RESPONSE OF CONCORD GRAPE VINE (VITIS LABRUSCA L.) TO VARIOUS LEVELS OF ESSENTIAL NUTRIENT ELEMENTS

By

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AN ABSTRACT

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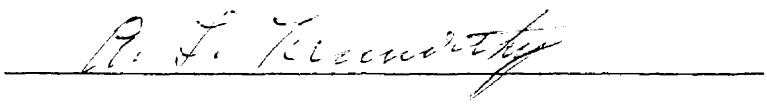
Approved 

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ABSTRACT

The response of Concord grape vines to various levels of essential nutrient elements was studied in the greenhouse with three experiments.

In Experiment I, one-year-old rooted cuttings were used. The check treatment was supplied with standard Hoagland solution, and high (5x) or low (0x) levels of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, copper, zinc, and molybdenum were obtained by adjusting the standard solution to the specific levels. High levels of calcium and potassium were tested in combination with both sulfate and chloride as anions. In Experiment II, ratios of 1.6 to 21.2 of $\frac{Ca+Mg}{K}$ in the solution were used to test the influence on growth and expression of potassium deficiency. In Experiment III, the effect of three levels of manganese (2x, 25x and 50x Hoagland solution manganese) upon plant growth was tested. In Experiments II and III, two-year-old plants were used and the standard solution was modified by doubling manganese and increasing copper by 50%.

Total linear growth, dry weight accumulation of roots, stems, petioles, leaf blades, and total dry weight were taken. The shoot/root ratios were calculated. Petioles and stems of each plant were analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, copper, zinc, and partially for chloride.

The check treatment produced most total linear growth, while low levels of major elements, with the exception of magnesium, depressed linear growth more than low levels of minor elements. The high level of molybdenum produced most total dry weight, while low levels of potassium and nitrogen, and high levels of potassium with chloride as anion were most depressive on total dry weight. Treatments deficient in nitrogen and phosphorus or high in magnesium and molybdenum caused the lowest shoot/root ratio. High levels of phosphorus and nitrogen, and low levels of magnesium caused highest shoot/root ratios.

A positive relationship between the specific nutrient element in the solution and in the petioles was observed for all elements except for iron and zinc. Petioles seemed to provide a better indication of normal or above normal levels of nutrition than the stems. The stems, however, seemed to indicate better low or deficient levels. The stem content was always equal to, or higher than, the petiole content under low or deficient nutrient conditions.

The $\frac{Ca+Mg}{K}$ ratios in the nutrient solution were of no direct influence on growth or on color of potassium deficiency symptoms. Indirectly, however, potassium, calcium, and magnesium exerted varied influences.

Chronological appearance of visible deficiency or toxicity symptoms

were not correlated with the depression of growth resulting from the specific element. All low level and four of the high level treatments produced visible leaf symptoms. Magnesium deficiency symptoms on leaves developed more rapidly with high potassium than when magnesium was omitted. Visible deficiency symptoms on plants coincided with the following values in petioles: nitrogen .51%, phosphorus .10%, potassium .47%, calcium .26%, magnesium .14%, manganese 18 ppm, boron 14 ppm, copper 28 ppm, and zinc 11 ppm.

Many significant interactions between nutrient elements were found. Generally major elements were of more influence on the minor elements and vice versa. High levels of major elements in the nutrient solution had more influence on nutrient absorption than high levels of minor elements. Some of the more striking interactions between elements were as follows: (1) Low nitrogen in the solution caused low phosphorus, low boron, and high calcium in the petioles. (2) High nitrogen produced high phosphorus and high boron petiole content. (3) Low phosphorus in petioles coincided with high manganese and high iron. (4) Very low levels of copper and zinc were found under deficient potassium conditions. (5) A specific amount of potassium appeared to be necessary for adequate absorption of calcium and manganese. (6) More potassium was absorbed with sulfate than with chloride as an anion. In the latter case, more calcium was found in petioles. (7) High nitrogen, phosphorus, potassium, manganese, and boron in petioles appeared under calcium

deficient conditions. (8) A significant positive correlation between total iron and manganese in the petioles was established. (9) Low phosphorus, potassium, calcium, and high magnesium were associated with high manganese values in petioles. (10) More boron was observed in petioles of plants treated with high levels of nitrogen, phosphorus, potassium, and low levels of calcium than in those plants treated with high levels of boron.

With extremely high manganese concentrations in the solution, manganese toxicity symptoms appeared on leaves. Growth was not affected at this level, however, the berries did not ripen evenly within clusters.

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INTRODUCTION

Michigan ranks third in the United States in the production of the Concord grape (Vitis labrusca). The income from grapes provides a large share of the farm income received by many fruit growers in the Southwestern counties of Michigan. The nutritional status of Michigan grape vineyards improved considerably after it was found that potassium was limiting grape production (Larsen, 1955).

In extreme cases, deficiency or toxicity symptoms may occur on leaves. If the shortage is not critical, the plant may show reduced growth and/or production. A visual diagnosis in this instance is very difficult. Petiole analyses have opened new avenues for interpretation and correction of nutritional disorders prior to the appearance of visual symptoms.

The purpose of the present investigation was to study the response of Concord grapes to various levels of essential nutrient elements, as shown by visual leaf symptoms, growth, petiole and stem composition. The data indicate the behavior of certain elements within the plant and their interactions with other elements. They also suggest possible correction of visual or hidden nutritional disorders in Concord grapes.

REVIEW OF LITERATURE

The influence of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn), sulphur (S), chlorine (Cl), and molybdenum (Mo) upon growth and production of grapes has been the subject of numerous investigations. The identification of certain deficiency or toxicity symptoms with the elemental composition of a certain plant part has been furthered in recent years. Lagatu (1927), after finding responses to N, P and K, applied in fertilizer by means of leaf analysis, wrote

> "The diagnosis based on the chemical composition of the leaf is as accurate and indicative for the intensity as it is for the nature of nutritional supply".

Since then, many different ways of expressing the most suitable elemental composition for a satisfactory production and a healthy plant have been presented. Lagatu and Maume (1940) felt that the ratio of $N:P_2O_5:K_2O$ in the leaves should be 41:8:51, whereas Vettori (1954) thought 45.5:9:45.5 was the best, and Liverant (1955) suggested a ratio of 64.1:11.6:24.3. Vidal (1955) added these three elements together and reported 3.9% dry weight as average for good vineyards with an optimum of 4.33%. Goodall and Gregory (1947) reviewed the various reports and concluded that no vines responded to fertilizer when the per cent dry weight content

of their leaves in fall was above 1.5 N, .19 P, and 1.03 K.

Beattie and Forshey (1954) observed in Ohio that a Concord grape petiole composition (per cent dry weight) of .77 N, .14 P, 2 K, .7 Ca, and .15 Mg was necessary to produce 3.5 tons of grapes per acre. These values are similar to Larsen's (1957) standard values (per cent dry weight) in petioles for Michigan, which are .8 N, .24 P, 1.91 K, 1.60 Ca, and .46 Mg. Other values mentioned by Larsen were 44 ppm Fe, 434 ppm Mn, 25 ppm B, 35 ppm Cu, and 23 ppm Zn. Coombe and Allan (1955) conducted a nutritional study of vinifera type grapes grown in deep white sand in Australia and found the following values (per cent dry weight) for leaves of vigorous plants: 2.55 N, .52 P_2O_5, 1.48 K_2O, 3.08 CaO, and .76 MgO.

Magoon et al. (1938), in a spectrographic analysis, compared Concord with the Ontario variety and found the following respective values in petioles: .61 and .76% P, 1.97 and 2.20% K, .57 and .47% Ca, .28 and .22% Mg, 190 and 220 ppm Fe, 180 and 220 ppm Mn, 17 and 16 ppm B, 41 and 47 ppm Cu, 450 and 410 ppm Al. Vidal (1955) drew attention to the fact that in Maroccan vinifera vineyards the nitrogen and phosphorus content in leaves was highest in 3- and 4-year-old plantations, and lowest in those of over 27 years old. He arrived at a combined value of 4.62% for young vineyards when N, P_2O_5 and K_2O content were added, and 3.69% for older ones, clearly indicating that with increasing age, nitrogen and phosphorus became deficient.

Nitrogen: The association of a definite amount of nitrogen in the plant with visual symptoms and without symptoms is not too clear because of ranges in composition and season of sampling. Shaulis and Kimball in New York (1956) suggested that a Concord grape petiole content of below 1.5% N in June as approaching a deficiency, and found a range of 1.7 to 2.4% N for vigorous yards. They also reported a seasonal decrease of nitrogen within the plant, which agreed with Lagatu's (1927) findings. Wagner (1924) reported 1.0 to 2.0% nitrogen in whole leaves and thought that a mature leaf should contain about 1.55% N. Maume and Dulac (1948) reported 2.6% N in leaves at the beginning of the season, and 1.6% N at maturity as normal for vinifera type grapes in France. McGeorge and Breazeale (1955) found a decrease from 2.3% N in April to .96% in leaves of Thompson seedless in Arizona, in July. Bergman and Kenworthy (1957) established the same trend in Concord grape petiole content from 1.34% N in June to .68% N in September, without appearance of visual N deficiency symptoms.

Herschler (1933), with pot experiments, as well as Hagler and Scott (1949), working with sand culture, found leaves turning yellowish green after a few weeks of growth without nitrogen. Shaulis and Kimball (1956) associated short internode length and stoppage of linear growth by mid-July with nitrogen deficiency. Whereas, Coombe and Allan (1955) found a higher

nitrogen content in leaves of stunted plants (2.87%) than in vigorously growing ones (2.55%), Kobayashi et al. (1955) found 2.28 to 2.75% N in leaves of non-bearing and 2.23 to 2.61% N in bearing plants of the Delaware variety.

Partridge and Veatch (1931), as well as Cooper and Vaile (1939) observed more vigorous growth and higher yields where nitrogen fertilizers were applied. Ulrich (1942a) reported an increase in nitrogen content of petioles by applying one pound of $(NH_4)_2SO_4$ per vine for three years. Petioles of untreated plants showed 1.09% N in May and .47% N in September, as compared to 1.49 and .62% N respectively of treated plants. Leaves from the same untreated plots had 3.48 and 2.21% N, whereas those from treated plots had 3.95 and 2.49% N.

Volk (1938) calculated the ratio of root to above-ground parts of plants grown for two years in water culture and established the following root/shoot ratios: for minus N 1:1.81; for high N 1:4.56, and for the check 1:3.6. The minus N plants had an excellent rootstock with light yellow to yellow brown color and more wood than leaves; the high nitrogen plants, however, produced many more leaves.

Phosphorus: Very few observations of phosphorus deficiency under field conditions have been reported. Cais (1954) found such a field in Italy and observed very short growth, small terminals, chlorotic leaves with occasional marginal dessication and flower drop. If, however, pollination

had taken place, the berries often dessicated but stayed on the vine, looking like "pepper grains". This condition was cleared up by the application of phosphorus fertilizers alone, whereas other fertilizers were of no influence. A similar field was observed by Stellwaag (1955) near Meran, Italy. This field was striking by the dark green appearance of the leaves and very short terminal growth.

Lagatu and Maume (1927), and Partridge and Veatch (1931) observed some response to phosphorus fertilizers, but felt the response was due to a better balance between N, P, and K rather than due to phosphorus alone. Cooper and Vaile (1939), as well as Randolph (1944), reported response of phosphorus on growth and yield of Carmen grapes in Texas. Herschler (1933), on the other hand, was not able to correct severe phosphorus deficiency sumptoms with phosphorus. The symptoms occurred on leaves having .22% P content. Wagner (1924) felt that .09% P in the leaf was sufficient inasmuch as there occurred a wide range under field conditions.

Maume and Dulac (1948) reported values in leaves varying from .1% P at the beginning of the season to .06% P at the end of the season. Archibald (1956) reported a seasonal decrease from .32 to .11% P, and Bergman and Kenworthy (1957) found a seasonal change from .27 to .21% P in petioles. Forshey (1955) observed that phosphorus is more constant in petioles than in leaf blades throughout the growing season.

Volk (1938), working with water culture, established the following root/shoot ratios: 1:3.03 for minus P treatments; 1:4.1 for high P treatments; and 1:3.6 for the check.

Potassium: Babo and Mack (1910), in their book on grape growing, described symptoms which are known today as being potassium deficiency under the name of "Blattbraeune", "Braunfleckigkeit", and "Brunissure". Wilhelm (1950) described three different potassium deficiency stages; stage 1 (easiest to correct) showed purpling on the upper surface (towards the light) of the leaf at the beginning of May, followed by browning from the margins and interveinal necrosis by June. Stage 2 exhibited purple coloring very early in the season with weakening of vines and uneven ripening of the berries. By the end of July, the basal leaves were necrotic, but the tip leaves were not affected. In stage 3, the flowers died and the vines showed a very poor yield as well as very weak growth. In this stage the leaves were pale green instead of dark green and blue-violet. Gollmick (1955) felt that these potassium deficiency symptoms were brought about by the "idle running" of the assimilation apparatus which, due to photo-oxydative destruction of chlorophyll, produced necrosis of cells. Beattie (1955) found two distinct symptoms on Concord grape leaves in Ohio. Whereas one type showed purplish-black areas between the veins, which developed into a black leaf, the other type exhibited only marginal scorch with later death of the tissue.

Larsen (1955) observed the same symptoms in Michigan vineyards.

Hagler and Scott (1953) developed similar symptoms on Muscadine plants in sand culture after four weeks of growth. Harding (1957) tried to reproduce the above described deficiency symptoms in nutrient culture on Concord grape vines, and was able to get only some purpling of the leaves.

Ulrich (1942b) reported 2.58% K in May, and .31% K in September in petioles from untreated plants, whereas plants treated for three years with potassium showed 3.59 and .8% K respectively. Leaf blades of the same plants showed a decrease from 1.02 to .44% K in untreated plants, and from 1.22 to .57% K in treated plants. This seasonal decrease of potassium was also reported by McGeorge and Breazeale (1955), Shaulis and Kimball (1956), Archibald (1956), and Bergman and Kenworthy (1957).

Larsen (1955) associated 1.0% K in petioles in late July with a crop of below four tons, and a petiole content of above 2.0% K with a crop of over six tons. Archibald (1956) associated petiole content and crop as follows: .88% K with four tons and over; .47% K with three to three and one-half tons; and .24% K with below two tons. Shaulis and Kimball (1956) found in vigorous vineyards a wide range of potassium (.4 to 2.0%) in petioles, but suggested that the plants became deficient if the petiole content was below .6% K in late August. Bergman and Kenworthy (1957) found black leaves in two vineyards during late August, one had a petiole content of .44% and the other .97% K.

Kobayashi et al. (1955) reported that with increasing potassium in leaves, the ratio of fruit to leaf is also increased; however, beyond a certain level of potassium, fruit yield and amount of foliage decreased again. They found an average of 2.1% K in leaves of bearing Delaware vines as compared to 1.5 to 1.73% K in leaves of non-bearing plants. Stunted Grenache grapes in Australia, according to Coombe and Allan (1955), had .68% K_2O in the leaves and vigorous plants 1.48% K_2O. They also observed leaves with marginal scorching and felt that .3% K_2O was a fairly low level. Boynton (1945) found severe potassium deficiency symptoms in September on Portland and Delaware leaves having .25% K content, but only slight symptoms on the ones having .61% K at the same time.

Calcium: No reports of calcium deficiency symptoms in vineyards have been found, and the symptoms described were all produced in nutrient solution cultures. Hagler and Scott (1953) produced calcium deficiency symptoms in Muscadine grape vines after eight weeks of growth by using a calcium deficient solution. Young leaves exhibited interveinal and marginal chlorosis followed by pinhead spots near the margin of the leaf, die-back of the tip and drop-off. Stellwaag and Knickmann (1955) described similar symptoms and mentioned a "beaklike" curling of the young leaves.

Sarosi (1956) analyzed leaves and roots of chlorotic vines in Hungary, which reacted favorably to calcium acetate treatments. He found in abnormal

leaves (smaller and thinner than normal) more iron, potassium, and sodium but less calcium than in healthy leaves. In other words, monovalent cations increased at the expense of divalent.

On the other hand, high levels of calcium may induce potassium deficiency. Harding (1957) induced chlorosis on Concord grape leaves in sand culture by adding high levels of calcium when potassium was deleted and prevented chlorosis when 4 mili-equivalents of potassium were added. Boynton (1945) observed 2.71% Ca in Portland, and 1.99% Ca in Delaware leaves when potassium was deficient.

Increasing levels of calcium with the advance of the season have been reported by Webster and Cross (1942). Concord leaves increased from .45% Ca in mid-June to 1.05%, and Worden leaves from .48% to .85%. Bergman and Kenworthy (1957) found a seasonal increase of calcium in Concord grape petioles from 1.0% in June to 1.6% in September.

Magnesium: Scott and Scott (1952) drew the attention to differences between varieties in the development of magnesium deficiency symptoms and in their response to spray or soil application treatments. They observed that when no response to magnesium application occurred, no increase in leaf magnesium took place, and associated chlorosis with levels below .18% Mg in leaves. Beyers (1955) described deficiency symptoms as a chlorotic pattern, extending between main veins, well defined with broad zones of pale green

along the margin of the leaf. The chlorotic pale green leaf tissue turned yellow in Waltham Cross (white grape), and red in Berlinka (blue grape). Older leaves, at the base of the plants, were first affected. On James and Scuppernong (Vitis rotundifolia), Lot (1948) observed in August that basal leaf tissue most remote from veins and margin turned pale green/yellow with the primary veins staying green. He associated severe symptoms on James with .09% Mg and on Scuppernong with .06% Mg. Gärtel (1957) described two distinct kinds of leaf symptoms. One occurred in spring when the light green interveinal chlorosis turned to reddish brown on Portuguese grapes (red grape), followed by dropping of the leaf. The other occurred only in fall with yellow interveinal chlorosis. In neither case was linear growth interrupted. Gerber and Bussmann (1955) in Switzerland found that premature fall coloring of leaves was controlled by several applications of 2.0% MgO or $MgSO_4$ sprays where no response had been found to Hoagland trace element solution or $MgSO_4$ soil application. MgO spray was more satisfactory in this case than $MgSO_4$ due to its resistance to rain washing. Larsen et al. (1957) reported no significant increase of magnesium in petioles of Concord grapes treated for five years by $MgSO_4$ soil application.

Hagler and Scott (1949) produced deficiency symptoms in sand culture on Muscadine grapes. Interveinal chlorosis appeared after four weeks on older leaves on the mid-section of the vine. These leaves dropped off later.

Stellwaag (1954) observed that magnesium deficiency symptoms could be found on plants with or without magnesium present. This phenomena more or less depended upon the composition of nutrient solution, e. g. excessive amounts of N and K would render assimilation of magnesium difficult.

Kenworthy (1957) found magnesium deficiency symptoms on Concord leaves where the petiole content was . 09% Mg. Petioles of healthy leaves within the same vineyard had . 21% Mg content. Gärtel (1955) calculated a definite ratio between K_2O and Mg in Riesling grape leaves. Healthy leaves had a content of 3. 91% K_2O and . 08% Mg, or a tratio of 48. 87. Vines with weak symptoms contained 4. 28% K_2O and . 004% Mg, or a ratio of 600. 57. He suggested that the K_2O ratio with potassium deficiency was below 1, whereas with magnesium deficiency the ratio was 30 - 100. Beyers (1955) observed in South Africa that vines treated with $(NH_4)_2SO_4$ had an increased magnesium and reduced potassium uptake, whereas in potassium treated plots, disorders due to potassium induced magnesium deficiency appeared. Larsen (1957), however, found no traces of magnesium deficiency symptoms on Concord vines where 1, 000 pounds of K_2SO_4 per acre were applied 3 years in succession.

Iron: Iron chlorosis in New Mexico was reported on grapes by Crawford (1939). Wann (1941) noted that the high lime content of the Utah soil was interfering with the normal utilization of iron. The chlorosis varied

from year to year, but the damage was most severe during mid-summer periods of high light intensity and high temperatures. Samish (1954) observed in Israel that lime-induced chlorosis caused late foliation, reduced shoot and length growth, poor germination of pollen, and thereby developed "shot" berries (millerandage) on Madeleine Oberlin grapes. In this case, leaf chlorophyll content, degree of pollen germination, and total shoot growth were directly related to the amount of active and total iron within the plant.

Manganese: Maume and Dulac (1952) reported more manganese in young than in old leaves. The greatest variation, however, was found to be due to location and soil. The same variety varied from 2 to 14 mg/100 grams dry matter of leaves in one location to 1.5 to 200 mg in another. Through analysis, Gärtel (1956) established that leaves and petioles were highest, berry skin and seeds lowest, and wood intermediate in manganese content. He also found that the manganese content was specific to soil and not to variety. Beattie and Forshey (1954) observed that manganese deficiency can be expected to occur when the petiole content of Concord grapes in July falls below 30 ppm. Bergman and Kenworthy (1957) reported a 5-fold increase of manganese during the growing season in fields having both high (from 540 ppm to 2, 700 ppm) and low levels (from 68 ppm to 320 ppm).

Löhmis (1951) increased the manganese content in grape leaves grown from cuttings from 620 ppm to 865 ppm when the manganese content of the

solution was changed from 12.5 mg Mn/liter to 50 mg Mn/liter.

Beyers (1955) observed an accentuation of manganese uptake through ammonium sulfate soil application. Ammonium sulfate applied at a rate of 800 pounds per acre increased nitrogen, magnesium and manganese in leaves from 1.62% N, .17% Mg, and 366 ppm Mn to 1.81% N, .19% Mg, and 646 ppm Mn, while potassium was decreased from .92 to .83%.

Beattie (1955) reported both manganese and potassium deficiency symptoms on leaves within the same Concord grape vineyard, but seldom found typical visual symptoms of both. Manganese deficiency appeared first during June-July on the basal leaves of current season shoot growth, and was indicated by the absence of green coloring matter in areas between veins which turned into light yellow green with dark green veination. Kenworthy (1957) found similar symptoms in a Michigan Concord grape vineyard. Applications of KCl and K_2SO_4 did not correct potassium deficiency. While petioles of untreated vines showed .41% K and 11 ppm Mn, vines treated with 300 pounds KCl showed .47% K and 18 ppm Mn, and vines treated with 360 pounds K_2SO_4 had a content of .34% K and 14 ppm Mn.

duPlessis (1948) suggested that mottling of grape leaves in South Africa might be due to excess manganese. However, he did not report any analyses.

Boron: According to Branas (1954), as early as 1894, LeCocq described a disease called "la maromba" on grapes in Portugal, which was later identified as boron deficiency by Dias (1953). Ono et al. (1956) reported from Japan that 20 to 40 pounds of boric acid per acre, or .3 to .5% sprays improved growth, fruit set, bunch weight and yield on grapes having "Ebi" disease.

Scott (1941) found great differences in varietal response to boron. Ontario, Carmen and Delaware varieties showed early season dwarfing and extreme lateral bud growth with no fruit production. Concord, Worden and Niagara were only moderately affected and exhibited chlorotic pattern on leaves, little stunting and low fruit production. Golden Muscat, Fredonia and Portland showed no apparent deficiency. Catawba leaves with deficiency symptoms contained 6 ppm B, as compared to 18 ppm B in healthy leaves. A similar comparison showed 6 ppm and 23 ppm for leaves of Delaware, and 24 ppm and 54 ppm for Ontario leaves. Scott (1944) reported that Concord vines were relatively low in boron, if only 7.4 ppm B could be found, but that the deficiency range was between 10 and 20 ppm as compared to the normal content range of 15 to 30 ppm. Deficient leaves exhibited yellowing between the veins and at the margins; no necrosis or premature defoliation occurred, but the leaf surface was abnormally rough with raised areas between veins. Short internodes and twisted flower clusters with little fruit set were noted.

Wilhelm (1952), Branas and Bernon (1954, 1956) and Gärtel (1954) described the same symptoms. Depending on the severity of boron deficiency and on the variety, the following symptoms have been reported: tip die-back, root die-back, curling of leaves, missing of internodes (double diaphragm) and completely white leaves with brownish spots which can be seen if held against the light. Gärtel (1956) found that Riesling leaves were deficient at 14 ppm B and had necrosis at 10 ppm B with the transition zone being between 13 and 15 ppm.

In sand culture, Meier (1937), Eaton (1944), Scott and Schrader (1947) and Gärtel (1956) produced essentially the same symptoms as found in vineyards. Eaton, by using .04 ppm B in solution, found 38 ppm B in Malaga leaves and 86 ppm in Sultanina leaves, which were fed with the same solution. Scott and Schrader observed water-soaked areas in the apical tendrils. They found 29 to 41 ppm B in stems, and 57 to 146 ppm B in leaves of the same plants with boron in solution, but only 20 to 25 ppm B in leaves where no boron was added to the solution. Gärtel (1956) found 8 ppm B in Riesling leaves when grown without boron, as compared to 38 ppm B when 1 mg boron per liter was added.

Askew (1944) reported a combined case of potassium and boron deficiency from New Zealand. The first symptom found on the leaves was a lightly chlorotic mottling between the main veins which later changed to a reddish-

brown color. At that time the margins of the leaf became scorched and curled upwards and inwards. The berry setting was very irregular and brown tissue appeared in the flesh of the berries. The boron content showed a seasonal fluctuation in the leaves, as well as in the berries. The lowest values were 10.3 ppm B and .32% K_2O in leaves, and 4.4 ppm B and .65% K_2O in berries.

