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THE EFFECT OF SEASONAL VARIATION AND  
ROOTSTOCK ON THE MINERAL COMPOSITION  
OF GOLDEN DELICIOUS APPLE LEAVES

by  
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EFFECT OF SEASON AND ROOTSTOCK

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## ABSTRACT

A study was conducted in the Bekaa Valley during the two growing seasons 1959 and 1960 to evaluate the effect of the date of sampling as well as that of the four rootstocks M. XVI, M. VII, M. II and French Crab on the mineral composition of Golden Delicious apple leaves.

The seasonal variation in the mineral composition of apple leaves was established. Nitrogen, phosphorus and potassium showed a gradual decrease from the beginning till the end of the growing season, however the decrease of potassium occurred at a faster rate. Magnesium and calcium showed an increasing trend at the beginning of the season, however a decrease late in the season was observed in the case of magnesium. No definite trend was established for iron and manganese.

The rootstock effect in respect to the inorganic mineral composition of scion leaves showed certain trends with some elements. M. XVI was associated with high nitrogen, magnesium and manganese. Leaves of trees topworked on M. VII were low in nitrogen. M. II was correlated with high phosphorus but low potassium and magnesium, and French Crab was associated with high phosphorus and potassium but low magnesium.

## INTRODUCTION

The seasonal variation in the mineral composition of apple leaves has been a subject of study in various experiment stations throughout the world. The results of such work is reported in the literature. In many instances experimental results have been interpreted in terms of mineral deficiencies. Little work has been performed, however, to determine the effect of the rootstock on the inorganic mineral composition of apple leaves.

The importation and use of a number of commercial apple rootstocks in Lebanon is recent. The behavior of the common scion varieties grown on the rootstocks has not been studied yet under local conditions of soil and climate.

It is hoped that this study will further a better understanding of the relation between scion leaf composition and the commercial rootstocks commonly found in Lebanon.

The seasonal variation in scion leaf composition was observed to determine the nutritional characteristics of apple trees throughout their growing season, and to establish a range of sufficiency of the different mineral elements in the apple leaf. This study involved the analysis for seven elements in the leaves of apple trees grown on four rootstocks, during the two growing seasons 1959 and 1960.



## REVIEW OF THE LITERATURE

The analysis of plants as a means of ascertaining the nutrient content of crops was undertaken early in the history of agricultural chemistry. De Saussure in 1804 analyzed the ash of plants and found that its composition varied with the soil, the part of the plant that was analyzed, and the age of the plant at the time of the analysis (63).

Liebig in 1852, and later Wolff in 1871, as reported by Ulrich (63), studied the maintenance of soil fertility. They reached the conclusion that the nutrients removed by the crops must be restored to the soil either directly or indirectly.

Hall (28) at Rothamsted in 1905 envisaged plant diagnosis as a determination of the "normal" nutrient content of the plant. He concluded that due to the considerable fluctuations in the potash content of barley straw, it is not always possible to interpret the results.

In 1928 Salter and Ames (51) concluded that so many factors influence the nutrient composition of the plant that the use of plant analysis as a guide for evaluating the fertilizer requirements of crops is precluded.

Notwithstanding the many difficulties, progress has been made in this field, and during the past 30 years increasing attention has

been paid to plant analysis as a guide to the nutritional requirements of plants, as distinct from the original conception of plant analysis as an index of soil fertility (7). In New York, leaf analyses have been found helpful in furnishing measures of the needs of fruit trees for potassium, magnesium and nitrogen fertilization (11).

Recently, leaf analysis has become a useful tool in evaluating the nutritive status of fruit trees. However, there is always the question of how accurately such data reflects the true nutrient supplying power of a given soil (29). A number of variables affect leaf concentration. Therefore, at any one time, a chemical analysis of the plant or part of the plant gives an integrated value of all the factors that have influenced its nutrient composition (63). In the refinement of foliar analysis techniques, a clear understanding of these influences is essential so that they can be properly considered in the final interpretation of results (23).

Several investigations have shown that moisture deficiency affects the total uptake as well as the leaf concentration of nutrient elements in various crop plants. Most of these studies indicated that there is an increase in nitrogen and a decrease in potassium with increasing moisture stress (30, 38). On the other hand, a number of workers have been unable to show any direct or indirect relationship between the moisture level and the phosphorus, calcium or magnesium content in samples of leaf tissue (31, 55).

In 1958 the results of experiments on the effect of water stress

confirmed the observations of previous investigators who had found that there is a decrease in leaf potassium concentration with increasing moisture stress (29). A suggested explanation for the reduced uptake under drought conditions is that the potassium ions may become fixed in an unavailable form (1).

In addition to the factors that affect the availability of elements to the plants, Boynton and Compton (11) in 1945 found that any condition resulting in inability of the root system or conducting tissue to function normally will be likely to reduce the potassium, magnesium and nitrogen percentage found in fruit tree leaves.

The size of the crop was found by Emmert (23) in 1954, to exert a strong influence on the nutritional condition of the leaf. Leaves from trees in a non-bearing season have generally been found comparatively lower in nitrogen, calcium and magnesium and higher in phosphorus and potassium. In that same experiment, Emmert also noted that the older trees were higher in calcium and magnesium than the younger ones.

A variable that has not been accounted for in the past, and which is very important in respect to leaf analysis interpretations, is leaching. Since early in the 19th century, many reports have indicated that mineral nutrients and organic constituents can be leached from the leaves. However, the extent of the leaching of the mineral elements from the above-ground parts of the plant has been only

recently demonstrated, and it has been suggested that these losses may be very important in crop production (5, 62). Leaching losses from very young leaves are small, but they increase with leaf maturity and are at their maximum when leaves approach senescence (53, 62). Measurable amounts of nutrients are lost from young leaves after only a very brief exposure to water (30 minutes), and after a 24-hour exposure, the loss may be more than 25% of the amount of certain nutrients in the leaves (62).

The relative leachability of certain radioisotopes was studied by Tukey et.al. and the trend was found to be as follows: sodium and manganese were easily leached, calcium, magnesium and potassium were moderately leached, and iron, zinc and phosphorus were very difficultly leached. One exception was potassium which was leached at a moderate rate from young leaves, but was the most readily leached nutrient from mature leaves (62).

Tukey and Tukey (61) reviewed the work of a number of investigators on the factors that affect leaching of mineral elements from the leaves. Commercial spraying for pest control, which involves the application of preparations that contain various amounts and combinations of chemicals including oils, increase the loss of nutrients from the foliage. Spray residues on fruit and foliage when wetted by rain and dew may influence leaching. Tukey and Tukey (61) reported that Dalbro in 1957 found that surface active agents, which are employed

to increase the effectiveness of sprays, increase leaching action by reducing the naturally hydrophobic properties of leaves, and especially of young leaves.

Corin et.al. in 1958, as reported by Tukey and Tukey (61), found that washing the samples prior to analysis may remove nutrients from the leaves.

Phillips and Mason (39) proved that dew is also effective in leaching. They concluded that the time of the day in relation to sampling should be considered and that for comparative purposes, leaf samples should be collected under comparable conditions with reference to precipitation and dew.

Many factors other than those stated above affect the mineral composition of leaves. However, we shall limit ourselves in this review to the two most important factors: namely, seasonal effect and rootstock effect.

The seasonal changes in the chemical composition of apple leaves follow a certain pattern due to physiological factors inherent to the tree. In order to comprehend the reason for these changes, studying the growth cycles of the apple tree becomes essential.

Mason and Whitfield (36) in 1960 suggested that the growth of young apple trees occurs in three distinct phases:

"a - a period of new tissue formation, the materials for which

are drawn from reserves in the tree, laid down during the previous year or years;"

"b - a period toward the end of May when the leaves are able to contribute photo-synthesized compounds from raw materials being currently absorbed through the roots and leaf surfaces. The newly-formed compounds are translocated to support the formation and expansion of further new tissue up to about the end of August;"

"c - with the cessation of further growth compounds of the nutrient elements are redistributed in the tissues, in some of which the concentrations are increased; e.g. nitrogen in the branches, magnesium in the younger wood, and calcium in the bark."

### Nitrogen

The first element to be considered is nitrogen. Nitrogen enters the roots from the soil solution as a salt of nitric acid, such as potassium or sodium nitrate, or sometimes as ammonia. Under certain conditions small amounts of other nitrogenous compounds are absorbed; and in case of deficiency, the leaves of certain fruit plants were found to absorb enough from certain nitrogen containing materials to relieve the deficiency symptoms (27). Most of the inorganic nitrogen absorbed is carried up the trunk and branches to the leaves where it is elaborated into amino acids and other organic compounds in the chloroplasts of the leaf mesophyll cells (27).

The amino-acids, which are the first products of elaboration,

are either used directly in the leaf or are conducted through the phloem to all parts of the plant where they are used in the build-up of every nitrogen-containing organic compound found in plants, as well as of certain nitrogen free organic substances such as: essential oils, resins and polyterpenes (27, 37).

Proteins, which result from the combination of the elaborated amino-acids, occur in all protoplasm. The most important of these nitrogenous organic compounds are the purines and pyrimidines which enter into the composition of nucleic acids, nucleins and nucleoproteins, substances characteristic of the cell nucleus (27).

