A STUDY OF THE POTASSIUM NUTRITION OF THE LEMON TREE

(Citrus limon Linn)

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by

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ABSTRACT

Villafranca lemon trees were grown for two years in containers and provided with a standard nutrient feed. Potassium was supplied differentially, usually as foliar sprays of potassium chloride. The magnitude of the effect of varying numbers of sprays on leaf potassium was determined, the main response being the short-term nature of this effect. Similarly the considerable benefits of a limited number of manganese or zinc sprays on the leaf concentration of these elements was demonstrated.

Determinations of the levels of the main minerals in the leaves showed the seasonal variations of each one, and led to a recommendation on sampling time for the determination of each element. It was also possible to demonstrate possible mineral element interactions, the most interesting being the lack of a potassium - magnesium antagonism. It was shown calcium levels fell with increased leaf-potassium to maintain the cation balance. But in another situation the range in plant nutrient status was such as not to maintain an equivalence in the cation/anion ratio or the total leaf cation content. In this latter instance this did not result in a predicted effect on leaf organic acid content.

The possible dangers of excessive chloride accumulation were considered; and the problem of leaf chlorosis where potassium is in low supply. A recommendation was made on the use of nutrient solution feeds for young citrus trees, especially with respect to trace element supply. Various effects of potassium supply on fruit quality were also demonstrated.

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CHAPTER I INTRODUCTION

Citrus is an important crop in many countries of the World, and in the literature there are numerous references to the culture and physiology of these fruits. In the field of mineral nutrition, a considerable body of information exists on this crop. Nutrition is a complex field, and with the effects of a given mineral supply depending on so many other factors it is not surprising that each important citrus growing area has its own research projects on mineral nutrition.

However, few detailed reports exist concerning the nutrition of citrus in New Zealand. Various reasearch projects are currently under way, mainly on a field scale, and in many cases detailed results will not be available for some time. The N.Z. - produced citrus fruits are mainly for local consumption, but there is a place for continued expansion in the industry. There is also a growing export trade in certain citrus products, of a processed nature. For such outlets fruit composition studies are particularly important. The citrus industry is then an important one, with good prospects for continued development in certain fields. Therefore it was considered useful to obtain some quantitative data on citrus nutrition, and in the present study selected aspects have been studied.

Of the many types of citrus, sweet oranges are of greatest commercial importance, and so it is natural that they will be the most studied of the citrus fruits.

The great bulk of citrus nutrition trials, involving such aspects as plant uptake, fruit quality effects, and leaf analysis, have been concerned with the sweet oranges. Theopportunity was therefore taken to study mineral nutrition in the lemon.

This work was in large part a study in leaf analysis of this crop - mainly mineral elements, but also certain other constituents. In modern crop production we find a special interest in leaf absorption of the various foliar - applied substances used, and uptake of foliar nutrient sprays is one aspect of this, and also was studied. For many years it has been considered by many authors there is no known specific role of potassium in plants, although many reports detail its considerable influence in citrus production. We often associate potassium with crop quality, and with the requirement for increasingly high quality this makes it a useful element to study in the hope also, of providing more information on its physiological role. An attempt was made also to obtain some information of this type.

With reference to the mineral elements, the following abbreviations are used:

N - nitrogen
P - phosphorous
K - potassium
Ca calcium
Mg magnesium

Fe - iron
Mn - manganese
Zn - zinc
Cu - copper

Al - aluminium
B - boron
Na - sodium
Cl - chlorine

CHAPTER II REVIEW OF LITERATURE

A LEAF ANALYSIS

1. The Principle.

For a long time people have had an interest in determining accurately the mineral requirements of crops, and to this end a large number of methods have been used with varying degrees of success. Tissue testing involved a measurement of plant nutrients contained in extracts of, usually, the stem or petioles of plants. Such extracts may have been obtained by the use of high pressures, or various chemical extractants. Some of these methods are satisfactory for field use to give an immediate but approximate indication of a plant's nutritional status - and are used in this way in commercial practice.

Leaf analysis has found considerable use, and it involves the measurement of the concentration of the total mineral nutrients in plant leaves at specific growth stages. Leaf analysis is based on the contention that changes in nutrient supply are reflected in the nutrient composition of the leaves, and that these concentrations at specific growth stages are related to crop performance (18). There is in fact a considerable body of data to show the mineral content of a plant has some controlling influence on growth, fruitfulness, and quality (160).

Goodall and Gregory (76) cover the development of plant analysis, and also indicate other ways of determining crop fertiliser needs. It is clear the concept of plant analysis is not new, and while it supposes the plant to be the best indicator of nutrient availability, (i.e. rather than soil tests), in leaf analysis it is assumed the leaf is the best part of the plant to use, or at least as sensitive an indicator of nutritional status as any other plant part. This is in fact found to generally be true (160), but there are some exceptions e.g. the petioles are a very useful indicator of potassium status in the grape (160).

Leaf analysis may be used for a number of purposes. These include the determination of fertiliser requirements of perennial crops, the identification of a particular nutrient deficiency or excess, and in crop nutrition research. The problem comes in the interpretation of leaf analysis data (72). For while leaf composition is primarily controlled by nutrient supply (172), it may be influenced by a large number of other external and internal factors (76, 160). For instance the weather may affect leaf composition (7), and for field use this suggests the need for annual adjustments of 'standard' levels for the particular season (7, 15), There is also important but complex problem of interactions, or the changes in concentration of one nutrient induced by changing the concentration of another. This has been discussed for a range of crops by different authors (17, 18, 56, 146, 160, 163, 168). Nitrogen is especially active in this way. Thus N fertiliser depressed leaf K and P, and increased Mg in young apple leaves (23), and in citrus, adding N affected (increased or decreased) the level of eight other elements in the leaves (160). Whereas the effects of N on tissue composition may vary greatly with different supplies of other elements, very few interactions of K have been found using Valencia sweet orange in sand culture (168). So it was concluded single variable studies with K would usually give reliable information about leaf mineral level effects.

It is considered that in plant nutrition two aspects are of importance, namely intensity and balance (17, 153). Thus if nutritionally a plant is 'balanced,' addition of one fertiliser (e.g. K) leads to an imbalance (low Mg), which shows as a growth or yield response, or perhaps leaf deficiency symptoms. It is suggested the numerous interactions of Mg and Na on K and Ca uptake by cotton plants demonstrate - "the importance of ion balance in the mineral nutrition of plants" (178).

A considerable amount of work has been done to obtain standard leaf composition values for different crops: (17, 27, 29, 55, 76, 104, 163). In such works we find leaf levels divided into various classifications e.g. low, optimum, high, or deficient, low, optimum, high excess. Usually major elements are expressed as percentage dry weight, and minor elements as parts per million (ppm), although milli equivalents and μ equivalents may be used (153).

2. Sampling

It is considered the time and type of tissue sampled is very important (160), and that sufficient material be taken to minimise the effect of leaf to leaf variation (163). Leaves are metabolically active organs, and so subject to change from many causes. For leaf analysis results to be reliable, standardisation of sampling is necessary, in fact critical. The size of a tree's crop, the nearness of fruits, and the presence of another growth flush all affect citrus leaf mineral composition (163).

(i) Fruiting -v.- non-fruiting terminals

In some cases we find an effect of fruit on the composition of nearby leaves.

On apple trees little difference has been found between composition of leaves from fruiting and non-fruiting shoots (179); and using orange leaves there was no appreciable difference in K level between leaves from these two types of shoots (31). In a survey of 22 sweet orange orchards (20), no significant differences were found in leaf Al, B, Fe, Mn, or Zn levels between these two types of sample.

However in the apple, fruits have been found to reduce leaf Mg level (123), and young citrus fruits compete with leaves for newly-absorbed N (192). Fudge (73) found differences in the composition of different portions of the grapefruit tree if fruit was present; and Satō reports (151) a higher leaf - K in leaves from non-fruiting trees than from fruiting trees. Highly significant larger amounts of N, P, K, S, and much lower levels of Ca, Mg have been found in leaves from non-fruiting orange terminals (86, 146). Thus it seem a choice between the two types of sample is important.

(ii) Leaf age

When leaves are to be compared they should be of a similar physiological age, and should be taken at the same period during the growing season.

In the first stage when leaves are young, with high metabolic rates, they have rather variable mineral content. In the third stage there is also a period of change in nutrient content as senescence approaches. Between these two is a brief period of stability. In citrus with several growth flushes a year, older leaves may also be difficult to identify, and it is often suggested citrus leaves 3 - 7 months old should be sampled (111, 146, 163, 165). There is now ample evidence to show the existence of a plateau in mineral level at about this point.

Generally in fruit crops, leaf concentration of N, P, K, Cu, Zn, is greater in young tissue, whereas Ca, Mg, Mn, Fe, B concentrations are greater in older tissue (39, 100, 160). Thus in the former group dilution occurs as the leaf enlarges, while the latter elements may enter the leaf at rates that prevent dilution. And so we get typical curves in leaf mineral concentrations through the season, or as leaf age increases (100, 163, 165). They show N to be the most plentiful mineral in very young leaves, the lead soon being taken by Ca for the rest of the leaf's life. P and K show a gradual decline from an early high level. Mg enters the leaf early in its life, and after reaching a steady level its concentration declines.

With the apple, comparisons must be made only between leaves from the same position on a shoot (107, 125). However in citrus compositional gradients along the stem axis are small or absent (112). In spite of this minor variation in composition along a given flush, a consistent sampling position is thought best (163).

In citrus, leaves from the summer flush contain more N, P, K, Mg and less Ca than spring or autumn flush leaves of the same age (31, 112), and compositionaltrends for each flush are similar. While these differences due to the season of origin may not be considered great (160, 165), comparisons of results from different flushes (but the same leaf age) may be considered of reduced significance (163).

(iii) Crop size

It has been seen that the presence or absence of blossom and fruit may affect leaf composition. While in the apple no correlation was found between the level of crop and leaf nutrients (182), crop size may influence leaf composition (115). Using biennial Marsh grapefruit (164) a higher leaf - Ca was associated with the "on" years, and in the presence of a heavy crop leaf N, K, Mg was decreased. So fruits affect the mineral composition of leaves other than just those adjacent to them.

3. Leaf Preparation

Suitabl prepared leaves are usually satisfactory for a meaningful analysis to be performed. But it has been considered doubtful if leaves earlier sprayed with Mn or Zn can be used satisfactorily for the determination of these elements (160), due to surface deposits of these metals. It has however been shown such leaves, if properly cleaned, can give important data on the status of these elements in the plant (120). It may then be expected no problem should occur with K analysis following the spray application of highly soluble potassium salts. In addition the leaf - Fe level determined would provide a clear indication of the effectiveness of leaf washing due to the grossly exaggerated values that would be obtained where dirt contamination was occuring. (Ratio of soil Fe to leaf Fe is usually 10^2 to 10^4 (194).

As in other aspects of leaf analysis the literature contains much information on the importance of proper and adequate leaf preparation and what this involves (16, 76, 116, 120, 163, 173). Usually it means washing in detergent, or acidified detergent, rinsing, drying, and grinding - at all stages care being taken to avoid contamination of the samples especially if trace elements are to be determined.

B FOLIAR NUTRITION

1. Leaf Absorption

In recent years there has been considerable interest in this phenomenon, and detailed information is available on the mechanism of leaf penetration, and also the nature of plant surfaces (40, 66, 68, 152, 157).

The active process of foliar absorption (84, 101) involves the uptake of a wide range of types of chemicals: insecticides (44), herbicides (65), antibiotics (103), non-essential elements (84), and mineral nutrients (19, 201). From a practical point of view it is important that not only does absorption occur through the leaves but also through the bark and fruit (19, 96, 183, 184). Expectedly a large number of factors influence the rate and total amount of uptake of each material (158, 185).

(i) The external environment

Due to the form of the plant cuticle, absorption of hydrophilic compounds at higher humidities is faster (3, 158, 185). Temperature and light also affects uptake (38, 185). One also finds reference to the influence of time of day on uptake (201), and this no doubt is intimately connected with the humidity and temperature conditions prevailing before and after foliar application.

The passage of time is important in considerations of foliar absorption. We may expect to find an initial brief period of rapid uptake followed by a period of a much slower rate of uptake (38, 113). Surprisingly large amounts of minerals can be absorbed in short periods of time (21). If applied in conditions unfavourable for absorption, significent uptake may not occur for some time. By various methods (rewetting the sprayed area, use of humectants etc.) it is possible to delay the onset of the period of slow rate of uptake (113). In studying foliar absorption it is necessary to distinguish between absorption, adsorption, and transport. It is possible that initially absorption will be very high compared with transport out of the leaf, and so leaf concentrations will increase greatly. At a later stage when uptake rate is low, transport may be still removing large quantities of material from the treated surfaces and thus causing a decline in leaf concentration.

The nutrient status of the plant is also important, and this is related to soil nutrient levels. McIntosh apples have shown a greater response to magnesium sulphate sprays under high soil - N than low - N (64). High absorption of urea by apple leaves is associated with an originally high leaf - N level (38). A decreased uptake of foliar applied P in the presence of a high P level in the root media is reported (185), and the recovery of K from potassium sprays was greater in the presence (cf. absence) of soil K (181). Using various crops, increase in nutrient content from NPK sprays occurred with both high and low NPK supply to the roots, and was approximately proportional to the concentration of the spray and the frequency of spraying (180). In applying a nutrient (A) as a foliar spray (AB), in the presence also of its soil supply, leaf content may not be a measure of leaf uptake of nutrient A, as B may increase uptake of A from the soil (181).

(ii) The plant material

It is best to apply foliar sprays to leaves at an early stage of growth, uptake being faster and greater in young leaves (185, 190, 195, 201) - although there may be some exceptions (201). Three month old Eureka lemon leaves absorbed urea three times as fast as mature leaves (94).

Both upper and lower leaf surfaces function in absorption.

In the apple lower leaf surfaces were found to absorb urea (38) and leucine (102) faster than the upper leaf surfaces. No differences were found in the absorption of zinc by citrus leaves when comparing upper and lower leaf surfaces (195).

The problem of the importance of stomatal entry has existed for some time. It is clear that cuticle penetration can occur whether stomata are present or not (202). While it might be considered stoma provide a major pathway for leaf penetration (38, 80, 102), there is considerable evidence this is not so (177, 189, 195). Franke (67) showed absorption of sucrose is greater by leaves rich in stomata, and that uptake is through the ectodesmata rather than the stomatal pore.

Uptake of a number of substances is greater in certain localised areas of leaves, such as midribs and guard cells (66, 185). Uptake of zinc was faster when applied near the centre of a leaf, rather than the margin (195). Absorption by apple leaves was greater by those near the base of the shoot, and near the tip of individual leaves (102).

The pH of the leaf surface affects uptake, absorption of nutrients by the grape (pH 3.5) being greater than the walnut (pH 6.5) (127). Differences between species will occur. Detached orange leaves absorbed 'foliarcure' at a faster rate than lemon leaves (91).

(iii) <u>The spray solution</u>

Various types of surfactants can be used to increase leaf absorption of herbicides (69), auxins (92, 171), and nutrients (61, 135, 186). This action of wetting or spreading agents in water sprays may be by a direct effect on the plant surface, or increasing the intimacy between the spray and plant surfaces (67, 69, 171, 136). Wetting agents may even decrease mineral uptake (61).

A chemical in the liquid phase on a leaf is absorbed relatively easily compared with the dry deposit (92, 149). So humid conditions after treatment, or the addition of hygroscopic agents may increase absorption by slowing the drying of the deposit (61, 91, 92, 113). In some cases addition of urea improves uptake of a spray.

The hygroscopicity of a foliar applied nutrient is important for uptake and transport (113). There are various reports of differences in mineral uptake according to the salt used (61, 79, 126), and in some cases this has been related to salt deliquescence and prevailing humidity (3, 4).

The pH of the applied solution may affect uptake (79, 177, 201). The rate of absorption is shown to be roughly proportional to spray concentration (94, 130, 185), although in the special case of iron, increasing the spray concentration over a low range did not improve the greening of deficent citrus leaves (79).

2. Foliar Feeding

Citrus leaves, like those of other plants are able to absorb various mineral elements applied to their outer surface (19, 75, 79, 85, 94, 134, 195). The effectiveness of a nutrient spray depends on absorption - to get the nutrient into the plant, and on transport - to move the nutrient to places where it is needed. Potassium can be very readily absorbed and translocated in the plant (31), and this suggests foliar application may be a very rapid way of correcting a deficiency. It has been shown

(25, 75) foliar potassium nitrate sprays are a promising practical method of supplementing soil applications of K fertilisers. To this end the nutrient may be applied as a foliar spray with wetter/spreader or with some material to increase penetration (e.g. as with urea with iron (10), DMSO with iron (122)), or mobility (e.g. TIBA with calcium and iron (106)).

Foliar feeding is not intended as a substitute for soil application, but simply to complement it. Foliar nutrition may be particularly important for special problems such as instances of high soil fixation, or where certain deficiencies suddenly appear affecting crop production (19), or while waiting for soil applications to become effective. In some orchards large soil applications of K are needed over many years to greatly increase tree - K level. Certain of the soils in Florida used for citrus growing have an exceptionally high calcium content, and one effect of this is that leaf - K cannot be increased very much, with even heavy soil applications of K fertilisers (25). Such low levels can be quickly remedied by the use of a few foliar sprays (29). Information on foliar nutrition of both major and trace elements is contained in a number of places (5, 19, 201), and most fruit-growing areas have local recommendations where applicable.

In commercial horticulture there are a number of common examples of the effectiveness of foliar nutrient sprays. Epsom salt sprays are used on a number of crops, calcium salt sprays are standard practice for control of apple bitter pit, urea sprays are often used to boost crop growth, and a range of trace element deficiencies are frequently treated by foliar sprays. On apples nitrogen sprays are often used to improve flowering and fruit set, and even to reduce apple black spot. Over several years, trees in the field receiving foliar urea yielded at least as well as trees getting the same amount of N as a soil application (60). In another study magnesium sulphate sprays to deficient apple trees had little effect on growth, but increased yield 19 -39% -- largely due to improved fruit set (63). In Californian orange orchards annual manganese sprays have increased yield 7 -19%, with a slight increase in juice soluble solids (113, 120). Fruit from plants sprayed with micro-nutrients is claimed to stand handling better, and on grapes to improve berry size, uniformity, and sugar content (127).

3. Some Leaf Effects Of Foliar Sprays

(i) The leaf content of the applied element

We can expect this rise after its leaf application, followed by a decline with its re-distribution. The extent of the increase will depend on a number of factors, as outlined earlier. Ganje et al (75) have shown six strong potassium nitrate sprays at weekly intervals to give large increases in leaf - K. Also trace element sprays can give large increases in leaf trace element concentration, in a short period (119). In work such as this there is always the possibility that the spray may affect uptake of that element from the root media (180).

(ii) Other elements

(a) The effects detailed here, of soil and leaf mineral uptake, must be known for an understanding and interpretation of tissue analysis data. When leaves absorb one element it may cause an increased uptake of other elements from the soil (180, 181), and so modify their leaf levels. Varying the soil supply of one element, alters plant composition of other elements. There are a host of reports demonstrating this effect, which is a complex one. When magnesium chloride was supplied to corn(175) certain effects on mineral levels were attributed to uptake of magnesium but in fact the chloride may have been an important antagonist. K deficiency induced iron deficiency in orange trees (32); and in maize, and the potato low K speeded up the appearance of iron deficiency symptoms (88). Such effect are likely to be due to effects on element distribution rather than uptake (38). It has been shown the common K - Mg effect is not true uptake antagonism, but an effect of high K on the distribution of magnesium within the plant organs (24).

The considerable number of effects of this type is shown for citrus in a table presented by Smith (160). For instance adding K effects the leaf concentrations of five other elements, and leaf - K is affected by the addition individuelly of nine different elements.

In orange trees, Mn sprays decreased leaf K, Ca, Zn, and zinc increased leaf Mn, and decreased N, Ca, Mg, Cu (117). Increasing leaf magnesium level by soil or foliar applications reduces leaf calcium, nitrogen, sulphur, and potassium (63, 175, 188); increasing leaf calcium decreases leaf potassium and magnesium (188); increasing leaf nitrogen decreased leaf phosphate, potassium, and several trace elements (146, 168); and increasing leaf potassium reduced leaf calcium, magnesium, nitrogen, sodium, and magnesium and increased trace element concentration in tung leaves (153). In citrus, zinc deficiency has been aggravated by high potassium (147, 199), but this aggravation may in fact result from a magnesium deficeincy (26) induced by the high potassium.

In at least some plants sodium can partially replace K in nutrition (174), and high sodium has been associated with low K concentration in tomato (98) and citrus (85) leaves.

The complexity of these interactions is shown by Smith *et al* (168) using citrus trees :

(a) Increasing N decreased leaf K concentration under low K supply, but not with high K supply.

(b) K decreased Mg at high N, but not with low N.

(c) Mg decreased Ca at low K level, but increased Ca at high K levels.

(b) Sum of cations

It is a long time since Liebig expressed the concept of cation - equivalent constancy, This states that under standardised environmental conditions, the sum of cation milliequivalents for any species tends to be constant, regardless of variation in mineral supply. This constancy of the sum of the cation equivalents is involved with the effects discussed above in which a change in one element results in changes in the concentration of other elements, and is shown in various reports.

Using variable soil - K applications, in the potato (197) magnesium was of importance in maintaining the plant cation balance; and Freeman (70) compares several crops. Thus calcium and magnesium in the French bean, and calcium, magnesium and sodium in the lettuce fuctioned in maintaining the cation balance; while in other crops calcium and magnesium content were relatively constant, and sodium almost completely balanced changes in leaf - K (70).

Following salt uptake by citrus leaves the sum of the main cations was found to remain rather uniform (50).

It has been claimed (114) the constancy of the ratio of cation to anion millicquivalents is more dependable.

(C) CONTAINER GROWING

In experiments in crop nutrition it is necessary to have strict control of the nutrient supply, and to be readily able to vary it. It depends on the aims of the experiment as to what degree of sophistication is required, and in some critical work considerable effort has been expended in developing the experimental techniques. Considerable data is now available on the feeding requirements of crop plants grown in culture solution or sand/peat type root media (88, 89). In such artificial conditions problems peculiar to such methods have required solution in order to grow healthy plants over long periods.

Container - growing offers a convenient and satisfactory method of growing plants (143) and of studying aspects of foliar absorption by growing citrus trees, but again there is no report on this technique in New Zealand.

1. The Container

Metal containers are often used, and for a lot of work are very satisfactory (89). Due to metal contamination it may be desirable to coat the surface with some non-toxic material. For this purpose bitumen and asphalt paints have often been used (42, 143).

2. The Root Media

In the past a large number of materials have been used either individually or together, each requiring its own handling technique. Thus one finds the use of aerated solutions (194), subsoil (162), quartz sand (150), sand/peat mixes (130), or sand/peat/wood shaving mixes (130) for citrus growing. Citrus seedlings were found to grow larger and healthier in a UC mix of 50% by volume each of fine sand and sphagnum peat, than in clay loam mix (129).

3. The nutrient feeds

When solid rooting media are used , feeding may be by watering with a nutrient solution (162), or the use of such a solution after the incorporation of base fertiliser (130). The list of nutrient solutions used for citrus growing is extensive e.g. see Table 1.

Nutrient feeds are often similar to those of Arnon and Hoagland, an example of which is given in Table 1. for comparison. There is no one correct mixture (concentration and balance) for unimpaired growth as this will depend on the solution volume used, its rate of renewal, the presence of solid matter, and the plant species (89).

When peat is used, it will form a very stable complex with copper, and at low salt concentrations this could lead to a copper deficiency (36).

Iron deficiency may become a problem, and many factors may be responsible for this. For instance this deficiency may be induced by excess phosphate (89), - when leaf P rises (194), and in avoiding iron/manganese deficiencies their ratio in culture solution

TABLE 1

Citrus Nutrient Solutions (ppm)

Culture	N	P	K	Ca	Mg	Mn	Zn	Fe	Cu	B	Mo	Na	SO_4'	REF.
Sand) Subsoil)	100	10	40	80	36	2	0.05	1	0.01	0.25	0.005		Trace	162
quartz sand	342	75	237	160	54	0.4	0.4	1	0.4	0.4				150
quartz sand	30-210	10	8-180	160-220	4-48	0.5	0.5	0.5	0.02	0.5				167
sand	162	34	185	159	54	0.1	-	1				7	216	143
sand	116	3	151	166	61	.25	.25	0.5				6.4	288	78
sand	84-338	17-68	92-370	79-316	27-108	Trace	-	Trace					108	144
sand	200	10	81	200	70	0.5	0.25	2	0.1	0.5	0.01			196
solution	100	10	40	80	36	2	0.05	1	0.01	0.25	0.001		5	159
Hoagland	210	10	234	160	48	0.5	0.05	0.6	0.02	0.5	0.01			89

was considered of more importance than their absolute concentration (170). Control of the pH of the root media is important. It is suggested the medium be kept at a pH 5 -6.5 (130), and as nutrient solutions tend to go alkaline in the containers (143, 150) some adjustment may be necessary. It is condsidered little change in pH will occur when 80% of the N is supplied by nitrate and 20% by ammonium sulphate (196).

(D) CITRUS NUTRITION

A vast amount of data has been collected on the nutrition of citrus crops (29), although only limited data exists from New Zealand. In a study of nutrition a host of aspects become apparent: crop requirements, root uptake, deficiency effects, etc, and we cannot consider a full review here. With regard to the present study a few comments are pertinent, especially in respect of potassium nutrition.

The specific role of potassium in the plant has been in doubt for some time, but a considerable amount of interesting data has been reviewed by Evans and Sorger (59). Potassium is used in large quantities by fruit crops, and its importance is often attributed to fruit quality effects. Rather than being incorporated in specific compounds within the plant, it would appear potassium functions as a cofactor for a wide variety of very important enzymes. K is an essential element, and when its supply is limiting sodium can partially replace it, and in these circumstances some plants can accumulate large amounts of sodium.

1. Leaf Mineral Levels

Leaf tissue may be analysed by a number of methods to provide a measure of the level of their mineral content. This level will vary with many factors other than soil supply or content, but with an appreciation of these factors and their importance, leaf analysis can provide useful information on crop nutrition.

In leaf analysis one can satisfactorily determine the levels of all the essential minerals. Usually the total of each element is determined, and the concentration of major elements is expressed as a percentage of dryweight, and that of the trace elements as parts per million (ppm) of dryweight. It is normally not necessary to analyse for all the minerals, but due to the effects of interactions several analyses are likely to be most useful. The study of potassium effects is simplified since its effects on tissue composition do not vary greatly with differing supplies of other elements (168). With low nitrogen levels, leaf - K tends to be high, and with high nitrogen, tissue K tends to be low, and in interpreting leaf analysis data it is considered pointless classifying the status of any element unless the leaf - nitrogen concentration is known (146). In fact the balance between the level of the critical element and the levels of all other elements in the leaf is important (198).