Wilhelm (1952) and Gärtel (1954) described boron toxicity symptoms. The leaves in these cases were cupped up or down with rolled-in margins, the dentation seemed to be lighter brown than the leaf and the margins were torn due to the tension exerted by uneven growth. Leaves which were normally five-lobed developed only into three lobes.

Leaf analysis by Gärtel showed the following results: healthy leaves 28.2 ppm B, weakly damaged 310 to 640 ppm B, and strongly damaged 620 to 852 ppm B.

Copper: Rough and unhealthy looking bark, short canes, severely restricted internodal growth, small, pale, slightly chlorotic leaves, poor roots, adventitious bud development near the soil surface, were symptoms of copper deficiency described by Teakle et al. (1943). Copper deficient Sultana leaves contained, in this case, 2.1 to 5.4 ppm Cu, as compared to 7.5 to 9.9 ppm Cu in healthy leaves, taken in December.

Zinc: "Little Leaf", "Reisigkrankheit", "court-noué", or "Arrici-

amento" are names in various languages for zinc deficiency (Dufrenoy, 1935). Bioletti and Bonnet (1917) described the following zinc deficiency symptoms: the affected leaves showed tendency to curl up and bands or patches of light-colored parenchyma tissue could be found. Furthermore, a gummy secretion in the conducting tissue, flatten canes with average internode length 50% shorter than normal, dark spots on roots, and non-setting of fruit were observed. Essentially the same descriptions were given by Chandler et al. (1933, 1934), Coombe (1949), Clore (1951), and Cook (1957). Coombe, Clore, and Cook mentioned dwarfing of leaves at shoot tips, interveinal yellowish to greyish-green color of leaves, and short shoot growth. Clore (1951) compared the leaf appearance of a zinc deficient plant with one injured by 2, 4-D. Cook associated visual deficiency symptoms on vinifera type grapes with 15 ppm Zn in the leaf.

Molybdenum: Basal leaves showing marginal necrosis developing concentrically from the leaf margin and terminal leaves showing chlorosis were reported as molybdenum deficiency by Bergman and Kenworthy (1956). Petioles of plants grown in nutrient culture, which showed these symptoms contained .2 ppm Mo, as compared to 3.4 ppm Mo in plants treated with molybdenum. The necrosis on basal leaves was described to be the expression of nitrate toxicity inasmuch as molybdenum is essential for the assimilation of nitrates.

Chlorine: While there has been no direct beneficial effect on chlorine reported, Thomas (1934) reported the following toxicity symptoms: premature opening of the buds, small leaves and fruits, defoliation and in extreme cases faulty fruit set, while marginal and interveinal necrosis were symptoms for severe toxicity. Ravikovitch and Bichner (1937) found brown spots all over the leaf blades and yellow tip leaves in addition to the above-mentioned symptoms. Under Palestine conditions described by the afore-mentioned, the NaCl content varied from .04 to 3.35%. Leaves of deteriorated Chasselas had the highest NaCl content, whereas healthy Muscat Hamburg had .15%, while nearly dead ones showed 1.5% NaCl. Woodham (1956) felt that petioles were better for determination of the chloride status than leaf blades. In undrained loam soils of Australia, when there were slight to severe leaf burns present in December, the chloride content was between .8 and 1.9%, and in severe cases values of 2.5% Cl and more were found in January. On healthy sites, no symptoms could be found in the presence of 1.7 to 2.0% Cl. There was always some chloride present where vines were affected, but without any visible symptoms. Dilley (1957a) reported that increasing levels of chloride and sulfate in nutrient culture depressed growth in proportion to the chloride level. The chloride level was in each case directly proportional to the supply in the solution. Increasing levels of chloride increased nitrogen, copper and zinc, but decreased magnesium in the petiole.

Sulfur: Dilley (1957b) and Harding (1957) found sulfur deficiency symptoms on Concord leaves in nutrient culture work by deleting the sulfate ion from the nutrient solution. At first the terminal leaves turned yellow and brownish spots appeared on the surface. These brownish spots later turned into purplish color in both cases. Dilley (1957a) used 192 ppm SO_4 in the solution and found .27% S in the petiole, when the SO_4 concentration was doubled, he found .37% S and .75% S when 624 ppm SO_4 were added.

Chloride vs. Sulfate: Vinet (1935) concluded, after a long-term study of KCl versus K_2SO_4 fertilizer, that the latter was the better source for potassium. High chloride decreased the effectiveness of potassium utilization, while sulfate did not. Shaulis (1954) also recommended potassium sulfate in favor of muriate of potash. Larsen et al. (1957) reported on a four-year field experiment with both fertilizers that fields with severe potassium deficiency recovered faster in the first year with K_2SO_4 but in the long run no significant difference in yield (25 and 26 pounds of grapes per vine) and petiole composition (2.14 and 2.08% K) were found.

EXPERIMENTAL PROCEDURE

The investigations to study the response of Concord grapes (Vitis labrusca) to various levels of essential nutrient elements were conducted in the greenhouse in three separate experiments from January to May, 1956 and 1957.

Experiment I was a study of the effects of high and low levels of eleven nutrient elements on the petiole composition and growth of grape plants.

Experiment II was a study of the influence of increasing levels of calcium and magnesium with constant levels of potassium in the solutions upon petiole composition and growth of grape plants. The manganese-potassium interrelationship was studied in Experiment III.

Experiments II and III were conducted simultaneously.

EXPERIMENT I

EFFECTS OF VARIOUS LEVELS OF 11 NUTRIENT ELEMENTS ON GROWTH, PETIOLE AND STEM COMPOSITION

In order to find the effect of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, copper, zinc, and molybdenum on the growth of Concord grapes, a randomized block experiment using nutrient solutions was established. The experiment contained 25 treatments with three replications of each treatment.

The nutrient solutions for the 25 treatments were obtained by using Hoagland and Arnon (1950) solution as check, and adjusting the solution to provide low and high levels of 11 nutrient elements. For low levels the specific element was completely deleted from the solution for all nutrients except nitrogen. Small quantities of nitrogen were added after four weeks in order to keep the plants alive. For high levels, the specific element was increased in amounts equal to five times their content in Hoagland solution. High levels of potassium and calcium were studied with two solutions--one using sulfate, and the other using chloride as the anion.

Stock solutions were prepared by dissolving C. P. grade chemicals in distilled water, and nutrient solutions were made up as needed by adding the necessary stock solutions to carboys containing 18 liters of distilled water (Appendix Tables 1, 2, 3 and 4).

One-year-old rooted Concord grape cuttings were dug from a nursery bed near Paw Paw, Michigan, on November 12, 1955 and placed in cold storage at 40° F until January 28, 1956, which provided sufficient cold to break dormancy, according to Magoon and Dix (1943).

On January 28, 75 plants were selected for the experiment. The plants were uniformly pruned to two buds and weighed. Due to the variability in weight, it was necessary to make three different weight groups, having average weights of 28, 33 and 41 grams. The 25 plants in each weight group fell within one standard deviation, each group composed a replication. Additional plants representative of each group were selected and used to establish the original dry weight in order to calculate later the total dry weight accumulation.

The rooted cuttings were planted in 12-inch clay pots, which had been painted with asphaltum paint to prevent contact of roots with the pot surface, and reduce evaporation through the sides of the pots. Watch glasses, 4 inches in diameter, were placed in the bottom of the pots to insure proper drainage. Coarse grade quartz sand was used as growth medium.

One greenhouse bench was used per replication. Treatments were assigned at random within each replication. The plants were heavily watered with distilled water during the first weeks and feeding began in the third week. Until the middle of March, the plants were fed three times each week, one

quart of nutrient solution per pot. Thereafter they were fed for one month every other day. From April 1 until termination of the experiment, watering every day was necessary. The plants were given nutrient solution two days in succession, and distilled water the third day.

When the experiment was terminated, the plants were harvested by replications on May 18, 19 and 20. Total linear growth and dry weight accumulation for petioles, leaf blades, stems and roots were established for each plant. Any plant part below the point of pruning at the beginning of the experiment was designated as roots, and the parts above this point, excluding petioles and leaf blades, as stems. The fibrous root particles were obtained by passing the roots through a fine sieve (U. S. 45, 350 microns opening) after drying.

Petioles and stems from each plant were analyzed in the laboratories of the Department of Agricultural Chemistry. Nitrogen was determined by the standard Kjeldahl method, and potassium by flame photometer. Phosphorus, calcium, magnesium, iron, manganese, boron, copper, and zinc were determined spectrographically. Chloride was determined by a modified method of Samson (1953).

RESULTS

DEFICIENCY AND TOXICITY SYMPTOMS OF STEMS AND LEAVES

Under normal conditions a plant seldom shows visual deficiency or toxicity symptoms on leaves, except under extreme stress for one or more elements. In this experiment, deficiency symptoms on leaves were observed for the low level of each of the 11 elements. On the other hand, only four of the 13 high level treatments exhibited leaf symptoms. These symptoms might have been due to toxicity of the individual element, or were characteristic of deficiency symptoms of other elements, induced by the high level of the element being applied in excess.

General Observations: A few of the plants, heaviest in initial weight, produced flowers shortly after initiation of growth. These flowers were removed in order to prevent any drain of nutrients associated with fruit formation.

The plants of the lightest weight group began to grow more rapidly than plants of the other two groups. However, after five weeks all plants were relatively even in growth, and at the termination of the experiment the plants of the heaviest weight group had made most linear growth, if not too severely affected by the various treatments.

Visual deficiency or toxicity symptoms on leaves appeared very slowly, except for the low nitrogen plants on which severe symptoms were present

after 4 weeks of growth. The other treatments produced leaf symptoms in the following chronological order: 5 N and 5 P after 6 weeks; - K and 5 K (SO_4) after 9 weeks; 5 K (Cl) and - Fe after 10 weeks; followed by - Mg, - Mn, - B, and - Cu one week later. - P, - Ca and - Zn had visual symptoms after 12 weeks of growth, and - Mo after 14 weeks. All other treatments did not show visual leaf symptoms, but linear growth and dry weight accumulation were in some cases very severely affected.

Nitrogen: The plants supplied with nutrient solution deficient in nitrogen showed a visible reduction in rate of linear growth after only 3 weeks. Leaves produced during this time showed a healthy green color, but began to put on a light green cast which shortly turned olive and finally yellowish green. At this point, terminal growth stopped completely. Dark brown pinhead like spots appeared on the upper surface of the basal leaves (Figure 1, top). These spots extended through the leaf and were visible on the lower epidermis. At first it was felt that these spots might be due to insect injury or pathogens. Thorough examination by plant pathologist and entomologist, however, ruled out either of these probabilities. On the other hand, only the minus nitrogen plants exhibited this symptom. At this time 42 ppm of nitrogen was being added to the nutrient solution in order to prevent complete starvation. The brown spots disappeared within a short time and the leaf color returned to a light green. Terminal growth began anew and new leaves, not

Figure 1. Top Grape leaf from the base of a nitrogen deficient plant, after three weeks of growth. The pin-head like dark brown spots were observed on the adaxial and abaxial surfaces of the leaves.

Bottom Grape plant supplied with high levels (1050 ppm) of nitrogen in the nutrient solution. The plant grew profusely and produced large, very dark green leaves. The terminals turned chlorotic after 10 weeks of growth.


-N
5N

quite as large as those of the check plants, developed. Some of the basal leaves dropped off later. Most of the leaves on the lower one-third of the shoots were like heavy paper, very stiff in texture. No lateral shoots were formed during the remaining growing season. Final chemical analysis of petioles showed .51% nitrogen, compared to 1.06% N in petioles of the check plants.

Plants supplied with high levels of nitrogen grew profusely and produced large, very dark green leaves. After 10 weeks, young terminal leaves appeared chlorotic (Figure 1, bottom), with each new leaf from then on having the same appearance. Shortly before termination of the experiment, the youngest leaves were very wavy in addition to being chlorotic. A symptom similar to the one described appeared at the same time on potassium deficient plants. Petiole analysis showed 5.19% nitrogen, and 1.57% potassium, which was the lowest potassium content of any treatment except for the low potassium treatment. However, the occurrence of potassium deficiency symptoms on terminal leaves seemed questionable. The possibility of zinc deficiency existed and will be discussed in connection with potassium.

Phosphorus: Plants grown without phosphorus showed no visual symptoms on the leaves for eleven weeks. The linear growth, however, was rather slow and restricted, and ceased completely in the late stage of the experiment. The leaves, in general, were dark green in color and very

heavy or leathery in texture. Actually, the first visual symptom on the leaf was the red coloration of veins on he abaxial side of the basal leaves (Figure 2, bottom left), which was followed by the disappearance of the green pigment from the leaf surface, beginning at the margin and progressing centripetally, as shown in Figure 2 top and bottom right). The affected leaves, however, stayed on the plant and did not drop off. Later petiole analysis showed .10% phosphorus content in petioles of these plants, as compared to .37% in petioles of the checks.

The plants supplied with high levels of phosphorus developed normally in every respect, and very little difference could be observed between these plants and the check plants. After 6 weeks, however, terminal leaves on lateral shoots were slightly chlorotic. This symptom never developed into a specific pattern and a diagnosis based on it would not have been reliable. Petiole analysis did not reveal, for certain, the cause of the chlorosis. Since 1.41% phosphorus and .64% calcium were found in the petiole, a slight case of calcium deficiency could be suspected.

Potassium: After 9 weeks of slow growth, the basal leaves on one plant grown without potassium began to show slight yellow interveinal chlorosis that extended to the leaf margin. The margin of these leaves later turned necrotic. The leaves on the other two plants, however, did not show this symptom but after 11 weeks had some purplish blotches (Figure 3, bottom

Figure 2. Top — Basal portion of a grape plant supplied with phosphorus deficient nutrient solution as observed after 11 weeks of growth.

Bottom left — Abaxial side of a basal leaf showing red coloration of veins, indicative of phosphorus deficiency.

Bottom right — Adaxial side of the same basal leaf.


-P

right) on the adaxial surface of the basal leaves. Tip leaves, in both cases, began to exhibit yellow brownish interveinal chlorosis after 11 weeks, with very wavy margins (Figure 3, top, and bottom left). Stem elongation was nearly at a standstill. All plants had very short internodes and the petioles were strikingly short, as found in vineyards having severe potassium deficiency. Petiole analysis showed a very low .12% potassium content, which combined with 25 ppm zinc, was the lowest content for either element in any treatment. The chlorosis of the terminal leaves could be suspected to be an expression of zinc deficiency.

Two treatments received high levels of potassium, one contained potassium sulfate and the other contained potassium chloride in the solution. Both treatments produced the same visual leaf symptoms. After 9 weeks of growth, the potassium sulfate treatment began to show brown irregular blotches in the interveinal fields of the basal leaves (Figure 4, bottom left). At first, because of very high sulfate content of the nutrient solution (1342 ppm SO_4), sulfate toxicity was expected, but then one week later the same symptoms appeared on the potassium chloride treatments, except the basal leaves were not first affected but rather those of the fourth and fifth internodes (Figure 4, top right). The blotches enlarged quite rapidly, began to join each other, and progressed centrifugally. The veins of these leaves were green at all times and a green margin was always present (Figure 4,

Figure 3. Top — Grape plant supplied with potassium deficient nutrient solution, as observed after 9 weeks of growth: chlorotic leaves at the terminals and purplish blotched leaves at the base.

Bottom right — Adaxial surface of a potassium deficient basal leaf with purplish blotches.

Bottom left — Leaf from terminal portion of a potassium deficient plant. Petiole analysis suggested zinc deficiency.


-K

Figure 4. Top left — Grape plant supplied with high levels (1171 ppm) of potassium sulfate, after 9 weeks of growth.

Top right — Grape plant supplied with high levels (1171 ppm) of potassium chloride, after 10 weeks of growth.

Note the identical symptoms on both plants.

Bottom left — First visual symptoms of nutritional disorder as observed on plants supplied with high levels of potassium with sulfate or chloride. This same symptom also appeared on leaves from the mid-section of plants supplied with magnesium deficient nutrient solution (see Figure 5, top).

Bottom right — The same leaf as on bottom left, a few days later. The veins were green at all times and a green margin was always present. The symptom was identified by petiole analysis as magnesium deficiency.


5 K SO4
5 KCL

bottom right). The brown tissue slowly dried out completely and the affected leaves fell off (Figure 4, top). On the potassium chloride treatment, this symptom spread both acropetally and basipetally. At the same time, similar symptoms appeared on magnesium deficient plants, and therefore both sulfate and chloride toxicity were ruled out in favor of magnesium deficiency. This was later verified by the petiole analysis, inasmuch as both high level potassium treatments had a petiole content of .14% magnesium and a very high potassium content of 9.86% for the potassium sulfate treatment and 8.88% for the potassium chloride treatment.

Magnesium: Plants grown without magnesium developed normally like the check plants and no difference could be seen until the 11th week when the basal leaves began to turn yellow in the interveinal spaces of the adaxial side (Figure 5, bottom). The yellow pigment, however, did not progress to the leaf edge. Figure 5 (top) shows a magnesium deficient plant with two different magnesium deficiency symptoms, one being the yellow interveinal coloring on basal leaves and the other one being like the description of the high potassium symptoms (Figure 4, bottom), which developed simultaneously. Magnesium deficient plants grown with magnesium deficient solution had .06% magnesium in the petiole.

Under high levels of magnesium, no visual leaf symptoms could be observed. The linear growth seemed, however, very much depressed.

Figure 5. Top Grape plant supplied with magnesium deficient nutrient solution, after 11 weeks of growth. Two distinct leaf symptoms appeared simultaneously, one at the base and the other at the mid-section of the plant. The symptom on the mid-section leaf was the same as observed on plants supplied with high levels of potassium (see Figure 4, bottom).

Bottom Magnesium deficient leaf with yellow interveinal chlorosis from the basal part of the plant.


-Mg

Calcium: The appearance of calcium deficiency symptoms on plants grown without calcium was actually expected to occur much sooner. The plants seemed to do well up to the 11th week, at which time the distillation apparatus broke down. During repair, a heavy deposit of calcium was removed from its inner walls. Within one week, a different appearance of the youngest leaves at the terminal could be observed. Whereas normal grape leaves have an equally lobed base, the new leaves had a cordate-oblong base. Also, the normally shallow toothed margins were in this case prominently toothed and the whole leaf had a rather oblong form. Soon these young leaves turned yellow and blackening of veins on the abaxial side of the leaf could be observed, as shown in Figure 6 (bottom left). Simultaneously, large water-soaked areas in the apical portions of the tendrils appeared which led to the dieback of the tendril at first, followed by dieback of the whole terminal portion of the shoot to the next internode (Figure 6, top right). Growth of the axillary buds (Figure 6, bottom right) at these immediate internodes was brought about by the dieback. By now, older leaves exhibited interveinal chlorosis combined with curling under the leaf blade, giving it a beak-like appearance, and all terminals, regardless of their location, began to break down (Figure 6, top right). Ultimately, the oldest portion of the stems became pitted in appearance, looking similar to severe hail damage caused by very fine hail stones (Figure 6, bottom right). The calcium content of these petioles was .26%.

Figure 6	Top left	Grape plant supplied with calcium deficient nutrient solution in the breakdown stage. The plant was very severely damaged, with all terminal portions showing die-back.
	Top right	Terminal portion of a calcium deficient grape. Note the beak-like appearance of the leaf, the withering tendrils, and the development of axillary buds.
	Bottom left	Blackening of the veins on the abaxial side and yellowing of the leaf, an early indication of calcium deficiency.
	Bottom right	Growth of an axillary bud brought about by die-back of terminal portions. Note the pitting of the stem and developing of double-bud.


-Ca
-Ca

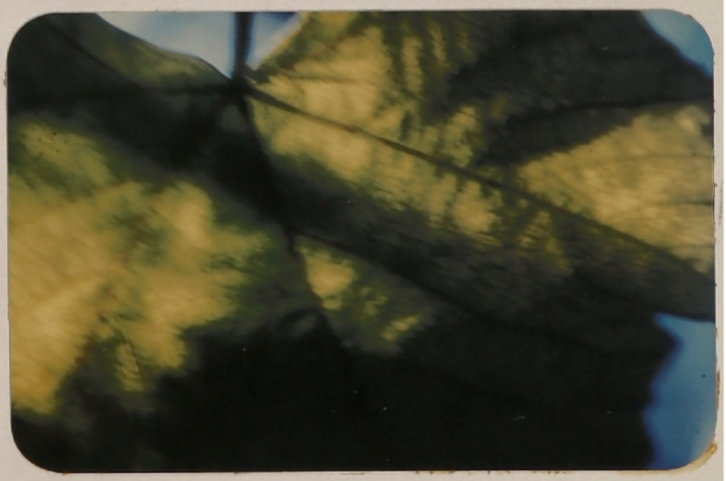
High levels of calcium were tested with two different nutrient solutions, one having sulfate and the other having chloride as the anion carrier of calcium. On neither treatment were visual leaf deficiency or toxicity symptoms observed. Actually, severe chloride injury was expected where calcium chloride was used because of the presence of 1418 ppm/liter of chloride, but only a severe depression in linear growth occurred. The calcium content of petioles from plants treated with calcium sulfate was .96% Ca compared to 2.55% ca in petioles of plants treated with calcium chloride.

Iron: Plants grown with low levels of iron produced slightly chlorotic leaves at the apical portions of the main stems and young shoots after ten weeks of growth. The symptom was, however, never pronounced enough to be considered of importance. The same held true for plants treated with high levels of iron, in which case only linear growth was depressed.

Manganese: After 11 weeks of growth, plants grown without manganese in the nutrient solution began to show light green color in the interveinal fields of young apical leaves of both main and lateral shoots. The veins themselves, however, never lost their normal green color (Figure 7, bottom left). Petioles of manganese deficient plants had only an 18 ppm manganese content compared to 63 ppm in the check.

The high level manganese plants grew like normal plants without any signs of variation. The petiole analysis in this case revealed 363 ppm Mn,

Figure 7	Top left	Terminal portion of a grape plant supplied with boron deficient nutrient solution, after 11 weeks of growth. The internodes were very short and the terminal appeared stunted. The tendrils showed water-soaked spots.
	Top right	Tendril of the same plant showing water-soaked spots, the beginning of breakdown and an early indication of severe boron deficiency.
	Bottom left	Young terminal of a grape plant supplied with manganese deficient nutrient solution, after 11 weeks of growth.
	Bottom right	Older leaf from boron deficient plant as observed from the abaxial side against sunlight.



which is nearly equal to a normal field sample content and it is, therefore, easily understandable why no symptoms occurred.

Boron: Plants grown without boron made a stunted appearance after 11 weeks of growth (Figure 7, top left). The terminal leaves were yellow and very stiff in texture. While with calcium deficiency these leaves turned from green to yellow, boron deficient leaves differed by being yellow from the time they unfolded. No blackening of the veins occurred at any time with boron deficiency, but as it was with the case of calcium deficiency, water-soaked spots appeared in the tendrils, as shown in Figure 7 (top right). The older yellow leaves seemed to be rather thin, and if held against strong sunlight, the veins appeared reddish and the impression arose that light could be seen through the leaf (Figure 7, bottom right). Later on, irregular yellow-brownish areas formed on the surface of these leaves. The petioles of these leaves contained 14 ppm boron.

No visual symptoms from the high level of boron were observed on any of the plants receiving that treatment.

Copper: Young unfolding leaves of Concord grapes have a purplish-reddish tinge, which disappears as soon as the leaves produce chlorophyll. Plants grown without copper behaved the same for about 11 weeks, at which time the young leaves retained this reddish tinge, rather than losing it. These leaves were very fine in texture and the lateral shoots that developed were

spindly (Figure 8, top left). As the leaves became older the reddish tinge changed into a golden color with the veins turning green color, as shown in Figure 8 (bottom left).

No visual expression of the high level of copper was observed on plants receiving that treatment.

Zinc: Leaf symptoms of zinc deficiency became visible after 12 weeks of growth without a supply of zinc. At first, the young terminal leaves showed a yellow-brownish interveinal chlorosis. The internodal growth slowed down considerably, and the entire expression of the terminal leaves changed. Normal Concord leaves have an equally lobed base and pinnate veins. In this case, however, the base changed to acute and the veins were palmate. Also, the normal shallow-toothed margins became prominently toothed and very wavy. Both the terminal and the lateral lobe apex grew acuminately instead of acute and the lateral sinus, which is normally obscure and sometimes notched, became deeply notched, as shown in Figure 8 (top and bottom right).

