orchards under study were located in the Akkar and Tripoli areas in north Lebanon, and between Damour and Bayyada in south Lebanon, as these constitute the major citrus producing areas in the country.

Separate leaf and soil samples were collected from each of six trees selected at random along the diagonals of each orchard, thus, 396 leaf and 396 soil samples were collected. The majority of the samples (288 leaf and 288 soil samples) were from Shammouti and Valencia oranges, the major orange varieties in the country, while the rest of the samples collected were from Mediterranean mandarines (Yusuf Afandi), Navel oranges (Abu Surra), and Sa'asly lemons. All samples were collected between August 10 and September 16, 1966. Information concerning cultural practices carried out in each orchard during the period 1963-1966, were compiled.

Each leaf sample was composed of 60 to 80 healthy spring cycle leaves from fruit-bearing terminals (Chapman, 1960; Steyn, 1960, pp 412). The leaves were picked during the early part of the day from all around the tree in a band 1.5 to 2 m from the ground (Steyn, 1960, pp 427).

Each soil sample, composed of about 1 kg, was collected from one side of the tree with a spade from the root zone, 30 to 40 cm deep, at the drip of the tree (Pratt et al., 1959, pp, 384; Labanauskas et al., 1962).

In the same day they were collected, the leaves were washed with a detergent, rinsed in running tap water, immersed in 0.1 percent hydrochloric acid solution for about 30 seconds, and then washed twice with distilled water (Smith et al., 1950; Smith, 1962b, pp 86; Labanauskas, 1966). After shaking off the excess water, the leaves were dried in perforated paper bags in an oven at 70 ± 1°C for at least 48 hours (Chapman, 1960; Willson, 1961, pp 121). The oven dried leaves were ground in a Wiley mill with a 40 mesh sieve (Willson, 1961, pp 121) and stored in air tight glass jars. Before weighing for analysis, the ground material was oven dried at 70 ± 1°C for not less than 12 hours and then cooled for a minimum of two hours in an evacuated disiccator.

All leaf samples were analyzed for total nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), boron (B), zinc (Zn), manganese (Mn), and copper (Cu).

The Modified Kjeldahl method (Jackson, 1958, pp 183-190) was used to measure total N. The extraction was made for determining the B contents by the dry ashing method, while the extraction for the determination of the rest of the elements under study was done by the wet digestion method using perchloric and nitric acids (Johnson and Ulrich, 1959). The leaf contents of P, Mg, Fe, and B were determined colorimetrically with a Beckman DU spectrophotometer. The K, Ca, and Na contents were determined with a flame attachment to the Beckman

Model B spectrophotometer, similar to the method used by Toth et al. (1948). The Perkin Elmer Model 303 atomic absorption spectrophotometer was used to determine the leaf contents of Zn, Mn, and Cu. The results were expressed in percentage of dry weight (% DW) for N, P, K, Ca, Mg, and Na, and in parts per million of dry weight (ppm DW) for the rest of the elements.

The soil samples were air dried for a minimum of 48 hours, then passed through a 4-mesh sieve (Jackson, 1958, pp 31), and stored in polyethylene bags. All samples were analyzed for exchangeable K and NH_4OAc extractable Mg, expressed in milliequivalents per 100 grams of soil; calcium carbonate, expressed in percentage; and soil reaction (pH).

The exchangeable K and extractable Mg were extracted in 1 N NH_4OAc as described by Jackson (1958, pp 86-87). Exchangeable K was determined with a flame attachment to the Beckman Model B spectrophotometer. The Perkin Elmer Model 303 atomic absorption spectrophotometer was used to determine the extractable Mg. Calcium carbonate content was determined by the acid neutralization method (Richards, 1954, pp 105). About 50 grams of soil from each sample were oven dried at $105 \pm 1^{\circ}C$ for a minimum of 48 hours to express the results on an oven dry basis (Jackson, 1958, pp 31). The pH was determined at 1:1 dilution of soil to water as suggested by Jackson (1958, pp 46) using the Fisher Accumet Model 210 pH meter.

The provisional set of standards suggested by Chapman (1960) for citrus leaf analyses (Table 1) were used to evaluate the nutritional status of the trees under this study.

Table 1. Ranges of 11 elements provisionally accepted as nutrient status standards for the evaluation of citrus leaf tissue analyses[1].

Elements	Unit (DW)	Ranges				
		Deficient (less than)	Low	Satisfactory	High	Excess (more than)
N	%	1.90	1.90 - 2.10	2.20 - 2.70	2.80 - 3.50	3.6
P	%	0.07	0.07 - 0.11	0.12 - 0.18	0.19 - 0.29	0.3
K	%	0.30	0.40 - 0.90	1.00 - 1.70	1.80 - 1.90	2.0
Ca	%	2.00	2.00 - 2.90	3.00 - 6.00	6.10 - 6.90	7.0
Mg	%	0.15	0.16 - 0.20	0.30 - 0.60	0.70 - 1.00	1.0
Na	%	-	0.01 - 0.06	0.10 - 0.15	0.20 - 0.25	0.25
Fe	ppm	40	40 - 60	60 - 150	150	-
B	ppm	15	15 - 40	50 - 200	200 - 250	250
Zn	ppm	15	15 - 24	25 - 100	110 - 200	200
Mn	ppm	20	21 - 24	25 - 100	100 - 200	300
Cu	ppm	4	4.1 - 5	5.1 - 15	15 - 20	20

1. Based on 4- to 10- month-old spring cycle leaves from fruit-bearing terminals (Chapman, 1960).

The interrelationships among the elements were expressed in terms of correlation coefficients which were compared to those set by Fisher (1958, pp 209). The statistical significance of the computed correlation coefficients was confirmed by the t-test (Fisher, 1958, pp 193).

IV. RESULTS AND DISCUSSION

This chapter summarizes the results of leaf and soil analyses obtained during the course of the present study, which was designed to investigate the nutritional status of citrus orchards in Lebanon. Due to the large amount of data collected, only the mean analytical values, referred to hereafter as "mean values", are reported for the 66 orchards selected. Each "mean value" represents the average of analyses for 3 or 6 samples (soil or leaf samples) collected from each orchard. To facilitate comparative studies, Table 5 lists the "mean values" for the leaf macroelements, Table 6 embodies the "mean values" for the leaf microelements, and Table 9 contains the "mean values" for the soil analyses, while Tables 2, 3, 4, 7, 8, 10, 11, and 12, and Figures 1 and 2 are supplementary and will be referred to in the course of the discussion. Pertinent field data from the 66 orchards appear in Appendices A, B, and C. However, to present background information about the orchards under study a brief review of the common fertilization practices is presented in the following paragraphs.

Fertilization Practices

Use of Inorganic Fertilizers

Compared to other cultural practices, fertilization was observed to be least in agreement among the citrus growers (Appendix B). Only nitrogen, phosphorous and potassium commercial carriers were applied in the orchards. Combinations of NPK were used in about 42 percent of the orchards between the years 1963 and 1966 (Table 2). During the same period, one third of the orchards were fertilized with various mixtures of nitrogen and phosphorous (NP) while the rest of the orchards were supplemented with nitrogen sources alone except that in one orchard inorganic commercial fertilizers were never applied.

Table 2. Different combinations of nitrogen (N), phosphorous (P) and potassium (K) used in the 66 citrus orchards under study, and number of orchards supplemented with each combination between the years 1963 and 1966.

Combinations of N, P, and K	Number of orchards
N	15
NP	22
NPK	28
None	1
Total	66

Inorganic nitrogen was supplied through different commercial carriers as can be seen in Table 3. This table reveals that ammonium sulfate was the most commonly used source of N followed by ammonium nitrate. Only in a very few cases were calcium nitrate or sodium nitrate used. In about one third of the orchards, N was supplied through commercial mixtures of different ratios and formulae of NP or NPK (Appendix B).

Table 3. Sources of inorganic nitrogen and number of orchards supplied consecutively with each between the years 1963 and 1966.

Source of inorganic nitrogen	Number of orchards
Ammonium nitrate	7
Ammonium sulfate	28
Ammonium sulfonitrate	2
Sodium nitrate	3
Different mixtures of the above including calcium nitrate	5
Commercials mixtures of NP or NPK	20
None	1
Total	66

Inorganic phosphorous, when used, was supplied through ordinary superphosphate in about 50 percent of the cases and through different commercial mixtures and formulae of NP or NPK in the rest of the cases, while K, whenever added, was supplied mostly through commercial mixtures. Muriate of potash was used in only a few cases (Appendix B).

The variation was much more diverse with regard to timing and levels of applications, and attempts to group them would complicate the picture. However, Appendix B shows that some growers used about 1 kg of inorganic fertilizer per tree per year, others used as much as 8 to 10 kg per tree per year, while still others supplied their trees with variable quantities between the two extremes, apparently ignoring the combination or source of the fertilizers, and irrespective of age or spacing of the trees in their orchards (Appendices A and B).

Use of Manure

Using manure, particularly goat barn manure, seemed to be the most agreed upon cultural practice in the majority of orchards, although the quantities used varied from orchard to orchard. However, 20 to 60 kg of manure were used per tree per year in at least 65 percent of the orchards under study (Table 4).

Table 4. Applications of manure in kg per tree per year and number of orchards in which it was applied between the years 1963 and 1966.

kg manure per tree per year	Number of orchards
0	6
5 - 15	17
20 - 30	32
45 - 60	11
Total	66

From the preceeding brief description it can be seen that there was a lack of agreement regarding fertilization practices among the growers of the 66 citrus orchards under study, and that nitrogen was the element most often supplied, phosphorous was the second most, while the least emphasis was put on potassium fertilizers. The other elements, particularly the microelements, were not supplied through commercial forms in any of the orchards.