Tables showing the degree of sufficiency of any level of a number of elements in citrus (usually sweet oranges) are given in various papers (27, 29, 39, 105, 163). Such works are the result of extensive experimentation and observation over a period by numerous workers. Care must be taken in comparing tables, as some relate to samples from fruiting terminals, rather than from the more usual non-fruiting terminals. For lemons the following leaf mineral concentration data has been obtained in work with various cultures and using leaves of various ages (28, 105).

TABLE II MINERAL COMPOSITION LEMON LEAVES

Element	Deficiency Symptoms	No Symptoms
N	< 2.0%	1.76 - 2.39%
P	0.082	0.113- 0.23
K	0.18	1.32 - 3.36
Ca	-	0.7 - 1.46
Mg	< 0.08	0.14 - 0.29
Na	0.003	0.003- 0.32
Fe	<47 ppm	> 55 ppm
Mn	< 5 ppm	>14 ppm
Zn	< 20 ppm	

Much more specific information is available for sweet oranges, a typical example of which is shown in Table III. It relates to 5 -7 month old spring-cycle leaves from non-fruiting orange terminals (45).

Chloride is readily absorbed by citrus leaves, especially older leaves (124), and after root or leaf absorption chloride tends to accumulate in the leaves (81). As a result lemons show pronounced burning and yellowing of leaf tips and margins, and possibly leaf curling, leaf bronzing and leaf drop (29, 87). With sweet orange seedlings only under conditions of nitrogen deficiency was leaf injury associated with high leaf - Cl levels (34).

TABLE III MINERAL COMPOSITION SWEET ORANGE LEAVES

	Deficient	Low	Optimum	High	Excess
N%	< 2.2	2.2 -2.3	2.4 -2.6	2.7 -2.8	> 2.8
P	< 0.09	.09- .11	.12- .16	.17- .29	> 0.3
K	< 0.4	.4 - .69	.7 -1.09	1.1 -2	> 2.3
Ca	< 1.6 (?)	1.6 -2.9	3 -5.5	5.6 -6.9	> 7 (?)
Mg	< 0.16	.16- .25	.26- .6	.7 -1.1	> 1.2 (?)
Na	?	?	< .16	.17- .24	> .25 (?)
Cl	?	?	< .3	.4 - .6	> .7
Fe ppm	< 36	36 - 59	60 - 120	130 - 200(?)	> 250 (?)
Mn	< 16	16 - 24	25 - 200	300 - 500(?)	> 1000 (?)
Zn	< 16	16 - 24	25 - 100	110 - 200	> 300

It appears a leaf - chloride level of 0.02 -0.20% is satisfactory (27), whereas a level of 0.75% or greater has been associated with leaf injury in citrus (29, 87).

2 Potassium Nutrition

(a) Deficiency symptoms

Potassium is a major nutrient of fruit crops and a deficiency may result in many symptoms. Unlike many other crops, in citrus there is a lack of specific leaf patterns with potassium deficiency (32). In a detailed description (30) of K deficiency symptoms in citrus, the leaves are said to become lustreless early with some vein yellowing and leaf marking - but no marginal leaf burn. Later leaves are twisted and crinkled, and new lateral shoots are spindly and S - shaped. In the lemon leaf puckering is less common, and the midrib becomes yellow - and later the main veins and mesophyll. The stems may yellow, and the bark shrivelled and pitted. Deficient leaves may curl downward more than usual (52).

Growth is reduced (30, 82), and heavy leaf fall occurs near flowering with low K supply (32).

As in other plants, iron chlorosis is induced by K deficiency (32). This could be due to a need for K to activate an enzyme important in the synthesis of porphyrins (22).

(b) Flowering

Under acute K deficiency oranges produced few flowers (32), and the new growth and flowers appeared more slowly in the spring (32). At higher K levels the trees produced more flowers and they also opened earlier (82).

(c) Fruit quality

There is considerable data on the effects of K level on citrus fruit quality. In oranges a low K level is associated with fruit of good eating quality (32, 199) i.e. the production of a high proportion of early maturing, well - coloured small fruit with a thin smooth rind, and relatively high in total soluble solids and low in acid (148).

High K levels produce a greater proportion of larger sized fruit that has a thick coarse rind and poor eating quality (30, 32, 136). There may be a yield effect, fruit colour is poor (148) and maturity may be delayed several weeks (145, 161). Fruit has lower total soluble solids, increased total acid, decreased juice content (167, 199, 203), and increased ascorbic acid (156).

In Table VI of reference (162) we note the following results from work with sweet oranges and grapefruit in U.S.A. and South Africa: with increasing rates K, these numbers of reports occur showing each effect:-

	+ve effect	-ve effect	no change
Fruit size	13		
Green colour	6		2
Rind thickness	7	1	3
Juice % weight		10	3
% solids	1	8	9
% acid	19		
TSS/Acid ratio		17	
Ascorbic acid conc.	10	3	1

The effect on fruit size, % acid, and TSS/Acid ratio being most marked.

It has been pointed out (166) some of these differences are partly due to errors in sampling. So that if fruits of the same size are analysed the differences in soluble solids and citric acid between K treatments are considerably reduced.

In the lemon, increasing the K supply has increased fruit size (32, 33), delayed fruit colouring (52), made fruit longer (52, 53), increased the percentage ascorbic acid (53), and had a major effect in increasing the amount of acid produced per ton of fruit or per acre (52, 53, 110). However, unlike other citrus, a high K level is associated with an increased percentage juice (52, 53, 54), a thinner smoother peel (41, 51, 53), and may increase total soluble solids (53). However when fruits of equal size are compared, lemons like oranges, show a lesser effect of leaf - K on percentage juice soluble solids (54).

(E) POTASSIUM PHYSIOLOGY

1. Organic acids

These compounds are undoubtedly important in plant physiology, but their role is not entirely clear and much work remains to be done with them. Increased yield has been associated with increasing organic anion content of plant (132), and organic acid metabolism is receiving considerable attention in the field of post harvest physiology.

Enzyme failure due to nutrient deficiency or imbalance leads to an accumulation of acid (especially malate) in plant tissue (176), and this effect has been used in an attempt to differentiate between iron and manganese deficiencies in citrus (9). It seems clear K nutrition may affect organic acid metabolism of the Krebs cycle, and the closely relatedglyoxylate cycle acids (71), and this enzyme effect may be due to a deranged protein metabolism (98).

Further, an interference with plant enzymes may also account for the abnormal carbohydrate metabolism that occurs in K - deficient plants.

Organic acids are important for growth, and play a part in balancing the charge of free cations in the cell vacuole. When excess cation uptake occurs, organic anions increase; and an excess anion uptake is balanced by a decrease in organic anion levels (176, 187).

The effect of K level on organic acids varies with the crop, and crops have been divided into three groups (71) by response;

(i) with increasing K, organic acids decrease.

(ii) with increasing K, total organic acids increase - in Guayule mainly due to citric acid (37).

(iii) K level has no effect on total acids of tomato (93), although the balance between individual acids changes.

In Valencia orange when leaf - K was increased, total water - soluble organic acids was unaffected, but leaf - oxalic acid level rose, and the levels of malic and citric were unaffected (141).

The relation between leaf and fruit organic acids is interesting. It has been suggested (131) organic acids are produced in the leaves and then transported to the fruits, although later information suggested their synthesis from sugars in the juice vesicles of the lemon fruit (154). A grafting experiment with lemons showed the fruits have their own metabolism, independent to the leaves that feed them (57). We saw above that K level did not affect orange leaf citrate level, whereas K has a large effect on fruit acid content - which is largely citrate. A recent study with lemons (14) demonstrated the presence of two enzymes in the fruits which could account for their malic/citric acid content. However there is still some doubt as to the importance of fruits in synthesising their organic acid content (93). Further data on the extent to which leaves modify fruit composition would be useful.

CHAPTER III MATERIALS AND METHODS

INTRODUCTION

This is a study in lemon leaf mineral analysis, following foliar applications of potassium salts. Data was also collected on the effect of potassium status on tree growth, fruit quality, and leaf organic acid content.

This study was intended to provide some information of physiological interest, and also to be relevant to commercial citrus production. So the methods of analysis selected for use were those most accurate and satisfactory within the limits of the equipment available. As far as possible the methods of leaf mineral analysis were the same as those used in current research and advisory work in New Zealand.

For experimental work to have field application, its results must be obtained under field-like conditions. Much laboratory work cannot thus be usefully extrapolated to commercial practice. It was convenient to grow the trees in containers outdoors, and this gives ready control of management, and a more uniform material. Tree behaviour in these conditions can be expected to be similar to that of orchard trees. Measurement of leaf absorption under glasshouse conditions, or in the laboratory using detached leaves is not capable of direct extrapolation to the field situation where the whole - plant condition, and the vagaries of the weather, are of utmost importance. In this study then, these objections cannot be sustained.

N ←

PLAN

*   Trial trees, numbers 1 - 24, A - E.

+   Assorted citrus and apple trees in containers.

Scale ½" = 6' 6".

```
  + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + +

  + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + +

+   +   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   +
        C   13  14  15  16  17  18  19  20  21  22  23  24  D   E

+   +   *   *   *   *   *   *   *   *   *   *   *   *   *   *   +   +
        A   1   2   3   4   5   6   7   8   9   10  11  12  B
_____________________________________________________________________
                             Brambles
```

A EXPERIMENTAL DESIGN

1 Materials

Lemon trees (Citrus limon) of the main commercial variety Villafranca were used. Thirty trees, two - years old, budded on sweet orange rootstocks were obtained from a nursery in Auckland. Trees were selected for good condition and uniformity, and were received on 28th May, 1968. Leaf colour was good, although spider mites had caused moderate damage.

The trees received balled in soil. Most of the soil was removed, and each tree then planted in a 5 - gallon tin, filled with a 50-50 mixture of peat and sand. Each tin was painted inside with a bituminous paint (89, 143), and provided with a drainage outlet. Nutrient feeds and water were provided as detailed below.

2. Layout

For frost protection the trees were placed beneath a large macrocarpa shelterbelt for the first four and one-half months. Then for three and one-half months until 31/1/69 the trees were placed in the orchard in randomised blocks in single line, the 24 most uniform trees being divided into four treatments with six replicates. It appeared this would provide useful data in this study (99).

After 31/1/69 the trees were randomised in plots as shown in the plan,, in an open situation reasonably sheltered from all winds, and clear of normal orchard spraying. For frost protection the soil was kept weedfree in the tree rows, and in the winter scrim was erected above each row.

Plate 1.
Trial area - two rows in foreground experimental trees.

Plate 2.
One tree as prepared for foliar spraying.
January 1970.

The trees were numbered 1 - 24 consecutively, so that

trees numbers:	2	5	9	16	19	22	were in treatment	1
" "	4	7	10	13	17	24	" " "	2
" "	1	6	11	15	20	21	" " "	3
" "	3	8	12	14	18	23	" " "	4

The five remaining trees were labelled A - E, and received the same management as the above trees.

A general view of the trial area is shown in Plate 1, the experimental trees being the two rows in the foreground. Plate 2, also taken on 27/1/70, shows one of the trees as it would be prepared for foliar spray treatment.

3 Management

(i) Nutrition/irrigation

Growing plants in containers aids standardisation of plant management and treatment, especially with respect to nutrition. The use of small containers requires special handling to avoid excess salt buildup or shortage of water.

Nutrient elements were supplied only as nutrient solution watered around each tree. In this way all essential elements except potassium were supplied. Potassium was supplied only as demanded by the experimental treatments.

For most of the time nutrients were applied at the equivalent of ;

(in ppm)

Ca 208	N 146	Mg 94	P 14	Na 10
SO_4'' 189	Fe 2.5	Mn 0.55	Zn 0.2	
Cu 0.07	B 0.3	Mo 0.02		

- being similar to that used by other workers (see Table I.)

With young apple trees in sand no growth response occurred from a nutrient solution containing >4 ppm P; and with a N supply of 60 ppm it was considered to be approaching the luxury range (12). Over the first six weeks the trees received P 31, and over the first eight months Mg 47 ppm.

Concentrated bulk solutions were prepared as shown in Appendix 1. For the first nine months the diluted nutrient solution was applied by hand and for the remainder of the period the concentrate solution was watered in by trickle irrigation. This system used ½" hose and Cameron trickle nozzles to provide each tree with a convenient source of water - especialy in the summer. The aim was to supply each tree with the equivalent of 2 - 4 litres per week of the above nutrient solution, the quantity varying with the season. Any extra water requirement was supplied only as water.

To avoid excess salts buildup each container received a heavy watering each 3- 4 weeks in summer (less often in winter), and at each watering enough was applied to provide some drainage loss. By such generous fertiliser applications, frequent renewal (by flushing) of nutrients, adequate watering, and frequent checking of uniformity of trickle output it was felt variation in nutrient supply between trees would be negligible. It is also fortunate for this study that the effects of potassium (and magnesium) are little affected (especially compared with nitrogen) by variation in supply of other elements (168).

Because of the possibilities of low copper supply in peat/sand culture (129) additional copper was applied. This was done by dissolving copper sulphate penta-hydrate in water, applying to the 29 remaining trees a total of 52 gms. and 26 gms. on 23/12/68 and 7/10/69 respectively.

(ii) Therapeutants

For pest/disease control it was necessary to apply certain sprays, which were kept to a minimum:

Difolatan fungicide (for verrucosis)
1968 - 28/6, 20/9, 6/11.
1969 - 4/9.
Systemic insecticide (for European mites)
1968 - 28/6, 20/9, 6/11.

(iii) Fruit thinning

The number of fruits on a given size tree has a considerable effect on fruit quality - fruit size, rind thickness, and juice, sugar and acid content (121). It was therefore necessary to standardise fruit number per tree. As expected (58, 142) fruit drop was heavy, and in mid-February 1969 when completed any trees carrying more than six fruitlets were thinned to six, although half the trees had three or less. Any flower buds, produced from this date were removed.

4. Treatments

(i) The experimental treatment was variable potassium supply. This element was not applied in the nutrient solution, but was applied mainly as foliar sprays to certain treatments. In this way trees with three or four K levels, from low to high would be produced. Various effects would then be studied in relation to K - status.

Season of K application

Treatment No.	Spring 1968	Summer '68/'69	Autumn 1968	Spring 1969
1				
2	X			
3	X	X		X
4	X	X	*	X

* soil application only

X signifies leaf K application

Potassium sprays were applied as the chloride, at 274.4 gms. KCl/11 litres (pH 6) plus Agral LN wetter at 0.09%. This is equivalent to 25 lbs KCl/100 gals., or 1.3% K. Sprays were applied with a hand sprayer in the morning thus:-

1968 Spring 12th Dec. and 17th Dec.
1969 Summer 5th March and 11th March.
Spring 10th Dec. only.

At the end of the first season, from 14/4/69 trees in treatment number 4. (and also tree B) received the equivalent of 100 ppm K as soil application (applied as the sulphate) with each nutrient application.

(ii) The trees A - E were used for various purposes:

(a) Trees A, B, D sprayed with KCl as above on 5th and 11th March, 1969 (Summer).

(b) Tree B received soil - K as above from 14/4/69.

(c) Sprays as follows applied on 10/12/69 (Spring):

A - potassium chloride

C - potassium nitrate

D - potassium carbonate

E - unsprayed

All sprays contained 1.3% K and 0.09% Agral LN.

As the extent of foliar absorption from potassium sprays was to be measured it was important to minimise soil contamination,

Immediately before spraying the container - grown trees a 2" layer of fine dry pumice was spread around each tree. The top of the tin was covered with a thick plastic cover securely tied to the tree stem to facilitate spray runoff (Plate 2). Beneath the tie to the tree was a thick wad of absorbent paper. After spraying any wetted pumice was discarded, and the absorbent paper renewed, and the plastic re-tied. This procedure was repeated after the second spraying, after which the plastic remained attached for 10 - 14 days. Water was applied as required during this period. When the plastic cover was removed the pumice was renewed, and the trees given a heavy watering.

It was considered any soil - K was negligible after this treatment.

(iii) Four young Meyer lemon trees growing in the field were sprayed as above on 10/12/69:-

Tree no. 1	potassium chloride
2	potassium nitrate
3	unsprayed
4	potassium carbonate

To minimise spray contact with the soil when spraying field-grown trees a plastic cover was placed beneath each tree during spraying, and left until the spray deposit had dried.

All sprays were applied to runoff.

(iv) Trace element sprays were applied as detailed below to the Villafranca trees. Based on the good results obtained elsewhere (119) both manganese and zinc were applied as the sulphate at 300 ppm of metal, with 0.09% Agral LN.

Details of trace element foliar sprays

Date	Block No.	Tree No's	Metal
28/1/70	1	1 - 4	Mn
	6	21 - 24	Mn
	3	9 - 12	Zn
	4	13 - 16	Zn
	2	5 - 8	Mn + Zn
	5	17 - 20	Mn + Zn
13/2/70	6	21 - 24	Mn
	4	13 - 16	Zn
	2	5 - 8	Mn + Zn

5 Sampling

(i) Container growing

Observation on tree growth and condition over a period, combined with the various measurements made, should indicate the success of this method of citrus culture : especially as regards medium - pH control and trace element availability, and adequacy of feeding and watering methods. This work could not however be considered as a detailed comparative study of container growing methods.

(ii) Seasonal changes in leaf mineral content

The trees were sampled on:

3/3/69, 11/4/69, 6/8/69, 10/12/69, and 7/1/70

and on each occasion leaf concentrations of nitrogen, potassium, phosphorous, calcium, magnesium, sodium, manganese, iron and zinc were determined. This would roughly indicate changes for each element through one season, or alternatively for leaves of increasing age.

Leaves (with petioles) sampled were of normal shape, undamaged, typical of the tree, and as far as possible taken only from non-fruiting spring flush terminals. At the final sampling care was taken to avoid terminals on which the summer flush had commenced.

Based on other work (46, 116, 120, 173) sample preparation was as follows. Leaves were collected mid-morning in separate linen-bags (6 - 9 leaves/tree) and immediately washed in 0.1% detergent, and quickly rinsed successively in three lots of water, and dried between sheets of blotting paper. Leaves were then placed in a 150 ml. beaker and dried for 36 - 48 hours at 75° - 80°C. Samples were finely ground in a grinder (largely aluminium) and kept at 65°C until analysed. Analyses were completed within three weeks of sampling.

(iii) Foliar Uptake

(a) Leaf potassium

Due to insufficient material leaf samples were not taken in the spring of 1968, the first samples being taken about 11 weeks after the first series of K sprays. Subsequently samples were taken up to two days before spraying, and also one month after spraying, with an intermediate harvest in winter.

This showed:

(a) The effect of K sprays on leaf - K over a period of one up to ten or more months, and a comparison between spring and summer sprays.

(b) In order to indicate the shorter - term effects of sprays on leaf K, trees A, B, D also were sprayed with the chloride on 5th and 11th March. Trees A - E were sampled on 3/3, 19/3, 27/3 and 11/4/69 i.e. 8, 16 and 31 days after spraying, for potassium determinations.

(c) Since we have seen salts vary in their capacity to alter plant composition a small investigation was made. Potassium salts with a range of hygroscopicity were applied at 1.3% K (see earlier). Changes in leaf - K were determined after one day in Meyer and Villafranca lemon, and also after eight days in Villafranca.

(d) The application of potassium to the rooting media from 14/4/68 produced trees with a high potassium level, and also enabled one to investigate root uptake/translocation over the winter.

(b) K effect on other elements

The extent and direction of any possible effects of tree - K level on the leaf concentration of eight other elements was determined. Certain clearcut effects are well documented following variations in soil uptake (98, 160, 168) but in only a few reports following leaf uptake (50, 188).

As an adjunct to this it was of interest to investigated the constancy of the cation equivalents, and the cation: anion ratio.

(c) Leaf chloride

Leaf accumulations of chloride can be very damaging, and this may be an important problem where citrus are grown in saline soils (29, 34, 74, 81), or through leaf absorption following sprinkler irrigation with saline water (85).

Since potassium was applied as the chloride in this study it was considered necessary to determine the degree of chloride accumulation. For this purpose a chloride analysis was performed on the samples of 6/8/69 and 7/1/70.

(iv) Potassium Effects

(a) Tree growth

Detailed observations were made of tree conditions and behaviour over the period, especially noting any effects on degree and earliness of flowering, fruit set, tree vigour, leaf-fall, and appearance of deficiency symptoms or phytotoxic symptoms.

(b) Fruit quality

In view of the apparent differences between orange and lemon response to K level, fruit was harvested on 3/12/69 and analysed for : peel colour, texture and thickness, fruit shape, juice content, ascorbic acid level, and titratable acidity.

(c) Leaf organic acids

Organic acids are important but poorly understood substances in plant metabolism. Commercially citrus fruit organic acids are important, but their relation to leaf organic acids is not perfectly clear. Plants vary their organic acid balance in response to increasing potassium supply (71), and more data is required relating to citrus.

Leaves sampled 7/1/70 were used in the determination of total nonvolatile organic acids, and also on 6/3/70 for oxalic acid concentration. One could thus examine certain effects on total acid content and balance.

B Analytical Methods

1. Nitrogen

The method used has been the standard method in advisory work, and is capable of giving very good results(200).

Method - Oven-dry sample (about 100 mg.) digested with 5 ml. 98% sulphuric acid and about 1.4 g. catalyst in a 20 cm. calibrated urea tube. Digestion continued for 80 minutes after clearing, cooled, and made up to 50 ml. with distilled water.

A 5 ml. aliquot is distilled in a Markham apparatus with

10 ml. sodium hydroxide. About 15 ml. distillate collected in 5 ml. 2% boric acid (and 4 - 5 drops indicator), and titrated with 0.01N HCl. (See Appendix 2 for reagent details)

Leaf - N was derived from the formula:

$$\% \text{ N (dry weight)} = \frac{14 \text{ x net titre x Normality acid}}{\text{dry weight (gms)}}$$

2. Phosphorus

This element was determined colorimetrically after wet ashing, by the molybdivanadophosphoric acid method, which is a rapid and sensitive method useful for many materials (108, 109).

Method - 0.250 gms, oven dry sample is digested in a 20 cm. graduated urea tube with 3 mls. conc. nitric acid and 2 mls. 72% perchloric acid for about one and one half hours, when dense white fumes appeared. Diluted to 50 mls. with hot distilled water and stood overnight.

In a 25 ml. volumetric flask 5 mls. vanadium molybdate reagent added to 5 mls. sample solution and 15 mls. water. Colour development was read at 450 mμ after one and one half hours, against a distilled water blank, and leaf - P calculated from a standard curve, and where : $\text{leaf - P (\% dry weight)} = \frac{\text{solution P (ppm}}{10}$

(See Appendix 3 for details)

At the first two samplings an Eel colorimeter was used, and subsequently a Hitachi spectrophotometer.

3. Potassium / Sodium

The same diluted, wet-ashed sample as prepared above for P was used.

Method - 5 mls. was made up to 25 mls. with distilled water and readings taken on a Gallenkamp flame photometer. Leaf - K and leaf - sodium were determined from standard curves prepared at each sampling, where :

$$\text{leaf \% K} = \frac{\text{solution K (ppm)}}{10}$$

The use of flame photometry for K, Na is an accepted, accurate method of determining these elements (35).

4. Magnesium, Calcium, Manganese, Iron, Zinc.

Each of these elements was determined by atomic absorption spectrophotometry, using a Techtron Spectrophotometer. This method is rapid, simple, and accurate (1, 2.)

Method - About 1.2 gm. finely ground oven-dry sample was ashed at 450°C for about ten hours. This produced about 100 mg. ash which was used in the determinations.

To each ashed sample add 10 mls. 2N HCl, filter, and take readings for manganese, zinc, and iron.

Then 1 ml. each sample made up to 50 mls. with 2N HCl and Strontium Nitrate (20 gms. in 3 litres), and readings taken for magnesium and calcium.

Two series of standards were made up :

(i) Mn+Zn+Fe - diluted with 2N HCl

(ii) Ca+Mg - diluted with 2N HCl + $Sr\ NO_3$

Usually it was sufficient to prepare each in 20, 10, 5, 2.5, 0 ppm for the preparation of a standard curve, then:

$$\text{Leaf - Mn, Zn, Fe, ppm (D, weight)} = \frac{\text{solution ppm. x10}}{\text{dry weight (gms)}}$$

$$\text{and leaf - Ca, Mg \% (D Weight)} = \frac{\text{solution ppm}}{\text{20 x Dry weight (gms.)}}$$

5. Chloride

Leaf - Cl was determined (35) following ashing a paste of about 1 gm. oven-dry material with about 0.25 gm. Ca O, at 550°C for one and one half hours.

On hot-plate add 15 ml. hot water to ash, stir, and filter, washing residue with 5 x 10 mls. hot water. Cool, add dilute acetic-acid to pH 6-7, add 5 drops 1% potassium chromate, and titrate with 0.05 N silver nitrate to permanent silver chromate colour. Leaf - Cl is derived from the formula :

$$\% \text{ Cl (Dry Weight)} = \frac{\text{titre} \times 0.1775}{\text{Dry Weight (gms.)}}$$

Fruit analysis was as follows:

6.

At harvest, for each fruit a record was kept of rind colour and texture, fruit length and width, peel thickness, and fruit weight. The juice was expressed by hand and weighed.

7.

Ascorbic acid was determined (6) as follows:

(a) Juice = 2 cc. juice mixed with 2 cc. extractant solution within one hour of juicing. Then titrated immediately with a standard indophenol solution.

(b) Peel Ascorbic acid concentration in the peel was also determined, but timing was especially important (49). Weighed 25 - 30 gm. peel and chopped coarsely. Within five minutes extracted in a Waring blender at high speed for two minutes, with 150 ml. extractant (no difference was found between peel : extractant ratio 1:5, 1:7½, 1:10).

Filter.

Within three hours of extraction 5 mls. aliquot mixed with 5 mls. extractant solution and titrated with indophenol.

In both cases ascorbic acid content was calculated from the net titre, compared with a standard ascorbic acid solution.

(See Appendix 4 for details of reagents)

8. Total soluble solids

This was determined for each juice using Abbe '60' refractometer.

9. Titratable acid

The standard method was used (95), involving heating 2 cc. juice until boiling began. Add 25 ml. distilled water and 5 drops 1% alcoholic phenolphthaloin, and titrate to distinct red colour with 0.1N NaOH. Then gms. acid/litre (expressed as citric) = 3.2 x Titre.

Leaf organic acids:

10. Oxalic acid

The method used was basically that of Palmer (135) as modified in other citrus work (141), but in addition:

(a) 3N NH_4OH

and (b) 0.02^N $KMnO_4$ were used.