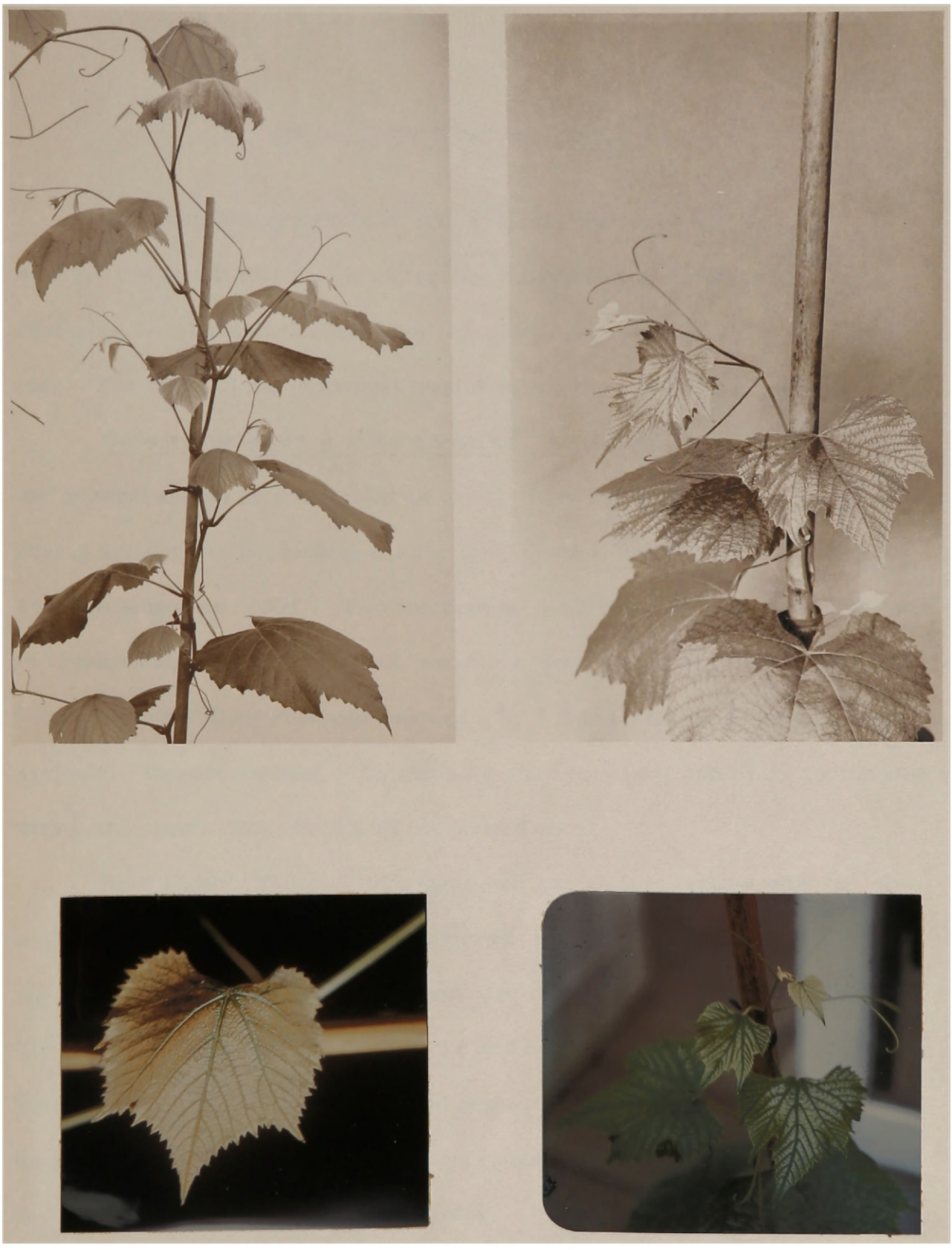
The high level of zinc produced no visual symptoms on the plants.

Molybdenum: Plants grown without molybdenum developed normally and only after 14 weeks some slightly chlorotic terminal leaves appeared. The chlorosis was expressed by yellow-brownish areas on the leaf surface. Only one plant produced necrotic margins on a few basal leaves. Both symptoms were not as distinctly expressed as described by Bergman and Kenworthy (1956).

The high level of molybdenum produced very healthy looking plants with large leaves and no ill effects were observed.

Figure 8.

Top left	Mid-section of a grape plant supplied with copper deficient nutrient solution, after 11 weeks of growth. Note the spindly appearance of shoots.
Top right	Terminal portion of grape supplied with zinc deficient nutrient solution.
Bottom left	Grape leaf showing copper deficiency symptoms. The leaves were golden colored, but veins remained green.
Bottom right	Terminal portion of a zinc deficient grape plant with wavy leaves showing yellow-brownish interveinal chlorosis, deep notched sinuses, and prominent apex lobes.



VISUAL SYMPTOMS ON ROOTS

The general appearance of root systems varied greatly between treatments. It was felt that the check treatment produced roots and a root system desirable for plants of this age and, therefore, served as a basis for comparison. The effect of the individual treatments on the roots is shown in Table 1.

General Appearance of Root System: Amount of roots, color, texture and general appearance was used as index. It was possible that treatments having small roots but looking healthy were given a "good". Of 25 treatments, 14 were judged as "good". Two treatments, - Ca and 5 Fe, had very poor, and two treatments 5 P and 5 Mo, had "excellent" root systems. 5 N, - P and - Fe produced rather poor root systems and - N, 5 B and 5 Cu produced very good systems. Two treatments, - Ca and 5 Fe, had very poor appearing root systems with brittle roots interwoven with many dead ones.

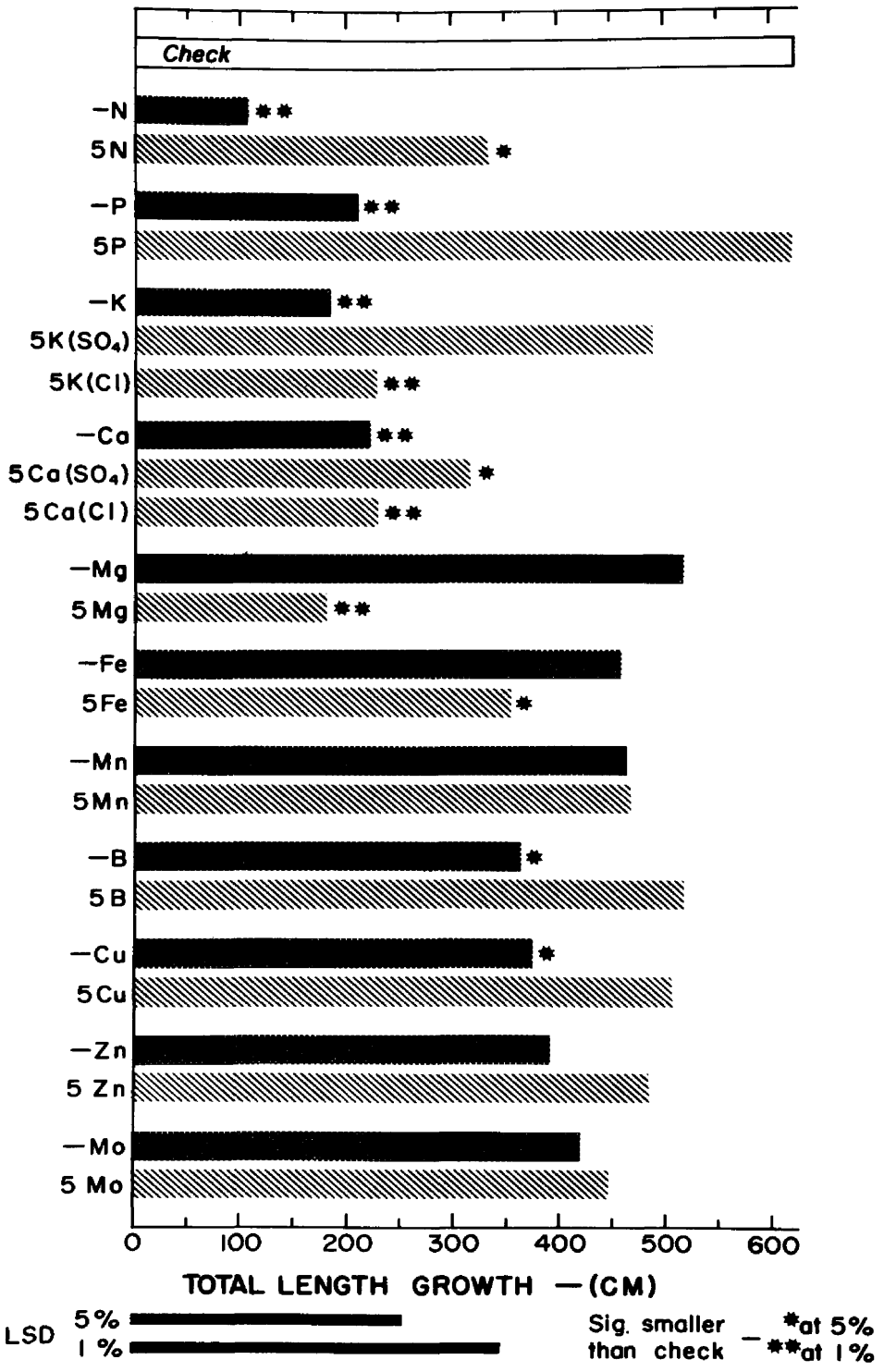
Root Color: The general appearance was closely related with the color of the roots. While most roots were brown, it seemed that with progressive higher ratings of the whole root system, the color of the roots became lighter. The two "excellent" root systems of 5 P and 5 Mo, as well as - Mo and 5 B, which were judged good and very good respectively, were light brown. On the other hand, - Ca and 5 Fe treatments produced black roots. The roots of - P and 5 Ca (Cl) were of reddish color.

TABLE 1

VISUAL EFFECT OF INDIVIDUAL TREATMENTS ON ROOTS

Treatment	General Appearance of Root System	Color of Roots	Remarks
Check	Good	Brown	Basis for comparison (Standard)
- N	Very good	Brown	Many fibrous roots
5 N	Poor	Brown	Few roots, many dead
- P	Poor	Reddish	Small roots
5 P	Excellent	Light brown	
- K	Poor	Brown	Very few roots
5 K (SO_4)	Good	Brown	Springy roots, some dead
5 K (Cl)	Good	Brown	Spring roots, many fibrous
- Ca	Very poor	Black	Very brittle roots, some dead
5 Ca(SO_4)	Good	Brown	Compact system with many fibrous roots
5 Ca (Cl)	Good	Reddish	Not too many roots but very thin
- Mg	Good	Brown	Small root system
5 Mg	Good	Brown	Very large system of wiry roots
- Fe	Poor	Black	Some roots with white tips
5 Fe	Very poor	Brown	Very brittle and many dead roots
- Mn	Good	Brown	
5 Mn	Good	Brown	Some roots with white tips
- B	Good	Brown	
5 B	Very good	Light brown	Small root system
- Cu	Good	Brown	
5 Cu	Very good	Brown	
- Zn	Good	Brown	Brittle roots
5 Zn	Good	Brown	Compact system with many fibrous roots
- Mo	Good	Light brown	
5 Mo	Excellent	Light brown	Very large compact system

Texture of Roots: On a few treatments some deviation in the texture of roots from the normal appearance was observed. - Ca, 5 Fe and - Zn roots seemed to be brittle, while roots of the two high potassium treatments were rather springy, and the 5 Mg roots were wiry.


Check
−N
5N
−P
5P
−K
5K(SO4)
5K(Cl)
−Ca
5Ca(SO4)
5Ca(Cl)
−Mg
5Mg
−Fe
5Fe
−Mn
5Mn
−B
5B
−Cu
5Cu
−Zn
5 Zn
−Mo
5 Mo
0
100
200
300
400
500
600
TOTAL LENGTH GROWTH — (CM)
LSD 5%
1 %
Sig. smaller than check — *at 5% **at 1%

GROWTH

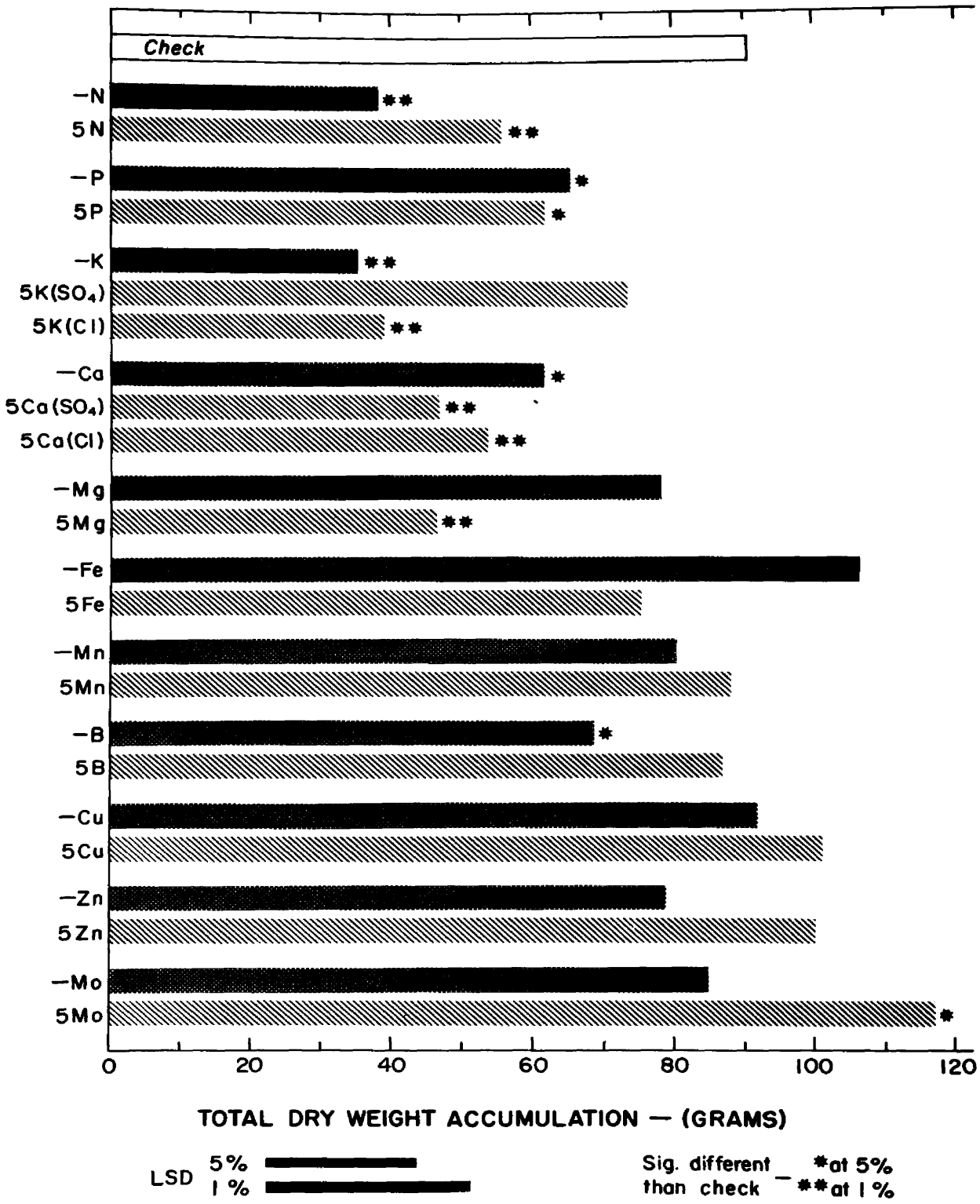
Data pertaining to total linear length growth, as well as total dry weight accumulation of roots, stems, petioles, and leaf blades are given in Appendix Table 5. Dry weight accumulation of roots, stems, petioles, and leaf blades, converted into per cent of total dry weight accumulation and shoot/root ratios are recorded in Appendix Table 6.

Total Linear Growth (see figure opposite)

The check treatment produced the greatest amount of linear growth (625 cm) and as may have been expected, the - N treatment produced least linear growth (109 cm).

When the check was compared statistically with the individual treatments, 5 N, 5 $Ca(SO_4)$, 5 Fe, - B and - Cu were significantly smaller at the 5% level and - N, - P, - K, 5 K (Cl), - Ca, 5 Ca (Cl) and 5 Mg were smaller at the 1% level.

There was a general tendency for the high level of the nutrients to result in less reduction of growth than the low level. This tendency was not found for magnesium, iron, and manganese. However, there were but few instances where there was a significant difference between the low and high level of a nutrient. The - P treatment produced significantly less linear growth than 5 P. The high level of magnesium produced significantly less


Check
−N
5N
−P
5P
−K
5K(SO4)
5K(Cl)
−Ca
5Ca(SO4)
5Ca(Cl)
−Mg
5Mg
−Fe
5Fe
−Mn
5Mn
−B
5B
−Cu
5Cu
−Zn
5Zn
−Mo
5Mo
0
20
40
60
80
100
120
TOTAL DRY WEIGHT ACCUMULATION — (GRAMS)
LSD 5%
1%
Sig. different than check
*at 5%
**at 1%

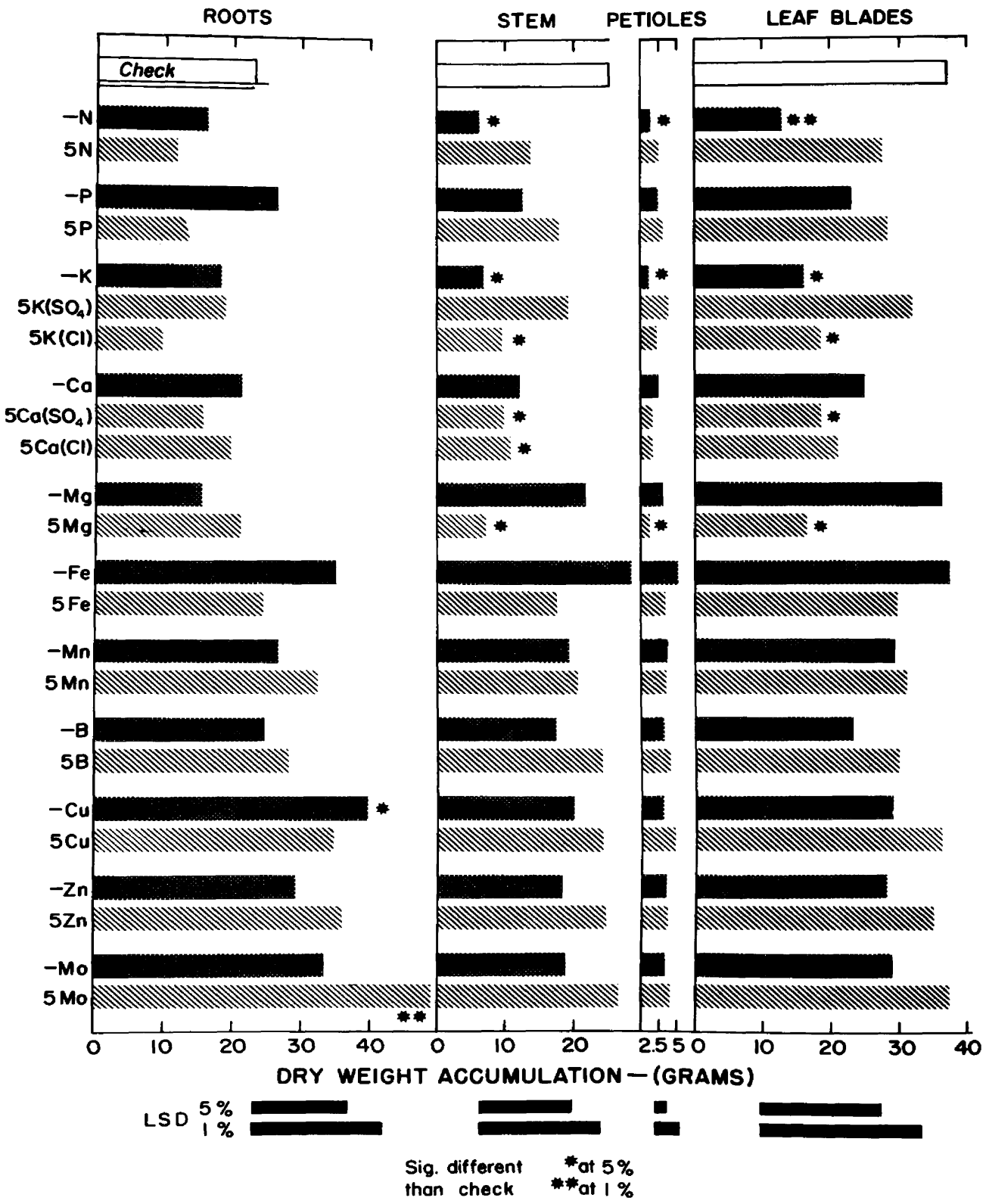
linear growth than - Mg. Both - K and 5 K (Cl) produced less growth than 5 K (SO_4).

Total Dry Weight Accumulation (see figure opposite)

The 25 treatments produced a large variation in total dry weight accumulation. The - K treatment resulted in the least production of dry matter (35.45 g). The high level of Mo produced the greatest amount of dry matter (117.75 g), while the check treatment produced 90.70 g of dry matter.

When the check was compared statistically with the individual treatments, only 5 Mo was significantly higher at the 5% level. The - P and - B treatments were lower than the check at the same level of significance. A 1% level of significant difference was found for - N, 5 N, 5 P, - K, 5 K (Cl), - Ca, 5 Ca (Cl), and 5 Mg. The 5 K (SO_4), - Mg, - Fe, 5 Fe, - Mn, 5 Mn, 5 B, - Cu, 5 Cu, - Zn, 5 Zn, and - Mo treatments did not differ significantly from the check. However, all treatments except - Fe, - Cu, 5 Cu, and 5 Zn were significantly below 5 Mo in the production of dry matter.

High and low levels of magnesium, iron, and molybdenum were significantly different from each other. There was a significant difference between the 5 K treatment using sulfate and the 5 K treatment using chloride, also between the 5 K treatment using sulfate and the - K treatment. No significant difference was found between the - K treatment and the 5 K treatment using chloride.


ROOTS
STEM
PETIOLES
LEAF BLADES
Check
−N
5N
−P
5P
−K
5K(SO4)
5K(Cl)
−Ca
5Ca(SO4)
5Ca(Cl)
−Mg
5Mg
−Fe
5Fe
−Mn
5Mn
−B
5B
−Cu
5Cu
−Zn
5Zn
−Mo
5Mo
0 10 20 30 40
0 10 20
2.5 5
0 10 20 30 40
DRY WEIGHT ACCUMULATION — (GRAMS)
LSD 5%
1%
Sig. different than check
*at 5%
**at 1%

Dry Weight Accumulation by Roots, Stems, Petioles and Leaf Blades (see figure opposite)

Roots: The 5 K (Cl) treatment produced the least root dry weight (9.85 g), with the check being in the middle (23.65 g) and 5 Mo producing most root dry weight (49.35 g).

When the check was compared statistically with individual treatments, only - Cu and 5 Mo were significantly higher, the former at the 5% level and the latter at the 1% level. None of the treatments produced significantly less root growth than the check treatment.

Comparing the low and high levels of the same element, only the low level of molybdenum was significantly below its high level in root growth. A comparison of root dry weight for the various nutrient element levels showed that there was a general trend for the major elements to produce less root growth at both the low and high levels than the check treatment. An opposite trend was observed for the minor elements--both low and high levels resulted in greater root growth than the check treatment. An exception to this trend was found for phosphorus where there was less root growth with each increment in the phosphorus supply.

Stems: The - K treatment produced least stem dry weight (7 g), - Fe most (28.75 g), and the check 25.6 g.

A comparison of the dry weight accumulation of stems for the various levels of a nutrient element showed a general trend for growth to be reduced by both low and high levels of each element. An exception was found for molybdenum where each increment in supply resulted in additional stem growth, whereas each increment of iron resulted in additional decrease in stem growth.

The following treatments were significantly lower (5%) than the check: - N, - K, 5 K (Cl), 5 Ca (SO_4), 5 Ca (Cl), and 5 Mg. Whereas, the 5 K (Cl) treatment produced significantly less stem growth than the check treatment, there was no significant reduction with the 5 K (SO_4) treatment. No treatment, however, was significantly larger than the check. Also none of the minor element treatments resulted in significantly less stem growth than was found for the check treatment. The low level of magnesium resulted in significantly more stem growth than the high level of magnesium.

Petioles: The - K treatment produced least petiole dry weight (1.1 g), - Fe most (5.11 g), and the check 4.3 g.