The elaboration of nitrates to amino-acids begins at the time the leaves are well developed and proceeds as long as they remain green. These elaborated nitrogen-containing compounds pass out of the leaves as fast as they are manufactured, and are used for new tissue development, for shoot growth, new leaves, increments to branches, trunks and roots, new roots and especially for fruit and seed development. However, not all of the nitrogen-containing compounds are present in metabolically active regions. A large fraction may be held permanently or temporarily as a storage reserve in the wood and bark, particularly in the fall when growth has ceased and before the leaves absciss (27, 36, 37, 48).

The apple tree exhibits marked seasonal fluctuations in nitrogen distribution. Early in the spring, growth and development is largely at the expense and in proportion to the amount of nitrogen

stored during the previous year. Consequently, all woody structures including the roots show a progressive decrease in nitrogen content from early spring till active growth has ceased (27, 37). Many workers are in agreement with these findings.

Mason and Whitfield reported in 1960 that they found a sharp decrease to a minimum value in nitrogen concentration in the whole tree at the time of rapid and vigorous shoot extension, which corresponds to a maximum of nitrogen in the wood of the extension shoots. Nitrogen is at a minimum simultaneously in the wood and the bark of the older parts of the tree. This may be interpreted as a temporary withdrawal of nitrogenous compounds from the older tissues which are transferred to the extension growth (36).

According to Murneek (37), non-bearing trees differ from bearing trees as far as the nitrogen content of their woody structures is concerned. When active growth has ceased, nitrogen gradually increases in the woody parts of non-bearing trees, while the increase in bearing trees is very slow until the fruit attains a considerable size and requires less nitrogen.

The seasonal variation of nitrogen in the spurs differs in whether the spur is a bearing or a non-bearing one. Non-bearing spurs have a maximum nitrogen content at the time of bud swelling and a minimum when vegetative elongation has ceased. Bearing spurs increase in nitrogen during flowering and fruit setting. The spurs draw heavily



on the nitrogen reserves of the older parts of the branches and possibly the roots. However, during autumnal removal of nitrogen from leaves, all spurs show a temporary increase in nitrogen (37).

Buds are relatively rich in nitrogen. Gardner and co-workers (27) have shown that the nitrogen content on a dry weight basis can go up as high as 3.77% in the cherry and 4.14% in the plum. As the buds open and the leaves unfold and start to grow, there is a steady decline in their percentage composition of nitrogen, though the total amount that they contain actually increases. This growth of leaves and flowers is conditioned by a rapid movement of nitrogen in the soluble form from the twigs and larger branches towards all peripheral regions of the tree (27, 37). Murneek (37) found that the total nitrogen content of one - and two-year branches increased at the period of leaf and flower growth, while that of the older branches decreased, and he concluded that reserve proteins are broken down in the older bark and wood and transferred to the regions of growth.

The recent work of Mason and Whitfield (36) on the location from which nitrogen is withdrawn by the young leaves confirms the findings of Murneek. Mason and Whitfield found that a sharp fall in nitrogen concentration occurs in the bark of extension growth, branches and trunk. They suggested that the nitrogenous compounds needed by young leaves may be supplied from the bark rather than the wood because the severest stress is occurring at the point nearest to leaf formation. They further stated that these withdrawals produced only a temporary

deficit which was replaced during the ensuing month.

The seasonal variation in the nitrogen composition of the leaf is different from that of the other parts of the tree. In the leaf two periods of rapid decrease are separated by a period in which the percentage composition is fairly constant. The first period of decrease is at the time when the leaf is growing rapidly and the available nitrogen supply is limited because of rapid and simultaneous shoot, wood and root development. The period of relatively constant nitrogen content occurs when nitrogen intake is very nearly balanced by the demands for new vegetative tissue and for the development of the fruit and seed. The second period of decrease indicates withdrawal from the leaf shortly before its abscission (27, 37).

However, when considering the absolute amount of nitrogen in the leaf, Gardner and co-workers (27) found that this amount increases in spring and summer, but it decreases sharply in the fall at the time of nitrogen withdrawal. He explains the discrepancies between the trend in percentage nitrogen and that of total nitrogen as follows: In young leaves, growth and carbohydrate formation proceed at such a rate as to reduce the percentage nitrogen even though the intake of nitrates during this period is greater than the outgo of elaborated nitrogen. During July and August, and sometimes later, the leaf supplies the branches with an amount of elaborated nitrogen about equal to the amount of nitrates taken in. From September on, however, the leaves receive less nitrate in proportion to the elaborated nitrogen

which passes back into the branches. A small amount of nitrogen remains in the leaves when they fall.

Many investigators have worked on the seasonal variation of leaf nitrogen and all reported a regular decrease in percentage leaf nitrogen from the beginning till the end of the growing season (7, 34, 36, 46, 48). Roach (46) working with a number of apple rootstocks found that all the rootstocks gave the same pattern: that is, a fairly regular decrease in percentage leaf nitrogen from the beginning (August) to the end (November) of sampling (46).

Rogers and co-workers (48) working on apple leaves found that the seasonal nitrogen level, expressed as percentage dry weight, tended to decline rather slowly up to 140 days from leaf unfolding and then decreased rapidly as leaf abscission approached. The percentage nitrogen was about three times as much at 140 days as at leaf fall.

In respect to the autumnal migration of nitrogen from the leaves into the woody structures of the apple trees, Murneek (37) found that 35% to 40% of the total nitrogen of the leaves is reabsorbed by the tree prior to their abscission. This movement is directed towards the young wood and spurs first, after which it migrates to the older wood and roots where large quantities of nitrogen are stored as reserve proteins. Rogers and co-workers (48) agree with the findings of Murneek, regarding nitrogen migra-

tion, and they presume that this translocated nitrogen constitutes an important source of supply for the following season's growth.

The nitrogen variation in the tree is influenced to a certain extent by flowering. Flowering is characterized by a marked increase in all active forms of nitrogen in the twigs, but especially in the bearing spurs. The amount that is translocated to the flowers, the young fruits, and the simultaneously developing leaves depends largely upon their number and the available nitrogen reserves of the tree. All of these organs show exceptionally high percentages of nitrogen at the beginning of the active season. The flowers in particular seem to make a sudden and heavy demand for nitrogen. From one third to one half of this nitrogen, however, is reabsorbed before the abscission of the majority of the flowers and seems to migrate to the leaves of the non-fruiting spurs. The demand for nitrogen by most of the flowers thus is largely of a transitory nature. Those that form fruit, exert a continuous and heavy drain on the nitrogen supply throughout the major part of the growing season (37).

### Phosphorus

Phosphorus is absorbed by plants chiefly as the monovalent orthophosphate ion,  $H_2PO_4^-$ , ordinarily referred to as phosphate (56). Although there is no direct evidence to show where the elaboration of inorganic phosphates to organic phosphorus-containing compounds takes place, the similarity between the variations in nitrogen and in phosphorus content of practically all tissues suggests

that phosphorus, like nitrogen, is elaborated for the most part in the leaf (27).

The amount of phosphorus assimilated appears to be closely related to the amount of illumination the plant receives and appears to be connected with photosynthetic activity. Gardner and co-workers (27) reported the work of Weber who found in 1875 that red and yellow light were more effective than blue or violet in promoting phosphorus assimilation. Wherever phosphorus is found in organic combination it exists as phosphate. Thus, it occurs in nucleic acids, nucleins and nucleoproteins, all of which are important components of the cell nucleus.

Phosphorus availability to the plant depends on many factors. Although phosphorus is present in mineral soils, a large proportion of it is in forms that are relatively insoluble in water, and thus unavailable, or only slowly available, for absorption by plants (8).

Bradfield et.al. (12) have outlined three different mechanisms that control phosphorus retention or fixation by soils. At pH levels below five phosphorus is precipitated as iron and aluminum phosphates, while at pH levels ranging from six to ten phosphorus is precipitated as calcium and magnesium phosphate. It is only between pH 4.5 to 7.5, that phosphorus, absorbed by the soil colloids, becomes slightly available to plants.

The presence and interaction of mineral nutrients in the soil

affects the phosphorus content of the leaves. Weeks et.al. (68) found by increasing the rates of nitrogen fertilization that the leaf phosphorus decreased while leaf nitrogen increased. These results confirm the data of Cain and Boynton (19) which shows a marked decrease in leaf phosphorus as the nitrogen application increased.

Other workers have observed the marked reciprocal relationship that exists between nitrogen and phosphorus in apple trees in spite of the fact that the seasonal fluctuations of phosphorus and of nitrogen parallel each other. Boynton and Compton (10) as well as Batjer and Degman (2), have found that increasing the nitrogen level of the substrate not only increased the nitrogen percentage of apple tree leaves, but it decreased their phosphorus concentration. According to them, a large part of this effect was due to growth responses to nitrogen. However, according to Cullinan and Batjer (22) this reciprocal relationship may not be present when phosphorus is severely limiting.

The phosphorus content of apple tree tissues was found to vary with different soil conditions. Boynton and co-workers (9) found in leaf samples taken in midsummer from 204 New York McIntosh apple orchards that these leaves ranged in percentage phosphorus from 0.12% to 0.41%.

Trzcinski and De Munter (59) observed that leaf phosphorus

was inversely proportional to potassium content. By increasing the application rate of potassium to the soil, leaf potassium increased while leaf phosphorus decreased.

Mason (35), working with apple trees grown at different soil moisture levels, found that under high-moisture conditions leaf phosphorus increased in concentration.