Method :- 0.0250 gm. dry tissue heated with 10 ml. 1N HCl on a steam bath for fifteen minutes, then cool and make up to 25 mls. Shake, stand overnight, filter and pipette 5 ml. into a 15 ml. centrifuge tube. Add 5 ml. phosphate tungstate reagent, mix, stand five hours, and centrifuge at 1500g for ten minutes.

Take 5 mls. supernatant in a centrifuge tube, and add $3N_4OH$ until phospho-tungstate is precipitated (1 - 3 drops). Add 3 mls. calcium chloride/acetic acid buffer, mix, stand overnight.

Centrifuge at 1500g for ten minutes, decant, wash sediment with about 5 mls. 5% acetic acid saturated with calcium oxalate. Stir and centrifuge.

Dissolve precipitate in 5 mls. 4N sulphuric acid, heat in water bath, and titrate hot with 0.002N potassium permanganate.

Then 10 ml. permanganate is equivalent to 0.09 mg. or 0.02 m.eq. of oxalic acid.

(See Appendix 5 for details of reagents.)

11. Total non-volatile organic acids

A sample of 7 - 9 leaves was collected from each tree on 7/1/70, as for mineral analysis, and wiped clean. Freeze - dried and stored at - 15°C until analysed. Samples then ground, and dried about one day at 70°C. The method was basically that of Palmer (135), acids being eluted from a prepared Dowex 1-X10 column with 6N acid.

Method About 0.3 gm. dry weight sample extracted with 80% alcohol (as has been used recently (123) by shaking with 10 cc. alcohol for half an hour at room temperature. Filter, reduce to about 2 cc. in rotary evaporator, and water bath at 30°C, elute through column. Reduce each of the first four 2 ml. fractions to dryness, add 2 cc. distilled water, and titrate against phenol red with 0.02N NaOH.

$$\text{Then m.eq. \% acid (Dry Weight)} = \frac{\text{titre x Normality x 100}}{\text{dry weight (gms.)}}$$

This does not include oxalic acid.

CHAPTER IV RESULTS AND DISCUSSION

A SEASONAL LEAF MINERAL LEVELS

The results of the leaf mineral analyses are given in Appendix 6, expressed as either percentage or parts per million (ppm) on an oven - dry weight basis. On some occasions results are given as milli-equivalents, and for certain purposes these figures were converted into this form (153). The means of each element at each harvest date, and for each treatment are shown graphically on Figure 1 - 8. For each harvest the level of each element has been compared between treatments by an analysis of variance, and then by Duncan's Multiple Range (48) where significance exists. Details of these analyses are shown in Appendix 7.

1. Nitrogen

The pattern of leaf - N is the same in each treatment. There is a difference of low significance between treatments at 11/4/69. On 10.12.69 treatment (3) is slightly higher. It seems this difference is unimportant and possibly due to a difference in N availability and is accounted for by two high reading samples, although it is of interest that the difference between treatment 3 and treatments 1, 2, 4 becomes greater at the 7/1/70 harvest. High K supply is likely to decrease leaf N, (160) but this does not occur here, where leaf N is very similar in the K - deficient treatments. Other than N, Cl supply is the only other element likely to affect - N. Again this factor, where treatments vary in leaf - Cl, cannot be used to explain tratment differences in leaf - N or the general decline in leaf N during the twelve

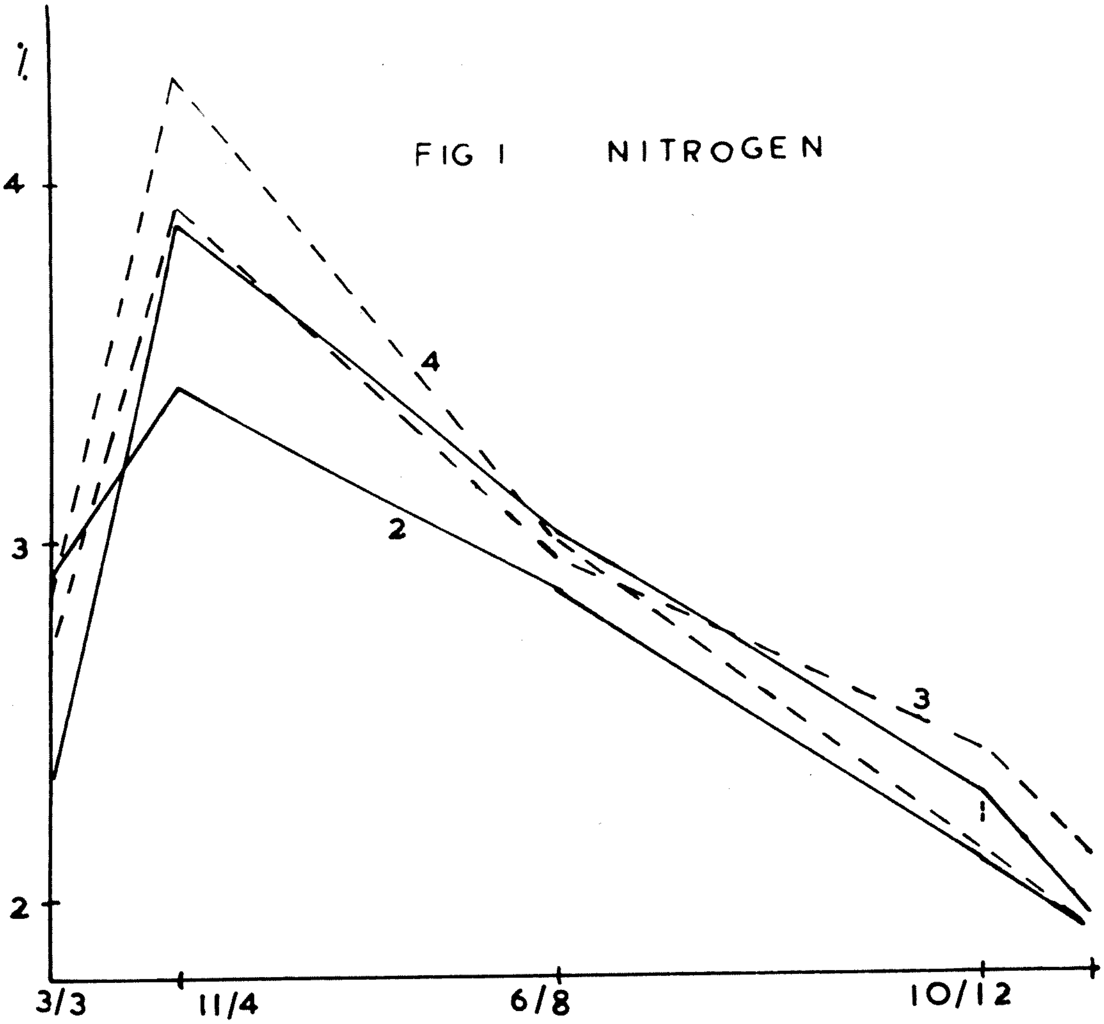


FIG 1 NITROGEN

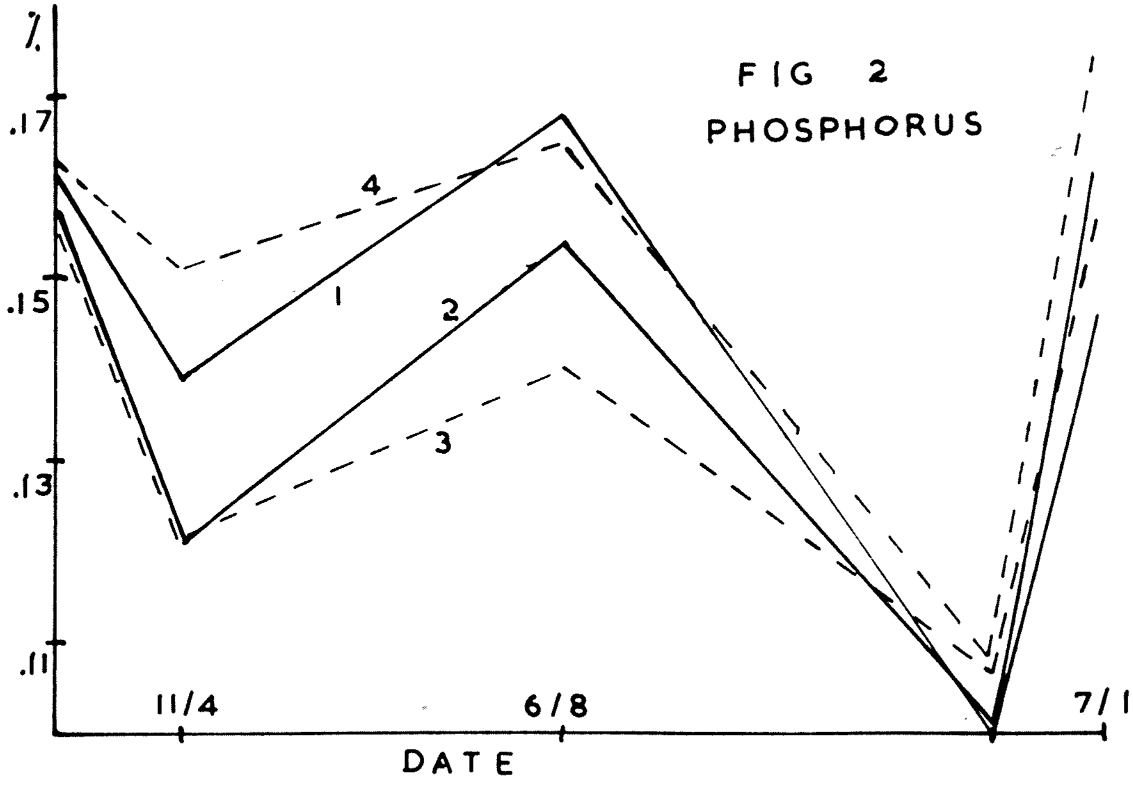


FIG 2 PHOSPHORUS

month period studied.

N uptake by orange trees is greatest in the period 6 - 30 weeks after bloom (150), and along with its great mobility and essentiality for growth we find leaf N highest in young leaves followed by a decline (163, 165), although the peak may occur somewhat later (100) as has occurred here in all four treatments. It would seem this peak is on the high side and could affect the levels of other elements at that time. The fall in leaf - N to August is expected, but the low spring levels in 1969/70 is surprising although not impossible. It would be intersting to know whether leaf N had risen to the optimum level of 2.5% by March 1970.

At a given sampling, leaf - N is usually higher in summer - flush than spring - flush leaves (165), but this effect is not noticeable here at 11/4/69 and 6/8/69 when up to 60% of samples in treatments 1, 2, 4 contained summer - flush leaves.

2. Phosphorous

While the pattern of leaf - P is the same in each treatment, again there is no obvious consistent relation between K level (i.e. treatment) and leaf - P. Foliar K sprays have increased P uptake from the soil (181), but since they also increased plant leaf area, the concentration of leaf - P may not have changed. In contrast to other reports (100, 165) these results show no marked decline in leaf - P from summer to winter, and as with leaf - N, a distinct plateau in leaf content is not present about April. For investigating this effect it is desirable for more frequent sampling than in the present instance.

Most commonly low P is associated with high N and the significant N - P correlation coefficient obtained demonstrates the presence of this relationship over the five harvests. The low leaf - P at 10.12/69 and the considerable increase over the next month was unexpected as leaf P concentration is usually found to be high in very young leaves, with a rapid fall over the next few months. The low December levels may be due to an uptake/mobility problem in the containers, although it does not coincide with a high leaf - N or a cold spring, both of which would reduce leaf - P. Summer P levels are within the optimum range.

3. Potassium

Figure 3 shows clearly the steady fall in leaf - K with increasing leaf age, and the reduced rate of change in concentration from about early April, so often reported. These trends exist in all treatments.

It is clear in the case of very low K supply (treatments 1 and 2) one sampling of five month old leaves (early March) as usually recommended, would be misleading. At this time leaf - K is in the optimum range, but within a month has fallen below it, whereas with a more moderate K supply five and six month old leaves are equally reliable. A recent report supports this need for special care in sampling lemon trees for K analysis, and it was stated a sample of leaves less than five months old may not indicate a deficient K level even though a deficiency exists (54).

The higher mean leaf - K for treatment 4 at 3/3/69 is mainly due to one tree, but is not significantly greater than in other trees treated similarly up to this time. The availability of soil K from early April has not increased leaf K for the rest

FIG 3 POTASSIUM

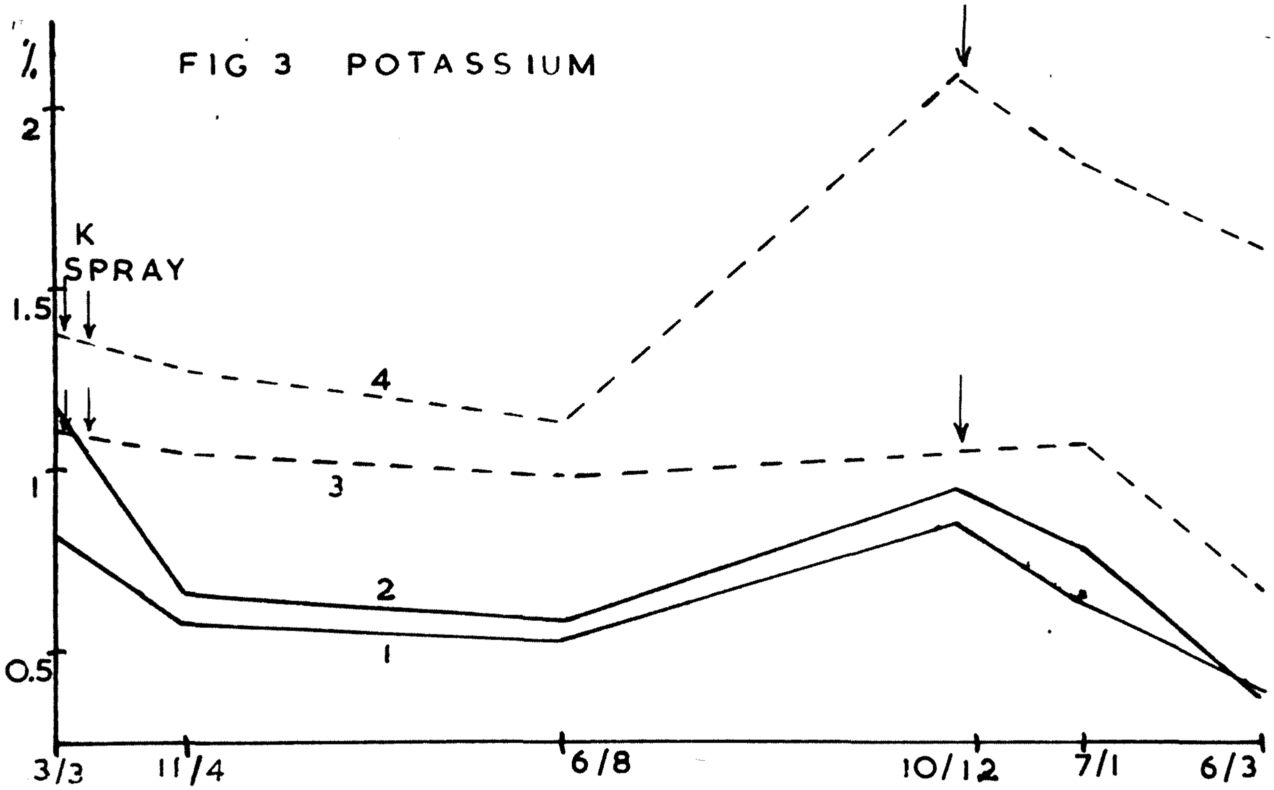
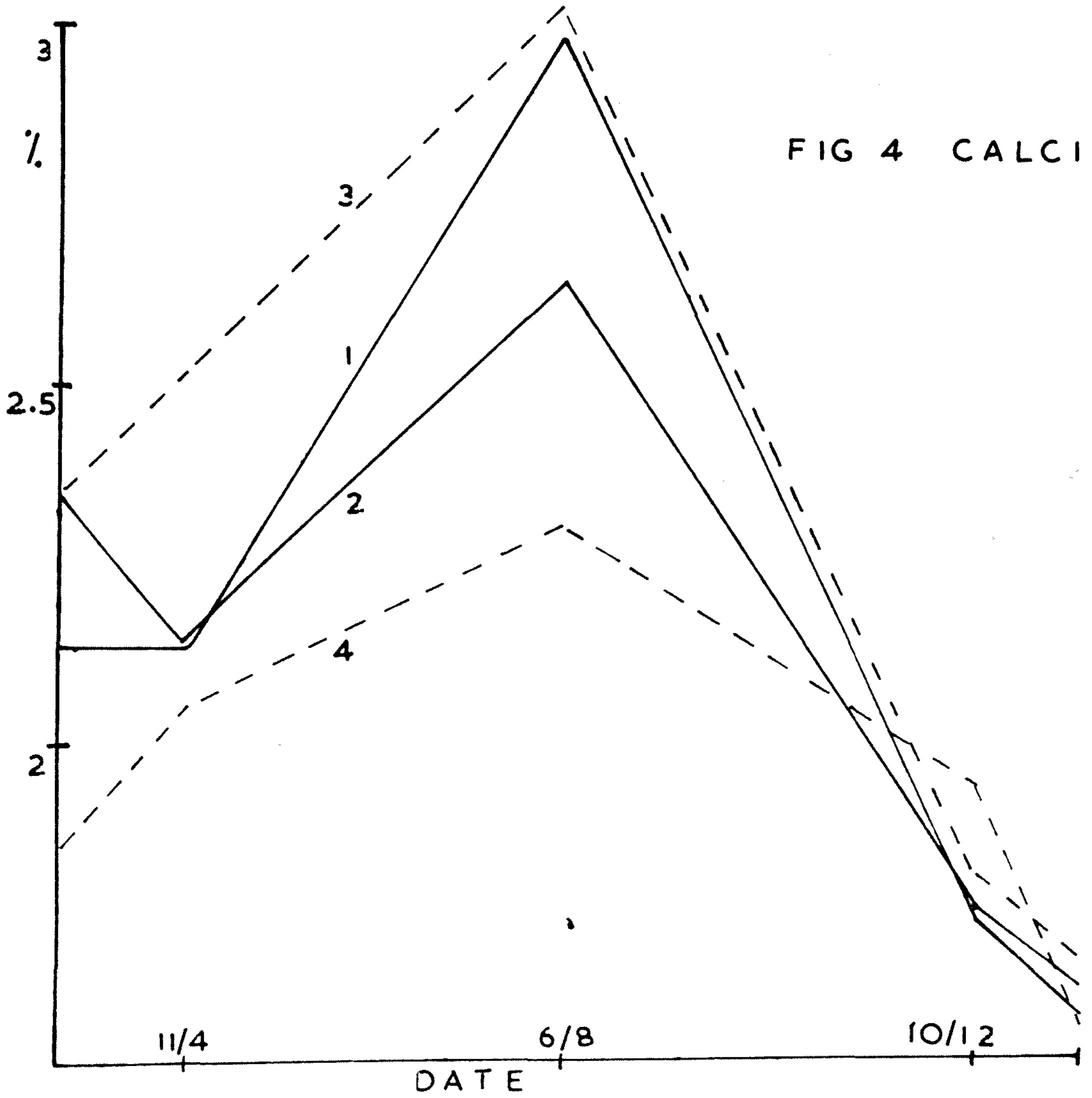


FIG 4 CALCIUM



of that growing season. Any K taken up in this period must remain in other parts of the tree, and such reserves probably contributed to the high leaf - K the following spring. Mineral uptake is low in winter (150), but with the resumption of growth in the spring such root-stored nutrients are quickly translocated to the aerial parts of the plant.

Fruits usually have a high K requirement, but these results suggest only a negligible effect of fruits on leaf - K. Virtually no fruit existed on treatment 4 trees in the summer of 1969, and even with a high K supply, leaf K shows no great increase in this period. Most trees of treatment 1 carried a light to heavy crop, but leaf K during the twelve months is little different from that in treatment 2, where again fruit wās almost totally absent. It would seem more likely that in the March - August period fruit K accumulates more at the expense of root/stem - K than leaf K, any leaf - K lost to fruits quickly being replaced by K from other parts of the tree.

It is not possible to indicate the influence of smaller fruits on leaf - K, since looking at the second season (up until March) the rate of fall in leaf - K is similar in all treatments and they each had bore a similar fruit number.

4. Calcium

The time sequence for leaf - Ca in all treatments shows the usual (100, 165) low level in young leaves with an increase to a peak in older leaves. The only occasion of significant differences between treatments is on 6/8/69, and there is no obvious relation then between leaf Ca leveland the leaf levels of those elements most likely to affect leaf - Ca, namely N, P, Mg, K.

FIG 5 MAGNESIUM

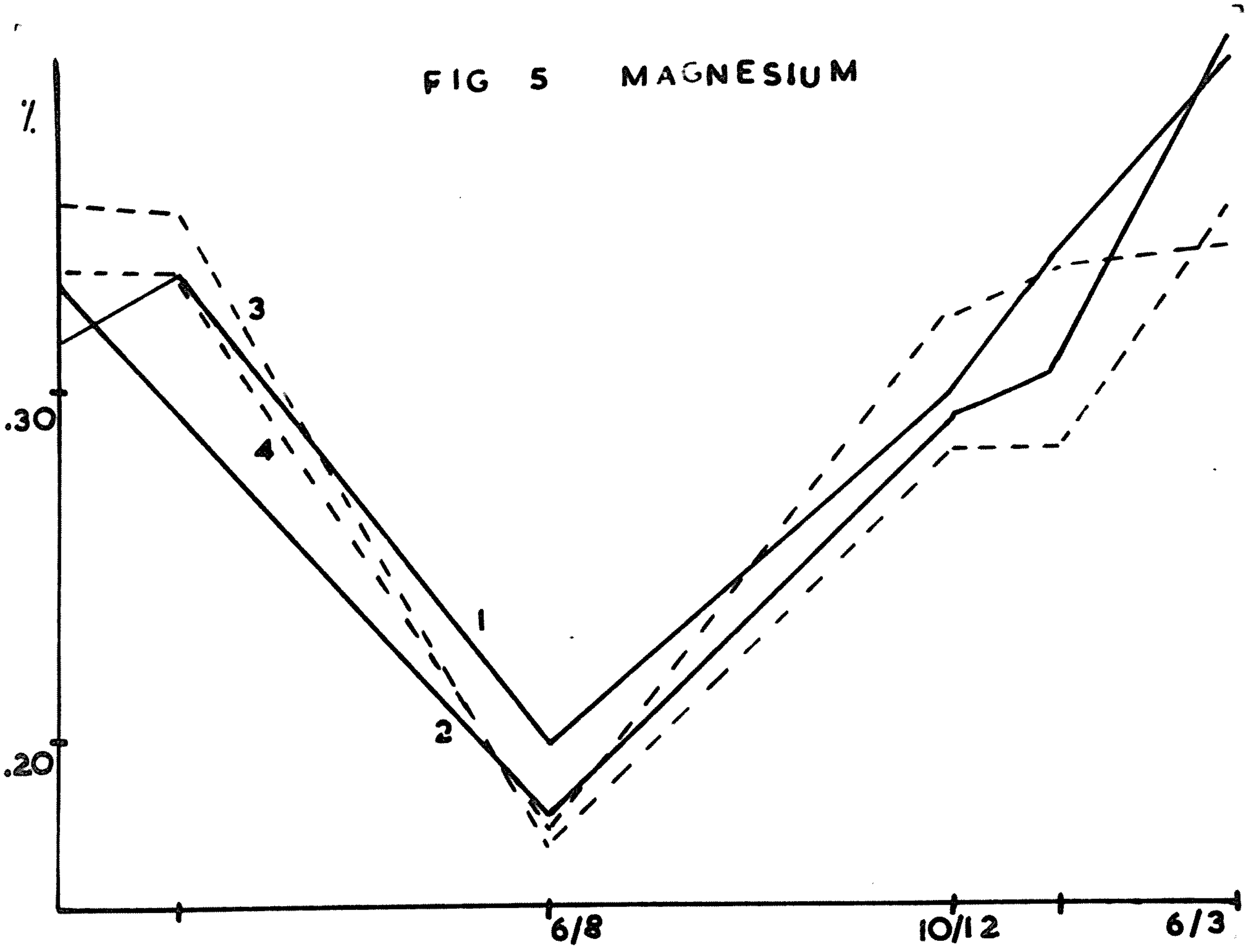
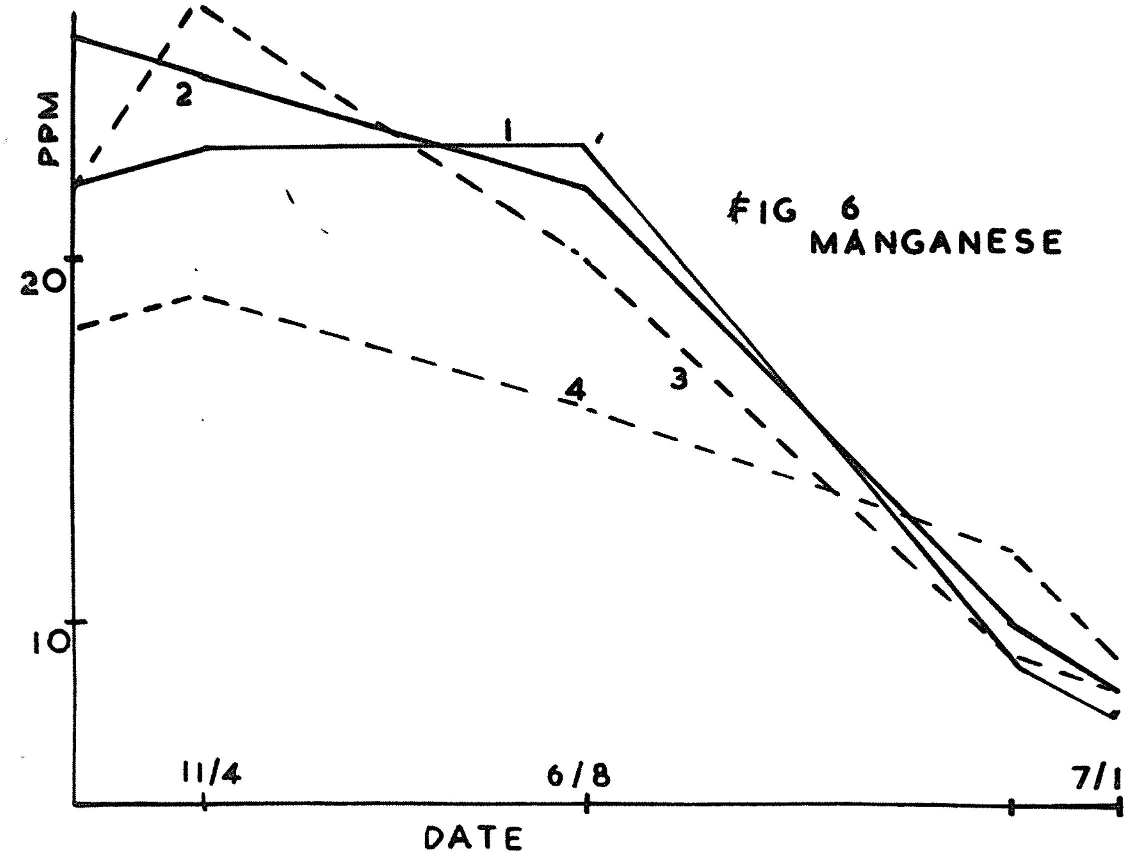


FIG 6 MANGANESE



As we have seen with other elements, any interrelationships between their leaf concentrations are not necessarily simple ones - in fact widely accepted in the field of leaf analysis.