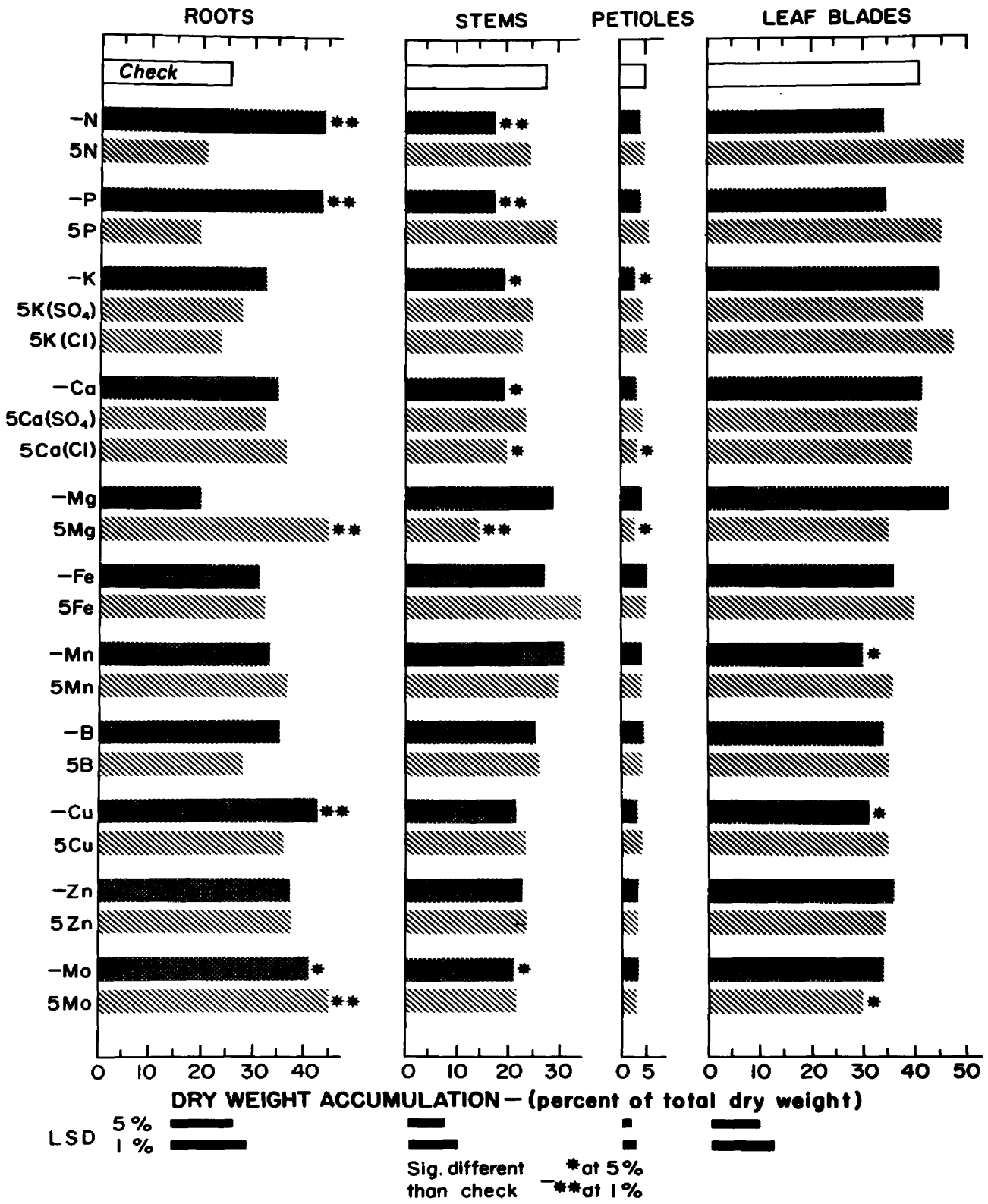
The same general trend as observed for stem dry weight was also present in petiole growth. Nine of 11 elements produced less petiole growth at both the low and high levels than the check treatment. With iron, there was a decrease in dry weight of petioles with increase in each increment in supply, whereas with each increment in the supply of copper there was an increase in petiole growth.

When the check was compared statistically with individual treatments, no treatment was significantly higher and only the - N, - K, and 5 Mg treatments were lower than the check. The 5 K (SO_4) treatment resulted in significantly more petiole growth than the - K treatment. The 5 Mg treatment produced less petiole growth than the - Mg treatment.

Leaf Blades: The - N treatment produced the smallest amount of leaf growth (13.2 g), and - Fe, 5 Mo, and the check, in descending order, had the largest amount of leaf growth (37.65, 37.50 and 37.15 g respectively).

The same general trend observed for the stem and petiole dry weight accumulation was found for leaf growth. Nine of 11 elements produced less leaf growth at both the low and high levels than found for the check treatment. Increasing levels of iron again decreased leaf dry weight and increasing levels of molybdenum increased it.

No statistical differences could be found between any minor element treatment and the check. The - N, - K, 5 K (Cl), 5 Ca (SO_4), and 5 Mg treatments resulted in significantly less leaf growth than the check treatment. The 5 K (SO_4) treatment did not result in a significant reduction of leaf growth. The 5 Mg treatment produced significantly less leaf growth than the - Mg treatment.


ROOTS
STEMS
PETIOLES
LEAF BLADES
Check
-N
5N
-P
5P
-K
5K(SO4)
5K(Cl)
-Ca
5Ca(SO4)
5Ca(Cl)
-Mg
5Mg
-Fe
5Fe
-Mn
5Mn
-B
5B
-Cu
5Cu
-Zn
5Zn
-Mo
5Mo
0 10 20 30 40
0 10 20 30
0 5
0 10 20 30 40 50
DRY WEIGHT ACCUMULATION — (percent of total dry weight)
LSD 5 %
1 %
Sig. different than check
*at 5%
**at 1%

Accumulation of Dry Weight Expressed in Per Cent of Total Dry Weight by Roots, Stems, Petioles, and Leaf Blades (see figure opposite)

A comparison of dry weight accumulation of the individual plant parts made it possible to evaluate the effect of the treatments upon roots, stems, petioles and leaf blades. By converting these values into per cent of the total dry weight accumulated by a plant, the influence of the treatments on specific plant parts in relation to the entire plant was demonstrated.

Roots: The roots were 26.29% of the total dry weight produced with the check treatment. No treatment had a significantly lower percentage of roots than the check. The - N, - P, - Cu, 5 Mg, - Mo, and 5 Mo treatments had a significantly larger percentage of roots than the check.

By comparing high and low levels of the individual elements, only nitrogen, phosphorus, and magnesium treatments were different statistically. The - N, - P, and 5 Mg treatments were larger at the 1% level than 5 N, 5 P and - Mg respectively. With increasing nitrogen and phosphorus, or decreasing magnesium in the solution, the percentage of roots decreased. A greater percentage of roots was produced in both low and high levels of all other elements than found for the check treatment.

Stems: No treatment was significantly larger in percentage of stem growth than the check. The - N, - P, - K, - Ca, 5 Ca(Cl), 5 Mg, and - Mo were smaller in percentage of stem growth than the check. By comparing

high and low levels of specific elements, the - P treatment had significantly less stem growth than the 5 P treatment, while the - Mg treatment had significantly less than the 5 Mg treatment.

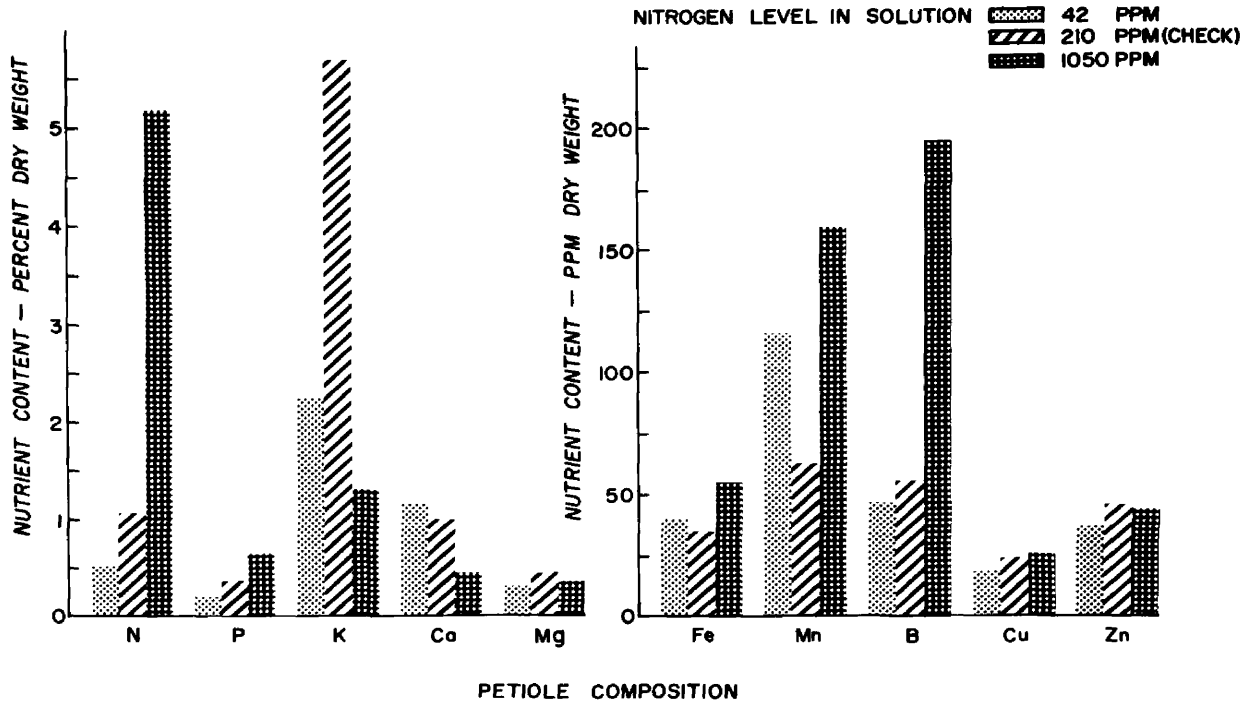
Petioles: Three treatments, - K, 5 Ca (Cl), and 5 Mg were significantly smaller in percentage of petioles than the check, but no treatment was larger than the check. The - K treatment had significantly less percentage of petiole growth than the 5 K (SO_4) and the 5 K (Cl) treatments. Also 5 Mg had significantly less percentage of petiole growth than the - Mg treatment.

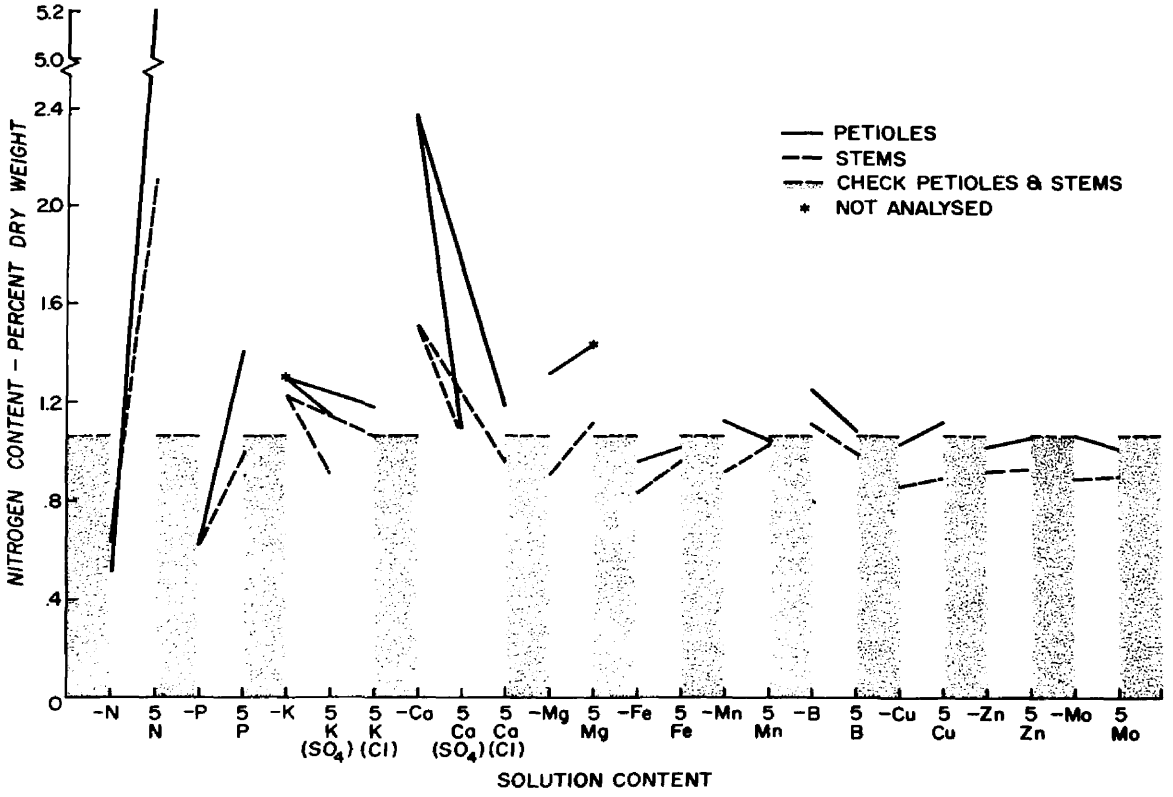
Leaf Blades: The most pronounced effect of any treatment was expressed by 5 N, which produced 30% more leaf blades than - N. While 5 N was the only treatment having significantly more leaf growth on percentage basis than the check, - Mn, - Cu, and 5 Mo had significantly less than the check. By comparing high and low levels of specific elements, - P and 5 Mg had less leaf growth on a percentage basis than 5 P and - Mg respectively.

Shoot/Root Ratio: By adding the dry weight of the above-ground parts, and dividing them by the root dry weight, the following shoot/root ratios were established:

Treatments	Ratio
5 P, - Mg	3.9
5 N	3.7
5 K (Cl)	3.1
Check	2.8
5 K (SO_4)	2.6
- Fe	2.2
- K, 5 Ca(SO_4), 5 Fe	2.1
5 B	1.9
- B, - Ca	1.8
5 Ca (Cl), - Mn, 5 Mn, 5 Cu, - Zn	1.7
5 Zn	1.6
- Mo	1.4
- N, - P, - Cu, 5 Mo	1.3
5 Mg	1.2

Increasing levels of nitrogen, phosphorus and potassium and decreasing levels of magnesium in the solution also increased the shoot/root ratio. Otherwise, the high and low levels of calcium and all minor elements produced lower shoot/root ratios than the check.


NITROGEN LEVEL IN SOLUTION
42 PPM
210 PPM(CHECK)
1050 PPM
NUTRIENT CONTENT – PERCENT DRY WEIGHT
NUTRIENT CONTENT – PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION


PETIOLES
STEMS
CHECK PETIOLES & STEMS
NOT ANALYSED
NITROGEN CONTENT – PERCENT DRY WEIGHT
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

NUTRIENT ELEMENT COMPOSITION OF PETIOLES AND STEMS

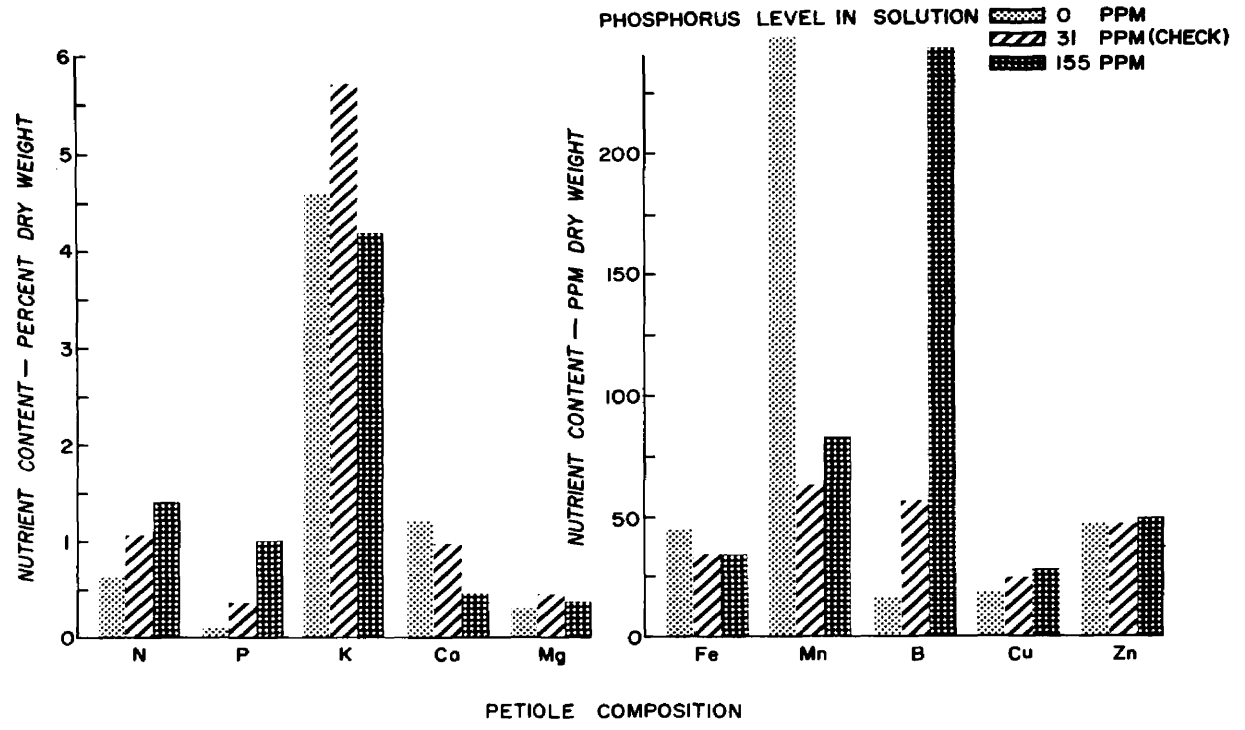
Data pertaining to the petiole and stem composition for plants treated with the various nutrient solutions are given in Appendix Tables 7 and 8. These tables and the following graphic illustrations and discussion show the effect on petiole composition when one specific element was varied and all other elements kept at a constant level, as represented in the check treatment and the influence of varying the supply of different elements upon petiole composition of a specific element.

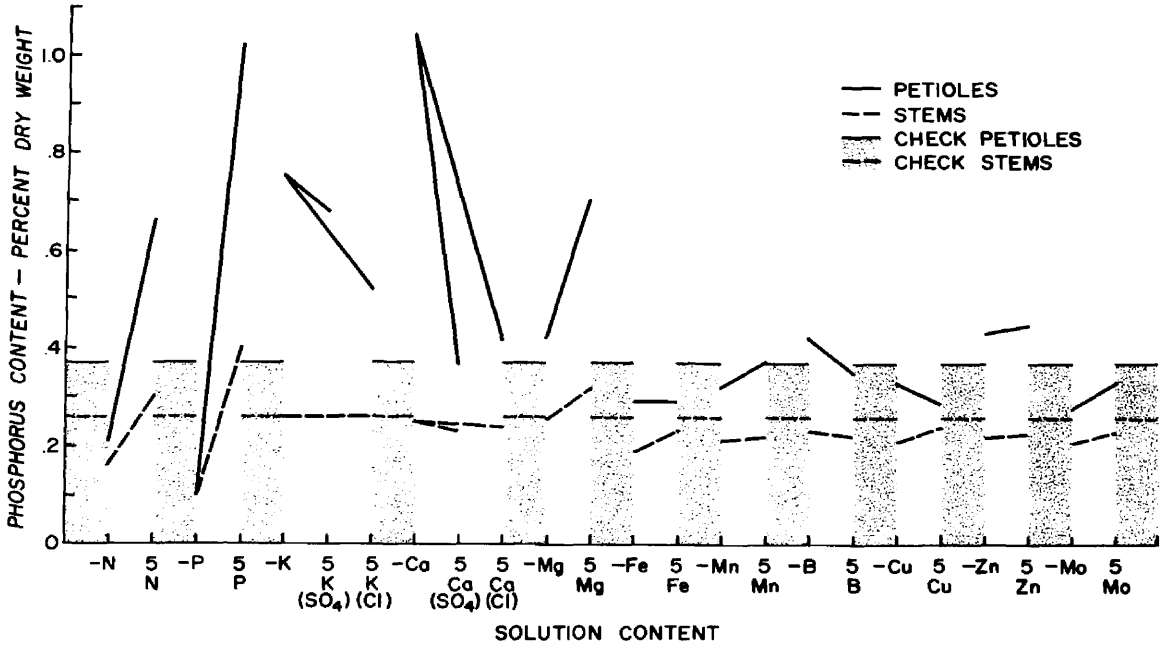
Nitrogen (see figure opposite)

With increasing levels of nitrogen in the solution (42, 210 - check, and 1050 ppm) nitrogen, phosphorus, boron and copper concentration of the petioles increased and calcium content of the petioles decreased. Potassium, magnesium and zinc were found to be highest with 210 ppm nitrogen, but decreased with either increased or decreased levels of nitrogen in the solution. Iron and manganese, on the other hand, showed an inverse relationship and increased with either increased or decreased nitrogen levels, and were lowest with 210 ppm nitrogen in the solution. A five fold increase of nitrogen in the solution increased the petiole nitrogen five times that of the check treatment, doubled phosphorus, tripled boron and raised manganese from 63 ppm for the check treatment to 159 ppm. At the same time, potassium was

decreased 60% and calcium 50% by increasing nitrogen to 5 N.

The lower graph shows that nitrogen in the solution had the largest effect on nitrogen in stem and petioles. Although the nitrogen content was lower in the petioles than in the stems of the - N treatment, both stem and petiole nitrogen content were nearly alike with 210 ppm nitrogen in the solution. The 5 N treatment showed 3% more actual nitrogen in the petioles than in the stems. In the - P treatment, nitrogen in petioles and stems was also very low and increased with increasing phosphorus in the solution. The only other treatment which seemed to significantly affect nitrogen was - Ca, where both stem and petiole nitrogen were very high. An increase in the supply of potassium and boron seemed to reduce the amount of nitrogen in both stem and petioles. An increase in the magnesium and iron supply appeared to increase nitrogen in both stem and petioles.


PHOSPHORUS LEVEL IN SOLUTION
0 PPM
31 PPM (CHECK)
155 PPM
NUTRIENT CONTENT — PERCENT DRY WEIGHT
NUTRIENT CONTENT — PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION


PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
PHOSPHORUS CONTENT — PERCENT DRY WEIGHT
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

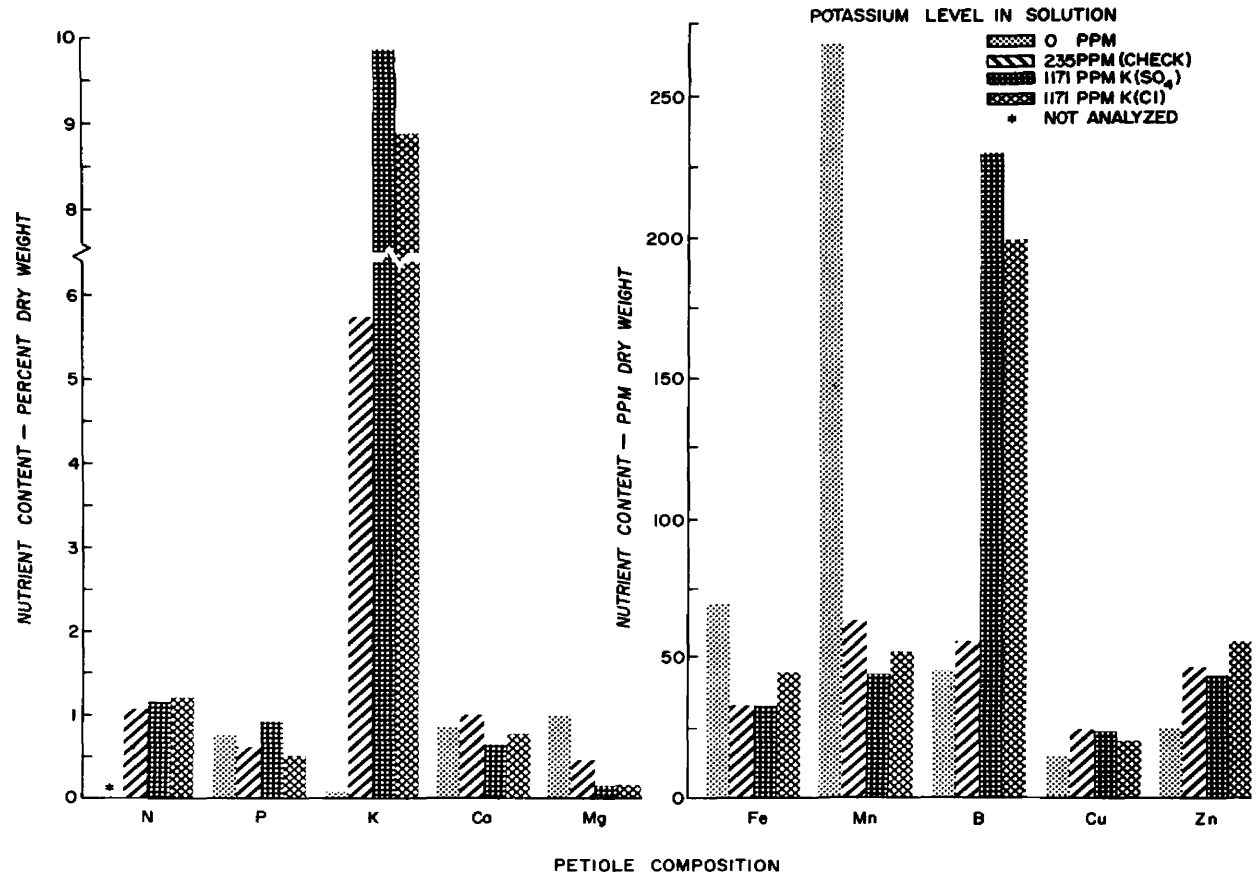
Phosphorus (see figure opposite)

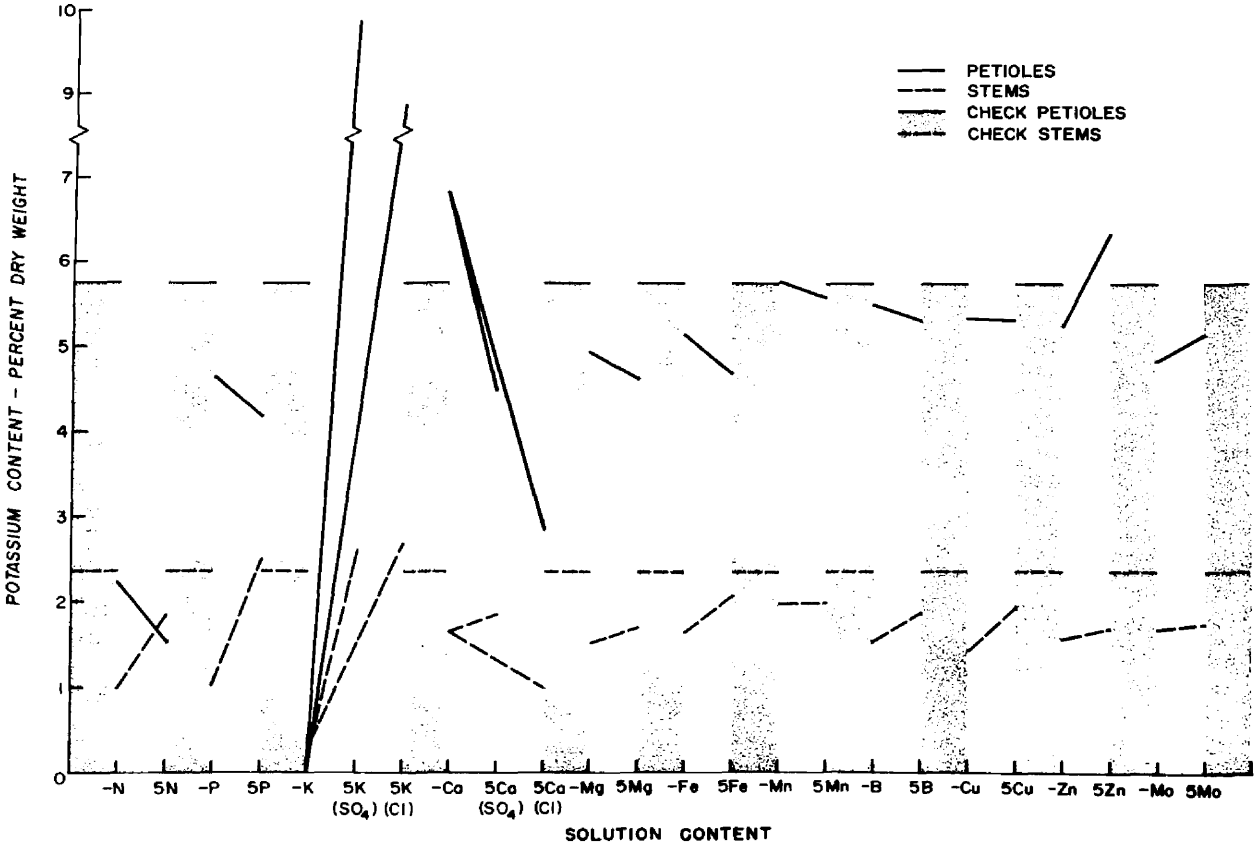
An increase in the supply of phosphorus in the solution (0, 31 - check, and 155 ppm), increased the amount of phosphorus, nitrogen, boron, and copper in the petioles and decreased the calcium content. Both potassium and magnesium were highest with 31 ppm phosphorus in the solution, but both decreased with either increased or decreased levels. Manganese showed a reverse relationship with 31 ppm of phosphorus in the solution resulting in the lowest manganese content.