Leaf Analyses

Nitrogen

In Table 5 it can be seen that the "mean values" of leaf N for the 66 orchards ranged from 1.44 percent to 2.58 percent. The lower "mean value" falls in the "deficient" range, according to the standards for citrus leaf analyses (Table 1). Grouping the 66 orchards according to their status of leaf N (Table 12 and Figure 1) reveals that in about 45 percent of the orchards the sampled trees were either "low" or "deficient" in N, while in the rest of the orchards, N was "satisfactory". No orchard had trees with a high N level. Table 5 shows also that the lowest "mean values" occurred primarily in the lemons, which were consistently "deficient" in N, in contrast to the other citrus trees under study. Moreover, field observations indicated that those orchards from which the lemons were sampled had many chloratic lemon trees characterized by the presence of newly formed flower buds. This observation bears out the suggestion of Embleton et al. (1959) that nitrogen deficiency in plants is associated with fruitfulness. Since the same standards of

Table 5. Citrus leaf composition (in percent of dry weight of nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na) from the 66 orchards under study, tabulated according to species and varieties. (Means for 3 or 6 sampled trees from every orchard).

Orchard No.	N %	P %	K %	Ca %	Mg %	Na %
			Shammouti oranges			
5a	2.31	0.18	0.82	4.88	0.24	0.26
6b	1.97	0.10	0.97	5.49	0.21	0.23
7b	2.10	0.09	0.65	6.70	0.15	0.18
8b	2.54	0.11	0.28	5.47	0.17	0.24
10a	2.12	0.12	0.67	6.15	0.25	0.12
12	2.00	0.09	0.64	7.40	0.19	0.13
14	2.18	0.10	0.69	6.54	0.19	0.19
15	2.31	0.11	1.03	5.75	0.17	0.13
16	1.97	0.10	0.65	6.64	0.13	0.20
17	2.17	0.12	0.95	5.94	0.18	0.38
18	2.25	0.17	1.31	6.22	0.18	0.12
19	1.98	0.13	1.10	6.49	0.16	0.21
20	2.00	0.12	0.66	6.82	0.16	0.24
21	1.91	0.12	0.84	6.11	0.15	0.19
22b	2.30	0.13	0.65	7.05	0.17	0.24
23	2.00	0.12	0.96	5.15	0.16	0.28

Table 5 (Continued)

Orchard No.	N %	P %	K %	Ca %	Mg %	Na %
25	2.32	0.12	1.20	5.18	0.19	0.21
26	2.29	0.11	0.97	5.90	0.12	0.14
27	2.14	0.17	1.35	6.52	0.12	0.16
28	2.17	0.12	0.94	6.17	0.14	0.28
29	2.07	0.23	1.12	6.04	0.17	0.33
30	1.82	0.14	0.75	6.98	0.14	0.38
31	2.08	0.15	0.83	6.94	0.15	0.22
32	2.02	0.10	1.10	6.40	0.11	0.16
33	1.96	0.11	1.12	6.82	0.08	0.19
35	2.00	0.11	1.15	6.10	0.10	0.16
36	1.99	0.13	1.21	7.55	0.09	0.14
37	2.12	0.12	0.93	6.83	0.13	0.28
38	2.20	0.14	0.92	5.84	0.16	0.21
39	2.09	0.13	1.02	5.09	0.13	0.13
40	2.17	0.13	0.52	5.89	0.27	0.41
57	2.06	0.13	0.86	6.48	0.23	0.21
59	2.09	0.16	0.94	6.10	0.16	0.18
61	1.97	0.12	0.65	7.36	0.15	0.14
			Valencia oranges			
1	1.93	0.10	0.45	7.69	0.14	0.18
2	2.25	0.13	0.81	5.82	0.43	0.21

Table 5 (Continued)

Orchard No.	N %	P %	K %	Ca %	Mg %	Na %
3	1.99	0.11	0.78	6.76	0.43	0.10
5b	2.27	0.22	1.27	4.80	0.27	0.29
47	2.12	0.13	0.74	8.37	0.22	0.12
49	2.32	0.12	0.51	7.24	0.16	0.08
50	2.18	0.13	0.63	7.19	0.16	0.16
52	2.17	0.14	0.62	8.30	0.17	0.17
55	2.38	0.14	0.56	7.46	0.20	0.17
56	2.41	0.13	0.39	7.57	0.30	0.32
62	2.20	0.12	0.41	7.61	0.20	0.13
63	1.86	0.11	0.41	9.64	0.20	0.11
64	1.90	0.13	0.48	6.78	0.21	0.14
65	2.58	0.12	0.45	6.81	0.18	0.24
66	2.03	0.11	0.42	8.06	0.25	0.18
			Naval oranges			
4a	2.34	0.13	0.97	6.78	0.45	0.13
24a	2.58	0.12	0.62	5.77	0.16	0.39
48	2.16	0.12	0.62	6.99	0.20	0.17
51	2.50	0.14	0.75	6.38	0.15	0.19
54	2.25	0.11	0.51	7.46	0.15	0.08
58	2.27	0.13	0.71	7.51	0.10	0.17
60	2.11	0.14	1.05	6.78	0.15	0.15

Table 5 (Continued)

Orchard No.	N %	P %	K %	Ca %	Mg %	Na %
			Mandarin			
4b	2.25	0.13	0.97	8.55	0.40	0.15
6a	2.25	0.12	0.64	6.97	0.22	0.28
7a	2.02	0.09	0.65	6.61	0.15	0.21
8a	2.19	0.11	0.24	6.80	0.17	0.14
9	2.36	0.13	0.78	6.70	0.18	0.32
10b	2.13	0.12	0.55	7.17	0.14	0.14
11	2.50	0.12	0.52	5.90	0.20	0.39
13	2.10	0.11	0.35	5.77	0.23	0.13
22a	2.15	0.11	0.29	8.02	0.24	0.19
24b	2.34	0.10	0.72	5.42	0.22	0.26
34	2.31	0.11	1.01	6.99	0.13	0.24
45	2.42	0.14	0.58	7.11	0.25	0.07
			Sa'asly lemons			
41	1.44	0.13	0.69	8.10	0.11	0.02
42	1.64	0.10	0.64	7.86	0.18	0.04
43	1.69	0.10	0.45	7.84	0.15	0.03
44	1.66	0.12	0.41	7.71	0.23	0.04

Table 5 (Continued)

Orchard No.	N %	P %	K %	Ca %	Mg %	Na %
46	1.80	0.15	0.62	5.11	0.18	0.21
53	1.84	0.11	0.49	8.43	0.21	0.12

a. Suffixes a and b at the right of some orchard numbers indicate that two species or varieties of citrus were sampled from each of those orchards. Each of these values represents the mean of analyses for 3 trees.

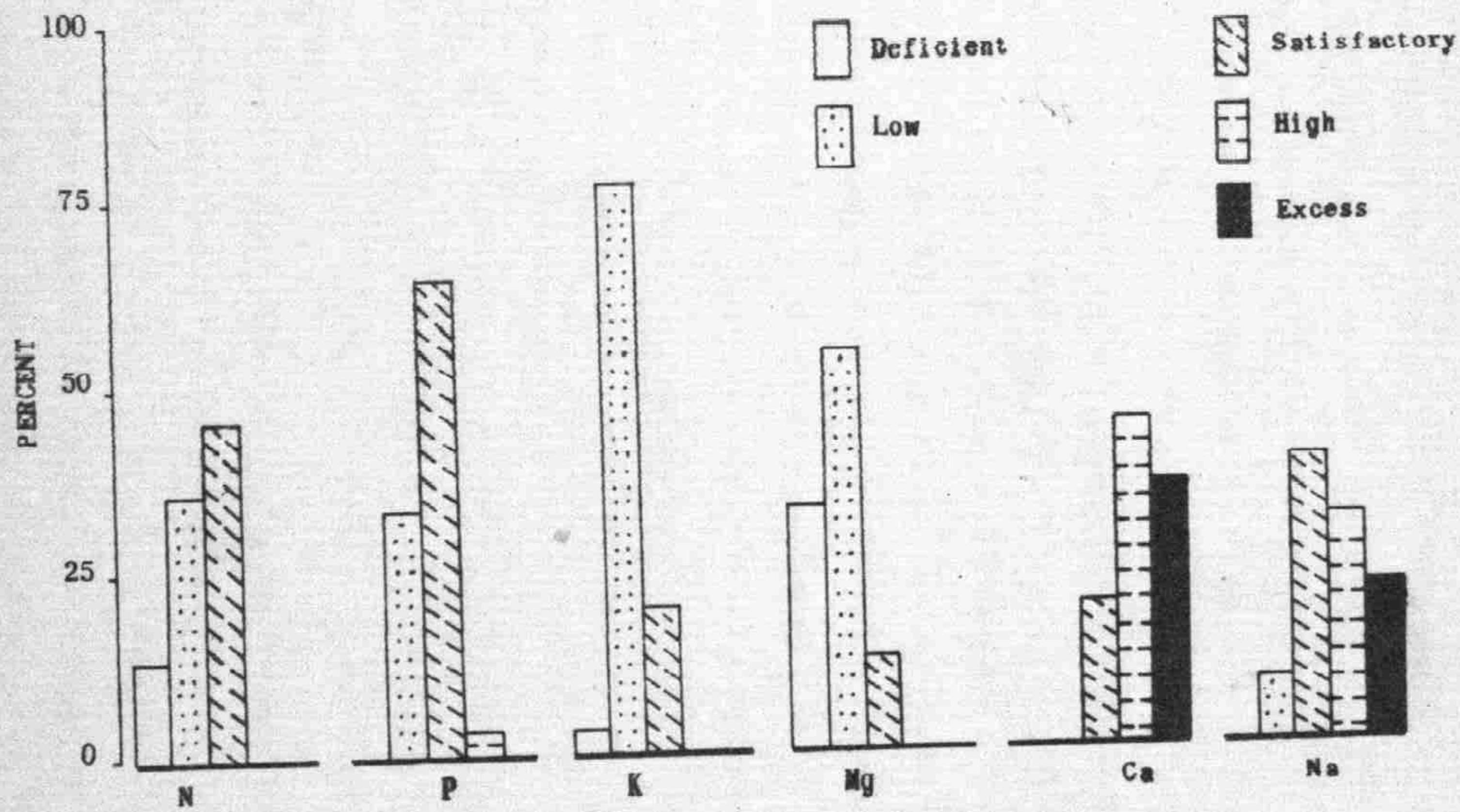

Figure 1. The nutritional status of 66 citrus orchards in Lebanon with respect to the conventional ranges of N, P, K, Mg, Ca, and Na in the leaves.

leaf analyses are used to evaluate the nutritional status of all the different species of citrus fruits (Table 1), it follows that the level of N in the lemon leaves was influenced by a factor or factors which do not seem to be present in the case of Shammouti, Valencia and Naval oranges, or in the case of the mandarines. In Appendix C it is shown that the lemon trees had not been irrigated for at least 45 days prior to the date of sampling. Withholding water from lemons is a common practice followed by Lebanese citrus growers to enforce a second bearing after the major harvest in mid July. Such a practice is not followed with any of the other citrus trees. From the foregoing observations it seems likely that the N reserves remaining in the trees after the major harvest had been translocated from the leaves to aid in the development of the new flower buds and had not been replenished due to the water shortage.