5. Magnesium

The results show a rise in leaf Mg in the spring a decline in autumn, and a plateau in leaves about five months old. The leaf Mg levels are similar at all harvests, and it is only fifteen months (6/3/70) after differential K treatments began that we get the first significant difference in leaf - Mg. This may be a direct K - Mg antagonism, a more minor effect if any being due to plant N or P content.

Summer leaf Mg is well within the optimum range.

6. Manganese

Seasonal trends are not readily apparent, leaf levels remaining stable at a level somewhat below optimum in the first season, and still lower in the young leaves. This latter effect may be accentuated due to the apparent low supply of this element. Often high N is associated with low Mn, but any such relationship is not a close one.

7. Zinc

The seasonal trend appears to be a decline with increasing leaf age, the fall possibly being earlier and steeper as zinc continues in low supply. Although analysis shows few significant differences the trend appears to be for high K to be associated with low Zn in the older leaves of the first season and with high Zn in younger leaves (especially in conditions

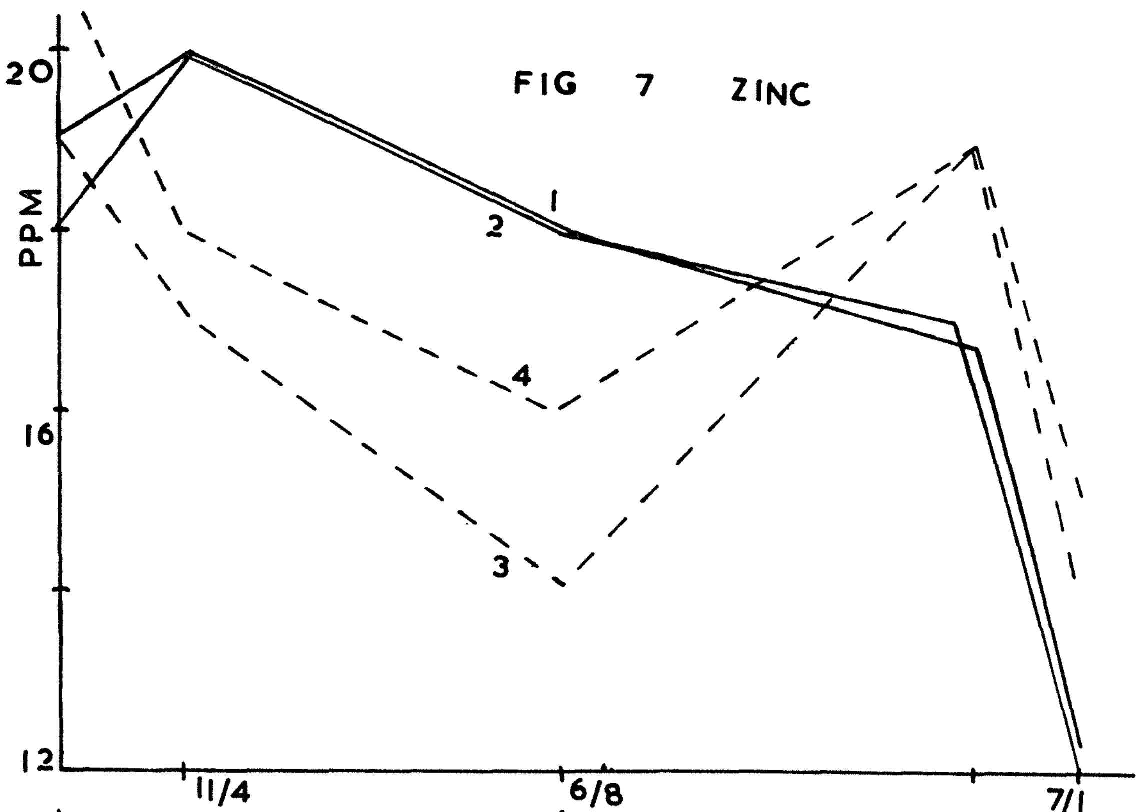


FIG 7 ZINC

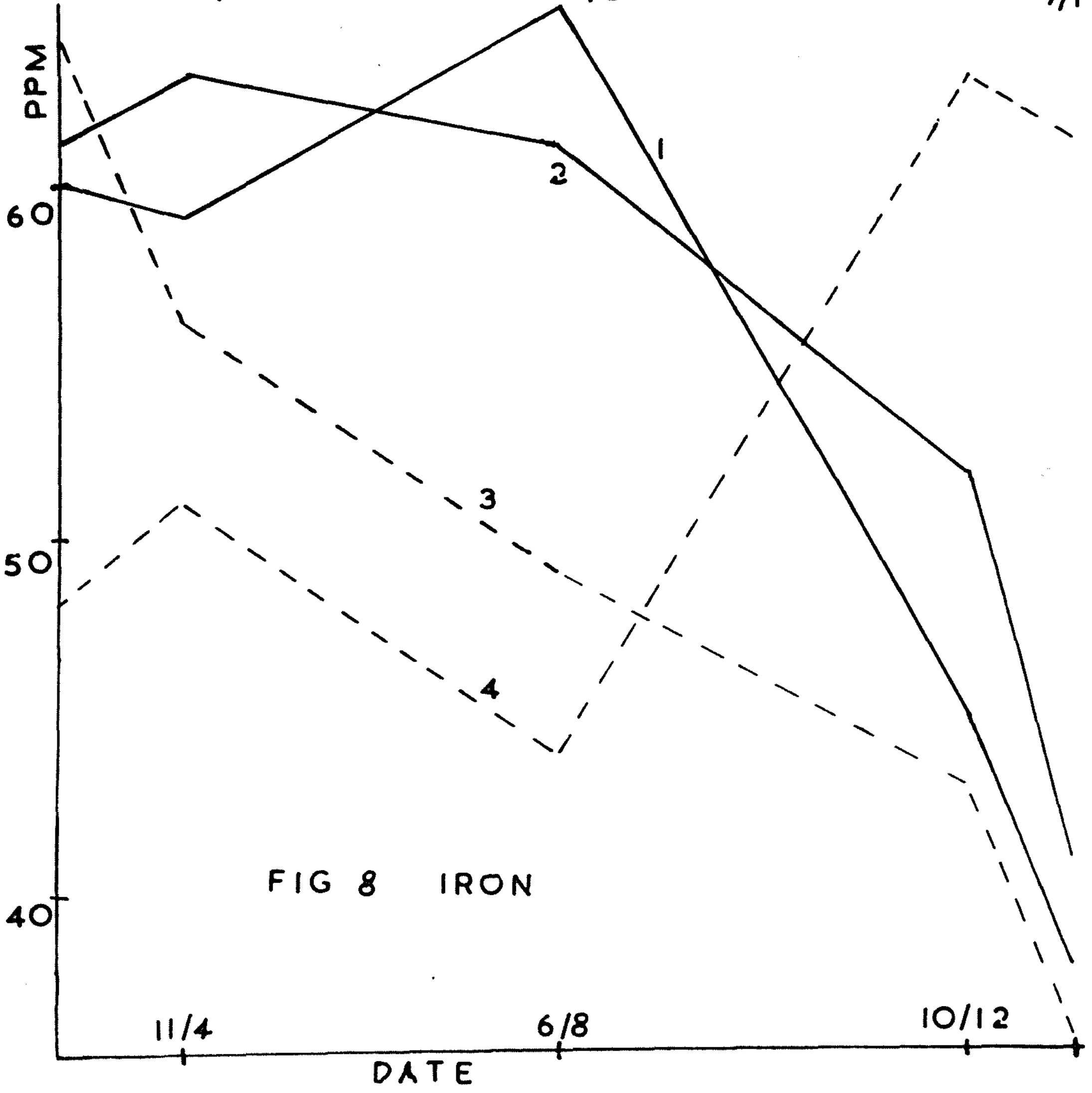


FIG 8 IRON

of low Zn supply).

8. Iron

In the abnormal situation of no soil - K iron seasonal trends are as for Mn, Zn. Data for the winter suggests the association high K - low Fe, the two extremes being almost significant at 1% level. This effect of high K - low metal has often been reported, but in this work the effect is most noticeable at the winter harvest (nine month old leaves), and in the order Fe > Zn > Mn.

The situation is different the next spring, when the treatment receiving soil - K, and with a significantly higher leaf - K also has a significantly higher leaf - Fe. It has been noted in citrus, K deficiency induces iron deficiency (32), and high K feeding increased leaf - trace elements (168). As opposed to the winter situation in old leaves of

(i) high K - low Fe
(ii) low K - high Fe

we find here in young spring leaves :-

(i) high K - high Fe
(ii) low K - low Fe (i.e. K = 1.1%)

These differences in behaviour may be due to the difference in leaf age, or to an interaction with a third element (168).

9. Sodium

While some plants are notable in the extent to which Na can replace K as a nutrient, and in citrus low leaf - K may be found associated with high leaf - Na (85) such a relationship is not apparent in these trees. The situation may have been different had the nutrient solution had a high Na content.

On the basis of these results it would seem that for the lemon April is the best month fo mineral leaf analyses. Variations from this are :-

(a) late March also suitable for Ca, Zn, Fe, Mn.

(b) early March to mid-April most suitable for Mg.

and (c) April - August suitable for K, but under conditions of high K April and May may be satisfactory.

B POTASSIUM SPRAYS

1. Foliar Absorption

(i) K C 1

Soil - applied K is more slowly effective on K - fixing soils, calcareous soils, or those with a high Mg concentration in the exchangecomplex (25, 54). Nutrient sprays offer promise where soil applications are ineffective, or while waiting for them to become effective. The effectiveness of these sprays will depend on absorption, and transport and for the latter foliar applied K becomes more generally distributed in other parts of the plant than P or N (183). We have seen chloride and nitrate salts to often be the most readily absorbed form of cation, and Fig.3 records the effects of sprays of [illegible] of these salts. Table IV indicates the degree of change in leaf - K from each harvest to the next.

(a) Spring sprays

Consequent on two December 1968 sprays to treatments 2, 3 and 4, at 3/3/69 leaf K was greater than in unsprayed trees (at 5% level) by 43, 36 and 69% on average. Treatments 2 - 4

TABLE IV

PERCENTAGE CHANGE IN LEAF - K FROM PREVIOUS HARVEST

		Treatment			
Date	Block	1	2	3	4
11/4/69	1	-35.4	-30.9	-33.6	- 2.2
	2	-36.2	-50.0	0.7	12.2
	3	-22.5	-38.0	17.3	8.2
	4	-34.4	-39.0	-14.7	- 1.5
	5	-32.0	-37.7	- 1.0	-22.9
	6	-16.4	-61.3	- 7.3	-46.9
	Average	-29.5	-42.8	- 6.4	- 8.9
6/8/69	1	4.8	-34.5	20.2	- 7.4
	2	- 2.0	- 1.4	-20.8	-14.2
	3	-23.2	2.0	-25.4	- 4.9
	4	-31.2	14.0	13.8	-15.4
	5	-20.7	-14.5	- 4.1	-22.9
	6	23.3	- 3.2	0	- 3.8
	Average	- 8.2	- 6.3	- 2.75	-11.4
10/12/69	1	79.5	87.7	0	98.4
	2	108.0	57.3	4.4	74.8
	3	66.0	96.0	43.9	67.2
	4	41.8	29.8	6.1	81.8
	5	88.1	50.8	- 5.4	114.3
	6	17.6	55.7	- 7.9	77.6
	Average	66.8	62.9	6.85	85.7

TABLE IV Cont.

Date	Block	Treatment 1	 2	 3	 4
7/1/70	1	-30.9	-28.0	1.0	-22.6
	2	-23.1	-18.7	-3.4	-10.8
	3	-27.3	-20.4	-4.6	- 4.6
	4	- 6.4	-16.2	11.4	- 7.0
	5	-34.1	-17.3	7.1	- 2.2
	6	-26.4	-28.4	5.4	-16.7
	Average	-24.7	-21.5	2.8	-10.65

TABLE V SHORT TERM CHANGES IN LEAF - K

Harvest Date	Tree	Days after last spray	% leaf K	Average % K	% change av. leaf - K
3/3/69	A	-	0.80	0.84	-
	B	-	0.84		
	D	-	0.89		
	C	-	1.34	1.02	-
	E	-	0.70		
19/3/69	A	8	1.40	1.30	+54.8
	B	8	1.27		
	D	8	1.22		
	C	-	0.87	0.72	-29.4
	E	-	0.57		
27/3/69	A	16	1.11	1.11	-14.6
	B	16	1.07		
	D	16	1.15		
	C	-	0.75	0.61	-15.3
	E	-	0.48		
11/4/69	A	31	0.80	0.86	-22.5
	B	31	0.87		
	D	31	0.92		
	C	-	0.51	0.44	-27.9
	E	-	0.37		
11/4/69	A, B, D	% change from 3/3/69		+ 2.4	
	C, E	" " " "		-56.9	

Note: Sprays applied to trees A, B, D on 5/3/69 and 11/3/69.

are not significantly different from each other, and the high value of 69% is largely due to one sample. Since no samples were taken prior to those sprays one cannot accurately assess the effects of spring sprays after this eleven week period - certainly they have probably had an effect on leaf - K but their effects have began to disappear.

In the next spring one spray on 10/12/69 to treatments 3 and 4 has had a large effect on leaf - K over a four week period. Instead of an average fall of 21.5 and 24.7%, the leaf K has either stayed about the same, or dropped about 10%. It is surprising that in treatment 4 with soil - K leaf K has fallen after this spray, and cannot be attributed to differences in fruit numbers or shoot growth at this period, since they were similar in all treatments.

At the 1% level, one December spray has resulted in a significantly greater leaf K one month later. It has not however had a significant effect at two month after spraying. It is difficult to see any such effect in the presence of a soil - K supply (treatment 4), for some obscure reason. In the previous spring, the effect of two sprays was almost lost at three month. These figures then show the time limits of effect on leaf - K by the given sprays.

(b) Summer sprays

Two sprays in early March resulted in trees having significantly greater - leaf K (at 1% level) one month later. So instead of a 30 - 40% fall to a low level (45), there has been about a 7% fall in this period. The benefit of this spray is still seen twenty one weeks later on 6/8/69. Over this time leaf - K shows little change in all treatments, and shows the re-distribution of absorbed K is completed within a month of spraying at this time of year.

The effects of four sprays are not noticeable on leaf - K the next spring (10/12/69), although leaf colour was better than where two or nil sprays had been applied. It is surprising how much K has been mobilised in the deficient trees, which also bore more fruit than treatment three.

The literature shows clearly the increase in plant nutrient content from foliar sprays is approximately proportional to spray concentration and frequency of spraying (180). For commercial use it is necessary to have an indication of the size of this increase in response to a given intensity of these two factors.

Fig. 9 <u>Short term K uptake</u>

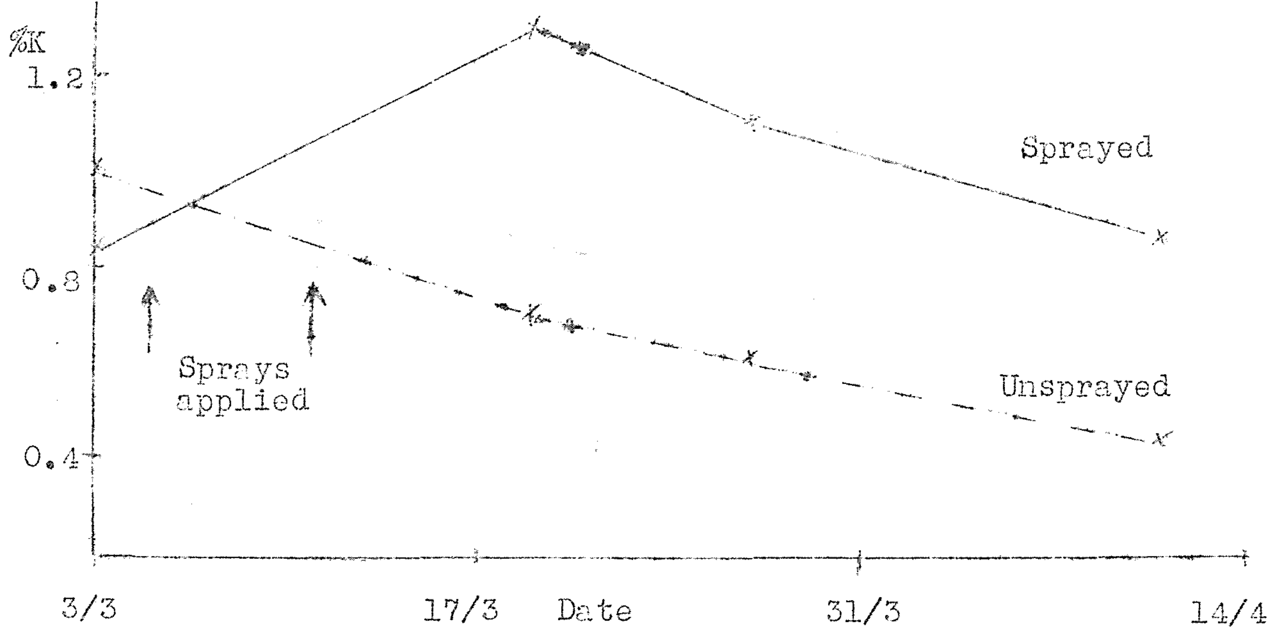


Figure 9 and Table V complete the picture of K changes in response to K sprays. One would expect the greatest increase in leaf - K soon after spraying, so that at some time leaf K concentration would be greater than that shown in Fig.3, one month after spraying. A small trial involving the five trees A - E shows that one week after the last of two summer K sprays, from a pre-spray leaf level of about 0.9%, K has risen by about 55%, compared with a 30% fall in unsprayed trees. Over the next three weeks the rate of fall is similar in all trees, so that a month after the time of the last spray leaf - K has fallen by over 50% from the pre-spray level in the control trees, and remained the same in the sprayed trees. We have seen the same effect in the main experiment.

It appears leaf - K tests would represent the true effect on tree - K so long as they were taken not less than about a month after spraying. Fig. 9 supports the earlier comment that under some conditions the beginning of March is too early for leaf sampling for K as concentration is still changing rapidly, the rate of change being very low however from about mid-April.

Thus we can suggest :

(a) one spring spray has one month later, caused leaf K to remain stable in both the presence and absence of soil K. This is significant, in that for instance in the absence of spray leaf K has fallen from about 0.92% to 0.70% where soil - K is very low. From an original leaf K about 1% one December spray (1.3%K) has not increased leaf K over unsprayed three months later. A similar result has been obtained using the nitrate salt on orange seedlings (134), with leaf K about 2.4%.

(b) two spring sprays resulted in a leaf - K level of about 1.2% eleven weeks later, compared with about 0.8%.

(c) two summer sprays kept K at about 1.2% over the next month, compared with a fall to 0.6% - under low soil - K conditions. One week after two summer sprays to trees with 1% leaf K, leaf K levels were 80% greater than in unsprayed trees, and after four months this difference has disappeared. One week after two sprays (1% spray solution) to trees with 0.4% leaf - K, leaf - K was 45% greater than controls (134). Many factors could account for these different results, including the original level of leaf - K.

(d) the effect of 1 - 5 sprays containing 1.3% K, on leaf - K is only temporary, so that even after five sprays spread over one year the sprays have not resulted in much of an increase in leaf K over a fifteen month period. In the meantime effects on growth, fruit quality etc. may have been obtained (25). Calvert (25) also showed KNO_3 sprays (0.9% K) mainly to increase leaf - K shortly after spraying, leaf levels then returning to that similar to unsprayed trees.

It is clear that in terms of supplying potassium, foliar sprays can be very effective, but it is not an effective method of permanently raising leaf - K. It has been shown (134) the first spray is the most efficient, and the use of 3 - 4 KNO_3 sprays (2% K) at weekly intervals recommended. This work supports that with orange trees (25, 134) that for any long term effect at all on leaf - K, not less than about four sprays containing not less than about 1.5%K are required. At these rates the final effect is very small.

In the results is a suggestion that especially when comparing original levels of leaf - K < 2.0% and t those > 2% foliar sprays in both spring and summer have had a more positive effect on leaf K in low K trees than in high - K trees where the natural decline in leaf - K continues more markedly over the next month. A greater leaf absorption of N by apple leaves occured in high - N leaves (38), and P absorption is reported (185) reduced in the presence of a high level of soil - P (and so presumably a high leaf - P). It cannot be denied, a high plant - K may result in reduced leaf uptake of K, a possibility discussed earlier.

In the present case, where leaf K was > 2% at spraying, these trees were also receiving soil - K. With sugar beets (181), soil - K appeared to reduce K uptake from a K spray, so that percentage recovery of K from a spray was reduced from 53% to 30% by K fertiliser. The present results may then indicate a less efficient absorption of K from a foliar spray due either to a high internal K status, or due to high K uptake from the soil. It is however, also possible plant growth was greater in the high K trees, resulting in a greatergrowth dilution effect in plant K over a four week period from spraying.

(ii) <u>Other salts</u>.

In crop production one is interested in the total uptake from foliar sprays, and the longer term effects - and sampling within hours of spraying may then be of little value.

This has also led to confusion in comparing uptake from different salts .

It has been shown (3) that apple leaves absorb Mg from the chloride and nitrate salts over about a two hour period from spraying. However most Mg uptake from the sulphate form occured rather later e.g. the following night. Thus unlike an early analysis a later one showed no difference in uptake between the three salts. This was explained by a need for higher atmospheric humidity e.g. at night cf. day, by the sulphate salt for its deposit to solubilise and be absorbed. It can be shown at 25°C an air vapour pressure equivalent to 22, 20, 10 mm. Hg will cause the salts KNO_3, KCl, and K_2CO_3 to dissolve. Under given conditions one might then expect a similar K uptake from the nitrate and chloride forms, and a much lesser uptake from the carbonate, over a short period of time.

The results of Table VI show at one and eight days from spraying:

(a) a similar actual and % change in leaf K, especially for the carbonate salt. The pattern of uptake and translocation for the chloride may in fact vary from that of the nitrate.

(b) a similar effect on leaf - K of the nitrate and chloride salts, with a much lesser effect of the carbonate.

(c) the increase in leaf - K was less in the Meyer than the Villafranca lemon. This may have been due to the higher leaf - N in the former (compare (64,), or the higher initial leaf - K (see also earlier) of the Meyer trees.

TABLE VI

K UPTAKE FROM DIFFERENT SALTS

Tree	Variety	Date	Spray	Days after spray	% leaf N	% leaf K	% change leaf - K from 10/12/69
A	VF	10/12/69	KCl	-	2.31	1.03	-
C			KNO_3	-	2.13	0.86	-
D			K_2CO_3	-	2.28	1.05	-
E			-	-	2.10	0.72	-
1	M	10/12/69	KCl	-	3.20	1.73	-
2			KNO_3	-	3.29	2.00	-
4			K_2CO_3	-	2.87	1.75	-
3			-	-	3.04	1.75	-
A	VF	11/12/69	Cl	1	-	1.42	37.9
C			NO_3	1	-	1.22	41.9
D			CO_3	1	-	1.21	15.2
E			-	-	-	0.76	5.5
1	M	11/12/69	Cl	1	-	2.00	15.6
2			NO_3	1	-	2.06	3.0
4			CO_3	1	-	1.74	0
3			-	-	-	1.71	-2.3
A	VF	18/12/69	Cl	8	-	1.52	47.6
C			NO_3	8	-	1.14	32.5
D			CO_3	8		1.22	16.2
E			-	-	-	0.77	6.9

Spray applied 10/12/69.

VF - Villafranca lemon

M - Meyer lemon

There is another aspect of interest with respect to the comparative effects of the SO_4^{--} and Cl^- anions on K uptake. In a study of this effect in K uptake by excised barley roots it was shown K accumulation was greater in the presence of the Cl^- ion, and this increase over a SO_4^{--} solution occurred in the first three - four hours after treatment. It was postulated the Cl^- enhanced the binding of the K to cytoplasmic constituents, this being one of the steps in K uptake (90). It would seem possible a similar phenomenon could occur with foliar absorption, and comparative studies over shorter periods of time could show the extent to which such a factor contributed to the differences in K uptake from different salts.

(iii) Chloride absorption

Because of the serious effects that high leaf - Cl can have, two such determinations were made to investigate this possibility. The Cl levels and statistical analyses are given in Appendix 8.

Data for 6/8/69 shows the two December sprays have not significantly increased leaf - Cl from the control mean value of 0.388%. This value seems high for young trees that have received no chloride for at least fifteen months. A total of four sprays to treatments three and four has given significantly higher leaf levels of 0.864% and0.736% respectively. All these levels are high (27). Leaf - Cl > 0.75% in Washington navels (33) has indicated serious growth retardation, but no obvious treatment differences in plant growth were observed in 1969 or 1970. At no time were the usual symptoms of excess Cl (33, 81) seen, and this may have been due to the high Leaf - N values in the 1968/69 season (34).

In the younger leaves of 7/1/70 leaf - Cl is much lower. The difference in level between treatments 1 and 2, and 3 and 4 would be largely due to the one December spray since Cl tends to accumulate in plant leaves (81), and there is little movement from old leaves to young ones (77).

It is clear even one spray of KCl can lead to a considerable accumulation of leaf - Cl, which may in some circumstances be sufficient to cause plant damage (33). Four sprays in a season is likely to produce dangerously high leaf - Cl values, especially under conditions of low N.