When phosphorus in the solution was increased to five times the control, the phosphorus content of the petioles was raised three fold and boron four fold that found in the control treatment, but calcium was decreased to 50% of the check. Manganese was most severely affected when the solution phosphorus was increased from 0 to 31 ppm. In this case, manganese in the petioles was lowered from 247 to 63 ppm.

A comparison of stem and petiole composition is shown in the lower graph. The stem phosphorus content was a little higher than the petiole content with 0 phosphorus in the solution. Here again, visual deficiency symptoms were found. The difference between stem and petiole content became larger with increasing phosphorus in the solution. At the 31 ppm phosphorus level, it compared .26 and .37%, and at the 5 P level .40 and 1.02% with the petioles being higher in both cases.

Considerable influence on phosphorus content in the petioles was exerted by the following treatments: 5 N, the three K treatments, - Ca and 5 Mg. In all cases, the petiole phosphorus content was significantly higher than that found for the check treatment. The - N treatment had a phosphorus petiole content that was significantly lower than the one found in the check treatment. The stem phosphorus content was not significantly different from the check for any of the treatments.


POTASSIUM LEVEL IN SOLUTION
0 PPM
235PPM (CHECK)
1171 PPM K(SO4)
1171 PPM K(Cl)
* NOT ANALYZED
NUTRIENT CONTENT — PERCENT DRY WEIGHT
NUTRIENT CONTENT — PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION


PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
POTASSIUM CONTENT - PERCENT DRY WEIGHT
-N
5N
-P
5P
-K
5K (SO4)
5K (Cl)
-Ca
5Ca (SO4)
5Ca (Cl)
-Mg
5Mg
-Fe
5Fe
-Mn
5Mn
-B
5B
-Cu
5Cu
-Zn
5Zn
-Mo
5Mo
SOLUTION CONTENT

Potassium (see figure opposite)

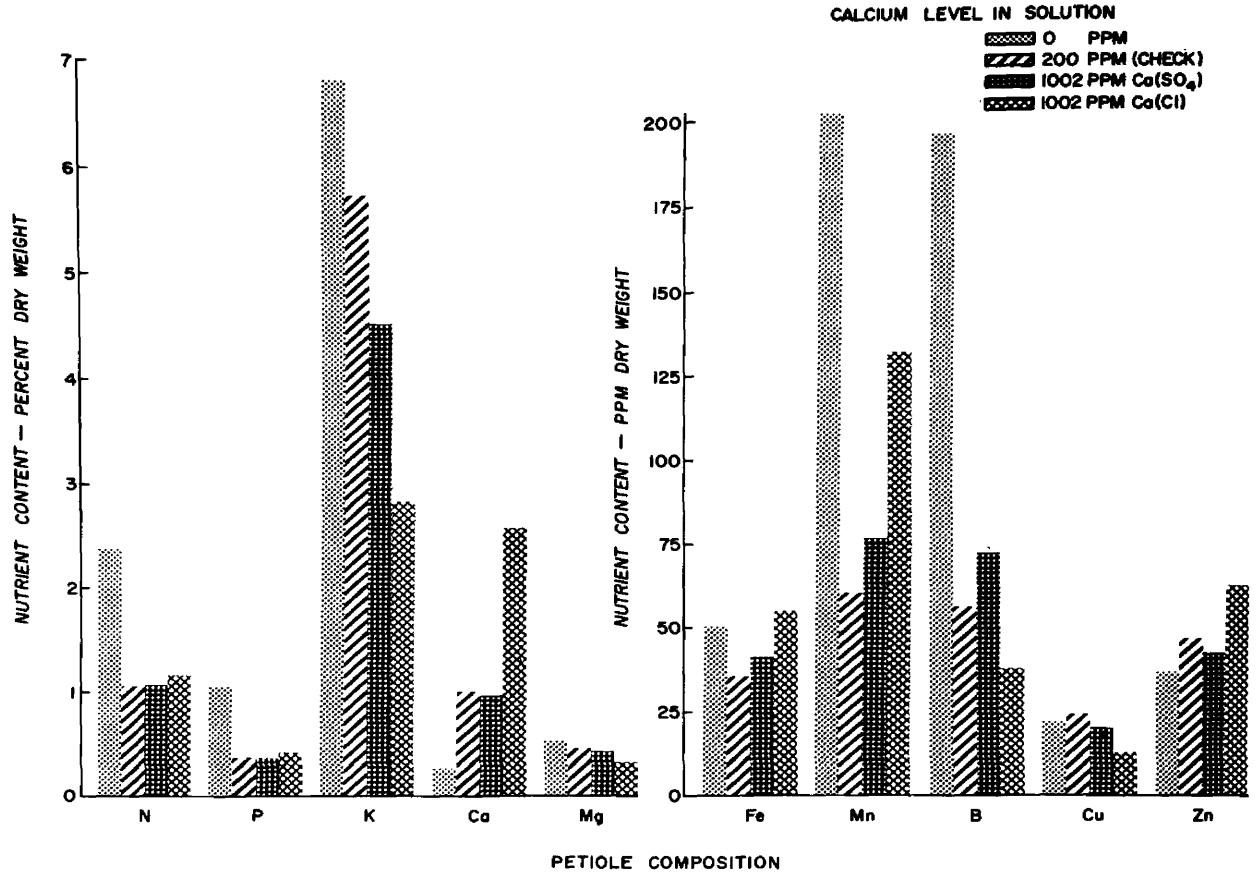
Increasing the level of potassium in the nutrient solution (0, 234 - check, 1171 ppm) increased the potassium, boron, and zinc content of the petioles, but decreased magnesium and manganese. The high level of potassium was tested with both sulfate and chloride as anions. With potassium sulfate, 1% more actual potassium was found in the petioles than with potassium chloride. Boron decreased from 229 to 198 ppm and phosphorus was also significantly lower when potassium chloride instead of potassium sulfate was used. With 0 level of potassium in the solution, the lowest petiole copper and zinc content of any treatment as well as the highest magnesium content were produced. The iron content of petioles was also comparatively high. When potassium was increased from zero to 234 ppm in the solution, the manganese content dropped from 268 to 63 ppm. The potassium petiole content of 5.72% was found when 234 ppm potassium were used in the check solution. This was nearly three fold the amount found in a normal field sample.

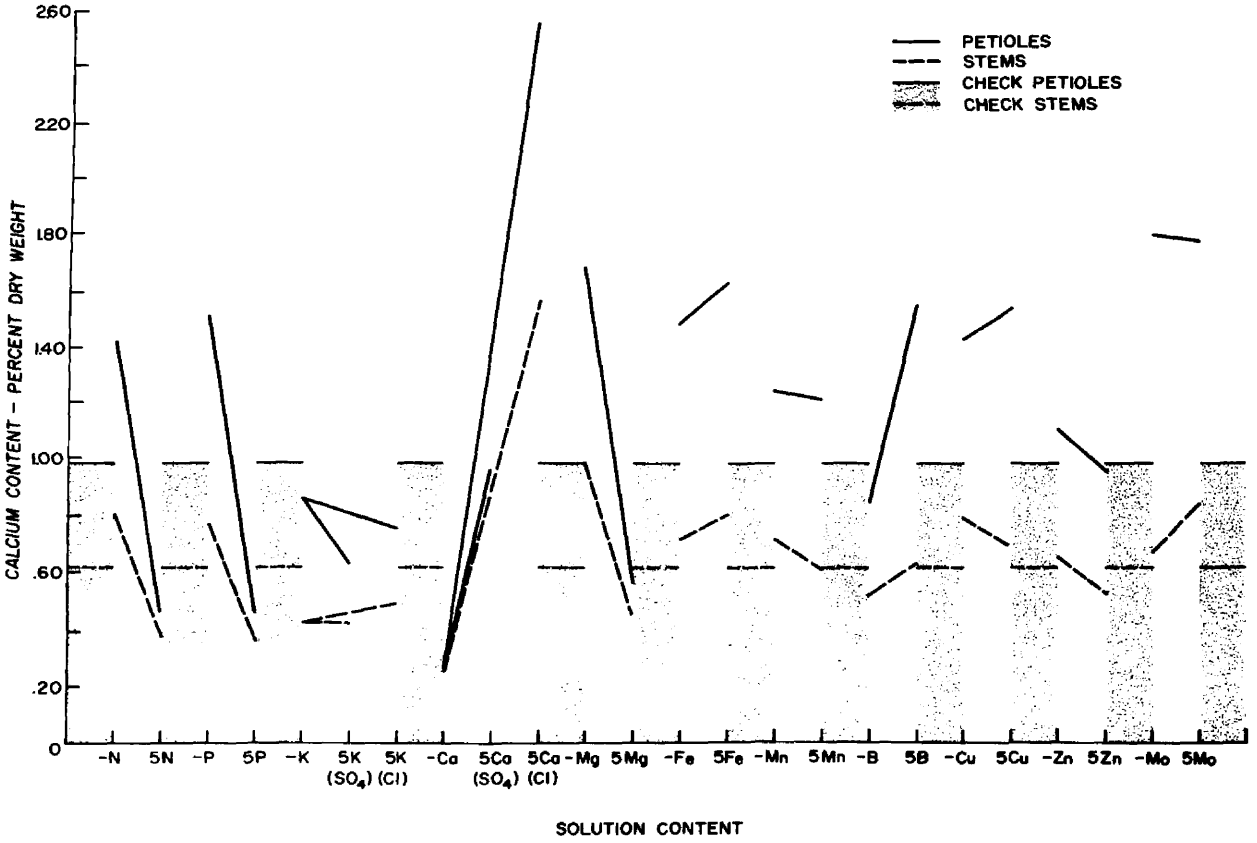
In the lower graph, a comparison of stem with petiole potassium content for the - K treatment showed that the stems had a higher potassium content than the petioles. When the potassium content of the solution was increased, the potassium content of the petioles was greater than the stem content. With 234 ppm potassium in the solution, the stems showed 2.37% and the petioles 5.72% potassium. This difference became even larger

with 1171 ppm in the solution where with the use of potassium sulfate the stems accumulated 2.61% and the petioles 9.86% potassium, as compared to 2.68 and 8.88% potassium respectively, when potassium chloride was used.

Furthermore, as shown in the lower graph, the potassium content of the petioles for the - N, 5 N, - P, 5 P, - K, 5 Ca, - Mg, 5 Mg, - Fe, 5 Fe, - B, - Cu, 5 Cu, - Mo and 5 Mo treatments was below that found for the check treatment. A potassium content higher than that found in the check treatment was in petioles from 5 K, - Ca, and 5 Zn treatments.

In all treatments, stem analysis for potassium was below that of the check treatment, except in the 5 P and 5 K treatments. The difference between petiole and stem analysis for potassium was less for the 5 N than - N, 5 P than - P, 5 Ca than - Ca, 5 Mg than - Mg, and 5 B than - B treatments. Petiole analysis showed that the potassium petiole content in these 5x treatments was lower than in their respective minus treatments, but a reverse relationship of potassium in the stems, as indicated by stem analysis, was found. Also the 5 Ca (SO_4) treatment resulted in less reduction of potassium content in both petiole and stem tissue than the 5 Ca (Cl) treatment.


CALCIUM LEVEL IN SOLUTION
0 PPM
200 PPM (CHECK)
1002 PPM Ca(SO4)
1002 PPM Ca(Cl)
NUTRIENT CONTENT – PERCENT DRY WEIGHT
NUTRIENT CONTENT – PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION

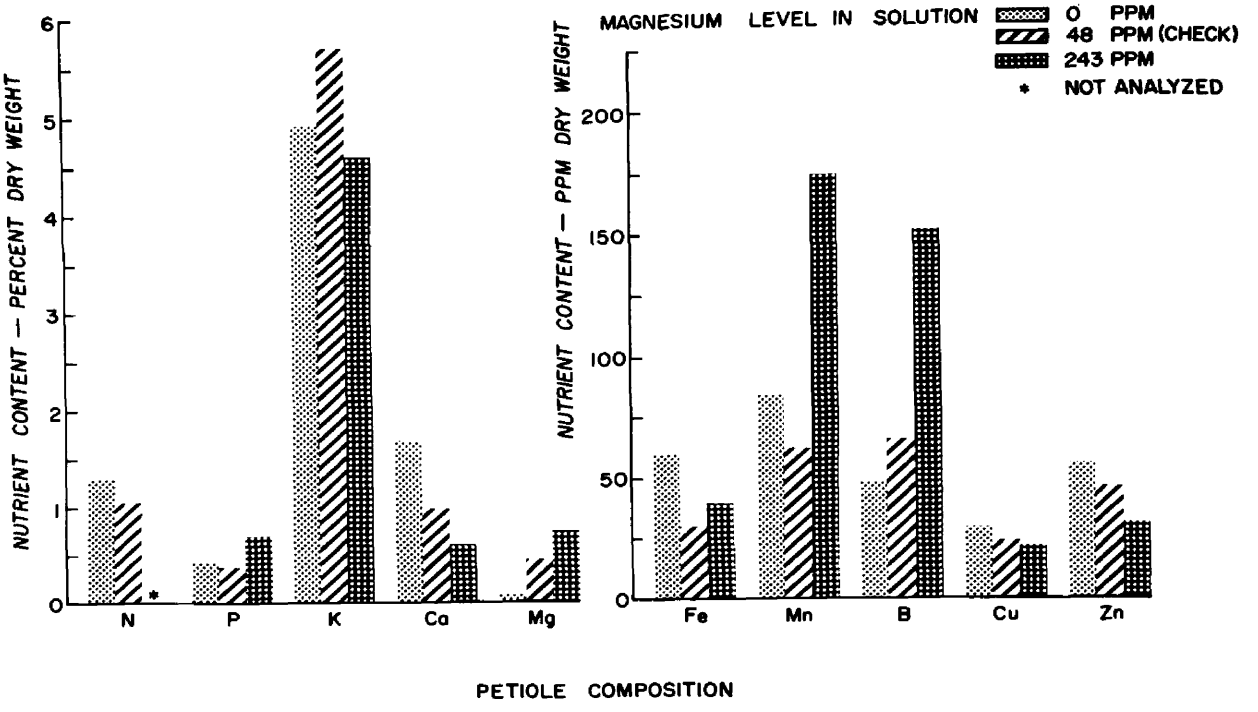

PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
CALCIUM CONTENT – PERCENT DRY WEIGHT
-N
5N
-P
5P
-K
5K (SO4) (Cl)
5K
-Ca
5Ca (SO4) (Cl)
5Ca
-Mg
5Mg
-Fe
5Fe
-Mn
5Mn
-B
5B
-Cu
5Cu
-Zn
5Zn
-Mo
5Mo
SOLUTION CONTENT

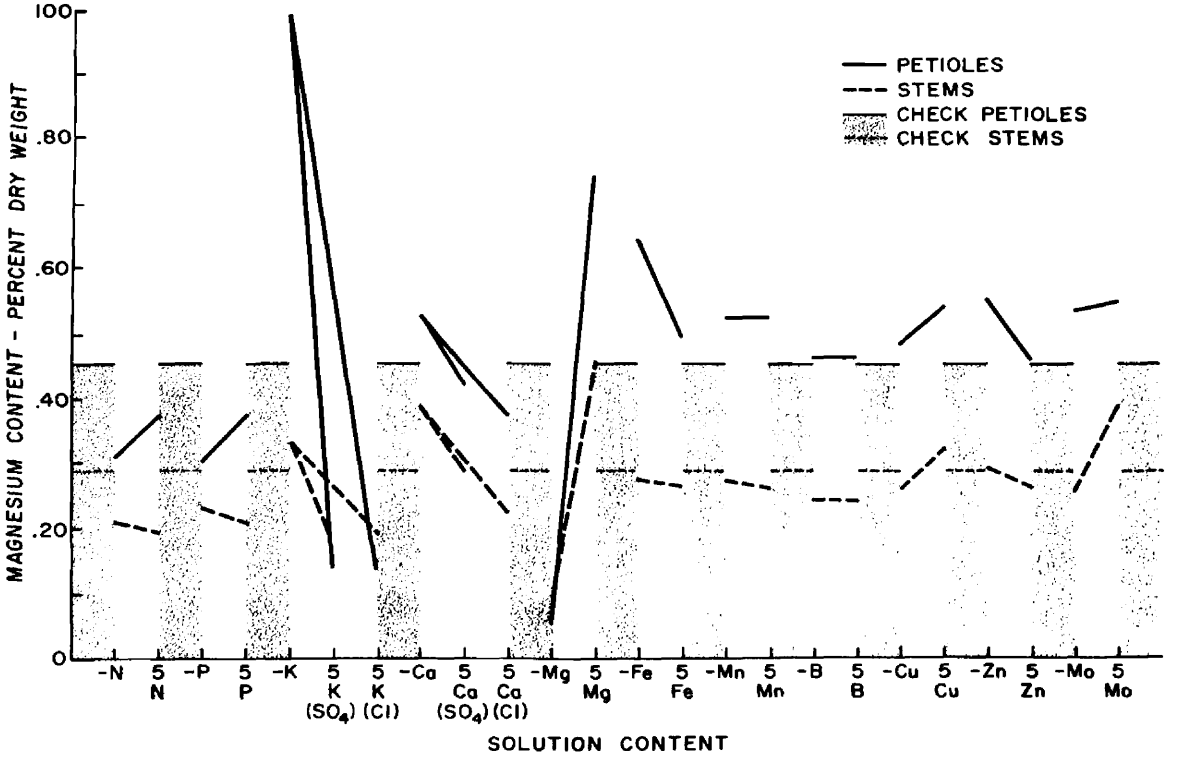
Calcium (see figure opposite)

With increasing levels of calcium in the solution (0, 200 - check, and 1002 ppm), calcium increased in the petioles, while potassium, magnesium, and boron decreased. Nitrogen and phosphorus content of the petioles were higher with - Ca than 5 Ca. Iron and manganese were lowest in the check treatment, and increased with either increased or decreased levels. Minor variations in the copper and zinc content of petioles were associated with a variable calcium supply. The high level of calcium was tested with both sulfate and chloride as anions. A highly significant increase of calcium in the petioles was observed when calcium chloride instead of calcium sulfate was used (2.55 and .96%). At the same time, there was a decrease in potassium (from 4.51 to 2.82%), manganese (from 131 to 76 ppm), and boron (from 67 to 37 ppm) when the calcium chloride was used instead of calcium sulfate.

Comparing stem and petiole analysis for calcium, as shown in the lower graph, the calcium content for both plant parts was nearly the same at the 0 level. This was found also where calcium sulfate was used, but with calcium chloride, the petiole content was 1% higher than the stem content. Although there was a marked increase in both stems and petioles, none of these treatments produced a higher calcium content of stems than in petioles. However, in the 5 N, 5 P and 5 Mg treatments, the calcium

in stems and petioles was very close. Significantly lower calcium petiole content than in the check was found in the following treatments: 5 N, 5 P and 5 Mg, while - N, - P, - Mg, - Fe, 5 Fe, 5 B, - Cu, - Mo and 5 Mo were significantly higher than the check. In the stems, only the - Mg treatment had a significantly higher calcium content than the check.


MAGNESIUM LEVEL IN SOLUTION
0 PPM
48 PPM (CHECK)
243 PPM
* NOT ANALYZED
NUTRIENT CONTENT — PERCENT DRY WEIGHT
NUTRIENT CONTENT — PPM DRY WEIGHT
0
1
2
3
4
5
6
50
100
150
200
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION


PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
MAGNESIUM CONTENT - PERCENT DRY WEIGHT
0
.20
.40
.60
.80
100
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

Magnesium (see figure opposite)

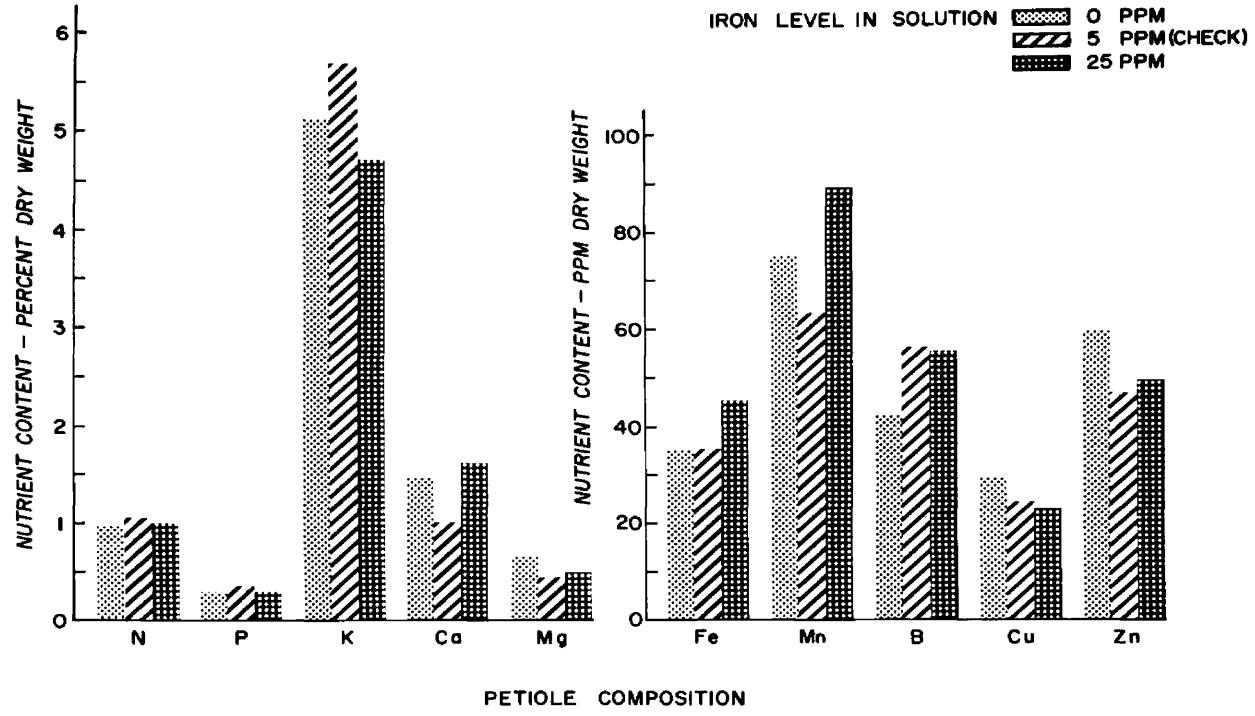
When the level of magnesium in the solution was increased (0, 49 - check, and 243 ppm), magnesium and boron increased in the petioles, whereas calcium, copper and zinc decreased. Phosphorus, iron and manganese were lowest with 49 ppm magnesium in the solution, and were increased when the level of magnesium in the solution was either increased or decreased. Potassium on the other hand, was highest with 49 ppm magnesium in the solution, and decreased with either an increase or decrease in the magnesium supply. Nitrogen showed a decrease in the petiole when magnesium was increased from 0 to 49 ppm. (Petioles of the 5 Mg treatment were not analyzed for nitrogen because of shortage of petioles).