Aside from the lemon trees, Table 5 shows no general trends among the reported "mean values" of leaf N for the rest of the orchards. Moreover, a comparison between the data in Table 5 and that of Appendix B shows that the generally low N levels in many cases seem to be unrelated to the amount or form of N supplied.

Phosphorous

The "mean values" of leaf P for the 66 orchards ranged from 0.09 percent to 0.23 percent (Table 5) indicating that this element was not deficient according to the standards for leaf P (Table 1) in any of the orchards. One third of the "mean values" were found to fall in the "low" range, about two thirds were in the "satisfactory" range, while in only 2 cases P was found to fall in the "high" range (Table 12 and Figure 1). Moreover, in those orchards falling in the "satisfactory" range, there was a general tendency for leaf P levels to be in the lower limit of the range. A comparative study of Table 5 and Appendix B reveals that at least 25 percent of the orchards were not supplied with P fertilizers between the years 1963 and 1966, yet the sampled trees in these orchards were neither deficient in P, nor they were particularly different in their leaf P content from those that received P fertilizers regularly. Apparently there was no differential response to the yearly applications of P as compared to no applications for 3 successive years. Several other workers also have pointed out that no beneficial effects were obtained by continuous applications of phosphatic fertilizers to field-grown citrus (Reuther et al., 1949, pp 82; Harding, 1953; Embleton et al., 1956; Koo et al., 1958; Bouma, 1959; Smith et al., 1963; Smith, 1966, pp 180).

Potassium

The "mean values" for leaf K ranged from 0.24 percent to 1.35 percent (Table 5). Table 12 and Figure 1 show that 77 percent of the "mean values" were found to fall in the "low" range suggested by Chapman (Table 1), while in 3 percent of the cases leaf K was found to be deficient. The remaining 20 percent of the "mean values" fell in the "satisfactory" range.

No general trend can be observed with regard to leaf K (Table 5) and K applications (Appendix B). This can be seen by comparing the "mean values" for the orchards that did not receive K fertilizers between the years 1963 and 1966 and those that were regularly supplied with K fertilizers either through muriate of potash or through different commercial combinations of NPK. The generally "low" K in the leaves may be attributed to the soil conditions as will be discussed in the section dealing with the relation of leaf K to the exchangeable K in the soil.

Calcium

The "mean values" of leaf Ca for the 66 orchards ranged from 4.80 percent to 9.64 percent (Table 5). The distribution of these "mean values" with regard to the leaf standards (Table 1) show that about 44 percent of these values fell in the "high" range, about 36 percent fell in the "excess" range, while the rest fell in the "satisfactory" range (Table 12 and Figure 1).

By referring to Appendix A and Table 5 it can be seen that there was a general tendency for leaf Ca to be relatively high in the leaves which were collected from Saidon and south Lebanon (orchard Nos. 1 and 41 to 66) as compared to those collected from other locations. Since leaf Ca apparently was not related to fertilizer applications (Appendix B), it is presumed that the excessive Ca contents of the leaves was governed by the calcareous nature of the soils in the orchards (Table 9).

Magnesium

Table 5 shows that the "mean values" of leaf Mg for the 66 orchards ranged from 0.08 percent to 0.45 percent. Data in Table 12 and Figure 1 indicate that only about 12 percent of these values fall in the "satisfactory" range suggested by Chapman (Table 1), while the rest fall either in the "low" or "deficient" ranges. In almost every orchard under study trees were observed with leaves showing interveinal or marginal chlorosis especially in the older leaves. These observations were similar to those which were described as symptoms of magnesium deficiency (Chapman, 1966, pp 226). The possible causes for the low levels of leaf Mg will be discussed in the section dealing with interrelationships among K, Mg, Ca, and Na.

Sodium

By referring to Table 5 it can be seen that leaf Na contents ranged from 0.02 percent to 0.41 percent. By comparing these values with the provisional standards for Na (Table 1) it was noted that about 50 percent of the values fell in the "high" and "excess" ranges, about 40 percent fell in the "satisfactory" range, while the rest of the values fell in the "low" range (Table 12 and Figure 1). Since sodium nitrate was used as a fertilizer in only 3 cases (Table 3 and Appendix B), this source may be eliminated as a possible cause for the generally high content of Na in the leaves. However, the characteristic symptoms of Na toxicity (Chapman, 1966, pp 415) were not particularly observed during the course of the present study. Smith (1962a) believes that there is no well established range of leaf Na concentration that can be used as an index for Na toxicity, but trees having 2000 to 2500 ppm Na in their leaves are less thrifty than normal. Since citrus trees absorb Na readily through their leaves (Chapman, 1966, pp 413) and since most of the orchards studied were located along the coastal strip, usually within 0.5 to 2 Km of the sea coast, it is likely that the generally high contents of Na in the leaves was due to the sea water coming to the orchards in the form of mists. Similar observations were reported by Reitz and Long (1953). Moreover, since healthy roots of citrus trees can exclude Na from the soil solution (Jones et al., 1952; Martin et al., 1961) it seems apparent that further studies are needed in Lebanon concerning the effect of excess Na in the leaves of citrus. Studies on the root conditions of Lebanese citrus trees with respect to Na accumulation and absorption are apparently needed.

Iron

The "mean values" of leaf Fe for the 66 orchards are listed in Table 6. These values ranged from 50 to 194 ppm. A study of these values, and reference to Table 12 and Figure 2 showed that 94 percent of the orchards fell in the "satisfactory" range suggested by Chapman (Table 1), while the few remaining ones fell either in the "low" or "high" ranges. Not one orchard, however, was found "deficient" in Fe. Iron does not appear to be a problem in citrus orchards in Lebanon.

Boron

Table 6 shows that the "mean values" of leaf B for the 66 orchards range from 54 to 167 ppm. All values fall in the "satisfactory" range according to the standards set by Chapman (Table 1). This trend is shown also in Table 12 and Figure 2. By comparing the data in Tables 5 and 6 it can be seen that the highest values of leaf B were associated generally with very high values of

Table 6. Citrus leaf composition (in parts per million of dry weight) of iron (Fe), boron (B), zinc (Zn), manganese (Mn) and copper (Cu) from the 66 orchards under study, tabulated according to species and varieties. (Means for 3 or 6 sampled trees from every orchard).

Orchard[a] No.	Fe (ppm)	B (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
			Shammouti oranges		
5a	85	72	15	17	6
6b	110	72	18	15	6
7b	50	87	14	22	8
8b	63	84	12	22	5
10a	50	92	11	20	7
12	68	67	15	15	5
14	92	82	16	22	6
15	72	66	17	14	6
16	91	54	16	13	6
17	76	90	14	13	5
18	70	59	16	14	5
19	94	65	14	12	5
20	107	64	18	15	10
21	142	55	38	12	8
22b	68	77	15	13	6
23	81	66	13	13	8

Table 6 (Continued)

Orchard[a] No.	Fe (ppm)	B (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
25	99	86	17	11	5
26	119	77	11	10	8
27	138	90	12	7	6
28	100	100	13	17	5
29	85	54	19	13	5
30	79	85	19	10	13
31	87	90	14	16	5
32	82	80	11	10	4
33	77	92	29	12	6
35	82	84	13	10	5
36	75	85	13	12	4
37	74	82	14	9	5
38	83	72	13	12	4
39	75	74	13	12	4
40	79	96	26	17	5
57	75	75	15	29	3
59	74	115	49	21	4
61	64	126	98	30	4
			Valencia oranges		
1	99	86	54	24	8

Table 6 (Continued)

Orchard[a] No.	Fe (ppm)	B (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
2	121	94	84	33	7
3	121	101	26	43	5
5b	93	89	13	20	7
47	68	123	22	28	5
49	64	95	16	28	6
50	62	86	21	26	5
52	55	114	13	25	7
55	62	84	16	18	4
56	90	86	16	29	5
62	64	100	36	26	7
63	62	129	13	20	5
64	74	90	111	16	6
65	71	115	14	21	7
66	81	118	13	16	7
		Navel oranges			
4a	107	103	19	40	6
24a	83	68	13	11	6
48	95	88	17	31	4
51	70	98	25	21	8
54	95	88	13	18	4

Table 6 (Continued)

Orchard[a] No.	Fe (ppm)	B (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
58	92	102	14	24	7
60	86	102	16	30	7
		Mandarin			
4b	128	129	20	45	6
6a	157	96	14	15	5
7a	52	90	17	23	8
8a	100	136	27	19	10
9	85	88	15	12	3
10b	61	96	11	15	9
11	72	92	22	13	5
13	69	89	15	15	5
22a	194	108	14	22	5
24b	89	110	15	7	5
34	83	107	17	8	5
45	79	153	16	22	6
		Sa'asly lemons			
41	70	125	50	24	29
42	98	167	48	15	13
43	74	156	66	16	15

Table 6 (Continued)

Orchard[a] No.	Fe (ppm)	B (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
44	90	100	39	20	14
46	85	92	17	14	12
53	74	109	235	15	7

a. Suffixes a and b at the right of some orchard numbers indicate that two species or varieties of citrus were sampled from each of those orchards. Each of these values represents the mean of analyses for 3 trees.