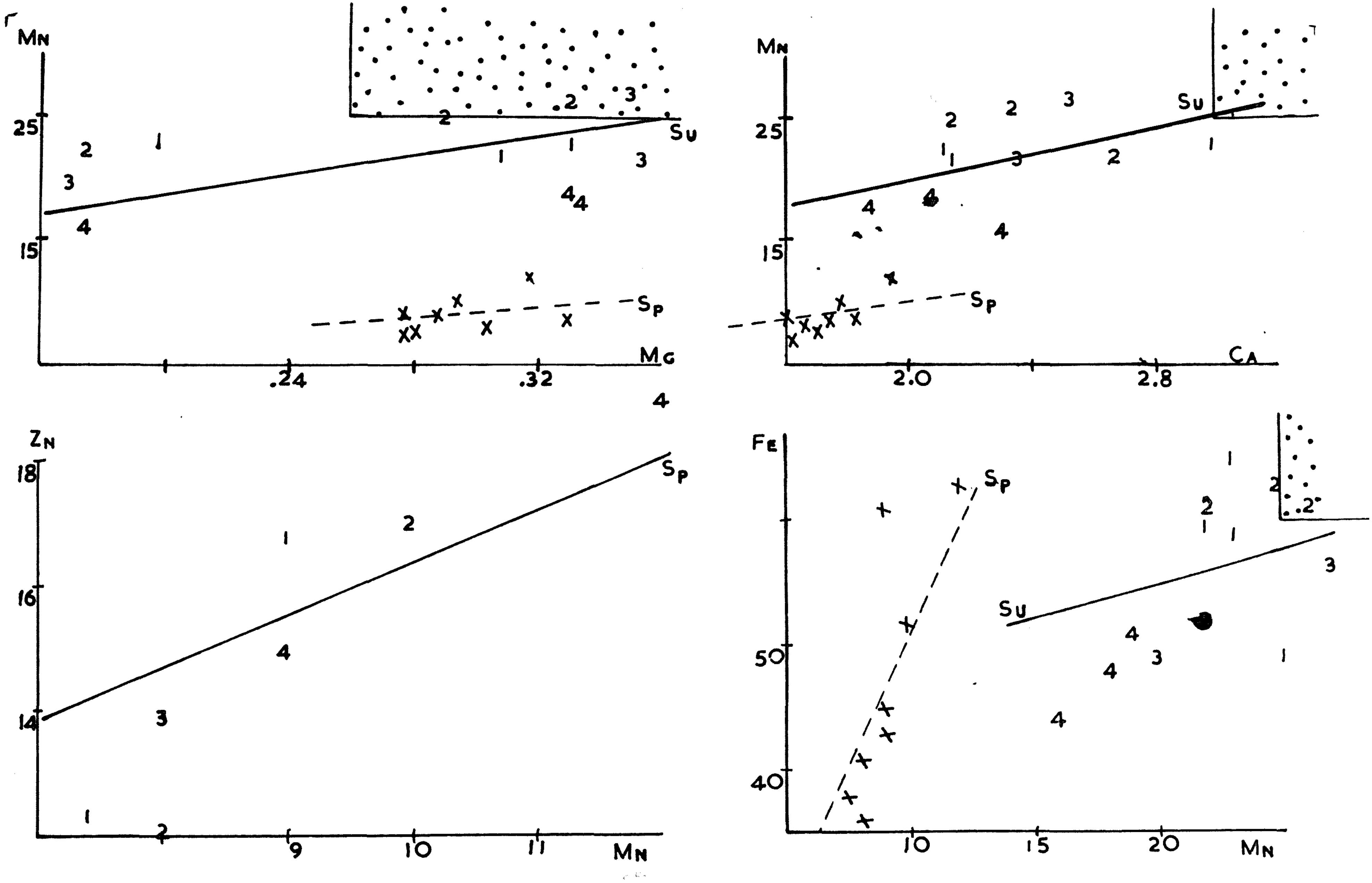
2 Soil K Uptake

It appears from Fig. 3 the availability of soilK from mid April has not shown any effect on leaf - K until the following spring, when it showed a marked increase over a nil supply. K absorbed during autumn and winter is apparently stored in non-leaf parts of the tree during this period.

C RELATIONSHIPS BETWEEN MINERAL ELEMENT LEVELS

1 Pairs of Elements

Brief reference has already been made to the presence or absence of a relationship between treatment (K level) and the leaf concentration of other elements. Examples of this type of relationship have been reported in many crops, under both field and culture solution conditions. We may now consider the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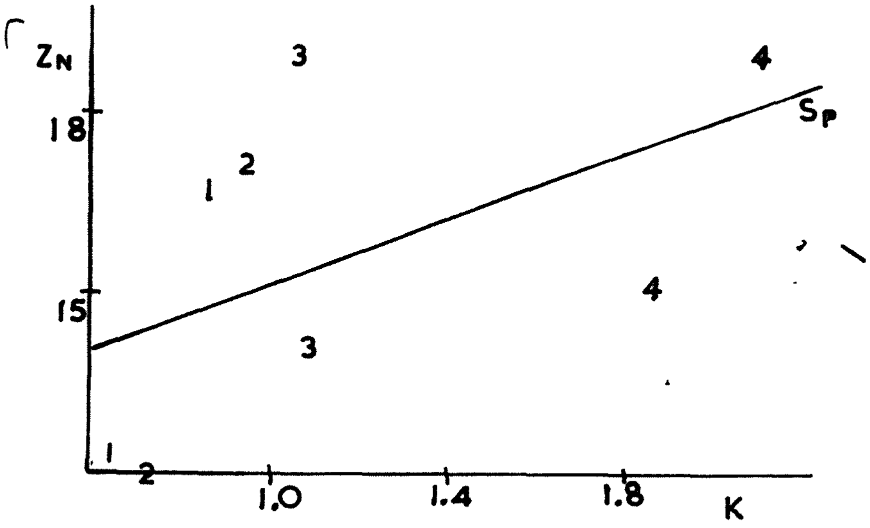
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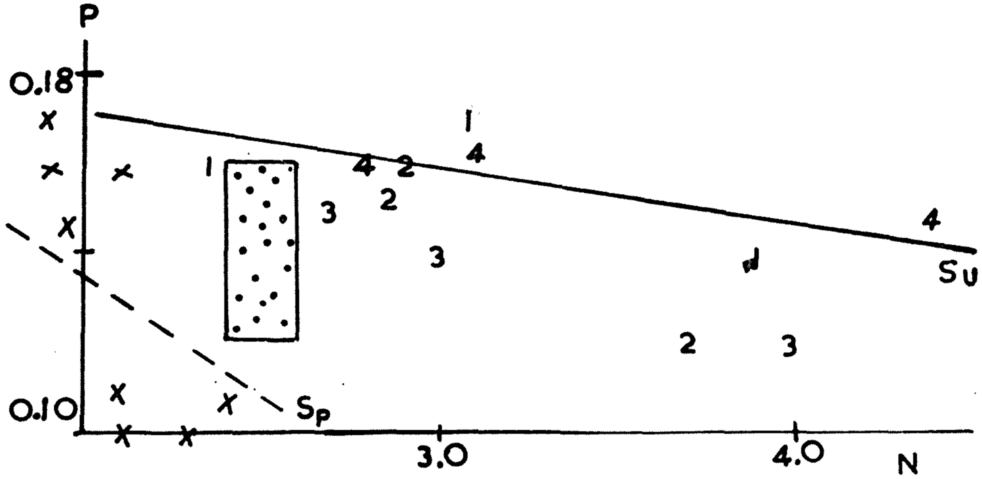
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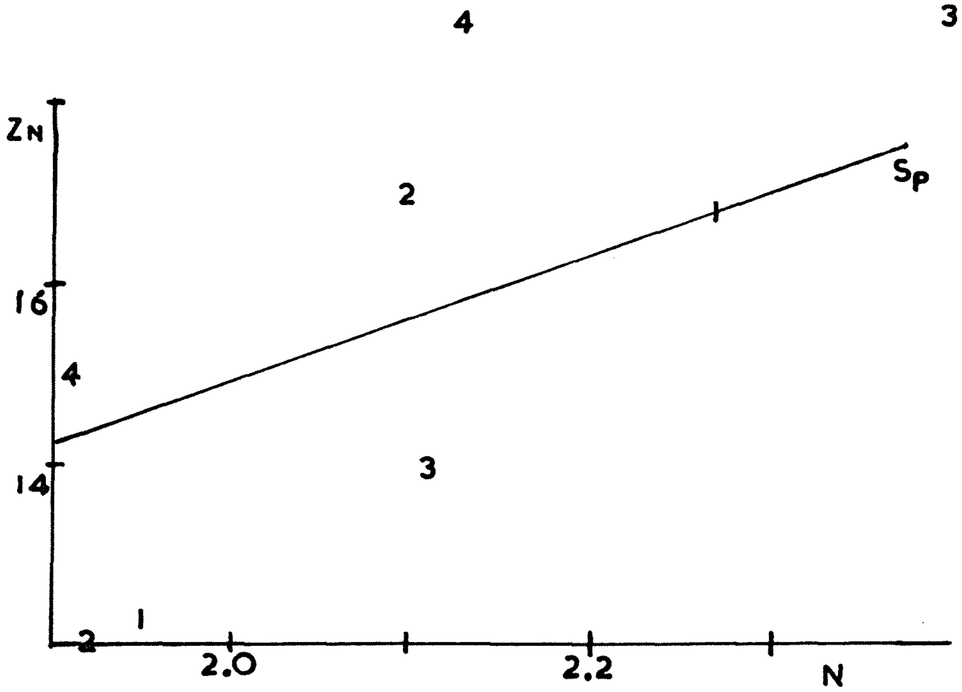
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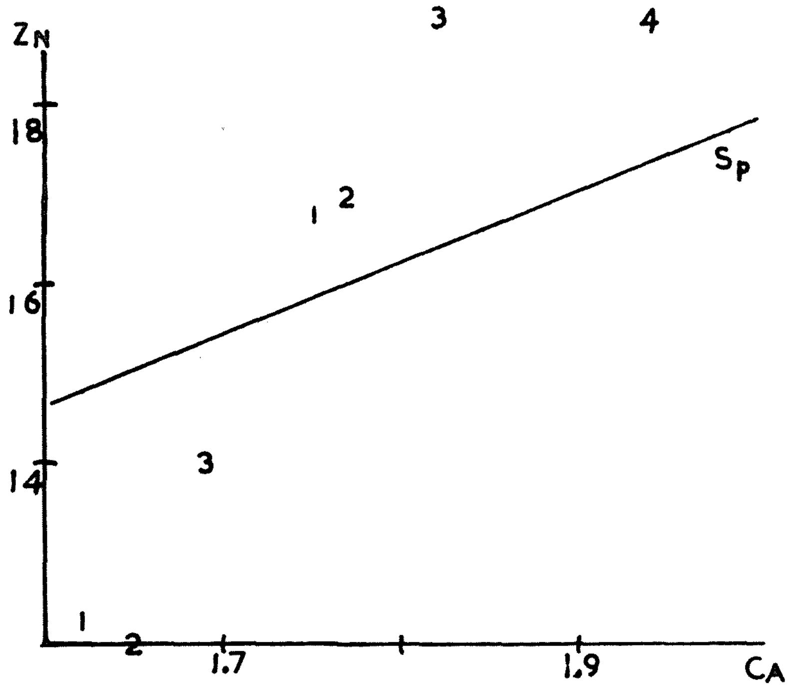
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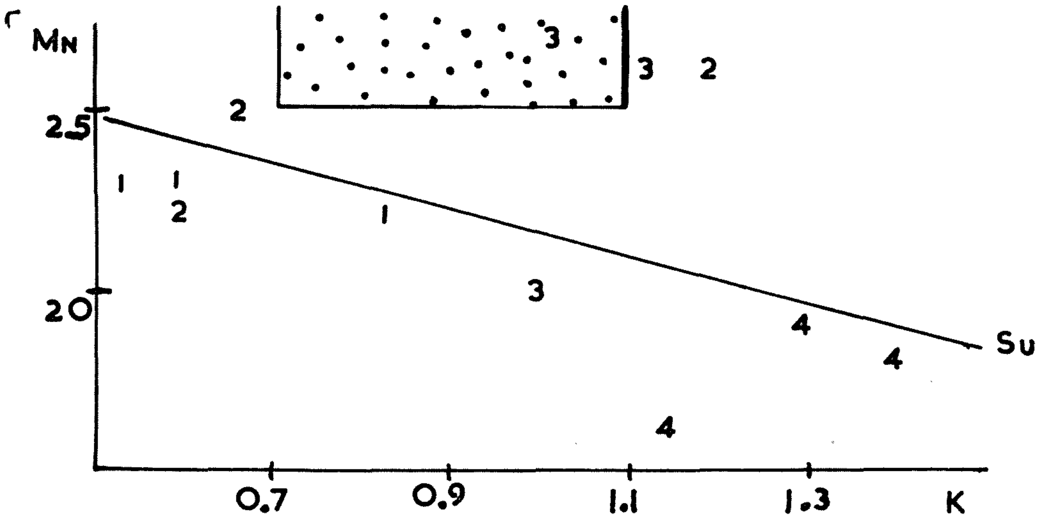
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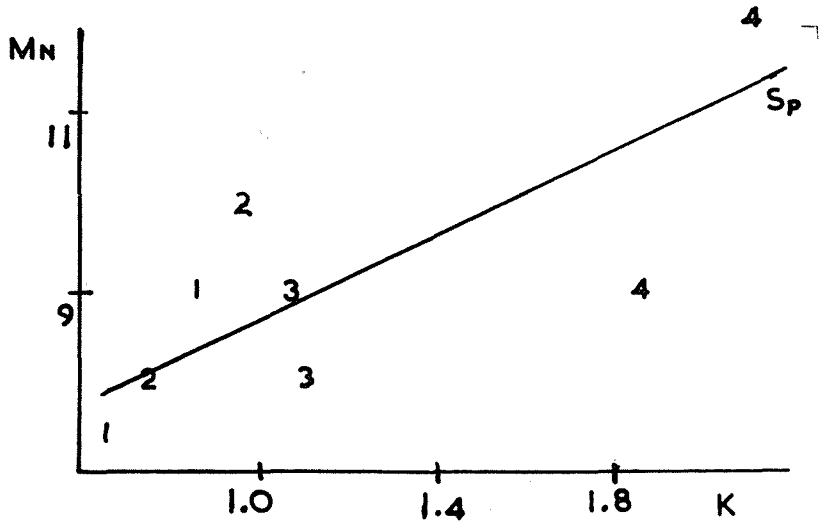
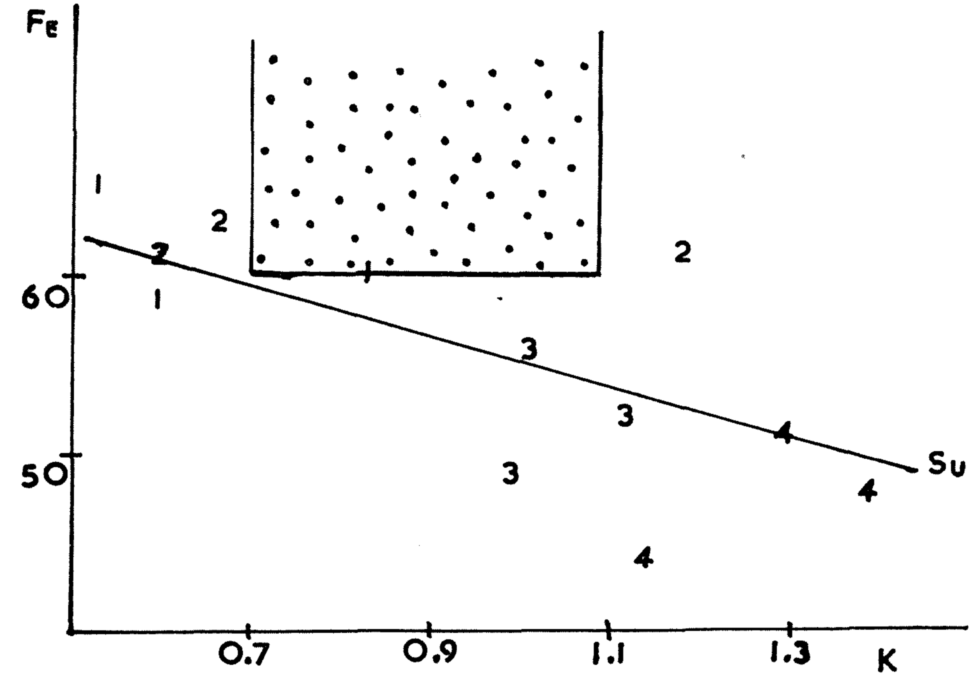
K
Su


MN
11
9
1.0
1.4
1.8
K
Sp


FE
60
50
0.7
0.9
1.1
1.3
K
Su

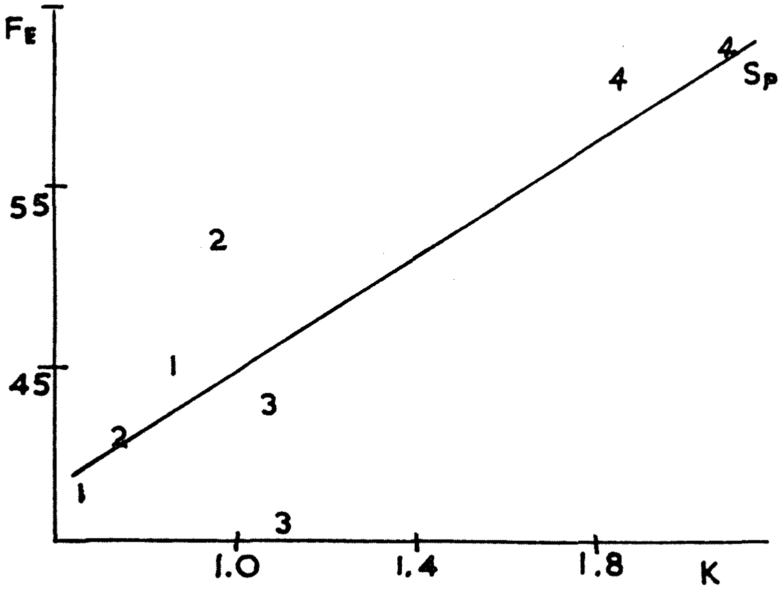

FE
55
45
1.0
1.4
1.8
K
Sp

Fig 10 <u>Selected regression lines of leaf mineral levels</u>

Each pair of elements is indicated, and the season of sampling to which the data refers:-

Sp - 10/12/69, 7/1/70.
Su - 3/3/69, 11/4/69, 6/8/69.

The numbers and crosses in the scatter diagram indicate the mean values at each harvest date, for each of the four treatments.

The stippled area indicates the optimum values 5 - 7 month old leaves of sweet orange terminals (45), and so is comparable only with Su data.

situation here in more detail where the University computer was used to indicate the significant relationships, and in some cases a regression line has been prepared. (Fig. 10).

Data for the two growing seasons was analysed separately

i.e. (1) for the harvests 3/3/69, 11/4/69, 6/8/69 i.e. more mature leaves and

(2) for the harvests 10/12/69, 7/1/70 i.e. younger leaves.

Significant correlation coefficients (r) for any pair of elements were selected by reference to Snedecor (169) and the detailed results given in Table VII. A causal relationship in these cases does not necessarily follow, but an awareness of them is useful in interpreting leaf analyses, and may also indicate some physiological relationship. The idea of a ratio (as opposed to a single absolute level) may be more meaningful or useful when it takes into account more than two elements (188). In tobacco leaves a ratio of $K:Ca+Mg$ of 1.3 has indicated a good quality leaf, and a ratio >1.7 a poor quality one (97). This type of relationship has not been investigated here.

If one considers mainly those instances where r is significant at 1% we may note :

(i) In some cases the concentration of a pair of elements are more closely related in one season than the other. It may be that leaf age is the more important criteria, and in some cases here the direction of the relationship has been reversed and if this is a cause and effect phenomena it must be remembered when say, sampling younger leaves than usually used in field advisory work.

It may be that the relationship between two elements is different in the two types of leaf, due to a different leaf mineral balance. This study did not consider complex relationships

TABLE VII : SIGNIFICANT MINERAL CORRELATIONS.

r - Coefficient of linear correlation

\+ - Significant at 5% level

++ - Significant at 1% level

Season 1 - Harvests 3/3/68 - 6/8/69

2 - Harvests 10/12/69 - 7/1/70

Element Pair (X-Y)	Season	r	Significance	
K - Ca	1	-0.3825	++	Y=3.0 - 0.66X
K - Mn	1	-0.3228	++	Y=28.13 - 6.62X
	2	0.5692	++	Y=6.47 + 2.3X
K - Fe	1	-0.3961	++	Y=69.43 - 14.4X
	2	0.6413	++	Y=28.75 + 16.08X
K - Mg	2	0.3952	++	Y=0.26 + 0.03X
K - Zn	2	0.4654	++	Y=12.49 + 2.74X
K - $^N/Ca$	6/8/69	0.404	+	Y=0.85 + 0.32
N - P	1	-0.3697	++	Y=0.19 - 0.01X
	2	-0.3695	++	Y=0.235 - 0.05X
N - Ca	2	0.3713	++	Y=1.07 + 0.31X
N - Zn	2	0.5934	++	Y=0.16 + 7.39X
N - Mn	2	0.2938	+	Y=3.89 + 2.50X

TABLE VII(Cont.)

Element Pair (X-Y)	Season	r	Significance	
P - Mn	1	-0.4560	++	Y=42.08 - 135.23X
P - Zn	2	-0.3822	++	Y=20.39 - 35.65X
P - Mg	1	-0.2751	+	Y=0.43 - 1.03X
	2	0.3306	+	Y=0.24 + 0.42X
Ca - Mn	1	0.4487	++	Y=9.18 + 5.33X
	2	0.3496	+	Y=3.04 + 3.54X
Ca - Zn	2	0.5418	++	Y=1.84 + 8.01X
Ca - Fe	1	0.2932	+	Y=41.17 + 6.17X
Mg - Mn	1	0.4741	++	Y=11.41 + 37.40X
	2	0.4655	++	Y=2.19 + 23.59X
Mg - Zn	1	0.3476	++	Y=14.09 + 14.55X
	2	0.3261	+	Y=8.57 + 24.14X
Mg - Fe	2	0.4135	++	Y=9.09 + 130.24X
Mg - Ca	2	0.2914	+	Y=1.3 + 1.46X
Mn - Zn	2	0.5738	++	Y=7.96 + 0.34X
Mn - Fe	1	0.2970	+	Y=44.28 + 0.53X
	2	0.7031	++	Y=7.56 + 4.37X
Zn - Fe	1	0.2662	+	Y=39.64 + 0.89X
	2	0.3883	++	Y=21.64 + 1.65X

involving large numbers of variable mineral.

In the first season, high K is associated with low Ca, Mn, Fe. However correlations are far better in the second season, when the sign is reversed and a high K is associated with a "high" level of each of the metal trace elements.

The relationship between leaf - K and leaf - trace element concentration is a confused one, in some cases there being a negative relationship (32, 147) in some a positive one (32), and in others no consistent relation to K level (160, 197, 199). These results show the time of sampling (physiologically) may determine the form of this relationship, since each type has been shown within a ten month period. The strength of the positive relationship is here by far the strongest.

In the coconut K and Na show antagonistic or synergistic effects according to the tree K level (139). In the present results there is a negative correlation between leaf K and Mn levels when Mn levels are "high" (15 ppm), but when Mn levels are "low (11 ppm) an increasing K level is associated with an increase in leaf - Mn. Such a relationship does not exist for the pair of elements K - Fe, and here perhaps leaf age or some other factor has more influence on the K - Fe relationship than the actual level of either of these elements. This factor may be the level of a third element as shown by Smith *et el* (168) for other elements.

It has been said (147) K seems to have little effect on the absorption of the heavy metal cations, although it has been shown Mn uptake is stimulated by increased K supply (133). In young leaves, a high K uptake would give a high leaf - K and leaf - Mn relative to trees receiving low K supply. i.e. r would be positive. As these leaves mature, the percentage dry matter increases. With low K supply, growth rates are lower than under high K supply where leaf area is likely to be somewhat greater (181). With this ageing process the leaf Mn is likely to show a dilution effect as soil absorption decreases. Such dilution would be greater in high K trees if growth continued later, and if at this time of year (from mid-summer) K was not greatly stimulating Mn uptake. Differences such as this may be enough to give a negative correlation coeficient, and perhaps of lesser significance, This explanation could also apply to other trace elements, but does not seem typical of other pairs of elements. The phenomenon just discussed may be atypical, in that:

(a) some K levels were due to foliar absorption

(b) it assumes the relations between a consecutive summer and spring, put in reverse, are the same as a spring and summer of the same growing season.

There was no evidence of a K - Zn antagonistic effect, as has been reported (147, 199). While the high - K treatments showed a lower leaf - Fe at 6/8/69 (means of 47 ppm cf. 61 ppm) this did not result in leaf chlorosis as has occurred with the application of stonger K sprays (25). The availability of soil K has had a profound effect on leaf - Fe. At 6/8/69 treatments 3 and 4 showed similar leaf - K and leaf - Fe concentrations, but with the sudden build up of leaf - K in the spring in treatment 4, leaf - Fe is now 50% greater than in treatment 3. It would seem this is more than aneffect of retarded winter/spring iron uptake by trees of sub-optimal K content.

(ii) It is only in the second season that K and Mg levels seem to show any relationship, and it is not an antagonistic one.

It has been shown K level has an antagonistic effect on Mg at high N levels, but not with low - N conditions (168).

When the present data was reanalysed for low - N samples (average 2.03% N, range 1.6 - 2.3%), and for high N samples (average 3.67 % N, range 2.9 - 4.4%), there was no significant correlation between leaf K and Mg ($r < 0.1$) in either group.

It has been found in the field that liberal applications of K fertiliser have not significantly affected the magnesium content of various parts of apple trees (13). The soils involved were inherently high in K, and it was suggested this lack of antagonism was due to the composition of the soil solution being unaffected by the fertiliser applications. In this work with the lemon the situation is different in that the K has entered the plant directly, avoiding the complicating effects of soil conditions. A study of leaf K and Mg levels over shorter periods after spraying, when leaf K concentraions were higher may have indicated a transitory effect on the leaf - Mg level.

It may have been meaningful to compare K, Mg values on a milliequivalent basis, but it is interesting that a commonly reported instance of ion antagonism was not even hinted at in leaf tissue. Such antagonism may have occurred in other parts of the tree. In the first season the high K trees maintained the same total cation as low K trees, but this was not done by any change (fall) in the leaf - Mg level of the former. In the second season high K levels may have actually increased total cation content of treatment (4), where Mg levels are also highest.
So it would appear foliar K has resulted in the re-distribution of some mineral other than magnesium.

(iii) A lowered leaf - Ca is usually associated with increased K absorption from the soil (199), but also from foliar sprays (50, 198). A similar relationship was shown here in more mature leaves, but the tendency was clearly the opposite in the young leaf samples, (nearly significant at 5% level).