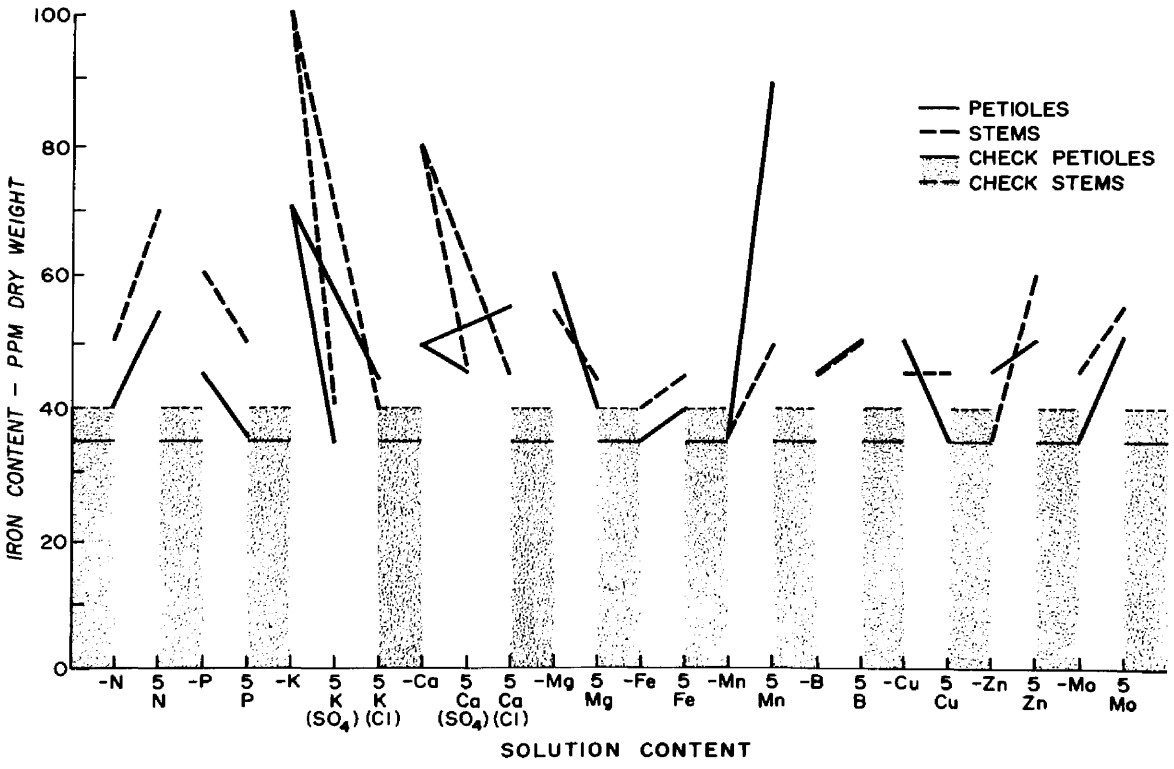
A five fold increase of magnesium in the solution nearly doubled the petiole magnesium and phosphorus concentration. Furthermore, manganese was increased significantly from 63 to 174 ppm and boron from 56 to 152 ppm.

In the comparison of stem with petiole composition, as shown in the lower graph, there was a general tendency for the stem magnesium to be lower than the petiole magnesium. This comparison was true for all treatments except for the 5 K (SO_4), 5 K (Cl) and - Mg treatments. With these treatments, the stem magnesium was higher than the petiole magnesium. In all three cases, visual deficiency symptoms on the leaves were

observed. The most pronounced effect on magnesium uptake was not exerted by the magnesium within the solution, but by the potassium. Here, the - K treatment produced a magnesium content in the petioles of .99%, which compared to the 74% Mg of the 5 Mg treatment.

Significant increases of petiole magnesium were found in the - K and - Fe treatments, while - N, - P, 5 K (SO_4), and 5 K (Cl) were significantly lower in petiole magnesium than the check.


IRON LEVEL IN SOLUTION
0 PPM
5 PPM (CHECK)
25 PPM
NUTRIENT CONTENT – PERCENT DRY WEIGHT
NUTRIENT CONTENT – PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION

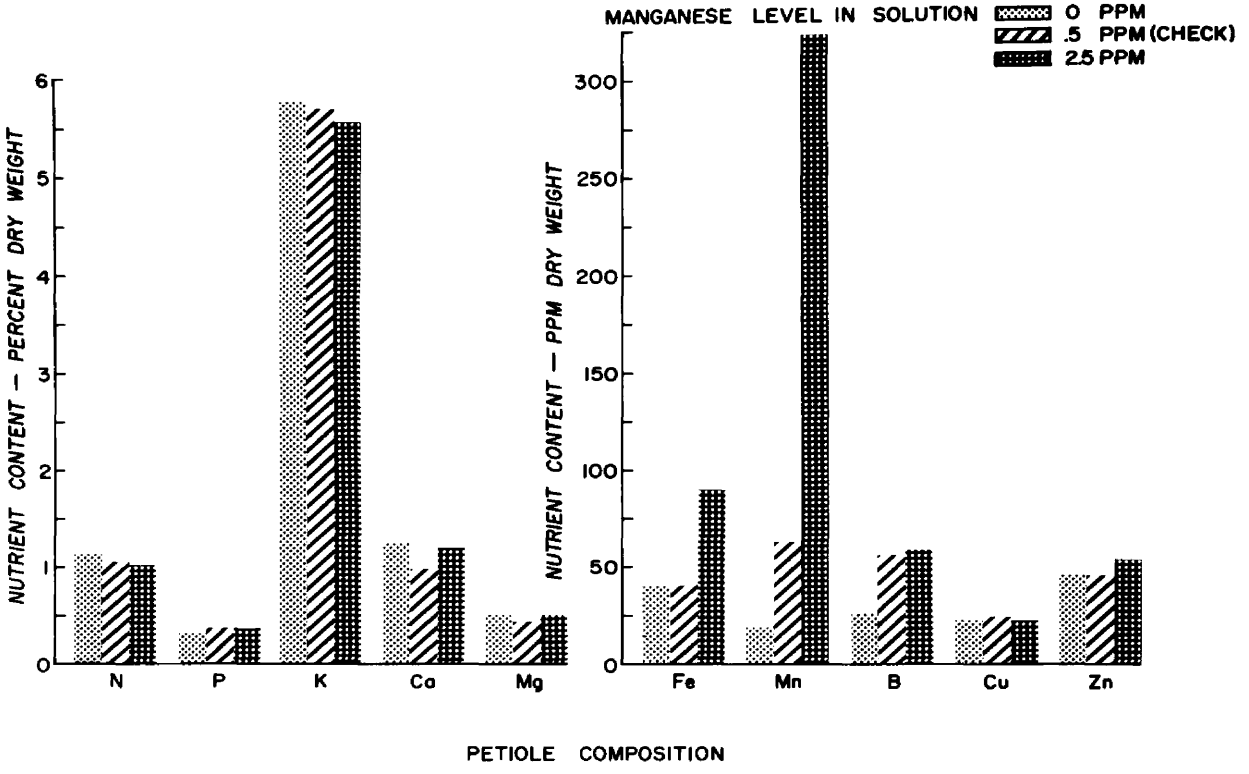

PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
IRON CONTENT – PPM DRY WEIGHT
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

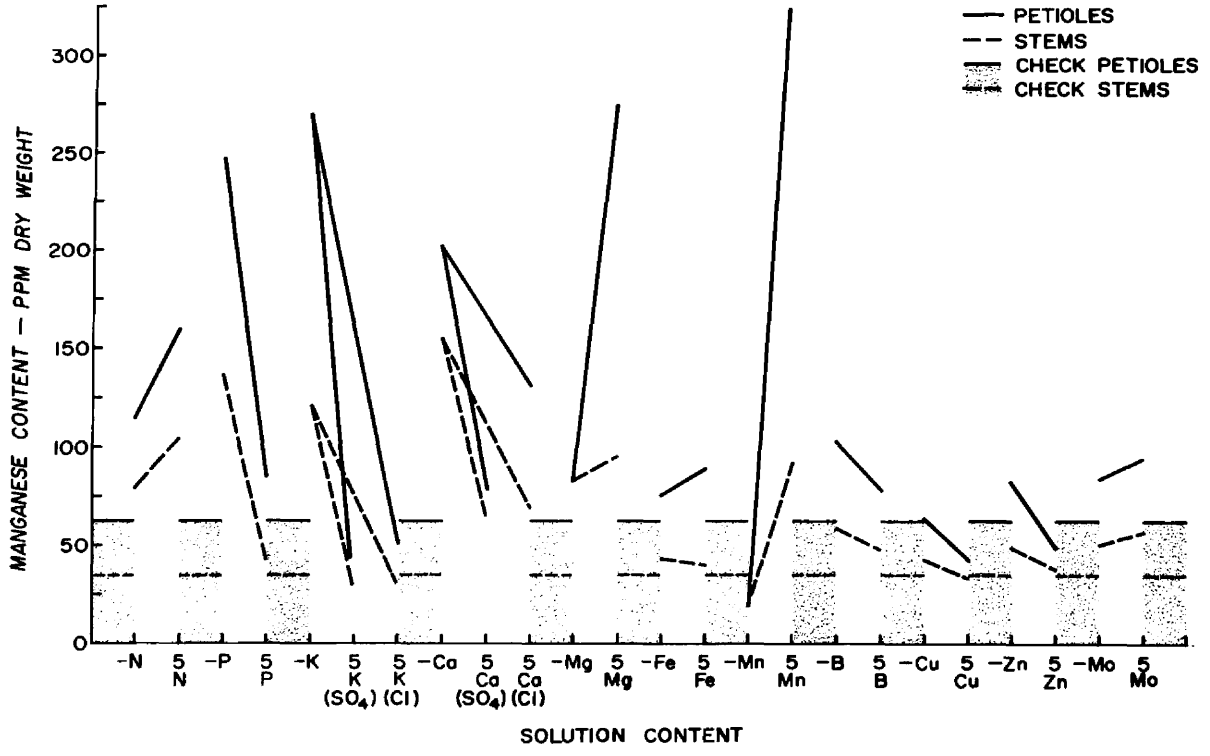
Iron (see figure opposite)

When the level of iron was increased in the solution (0, 5 - check, and 25 ppm), very little effect upon iron in the petioles could be observed. Most of the elements showed no significant increase or decrease in the petioles. When iron in the solution was increased from 5 to 25 ppm, calcium increased significantly, whereas potassium decreased in the petioles. An increase of iron from the 0 level to 5 ppm in the solution brought about a significant decrease of magnesium in the petioles from 65 ppm to 45 ppm. A general tendency prevailed for 5 ppm iron to result in either the highest or the lowest value in the petiole for other elements which increased or decreased when iron was either increased or decreased in the solution.

From the comparison of the stem and petiole iron content, as shown in the lower graph, it can be observed that the iron in the solution has very little effect upon iron in both stems and petioles. In all three iron treatments, the stem iron was higher than the petiole iron, which actually was the case in most other treatments. However, an interesting exception to this was the 5 Mn treatment. Here, the petiole iron content was 90 ppm compared to 50 ppm in the stems. Also there was a greater amount of iron in the petioles than in the stem for the - Mg and - Zn treatments. On the other hand, the - K treatment had 100 ppm iron in the stem and 70 ppm in the petioles. The - Ca

treatment had a similar relationship with 80 ppm iron in the stem and 50 ppm in the petioles. Otherwise, the iron values for both petioles and stems were closely grouped with the exception of the above mentioned treatments, and no significance was found in the analysis of variance for iron in either of the two plant parts.


MANGANESE LEVEL IN SOLUTION
0 PPM
.5 PPM (CHECK)
2.5 PPM
NUTRIENT CONTENT — PERCENT DRY WEIGHT
NUTRIENT CONTENT — PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION


PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
MANGANESE CONTENT — PPM DRY WEIGHT
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

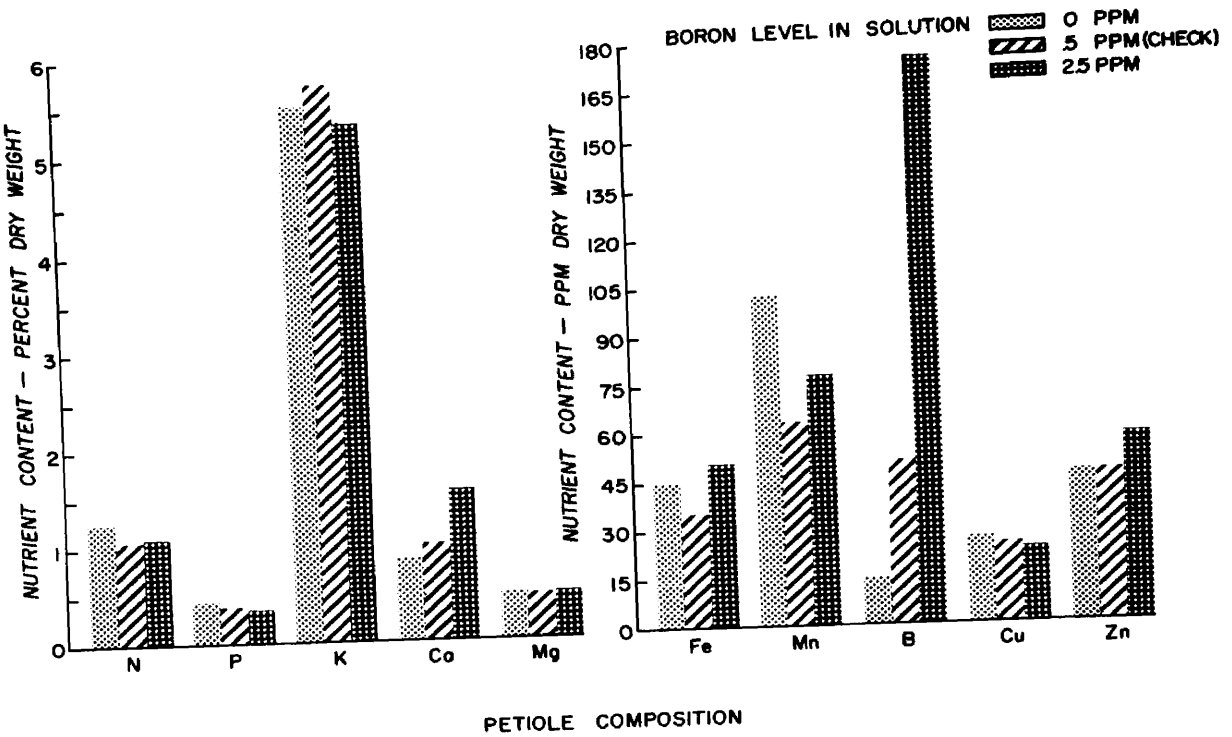
Manganese (see figure opposite)

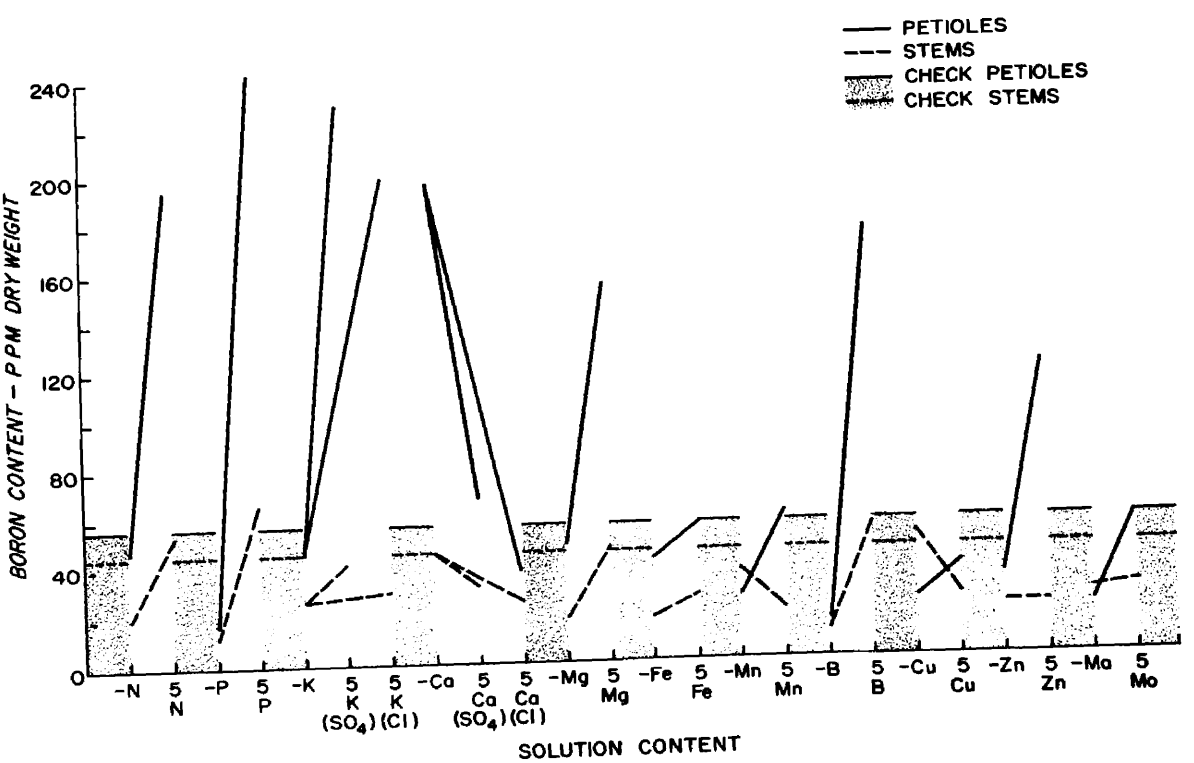
Increasing levels of manganese in the solution (0, .5 - check, and 2.5 ppm) brought a significant change of manganese in the petioles. The other elements except iron were affected, but very little. Iron in the petioles increased from 35 ppm in the - Mn treatment to 90 ppm when high levels of manganese were used in the solution.

The lower graph shows a comparison between stem and petiole content of manganese. Although the difference between stem and petiole manganese content increased with increasing levels of manganese in the solution, the - Mn treatment showed a higher manganese concentration in the stems than in the petioles. Here, too, visual deficiency symptoms on leaves were observed.

Other elements exerted a greater influence upon manganese uptake than manganese upon other elements. If the check is taken as a basis of comparison, the following treatments significantly increased manganese in the petioles: 5 N, - P, - K, - Ca and 5 Mg.

In general, all manganese petiole values were rather low in comparison with average field samples. This was also observed for the high level of manganese with 2.5 ppm of manganese in the solution.

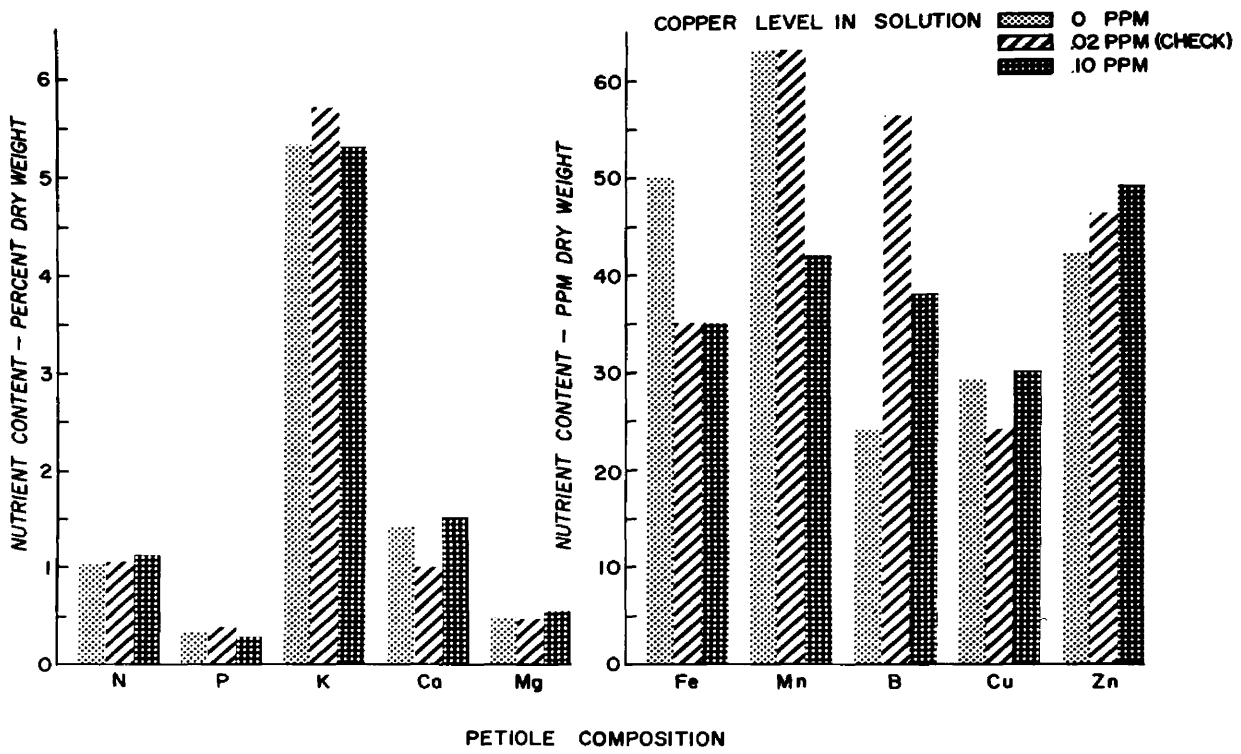

BORON LEVEL IN SOLUTION
0 PPM
5 PPM(CHECK)
2.5 PPM
NUTRIENT CONTENT – PERCENT DRY WEIGHT
NUTRIENT CONTENT – PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION

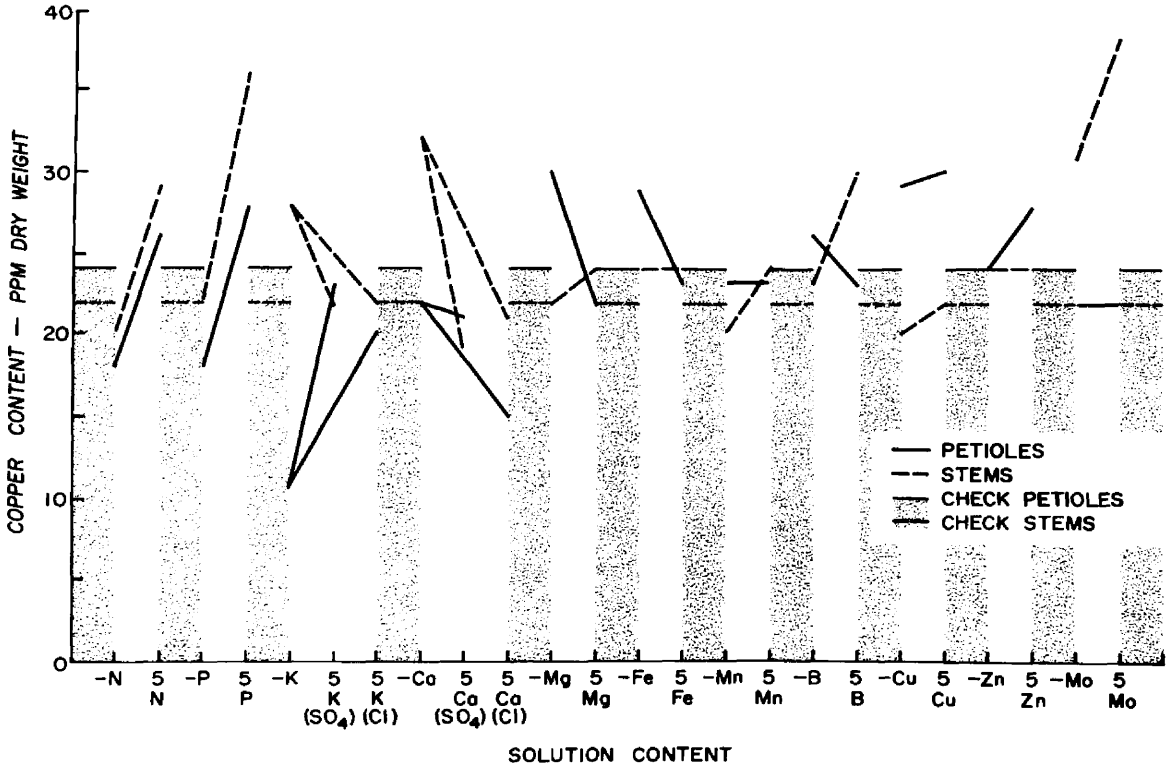

PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
BORON CONTENT – PPM DRY WEIGHT
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

Boron (see figure opposite)

Increasing the level of boron in the solution (0, .5 - check, and 2.5 ppm) brought about a significant increase in the boron and calcium content of the petioles and a significant decrease in phosphorus and copper concentrations. A five fold increase of boron in the solution resulted in a three fold increase in the petiole boron. Potassium was highest with .5 ppm of boron in the solution and decreased with either lower or higher levels of boron. Nitrogen, magnesium, iron and manganese had a reverse relationship and increased with either low or high levels of boron.