The fruit crop exerts a strong influence on the nutritional condition of the leaf. When comparing non-bearing and bearing trees, Emmert (23) found that non-bearing trees were higher in phosphorus. Similar results were obtained by Cain and Boynton (19) and with a heavier crop a greater decrease in leaf phosphorus was observed.

Phosphorus concentration in apple tree tissues more closely approximates that for magnesium than that for nitrogen, potassium or calcium (8). The distribution of phosphorus in the tree, however, is very similar to that of nitrogen. In apple trees, young tissue is richer in phosphorus than older tissue, and young leaves and young bark are particularly rich. Moreover, the same relationships regarding the elaboration, storage and utilization of nitrogen hold true in the case of phosphorus (8, 27).

Most tissues contain approximately six times as much nitrogen as phosphorus. The general constancy of the phosphorus-nitrogen ratio indicates that the two elements may be combined in the same molecule. Nucleins, nucleo-proteins and lecithin contain both ele-

ments and are of universal occurrence in all living plant tissues (27).

The young leaf has about the same high percentage of phosphorus as the bud, but this percentage decreases rapidly with age. Two periods of rapid decline are noticed, one in May when the shoots are growing vigorously, and another one in September just before leaf abscission (8, 27).

The decrease in percentage leaf phosphorus is confirmed by a number of workers. Roach (46) found that phosphorus declined fairly regularly during the growing season. Rogers and co-workers (48) obtained a steady decrease throughout the growing season, however, the decline was greatly accelerated during the latter part of the season. They consider that this greater decrease in percentage leaf phosphorus is due to the fact that a greater amount of phosphorus migrates from the leaf before abscission occurs, and that this translocated phosphorus constitutes an important source of supply for the following season's growth.

Boynton and co-workers (9) analyzing the leaves of 30 year-old McIntosh trees at the Cornell University Orchard, found that leaf phosphorus varied from 0.42% at the beginning of the growing season to 0.12% at the end of the growing season just before the occurrence of leaf abscission.



The recent work of Mason and Whitfield (36) is in agreement with what other workers have found concerning the trend of phosphorus in apple leaves. They reported that the concentrations in the leaves and in the blossoms were high at the beginning of the season and that they decreased rapidly to a stable figure of about 0.2%. In the bark, a sharp decline to a minimum concentration was noticed at the end of April, which coincided with a similar decline in the concentration of nitrogen.

A trend similar to that of nitrogen is noticed in the branches, trunks and roots of apples. Phosphorus is present in greatest amounts in the younger roots and branches, and it is at a maximum in nearly all apple tissues when the buds are swelling. However, the difference between phosphorus and nitrogen is that phosphorus reaches a minimum in most tissues in May, when the tree is in active growth, while nitrogen does not reach a minimum until July when active growth is over (23).

Mason and co-workers (36) studying the concentration of phosphorus in the woody parts of the tree, found that the phosphorus concentration rose to a maximum in April, followed by a minimum in May. This is in agreement with the findings of other investigators (9, 27, 48).

There is an accumulation of phosphorus in all woody tissues in the fall. This is explained by Gardner, Bradford and Hooker (27)

as follows: The inorganic phosphorus-containing compounds that are built up in the leaves pass out of the leaves as fast as they are made, and are used by the developing fruit and in the growth of vegetative tissues. Before the leaves absciss, a considerable amount of their phosphorus is withdrawn and stored in the phloem. The phosphorus used in the first stages of growth in the spring and in the initiation of fruit development is obtained from stored compounds. This explains why a minimum in phosphorus concentration of woody tissues is obtained in spring, while the concentration rises to a maximum in early fall.

#### Potassium

Potassium is present in great amounts in the surface soil and is relatively stabilized as a result of its presence in the exchange complex. Potassium is absorbed by plants as the potassium ions through contact exchange of the roots with potassium ions held on the surfaces of clay crystals (8, 56).

The exact role of potassium in plant nutrition is not clearly known. Potassium seems to serve some metabolic functions in the cell division of tissues. It appears to be necessary for carbohydrate and protein synthesis in plants. However, it is not known where potassium is elaborated, and there is no evidence to show that the inorganic potassium taken from the soil is combined in organic form in the leaves to any greater extent than in any other part of the plant. Moreover, it is also unknown in what organic formation potassium

is necessary for the proper activity of the plant (8, 27).

The potassium content of the plant is subject to variations because of the intervening of different factors. Mason (35), studying the effect of soil moisture on the mineral composition of apple trees, observed a significant increase in the percentage of potassium with an increased in soil moisture. Weeks et.al. (68) observed a decrease in leaf potassium with increasing rates of nitrogen fertilization. These results were similar to those reported in other studies (16, 17, 19).

Cain (15), working on the interrelationships between calcium, magnesium and potassium in one-year old McIntosh apple trees, noticed a decrease in the potassium content of leaves with an increase in the magnesium supply of the nutrient solution.

The effect of the crop on reducing the potassium content of the leaf can be readily demonstrated by defruiting trees in early summer and comparing their leaf analyses with adjacent trees with ripe fruit. Heavy crops were found to reduce the potassium content of the leaves (32). Emmert (23) obtained similar results. Since large amounts of potassium are used in the fruit, the extreme mobility of this element in the plant causes its migration from the leaves to the fruit in periods of heavy demand (32).

Unlike nitrogen, the concentration of potassium per unit of dry matter in the whole tree varies considerably over the year (36).

Rogers and co-workers (48) found that the trend of potassium percentage in the leaves shows almost a straight-line decrease throughout the season. At leaf fall the percent was about one-half as much as at the beginning of the season. Boynton et.al (9), studying the mean changes in percentage of potassium in the leaf samples of 30 year old McIntosh trees at the Cornell University orchard, observed that the percentage of potassium decreased from 1.58 when terminal growth was active and when the leaves were less than half their final area to 0.78 when abscission of leaves was occurring at a rapid rate.

Roach (46), working with different Malling rootstocks, found that the fairly regular decrease in leaf potassium during the season was the same for all rootstocks used. Similar results were obtained by Reuther and Boynton (44) when they studied the variations in the potassium content of apple leaves in certain New York Orchards. They found a fairly uniform decrease in the percentage of potassium in the dry matter. However this rate of decrease appeared to be somewhat slower in the period from the middle of July until the first of September.

Gardner, Bradford and Hooker (23) reported that potassium is stored in both the sapwood and the bark, and in the old branches, during winter and that it is translocated and used in the development of new tissue in the spring, but preeminently for fruit and then for leaves. Moreover, in contrast to the conditions presented by phos-

phorus, fruit buds were found to be much richer in potassium than leaf buds.

Mason and Whitfield (36) studied very thoroughly the potassium variation in the bark of shoots, branches and trunk. It was found that there is a sharp decline in the concentration of potassium in the bark of shoot, branches and trunk that coincided with rapid leaf growth, while concurrently a sharp rise in the concentration of this element was observed in the bark and wood of the root. At the time of rapid shoot extension in the latter part of June there was a fall in concentration in the bark, particularly of the older parts of the tree. At the same time there was a sharp rise to a maximum in the wood of both the previous year's and current year's shoots.

### Magnesium

Magnesium was known to be an essential element long before being known as a constituent of chlorophyll and of a compound that may be a precursor of chlorophyll; and it is now also known to function as an activator of many enzyme systems (20).

Magnesium is present in the soil in a number of minerals. Most of the readily available magnesium is usually in the exchange mechanism of the soil colloids, and when apple tree roots come in contact with soil colloids, they absorb magnesium (8). However, the absence of oxygen or the absence of available moisture in the rooting medium causes inability of the apple tree roots to absorb magnesium.

Compton in his controlled aeration experiments with apple tree seedings, as reported by Boynton (8), found that absorption of magnesium increased as the oxygen pressure of the nutrient medium was increased.

Mason (35), studying the effect of soil moisture on the mineral composition of apple trees observed an increase in the concentration of magnesium in the whole plant under moist soil conditions.

The magnesium concentration of apple trees is influenced to a great extent by the addition of mineral elements to the soil. The changes in leaf magnesium brought about by increasing rates of nitrogen fertilization, as reported by Weeks et.al. (68), are similar to those reported in other studies (16, 17, 19). The said workers found that as leaf nitrogen increased, potassium and phosphorus decreased and calcium and magnesium increased. Cain (15), when studying the inter-relationships between calcium, magnesium and potassium in one-year old McIntosh apple trees, observed the following:

(1) each cation increased in the leaves as its respective supply was increased in the nutrient solution.

(2) the increase is in both leaves and stems, being more pronounced in the leaves than in the stems for magnesium and potassium.

(3) calcium and magnesium decreased sharply with an increase in potassium, and the decrease is mostly in the leaves while the magnesium content of the stems is relatively unchanged.

The effect of potassium and magnesium on the absorption of

nutrients by apple trees was investigated very thoroughly by Cain in 1955, and he came to the conclusion that neither potassium nor magnesium influence the rate of absorption of the other. However, a high level of supply of either may result in a lower tissue concentration of the other. He postulates that these effects are associated with growth and transport phenomena and are possibly related to the specific function of these nutrients by the plants. He observed that when potassium and magnesium are used in equivalent concentrations, the effect of potassium in reducing the leaf concentration of magnesium is much greater than that of magnesium in reducing leaf concentration of potassium. He assumes that the interaction or antagonism between these two nutrient elements is associated entirely within the plant and is in no way related to external supply except as the external supply of one element influences its own absorption by the plant (18).