In a discussion of the use of ratios of leaf mineral contents as an indication of the metabolic state of a plant (43), a constancy was attributed to the product K^{+} x Ca^{++}. No doubt as a consequence of the low r value for these two elements these data show a highly significant difference in the product K x Ca (expressed as m.eq %) between high K and low K trees - see Appendix 9. This suggests as do the above results, a not very strong antagonism between the two elements, over a fairly long period of differential treatment.

In a contribution to the subject of element balance in plant nutrition (198) it was found the N/Ca ratio had an effect on leaf - K. When the present data for the two dates 6/8/69 and 7/1/70 were studied in this way, it was found there was a significant (5%) positive correlation only in August. This has perhaps resulted from the K - Ca "antagonism" at this time, in trees of a similar N content. In the same way we might expect a negative correlation in young leaves, and this in fact is the case (-0.01). The very low value may have resulted from the highly significant positive N - Ca correlation in these leaves, a relationship shown to be absent in the older leaves where r = -0.01. It is not suggested the N/Ca ratio is of particular physiological importance, but this example perhaps illustrates that, as with individual elements, ratios must be related to the time of sampling and that they may be too simple for an accurate expression of plant growth.

(17) Leaf P bore virtually no relation to leaf K, but rather more surprisingly K and N did not come near showing the negative

correlation usually reported. While increasing K supply has reduced leaf N (199), the greater effect may in fact be of increasing N causing a reduction in leaf - K concentration (168). This would appear resonable as increasing N supply is likely to have a greater effect on leaf area than is increasing K supply, and so a more diluting effect on the other minerals concentrations.

(v) The large increases in leaf - Cl that may result from chloride foliar sprays have been discussed, and as part of the generally detrimental effect such accumulations have we might expect a modification of the plants' mineral levels. In some plants it has been shown(114, 191) an increase in Cl absorption results in a lowering of leaf - N. A study of the data for the two occasions on which Cl determinations were made shows there was no close correlation between Cl and N levels in these lemon leaves.

(vi) Table VII indicates more fully the relationship between various pairs of elements, many already reported. This includes the negative correlation between N, P and the positive correlation between both Ca and Mg and each of the trace elements. An interesting point is whether it is the K or Mg level that has been more causal in changing leaf trace element concentrations. It is possible it is the latter, so that in young leaves the K level has affected leaf - Mg, which has in turn affected leaf - trace element, through either its influence on their uptake or distribution. This sequence of events has been suggested to explain the effect of K level on zinc deficiency in sweet oranges (147). In the first season K level has apparently not had an overriding influence on leaf - Mg (leaf - N may have been important here).

Because of this complex type of inter-relationship, when considering changes in leaf trace element levels it may be necessary to use an index consisting of K, Mg, N, Mn, Zn, Fe.

This is also shown by the r values for the element pairs Mn-Zn, Mn-Fe, Zn-Fe which are usually significant, especially in the 2nd season (Table VII). Since no one trace element was differentially applied it may be more reasonable to suppose their concentrations bear such a close relationship as a result of their being similarly affected by some other element e.g. calcium, nitrogen or directly by K level.

It is very difficult to adequately interpret the data presented in Table VII, and so some of the more interesting data was analysed further. This was done by the calculation of a number of partial correlations (r_p) the results of which are given in Table VIIA. This allows a better consideration of a significant value of r between two minerals, where each also bears a significant linear correlation with a third element.

It is seen from Table VIIA that the best relationships are ones in the second season (young leaves) between K and the trace - elements (especially Mn and Fe); and between Fe and Mn in the same leaves. There is still shown to be a highly significant negative partial linear correlation between K and Ca, Fe, and Mn in the older leaves.

Table VIIA shows the correlation between Mg and the elements in the younger leaves does not in fact exist, although there may still be a close relationship in the older leaves. The other important change made by this further calculation is that the significant correlation between leaf K and Mg levels has virtually disappeared i.e. no positive linear relationship exists between them.

TABLE VIIA PARTIAL CORRELATIONS (r_p) LEAF MINERAL LEVELS.

++ Significant at 1%
+ " " " 5%
NS Non-significant

Element Pair	Season	Constant Element	r_p	Significance
K - Ca	3/3 - 6/8/69	Fe	-0.3023	++
K - Fe	3/3 - 6/8/69	Ca	-0.3214	++
K - Mn	10/12- 7/1/70	Mg	0.4738	++
K - Fe	3/3 - 6/8/69	Mn	-0.3322	++
K - Fe	10/12- 7/1/70	Mn	0.4124	++
K - Fe	10/12- 7/1/70	Zn	0.4524	++
K - Mn	10/12- 7/1/70	Zn	0.4154	++
K - Fe	10/12- 7/1/70	Mg	0.5714	++
K - Zn	10/12- 7/1/70	Mg	0.3875	++
Fe - Mn	10/12- 7/1/70	Zn	0.6365	++
K - Ca	3/3 - 6/8/69	Mn	-0.2810	+
K - Mn	3/3 - 6/8/69	Fe	-0.2340	+
K - Zn	10/12- 7/1/70	Fe	0.3060	+
K - Mg	10/12- 7/1/70	Zn	0.2909	+
K - Mn	10/12- 7/1/70	Zn	0.3590	+

TABLE VIIA (Cont.)

Element Pair	Season	Constant element	r_p	Significance
K - Mn	3/3 - 6/3/69	Ca	-0.1831	NS
K - Mg	10/12- 7/1/70	Mn	0.1790	NS
K - Mn	10/12- 7/1/70	Fe	0.2168	NS
K - Zn	10/12- 7/1/70	Mn	0.1874	NS
K - Mg	10/12- 7/1/70	Fe	0.1861	NS
Mg - Zn	10/12- 7/1/70	Mn	0.0785	NS
Mg - Mn	10/12- 7/1/70	Fe	0.2699	NS
Mg - Fe	10/12- 7/1/70	Mn	0.1370	NS
Fe - Zn	10/12- 7/1/70	Mn	0.0321	NS

Trace element levels can affect the leaf concentration of other trace elements, as has been shown by work in sweet oranges (117). A comparison of the data in Appendix 7 with Tables II and III shows that iron levels always appear satisfactory, zinc levels are probably always deficient, and manganese tends to be deficient. This was reflected in tree appearance, leaf chlorosis being especially noticeable in treatment 1 and 2, from the winter of 1969. However Table VII does not indicate a negative correlation between any two trace elements. The effects of low Mn, Zn affected the trees' appearance more than any lowering of leaf - Fe caused by foliar sprays. With this situation certain trace element sprays were applied, with effects as discussed in the next section.

(vii) Trace element sprays

Detailed results are given for this interesting work in Table VIII, but it was not possible to analyse them statistically. In spite of the obvious improvement in leaf - trace element concentrationwith spraying, tree appearance was largely unaffected.

TABLE VIII EFFECTS OF TRACE ELEMENT SPRAYS

	Leaf levels ppm 7/1/70			Leaf levels 6/3/70			% change		
Treatment	Mn	Zn	Fe	Mn	Zn	Fe	Mn	Zn	Fe
1 Mn	6.4	16	39	33.7	14.7	43	426	- 8	10
	5.5	14	32	37.6	11.8	36	642	-16	12
	10.8	19	79	44.9	19.6	82	316	3	4
	11.9	14	53	40.7	15.9	67	242	14	26
2Mn	8.1	13	45	59.2	12.9	46	630	- 8	2
	9.2	11	38	55.1	11.4	35	498	4	- 8
	11.7	16	59	55.7	26.5	60	376	66	2
	7.8	12	45	56.3	12.3	53	622	2	18
1Zn	7.8	12	40	12.6	33.7	34	61	181	-15
	8.6	12	37	14.8	48.6	49	72	305	32
	10.1	15	31	10.9	60.7	61	8	305	97
	9.5	12	60	12.9	49.5	49	36	312	-18
2Zn	6.8	13	41	10.6	53.1	53	56	308	29
	9.2	16	43	11.2	69.8	70	22	336	39
	8.4	14	37	11.4	71.2	71	36	409	92
	6.3	10	31	8.7	62.2	62	38	522	100

TABLE VIII   EFFECTS OF TRACE ELEMENT SPRAYS   Cont.

	Leaf levels ppm 7/1/70			Leaf levels 6/3/70			% change		
Treatment	Mn	Zn	Fe	Mn	Zn	Fe	Mn	Zn	Fe
1	5.9	11	27	31.3	44.7	45	430	306	67
(Mn + Zn)	7.7	15	53	33.6	50.5	50	336	303	- 6
	7.4	14	43	32.2	35.9	36	335	156	-16
	6.9	12	31	30.9	35.3	35	348	194	13
2	8.3	13	43	49.8	38.7	39	500	198	- 9
(Mn + Zn)	6.5	14	35	62.0	49.1	49	853	251	40
	8.6	13	45	48.2	44.5	44	460	242	- 2
	10.0	14	72	62.4	57.1	57	524	308	-21

Nine weeks after the second spray, only the high K trees (treatment 4) were largely non-chlorotic, all others regardless of trace element treatment being moderately - severely chlorotic. Presumably only small amounts had been absorbed by the older chlorotic leaves, or they had not been able to synthesise new green pigments.

One or two manganese sprays increased leaf - Mn from about 9 up to 39 and 9 up to 56 ppm. respectively, an increase of up to 500%. Although no unsprayed trees were included, there is no marked effect of these sprays on leaf - Zn or leaf - Fe.

As with Mn, two Zn sprays have given a similar increase in leaf - Zn over one spray, of about 40%. Zinc sprays have given a large increase in leaf levels over the original concentration - up to 57 ppm. There may have been an increase in leaf Mn and more especially Fe as a result of these sprays, and Labanauskas (117) found such an effect on leaf Mn.

Combined Mn, Zn sprays have not affected leaf - Fe, but increased leaf Mn and Zn. However two such sprays appears to have resulted in a lesser increase in leaf - Zn (13.5 to 47.3 ppm) than two zinc sprays (13.2 to 64.1 ppm). Where this effect was noted in sweet oranges it was attributed to the reduction in free Zn^{++} ions in the combined spray solution (117), and this presumably accounts for those differences here.

2.

(i) Sums of cations (K+Na+Mg+Ca in m.eq.%)

The constancy of this sum, when comparing plants with a differing soil nutrient supply has been shown in conditions of both soil and culture media conditions. It has also been shown to apply following foliar uptake of various salt conditions by seedlings and cuttings (50). Thus as plant - K is increased, constancy is maintained by a fall in plant Ca, Mg and/or sodium. In this work only Ca has shown any tendency to fall with increasing K.

Appendix 10 shows present data in this form for each harvest date. Overall there was no effect of treatment on the sum of cations, although at the final harvest analysis showed the total treatment 4 to be greater at the 5% level. Also at 10/12/69 treatment 4 was higher than the other treatments, at the 1% level. This provides a more substantial proof of constancy following leaf uptake of a major cation in the normal range of plant mineral content in a given season. The situation in the second season is not so clear, but it would appear that in the case of the unusually high accumulation of a major cation, temporarily at least the plant is nutritionally of a different type from one with a lesser supply of that cation.

There was a significant harvest x treatment interaction, and difference between harvests. While not statistically analysed, it is possible Appendix 10 demonstrates a general small increase in total cations as the season advances.

(ii) Cation/Anion ratio $\frac{K+Na+Ca+Mg}{P+N}$ m.eq.%

In some cases the sum of cations has been found to be not constant (8), and the use of this ratio may be more meaningful (114). The analysis of the data, presented in Appendix 11 shows an overall nonsignificant treatment effect, although the ratio tends to be greater in treatment 4 (high K) in the second season - at 1% level at both harvest. This is also the time total cations (K+Na+Ca+Mg) are greater in this treatment, total anions (N+P) being very similar in all treatments.

There is a significant harvest x treatment interaction. The low ratio at 11/4/69 is unusual, and the significant harvest effect on the cation/anion ratio is really also a difference between seasons, and appears totally due to the high values obtained in treatment 4 in the second season. Some factor then appears to have affected this ratio, and it has been claimed a large number of factors, including plant maturity and nutrition can affect the cation/anion ratio (8). In this instance it may be largely due to the pattern or manner of K supply.

These results show that in young leaves with a high K level (2%), possibly only as a result of a recent burst of K accumulation, the total cation level (and so also cation/anion ratio) has not over a fairly long period become stabilised at its "normal" level by mineral re-distribution, or has produced a basically different plant.

In the second season, trees of treatment 4 may, because of their unusually high K level, illustrate an extreme case of mineral supply and so excepted from Liebig's concept of cation - equivalent constancy within a non-extreme range of mineral supply. This work provides evidence that under certain conditions both total cations and the cation/anion ratio may not be constant. It does not however suggest that it is foliar supply *per se* (as opposed to soil supply) that is the important factor behind this effect.

3 Leaf Organic Acids

It is generally accepted that the imbalance of positive and negative charges in tissues, resulting from unequal cation and anion concentrations, is corrected by changes in the level of organic anions. By this means neutrality of cell charge is maintained under varying conditions of mineral uptake. This implies the equality : total inorganic-cations = total inorganic anions or with respect to the elements and their ionic states in the plant : $(K^{+}+Na^{+}+Mg^{++}+Ca^{++})$m.eq.% = $(SO_4^{--}+Cl^{-}+H_2PO_4^{-}+NO_3^{-})$ m.eq.% + organic anions m.eq.%. With two exceptions this mineral data was available for 7/1/70, and so it was possible to calculate total organic acid levels for each treatment. To determine the level of inorganic sulphur, firstly organic sulphur was calculated from Kjeldahl - N by multiplying by 0.027 (17).

This was then subtracted from a constant figure, assuming a total leaf - S level of 0.31% in all trees (29). In the absence of leaf - NO_3 determinations, these levels were assumed to be nil. Thus the estimate for total inorganic anions is only an approximation.

The results of this calculation for 7/1/70 are given in Appendix 12 and indicate a higher organic anion content in the one treatment with a significantly greater total cation content, i.e. number 4. This association is a common one (176). Plant N nutrition is an important factor in determining plant organic acid content (16), and K nutrition has an effect that varies with the crop (71). On this date only K, Fe, Zn are significantly different (higher) in treatment 4, suggesting we can expect an increased total organic acid content in response to the increased K level.

Leaf oxalic acid was determined on 7/1/70 and 6/3/70 (Appendix 13). On neither date was there a significant difference in its concentration, between treatments. Concentrations did however more than double over this period, indicating either an increase in total acids or a change in the proportions of individual acids with the increasing leaf age. Part of the increase may have been due to the continuing low levels of manganese (9), but it could have been largely due to the changes in leaf - Ca over this period (141).

Extrapolating from work on sweet oranges (141) one would have found a large increase in oxalic acid as K levels increased; this did not occur.

A quick test of total non-volatile organic acids gave an indication of actual plant acid levels in each treatment when added to the oxalic acid levels (Table IX). The results do not give a clear indication of the expected trend in plant acid level, although Rasmussen _et al_ (141) found total water soluble organic

TABLE IX PLANT ORGANIC ACIDS - Determined by experiment

Treatment	Rep. No.	Non-volatile acids m. eq.%	Total organic acids m.eq. %	Treatment mean.
1	1	30.9	75.3	66.65
	2	39.97	74.37	
	3	32.37	70.37	
	4	26.71	48.71	
	5	26.09 +	68.49	
	6	25.87	62.67	
2	1	38.85	71.65	74.04
	2	40.84	83.24	
	3	35.55	75.55	
	4	44.07	76.47	
	5	49.9	77.9	
	6	34.62	59.42	
3	1	24.54	62.14	67.34
	2	48.57	87.37	
	3	45.13	87.13	
	4	30.12	61.72	
	5	22.15	57.35	
	6	15.94	48.34	
4	1	42.08	75.28	75.06
	2	44.53	83.73	
	3	36.11	74.11	
	4	51.69	84.89	
	5	25.96	66.76	
	6	33.58	77.58	

\+ Missing plot calculation

Analysis of variance (Total acids)

	df.	MS	F	Prob.
Treatment	3	155.859	1.661	NS
Block	5	207.749		
Error	14	93.862		
Total	22			

Standard error treatment mean = 3.95

V =13.7%

acids in Valencia orange leaves were unaffected by large variations in leaf - K.

A check of some samples by paper - chromatography showed citric acid to be either absent or present in small quantities, there being larger quantities of malic acid, and a spot of R_f 0.28 which could have been aspartic or hydroxpyruvate. It has been shown the concentration of plant acids in citus foliage in decreasing order is oxalic > malic > citric (155). It would have been interesting to determine the levels of individual acids at both harvests in the seond season, and this may have given an indication of the role of K in lemon leaf physiology (e.g. see (138).

It would seem :

(i) That like sweet oranges, lemons would be included with tomato in Freeman's classification (71), of plants showing no change in leaf organic acid content with changing K level.
In the tomato this constancy was maintained by a fall in malic and oxalic acids, with a concomitant increase in glyoxylic and other acids, as K level decreased. In the lemon leaf, oxalic acid does not seem to have shown such changes. The reason for the discrepancy between the forecast and measured effect of leaf K on total leaf organic acids is not clear, but perhaps high K resulted in increased organic anions, other than the organic acids determined in this procedure.

(ii) Malic acid is a major leaf acid in lemon, and its level is likely to change little with K level.

(iii) In the period from 7/1/70 - 6/3/70 leaf Ca would be increasing and leaf K decreasing, these changes having an increasing and decreasing effect respectively on leaf oxalic acid, (141). With the doubling of leaf oxalic acid in this time, the variation in leaf Ca would seem to have had the dominant effect.

(iv) We may accept oxalic and malic as being the main leaf acids: and the above results, and those of Rasmussen *et al* (141) that a fall in K has no effect on total or malic acids, and increasing Ca increases both total and malic acids. In the period 7/1/70 - 6/3/70 K and Ca would be changing in these ways, so the increase in leaf - oxalic acid would indicate an increase in total acids, rather than a change in their proportions.

(v) Insufficient information was obtained to give any indication of the relationship between leaf acids and fruit acids, in high - K trees as compared with low - K trees.

D TREE GROWTH

1 General

(i) Leaf chlorosis

Records of tree appearance were kept in order to detect any treatment effects.

Tree growth was generally satisfactory and while there were differences between trees, there were no marked differences between treatments. In the first summer some trees had few spring -cycle leaves, but this was related more to a heavy crop load.

Leaf chlorosis is a common symptom of low - K in citrus either as a bronzing of older leaves (52), or the development of

Plate 3. Right: Leaf chlorosis of autumn flush leaves, low - K tree.
Left : Green terminal leaves high - K tree 2/12/69.

Plate 4: A range of leaf chlorosis symptoms of older leaves on low - K trees cf. high - K tree. (Chlorosis lemon-yellow colour rather than as shown).

iron-chlorosis (32).

In the winter of 1969 leaf bronzing and chlorosis developed in the older leaves of most trees, and by the end of September interveinal chlorosis of autumn flush leaves was marked on 15 of the 18 trees in treatments 1 - 3. It was clearly a K level effect, with an absence of chlorosis in high - K trees. This effect was noticeable at all subsequent dates, chlorosis being almost absent in treatment 4, severe in treatments 1 and 2, and intermediate in treatment 3. In the second season chlorosis was mainly in the previous year's leaves, and symptoms were more typical of Mn/Zn deficiency than iron deficiency. No chlorotic spring flushes occurred. At both 10/12/69 and 7/1/70 only K, and Fe levels were significantly greater in treatment 4. In the previous season in all treatments leaf - Fe was satisfactory, while both Zn, Mn were low.

An example of the leaf chlorosis is shown in Plate 3, taken on 2/12/69, and compares leaves from a tree receiving high - K, with the chlorotic autumn flush leaves present on a terminal of a low - K tree. It should be noted that such chlorotic leaves were not used in the usual leaf sampling for mineral analysis, although such leaves did provide the results of Table X. Otherwise leaf mineral content data relates to leaves largely green, but from trees bearing older leaves of some degree of chlorosis.

Leaf samples of affected (non-affected in treatment 4) autumn flush leaves collected on 5/1/70 gave the results shown in Table X. This did not indicate the cause of the chlorosis. The Mn/Zn sprays applied later that month did not correct this chlorosis.

TABLE X ANALYSIS OF OLD LEAVES 5/1/70

Leaves	Tree numbers	(ppm) Mn	Leaf levels Zn	Fe	(%) Ca	Mg
Chlorotic	17, 22	13.7	9.5	35.5	1.64	0.146
Chlorotic	4, 13	13.8	10.2	52.6	1.75	0.148
Chlorotic	7, 10	12.6	9.9	48.7	1.87	0.144
Green	3, 14, 18	12.5	13.4	50.9	1.82	0.143

Therefore, while leaf symptoms indicated chlorosis due to Mn and Zn deficiency, sprays of these elements did not correct the chlorosis, and leaf analysis did not indicate their levels were significantly higher in trees of the non-chlorotic treatment - in fact they tended to be lower there in the first season.

Checks of container leachates in the growing season gave an average pH of 5.7 although it was often around 5.1. Further orange leaves do not show chlorosis until leaf - Fe is less than 43 ppm., and severe chlorosis until <18 ppm (193). These facts further support the idea of iron deficiency not being the cause of the observed chlorosis. It has been found the critical leaf - Fe for citrus fruit production is lower than the optimum for chlorophyll development (194). Although some of the early data is suspect, a lot of work has indicated the iron content of chlorotic leaves may be greater than in green ones, suggesting some factor in the former is causing the iron to be less effective in metabolic processes. This factor could be the balance between various elements, which would be present to a greater degree in the three chlorotic treatments, and thus causing the plant to make less effective use of its apparently reasonable iron content.

The early chlorosis appears related to a low leaf - Mn and Zn, associated with low leaf - K and adequate leaf - Fe (high relative to Mn, Zn). This agrees with the earlier conclusion that in considering a trace element deficiency, all these elements must be considered together with it. The level of no one element alone appears directly responsible for the chlorosis.

At the end of the second season tree chlorosis was related mainly to the main treatments. A visual tree rating on 8/6/70 showed chlorosis to be worse (severe) on the old leaves on each tree, only the high - K trees being largely free of this condition. Chlorosis of the current season's leaves was slight-moderate, being distinctly less on the trees of treatment 4. With regard to trace element spray treatment, leaf chlorosis was similar in all treatments, the only tendency being for it to be less on trees sprayed twice with (Mn plus Zn). This implies a requirement for both elements. Plate 4 shows a leaf from a high - K tree compared with the range of symptoms shown by leaves of the other treatments, as present in early June 1970.

(ii) Spray phytotoxicity

Spray damage due to the use of KCl sprays with 1.3% K was absent, except in a very few cases where very young leaves (< 1" long) were present at the time of application, and these showed burned tips or margins.

Some damage was associated with the use of potassium carbonate sprays. About a week after one spray to trees in the field, leaf fall occurred, although it was not serious.

This was observed on trees sprayed on either 24/11/69 or 10/12/69, of the varieties Carters' Navel orange, Morrisons' and Wheeny grapefruit, and Meyer lemon. In each case heavy rain fell two days after spraying. This points to the necessity of using a salt other than the carbonate when supplying potassium by foliar sprays.

(iii) Nutrient solution

With respect to the nutrient supply given these plants a few comments can be made. The availability of P and Mg appears adequate. Ca supply appeared to be low, especially in the second season when N supply also was probably below optimum. Especially in the second season supply of minor elements was low. This apparently low supply was no doubt due in part to the tree roots becoming increasingly pot-bound, ahd that the rate of nutrient supply was a little lower in the second season, compared with the first.

The problem is a matter of increased rates of supply of Ca, N and trace elements than those used, rather than a change in nutrient solution balance - with one exception.

With regards the trace elements, iron supply seems adequate (especially if it was to be supplied as a chelate), but Mn and Zn supply was too low. Nutrient solution Mn was well within the usual range, but due to the increased Fe concentration used it may have been inadequate. The ratio of Fe/Mn in a culture solution has been found most important to avoid deficiency symptoms of either element (170). The optimum for wheat was 1:0.4 (140) about 1:0.5 for soybeans (170), and the ratio usually used for citrus (see Table I) is 1:0.25 - 1.0. In this work it was 1:0.22. A similar explanation may account in part for the low zinc availability.

TABLE XI LEAF TRACE ELEMENT RATIOS

Treatment		Harvest Date						
	[illegible]	3/3/70	11/4/70	6/8/69	Av.	10/12/69	7/1/70	Av
(a) Fe/Mn	1	2.73	2.56	2.83	2.71	5. 0	5.14	5.07
	2	2.35	2.52	2.77	2.55	5. 2	5.13	5.16
	3	2.36	2.07	2.45	2.29	4.78	4. 5	4.64
	4	2.67	2.68	2.75	2.70	5.25	6.78	6.01
(b) Fe/Zn	1	3.16	2.95	3.61	3.24	2.68	3.09	2.88
	2	3.39	3.15	3.39	3.31	3.06	3.42	3.24
	3	2.74	3.29	3. 5	3.18	2.26	2.57	2.41
	4	2.28	2.83	2.75	2.62	3.32	4.07	3.69

It has been suggested for normal healthy plant, that within certain limits it is not the total quantities of Fe and Mn in their tissues that is important, but rather their ratio (170). Table XI gives the mean leaf Fe/Mn & Fe/Zn ratios at each harvest. These suggest lower ratios (as one would expect) in treatment 3 compared with the more chlorotic treatments 1 and 2. The high leaf - Fe levels in the second season of treatment 4 make the ratios for this treatment appear anomalous. In this work then, the leaf Fe/Mn or Fe/Zn ratios go little way in describing the leaf chlorosis shown by the trees.

It appears likely the usual type of nutrient solution is adequate; or in any modification, the relationship between the minor elements in the feed must be especially noted. Rates of supply for young trees would apparently have to be not less than about 2 -3 litres/tree/week during the growing season, and slightly higher as the trees get older.

2 Flowering and Fruiting

At no time was there an obvious relationship between time of flowering or flower numbers, and treatment. Even in the second season this applied, when there were low - K trees producing just as many flowers as high - K ones. Now that trees of widely different K level have been obtained, measurement may show a difference in future.

In the second season a similar number of fruits were set in each treatment. A light set was usually associated with light flowering, and in half of these cases the previous crop had been relatively heavy. The percentage fruit drop was determined in the second season, up to 23/2/70, and there was a tendency for it to be higher in treatment 4 (i.e. mean 17% cf. 6, 4, 9%). Such an effect could partly account for the positive effect of K supply on fruit size (82, 148, 162) in citrus.