By comparing the petiole and stem analysis for boron, as shown in the lower graph, the difference between stem and petiole, boron concentration increased with increasing boron in the solution. With high levels of all nutrients the petiole content for boron was always higher than the stem content. In three treatments (- Mn, - Cu, - Mo), the stem boron content was higher than the petiole content. The graph also shows that the boron content was influenced more by the variation of other elements in the solution than by boron itself. The - P treatment produced nearly the same low values for boron in petioles and stems as the - B treatment. The 5 P treatment produced the highest boron petiole content for all treatments. Treatments other than 5 B that had a significantly higher petiole boron content than the check treatment were 5 N, 5 P, 5 $K(SO_4)$, 5 K(Cl), - Ca, 5 Mg and 5 Zn.

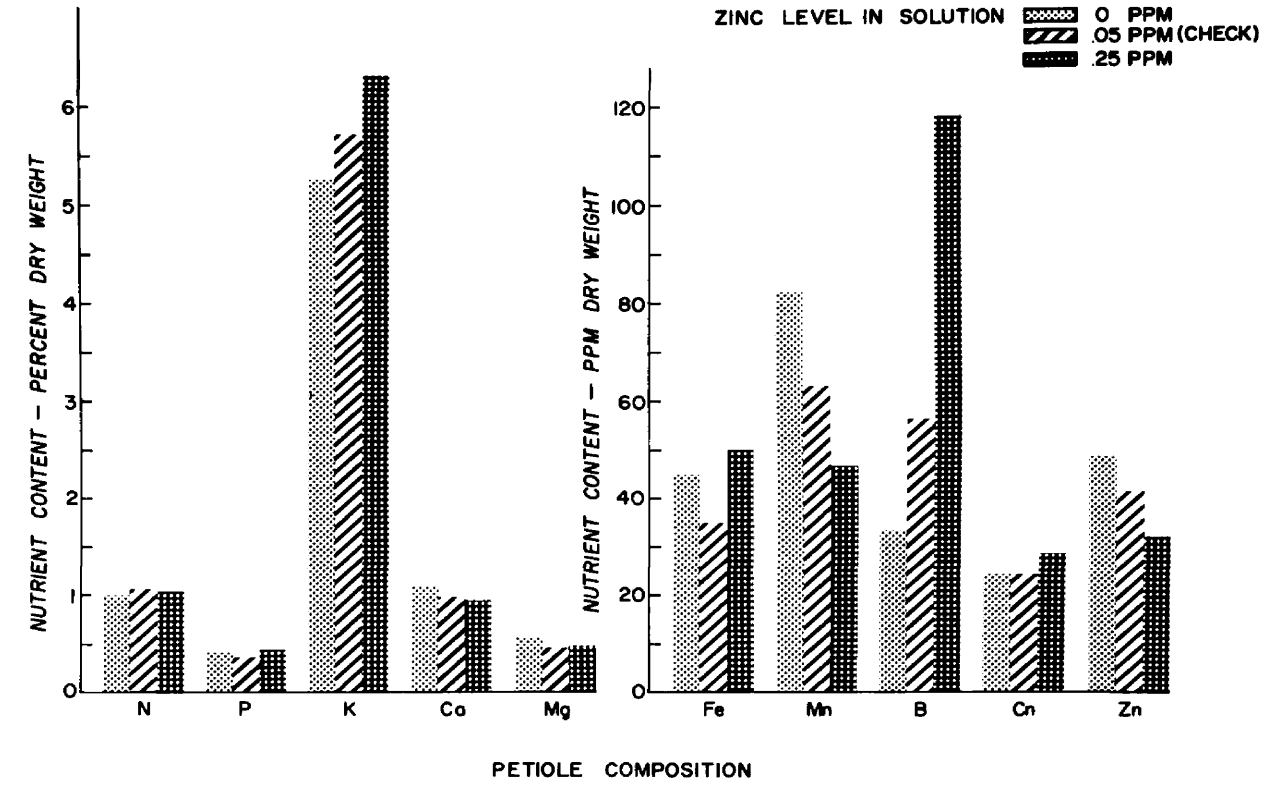

COPPER LEVEL IN SOLUTION
0 PPM
.02 PPM (CHECK)
.10 PPM
NUTRIENT CONTENT – PERCENT DRY WEIGHT
NUTRIENT CONTENT – PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cu
Zn
PETIOLE COMPOSITION

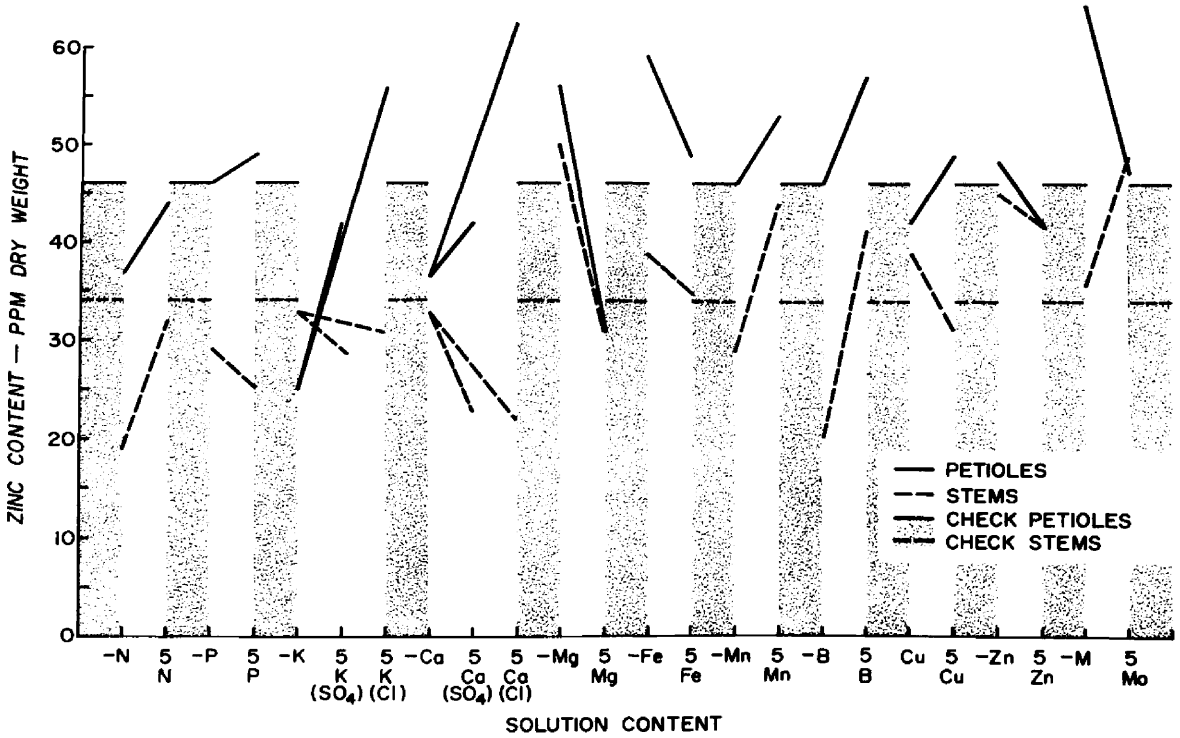

COPPER CONTENT – PPM DRY WEIGHT
PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
-Cu
5 Cu
-Zn
5 Zn
-Mo
5 Mo
SOLUTION CONTENT

Copper (see figure opposite)

Increasing levels of copper in the solution (0, .02 - check, and .1 ppm) had no significant effect on any element except calcium. In both 0 and .1 ppm copper levels, calcium was significantly higher than in the check treatment. The other major elements were affected very little. While iron and manganese were highest with 0 copper in the solution, boron was highest with the .02 ppm level of copper whereas copper and zinc were highest with .1 ppm copper in the solution.

The lower graph shows a comparison between stem and petiole copper concentration. It was obvious that a large number of treatments resulted in higher copper contents in the stems than in the petioles; however, the three treatments varying in copper content of the nutrient solution were higher in petiole copper than in stem copper. Other treatments which followed this more normal trend were 5 $K(SO_4)$, 5 $Ca(SO_4)$, - Mg, - Fe, - Mn, - B and 5 Zn. The lowest copper content of petioles was found in the petioles of the - K treatment, while the - Cu treatment produced a high copper content. Both stem and petiole analysis for copper showed no significance between treatments, which was also observed in the analysis of variance for iron. The low petiole copper values, however, in the - K and 5 Ca(Cl) treatments as well as the high stem copper content of the treatment 5 Mo merit attention.


ZINC LEVEL IN SOLUTION
0 PPM
.05 PPM (CHECK)
.25 PPM
NUTRIENT CONTENT – PERCENT DRY WEIGHT
NUTRIENT CONTENT – PPM DRY WEIGHT
N
P
K
Ca
Mg
Fe
Mn
B
Cn
Zn
PETIOLE COMPOSITION

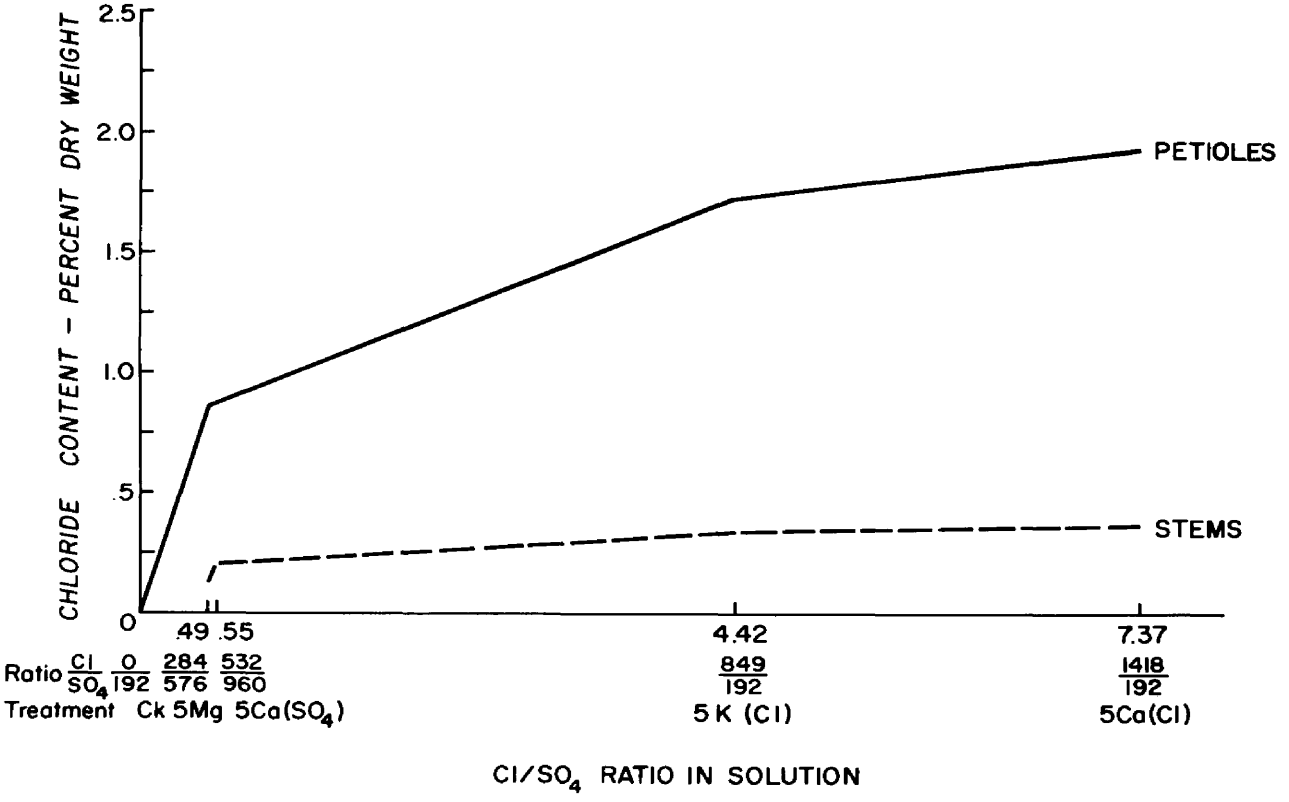

ZINC CONTENT – PPM DRY WEIGHT
PETIOLES
STEMS
CHECK PETIOLES
CHECK STEMS
-N
5 N
-P
5 P
-K
5 K (SO4)
5 K (Cl)
-Ca
5 Ca (SO4)
5 Ca (Cl)
-Mg
5 Mg
-Fe
5 Fe
-Mn
5 Mn
-B
5 B
Cu
5 Cu
-Zn
5 Zn
-M
5 Mo
SOLUTION CONTENT

Zinc (see figure opposite)

An increase in the levels of zinc in the nutrient solution (0, .05 - check, and .25 ppm) resulted in an increase in potassium and boron in the petioles, but decreased manganese and zinc. The only element which was significantly affected was boron.

As shown in the lower graph, 23 of the 25 treatments had a higher zinc content in the petioles than in the stems. Only - K and 5 Mo had lower zinc concentrations in the petioles than in the stems. The highest zinc petiole content was found in the - Mo and 5 Ca(Cl) treatments, while the lowest content was observed in the - K treatment. The lowest zinc stem content was found in the - N treatment and the highest in the - Mg treatment.

Zinc stem values showed significant differences but not the petiole values. When magnesium in the solution was increased from 0 to 243 ppm, the zinc content of stems decreased significantly. On the other hand, increased levels of boron in the solution (from 0 to 2.5 ppm) increased significantly the zinc content of stems.


CHLORIDE CONTENT – PERCENT DRY WEIGHT
2.5
2.0
1.5
1.0
.5
0
PETIOLES
STEMS
.49
.55
4.42
7.37
Ratio Cl/SO4 0/192 284/576 532/960 849/192 1418/192
Treatment Ck 5Mg 5Ca(SO4) 5 K (Cl) 5Ca(Cl)
Cl/SO4 RATIO IN SOLUTION

Chlorine (see figure opposite)

As mentioned earlier, high levels of potassium and calcium were tested with sulfate--5 K (SO_4) and 5 Ca(SO_4) treatments--and with chloride--5 K(Cl) and 5 Ca (Cl) treatments--as anions. Some chloride also was added to the high magnesium (5 Mg) treatment. The graph opposite shows the chloride concentration of stems and petioles in comparison with the $\frac{Cl}{SO_4}$ ratio in the solutions of the check, 5 Mg, 5 Ca(SO_4), 5 K (Cl) and 5 Ca(Cl) treatments. Increasing ratios brought increasing stem and petiole chloride contents. The stems, however, did not increase in chloride as much as the petioles and the difference between these two plant parts became larger with increasing chloride/sulfate ratios in the solution.

The chloride content of petioles from the check treatment was .07%. Chloride values of 1.70% for the 5 K(Cl) treatment and 1.89% for the 5 Ca(Cl) treatment were in the approximate range of toxicity. However, no chloride toxicity sumptoms on leaves were observed.

DISCUSSION

The composition of the nutrient solutions used in this experiment seemed to be the main factor influencing growth and development of the plant. Bonner and Galstone (1952) described growth as quantitative matter which can be measured (length and weight) while development is a qualitative expression and can only be observed. The results, therefore, should be broken down into dry weight accumulation and length of shoots as growth, while visual deficiency or toxicity symptoms as well as variations of leaf characteristics should be treated as development. However, both growth and development express themselves as an entity and will be treated as such. Shear, Crane and Meyers' (1946) concept of nutrient balance and intensity can be taken as a basis for evaluation of the solutions in respect to dry weight accumulation and linear growth. These authors felt that a more ideal balance between the essential nutrient elements has to exist before higher yields can be obtained by intensifying nutrition.

Preliminary experiments showed that the 1x level of the No. 1 solution proposed by Hoagland and Arnon (1950) might be suitable as a standard solution and all other treatments were adjusted accordingly. A comparison of the petiole composition of this check treatment with the standard petiole composition for Michigan Concord grapes, as established

by Larsen (1957) over a number of years, revealed some marked differences. Table 2 shows this comparison.

TABLE 2

COMPARISON BETWEEN STANDARD PETIOLE VALUES OF FIELD SAMPLES (LARSEN, 1957) AND VALUES OF THE CHECK TREATMENT

Element		Field Standard Values	Nutrition Solution Check Treatment Values
Nitrogen	%	.80	1.06
Phosphorus	%	.24	.37
Potassium	%	1.91	5.72
Calcium	%	1.60	.99
Magnesium	%	.46	.45
Iron	ppm	44	35
Manganese	ppm	434	63
Boron	ppm	25	56
Copper	ppm	35	24
Zinc	ppm	23	46

Inspection of these values shows that potassium in petioles of the check treatment was three times higher than the standard field average. Calcium, on the other hand, was 50% lower, while boron and zinc showed double the amount found under field conditions. The largest variation, however, was for manganese where the field sample was seven times higher than that for the nutrient solution sample. The responsibility for such a marked variation could lie in the following possibilities:

1. The solution is either too high or too low in the specific element.
2. Interaction of other elements might prevent or enhance uptake of the specific element.
3. Luxury consumption might occur where extreme high levels are present.
4. The element might be tied up in the solution and not available to the plant.

Before these possibilities can be definitely identified, other factors, such as petiole composition of other treatments, as well as dry weight accumulation and linear growth, have to be considered.

The first visual deficiency symptoms occurred on the - N treatment and were so severe that 42 ppm of nitrogen had to be added in order to keep the plant alive. Ultimate analysis of petioles showed .51% and that of stem revealed .63% nitrogen, in other words, more nitrogen was in the stems than in the petioles. These values must definitely be deficient, inasmuch as literature generally agrees that .80 to 1.5% N are essential for normal plant growth and production. The low values expressed themselves in severe depression of linear growth and dry weight accumulation as well as in low phosphorus and potassium, but rather high calcium values in the petioles. The interaction with potassium and calcium became more pro-

nounced under high nitrogen conditions. Here, the reverse was prominent. It seems, therefore, that depression of growth under high nitrogen levels may be due to antagonism on other elements and an indirect effect of nitrogen rather than a direct one, as is the case under nitrogen deficient conditions.

Various symptoms of potassium deficiency, as described by Wilhelm (1950) were expected, however, after five weeks of growth, only the purple symptoms appeared. These various potassium deficiency symptoms will be discussed in connection with Experiment II. Petiole analysis and stem analysis from plants treated with potassium deficient solution showed .12% and .30% K respectively, values which are far below those reported for normal field conditions. It is generally accepted that potassium has a regulating effect on plant metabolism, and is involved in most biological reactions, however, its specificity has not been established. Therefore, it is not surprising that a severe potassium deficiency will depress dry weight accumulation and linear growth.

The high level of potassium had the same effect on growth as the low levels. Leaf symptoms, which were identified by petiole analysis as magnesium deficiency, appeared after nine weeks of growth. The two high potassium treatments, however, did not react alike. While the leaf symptoms were the same, KCl depressed growth far more than K_2SO_4. Both treatments had the same magnesium petiole content, however, the Cl/SO_4 ratio might have been of influence inasmuch as with chloride in the solution, 1.71%

chloride was found in the petioles. This would be expected to give an additional depressive effect on potassium, which would agree with the findings of Dilley (1957a). The reduced absorption of both magnesium and potassium in the solution containing KCl may account for growth being less for this treatment than for the solution containing K_2SO_4.

Furthermore, the boron petiole content in both treatments was relatively very high. Gärtel (1954) observed weak boron toxicity damage in vinifera type grapes with high phosphorus and potassium levels, which could have occurred in this case, even though no visual symptoms were found. It could, therefore, be concluded that the depression of growth by high levels of potassium is due to a combination of factors, such as induced magnesium deficiency, as well as extreme boron, sulfate and chloride levels.

One week after magnesium deficiency symptoms occurred on the high potassium treatments, similar symptoms were observed on the basal leaves of magnesium deficient plants. The petioles and stems of these plants showed .06 and .07% magnesium, respectively, which is low and below the critical point of about .2% (Kenworthy, 1956). Magnesium plays an important role as a constituent of chlorophyll, which, in turn, is involved in photosynthesis. Inasmuch as magnesium is very mobile and easily translocated from the basal leaves to the terminals, it is understandable that there was very little

depression in linear growth. Furthermore, nitrogen and phosphorus were slightly higher and calcium was two-thirds higher than in the petioles of the check; potassium was somewhat lower while the minor elements seemed to be little affected. The somewhat stronger depression of total dry weight accumulation might also be explained on this basis.

There was a large difference, however, in the shoot/root ratio between - Mg and 5 Mg. The latter had the largest ratio and was also more depressing in the total linear growth and total dry weight accumulation. If dry weight accumulations of the vaious plant parts are compared on the basis of per cent of the total, the largest difference is found in the roots where 5 Mg had 46% and - Mg had 20%, while the check produced 26%. Petiole analysis showed that 5 Mg resulted in a depression of calcium and potassium, but increased phosphorus and boron. Experiment II will deal with these interactions.

Calcium deficiency symptoms were found to coincide with . 26% calcium petiole content, and agreed with the reports of Hagler and Scott (1953) and Stellwaag and Knickmann (1955). Since calcium is part of the cell composition and very immobile, the breakdown occurred in the terminal regions. Very low calcium content in the petioles was combined with high nitrogen, phosphorus, potassium and boron, as well as increased magnesium and manganese levels. Since nitrogen, phosphorus and potassium are present in large quantities and magnesium is above normal, the metabolic process

of the plant can go on except for the fact that the main cell wall constituent is missing without which no elongation or accumulation can occur. Also, the development of the shoots from axillary buds can thus be explained. Further discussion of calcium in relation to growth will be found in Experiment II.

After twelve weeks of growth, phosphorus deficiency symptoms appeared on - P plants. Petiole and stem analysis showed .10 and .11% phosphorus, respectively. No phosphorus deficiency has as yet been observed in Concord grape growing regions, and a petiole content of .2% is accepted as normal. Phosphorus is the source of energy in the metabolic process and any deficiency should automatically slow down the growth process. It seems that deficient levels of phosphorus are coupled with very low nitrogen values. A depression in potassium but rather high levels of calcium occurred at the same time.

High levels of phosphorus in the solution produced nearly as much linear growth as the check, but total dry weight accumulation was depressed. High levels of nitrogen and boron as well as low levels of calcium were present under this condition. The difference between total linear growth and dry weight accumulation might be explained by the presence of high nitrogen and high boron. High nitrogen furthers linear growth (Kraus and Kraybill, 1913) and boron, according to the review of Gauch and Dugger (1954)

gives the cell elasticity in addition to having other functions. Inasmuch as elongation is enhanced under this condition, the cells may be stretched with less than normal calcium in the walls, which, in turn, would produce less dry weight.

The experiment showed under direct or indirect major element deficiency conditions that, in every instance, the stem composition was at least equal to, if not higher than, the petiole composition, as shown in Table 3.

The amount of nitrogen in stems and petioles of the check treatment was very close, 1.05 and 1.06% respectively. Based on the comparison with the deficient treatments, it must be concluded that the check treatment was below normal for nitrogen and probably more growth could have been achieved with more nitrogen present in the plant.

Minor elements were of less influence on linear growth and dry weight accumulation than the major elements. This general effect may have been due to a more sufficient reserve supply of the minor elements within the plants. This reserve supply had to be diluted before growth was affected.

Manganese, boron, and copper deficiency symptoms appeared at the same time. Plants with manganese deficiency symptoms had 18 ppm Mn in petioles and 23 ppm in stems. Beattie and Forshey (1954) reported that manganese deficiency can occur when the July petiole content drops below 30 ppm. Maume and Dulac (1952) found very large variations of manganese content in

TABLE 3

COMPARISON BETWEEN STEM AND PETIOLE CONTENT OF ELEMENTS DEFICIENT OR APPROACHING DEFICIENCY IN THE PLANTS

Treatment	Specific Element Deficient	Content Per Cent - Dry Weight		Visible Deficiency Symptoms
		Petioles	Stems	
- N	N	.51	.63	Nitrogen
- P	N	.62	.62	Phosphorus
- P	P	.10	.11	Phosphorus
- K	K	.12	.27	Potassium
5 N	K	1.57	1.87	Unidentified
5 $K(SO_4)$	Mg	.14	.18	Magnesium
5 K(Cl)	Mg	.14	.19	Magnesium
- Mg	Mg	.06	.07	Magnesium
- Mn	Mn	.0018	.0023	Manganese
- K	Zn	.0025	.0033	Potassium base zinc terminals

plants within the same grape variety and came to the conclusion that location and soil are the main causes of variation. The 323 ppm of manganese of the 5 Mn treatment was below the values found in normal field samples. Inasmuch as Experiment III deals with manganese more specifically, the respective discussion will be given later. The standard solution, however, was definitely too low in manganese content.

Petioles of boron deficient plants had a content of 14 ppm, and stems of the same plants had 11 ppm boron. According to Scott (1954) the range of deficiency under field conditions lies between 10 and 20 ppm, while Gärtel (1956) felt the transition zone should be between 13 and 15 ppm. Since boron deficiency impairs photosynthesis and translocation of sugars from leaves due to disarrangement of the phloem (Reed, 1947), a growth depression and breakdown of terminal portions must be expected.

Even though copper deficiency symptoms were present, the petiole analysis did not show it. Both - Cu and 5 Cu produced more total dry weight than the check; however, in total linear growth both were below the check. Comparison of petiole and stem analysis showed that in most treatments the stem copper content was higher than the petiole content. Based on the comparison between petioles and stems for major elements, this would indicate that copper was deficient in most treatments. This will be discussed further in Experiment II.