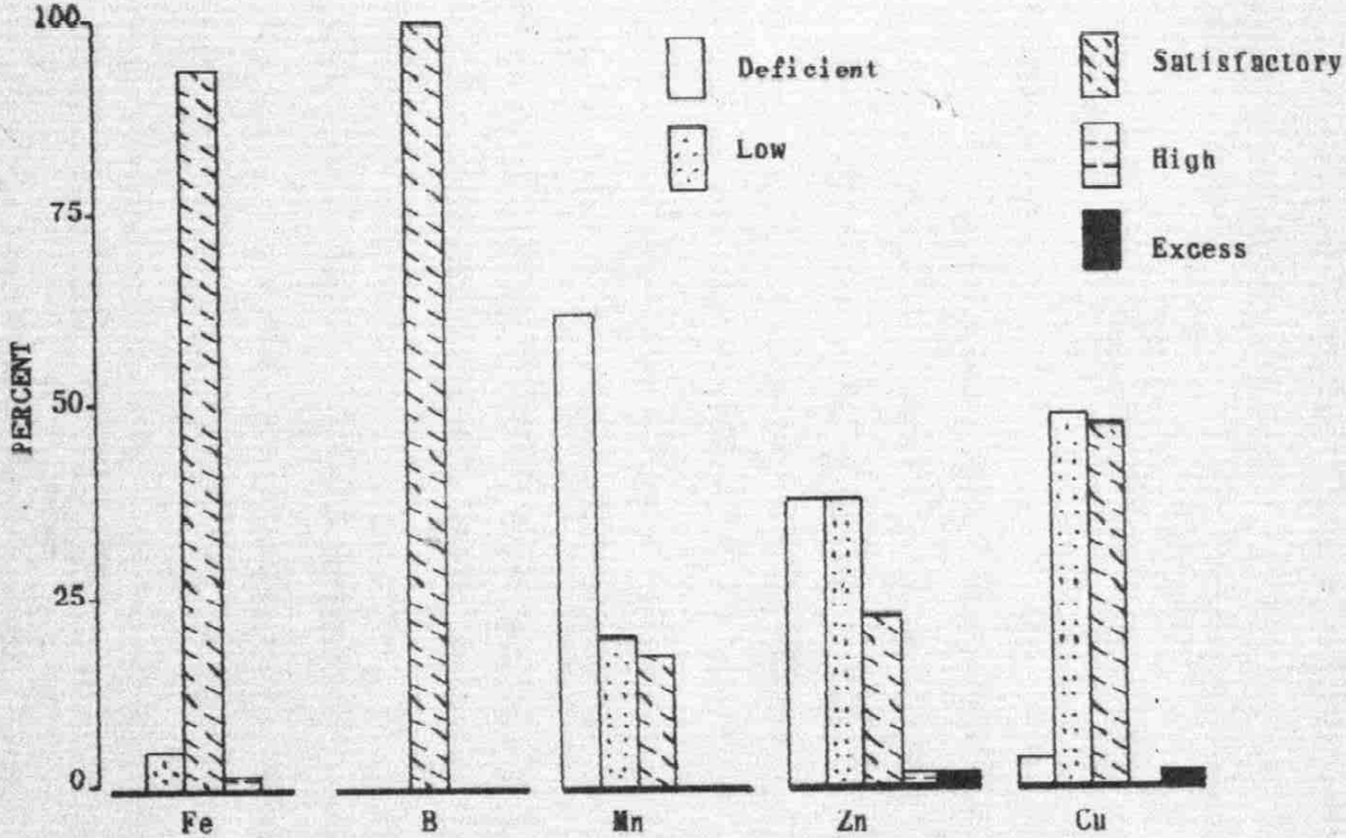

Figure 2. The nutritional status of 66 citrus orchards in Lebanon with respect to the conventional ranges of Fe, B, Mn, Zn, and Cu in the leaves.

leaf B were associated generally with very high values of leaf Ca. This observation seemes to concur with the finding of Jones and Scarseth (1944) who found that high Ca levels were associated with high levels of B and vice versa.

Zinc

A study of the "mean values" of leaf Zn (Table 6) shows that these values ranged from 11 to 235 ppm. By referring to Table 12 and Figure 2 it can be seen that in about 75 percent of the orchards leaf Zn was found to be either "low" or "deficient", while in about 21 percent of the cases Zn was found to fall in the "satisfactory" range according to the conventional standards for leaf Zn (Table 1). Table 6 shows also that the "mean values" of Zn for orchard No. 53 (lemons) and orchard No. 64 (Valencia oranges) were exceedingly high compared to those of other orchards. This was consistant with every sampled tree from these two orchards. The cause for this was not clear, since these trees did not seem to differ from the others either with respect to fertilizers (Appendix A and B) or with regard to other leaf constituents (Tables 5 and 6). Although Dithane-Z, and Zineb (Zn containing fungicides) were included in the spraying programs of a few orchards including orchard No. 53 (Appendix C), no general trend was observed with respect to the relation of spray programs to Zn levels in the leaves.

By referring to Table 6 and Appendix B it can be seen that leaf Zn tended to be high in the leaves collected from orchards in which no superphosphate was applied during the period 1963 to 1966.

It was reported by Jurinak and Thorne (1955) that Zn solubility in soils was at a minimum in the pH range 6.0 to 8.0. It is also known that phosphate fertilizers in calcareous soils will induce Zn deficiency (Bingham and Martin, 1956; Labanauskas et al., 1962). Thus, since the soils of the orchards under this study were calcareous (Table 9) it seems likely that the high incidence of Zn deficiency met in this study was due to the soil nature and reaction coupled with the continuous application of superphosphate fertilizers.

Manganese

The "mean values" of leaf Mn (Table 6) ranged from 7 to 45 ppm. By grouping these values according to the conventional standards for leaf Mn (Table 1) it was found that 62 percent of the values were in the "deficient" range, about 20 percent were in the "low" range and the rest were in the "satisfactory" range (Table 12 and Figure 2). Smith and Rasmussen (1959b) and Labanauskas et al. (1962) reported that ammonium sulfate coupled with high lime in the soil induced Mn deficiency in citrus trees. Moreover, Mn deficiency commonly occurs in calcareous soils and in soils having a reaction of pH 6.5 and higher, as the manganous form is oxidized to the manganic form, thus rendering manganese almost unavailable to plants (Chapman, 1966, pp 267). Since ammonium sulfate was found to be used in at least 42 percent of the cases (Table 3 and Appendix B), and in view of the calcareous nature of the soils and their high pH values (Table 9), it is likely that these conditions contributed to the occurance of the high incidence of Mn deficiency in the orchards studied.

Copper

The "mean values" of leaf Cu for the 66 orchards are reported in Table 6 which shows that leaf Cu ranged from 3 to 29 ppm. By comparing these values to the conventional standards (Table 1) and by referring to Table 12 and Figure 2 it can be seen that almost 50 percent of the cases fell in the "low" range, 47 percent fell in the "satisfactory" range, and only a very few cases appeared in the "deficient" range. In one case (orchard No. 41) leaf Cu was found to be "in excess". By comparing the values of leaf Cu (Table 6) with fertilization practices (Appendix B) it can be seen that no consistant relationship existed between P application and Cu in the leaves. Among the orchards having the lowest "mean values" of leaf Cu there were 15 in which no P fertilizers were applied between the years 1963 and 1966. Also, some of the lemon trees were not supplemented with P fertilizers, yet, these trees had the highest values of leaf Cu. This is true also for orchard No. 41 where inorganic fertilizers were never applied. On the other hand several orchards with relatively high "mean values" of Cu were regularly supplemented with P fertilizers. These observations seem to be contrary to those of Bingham and Martin (1955), Bingham et al., (1958), Spencer et al., (1960), and Labanauskas et al., (1960) who reported that phosphatic fertilizers applied to citrus trees had induced Cu deficiency.

The Relation of Leaf Nitrogen and Phosphorous to Other Elements in the Leaves

The Relation of Leaf N to P, K, Ca, Mg, Na, Fe, B, Zn, Mn, and Cu Contents of the Leaves

By a comparative study of the data in Table 5 and by referring to the correlation coefficients determined for the relationship of N with the other elements present in the leaves (Table 7), it can be seen that a negative correlation existed between N and P, K, and Ca. However, leaf N had a positive correlation with Na but had no significant correlation with Mg. A similar relationship between N and P and between N and Ca was reported by Reitz and Long (1953). A negative relationship between N and K in the leaves was also reported by Boynton and Compton (1945, pp 350) and Reuther and Smith (1950). The lack of a significant relationship between Mg and N was also reported by Sheikh (1966). However, the present finding was neither in line with those of Wallace et al., (1952) who found N to depress Mg in citrus leaves, nor with those of Reitz and Koo (1960) who reported a significant positive correlation to exist between N and Mg in the leaves.

By comparing the "mean values" of N (Table 5) to those of B, Fe, Zn, Mn, and Cu (Table 6), it can be seen that the lowest "mean values" of leaf N were associated with corresponding high "mean values" of B, Zn, and Cu. This can be particularly seen in the case of lemon trees which were deficient in N. On the other hand no consistent relationship can be detected between N and Fe or Mn. These observations were confirmed by the calculation of the correlation

Table 7. The relation (in terms of correlation coefficients) of nitrogen (N) to phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), boron (B), zinc (Zn), manganese (Mn), and copper (Cu) in the leaves of citrus trees from 66 orchards in Lebanon.