(i) First fruit harvest

Most fruit was harvested on 3/12/69, the results of their analysis being shown in Table XII. The low numbers of fruits did not allow detailed comparisons. There were no marked effects of treatment on fruit colour, fruit shape, peel thickness, or rind texture. Patt et al (137) have shown peel quality of the Shamouti orange is determined by conditions shortly after set, the main growing season having little effect. The same may apply to the lemon, and initially these fruits would have all been under

TABLE XII

FRUIT ANALYSIS

Tree No.	Harvest Date	Fruit wt.(g)	L/W ratio	Av. Peel (mm)	% wt. Juice	Peel ascorbic (mg/100g)	Juice ascorbic (mg/100g)	Peel juice ascorbic	% TSS	Acid g/l. (citric)	TSS Acid
16	14/ 8/69	112.5	1.26	8	2.6	111	40.3	2.75	9		-
	9/ 9/69	116.4	1.23	8.2	8.4	107.1	38	2.82	7.5	45.4	1.65
	3/12/69	168.3	1.14	8.2	4.3	144	34.3	4. 2	6.1	46.8	1.30
2	3/12/69	112.5	1. 5	9.2	4	137	34.3	3.99	7.5	53.6	1. 4
		113	1.21	7.7	8.2	152	32.2	4. 7	6.2	48.4	1.28
		117	1.26	7.7	7.6	151	32.9	4. 6	6.5	48.13	1.35
5	3/12/69	107	1.28	7.5	7	102	37.7	2. 7	6.7	48.8	1.37
		135	1.27	8.2	7.1	122	36.4	3.35	6.6	49.1	1.34
19	3/12/69	151.7	1.26	8.2	8.2	121	32.9	3. 7	6.4	44	1.45
		81.7	1. 1	6.2	8.8	109	37.1	2. 9	6.7	46.7	1.43
		101	1.23	7.2	7.2	125					
		101	1.22	7.7	5.2	141	36.4	3.65			
		83	1. 3	7.2	5.7	134					
17	3/12/69	114	1. 3	8.5	3.5	143	31.5	4.54	6.6	51.4	1.28
1	9/ 9/69	57.9	1.23	7.2	1.3	115	-	-	7.7		
	22/ 9/69	90.8	1.28	8.5	0.7	-	-	-	7.7		
	3/12/69	80	1.37	7.7	6.5	147	32.9	4.5	6.8	47	1.45
		98	1.31	7.7	8.26	165	32.9	5	5.8	43	1.35
18	3/12/69	-	1.18	8.7							
B	14/ 8/69	62	1.36	8.0	-	132	-	-	9.5		
	3/12/69	125	1.24	7.5	9.6	151	32.9	4.6	6.3	52.2	1.21

TABLE XII Cont.

(Means for 3/12/69)

	Length width	Peel mm	% Juice	Juice Ascorbic	Peel asc.	Peel juice asc.	Acid g/l	TSS acid
low K	1.25	7.9	6.4	34.9	132	3.83	48.5	1.35
high K	1.28	7.9	8.1	32.9	154	4.69	47.4	1.34

similar nutritional conditions. This point would be worth further study. The same thing may apply to fruit ascorbic acid content as it accumulates most rapidly in young developing fruits, and more slowly thereafter (49) - although the present results may indicate a treatment effect.

In the lemon fruit total acid content increases rapidly as maturity approaches, but it has been shown (11) the juice's true acidity (measured as pH) increased very little after an early stage (in this report after about 3.8 cms. diameter). Should early K nutrition be of major importance in the development of fruit acidity, this could account for the lack of treatment differences here. In comparisons of acid content there are also the complicating factors : (a) fruit acid content varies considerably between fruits on the same tree, and (b) juice acidity increases with increasing fruit size, and such an effect would be expected with the range of fruit sizes used here. No conclusions are possible on the other aspects of fruit quality from this first harvest.

(ii) Second fruit harvest

On 20/7/70 fruit was harvested from blocks 1 - 4 and analysed. As far as possible six equally - sized fruits were taken from each tree, and a summary of the results is given in Table XIIA.

Considering these results by treatment it is clear that even with this method of harvesting an increased fruit size is associated with increased K, in spite of the fact the latter treatment accidentally tended to have more fruits/tree at harvest. This size increase is associated with only a slight tendency for an increase in peel thickness, but it may in fact have been enough to account for the increased fruit weight.

Peel colour was a similar light yellow and pale green in all fruits, except those from tree 12 which were not used to prepare the overall treatment means of Table XIIA. Because of the effects of fruit size on fruit quality, these results apply to groups of fruit within an average 20 gm. weight range in an attempt to minimise these effects.

Usually the peel was relatively smooth in treatments 1 and 2, and usually rough in treatment 4, and a little less rough in treatment 3.

Treatment 4 fruits differed from the others in showing a tendency for the fruit to be less rounded in shape. This appears as an effect when leaf - K at the usual sampling time is >1.7% as compared with a level of about 0.7%, as do some of the other effects reported here.

Regarding internal quality, juice citric acid concentration only in treatment 4 appears to differ, its fruits showing an expected increased concentration. - by about 20%. This may

TABLE XIIA FRUIT COMPOSITION (Harvest 20/7/70)

Treatment	Total fruits/ tree	Tree	Av. fruit wt.	mm. peel	% juice	L/W ratio	% TSS	% citric	TSS/ Acid
1	14	9	91.4	7.42	19.59	1.13	8.68	5.34	1.63
	14	5	82.7	6.00	19.47	1.133	8.72	5.14	1.70
	15	2	84.38	5.67	18.53	1.257	8.8	5.36	1.64
	14	16	88.8	5.88	19.4	1.06	8.85	5.88	1.51
2	15	4	93.5	6.25	18.45	1.143	9.02	5.33	1.69
	15	7	83.9	6.50	17.58	1.126	8.37	5.07	1.65
	15	10	78.2	6.08	19.83	1.097	8.58	5.63	1.52
	15	13	88.3	6.03	20.6	1.03	8.03	5.08	1.58
3	20	1	85.0	6.67	18.75	1.16	9.0	5.27	1.71
	17	6	99.5	6.83	13.63	1.171	8.7	5.48	1.59
	16	11	102.2	7.92	14.57	1.13	8.5	5.62	1.51
	20	15	93.5	6.25	19.83	1.14	9.36	6.4	1.46
4	21	8	97.3	6.92	20.43	1.290	8.77	6.51	1.35
	14	3	100.2	6.50	19.42	1.258	8.73	6.18	1.41
	4	12	59.3	6.5	11.30	1.126	8.4	5.33	1.58
	23	14	101.4	6.08	22.13	1.23	8.33	6.52	1.28

Each figure usually the average of six fruits.

MEANS

Treatment	Total fruits/ tree	Tree	Av. fruit wt.	mm. peel	% juice	L/W ratio	% TSS	% citric	TSS/ Acid
1	14.2		86.82	6.24	19.26	1.145	8.76	5.43	1.62
2	15		86.0	6.23	19.11	1.099	8.50	5.22	1.61
3	18.2		95.0	6.92	17.96	1.15	8.89	5.69	1.57
4	19.2		99.6	6.50	20.66	1.635	8.61	6.40	1.35

be a high - K effect, but is also an effect associated in the literature and to some extent here with increased crop load and increased fruit size. In other respects too it is not clear which factor is in fact causal for the results obtained.

The difference in acid level is also reflected in the sugar/acid ratio, the % TSS being similar in all treatments. It was also noticed that within a tree, juice acid concentration and soluble solids level were remarkably constant between fruits. It appears there may be an association of an increase in % juice with treatment 4.

While crop load can have marked effects on fruit composition of the Washington navel, this effect does not seem apparent within the limits of these trees. The present results could though be taken as support for the reported association of increased juice acidity and peel thickness with increased fruit size (85 gm. cf. ≥ 95 gm. weight).

Alternatively we may consider treatments, and associate high K (i.e. that of treatment 4) with an increase in fruit size, fruit length/width ratio, peel roughness, and juice acidity and possible also in peel thickness. In some effects treatment 3 fruits are intermediate between the low - K and the high - K treatments.

It therefore appears, in considering the range in plant K here, the results agree with the literature in their being sufficient to result in the given increases in fruit size, fruit longness, juice acidity, and possibly a small change in juice percentage. They do not agree that increasing K produces a thinner smoother peel in lemons, but that they respond in the same way as sweet oranges.

During the time these fruits were on the trees, at the times for which leaf analysis data is available only K, Fe, Zn varied between treatments, and it does not seem unreasonable to attribute the effects on fruit quality to the extremes of plant K level then. The probable absence of such extremes may have partly accounted for the lack of treatment effects at the first fruit harvest. However the marked effects noted at 20/7/70 may in fact have resulted from the different K levels occurring early in fruit development (a suggestion made earlier), rather than simply due to the increased range of K levels.

CHAPTER V FINAL DISCUSSION

This work has provided some information on the mineral nutrition of the lemon tree, which in general is in agreement with published overseas work with citrus. In addition to demonstrating the direction of an effect, the results show the extent of this effect. This is useful in that it must be possible to indicate to a fruit grower in any area the magnitude of the response to various treatments, and the relationship between some parameter and varying plant nutrient status. Foliar nutrition is of interest to many producers, and this work shows some of the effects of this method of feeding crops.

It appeared the usual method of leaf washing is adequate for a meaningful leaf - K determination to be made, after an earlier foliar spray of a potassium salt. In the case of trace - element determination subsequent to manganese or zinc sprays the same preparation also appears satisfactory.

Thus leaf analyses on 6/3/70, 3 - 5 weeks after applying Mn and/or Zn sprays, show largely consistent changes in leaf trace element level within each treatment. This is especially evident when considering the parts per million change in each element, rather than the percentage changes in element concentration. At all times too, leaf - Fe levels do not show the high values one would expect from dirt contaminants.

The results show how useful one or two Mn or Zn sprays can be in increasing leaf levels of these elements when applied as a spray containing 300 ppm. metal. One month after one or two early February Mn sprays a low level of about 9 ppm. was increased by 30 and 47 ppm. respectively; and for Zn sprays a level of 13 ppm. was increased by 35 and 51 ppm. Combining these two elements in a spray reduced the uptake (?) of Zn, especially when two sprays were applied: one Zn spray and two (Mn + Zn) sprays had the same effect on leaf Zn.

The suggestion was also made that leaf - K determinations made about a month after applying K sprays gave the most realistic indication of the spray's effect on plant - K. In the case of early March sprays at least, reasonable comparisons could apparently be made a week later, but after a further three weeks the rate of change in leaf - K in sprayed and unsprayed trees was almost identical.

While the data has shown useful effects of foliar K sprays on leaf K in the short term the situation is rather different over a fifteen month period. It was shown that eight days after the second of two weekly - spaced March KCl sprays (1.3%K), leaf K had increased by 55% (i.e. from 0.84% to 1.30%) compared with a fall of 29% in unsprayed trees. This effect fell off to show a return to the original leaf - K level one month after spraying, as compared with a fall of 28 - 57% in this time where no spray was applied. There was a change in percentage leaf - K from 0.82 - 1.18 down to 0.23 - 0.58 during March, under conditions of negligible soil - K in the absence of foliar potassium sprays. Changes of a similar magnitude occurred following one December spray. For some reason leaf - K was not improved by this spray to the same extent in the presence of a moderate supply of soil - K. This may be a direct effect of soil K on foliar K uptake, or related to the differences in original plant - K status. Thus over December the percentage leaf - K of high - K trees receiving soil and foliar K fell by about as much (2.11 - 1.87%) as low K trees receiving no K (0.86 - 0.65%). But trees of intermediate K status receiving only foliar K showed no change in leaf - K in this period, (1.07 - 1.09%).

Eleven weeks after two December potassium sprays there was virtually no effect on leaf K levels, and this effect continued over the next twelve months. A total of four "summer" sprays in one season resulted in higher leaf K in the leaves in August, but the effect was lost in young leaves in mid-December. The absence of a significant effect in the following season was due to the apparent high degree of mobilisation of tree - K in trees deficient in this element. The increased K from foliar uptake had apparently been used elsewhere, possibly accumulating in the fruits, or promoting plant growth. It is clear that in the absence of soil K, even four strong foliar sprays affected leaf - K concentration only for that season. Leaf K in the next season was improved only when soil - K was available, and it was a little surprising to find soil K from early April did not seem to have any affect on leaf K over the next four months.

In a comparison of three potassium salts, foliar uptake was similarly high over one - eight days from spraying from the chloride and nitrate salts, although the chloride may have been more effective. The carbonate was only about half as effective over this period, and caused a small amount of leaf drop on a number of citrus varieties. Spray damage from KCl (1.3%K) sprays was only slight, affecting newly unrolled tip leaves. The foliar uptake of K by Meyer lemons, was lower than by Villafranca, possibly due to differences in their mineral status.

It was anticipated the chloride sprays may have resulted in excessive accumulations of leaf - Cl. While there were no visible effects of high chloride levels, it was clear a small number of KCl sprays did greatly affect leaf - Cl. One December spray increased leaf - Cl two and one half times one month later, although two sprays had not significantly increased leaf - Cl eight months later. However four early season sprays had doubled leaf - Cl five months later to a high level.

The observed differences in leaf K had a marked effect on leaf colour. Trees with about $\leq 1\%$ leaf - K in autumn developed interveinal chlorosis of the older leaves during the winter, and this was more severe where leaf K was $\leq 0.6\%$. In the second season also, chlorosis was no more than slight in the high - K treatment, but moderate - severe in the older leaves of treatments one and two. This chlorosis characteristic of potassium deficiency, was typical of Mn and Zn deficiency and not of Fe deficiency. The leaf Fe concentrations, and the known acid pH of the container leachates also did not indicate a deficiency of this element to be the cause of the chlorosis. Leaf Mn and Zn levels were at a low level, especially in the second season, but this applied to all four treatments. There was no clear indication of the low leaf - Zn resulting from the well-known antagonism of high phosphate, although the two elements showed a significant negative correlation in the second season. The low values of leaf Mn and Zn may have resulted from an imbalance in the proportions of these elements in relation to the iron concentration in the nutrient feed. However sprays of Mn and/or Zn appeared to have little effect on tree chlorosis, suggesting the leaf level of these elements alone was not important. It was suggested that in characterising the chlorosis shown by these trees it is necessary to refer to the nutrient status of several elements, and that for this the elements N, K, Mn, Zn, Fe, are important. This is not an uncommon phenomenon as difficulty is often found in looking at mineral levels in isolation, or even as ratios. The need to look at the levels of several elements together is accepted today, as for instance in the case of bitter pit in apples and peteca in lemons.

In looking at the seasonal variations in leaf levels of each element for each treatment it was difficult to see many clear relationships with leaf K level. Sodium level was about 0.1% in the older first season leaves, and 0.06% in the younger second season samples, and showed no evidence of substituting for potassium. It was apparent the provision of potassium by leaf application usually gave the same changes in leaf mineral concentrations with increasing leaf age, as for soil K or nil K applications. Thus N, K, Mn, Zn, Fe levels declined with increasing leaf age, Ca increased, Mg rose then fell, whereas P concentrations rose steeply in early summer and varied somewhat over the summer. With the rather large intervals between samples, in some instances a distinct plateau in leaf mineral level was not apparent. It is suggested April was the best month for sampling lemon leaves for leaf mineral determinations, although this could be varied somewhat with certain elements. Particular attention must be made to avoid too early sampling of trees receiving a low potassium supply, where this element is to be measured.

When one considers the leaves sampled between March and August, K level showed the usual negative correlation with leaf Ca, Fe, Mn, and in the young leaves of December and January a significant positive correlation with Mn, Zn, Fe. There was no evidence of an antagonistic effect of K level on leaf Mg (or N). One possible explanation is that a foliar K supply differs from a soil K supply in not altering the plants Mg - distribution pattern in the way that usually accounts for the antagonistic behaviour of these two elements. It is also possible for the pattern of this antagonism to be influenced by the accompanying anion, and the levels of other nutrient elements. In this respect we may note the considerable reduction in leaf - Cl in the second season which coincides with the possible emergence of a K - Mg antagonistic effect. It would appear that, as sometimes reported, in the older leaves high K is associated with low Fe, Mn. The situation in the younger leaves is confused as the "high" leaf trace elements associated with high K, also bear significant correlations to one another. .. winter soil K supply had a marked stimulatory effect on leaf - Fe. This difference in relationship with season may be due to a difference in leaf age, or to the very low levels of Mn, Zn in the younger leaves.

The other notable association were of high N - low P, and high Mg - high TE, in both seasons.

In the same way that K sprays affect leaf levels of other minerals, it appeared Zn sprays had an effect on the other trace elements.

The negative correlation between K and Ca in the first season was referred to above, and at the leaf - K levels of treatment 4 there appeared a consistent reduction of leaf-Ca compared with the other treatments. In this way the total leaf cations were kept at a similar level in all trees i.e. only Ca was involved in maintaining the cation balance with increased K supply. However in the second season the younger leaves did not show this effect. The highest K level resulted in an increased total cation content (and so too cation/anion ratio), there being no differences in leaf - Ca at this early stage - although by 6/3/70 there was evidence of a lowering of leaf - Mg. Therefore the cation/anion ratio, and the sums of cations were not constant in young lemon leaves with the extremes of K present, but this was not related to the method of K application.

Using data of 7/1/70 it was predicted the increased total cation content would result in a significant increase in leaf organic anion content. It was however found there was no increase in leaf total organic acids - the expected change in organic anion content may have occurred in substances not determined here. In the second season there was no effect of K treatment on leaf oxalic acid content, although such a response has been obtained in sweet oranges (141). It is surmised the doubling of leaf - oxalic acid during January and February was due to an increased leaf Ca, although increased leaf Mg levels may have also played a part. Any change in balance in leaf organic acids due to increased K supply will have involved only the minor acids.

The method of feeding the trees in this work was basically sound, but it is suggested that rates of nutrient solution application must be carefully watched as requirements can easily not be met. This seemed to occur here in the second season, especially with respect to calcium and nitrogen supply. Trace element supply was also on the low side, and it is considered the most important aspect of this is to maintain a satisfactory balance between iron and the elements manganese and zinc in the nutrient solution.

The most obvious effect of differential K supply under these conditions was on leaf colour. There was no obvious effect on flowering but there were effects on fruit quality - especially fruit size, peel quality, juice acid content, and fruit shape. It is suggested that it is early in the fruits' development that tree nutrition has its greatest effect on fruit quality.

APPENDIX 1.

The four concentrated stock solutions were made:

(1) 615 gm $Ca(NO_3)_2.4H_2O$ made up to 45 litres

(2) 484 gm $Mg SO_4.7H_2O$ in 45 litres

(3) 35 gm $NaH_2PO_4.2H_2O$
1.115 gm $MnSO_4.4H_2O$
0.135 gm $CuSO_4.5H_2O$
0.435 gm $ZnSO_4.7H_2O$ in 45 litres
0.930 gm H_3BO_3
0.0175 gm $(NH_4)_6Mo_7O_{24}.4H_2O$

(4) 7.5 gm Fe citrate $5H_2O$ made up to 2½ litres

The nutrient content of 2.2 litres of the final nutrient solution, for 29 trees, is contained in a mixture of 6 litres of solutions (1), (2), and (3), and 330 cc of solution (4).

APPENDIX 2. N DETERMINATION REAGENTS.

NaOH	11N
Catalyst:	Mix 10 gms. selenium with 500 gms. K_2SO_4
Indicator:	Brom-cresol green/Methyl red.

APPENDIX 3. P DETERMINATION REAGENT.

V/Mo reagent - Dissolve 10 gms. ammonium vanadate in water over heat, then add 1400 cc. conc. HNO_3. Add 200 gms ammonium molybdate after dissolving in water.

Standard curve prepared from solutions potassium dihydrogen, phosphate containing 0.5, 1.0, 1.5, 2.0, 2.5 ppm P.
(2.196 gms chemical in 250 litres = 2 ppm P)

APPENDIX 4. ASCORBIC ACID DETERMINATION REAGENTS.

Extracting solution - To 50 cc 40% W/V sodium polymetaphosphate add 50 cc glacial acetic acid. Dilute to 50 cc with water.

Standard indophenol solution - Dissolve 0.250 gms sodium 2.6 - dichlorophenol-indophenol in 25 cc distilled water. Add 0.021 gms $NaHCO_3$, make up to 200 cc. Filter, and will keep one week in refrigerator.

APPENDIX 5. OXALIC ACID DETERMINATION REAGENTS.

Tungstate reagent - Dissolve 12 gms sodium tungstate in water, add 20 cc phosphoric acid (specific gravity 1.75). Dilute to 500 cc.

Buffer - Dissolve 6.25 gms anhydrous calcium chloride in 125 cc 50% V/V acetic acid. Add to this 82.5 gms sodium acetate trihydrate made up to 125 cc with water.

APPENDIX 6. LEAF ANALYSIS RESULTS.

Element concentrations are given for each replicate number 1 - 6, and expressed as % Dry Weight for N, P, K, Ca, Mg, Na, and as ppm Dry Weight for Mn, Zn, Fe.

HARVEST DATE: 3/3/69.

Treat. No.	N	P	K	Ca	Mg	Na	Mn	Zn	Fe
1	1.87	0.134	0.65	1.36	0.37	0.094	25.8	15.0	51.6
	2.74	.155	.80	1.79	0.28	.06	30.3	22	82.6
	2.78	.153	.89	3.00	0.29	.09	16.2	22	71.0
	2.90	.215	1.22	1.82	0.25	.072	13.0	21	46.0
	1.61	.172	.78	1.79	0.26	.20	17.0	17	57.0
	2.23	.138	.61	2.53	0.42	.09	28.0	19	51.0
2	3.46	0.172	1.26	2.01	0.30	.09	34	24	57
	2.66	.176	1.38	1.22	.25	.05	13	16	47
	2.87	.136	.79	3.31	.39	.09	33	15	58
	2.87	.151	.82	2.90	.36	.10	25	13	80
	2.78	.149	1.22	2.47	.37	.10	30	18	64
	2.77	.157	1.63	2.11	.31	.10	20	21	59
3	2.96	0.162	1.19	2.00	0.33	0.1	16	20	124
	2.77	.157	1.43	1.63	.22	.09	14	15	49
	2.74	.131	1.04	2.98	.45	.09	41	21	57
	2.93	.176	1.02	3.43	.51	.1	24	26	62
	2.50	.151	.98	2.43	.33	.54	19	18	52
	2.22	.151	1.09	1.68	.28	.08	17	15	41
4	3.18	0.129	1.38	2.04	0.31	0.13	21	13	59
	2.62	.157	1.30	1.60	.32	.07	16	17	41
	2.54	.181	1.12	1.60	.32	.18	17	31	45
	2.78	.145	1.32	2.05	.36	.11	22	20	51
	2.87	.183	1.34	1.91	.33	.14	22	18	55
	2.80	.185	1.91	1.35	.36	.05	10	25	35

APPENDIX 6. LEAF ANALYSIS RESULTS. (Cont.)

HARVEST DATE: 11/4/69.

Treat. No.	N	P	K	Ca	Mg	Na	Mn	Zn	Fe
1	3.90	0.116	0.42	2.15	0.37	.08	27.7	15	43
	4.11	.114	.51	2.54	.38	.10	31.4	25	86
	3.56	.157	.69	1.87	.27	.10	12.6	18	63
	3.80	.162	.80	1.69	.27	.10	13.6	18	45
	4.10	.150	.53	2.36	.33	.19	23.2	22	63
	4.12	.133	.60	2.13	.37	.09	30.5	24	55
2	4.12	0.120	0.87	2.58	0.33	.07	28	24	66
	3.00	.137	.69	1.64	.25	.10	16	19	69
	3.60	.126	.49	2.32	.34	.10	29	18	53
	3.04	.106	.50	1.68	.24	.12	21	15	57
	-	.126	.76	2.15	.33	.12	31	20	57
	-	.110	.63	2.19	.26	.10	23	23	75
3	3.76	.150	.79	3.09	.39	.1	20	15	58
	4.36	.116	1.44	2.54	.29	.09	18	18	67
	3.18	.114	1.22	2.17	.37	.13	41	16	56
	3.74	.123	.87	2.69	.40	.11	31	18	60
	4.08	.116	.97	2.16	.29	.11	23	17	54
	4.55	.106	1.01	2.57	.36	.09	28	17	43
4	4.41	0.157	1.35	2.62	0.34	.10	21	16	55
	3.97	.165	1.48	1.50	0.28	.06	14	18	54
	4.20	.150	1.22	1.43	0.29	.1	15	16	41
	4.18	.114	1.30	2.58	.39	.12	23	19	53
	4.39	.157	1.09	2.56	.37	.12	27	20	59
	4.68	.162	1.30	1.66	.31	.08	15	20	46

APPENDIX 6. LEAF ANALYSIS RESULTS. (Cont.)

HARVEST DATE: 6/8/69.

Treat. No.	N	P	K	Ca	Mg	Na	Mn	Zn	Fe
1	2.79	0.204	.44	2.96	0.22	.11	25	13	45
	2.85	.177	.50	2.57	.23	.10	32	21	77
	2.76	.167	.53	3.01	.15	.12	15	19	64
	3.34	.167	.55	2.78	.17	.09	20	18	93
	3.68	.133	.42	3.03	.22	.09	22	18	61
	2.73	.163	.74	2.53	.20	.11	23	18	48
2	2.82	0.177	.57	2.98	0.15	.10	25	21	60
	2.47	.141	.68	2.36	.14	.09	17	17	92
	2.52	.156	.50	2.68	.19	.14	20	16	47
	2.38	.152	.57	2.39	.20	.09	17	13	53
	3.65	.141	.65	2.71	.22	.1	28	16	51
	3.30	.160	.61	2.78	.15	.1	22	24	66
3	3.23	0.167	.95	2.62	.14	.10	14	12	45
	2.75	.133	1.14	2.97	.14	.09	15	15	53
	2.38	.118	.91	4.36	.22	.13	34	13	54
	2.11	.152	.99	2.61	.17	.09	21	14	48
	3.48	.130	.93	2.82	.17	.1	20	15	50
	3.44	.141	1.01	2.79	.17	.09	19	15	42
4	3.15	0.182	1.25	2.73	0.16	.11	16	14	45
	2.93	.156	1.27	3.07	.16	.11	14	16	45
	2.87	.177	1.16	2.05	.19	.11	15	16	43
	2.83	.156	1.10	2.47	.19	.08	19	15	44
	3.43	.152	0.84	2.66	.19	.09	18	17	50
	2.85	.167	1.25	1.81	.15	.11	15	18	38

APPENDIX 6. LEAF ANALYSIS RESULTS. (Cont.)

HARVEST DATE: 10/12/69.