Fruiting in apple trees was found by Emmert (23) to have a certain influence on the magnesium content of leaves; and his observations are similar to those of Cain and Boynton (19). Leaves from trees in a non-bearing season are generally found comparatively lower in nitrogen, calcium, magnesium and higher in phosphorus and potassium.

The magnesium concentration of apple leaves was found by many workers to vary with the season (7, 9, 27, 34, 36, 46). Mason and Whitfield (36) noticed that there were two periods when well-marked changes in magnesium content of apple leaves occurred; one was at

the end of April when rapid leaf growth began, and the second was at the end of June when shoot extension was vigorous.

Since the bulk of magnesium in the tree is contained in the leaf chlorophyll, the concentration and actual amount of this element in the whole tree should, according to Mason and Whitfield, show a starting rise in April to a maximum in July and then a decline as the leaves are shed (35). These findings confirm those of Roach (46) who observed a steady increase in leaf magnesium followed by a sharp decrease at leaf shedding. Boynton and co-workers (9) in studying the chemical composition of McIntosh apple leaves in New York Orchards, observed a change in magnesium from 0.17% when the leaves were half their final area, to 0.25% when abscission of leaves was occurring.

Gardner, Bradford and Hooker (27) explain the seasonal variation in leaf magnesium by assuming that magnesium keeps pace with leaf development, increasing with an increase in the chlorophyll content of the leaf, and that magnesium is withdrawn from the leaves to the branches late in the season.

Magnesium is very mobile in the plants, and it moves from the older parts and older leaves to the growing points (20), and to the growing seeds (27). Mason and Whitfield (36) studied the concentration of magnesium in the woody parts of the tree, and they observed that the concentration was higher in winter and early spring than



in summer. This behaviour was explained on the basis of the mobility of the element in the plant at the time of heavy demands when the tree withdraws the element from the wood and from the roots.

### Calcium

Calcium is found in apple tree tissues in about the same range of concentration as are potassium and nitrogen. A large proportion of the absorbed calcium goes to the leaves and becomes fixed there in forms that are not soluble in water and seem to be relatively immobile (8).

Calcium is for the most part absent from the growing points and from embryonic tissues generally, and it accumulates in all tissues with age. This indicates that calcium is utilized in ways very different from the other essential elements. Calcium is found organically combined in calcium oxalate crystals, in calcium pectate in the middle lamella which holds adjoining cells together and is prevalent also as calcium carbonate (27).

The calcium content of apple leaves is subject to variation. In a controlled study with yearling apple trees conducted by Cain (15), the calcium content both of leaves and woody tissues was found to be greatly decreased by increasing the potassium supply. Magnesium appeared to have a less noticeable effect than that of potassium, but the trend was in the same direction.

Increasing the nitrogen level of the apple leaves, appears

to decrease the potassium percentage, and increase the magnesium as well as the calcium content. These results presented by Weeks and co-workers (68) are in agreement with what is known from the work of Cain and Boynton (19) and Cain (16, 17) on the effect of nitrogen on the calcium content of apple leaves.

When comparing the analysis of leaves in a year of crop failure with a year of heavy crop, Cain and Boynton (19) found that the leaf nitrogen, calcium and magnesium were higher in the crop year, and that potassium was lower.

The results of Emmert (23) confirm the findings of Cain and Boynton (19) as to the effect of bearing on the mineral composition of apple leaves.

Dry weather did not seem to have as marked an effect on calcium absorption as on absorption of magnesium and potassium, but leaf calcium was a little higher in the dry year than in the wet year of the study of Boynton et.al. (9).

The seasonal variation in apple leaf calcium was studied by a number of workers, and their results are in agreement (8, 34, 36, 46, 48). Rogers and co-workers (48) observed a rapid increase in leaf calcium during the first 65 days after leaf unfolding, followed by a period during which this element remained constant. However, during the last few weeks of the season a significant increase in

calcium was evident. A similar trend was observed by Mason (34) who found a progressive increase in leaf calcium as the leaves pass from the rudimentary to the fully mature state. Roach (46) observed a similar variation in the concentration of leaf calcium when using different rootstocks.

Boynton and co-workers (9) observed an increase in calcium concentration of apple leaves from 0.73% when leaves were less than half their final area to 2.43% when abscission of leaves was occurring at a rapid rate.

The calcium content of buds is not great as compared with that of other plant tissues. However, very heavy deposits of calcium oxalate in the buds were reported by Gardner, Bradford and Hooker (27). In resting fruit buds these deposits were found to decrease after growth began.

### Iron

Iron occurs in rather large amounts in nearly all soils, but it is present in relatively small amounts in plant tissues (13). Growing plants require a continuous supply of iron and experimental results have shown that plants will grow better from a single large application of iron than when the same amount is applied in several subadequate doses (66).

Iron is found in organic combination in some nucleic acids. Its precise functions are not too well understood but it is in some

way associated with the synthesis of chlorophyll. It also appears that a lack of iron in the plant seriously interferes with the proper utilization of nitrates (27).

Many factors influence the availability of iron to the plant, and hence, to the concentration of iron in the leaves. Soil pH is one of these important factors. Insoluble forms of iron are brought into solution by the action of acids, and iron availability increases with acidity and is greatly reduced by high pH values (56). Another factor causing a change in the iron concentration in the leaf is the presence of manganese in the soil. Wiederspahn (69) observed a significant increase in soluble iron in the leaf tissue as the level of manganese was decreased in the nutrient solution.

Trzcinski and De Munter (59) observed that the addition of high-potassium fertilizers to apple trees caused an increase in the iron concentration of the leaf.

The seasonal variation in the iron content of apple leaves was studied by Roach (46) at the East Malling Research Station in 1951. He observed no regular change in the iron content of the leaves. Similar results are reported by Gardner, Bradford and Hooker (27). The percentage composition of iron in the leaf remains fairly constant throughout the growing season.

#### Manganese

Manganese is present in mineral soils in widely different

concentrations and forms. Since it is a cation it is present in the exchange complex, and in addition, it may be present in mineral and in intermediate oxidized and reduced forms (8).

Manganese was rather recently found to be an essential element used by the plant in very small amounts (20). This is why little work has been done on the manganese content of apple trees.

Different factors affect the availability of manganese and thus its concentration in the leaves. Boynton (8) reported that alkaline soils favor the presence of manganic irons, and acid soils favor the manganous forms which are readily available to plants, and that plants in acid soils are less subject to manganese deficiency.

This is in agreement with the work of Erkama (26) who found that plants growing in neutral soils had a low manganese content which was not due to manganese deficiency in the soil.

The interrelations of manganese to iron was studied by Wiederspahn (69). He observed that as the soluble iron concentration of the leaves increased, the soluble and insoluble concentrations of manganese decrease in that same leaf tissue.

The antagonism between manganese and copper was studied by Erkama (26). He found that plants with a high copper content always were low in manganese. Moreover, he noticed that a negative correlation existed between the nitrogen content and the manganese content

in both leaves and fruits.

The seasonal variation in the leaf concentration of manganese in apple and peach trees was studied by a number of workers (4, 25, 34). Mason (34) observed a progressive increase in the concentration of manganese of apple leaves during the period where vigorous growth occurs, and where the leaves pass from the rudimentary to the fully mature state. Similar results were obtained by Bell and Childers (4) who observed that leaves sampled in June contained less manganese than did those sampled in August. Moreover, Epstein and Lilleland (25) observed that higher manganese concentrations were obtained in July than in June, and that the change in the manganese content during summer was not great.

Fruit trees seem to have a considerable ability to accumulate manganese in their leaves. Epstein and Lilleland (25) studied the manganese content in a number of non-deficient apple trees and found an average of 81 ppm, while leaf samples from a manganese deficient apple orchard gave an average of 5 ppm of manganese. They suggested that high luxury consumption of manganese is very probable in fruit trees.

#### Rootstock and Scion Effects

Most fruit trees are built up of two different varieties, or even species: a top, or scion, variety budded or grafted on another variety, the rootstock. This combination is found convenient in

practice because most of the more valuable varieties of fruit do not come true from seed and are not easily propagated on their own roots. They are, therefore, worked on varieties that do root freely and whose roots are adapted to the particular soil conditions. Such varieties have long been propagated for use as rootstocks. However, each of these rootstocks influences the scion variety worked on it in many important respects, e.g., vigour of tree, precocity or earliness of fruiting, season of fruit maturity, size and quality of fruit, resistance or susceptibility to insect pests and fungus diseases, resistance to winter frost and others (45).

Although the scion has a definite effect on tree size, the rootstock has been found to have an even greater influence (65). For instance, when the apple variety Bramley's Seedling, growing on the dwarfing rootstock, M. IX, forms scion roots, it grows very vigourously (49).

The most striking effect of different rootstocks upon a scion variety is in the control of tree size (65). Thirty-year old trees of the apple, Lane's Prince Albert, on different clonal rootstocks showed four distinct vigour groups. These range from trees on the dwarfing M. IX to those on the very vigorous M.XVI. Between these two groups are trees on M. VII and M. IV of intermediate size, followed by those on the vigorous rootstocks M. I and M. II (41). Similar results were reported by other investigators (52, 54, 60).