Nature of the relation	Correlation coefficient (r)[a]	t-values (t-test for the r values)
N versus P	-0.758[xx]	9.883[xx]
N versus K	-0.466[xx]	4.475[xx]
N versus Ca	-0.316[xx]	2.830[xx]
N versus Mg	0.199 n.s.	- n.s.
N versus Na	0.399[xx]	3.706[xx]
N versus Fe	-0.002 n.s.	- n.s.
N versus B	-0.395[xx]	3.653[xx]
N versus Zn	-0.352[xx]	3.196[xx]
N versus Mn	0.104 n.s.	- n.s.
N versus Cu	-0.573[xx]	5.942[xx]

a. The correlation coefficients were calculated for 74 pairs of "mean values" except in the case of Zn where only 72 pairs were used. The t-test was used to confirm the statistical significance of the (r) values.

n.s. Non-significant

xx. Significant at the 0.01 level.

coefficients which are presented in Table 7 which shows that leaf N had a negative correlation with each of B, Zn, and Cu, but had no significant correlation with Fe or Mn. A similar relationship between N and B in the leaves was reported by Muhr (1942) and by Wallace et al., (1952). The negative correlation between N and Zn or Cu and the lack of association between N and each of Fe and Mn, as presently reported, does not appear to be in line with the idea that deficiencies of the heavy metals (Fe, Cu, Zn, Mn, and Mo) are typically associated with "high" N and K and "low" Ca in the leaves (Smith, 1966, pp 216). In the present study no orchard was found to be "high" in leaf N, and leaf K was generally "low", while Ca was generally "high" and "in excess" in the leaves (Table 12 and Figure 1), yet, Zn and Mn were found to be "deficient", and Cu was not particularly "deficient", while Fe was mostly "satisfactory" (Table 12 and Figure 2).

The Relation of Leaf P to K, Ca, Mg, Fe, B, Zn, Mn, and Cu Contents of the Leaves

By referring to the correlation coefficients as calculated for leaf P with the other elements in the leaves as presented in Table 8, it can be seen that leaf P correlated positively with leaf K, and negatively with leaf Ca, but had no significant correlation with leaf Mg, Fe, B, Zn, Mn, or Cu. The relationship between P and K in the leaves was not in agreement with the finding of Jones and Parker (1950) who found P to depress K in citrus leaves. However, these workers attributed the apparent depressing effect of P on K to the Ca in the calcium phosphate used in their experiment. The negative

Table 8. The relation (in terms of correlation coefficients) of phosphorous (P) to potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), boron (B), zinc (Zn), manganese (Mn), and copper (Cu) in the leaves of citrus trees from 66 orchards in Lebanon.

Nature of the relation	Correlation[a] coefficient (r)	t-values (t-test for the r values)
P versus K	0.402[xx]	3.730[xx]
P versus Ca	-0.668[xx]	7.621[xx]
P versus Mg	0.098 n.s.	- n.s.
P versus Fe	-0.02 n.s.	- n.s.
P versus B	-0.186 n.s.	- n.s.
P versus Zn	-0.049 n.s.	- n.s.
P versus Mn	0.012 n.s.	- n.s.
P versus Cu	-0.059 n.s.	- n.s.

a. The correlation coefficients were calculated for 74 pairs of "mean values" except in the case of Zn where only 72 pairs were used. The t-test was used to confirm the statistical significance of the (r) values.

n.s. Non-significant

xx. Significant at the 0.01 level.

correlation between P and Ca confirmed the findings of Reitz and Long (1953) who studied citrus trees grown on calcareous soils, but did not agree with those of Embleton et al., (1952) and Reuther et al., (1949, pp 82) who worked with Valencia oranges growing in acid soils of low exchange capacity. All the soils of the orchards under study were found to be calcareous (Table 9). The latter condition seems to give a possible explanation for the apparent positive correlation that existed between P and K, whereby P and K are presumably depressed simultaneously by the "excess" Ca concentrations. A poor correlation between P and Fe or Mn was also found by Bingham and Martin (1955). The relation of P to Zn was similar to that which was reported by Smith et al., (1963), while the relation between P and B was in agreement with that reported by Smith (1962b pp 98).

The Interrelationships Among Potassium, Calcium, Magnesium, and Sodium

The Relation of Leaf K to the Exchangeable K in the Soil

The "mean values" of the exchangeable K in the soils of the 66 orchards are listed in Table 9. Upon comparing these values to those of leaf K (Table 5) it was seen that there was no consistant relationship between them. This was confirmed by the low and non-significant correlation coefficient calculated for leaf K versus exchangeable K (Table 10). Table 9 shows that all of the surveyed orchards had soils with calcium carbonate ($CaCO_3$) contents ranging from 1.84 percent to 58.37 percent indicating that all of the soils were calcareous. It has been reported that high soil applications of

Table 9. Exchangeable potassium (K) and NH_4OAc-extractable magnesium (Mg) in milliequivalents per 100 g of soil; K/Mg ratios in the soils; percent calcium carbonate (% $CaCO_3$); and pH values of the soils from 66 citrus orchards in Lebanon, tabulated according to the species and varieties studied. (Means for 3 or 6 sampled soils from every orchard).

Orchard[a] No.	Exchangeable K (meq/100 g soil)	NH_4OAc-extractable Mg (meq/100 g soil)	K/Mg ratios (in soils)	$CaCO_3$ %	pH
5a	1.67	7.81	0.21	14.98	7.7
6b	1.31	5.02	0.26	20.81	7.7
7b	1.34	5.66	0.24	45.31	7.6
8b	0.40	4.31	0.09	9.59	7.8
10a	1.38	4.86	0.28	21.32	7.5
12	2.24	6.03	0.37	18.75	7.4
14	1.52	3.83	0.40	11.40	7.5
15	2.49	3.61	0.69	25.34	7.5
16	1.76	5.15	0.34	25.14	7.7
17	0.99	4.98	0.20	23.80	7.6
18	1.50	5.15	0.29	33.03	7.6
19	0.84	3.49	0.24	33.92	7.6
20	1.51	8.11	0.19	11.44	7.7
21	1.26	5.09	0.25	7.96	7.6
22b	0.76	5.07	0.15	9.49	7.7
23	1.20	3.70	0.32	28.50	7.7
25	1.98	7.74	0.26	3.86	7.5

Table 9 (Continued)

Orchard[a] No.	Exchangeable K (meq/100 g soil)	NH_4OAc-extractable Mg (meq/100 g soil)	K/Mg ratios (in soils)	$CaCO_3$ %	pH
26	1.97	3.13	0.63	10.19	7.4
27	1.01	3.99	0.25	58.37	7.7
28	0.87	5.18	0.17	3.78	7.5
29	0.26	3.80	0.70	21.16	7.9
30	0.77	4.13	0.19	33.16	7.8
31	0.93	6.38	0.14	5.41	7.2
32	0.67	2.34	0.29	22.48	7.5
33	0.69	1.61	0.43	10.95	7.7
35	1.27	3.02	0.42	8.16	7.5
36	1.93	3.77	0.51	28.72	7.7
37	1.77	2.32	0.76	5.46	7.6
38	1.55	2.58	0.60	7.35	7.6
39	1.12	1.22	0.92	30.58	7.8
40	1.49	5.86	0.25	19.48	7.8
57	1.14	3.69	0.31	48.74	7.8
59	1.93	9.76	0.20	34.47	7.7
61	1.09	10.91	0.10	13.87	7.9
		Valencia oranges			
1	3.24	8.78	0.37	5.13	7.4

Table 9 (Continued)

Orchard[a] No.	Exchangeable K (meq/100 g soil)	NH_4OAc-extractable Mg (meq/100 g soil)	K/Mg ratios (in soils)	$CaCO_3$ %	pH
2	1.04	9.74	0.11	2.48	7.9
3	2.57	4.24	0.61	2.63	7.3
5b	1.46	7.20	0.20	21.48	7.9
47	2.92	5.76	0.51	33.35	7.7
49	2.83	6.97	0.41	25.55	7.5
50	1.77	8.02	0.22	36.44	7.7
52	2.58	9.02	0.29	30.60	7.5
55	3.95	7.00	0.56	8.28	7.4
56	2.25	6.86	0.33	3.13	7.2
62	2.44	10.82	0.22	27.88	7.7
63	1.43	10.19	0.14	37.22	7.8
64	2.64	14.44	0.18	17.94	7.7
65	1.48	1.80	0.12	18.78	8.0
66	1.96	18.13	0.11	11.04	7.9
		Navel oranges			
4a	1.77	4.27	0.41	1.84	7.2
24a	2.18	8.06	0.27	3.29	7.2
48	1.18	5.58	0.21	32.62	8.0
51	2.47	7.89	0.31	33.68	7.7

Table 9 (Continued)

Orchard[a] No.	Exchangeable K (meq/100 g soil)	NH_4OAc-extractable Mg (meq/100 g soil)	K/Mg ratios (in soils)	$CaCO_3$ %	pH
54	1.48	12.80	0.12	5.24	7.7
58	1.94	7.46	0.26	33.02	7.7
60	0.48	2.73	0.18	53.49	8.1
		Mandarin			
4b	1.27	3.97	0.32	3.78	7.3
6a	1.13	4.82	0.23	25.90	7.8
7a	1.23	5.17	0.24	45.88	7.7
8a	0.62	4.11	0.15	13.48	7.6
9	0.81	2.74	0.30	29.14	7.5
10b	2.14	4.59	0.47	24.95	7.5
11	0.89	4.70	0.19	25.92	7.6
13	1.22	4.85	0.25	20.64	7.6
22a	1.49	3.74	0.40	11.36	7.5
24b	2.24	4.60	0.49	26.24	7.5
34	1.27	3.43	0.37	21.47	7.5
45	2.51	5.49	0.46	41.24	7.7
		Sa'asly lemons			
41	1.71	1.00	1.71	34.17	8.0

Table 9 (Continued)

Orchard[a] No.	Exchangeable K (meq/100 g soil)	NH_4OAc-extractable Mg (meq/100 g soil)	K/Mg ratios (in soils)	$CaCO_3$ %	pH
42	2.52	2.50	1.01	34.34	7.8
43	2.03	3.06	0.66	33.87	7.5
44	2.45	4.68	0.52	34.21	7.6
46	1.27	3.94	0.32	45.32	7.9
53	2.36	6.76	0.34	33.36	7.6

a. Suffixes a and b at the right of some orchard numbers indicate that two species or varieties of citrus were sampled from each of those orchards. Each of these values represents the mean of analyses for 3 soils.

Table 10. The relationships (in terms of correlation coefficients) between leaf K and exchangeable K; between leaf Mg and NH_4OAc- extractable Mg; and between leaf Mg and K/Mg ratios in the soils from 66 citrus orchards in Lebanon.