Treat. No.	N	P	K	Ca	Mg	Na	Mn	Zn	Fe
1	2.35	0.091	0.81	1.88	0.29	.061	6.9	17.3	35
	2.42	.114	1.04	1.79	.32	.057	12.2	19.8	56
	2.52	.102	.88	1.76	.30	.056	10.1	17	19
	2.05	.099	.78	1.48	.25	.054	6.6	14	39
	2.00	.106	.79	1.65	.28	.056	8.4	15.3	48
	2.28	.091	.87	1.67	.29	.054	10.1	17.2	45
2	2.21	0.122	1.07	1.64	0.31	.04	13.5	19	62
	2.26	.097	1.07	1.74	.27	.049	10.1	15	48
	2.17	.099	.98	1.72	.31	.052	10.7	16	47
	2.11	.091	.74	1.83	.28	.061	6.7	16	44
	1.60	.092	.98	1.80	.28	.066	8.9	17	43
	2.26	.102	.95	1.38	.31	.061	10.9	18	71
3	2.67	0.114	0.95	1.97	0.28	.074	8.7	20	42
	2.29	.114	1.19	1.44	.27	.045	9.3	21	42
	2.63	.119	1.31	2.25	.34	.078	13.1	21	42
	2.25	.113	1.05	2.05	.28	.049	9.0	19	41
	2.47	.092	0.98	1.59	.26	.057	7.0	16	36
	2.23	.091	.93	1.65	.23	.056	8.7	17	55
4	2.27	0.126	2.48	1.96	.34	.067	12	23	58
	2.11	.097	2.22	1.09	.32	.091	13	18	84
	2.27	.099	1.94	1.87	.30	.076	12.5	15.	72
	2.33	.110	2.00	1.93	.29	.061	10.7	21	48
	1.63	.102	1.80	1.75	.33	.037	10.0	17	62
	2.17	.113	2.22	2.12	.32	.096	11.2	19	56

HARVEST DATE: 7/1/70.

Treat. No.	N	P	K	Ca	Mg	Na	Mn	Zn	Fe
1	1.97	.136	0.56	1.70	.342	.059	5.5	14	32
	1.97	.151	.80	1.43	.62	.042	8.3	13	43
	1.98	.162	.64	1.67	.304	.026	7.8	12	40
	1.70	.134	.73	1.48	.231	.080	6.3	10	31
	2.08	.168	.52	1.39	.252	.048	7.4	14	43
	1.99	.123	.64	1.52	.256	.055	9.2	11	38
2	2.06	.175	0.77	1.17	.37	.062	11.9	14	53
	2.05	.187	.87	1.78	.292	.055	8.6	13	45
	1.79	.147	.78	1.86	.331	.053	8.6	12	37
	1.88	.142	.62	1.94	.308	.070	6.8	13	41
	1.91	.165	.81	1.51	.273	.044	5.9	11	27
	1.81	.151	.68	1.35	.304	.057	7.8	12	45
3	2.40	.162	0.96	1.65	.219	.066	6.1	16	39
	2.14	.176	1.15	1.70	.35	.045	6.5	14	35
	2.17	.150	1.25	1.63	.283	.065	10.1	15	31
	1.84	.173	1.17	2.01	.322	.091	8.4	14	37
	1.99	.142	1.05	1.85	.219	.066	6.9	12	31
	2.20	.131	0.98	1.49	.279	.060	8.1	13	45
4	1.96	.212	1.92	1.60	.45	.047	10.8	19	79
	1.87	.162	1.98	1.68	.272	.060	10	14	72
	1.92	.154	1.85	1.35	.235	.051	9.5	12	60
	2.05	.205	1.86	1.77	.326	.071	9.2	16	43
	1.71	.160	1.76	1.48	.292	.059	7.7	15	53
	-	.153	1.86	1.71	.318	.060	11.7	16	59

STATISTICAL ANALYSES.

NS	non-significant
+	significant at 5% level
++	significant at 1% level
V	coefficiant of variation
e	standard error of treatment mean
$e_{.05}$	standard error of treatment mean where P = 0.05 (from Table 3 Fisher and Yates (62)).

Treatment means not significantly different by Duncan's test (48) at the stated level of probability are underscored together.

APPENDIX 7. SIGNIFICANCE TESTS OF LEAF MINERAL LEVELS BETWEEN TREATMENTS AT EACH HARVEST.

Analysis of Variance.

(a)

3/3/69		df.	MS	F	Result
N	Treatment	3	0.34	2.79	NS
	Block	5	0.13		
	Error	15	0.122		
	Total	23			

V 13% e 0.14 $e_{.05}$ 0.298

APPENDIX 7.

Analysis of Variance. (Cont.)

(a) 3/3/69		df.	MS	F	Result
P	Treatment	3	.0000967	0.171	NS
	Block	5	.00029		
	Error	15	.00056613		
	Total	23			

V 15%   e 0.01 $e_{.05}$ 0.021

		df.	MS	F	Result
K	Treatment	3	0.332	5.13	+
	Block	5	.0596		
	Error	15	.0647		
	Total	23			

V 22.5%   e 0.1 $e_{.05}$ 0.21

Treatment		1	3	2	4
Mean	1%	.825	1.125	1.183	1.395

		df.	MS	F	Result
Ca	Treatment	3	.321	1.38	NS
	Block	5	.847		
	Error	15	.232		
	Total	23			

V 22%   e 0.2 $e_{.05}$ 0.426

APPENDIX 7.

Analysis of Variance. (Cont)

(a) 3/3/69.

		df.	MS	F	Result
Mg	Treatment	3	.00407	.964	NS
	Block	5	.00541		
	Error	15	.00422		
	Total	23			

V = 19.6% e = 0.027 $e_{.05}$ = 0.057

		df.	MS	F	Result
Mn	Treatment	3	61.4	0.93	NS
	Block	5	43.06		
	Error	15	65.9		
	Total	23			

V = 37% e = 3.3 $e_{.05}$ = 7.03

		df.	MS	F	Result
Fe	Treatment	3	312.5	0.87	NS
	Block	5	296.16		
	Error	15	358.2		
	Total	23			

V = 32.5% e = 7.7 $e_{.05}$ = 16.4

APPENDIX 7.

Analysis of Variance. (Cont.)

(b)

11/4/69		df.	MS	F	Result
N	Treatment	3	0.4640	3.933	+
	Block	5	0.2973		
	Error	13	0.11798		
	Total	21			

V = 8.7% e = 0.14 $e_{.05}$ = 0.299

Treatment	2	1	3	4
Mean	3.62	3.93	3.94	4.3

1%

		df.	MS	F	Result
P	Treatment	3	.0000997	7.02	++
	Block	5	.00009		
	Error	15	.0000142		
	Total	23			

V = 2.8% e = 0.003 $e_{.05}$ = 0.006

Treatment	2	3	1	4
Mean	0.121	0.121	0.139	0.151

1%

		df.	MS	F	Result
K	Treatment	3	0.65769	20.5	++
	Block	5	.0191		
	Error	15	0.03211		
	Total	23			

V = 20% e = 0.07 $e_{.05}$ = 0.149

APPENDIX 7.

Analysis of Variance. (Cont.)

(b) 11/4/69.

K	Treatment	1	2	3	4
	Mean	0.592	0.657	1.05	1.29
	1%				

		df.	MS	F	Result.
Ca	Treatment	3	0.2642	1.66	NS
	Block	5	0.2346		
	Error	15	0.1591		
	Total	23			

V = 18% e = 0.16 $e_{.05}$ = 0.341

		df.	MS	F	Result
Mg	Treatment	3	0.0036	1.42	NS
	Block	5	0.001406		
	Error	15	0.00254		
	Total	23			

V = 15.5% e = 0.021 $e_{.05}$ = 0.045

		df.	MS	F	Result.
Zn	Treatment	3	15.7	2.36	NS
	Block	5	3.5		
	Error	15	6.65		
	Total	23			

V = 13.7% e = 1.0 $e_{.05}$ = 2.13

APPENDIX 7.

Analysis of Variance. (Cont.)

(b) 11/4/69.		df.	MS	F	Result
Fe	Treatment	3	141.2	1.5	NS
	Block	5	141.16		
	Error	15	94.3		
	Total	23			

V = 17% e = 4 $e_{.05}$ = 8.52

(c)

6/8/69.		df.	MS	F	Result
N	Treatment	3	1.11608	1.56	NS
	Block	5	0.46045		
	Error	15	0.71341		
	Total	23			

V = 28.5% e = 0.34 $e_{.05}$ = 0.72

		df.	MS	F	Result
P	Treatment	3	0.0009717	8.19	++
	Block	5	0.000807		
	Error	15	0.00011867		
	Total	23			

V = 7% e = 0.004 $e_{.05}$ = 0.008

Treatment	3	2	4	1
Mean	0.14	0.154	0.165	0.168

1%

APPENDIX 7.

Analysis of Variance. (Cont.)

(c) 6/8/69.		df.	MS	F	Result
K	Treatment	3	0.5357	55.7	++
	Block	5	0.0219		
	Error	15	0.00961		
	Total	23			

V = 12% $c = 0.04$ $c_{.05} = 0.08$

Treatment	1	2	3	4
Mean	0.53	0.597	0.988	1.145

1%

		df.	MS	F	Result
Ca	Treatment	5	0.0676	3.32	+
	Block	5	0.0154		
	Error	15	0.02036		
	Total	23			

V = 5.2% $c = 0.06$ $c_{.05} = 0.128$

Treatment	4	2	1	3
Mean	2.308	2.65	2.98	3.033

1%

		df.	MS	F	Result
Mg	Treatment	3	0.001005	1.16	NS
	Block	5	.000021		
	Error	15	.0008639		
	Total	23			

V = 16.5% $c = 0.012$ $c_{.05} = 0.026$

APPENDIX 7.

Analysis of Variance. (Cont.)

(c) 6/8/69.		df.	MS	F	Result.
Mn	Treatment	3	19.93	1.47	NS
	Block	5	4.45		
	Error	15	34.05		
	Total	23			

V = 28.8%   e = 2.4 $e_{.05}$ = 5.1

		df.	MS	F	Result.
Zn	Treatment	3	20.055	3.33	+
	Block	5	8.267		
	Error	15	6.022		
	Total	23			

V = 11.9%   e = 1.0 $e_{.05}$ = 2.1

Treatment	3	4	1	2
Mean	14	16	18	18

5%

		df.	MS	F	Result
Fe	Treatment	3	588.7	4.10	+
	Block	5	201.8		
	Error	15	143.5		
	Total	23			

V = 21.9%   e = 4.9 $e_{.05}$ = 10.4

APPENDIX 7.

Analysis of Variance. (Cont.)

6/8/69

Fe	Treatment	4	3	2	1
	Mean	44	49	61	65
	5%				

(d) 10/12/69

		df.	MS	F	Result.
N	Treatment	3	0.1309	4.17	+
	Block	5	0.1166		
	Error	15	0.03134		
	Total	23			

V = 7.9% e = 0.07 $e_{.05}$ = 0.149

Treatment	2	4	1	3
Mean	2.1	2.13	2.27	2.42
5%				

		df.	MS	F	Result.
K	Treatment	3	2.0093	84.1	++
	Block	5	0.0385		
	Error	15	0.0239		
	Total	23			

V = 12.4% e = 0.06 $e_{.05}$ = 0.128

Treatment	1	2	3	4
Mean	0.862	0.965	1.068	2.11
1%				

APPENDIX 7.

Analysis of Variance. (Cont.)

(d) 10/12/69

		df.	MS	F	Result
Ca	Treatment.	3	0.0499	1.26	NS
	Block	5	0.0266		
	Error	15	0.03959		
	Total	23			

V = 10.4%   e = 0.08 $e_{.05}$ = 0.17

		df.	MS	F	Result
Mn	Treatment	3	7.728	2.95	NS
	Block	5	7.781		
	Error	15	2.621		
	Total	23			

V = 16.2%   e = 0.7 $e_{.05}$ = 1.49

		df.	MS	F	Result
Fe	Treatment	3	641.9	10.81	++
	Block	5	1534.5		
	Error	15	59.37		
	Total	23			

V = 15.2%   e = 3.1 $e_{.05}$ = 6.60

Treatment	3	1	2	4
Mean	43	45	52	63

5%

APPENDIX 7.

Analysis of Variance. (Cont.)

(d) 10/12/69.		df.	MS	F	Result
Zn	Treatment	3	9.44	2.12	NS
	Block	5	5.666		
	Error	15	4.445		
	Total	23			

V = 11.7% e = 0.86 $e_{.05}$ = 1.83

Na		df.	MS	F	Result
Na	Treatment	3	0.00033	1.57	NS
	Block	5	0.00011		
	Error	15	0.00021		
	Total	23			

V = 24% e = 0.006 $e_{.05}$ = 0.013

(e) 7/1/70		df.	MS	F	Result
N	Treatment	3	0.0611	3.21	NS
	Block	5	0.0238		
	Error	14	0.01903		
	Total	22			

V = 6.99% e = 0.056 $e_{.05}$ = 0.12

APPENDIX 7.

Analysis of Variance. (Cont.)

(e) 7/1/70

		df.	MS	F	Result
P	Treatment	3	0.00086	2.32	NS
	Block	5	0.00055		
	Error	15	0.00037		
	Total	23			

V = 12.1% e = 0.008 $e_{.05}$ = 0.017

		df.	MS	F	Result
K	Treatment	3	1.83139	261.25	++
	Block	5	0.01672		
	Error	15	0.00701		
	Total	23			

V = 7.7% e = 0.03 $e_{.05}$ = 0.064

Treatment	1	2	3	4
Mean	0.648	0.755	1.093	1.87

		df.	MS	F	Result
Mg	Treatment	3	0.003598	1.397	NS
	Block	5	0.002954		
	Error	14	0.002574		
	Total	22			

V = 17.1% e = 0.021 $e_{.05}$ = 0.045

APPENDIX 7.

Analysis of Variance. (Cont.)

(c) 7/1/70		df.	MS	F	Result
Zn	Treatment	3	11.93055	5.93	++
	Block	5	4.9417		
	Error	15	2.09722		
	Total	23			

$V = 10.9\%$ $e = 0.6$ $e_{.05} = 1.28$

Treatment		2	1	3	4
Mean		12	12.3	14	15
	5%				

		df.	MS	F	Result
Fe	Treatment	3	785.7083	12.78	++
	Block	5	116.675		
	Error	15	61.475		
	Total	23			

$V = 17.8\%$ $e = 3.2$ $e_{.05} = 6.8$

Treatment		3	1	2	4
Mean		36	38	41	61
	1%				

		df.	MS	F	Result
Na	Treatment	3	0.00021	2.1	NS
	Block	5	0.00046		
	Error	15	0.0001		
	Total	23			

APPENDIX 7.

Analysis of Variance. (Cont.)

(c) 7/1/70.

Na V = 17.4% c = 0.004 $c_{.05}$ = 0.008

(f) 6/3/70.

		df.	MS	F	Result
K	Treatment	3	1.96111	24.44	++
	Block	5	0.1871		
	Error	15	0.08024		
	Total	23			

V = 35.4% c = 0.116 $c_{.05}$ = 0.247

Treatment	1	2	3	4
Mean	0.396	0.487	0.693	1.642

1%

		df.	MS	F	Result
Mg	Treatment	3	0.005050	4.1	++
	Block	5	0.001833		
	Error	15	0.001228		
	Total	23			

V = 9.52% c = 0.014 $c_{.05}$ = 0.030

Treatment	4	3	1	2
Mean	0.336	0.350	0.389	0.395

5%

APPENDIX 8. LEAF CHLORIDE. (% Dry Weight)

Date	Block	Treatment number			
		1	2	3	4
6/8/69	1	0.366	0.329	0.797	0.806
	2	0.365	0.386	0.954	0.783
	3	0.317	0.491	0.871	0.849
	4	-	-	0.949	0.600
	5	0.532	0.510	0.749*	-
	6	0.358	0.370	-	0.644
	Mean	0.388	0.417	0.864	0.736
		*Missing plot calculation.			
7/1/70	1	0.254	0.289	0.309	0.337
	2	0.142	0.119	0.369	0.340
	3	0.110	0.174	0.404	0.393
	4	0.116	0.227	0.317	0.353
	5	0.112	0.098	0.321	0.388
	6	0.093	0.103	0.290	0.345
	Mean	0.138	0.168	0.388	0.359

Analysis of Variance.

		df.	MS	F	Result		
6/8/69	Treatment	3	0.29109	34.7	++	V	15.1%
	Block	4	0.00697			e	0.041
	Error	11	0.008388			$e_{.05}$	0.09
	Total	18					

Treatment	1	2	4	3
Mean.	0.388	0.417	0.736	0.864

1%

APPENDIX [illegible] Cont.

Analysis of Variance

		df.	MS	F	Result		
7/1/70	Treatment	3	0.08337	61.98	++	V	13.9%
		5	0.2542			e	0.015
		15	0.001345			$e_{.05}$	0.032
	Total	23					

Treatment	1	2	4	3
Mean.	0.138	0.168	0.359	0.388

1%

APPENDIX 9. PRODUCT OF LEAF K.Ca (m.equivalent %)

TREATMENT.

Date	Block	1	2	3	4
3/3/69	1	1540	3230	3003	3593
	2	1830	2150	2979	2657
	3	3413	3337	3955	2290
	4	2833	2409	4466	4468
	5	1786	3844	3042	3269
	6	1969	4391	2338	3296
11/4/69	1	1255	2870	3115	4509
	2	1647	1448	4666	2835
	3	1651	1447	3379	2228
	4	1728	1073	2892	4273
	5	1602	2383	2673	3563
	6	1626	1760	3307	2757
6/8/69	1	1669	2171	3176	4154
	2	2230	2050	4327	3357
	3	2013	1711	5070	3038
	4	1956	1742	3334	3462
	5	1618	2244	3349	2853
	6	2385	2164	3591	2890

APPENDIX 9. (Cont.)

Date	Block	1	2	3	4
10/12/69	1	1942	2241	2389	6210
	2	2375	2378	2186	5640
	3	1975	2154	3762	4628
	4	1476	1726	2725	5059
	5	1662	2254	1990	4024
	6	2081	2279	1959	6009
7/1/70	1	1212	1444	2024	3918
	2	1513	1980	2493	4249
	3	1366	1856	2602	3188
	4	1380	1539	3044	4203
	5	1254	1559	2187	3321
	6	1243	1155	1865	4106

Analysis of Variance.

		df	MS	F	Result		
3/3/69	Treatment	3	1,607,303	0.86	NS	V	45.6%
	Block	5	590,032			e	559
	Error	15	1,873,257			$e_{.05}$	1190
	Total	23					
11/4/69	Treatment	3	5,454,652	10.72	++	V	28.2%
	Block	5	268,255			e	291
	Error	15	508,596			$e_{.05}$	620
	Total	23					

Treatment	1	2	3	4
Mean.	1585	1830	3339	3361

1%

APPENDIX 9. (Cont.)

		df	MS	F	Result		
6/8/69	Treatment	3	5,161,634	17.06	++	V	19.7%
	Block	5	148,991			e	224
	Error	15	302.571			$e_{.05}$	477
	Total	23					

Treatment	1	2	4	3
Mean	1992	2014	3342	3808

1%

		df	MS	F	Result		
10/12/69	Treatment	3	14,426,407	43.11	++	V	19.5%
	Block	5	325,445			e	236
	Error	15	334,658			$e_{.05}$	503
	Total	23					

Treatment	1	2	3	4
Mean.	1918	2172	2502	5262

1%

		df	MS	F	Result		
7/1/70	Treatment	3	7,594,095	73.64	++	V	14.1%
	Block	5				e	131
	Error	15	103,122			$e_{.05}$	279
	Total	23					

Treatment	1	2	3	4
Mean	1328	1589	2369	3831

1%

APPENDIX 10. SUMS OF CATIONS. (m.eq.%)

Harvest Date	Treatment				Total
	1	2	3	4	
3/3/69	945.2	1067.1	1076.2	964.9	4053.4
11/1/69	929	913	1116.3	1002.3	3960.6
6/8/69	1098.3	998.1	1168.9	978.9	4244.2
10/12/69	809.7	836.6	861.7	1081.5	3589.5
7/1/70	733.4	774.3	828.5	944.5	3280.7
Total	4515.6	4589.1	5051.6	4972.1	

(Each figure is the total for the six replicates)

Analysis of Variance.

	df.	MS	F	Result
Treatment	3	2411.128	2.478	NS
Block	5			
Error	14	973.17		
Harvest	4	6229.198	15.943	++
H x Treat. Interaction	11	1388.329	3.553	++
Error	80	390.72		
Total	117			

V = 19.6%

10/12/69

Treatment	3	2586.402	11.88	++	V 9.87%
Block	5	147.59			e 6.02
Error	15	217.726			
Total	23				

APPENDIX 10.

Analysis of Variance. (Cont.)

Treatment	1	2	3	4
Mean	134.95	139.43	143.62	180.25
1%				

7/1/70	df.	MS	F	Result		
Treatment	3	1397.8	9.176	++	V	1.5%
Block	5	161.57			c	5.0
Error	14	152.334				
Total	22					

Treatment	1	2	3	4
Mean	122.23	129.05	138.1	157.4
5%				

APPENDIX 11. CATION/ANION RATIO

This value $\left(\frac{K+Na+Ca+Mg}{P+N}\right)$ calculated from the leaf mineral concentrations expressed as m.eq.%, is shown in the table as the total of the six replicates for each treatment and harvest.

	Treatment.				
Harvest	1	2	3	4	Total
3/3/69	1.8392	1.657	1.767	1.541	6.8042
11/4/69	1.0711	1.1424	1.306	1.059	4.5785
6/8/69	1.6431	1.59	1.852	1.455	6.5401
10/12/69	1.6116	1.817	1.603	2.30	7.3316
7/1/70	1.664	1.774	1.743	2.186	7.367
Total	7.829	7.9804	8.271	8.541	

Analysis of Variance

	df.	MS.	F	Result
Treatment	3	0.00332457	0.749	NS
Block	5	0.0030625		
Error	12	0.00443639		
Harvest	4	0.05444383	48.64	++
H x Treat. Interaction	9	0.0142643	12.74	++
Error	83	0.00111937		
Total	116			

APPENDIX 11.

Analysis of Variance. (Cont.)

		df.	MS	F	Result	
10/12/69	Treatment	3	0.0177924	15.29	++	V 1.86%
	Block	5	0.001197			e 0.0139
	Error	15	0.0011633			$e_{.05}$ 0.0297
	Total	23				
	Treatment	1	3	2	4	
	Mean	0.2669	0.2672	0.3028	0.3833	
	1%	———	———	———	———	
7/1/70	Treatment	3	0.0091358	7.016	++	V 11.7%
	Block	5	0.0013412			e 0.0147
	Error	14	0.0013021			$e_{.05}$ 0.0314
	Total	22				
	Treatment	1	3	2	4	
	Mean	0.2773	0.2905	0.2957	0.3643	
	1%	———	———	———	———	

APPENDIX 12. ESTIMATED TOTAL LEAF ORGANIC ACIDS (7/1/70)

Treatment	Total cations (K Na Ca Mg) m. eq.% "A"	Est. org. S expressed as m. eq.% SO_4^{--}	Thus inorg. SO_4^{--} m.eq.%	Cl^- m.eq.%	$H_2PO_4^-$ m.eq.%	Total inorg. anions m.eq.% "B"	Est. org. acids m. eq.% (A-B)
	129.9	3.32	16.05	7.16	4.39	27.6	102.3
	116.5	3.32	16.05	4.0	4.87	24.92	91.58
1	125.8	3.31	16.03	3.1	5.23	24.36	101.44
	115.0	2.868	16.5	3.27	4.32	24.09	90.91
	130.5	3.509	15.86	3.16	5.42	24.44	106.06
	115.7	3.36	16.01	2.62	3.97	22.6	93.1
	126.2	3.47	15.4	8.15	5.64	29.19	97.01
	137.5	3.46	15.91	3.35	6.03	25.29	112.21
2	142.4	3.02	16.35	4.90	4.74	25.99	116.41
	141.1	3.17	16.2	6.4	4.58	27.18	113.92
	120.0	3.22	16.15	2.76	5.33	24.24	95.76
	107.1	3.05	16.32	2.9	4.87	24.09	83.01

APPENDIX 12. (Cont.)

Treatment	Total cations (K Na Ca Mg) m. eq.% "A"	Est. org. S expressed as m. eq.% SO_4^{--}	Thus inorg, SO_4^{--} m.eq.%	Cl^- m.eq.%	$H_2PO_4^-$ m.eq.%	Total inorg. anions m.eq.% "B"	Est. org acids m.eq.% (A-B)
3	127.8	4.05	15.32	8.71	5.23	29.26	98.54
	145.0	3.61	15.76	10.4	5.68	31.84	113.16
	139.4	3.66	15.71	11.39	4.84	31.94	107.46
	162.2	3.10	16.27	8.94	5.58	30.79	131.41
	131.6	3.35	16.01	9.05	4.58	29.64	101.96
	122.5	3.71	15.66	8.17	4.23	28.06	94.44
4	168.0	3.31	16.06	9.5	6.84	32.4	135.6
	159.5	3.15	16.22	9.58	5.23	31.03	128.47
	140.4	3.24	16.13	11.08	4.97	32.18	108.22
	165.8	3.46	15.91	9.95	6.61	32.47	133.33
	145.4	2.93	16.44	10.94	5.16	32.54	112.86
	165.4	3.22	16.15	9.72	4.94	30.81	134.59

APPENDIX 12. (Cont.)

Analysis of Variance.

		df.	MS	F	Result	
7/1/70.	Treatment	3	878.35	6.439	++	V 10.7%
	Block	5	128.692			e 4.77
	Error	15	136.403			$e_{.05}$ 10.16
	Total	23				

Treatment	1	2	3	4
Mean	97.56	103.05	107.83	125.51
1%				

APPENDIX 13. LEAF OXALIC ACID. (m.eq.% Dry Weight)

Harvest Date	Block No.	Treatment			
		1	2	3	4
7/1/70	1	44.4	32.8	37.6	33.2
	2	34.4	42.4	38.8	39.2
	3	38	40	42	38
	4	22	32.4	31.6	33.2
	5	42.4	28	35.2	40.8
	6	36.8	24.8	32.4	44
	Mean	36.3	33.4	36.3	36.1
6/3/70	1	86.2	72.4	87.7	80
	2	71.3	73.4	73.6	79.4
	3	85	94.4	72.9	65.4
	4	67.2	89.4	106.6	93.4
	5	82.6	75.6	73.2	83.6
	6	79.3	68.4	71.6	79.2
	Mean	78.6	78.9	80.9	80.2

Analysis of Variance.

7/1/70	df.	MS	F	Result		
Treatment	3	22.4	0.72	NS	V	15.5%
Block	5	49.24			e	5.2
Error	15	31.147			$e_{.05}$	11.1
Total	23					

6/3/70						
Treatment	3	7.059	0.065	NS	V	13.1%
Block	5	117.893			e	4.2
Error	15	108.63			$e_{.05}$	8.9
Total	23					

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