When considering productivity, however, mere tree size is not necessarily the deciding factor. With apples grown under comparable conditions, trees on M. IV rootstock have, over a period of 30 years, yielded 45% more fruit than trees on M. X that are of similar size. Trees on M. XVI although slightly smaller than those of M. XII have yielded 25% more fruit over the same period (41).

However, Preston (42), working on Cox's Orange Pippin grown on clonal rootstocks, found somewhat different results as far as yield was concerned. Trees on the dwarfing M. IX yielded the heaviest accumulated crop during the early years but they were surpassed by trees on the moderately vigorous M. IV by the fifteenth year, these trees in turn being surpassed by those on the vigorous M. II by the twenty fifth year. Trees on M. II were eventually surpassed by those on the very vigorous M. XVI by the thirty-second year.

Rootstocks also influence the size of the fruit, and Preston (43) found when working on Worcester Permain grown on different clonal rootstocks that trees on M. IX bore the largest fruits.

Another influence of the rootstock is on fruit colour. This effect seems to be an indirect one because rootstocks that induce early bearing result in trees with relatively heavy crops which weigh down the slender branches and thus expose the fruit to the sun and dew, both of which markedly affect colouring (41).

The degree to which a selected rootstock can influence the



the resistance or susceptibility of the scion to disease incidence seems worthy of further investigation. Preston (41) reports the work of Moore in 1930 who observed a greater susceptibility of trees of Cox's Orange Pippin, not sprayed with fungicide, to powdery mildew (Podosphaera leucotricha) when worked on M. I than when worked on M. XIII or M. XV. Similarly, the incidence of apple scab (Venturia inaequalis) on the same variety was more severe on M. I, M. II, M. V and M. IX than on M. XIII and M. XV.

Trees on different clonal rootstocks appear to vary in the uptake of minerals and in their susceptibility to mineral deficiencies. Van Belle (64) observed that the leaves of the two varieties, Jonathan and Golden Delicious, had higher percentages of potassium when grown on M. IV. Moreover, he noticed that when trees on M. IX and M. XI show marginal leaf scorch as a result of potash deficiency those trees on M. IV often show no trace of it.

Roach (45), when comparing the influence of different rootstocks on the mineral nutrition of the scion, found that M. XII induced the highest content of magnesium, boron and iron and M. IX the lowest, M. V being intermediate in this respect. The order for calcium and strontium was the reverse. The order for potassium was as follows: M. XII had the highest percentage, followed by M. IX and M. V. Manganese showed a different type of results, leaves on M. IX always contained more manganese than those on M. V, and those on M. XII were extremely variable, some being higher than those on

M. IX and some being lower than those on M. V. The figures for phosphorus varied from 0.2 to 0.4 per cent, but there was no suggestion of a definite rootstock effect.

Borgman (6) studied the incidence of potassium and magnesium deficiency in apples on M. XVI, Crab, M. IV and M. IX rootstocks at various levels of soil potassium and magnesium. He concluded that the type of rootstock determines the incidence of potassium and magnesium deficiency in the trees, provided the soil contains certain reserves of plant nutrients. In general, the rootstock acts as the absorber of all mineral elements and water; and the scion, with its leaves, is responsible for the assimilation of carbon dioxide and the building up of carbohydrates and most of the auxins. Beakbane and Rogers (3), basing their discussion on the above mentioned facts, suggested that the characteristic rootstock influence is given by the roots themselves.

Bukovac, Wittwer and Tukey (14) studied the stock-scion inter-relationships in the apple by the use of radioactive phosphorus and calcium. They suggest that the reduced quantity of radioactive phosphorus and calcium observed in the scions of the dwarfing stock M. IX may be attributed to reduced absorption or transport by the rootstock, or to a combination of the two processes, since they are interdependent. They feel that a limited supply of an essential nutrient or metabolite from the rootstock during early summer when the growth of the scion is at a maximum may be partially

responsible for the dwarfing response observed in the scion.

In considering the rootstock stem effect, Beakbane and Rogers (3) found that the presence of a rootstock stem tended to enhance the rootstock effect, but the stem effect was much smaller than that of the roots. On the basis of similar findings these authors, in a different article (49), suggested that the rootstock stem, or any interstock, can presumably only affect the tree by limiting the transport of materials, or by modifying these materials in the course of transit.

Bukovac and co-workers (14) also studied the dwarfing effect of interstems and rootstock stems by using radioactive tracers. They found that the dwarfing effect of interstems and rootstock stems cannot be adequately explained on the basis of reduced absorption. They suggested that interstems and rootstock stems exert their influence by altering nutrient transport or the physiology of the plant, and thus indirectly affecting nutrient uptake.

Scions also exert a certain influence on the rootstock. This effect of the scion on the development of the root system of the rootstock was studied by Lincoln (33) and by Rubin (5). Both of these investigators observed a definite scion effect on root formation and distribution. However, work on the influence of scion stems on the growth rate of rootstocks has been hampered by the difficulty of measuring the increase in size of a root system growing in soil (45).

## MATERIALS AND METHODS

The experiment was conducted in the Bekaa Plain at Istabél, about 50 kms. East of Beirut, near the Beirut-Damascus road. The apple orchard, in which the research was conducted, has an altitude of about 900 meters above sea level.

The trees were planted in January 1955 on different rootstocks: French Crab, Malling XVI, Malling VII and Malling II. The scion variety used was Golden Delicious.

The orchard was divided into small plots of about ninety by eighty meters. Every one of the plots was protected by wind-breaks (Cupressus arizonica) because of the prevalence of strong North-West winds in the area. A drainage ditch runs around every plot.

The trees on M. XVI were planted according to the triangular system in a separate plot with a distance of nine meters between trees. The other rootstocks were planted in one plot according to the same system of planting, but with a different arrangement. One row is planted with trees on French crab that alternates with trees on M. VII. The distance between consecutive trees is 4.5 meters. The second row follows a similar pattern but with trees on M. II and M. VII.

In this orchard, the modified-leader system of pruning was followed. Five to seven well spaced scaffold branches were left on

the leader. When the trees reached 4 years of age the leader was cut back to a stub of 10 to 15 centimeters, and the upper lateral was allowed to over grow it. Pruning is usually severe on French crab and M. XVI, and stubs, 15 to 30 centimeters in length, are left between the permanent scaffolds. Trees on M. II and especially on M. VII were very lightly pruned. The average yield in 1959 consisted of few apples on M. XVI and French crab, while M. II and M. VII yielded 40 and 30 kilograms, respectively. In 1960 the average yield for M. II, M. VII, M. XVI and French crab was 55, 45, 20 and 10 kilograms, respectively.

In former years flooding was the irrigation system employed in this orchard. However, because of governmental restrictions on water usage, the basin system of irrigation was utilized in 1959 and 1960. Three cultivations were usually performed per year. The first cultivation was done in the late fall to incorporate the organic matter and fertilizers into the soil. The second and third cultivations were carried on in the spring and early summer for the removal of weeds that grow very extensively. These cultivations were done with a tractor to a depth not exceeding 15 centimeters.

The yearly fertilizer program for every tree was as follows:

(1) 5 kg. of an organic compost that contains by weight 75% of dry organic matter, having a C/N ratio of 9; 4% of organic nitrogen; 1% of  $P_2O_5$  and 1% of  $K_2O$ .

(2) 1.25 kg. of superphosphate (18-20%  $P_2O_5$ ).  
(3) 0.6 kg. of potash (50%  $K_2O$ ).  
These fertilizers were applied in late fall and plowed under.  
In mid-February, depending on favorable climatic conditions,  
every tree received 0.75 kg. of Calcium Ammonium Nitrate (20% N.),  
followed by a similar application before the first irrigation.

The insect and disease program consisted of a dormant spray  
with petroleum oil, containing 1.5% D.N.O.C., used at the rate of  
1 kg. per 20 liters of water. At petal fall, DDT 50% w.p. (50 grams  
per 20 liters) and Karathane w.p. (15 grams per 20 liters) are used.  
Fifteen days later, Parathion, 50% emulsion, was used at a rate of  
10 grams per 20 liters of water. After 10 days, a spray similar to  
that utilized on petal fall was applied. The DDT-Karathane spray  
was followed, after a period of 15 days, by a spray of parathion 50%  
emulsion (10 grams per 20 liters) to which Kelthane was added (40  
grams per 20 liters). Parathion sprays were then utilized every 10  
days until the end of the season. However, Kelthane was only used  
when necessary against red mites.

Five Golden Delicious trees were chosen at random from every  
one of the four different rootstocks namely French crab, M. XVI,  
M. VII and M. II, and every tree was given a number. Leaf samples  
from these 20 trees were taken at the beginning of June, July, August,  
September and October and for two consecutive seasons. The leaves  
chosen were normal leaves, free from diseases, malformations or any

Different methods were used for the inorganic analysis of the

other disorder, such as adhering foreign material. Every sample consisted of thirty to forty leaves depending on the size of the leaves. For greater uniformity the leaf samples were taken in the morning from the upper half of the shoot, and no more than two leaves were taken from any shoot at any one time.

All leaf samples collected were taken to the laboratory where they were washed with detergent (13, 67). Every leaf was scrubbed with a cheesecloth on both surfaces. Then the leaves were rinsed in water, scrubbed with 0.1N.HCl, rinsed once in tap water and twice in distilled water (13).