Nature of the relationship			Correlation[a] coefficient (r)	t-values (t-test for the r values)
Leaf K	versus	exchangeable K	0.223	1.944 n.s.
Leaf Mg	versus	NH_4OAc- extractable Mg	0.180 n.s.	- n.s.
Leaf Mg	versus	K/Mg in the soil	-0.479[xx]	4.637[xx]

a. The correlation coefficients were calculated for 74 pairs of "mean values". The t-test was used to confirm the statistical significance of the (r) values.

n.s. Nonsignificant.

xx. Significant at the 0.01 level.

K have relatively small effects on leaf K contents of citrus trees grown on calcareous soils (Smith, 1966, pp 215). According to Reitz and Long (1953) K absorption by oranges was more difficult in the calcareous soils of the coastal regions of Florida than in the non-calcareous soils of central Florida. Thus, it seems probable that the low contents of K in the leaves (Table 5), despite the relatively high contents of exchangeable K in the soil (Table 9), was due to the antagonistic effect of Ca on K as governed by the calcareous nature of the soil.

The Relation of Leaf Mg to the NH_4OAc- Extractable Mg in the Soil

A comparative study of the "mean values" for leaf Mg (Table 5) and the corresponding values of NH_4OAc-extractable Mg (Table 9) revealed that no consistent relationship existed between these values. This was confirmed by the nonsignificant correlation coefficient calculated for this relationship (Table 10). This finding was in agreement with that of Nearpass and Drosdoff (1952) and Bingham et al. (1956). The latter workers attributed the poor correlation to the difficulty of determining exchangeable Mg in the soils containing $CaCO_3$. Such was the case under this study, since no attempt was made to correct for the soluble Mg from the NH_4OAc extract.

The Relation of Leaf Mg to the K/Mg Ratio in the Soil

Table 10 shows that a negative relationship was found to exist between the leaf Mg contents (Table 5) and K/Mg ratios in the soil. The present finding seems to parallel those of Bingham et al. (1956), McColloch et al. (1957), and Pratt et al. (1957), all of whom reported that exchangeable K/Mg ratios above 0.4 were suggestive of Mg deficiency in citrus and that the soil K/Mg ratio would be a good index for predicting leaf Mg. The K/Mg ratio in the Lebanese soils were found to be less than 0.4 in the majority of the orchards, yet Mg was found to be deficient. This may be because no correction was made for the soluble Mg in the soil which might have been found in the NH_4OAc extract. The negative relationship found between leaf Mg and the K/Mg ratio in the soil (Table 10), suggests that any attempts to raise leaf K levels through soil applications without taking into consideration the available Mg in the soil will most probably aggravate the Mg deficiency problem met in many cases during this investigation.

The Interrelationships Among K, Ca, Mg, and Na in the Leaves

By referring to Table 5 it was seen that the lowest "mean values" of K were associated generally with the "mean values" of Ca falling in the "high" or "excess" ranges (Table 1), while relatively high "mean values" of K were associated with relatively low "mean values" of Ca. Moreover, Table 11 shows that a negative correlation existed between K and Ca in the leaves. A similar relationship between K and Ca in leaves was reported by Fudge (1946), Jones and Parker (1950), Embleton et al. (1956), Smith and Rasmussen (1959a), and Jacobson et al. (1960). Since leaf K was found to be mostly "low" or "deficient" and Ca was found to be mostly "high" or "in excess" (Table 12 and Figure 1), and since there was very little correlation between leaf K contents and exchangeable K contents in

Table 11. The interrelationships (in terms of correlation coefficients) among potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) in the leaves of citrus trees from 66 orchards in Lebanon.

Nature of the relationship	Correlation[a] coefficient (r)	t-values (t-test for the r values)
K versus Ca	-0.612[xx]	6.576[xx]
K versus Mg	-0.158 n.s.	- n.s.
K versus Na	0.127 n.s.	- n.s.
Ca versus Mg	-0.028 n.s.	- n.s.
Ca versus Na	-0.463[xx]	4.442[xx]
Mg versus Na	-0.003 n.s.	- n.s.

a. The correlation coefficients were calculated for 74 pairs of "mean values". The t-test was used to confirm the statistical significance of the (r) values.

n.s. Nonsignificant.

xx. Significant at the 0.01 level.

the soil (Table 10) it is apparent that the presumption that low K in the leaves was due to the calcareous nature of the soil is corroborated.

Tables 5 and 11 show that a poor correlation existed between Ca and Mg in the leaves. This finding agrees with that of Reitz and Long (1953) who found a nonsignificant correlation to exist between Mg and Ca when Mg was "very high" and Ca was "low". A similar inconsistant relationship existed between K and Mg in the leaves as can be seen by the data in Table 5 and as revealed by the nonsignificant correlation coefficient of K versus Mg (Table 11). Smith et al. (1954) reported that the interaction between K and Mg depends upon the N status in the leaves, whereby K depresses Mg with intermediate and high N, but not at low N levels. The latter workers reported also that K antagonized Mg when present at high concentrations but not when both were low. As stated by Smith (1966, pp 192), the stoichiometric relationships among K, Mg, and Ca may disappear when any of these elements is present in extreme proportions. In light of the above and since N, K, and Mg were found to be mostly "low" or "deficient", while Ca was found to be mostly "high" or "in excess", it is likely that the usual antagonism between K and Mg in the leaves was upset under the conditions of the present investigation.

By comparing the "mean values" of Na with those of K, Ca, and Mg (Table 5) it will be seen that no consistant relationship existed between Na and either K or Mg in the leaves. However, high "mean values" of Na were associated with relatively low "mean values" of Ca or vice versa. Table 11 shows also that a nonsignificant correlation was found between Na and each of K or Mg, while a significant negative correlation existed between Na and Ca in the leaves. The relationship between leaf Na and leaf Ca was in agreement with that reported by Chapman and Brown (1943, pp 98), Shear *et al*. (1946), and Jacobson *et al*. (1960). A similar result was reported by Smith *et al*. (1954) as regard to the relationship between Na and Mg.

Table 12. The nutritional status of 66 citrus orchards in Lebanon, distributed with respect to the conventional ranges of 11 elements in the leaves.

Element		Deficient		Low		Satisfactory		High		Excess	
		Orchards	%	Orchards	%	Orchards	%	Orchards	%	Orchards	%
Boron	(B)					= 66	100.0				
Calcium	(Ca)					13	19.7	29	43.9	24	36.4
Copper	(Cu)	2	3.0	32	48.5	31	47.0			1	1.5
Iron	(Fe)			3	4.6	62	93.9	1	1.5		
Magnesium	(Mg)	22	33.3	36	54.6	8	12.1				
Manganese	(Mn)	41	62.1	13	19.7	12	18.2				
Nitrogen	(N)	9	13.6	27	40.9	30	45.5				
Phosphorous	(P)			22	33.3	42	63.7	2	3.0		
Potassium	(K)	2	3.0	51	77.3	13	19.7				
Sodium	(Na)			6	9.1	26	39.4	20	30.3	14	21.2
Zinc	(Zn)	25	37.9	25	37.9	14	21.2	1	1.5	1	1.5

V. SUMMARY, CONCLUSION, AND RECOMMENDATION

A survey was conducted to investigate the current nutritional status of Lebanese citrus orchards with regard to the leaf contents of N, P, K, Mg, Ca, Na, Fe, B, Zn, Mn, and Cu as compared to currently available conventional standards of citrus leaf analyses; to determine the relationship between leaf N and P to the other elements; and to study the interrelationships among K, Mg, Ca, and Na, pointing particularly the interrelationship between K and Mg in the leaves and soils.

Six leaf and six soil samples were collected between August 10 and September 16, 1966, from each of 66 citrus orchards located on the coastal area between Cheikh Zendi in the Akkar plain in North Lebanon and Bayyada in South Lebanon. Thus, 396 leaf and 396 soil samples were collected. The majority of the samples (288 leaf and 288 soil samples) were collected from Shammouti and Valencia oranges, while the rest of the samples collected were from Navel orange, Mediterranean mandarin, and Sa'asly lemon trees. Information on the cultural practices followed in the orchards between the years 1963 and 1966 was compiled.

Chemical leaf analysis was carried out to determine the inorganic constituents of N, P, K, Mg, Ca, Na, Fe, B, Zn, Mn, and Cu, while the soils were analyzed for exchangeable K, extractable Mg, $CaCO_3$ contents, and soil reaction (pH). The results are reported on a dry wheight basis and presented in "mean values" of the chemical analyses from each orchard. The interrelationships among the various elements studied, are expressed in terms of correlation coefficients. The t-test was used to confirm the statistical significance of the correlation coefficients.

Field studies revealed much disagreement among the growers of the orchards with respect to cultural practices and particularly in the case of fertilizer applications. Inorganic fertilizers were applied in different combinations as N, NP, or NPK in amounts ranging from 1 to 10 kilograms per tree per year. Ammonium sulfate, superphosphate and goat manure were the most commonly used fertilizers. There was a tendency to prolong irrigation intervals in most of the orchards particularly in the case of lemons.

By comparing the leaf inorganic contents with the provisional standards set out by Chapman (1960), it was found that in the majority of the orchards, the N and K contents tended to fall in the "low" range. A similar tendency, but to a lesser extent was observed in the case of P. The Ca and Na contents were either "high" or "in excess" in most of the cases. Most of the sampled trees were found to be either "deficient" or "low" in their leaf contents of Mg, Zn, and Mn, and to a lesser extent in Cu. However, the Fe and B contents were found to fall in the "satisfactory" range in most of the orchards.

The soil chemical analyses revealed all the soils to be calcareous with pH values between 7.3 and 8.1.

Studies on the relation of leaf N and P to the other leaf elements showed N to correlate positively with Na and negatively with P, K, Ca, B, Zn, and Cu, but N did not correlate with Mg, Fe, or

Mn. Leaf P correlated negatively with N and Ca, positively with K, but it had no significant correlation with the other leaf elements.