Excess water was shaken off and the washed leaves were placed in tagged cheesecloth bags and dried in a forced-draft oven at  $70^{\circ}\text{C} \pm 1^{\circ}\text{C}$  for at least 24 hours (40, 55), so as to remove the water rapidly from the immediate vicinity of the samples as recommended by Piper (40), and to prevent as much as possible any loss of materials through the respiratory processes (40). The bags employed were washed the same way as the leaves.

The dried leaf samples were ground in a Wiley mill, using a 40 mesh sieve, and stored in screw top sampling bottles.

Before analysis, the samples were dried in a vacuum oven at  $70^{\circ} \pm 1^{\circ}\text{C}$  overnight (14-16 hours) and cooled in a dessicator before weighing a sample for the analysis (21).

Different methods were used for the inorganic analysis of the

leaf tissues. Nitrogen was determined by the Kjeldahl method (58). Manganese, iron, phosphorus and magnesium were determined colorimetrically with a Beckman Model B Spectrophotometer, using the method described by Toth et.al. (57), while potassium and calcium were determined spectrographically with a Beckman flame attachment to the Beckman Model D Spectrophotometer using the same method (57).

The results were calculated on the dry weight basis (24) and presented as percentage or parts per million.

The method of statistical analysis used in this study was the analysis of variance. This analysis is based on the assumption that "the experimental errors to which the data are subjected are independently and normally distributed with the same variance, the latter restriction being the most important." (47).



## RESULTS AND DISCUSSION

Nitrogen: The results of the nitrogen content of apple leaves for the year 1959, as given in Table 1, show that the nitrogen content of the leaf decreased from 2.83% in June to a value of 2.26% in October. The reason for this decrease throughout the growing season is due to the rapid translocation of the nitrogen-containing compounds elaborated in the leaves to the growing parts of the plant, namely, new shoot, new leaves and root growth, fruit and seed development.

A careful examination of the trend of the nitrogen in the leaf shows two periods of rapid decrease which are separated by a period during which the percentage composition does not vary greatly. The first period of significant decrease occurs between June and July and is due to a limited nitrogen supply. Simultaneous rapid leaf, shoot, wood and root development use the available nitrogen supply at a fast rate, and the newly formed nitrogenous products do not keep pace with the increased demand.

During August and September, the rate of growth of the leaf decreases, and the nitrogen intake is more or less balanced with the demand for the formation of new vegetative tissue and for the development of the fruit and seed. During this period, a leveling off in the decrease of the percentage of nitrogen is noticed.

Between September and October, the percentage of nitrogen in

Table 1: Variations in the percentage of nitrogen in apple leaves as influenced by rootstocks and date of sampling during 1959.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	2.84	2.57	2.58	2.66	2.25	2.58
M.VII	2.75	2.56	2.41	2.48	2.25	2.49
M.II	2.83	2.65	2.54	2.54	2.32	2.57
F.C.	2.90	2.67	2.49	2.47	2.23	2.55
Mean	2.83	2.61	2.50	2.54	2.26	

L.S.D. between means at the levels	5%	and	1%
Date of sampling	0.06		0.08
Rootstocks	0.05		0.07

the leaf falls from 2.54% to 2.26%. This significant decrease is the result of withdrawal of the nitrogenous products from the leaf shortly before leaf fall.

The results of the 1960 growing season, given in Table 2, show a similar trend. A gradual decrease in the percentage of nitrogen is noticed from the beginning till the end of the growing season, namely from 2.99% to 2.21%, respectively. Moreover, the two periods of rapid decrease are significant. However, there is a delay in the occurrence of the first period of decrease. This delay is thought to be due to the unfavorable climatic conditions, namely warm winter and rain that occurred during the beginning of the growing season. These climatic conditions must have caused a retardation in the growth cycle of the trees through their influence on the rest period. Furthermore, the amount of nitrogen in the leaf in 1959 did not vary greatly as compared to 1960. This is an indication that the nitrogen amount in non-deficient trees is more or less stable from year to year, varying from a maximum of 2.99% at the beginning of the season to a minimum of 2.21% at the end of the season. These figures could be used as an approximate index of sufficiency for the area, variety and age of trees used.

The results discussed above, are in confirmation with the findings of many investigators who reported a regular decrease in percentage leaf nitrogen from the beginning until the end of the growing season (7, 34, 36, 46, 48).

Table 2: Variations in the percentage of nitrogen in apple leaves as influenced by rootstocks and date of sampling during 1960.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	3.00	2.84	2.69	2.50	2.35	2.68
M.VII	2.96	2.88	2.57	2.33	2.16	2.58
M.II	3.04	3.02	2.50	2.34	2.12	2.60
F.C.	2.98	2.94	2.58	2.38	2.19	2.61
Mean	2.99	2.92	2.58	2.39	2.21	

L.S.D. between means at the levels	5%	and	1%
Date of sampling	0.06		0.07
Rootstocks	0.05		0.07

As far as the effect of the rootstock on the nitrogen content of the leaf is concerned, the results of the two consecutive seasons indicate that M. XVI induced the highest mean percentage of nitrogen, while M.VII induced the lowest mean percentage. The results of 1959 show that there is a significant difference between M. VII and the other rootstocks. M. VII induced the lowest percentage of nitrogen, namely 2.49%, while the three other rootstocks did not vary significantly, the percentage being 2.58%, 2.57% and 2.55% for M. XVI, M. II and French Crab, respectively. In 1960, as it appears in Table 2, M. XVI induced a significantly higher percentage of nitrogen than the other rootstocks. The results are 2.68% for M. XVI, while the other three rootstocks. M. VII, M. II and French Crab gave 2.58%, 2.60% and 2.61%, respectively. There was no difference between M. II and French Crab for the two consecutive seasons, as far as the nitrogen content of the leaves is concerned. However, they did not behave similarly during 1959 and 1960.

Phosphorus: The results obtained in this study, as presented in Tables 3 and 4, show that the trend for phosphorus in the apple leaf is very similar to that of nitrogen. This similarity in the variation of the percentages of phosphorus and nitrogen in the leaf was reported in the literature by a number of workers (8, 27).

The phosphorus content of the leaf varied during 1959 from 0.174% at the beginning of the season to 0.089% at the end of the growing season. A similar regular reduction in phosphorus was obtained during

the 1960 growing season, and the amounts found were 0.189% and 0.113% for June and October, respectively.

Upon careful examination of the results obtained for phosphorus during the two consecutive seasons, it appears that a slight difference exists between the trends showing the variation in leaf phosphorus for 1959 and 1960. In 1959 the percentage of phosphorus increased during the month of August. This increase in phosphorus could be attributed to a number of causes. It is already known that under high moisture conditions, the phosphorus in the leaf increases in concentration (35). Therefore, an irrigation made a few days before sampling could have caused this increase in the percentage of leaf phosphorus. Moreover, it was reported in the literature (27) that the amount of phosphorus assimilated is closely related to the amount of illumination the plant receives which may indicate a relation with the photosynthetic activity. Therefore, any factor that causes a retardation in the activity of the leaf would result in a decrease in the rate of elaboration of inorganic phosphates to organic phosphorus containing compounds and hence in the accumulation of phosphorus in the leaf.

As stated previously, the phosphorus trend, reported in Tables 3 and 4, is similar to that of nitrogen. Two periods of rapid decrease in phosphorus are noticed. During the 1959 growing season these two periods of rapid fall in the percentage of phosphorus in the leaf were highly significant. The first rapid drop occurred on June and July,

Table 3: Variations in the percentage of phosphorus in apple leaves as influenced by rootstocks and date of sampling during 1959.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	.177	.141	.152	.132	.069	.134
M.VII	.163	.126	.143	.124	.090	.129
M.II	.177	.128	.147	.125	.096	.135
F.C.	.180	.131	.150	.119	.099	.136
Mean	.174	.132	.148	.125	.089	

L.S.D. between means at the levels	5%	and	1%
Date of sampling	0.005		0.006
Rootstocks	0.004		0.006

with 0.174% and 0.132% respectively. This was followed by an increase in August of 0.016% over July. The second period of rapid decrease occurred between August, September and October, with 0.148%, 0.125% and 0.089%, respectively.

During 1960, the first period of rapid decrease occurred between July and August, with 0.176% and 0.134% respectively. By comparing the results obtained during 1960 with the data obtained during 1959, it is noted that the magnitude of the drop is the same. However there is a delay in the occurrence of this decrease during 1960. This delay, as it was explained in the case of nitrogen, is thought to be due to the unfavorable climatic conditions that were prevalent during 1960, and which must have caused a retardation in the growth cycle of the tree. Also, the slight increase that occurred in August of 1959 was not apparent, instead the decrease was uniform throughout the season.

Because of these unfavorable climatic conditions that were prevalent during 1960, the extent of the second period of rapid fall in the percentage of phosphorus was not as important between September and October as that of 1959. Phosphorus varied only from 0.123% to 0.113% while during the same period in 1959, the variation was from 0.125% to 0.089%. Rogers and co-workers (48), while studying the variation in the phosphorus content of the leaf, observed a similar decrease at the end of the growing season. They consider that this



Table 4: Variations in the percentage of phosphorus in apple leaves as influenced by date of sampling and rootstocks during 1960.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	.173	.173	.142	.124	.112	.145
M.VII	.189	.183	.132	.117	.112	.147
M.II	.195	.176	.131	.122	.114	.148
F.C.	.199	.173	.131	.130	.116	.150
Mean	.189	.176	.134	.123	.113	

L.S.D. between means at the levels	5%	and	1%
Date of Sampling	0.005		0.007
Rootstocks	0.005		0.006

decrease in percentage leaf phosphorus is due to the migration of large amounts of phosphorus before leaf abscission occurs. This translocated phosphorus is the important source of supply for the following season's growth.

The rootstock effect is not very pronounced for phosphorus. During the 1959 growing season, M. VII was found to be associated with significantly lower phosphorus content in the leaves than the other rootstocks. The percentage phosphorus in the leaves of trees topworked on M. VII was 0.129%, while M. XVI, M. II and French Crab gave 0.134%, 0.135% and 0.136% respectively. However, this was not the case in 1960, and a significant difference at the 5% level existed only in the case of M. XVI and French Crab. But when considering these two rootstocks in respect to M. VII and M. II, no significant difference was found to exist.

From the combination of the results of the two consecutive seasons, it becomes apparent that French Crab and M. II were always in the group that was associated with the highest amount of phosphorus in the leaf.

Potassium: Many investigators have observed an increase in the potassium content of apple leaves until a maximum is reached in June. After this date a rapid decrease in the potassium content is noticed (9, 27, 44, 46, 48).

The results of the 1959 growing season, as given in Table 5,

show that potassium is at a maximum in June, with a value of 2.53%. This percentage starts decreasing until it reaches 1.83% of the dry weight of the leaf, in October. This normal trend of potassium in the leaf is clearly explained by Gardner, Bradford and Hooker (27). During winter, potassium is stored in both the sapwood and the bark, and in the old branches. This stored potassium is translocated in the spring and is used for the development of new leaves and shoots and mostly for the development of the fruit. Since vigorous growth of the leaf does not start until June, the amount of potassium that is translocated to the leaves will accumulate there. This explains the increase in the potassium content of the leaf at the beginning of the season, with a maximum attained in June. From June until the end of the season the demand for potassium is greater than the amount translocated to the leaves, and the potassium content of the leaf starts decreasing, until a minimum is reached just before leaf abscission occurs (27).

Similar results were obtained during the 1960 growing season, as reported in Table 6. Potassium was at a maximum in June, with a value of 1.80% and it dropped to a minimum of 1.07% in October. A careful examination of this trend of potassium in the leaf also shows that, although potassium decreases from June to October, a period exists during which the rate of fall in the potassium content of the leaf is slower than during the remainder of the growing season. This behavior is very clearly shown in August and September of 1960

Table 5: Variations in the percentage of potassium in apple leaves as influenced by rootstocks and date of sampling during 1959.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M. XVI	2.33	2.41	2.35	1.92	1.78	2.16
M. VII	2.45	2.37	2.24	1.96	1.78	2.16
M. II	2.57	2.19	2.09	1.76	1.73	2.07
F.C.	2.78	2.54	2.40	2.06	2.05	2.37
Mean	2.53	2.38	2.27	1.92	1.83	

L.S.D. between means at the levels	5%	and	1%
Date of Sampling	0.07		0.09
Rootstocks	0.06		0.08

where the percentage of potassium varied from 1.49% to 1.47%. Similar results were obtained by Reuther and Boynton (44) during their study on the variation of the potassium content of the leaf. They observed that during a certain period in the growing season, the rate of fall of the potassium in the leaf is slower than the rate of fall at the beginning or at the end of the growing season. In this study this reduced fall was not very apparent in the 1959 results where the potassium level in the leaves was relatively higher than in 1960. This may indicate that under a low leaf content of potassium, the seasonal effect is more pronounced.

According to Gardner and co-workers (27) this period in which a slow rate of fall in the leaf is noticed, is due to a balance between the amount of potassium utilized by the plant and the amount that is absorbed by the roots and translocated to the leaves.

A comparison between the results obtained in 1959 and 1960, as given in Tables 5 and 6, shows that the percentage of potassium in the leaf was higher in 1959. Emmert (23) studied the effect of the crop on the mineral content of the leaf, and he found that potassium content was lower in the case of bearing trees. The larger crop is probably the cause of the lower percentage of potassium in the apple leaves of the 1960 growing season.

The rootstock effect was very significant in influencing the

Table 6: Variations in the percentage of potassium in apple leaves as influenced by rootstocks and date of sampling during 1960.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	1.79	1.63	1.48	1.52	1.15	1.51
M. VII	1.70	1.87	1.41	1.29	0.98	1.45
M.II	1.75	1.67	1.45	1.33	0.94	1.43
F.C.	1.95	1.60	1.61	1.74	1.22	1.62
Mean	1.80	1.69	1.49	1.47	1.07	

L.S.D. between means at the levels	5%	and	1%
Date of sampling	0.07		0.10
Rootstocks	0.06		0.09

potassium content of the leaves. During the two consecutive seasons French Crab was associated with a significantly higher percentage of potassium as compared to the other three rootstocks, namely 2.37% in 1959 and 1.62% in 1960. The difference in the values obtained during the two seasons, is due, as previously explained to the influence of the crop in 1960, in reducing the potassium content.

Another definite rootstock effect was that of M. II. This rootstock was associated with significantly lower percentages in Golden Delicious leaves than M. XVI and French Crab. This rootstock behaved similarly during both seasons. M. VII behaved differently during the two growing seasons. In 1959, M. VII was similar to M. XVI in respect to the potassium content of the leaves of Golden Delicious growing on these two rootstocks. In 1960 however, M. VII behaved like M. II and was associated with a low percentage of potassium in comparison to the other rootstocks.

Magnesium: The magnesium content of apple leaves, as shown in Tables 7 and 8, clearly indicates wide variations between the different dates of sampling. During 1959, the results of Table 7 point out a significant rise from 0.36% in June to a maximum of 0.45% in July. This significant increase is followed by a highly significant decrease to a value of 0.28% in August. However, a late season increase in the magnesium content of apple leaves is noticed in September, before the level of magnesium in the leaf drops back to a low value of

Table 7: Variations in the percentage of magnesium in apple leaves as influenced by rootstocks and date of sampling during 1959.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	.42	.55	.35	.43	.36	.42
M.VII	.36	.44	.28	.36	.32	.35
M.II	.33	.40	.25	.31	.28	.30
F.C.	.35	.40	.25	.26	.25	.30
Mean	.36	.45	.28	.34	.30	

L.S.D. between means at the levels	5%	and	1%
Date of Sampling	0.02		0.03
Rootstocks	0.02		0.03



0.30% in October. A similar trend is observed in 1960, as shown in Table 8. Magnesium in the leaf increased significantly from 0.32% in June to a maximum of 0.42% in August. A significant decrease followed this maximum, and in September and October, the magnesium level was maintained at the values 0.34% and 0.36%, respectively.

Gardner and co-workers (27) explain the seasonal variation in leaf magnesium by assuming that magnesium, which is an important constituent of leaf chlorophyll, keeps pace with leaf development, increasing with an increase in the chlorophyll content of the leaf, until a peak is reached. Magnesium will decrease afterwards because of its withdrawal from the leaves to the branches late in the season. Similar results were obtained by Mason and Whitfield (36) and by Roach (46) when they studied the variation of magnesium in apple leaves.

The rootstock effect on magnesium in the scion leaf is highly significant, and was found to repeat itself over the two seasons. In 1959, the data of Table 7 show that the four rootstocks could be separated into three categories, each one differing significantly from the other. M. II and French Crab were associated with the lowest content of magnesium or 0.31% and 0.30% magnesium respectively. M. VII was associated with a comparatively medium magnesium content with 0.35%, while M. XVI was associated with the highest magnesium content with 0.42%. Very similar results were found in 1960. Table 8 shows that M. II and French Crab were associated with the lowest concentration



among the four rootstocks with respectively 0.32% and 0.33% magnesium. M. VII was associated with a significantly higher magnesium content with 0.36%, but it was significantly lower than M. XVI, which showed the highest magnesium content in the leaf with 0.43% magnesium. The influence of the rootstock on the magnesium content of the leaf has been definitely established for the two successive years with a similar trend repeating itself. This could be cited as the first case in this study were the findings of one year repeated themselves during the second year.

Calcium: The seasonal variation in the calcium content of Golden Delicious leaves, as shown in Table 9 and 10, is not in full confirmation with the findings of other investigators. Mason (34) observed a progressive increase in the calcium content of the leaf, as the leaves pass from the rudimentary to the fully mature stage. Moreover, Rogers and co-workers (48) observed a rapid increase in leaf calcium during the first 65 days after leaf unfolding. This rise was followed by a period during which this element remained constant, and later, a significant increase in the calcium content of the leaf occurred, during the last few weeks of the season.

A careful study of the results given in Tables 9 and 10 shows that during 1959 calcium significantly increased from 2.04% in June to 2.51% in October, while during 1960 the significant increase was from 1.69% in June to 2.36% in October. This increase in the calcium

Table 9: Variations in the percentage of calcium in apple leaves as influenced by rootstocks and date of sampling during 1959.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	2.04	2.44	2.39	2.36	2.62	2.37
M.VII	1.92	3.22	2.23	2.16	2.58	2.42
M.II	2.10	2.39	2.26	2.27	2.57	2.32
F.C.	2.10	2.40	2.26	2.22	2.29	2.25
Mean	2.04	2.61	2.28	2.25	2.51	

L.S.D. between means at the levels

	5%	and	1%
Date of Sampling	0.10		0.13
Rootstocks	0.09		0.12

content of the leaf is in confirmation with the results of other investigators (34, 48) as explained above.