By studying the interrelationships among the cations in the leaves and soils, leaf K was found to correlate negatively with leaf Ca, but it had a poor positive correlation with the soil exchangeable K in the root zone (30 to 40 cm). Leaf Mg correlated negatively with the K/Mg ratio in the soil, however, it had a nonsignificant correlation with the NH_4OAc extractable Mg in the root zone; leaf Ca; or leaf K. Leaf Na had a negative correlation with Ca, but it had a nonsignificant correlation with K or Mg in the leaves.

From the present findings it may be concluded that citrus trees in Lebanon have a nutritional imbalance presumably due to the calcareous nature of the soils. Apparently the excess free calcium, as judged by its contents in the leaves, coupled with water shortage due to prolonged irrigation intervals have upset the absorption and accumulation of other elements. It seems likely that the problem is further aggravated by the high pH and the indiscriminate use of superphosphate and ammonium sulfate. This seems to be particularly true in the case of Zn and Mn. The close association between leaf Mg and K/Mg ratio in the soil indicates a probable antagonistic effect of high accumulation of K on the absorption of Mg. An attempt to correct the K status in the leaves by soil applications without taking into consideration the level of available Mg in the soil may aggravate Mg deficiency. The generally "high" Na concentrations in the leaves may have resulted from sea water coming to the orchards in the form of mists or from irrigation water, since sodium nitrate was found to be used in 3 orchards only and since other Na carriers were not applied in any of the orchards between the years 1963 and 1966.

Hence it is recommended that the use of superphosphate and ammonium sulfate should be given a special attention in Lebanese citrus orchards. Yearly applications of superphosphate must be restricted. N may be supplemented through ammonium nitrate carriers. Foliar sprays of K, Mg, Mn, Zn, and Cu may be given a particular attention in future studies. It is recommended also to consider in future studies the possible accumulation of Na in the roots and the effect of this accumulation on the absorption of other elements particularly the cations.

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APPENDICES

Appendix A

Locations of orchards, varieties sampled, age of trees, and spacing between the trees in the 66 citrus orchards under study.

Orchard No.	Location	Variety[a] and species	Age (years)	Spacing (meters)
1	Adloun (South Lebanon)	Valencia orange	12	5 x 5
2	Tel-Abbas (Akkar)	Valencia orange	4	3 x 3
3	Tel-Indi (Akkar)	Valencia orange	4	3 x 3
4a	Tel-Indi (Akkar)	Navel orange	4	5 x 5
4b	Tel-Indi (Akkar)	Mandarin (Mediterranean)	4	4 x 4
5a	Tel-Hayyat (Akkar)	Shammouti orange	15	4 x 4
5b	Tel-Hayyat (Akkar)	Valencia orange	15	4 x 4
6a	Tel Hayyat (Akkar)	Mandarin (Mediterranean)	32	4.5 x 4.5
6b	Tel-Hayyat (Akkar)	Shammouti orange	35	4.5 x 4.5
7a	Abdeh (Akkar)	Mandarin (Mediterranean)	30	3.5 x 3.5
7b	Abdeh (Akkar)	Shammouti orange	30	3.5 x 3.5
8a	Bhanneen (Nahr El-Bared)	Mandarin (Mediterranean)	22	3 x 3

Appendix A (Continued)

Orchard No.	Location	Variety[a] and species	Age (years)	Spacing (meters)
8b	Bhanneen (Nahr El-Bared)	Shammouti orange	25	3.5 x 3.5
9	Minieh (Nahr El-Bared)	Mandarin (Mediterranean)	5	3.5 x 3.5
10a	Minieh (Nahr El-Bared)	Shammouti orange	60	5 x 5
10 b	Minieh (Nahr El-Bared)	Mandarin (Mediterranean)	15	4 x 4
11	Minieh (Nahr El-Bared)	Mandarin (Mediterranean)	17	3 x 3
12	Minieh (Nahr El-Bared)	Shammouti orange	70	4 x 4
13	Ein El-Baida (Nahr El-Bared)	Mandarin (Mediterranean)	18	3.5 x 3.5
14	Baddawi (Tripoli)	Shammouti orange	42	4 x 4
15	Baddawi (Tripoli)	Shammouti orange	45	4 x 3
16	Baddawi (Tripoli)	Shammouti orange	45	3 x 3
17	Minqara (Tripoli)	Shammouti orange	55	2.5 x 2.5
18	Tripoli	Shammouti orange	56	3 x 3
19	Saqi Wastani (Tripoli)	Shammouti orange	70	3 x 3
20	Batroun	Shammouti orange	35	4 x 4

Appendix A (Continued)

Orchard No.	Location	Variety[a] and species	Age (years)	Spacing (meters)
21	Batroun	Shammouti orange	35	4 x 4
22a	Kubba	Mandarin (Mediterranean)	21	3 x 4
22b	Kubba	Shammouti orange	22	3 x 4
23	Kubba	Shammouti orange	35	4 x 4
24a	Amsheet	Navel orange	6	3 x 3
24b	Amsheet	Mandarin (Mediterranean)	6	3 x 3
25	Amsheet	Shammouti orange	8	2.5 x 2.5
26	Jubeil	Shammouti orange	25	5 x 5
27	Jubeil	Shammouti orange	30	3 x 3
28	Artboun	Shammouti orange	11	4 x 4
29	El-O'Kaiba (Nahr Ibraheem)	Shammouti orange	30	4 x 5
30	Boar (Nahr Ibraheem)	Shammouti orange	30	3.5 x 3.5
31	Tabarja	Shammouti orange	25	4 x 5
32	East Naqqash (Antilias)	Shammouti orange	40	3 x 3

Appendix A (Continued)

Orchard No.	Location	Variety[a] and species	Age (years)	Spacing (meters)
33	West Naqqash (Antilias)	Shammouti orange	55	5 x 6
34	West Naqqash (Antilias	Mandarin (Mediterranean)	20	3.5 x 3.5
35	Haret El-Na'ameh	Shammouti orange	30	4 x 3.5
36	Damour	Shammouti orange	8	5 x 6
37	Damour	Shammouti orange	20	5 x 5
38	Damour	Shammouti orange	20	5 x 5
39	Damour	Shammouti orange	22	3 x 3
40	Jiyyeh	Shammouti orange	18	4 x 4
41	Saidon	Sa'asly lemon	85	4 x 4
42	Saidon	Sa'asly lemon	95	5 x 5
43	Saidon	Sa'asly lemon	70	5 x 5
44	Saidon	Sa'asly lemon	20	4 x 4
45	Rmayleh	Mandarin (Mediterranean)	25	4 x 4
46	El-Ghazeyyeh	Sa'asly lemon	12	4 x 4
47	El-Ghazeyyeh	Valencia orange	4	7.5 x 7.5

Appendix A (Continued)

Orchard No.	Location	Variety[a] and species	Age (years)	Spacing (meters)
48	El-Ghazeyyeh	Navel orange	5	3 x 3
49	Zahrani	Valencia orange	12	3 x 3
50	Sarafand	Valencia orange	7	6 x 6
51	Zahrani	Navel orange	6	6 x 6
52	Khaizaran	Valencia orange	10	6 x 6
53	Khaizaran	Sa'asly lemon	12	6 x 6
54	Adloun	Navel orange	10	5 x 5
55	Abu El-Aswad	Valencia orange	16	6 x 6
56	Eitaniyyeh	Valencia orange	12	6 x 6
57	Qasmiyyeh	Shammouti orange	15	5 x 5
58	Joret El-Ein (Tyre)	Navel orange	15	6 x 6
59	Shabriha (Tyre)	Shammouti orange	16	5 x 5
60	Buss (Tyre)	Navel orange	7	4 x 4
61	Burj El-Shamali	Shammouti orange	13	5 x 5

Appendix A (Continued)

Orchard No.	Location	Variety[a] and species	Age (years)	Spacing (meters)
62	Burj El-Qibli	Valencia orange	12	5.5 x 5.5
63	Ras El-Ein	Valencia orange	14	6 x 6
64	Ezziyyeh	Valencia orange	20	7 x 6
65	Bayyada	Valencia orange	12	5 x 5
66	Bayyada	Valencia orange	12	6 x 6

a. All varieties and species are budded to sour orange root stock (Abusfair).

Appendix B

Fertilization programs followed between the years 1963 and 1966 in the 66 citrus orchards under study.

Orchard No.	Inorganic fertilizers			Barnyard manure	
	Type and formula	kg per[a] tree per year	Season of application	kg per[a] tree per year	Season of application
1	15-15-15	1.5	Summer	60	Fall
2	1:1 ammonium sulfate + 20-20-10	2	Summer	10	Fall
3	13-13-21	1	Summer	20	Fall
4a	14-14-0	1	Summer	15	Fall
4b	14-14-0	1	Summer	15	Fall
5a	2:1 ammonium sulfate + superphosphate	4	Summer	60	Spring
5b	2:1 ammonium sulfate + superphosphate	4	Summer	60	Spring
6a	2:1 ammonium sulfate + superphosphate	6	Spring	60	Fall

Appendix B (Continued)

Orchard No.	Inorganic fertilizers: Type and formula	Inorganic fertilizers: kg per[a] tree per year	Inorganic fertilizers: Season of application	Barnyard manure: kg per[a] tree per year	Barnyard manure: Season of application
6b	2:1 ammonium sulfate + superphosphate	6	Spring	60	Fall
7a	ammonium sulfate	1.5	Fall	15	Fall
7b	ammonium sulfate	1.5	Fall	15	Fall
8a	ammonium nitrate	3.5	Spring	10	Spring
8b	ammonium nitrate	3.5	Spring	10	Spring
9	ammonium nitrate	2.5	Spring	20	Fall
10a	ammonium nitrate	10	Spring	20	Spring
10b	ammonium nitrate	10	Spring	20	Spring
11	ammonium nitrate	2.5	Spring	10	Fall
12	6:1 ammonium sulfate + superphosphate	3.5	Spring	30	Summer
13	1:1:1 ammonium sulfate + calcium nitrate + 15-10-10	3	Spring	20	not specified

Appendix B (Continued)