In 1959, the results of Table 9 show that calcium increased to a very high level in July, and then a highly significant drop in the percentage of calcium was noticed. This sudden steep drop followed by a subsequent increase is not accounted for in the literature.

The results of the 1960 growing season are closer to what is reported in the literature in relation to the variation of this element. However, the 1959 picture was repeated in that a significant fall in the percent calcium was noticed in September, followed by the usual rise in October.

The rootstock effect was found to vary from one year to the other in the case of calcium. In 1959, the results of Table 9 show a significant difference between French Crab and the two rootstocks: M. VII and M. XVI. French Crab was associated with a low percentage of calcium with 2.25% while M. XVI and M. VII were associated with a high percentage with 2.37% and 2.42% respectively. Moreover, there was no significant difference between M. II and French Crab or M. XVI, but a significant difference existed between M. II and M. VII, with 2.32% and 2.42% respectively.

The results are somewhat different for 1960. The data from Table 10 shows a significant difference between M. VII and M. II

Table 10: Variations in the percentage of calcium in apple leaves as influenced by rootstocks and date of sampling during 1960.

Rootstocks	Dates of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	1.71	1.88	2.23	2.18	2.37	2.07
M.VII	1.56	1.84	2.10	2.03	2.40	1.99
M.II	1.76	1.81	2.46	2.25	2.38	2.13
F.C.	1.71	1.70	2.32	2.20	2.31	2.05
Mean	1.69	1.81	2.28	2.16	2.36	

L.S.D. between means at the levels

	5%	and	1%
Date of sampling	0.10		0.13
Rootstocks	0.09		0.12

rootstocks. M. II was associated with a high percentage of calcium with a value of 2.13% of the dry weight of the leaf, while M. VII was associated with a low value with 1.99% only. Moreover, no significant difference existed between M. VII, French Crab and M. XVI, or between French Crab, M. XVI and M. II.

The rootstock effect on the calcium content of the scion leaves did not seem to repeat itself in the two years of study, and a prolonged study is required before any definite conclusion as to rootstock behavior concerning this element could be drawn.

Iron: The variation in the parts per million of iron in the leaves for the two growing seasons 1959 and 1960 are presented in Tables 11 and 12, respectively. During 1959, iron in the leaves increased significantly from 72 ppm. in June to 87 ppm. in August, followed by a significant decrease to 61 ppm. in September and a further significant increase to 84 ppm. in October. However, a different behavior was noticed in the trend of iron during 1960, as presented in Table 12. The iron content was higher throughout the year, also during 1960, the iron in the leaf decreased from a maximum of 152 ppm. in June, to a minimum of 78 ppm. in September, followed by a very slight insignificant increase at the end of the growing season, namely in the month of October.

From these results, it seems that the iron content of the leaf varies from one year to the other without following a particular





Table 12: Variations in the parts per million of iron in apple leaves as influenced by rootstocks and date of sampling during 1960.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	137	128	110	74	83	106
M.VII	157	131	113	84	80	113
M.II	152	133	110	75	82	110
F.C.	161	131	103	81	91	113
Mean	152	131	109	78	84	

L.S.D. between means at the levels

	5%	and	1%
Date of Sampling	8		10
Rootstocks	7		9

trend. Similarly, at the East Malling Research Station, Roach (46) during his studies on the variation of the iron in apple leaves found that, although iron varies continuously in the leaf, no regular trend could be observed.

Concerning the rootstock effect, the results presented in Table 11 show, that during 1959, M. VII was associated with a significantly higher content of iron in the leaf than the other rootstocks, the results being 83 ppm. for M. VII and 77, 74 and 71 ppm. for the three rootstocks M. XVI, French Crab and M. II, respectively. The results also show that no significant difference existed between M. II and French Crab or between French Crab and M. XVI. However, a significant difference existed between M. II and M. XVI.

During 1960, the results of Table 12 indicate a difference between M. XVI and the other rootstocks, but this difference is not significant. This lack of significant differences could be due to the fact that the amount of iron during 1960 was higher than 1959, and as such the stress for iron seemed to be less during 1960. This reduced stress for iron may partially explain the lack of differences between rootstocks which is always more apparent when the amount of an element is not abundant.

Manganese: The manganese content of apple leaves, as given in Table 13 and 14, shows that the seasonal variation in this element was not regular over the two growing seasons 1959 and 1960.

Table 13: Variations in the parts per million of manganese in apple leaves as influenced by rootstocks and date of sampling during 1959.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	273	237	208	178	223	224
M.VII	183	168	167	158	211	177
M.II	253	236	208	192	212	220
F.C.	226	168	146	135	156	166
Mean	234	202	182	166	200	

L.S.D. between means at the levels

	5%	and	1%
Date of Sampling	15		20
Rootstocks	13		18

During 1959, the results of Table 13 show a significant decrease in the manganese content of apple leaves, from a maximum of 234 ppm. in June to a minimum of 166 ppm. in September. This decrease was followed by a sharp increase to a value of 200 ppm. in October.

A somewhat different picture is noticed in the 1960 results. The general trend for manganese was an increasing one, starting with a value of 202 ppm. in June, and ending with a value of 255 ppm. in October. However, during this season, two periods of significant decrease were observed in July and September, with values of 180 ppm. and 200 ppm., respectively. These results are not in full confirmation with the work of Mason (34), Bell and Childers (4) and Epstein and Lilleland (25). These workers have observed a gradual increase in the manganese content of the leaf during the growing season, with no sudden decrease in the manganese content of the leaf during summer.

An explanation for such discrepancies in the results could be explained on the basis of the studies, carried by Epstein and Lilleland (25). These investigators assumed that high luxury consumption of manganese is very probable in fruit trees.

From our results, manganese seemed to be high all through the growing season, as compared to the results of Epstein and Lilleland (25), who observed that manganese in non-deficient apple trees

Table 14: Variations in the parts per million of manganese in apple leaves as influenced by rootstocks and date of sampling during 1960.

Rootstocks	Date of Sampling					Mean
	June	July	Aug.	Sept.	Oct.	
M.XVI	230	201	227	218	288	233
M.VII	173	166	190	183	247	192
M.II	201	177	217	199	241	207
F.C.	206	177	214	199	244	208
Mean	202	180	212	200	255	

L.S.D. between means at the levels	5%	and	1%
Date of Sampling	16		21
Rootstocks	14		19

averaged 81 ppm. This may indicate high available amounts of manganese in the soil that was taken and accumulated in the leaves. The study of Wiederspahn (69) on the antagonism between iron and manganese may explain the low levels of iron obtained in this study. It is possible that the high levels of manganese in the leaf might have induced a low level of iron.

In respect to the rootstock effect on the manganese content of apple leaves, Table 13 shows that during 1959, M. XVI and M. II were associated with significantly high manganese in the leaves with 224 ppm. and 220 ppm., respectively when compared to M. VII and French Crab which were associated with 177 ppm. and 166 ppm., respectively.

The 1960 results still show that M. XVI was associated with a high concentration of manganese in the leaf, with 233 ppm., when compared to the other rootstocks. M. II and French Crab were similar in that they were associated with 207 ppm. and 208 ppm. of manganese, respectively. However, they differed significantly from M. VII which gave 192 ppm. only.

From the results of the two consecutive seasons, it becomes apparent that M. XVI has the tendency to be always associated with higher manganese content in apple leaves than the other rootstocks.

## SUMMARY AND CONCLUSION

The study reported in this thesis was undertaken to evaluate the effect of date of sampling and rootstock on the inorganic mineral composition of Golden Delicious apple leaves.

The conclusions drawn from this study follow:

1. The seasonal variation in the mineral composition of apple leaves was established, and apple leaves were found to vary in their mineral composition during the growing season.

2. The trend for the elements studied during the two seasons revealed the following:

- a. Nitrogen: rapid decreasing trend from the beginning till the end of the season, with a slowing down in the rate of decrease towards July-August.
- b. Phosphorus: decreasing trend throughout the growing season, except for a small increase in August of 1959.
- c. Potassium: rapid decrease from a maximum in June to a minimum in October.
- d. Magnesium: rapid increase to a maximum in July-August, followed by a rapid decrease in September-October, before leaf abscission occurs.
- e. Calcium: rapid increase from June till July-August, followed by a decrease, and later by a further increase before the end of the season.

- f. Iron: no definite trend was observed for iron in the two seasons of the study.
- g. Manganese: besides a decrease from June to July and an increase at the end of the season no regular trend was observed during the two seasons.

3. The rootstock effect for the elements studied during the two growing seasons varied in most cases from one year to the other. Certain rootstock effects, however, were found to occur over the two seasons:

- a. M. XVI was associated with high nitrogen, magnesium and manganese.
- b. M. VII was correlated with low nitrogen in apple leaves.
- c. M. II was associated with high phosphorus, but low potassium, and low magnesium.
- d. French Crab was correlated with high phosphorus and potassium, but low magnesium.

It is understood that the rootstock effects were studied separately for each element, and under the same conditions.

4. It is apparent from this study that although a definite seasonal variation and rootstock effect were found, no definite conclusion is justified at this stage. Further studies are required for a number of years, under different conditions before a definite conclusion could be brought out.



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