Orchard No.	Inorganic fertilizers			Barnyard manure	
	Type and formula	kg per[a] tree per year	Season of application	kg per[a] tree per year	Season of application
14	2:1 ammonium sulfate + superphosphate	5	Spring	15	Spring
15	ammonium sulfate	4	Spring	50	Summer
16	2:1 ammonium sulfate + superphosphate	5.5	Spring	45	Fall
17	2:1 ammonium sulfate + superphosphate	5.5	Spring	45	Fall
18	ammonium sulfate	3	Spring	15	Summer
19	3:2:1 ammonium nitrate + superphosphate + mutiate of potash	4	Summer	15	Summer
20	10-10-10	8	Spring	not used	-
21	10-10-10	8	Spring	30	Spring
22a	2:2:1 ammonium sulfate + superphosphate + muriate of potash	8	Spring	15	Summer

Appendix B (Continued)

Orchard No.	Inorganic fertilizers: Type and formula	Inorganic fertilizers: kg per[a] tree per year	Season of application	Barnyard manure: kg per[a] tree per year	Barnyard manure: Season of application
22b	2:2:1 ammonium sulfate + superphosphate + muriate of potash	3	Spring	20	Spring
23	1:1:1 ammonium sulfate + superphosphate + muriate of potash	3.5	Spring	10	Spring
24a	1:1:1 ammonium sulfate + superphosphate + muriate of potash	4.5	Spring	10	Spring
24b	1:1:1 ammonium sulfate + superphosphate ± muriate of potash	3.5	Spring	10	Spring
25	5:1 ammonium sulfate + superphosphate	5	Spring	60	Spring
26	3:1:1 ammonium sulfate + superphosphate + muriate of potash	4.5	Summer	20	Spring
27	2:2:1 ammonium sulfate + superphosphate + muriate of potash	1	Spring	15	Spring

Appendix B (Continued)

Orchard No.	Inorganic fertilizers			Barnyard manure	
	Type and formula	kg per[a] tree per year	Season of application	kg per[a] tree per year	Season of application
28	ammonium sulfate	3	Spring	10	Spring
29	1:1 ammonium sulfate + superphosphate	1	Spring	not used	-
30	3:2 ammonium sulfate + superphosphate	5	Spring	not used	-
31	1:1 ammonium sulfate + superphosphate	5	Summer	not used	-
32	14-14-0	5	Summer	25	Spring
33	10-10-13	3.5	Spring	15	Spring
34	sodium nitrate	2.5	Fall	20	Spring
35	13-13-20	1.5	Spring	5	Summer
36	13-13-20	1.5	Spring	30	Spring
37	13-13-20	4	Spring	20	Spring
38	13-13-20	3	Summer	30	Fall
39	sodium nitrate	1.5	Spring	25	Spring

Appendix B (Continued)

Orchard No.	Inorganic fertilizers: Type and formula	kg per[a] tree per year	Season of application	Barnyard manure: kg per[a] tree per year	Season of application
40	13-13-20	2.5	Fall	20	Fall
41	not used	-	-	25	Fall
42	ammonium sulfate	1	Spring	not used	-
43	1:1 ammonium sulfate + superphosphate	4	Spring	30	Summer
44	13-13-20	1.5	Spring	10	Summer
45	10-10-10	4	Summer	30	Summer
46	15-10-10	1.5	Spring	30	Fall
47	1:2 ammonium sulfonitrate + 13-13-20	3	Summer	15	Spring
48	13-13-20	4	Summer	20	Spring
49	1:1 ammonium sulfonitrate + ammonium nitrate	4	Summer	60	Summer
50	4:2:1 ammonium sulfate + superphosphate + muriate of potash	6.5	Fall	25	Summer

Appendix B (Continued)

Orchard No.	Inorganic fertilizers			Barnyard manure	
	Type and formula	kg per[a] tree per year	Season of application	kg per[a] tree per year	Season of application
51	14-14-14	4	Spring	30	Fall
52	1:1:1 ammonium sulfate + superphosphate + muriate of potash	3	Summer	30	Spring
53	ammonium sulfate	5	Spring	30	Summer
54	ammonium nitrate	4	Spring	20	Fall
55	14-14-0	5	Spring	60	Fall
56	ammonium sulfonitrate	2	Spring	20	Fall
57	Humocap 4-1-1 (76% org. matter)	3	Spring	20	Fall
58	ammonium sulfate	1.5	Summer	20	Fall
59	1:1 ammonium sulfonitrate + sodium nitrate	6	Summer	20	Summer
60	3:2:2 sodium nitrate + superphosphate + muriate of potash	7	Spring	60	Spring

Appendix B (Continued)

Orchard No.	Inorganic fertilizers			Barnyard manure	
	Type and formula	kg per[a] tree per year	Season of application	kg per[a] tree per year	Season of application
61	2:3 ammonium nitrate + 15-15-15	5	Spring	15	Fall
62	3:2:1 ammonium sulfate + superphosphate + muriate of potash	6	Fall	60	Fall
63	1:1:1 ammonium sulfonitrate + ammonium nitrate + sodium nitrate	6	Summer	not used	-
64	ammonium sulfate	1	Summer	60	Summer
65	2:1:2 ammonium sulfate + superphosphate + 20-14-14	5	Spring	20	Summer
66	2:2:1 ammonium sulfate + superphosphate + muriate of potash	5	Summer	20	Fall

a. Average of 3 years (1963-1966).

Appendix C

Irrigation, cultivation, and chemical sprays used between the years 1963 and 1966 in the 66 citrus orchards under study.

Orchard No.	Irrigation intervals (days)	No. of cultivations per year	Sprays
1	18 - 20	1	Zineb + summer oil + sevin
2	18 - 20	4	Sulfer + summer oil
3	30 - 40	4	Parathion + sulfer
4a	15 - 20	2	Sulfer + summer oil
4b	15 - 20	2	Parathion + sulfer
5a	25 - 30	5	Parathion + sulfer
5b	25 - 30	5	Parathion + sulfer
6a	30 - 40	4	Parathion + sulfer
6b	30 - 40	4	Parathion + sulfer
7a	30 - 40	3	Parathion + sulfer
7b	30 - 40	3	Parathion + sulfer
8a	20 - 25	4	Parathion + sulfer

Appendix C (Continued)

Orchard No.	Irrigation intervals (days)	No. of cultivations per year	Sprays
8b	20 - 25	4	Parathion + sulfer
9	30 - 40	2	Parathion + sulfer
10a	30 - 35	1	Parathion + sulfer
10b	30 - 35	1	Parathion + sulfer
11	15 - 20	3	Parathion + sulfer
12	35 - 40	3	Parathion + sulfer + summer oils
13	25 - 30	2	Parathion + sulfer
14	30 - 40	3	Parathion + sulfer
15	25 - 30	2	Parathion
16	30 - 35	2	Parathion
17	30 - 35	3	Parathion + sulfer
18	30 - 35	2	Parathion + sulfer
19	30 - 35	2	Parathion + sulfer

Appendix C (Continued)

Orchard No.	Irrigation intervals (days)	No. of cultivations per year	Sprays
20	25 - 30	2	Parathion + sulfer
21	25 - 30	2	Malathion ± sulfer + sevin
22a	20 - 25	2	Malathion + sulfer
22b	20 - 25	2	Malathion + sulfer
23	25 - 30	2	Parathion + sulfer + sevin
24a	10 - 15	3	Dimol + sulfer
24b	10 - 15	3	Dimol + sulfer
25	8 - 10	5	Parathion + sevin
26	25 - 30	1	Parathion + sulfer + sevin
27	15 - 20	2	Sulfer
28	10 - 15	2	Parathion + sulfer
29	5 - 8	2	not applied
30	10 - 15	2	not applied

Appendix C (Continued)

Orchard No.	Irrigation intervals (days)	No. of cultivations per year	Sprays
31	20 - 25	2	Sevin + sulfer + summer oils
32	25 - 30	5	Calmathion + sulfer
33	30 - 35	3	Parathion + sulfer + sevin
34	20 - 25	2	Sevin ± sulfer
35	15 - 20	2	Calmathion + sulfer
36	15 - 20	3	Calmathion + sulfer
37	10 - 15	3	Calmathion + sulfer + sevin
38	10 - 15	3	Calmathion + sulfer + summer oils
39	10 - 15	3	Malathion + sulfer
40	15 - 20	3	Sulfer + sevin
41	10 - 15[a]	1	Sulfer + summer oils
42	10 - 15[a]	1	Calmathion + sulfer + summer oils

Appendix C (Continued)

Orchard No.	Irrigation intervals (days)	No. of cultivations per year	Sprays
43	10 - 15[a]	2	Sevin + sulfer
44	15 - 20[a]	3	Calmathion + sulfer
45	15 - 20	2	Calmathion + sulfer
46	10 - 15[a]	2	Sevin + sulfer
47	10 - 15	3	Sevin + sulfer
48	20 - 25	4	Calmathion + sevin + sulfer
49	10 - 15	2	Sulfer
50	25 - 30	1	Dithane - Z + sulfer
51	10 - 15	2	Malathion + sulfer
52	10 - 15	2	Malathion + sulfer + summer oils
53	18 - 20[a]	3	Dithane - Z + sulfer
54	25 - 30	3	Calmathion + sulfer
55	35 - 40	3	Calmathion + sulfer + summer oils.

Appendix C (Continued)

Orchard No.	Irrigation intervals (days)	No. of cultivations per year	Sprays
56	30 - 35	2	Sevin + sulfer
57	10 - 15	2	Calmathion + sevin + sulfer
58	20 - 25	3	Sevin + sulfer
59	15 - 20	4	Calmathion + sulfer
60	15 - 20	3	Calmathion + summer oils
61	10 - 15	3	Sevin
62	15 - 20	2	Calmathion + sulfer
63	15 - 20	3	Calmathion + sevin + sulfer
64	10 - 15	2	Calmathion + sulfer
65	25 - 30	2	Calmathion + sulfer
66	10 - 15	3	Calmathion + sulfer + summer oils

a. No irrigation between the 2nd week of July and late September.