Deficient plants had more zinc in their petioles than plants fed with 5Zn solution, but deficiency symptoms were definitely present. The only treatment resulting in less zinc in the petioles than in the stems was potassium. Zinc has an essential function in the production of growth regulating substance which takes place in the meristematic regions of the plant. The possibility exists that symptoms observed on the terminal portions of the - K treatment

plants were due to zinc shortage because petiole analysis showed 25 ppm zinc in the petioles, which was the lowest concentration found in any treatment. Furthermore, the zinc content of stems from the - K treatment was 33 ppm. Similar symptoms observed on the terminals of the 5N treatment were also believed to be zinc deficiency, since high levels of nitrogen brought a severe depression of potassium, which, in turn, seemed to be related to the zinc content of the petioles. The petiole analysis, however, did not indicate a deficient zinc level. On the other hand, since the petioles of the whole plant were analyzed together, and, therefore, the values would be an indication of their average zinc content, they would not show the deficient level of the terminal portion.

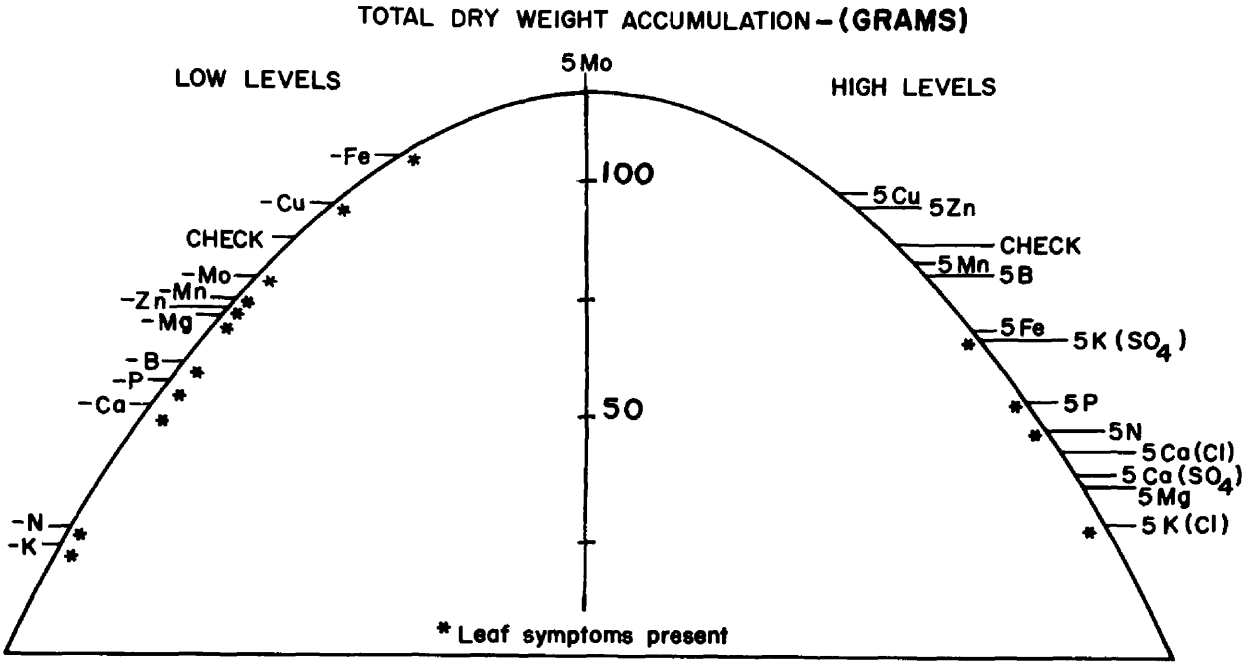
Both - Mo and 5 Mo had some depressing effect on total linear growth but 5 Mo produced most dry weight, while - Mo produced slightly less than the check. Petiole analysis showed that both were very high in calcium; - Mo was low in boron, while 5 Mo was slightly above the check. A combination of high calcium, a better utilization of nitrate nitrogen for which molybdenum is essential (Bergman and Kenworthy, 1956) and sufficien nitrogen, phosphorus, potassium, magnesium, and boron were probably responsible for the high dry weight accumulation. The - Mo plants were low in molybdenum and boron in combination with high calcium and lower potassium concentrations.

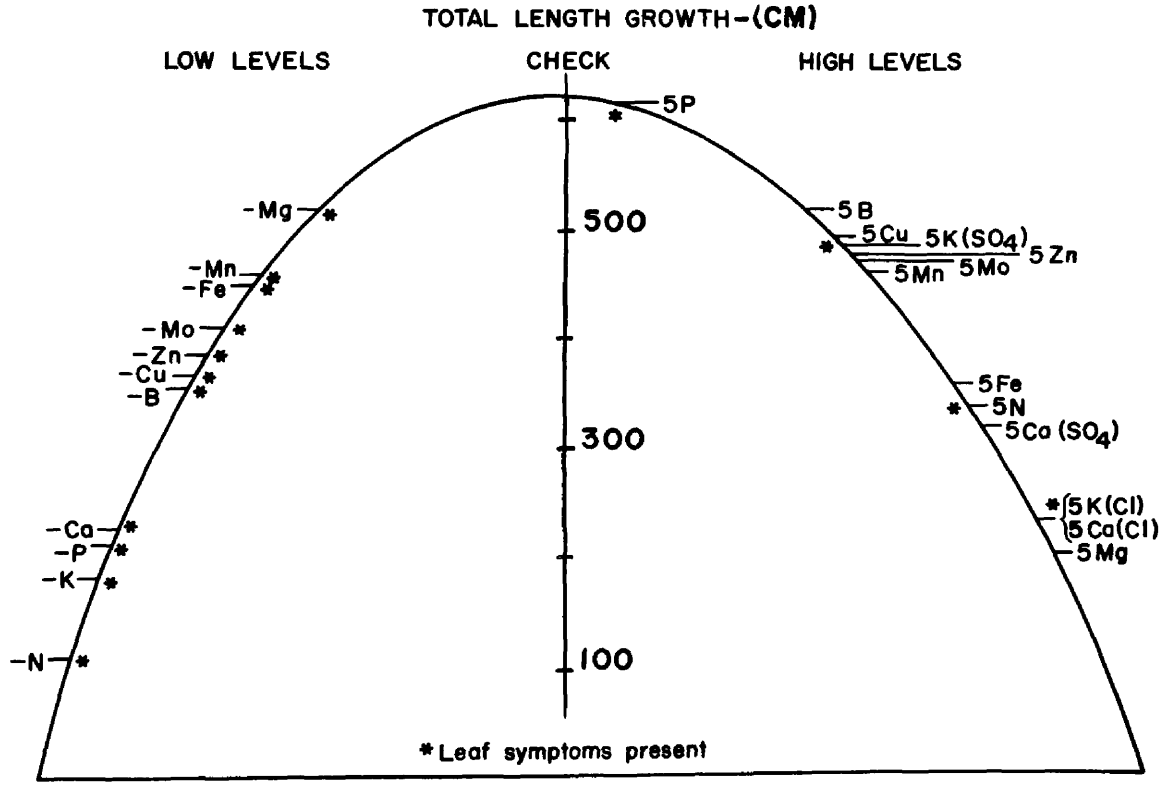
Total dry weight accumulation was little affected by iron deficient nutrient solution, but total linear growth was depressed. High levels of iron depressed both measurements. In most treatments iron was higher in the stems than in the petioles, which would suggest that iron was low or deficient in the check solution. However, iron source and poor translocation might be of influence. Both low and high iron treatments were about equal in per cent distribution of the plant parts and in the shoot/root ratios. There was, however, a very distinct difference in the appearance of the root system with high iron plants having very poor, very brittle and many dead roots, while -Fe had a poor root system with black roots, but brittleness and dead ones were missing. Both treatments produced high calcium levels in the petioles and the potassium value with 5 Fe was 1% lower than the check. This potassium depression seems to match the high iron value under potassium deficient conditions.

The total dry weight accumulation and total linear growth are presented in form of curves in Figure 9. These curves are based on the law of diminishing return with the treatments giving highest results in each case at the apex and the other treatments arranged in depressing order towards the base on each side. As shown in Figure 9, the relative effect of a specific element upon dry weight accumulation or linear growth depends on the specificity of the element in the metabolic process and its interaction with other elements.

Figure 9 Top Total dry weight accumulation of each of the 25 treatments arranged on a curve with the treatment producing the largest amount of dry weight (5 Mo treatment) in the center on the highest point. Low level treatments were arranged on the left side in decreasing order of depression from the base line towards the highest point on the curve, and the high level treatments from this point towards the right in increasing order of depression. The vertical distance from the base line to any treatment is directly proportional to its total dry weight accumulation.

Bottom Total linear growth for each of the 25 treatments arranged on a curve with the treatment producing most total linear growth (check treatment) in the center on the highest point. Low level treatments were arranged on the left side in decreasing order of depression from the base line towards the highest point on the curve, and high level treatments from this point towards the right in increasing order of depression. The vertical distance from the base line to any treatment is directly proportional to its total linear growth.


TOTAL DRY WEIGHT ACCUMULATION-(GRAMS)
LOW LEVELS
HIGH LEVELS
5Mo
100
50
-Fe
-Cu
CHECK
-Mo
-Mn
-Zn
-Mg
-B
-P
-Ca
-N
-K
5Cu
5Zn
CHECK
5Mn
5B
5Fe
5K (SO4)
5P
5N
5Ca(Cl)
5Ca(SO4)
5Mg
5K(Cl)
* Leaf symptoms present


TOTAL LENGTH GROWTH-(CM)
LOW LEVELS
CHECK
HIGH LEVELS
5P
500
300
100
-Mg
-Mn
-Fe
-Mo
-Zn
-Cu
-B
-Ca
-P
-K
-N
5B
5Cu
5K(SO4)
5Zn
5Mn
5Mo
5Fe
5N
5Ca(SO4)
5K(Cl)
5Ca(Cl)
5Mg
*Leaf symptoms present

The plants used in this experiment were rooted under normal field conditions and then subjected to severe nutritional conditions. The curves demonstrate the value of balanced nutrition (Shear, Crane and Myers, 1946); however, they do not show the relative effect of an element, should the deficiency continue to exist. In every case this would probably drop the values to zero with the time required depending on the element in question.

Increasing levels of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, and boron in the nitrient solution brought an increase of each specific element in the petioles and in stems. Iron, copper and zinc did not follow this tendency. Scharrer and Jung (1956) found a similar situation in an experiment with minor elements on corn and field beans. With corn, only iron was irregular, while copper and zinc increased with increasing levels in the nutrient solution. In field beans, however, all three elements behaved irregularly.

EXPERIMENT II

EFFECTS OF $\frac{Ca + Mg}{K}$ RATIOS ON GROWTH, PETIOLE AND STEM COMPOSITION

In Experiment I potassium deficiency appeared on leaves in the form of a purple coloring. Various visual symptoms have been reported for potassum deficiency under field conditions (Wilhelm, 1950). It has been suggested that these various patterns of potassium deficiency may be related to the presence of various levels of calcium and magnesium. Experiment II was set up to test this possibility.

EXPERIMENTAL PROCEDURE

The inter-relationship of calcium, magnesium and potassium and its effect upon Concord grape vines was tested with four replications of 18 treatments, as described in Appendix Table 9. Treatments 3 to 18 were a factorial study of four levels of calcium and magnesium in the nutrient solution with all other elements being constant. Treatments 1 and 2 contained 117 ppm potassium, while all other treatments had only 23 ppm. Treatments 1 and 3 and treatments 2 and 13 had the same calcium-magnesium combination, which made a comparison of the potassium effect possible.

One-half strength of the check solution for Experiment I (Appendix Table 1) was used as the basis for the experiment. The solution was modified,

according to the result of Experiment I, by doubling the manganese and increasing the copper content by 50%. Also, ferrous lactate was replaced as the iron source by Sequestrine. Appendix Table 10 shows the composition of the 18 solutions and their increasing $\frac{Ca+Mg}{K}$ ratios. Treatment 1 had a composition equal to one-half of the check solution.

Two-year-old plants were stored, pruned, and planted on January 17, 1957, as described in Experiment I. After planting they were arranged into four weight groups, and each group was considered as a replication. The average weight per group was 43, 62, 78 and 93 grams. The plants were fed for the first time on February 2.

All but 13 of the plants produced flower clusters, which were left on the plants in order to further the drain of potassium and to see if berries have any effect on deficiency symptoms. The flower clusters were "flicked" every day to enhance pollination.

When harvested on May 28, 29 and 30, total linear growth and dry weight accumulation of roots, stems, berries, petioles and leaf blades were determined. The stem and petiole tissues were analyzed as described in Experiment I. The data were statistically analyzed as a randomized block experiment (treatments 1 to 18) and as a factorial design (treatments 3 to 18).

Figure 10. Concord grape leaf injured by Aramite spray application as observed in the greenhouse.

RESULTS

GENERAL OBSERVATIONS

Breaking of buds occurred very evenly, with the plants of replication 1 (lightest in weight) being a little ahead of the other three replications. This gain was equalized later and no difference in rate of growth could be observed.

A spray application of Aramite (2-(p-tert-Butylphenoxy) isopropyl-2-chloroethyl sulfite) was used to control a severe mite infestation that developed after four weeks of growth. Leaf symptoms of injury, as shown in Figure 10, appeared on most leaves 24 hours later. A combination of the general conditions of the plants, temperature and moisture was suspected as the cause, because the standard concentration (1 oz. /3 gal.) that was applied does not normally injure greenhouse plants. The injured leaves did not drop off during the experiment, although some of the leaves were permanently injured.

The spray injury made it difficult to fully recognize potassium deficiency symptoms on these damaged leaves. New leaves, unfolding after the spray damage had occurred, were completely normal without any effect. Some leaves developed the purple casting as described in Experiment I. No so-called "black leaf" or brown leaves, as have been observed under field conditions, appeared. Stem and petiole analysis identified the purpling again as potassium deficiency.

Some leaves on plants receiving treatments 4 and 6 were very chlorotic and iron chlorosis was suspected.

VISUAL APPEARANCE OF ROOTS

There was very little variation in the general appearance of the root systems of plants in this experiment. All were judged as good in comparison with the standard of Experiment I. The only difference between the treatments was the color, which varied from dark brown to very light brown. No brittle roots were found, however, root dry weight accumulation varied considerably.

Roots of treatments 1 and 2 were darkest, while those of treatment 5 were nearly colorless. The roots of treatments included in the factorial treatments appeared as shown in Table 4 (numbers in parentheses are treatment numbers).

TABLE 4

VISUAL APPEARANCE OF ROOTS

Calcium	Magnesium Concentration (Ppm)			
Concentration - ppm	24	49	73	97
	(3)	(4)	(5)	(6)
100	Dark brown	Brown	Very light	Brown
	(7)	(8)	(9)	(10)
200	Dark brown	Brown	Light brown	Brown
	(11)	(12)	(13)	(14)
301	Dark brown	Brown	Light brown	Brown
	(15)	(16)	(17)	(18)
401	Dark brown	Dark brown	Dark brown	Light brown

GROWTH

Data pertaining to dry weight of roots, stems, berries, petioles, leaf blades and total for the plants, together with linear growth, are recorded in detail in Appendix Table 11. Dry weight determinations of the various plant parts were converted to per cent of the total dry weight accumulation for each treatment and shoot/root ratios were calculated. These values are recorded in Appendix Table 12.

Statistical analysis of the factorial portion of the experiment showed no significant differences for any of the above mentioned plant parts. Statistical analysis for the entire experiment as a randomized block design of 18 treatments showed that the treatments having a higher potassium content in the solution (treatments 1 and 2) were significantly different from treatments having a lower potassium content in the solution.

Although the $\frac{Ca+Mg}{K}$ ratio was increased from 5.3 to 21.2, there was no significant difference in the growth of any part of the plant, or the entire plant. The variations in the $\frac{Ca+Mg}{K}$ ratio were established by varying the calcium and magnesium content of the solution while potassium was maintained at the same level (23 ppm). An increase in the potassium content of the solution (ratios 1.6 and 3.2) resulted in significantly greater root growth and greater production of dry matter for the entire plant.

ELEMENTAL COMPOSITION OF PETIOLES AND STEMS

Detailed data pertaining to petiole and stem composition can be found in Appendix Tables 13 and 14. Significance of F values, as established in the statistical analysis of the factorial design are reported in Appendix Table 15.

The $\frac{Ca+Mg}{K}$ ratio in the nutrient solution was of no direct influence upon nutrient composition of petioles and stems for any one element; however, varied levels of calcium and magnesium in the solution had a significant influence upon certain nutrients. Also potassium was of influence as shown by the comparison of treatments 1 with 3 and 2 with 13,

Nitrogen: Large variations in nitrogen content of petioles and stems occurred, even though nitrogen was constant in all solutions. No statistical analysis was made for petiole nitrogen because of poor petiole growth in some treatments.

A comparison of treatments 1 and 2 (117 ppm K) with treatments 3 and 13 (23 ppm K) showed that when calcium and magnesium were at the low level of supply, and increase in the potassium supply resulted in a decrease of nitrogen in stems and petioles. Statistical analysis of the factorial design showed a significant F value for the effect of calcium on nitrogen content of stems. Increasing levels of calcium in the solution produced decreasing levels of nitrogen in the stems, as shown in Table 5. This influence of

TABLE 5

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON NITROGEN CONTENT (%-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	1.45	1.89	1.45	1.64	1.68
200	1.30	1.49	1.49	1.37	1.41
301	1.41	1.32	1.41	1.32	1.37
401	1.33	1.26	1.33	1.27	1.30
Means for Mg levels	1.41	1.49	1.46	1.40	
LSD Calcium levels		5%		.12	
		1%		.17	
Magnesium levels		NS			

TABLE 6

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON POTASSIUM CONTENT (%-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means of Ca Levels
100	.76	.80	.66	.76	.74
200	.68	.72	.64	.45	.62
301	.51	.46	.52	.54	.51
401	.79	.98	.64	.60	.75
Means for Mg levels	.68	.74	.61	.59	
LSD Calcium levels		5%		.19	
Magnesium levels		NS			

increasing levels of calcium was not observed in the petiole analysis, except where 97 ppm (3x) magnesium was used. Here, the nitrogen concentration of the petioles was reduced from 3.15 to 2.43% dry weight as the calcium supply in the solution was increased.

Potassium: Petioles of treatment 3 (23 ppm K) contained .76% potassium compared to 5.86% in the petioles of treatment 1 (117 ppm K), or treatment 1 had five times more potassium in the solution and 7.7 times more in the petioles than treatment 3. The difference in stem potassium was much smaller (.48% for treatment 3 and .74% for treatment 1). Treatment 2, with the same amount of potassium in the solution as treatment 1, but three times more calcium and magnesium, had 3.21% potassium in the petioles and .80% in the stems. Treatment 13, on the other hand, which was equal to 2 except for the lower potassium level, had only .52% potassium in stems and petioles.

Statistical analysis of the factorial design showed that the calcium levels in solution had a significant influence on petiole potassium. Potassium decreased as the calcium level in the solution was increased up to 301 ppm (3x), but an increase to 401 ppm calcium resulted in an increase of the potassium content in the petioles, as shown in Table 6.

The potassium content of stems was equal to, or higher than, the potassium content of petioles for treatments that received 301 ppm calcium (3x) in the solution.

Phosphorus: Treatments 1 and 2, which had 117 ppm potassium in the solution, had a lower phosphorus content of both petioles and stems than treatments 3 and 13, respectively (23 ppm potassium). Treatment 2 with three times as much calcium and magnesium in the solution as treatment 1 was significantly higher than treatment 1 in phosphorus for both stems and petioles.

The effect of calcium and magnesium in the solution upon petioles (Table 7) and stems (Table 8) was expressed by highly significant F values. An increase in calcium supply resulted in a decrease in petiole phosphorus, while an increase in magnesium supply caused an increase in petiole phosphorus. The phosphorus content of the stems was increased with higher levels of magnesium. A depression in stem phosphorus occurred when the solution calcium level was raised from 100 to 200 ppm, but further additions of calcium brought slight increases of phosphorus.

Calcium: The petioles of treatment 1 had the highest calcium content (2.40%) of any treatment. Plants of treatment 3, which had less potassium in the solution than treatment 1, had less calcium in the petioles (.64%) even though the calcium supply was equal. Furthermore, treatment 2, with the same potassium level as treatment 1 but three times more calcium and magnesium, was lower in petiole calcium (1.64%) than treatment 1. Treatment 13 resulted in less petiole calcium than treatment 2 with equal calcium supply and less potassium supply.

TABLE 7

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON PHOSPHORUS CONTENT (%-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	.73	.74	.75	.77	.75
200	.50	.62	.66	.71	.62
301	.57	.58	.58	.58	.58
401	.52	.56	.53	.59	.55
Means for Mg levels	.58	.63	.63	.66	
LSD Calcium levels and Magnesium levels		5%	.05		
		1%	.06		

TABLE 8

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON PHOSPHOROUS CONTENT (%-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	.26	.35	.30	.35	.31
200	.29	.27	.29	.27	.27
301	.27	.26	.29	.29	.28
401	.29	.29	.28	.29	.29
Means for Mg levels	.27	.30	.29	.30	
LSD Calcium and Magnesium levels		5%	.02		
		1%	.03		

The calcium level of the solution had a highly significant effect on stem and petiole calcium. The magnesium level of the solution had a significant influence on the calcium content of stems but not on petioles. Increasing calcium levels in the nutrient solution resulted in an increase in calcium of petioles (Table 9) and stems (Table 10). An increase in magnesium in the solution resulted in a decrease of the calcium content in stems.

Magnesium: The highest magnesium content for petioles was found in treatment 10 (200 ppm Ca, 97 ppm Mg, and 23 ppm K), and the lowest in treatment 1 (100 ppm Ca, 24 ppm Mg, and 117 ppm K). Treatment 2, equal in potassium content, but with three times more calcium and magnesium in the solution than treatment 1, had nearly twice as much magnesium in the petioles than treatment 1. Treatment 13, equal to 2 except for lower potassium, had slightly more magnesium in the petioles than 2. The stem analysis followed the same trend.

In the factorial experiment, the magnesium and calcium levels had a highly significant effect on the magnesium concentration in the petioles, but not in the stems (Table 11). Increasing levels of magnesium in the solution, resulted in an increase in petiole magnesium. An increase in the calcium content of the solution from 100 to 200 ppm resulted in an increase of the magnesium content of petioles. Increasing the calcium content of the solution to 301 and 401 ppm resulted in values for petiole magnesium below that found for the ones with 200 ppm of calcium in the solution.

TABLE 9

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON CALCIUM CONTENT (%-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	.64	.45	.44	.44	.49
200	.95	.85	.88	.83	.87
301	1.05	.85	.62	.71	.80
401	1.05	1.05	.84	.78	.93
Means for Mg levels	.92	.80	.69	.68	
LSD Calcium and magnesium levels		5%	.12		
		1%	.16		

TABLE 10

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON CALCIUM CONTENT (%-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	.39	.42	.43	.42	.41
200	.57	.49	.44	.42	.48
301	.55	.55	.48	.52	.53
401	.64	.68	.59	.64	.60
Means for Mg levels	.53	.54	.49	.50	
LSD Calcium and magnesium levels		5%	.05		
		1%	.07		

TABLE 11

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON MAGNESIUM CONTENT (%-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	.74	.88	.88	1.29	.95
200	.78	1.10	1.24	1.71	1.20
301	.88	1.29	1.13	1.25	1.14
401	.69	.84	1.08	1.15	.94
Means for Mg levels	.77	1.03	1.08	1.35	
LSD Calcium and magnesium levels		5%	.18		
		1%	.24		

TABLE 12

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON MANGANESE CONTENT (PPM-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	128	210	169	236	186
200	111	208	165	186	167
301	172	152	139	189	163
401	142	132	111	132	129
Means for Mg levels	138	175	186	146	
LSD Calcium and magnesium levels		5%	27		
		1%	36		

Manganese: Although the manganese content of the petioles varied between 371 and 890 ppm, the analysis of variance showed no significant differences between the treatments when analyzed as a randomized block design.

However, the analysis of the factorial treatments showed that calcium and magnesium had a significant influence on the manganese content of stems (Table 12). Increasing levels of calcium in the solution significantly depressed the manganese content of stems. The first three levels of magnesium in the solution enhanced the manganese content in the stems, but the fourth level depressed the manganese content below that found for the 73 and 97 ppm (2x and 3x) levels.

Iron: Petiole and stem content of iron was lowest in treatments 1 and 2, which contained 117 ppm of potassium. The highest level of potassium in the solution resulted in significantly less iron in the stems, regardless of the levels of calcium and magnesium, but had no effect when the calcium and magnesium was increased.

The influence of calcium on iron in the stems was also significant, with 100 ppm (1x) calcium having the highest iron content and 200 ppm (2x) calcium having the lowest iron content. The iron content of stems increased, however, above that found for 200 ppm, when 300 ppm (3x) and 400 ppm (4x) calcium were added (Table 14).

The calcium-magnesium interaction was highly significant for iron

TABLE 13

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON IRON CONTENT (PPM-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm)				Means for Ca Levels
	24	49	73	97	
100	101	107	94	83	96
200	75	108	106	103	98
301	124	107	72	85	97
401	86	90	95	98	92
Means for Mg levels	96	103	92	92	
LSD Calcium and magnesium levels			NS		
Calcium-magnesium interaction			5%	30	
			1%	40	

TABLE 14

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON IRON CONTENT (PPM-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm)				Means for Ca Levels
	24	49	73	97	
100	105	131	104	131	118
200	85	89	97	85	89
301	86	93	91	104	93
401	99	98	94	101	98
Means for Mg levels	94	103	97	105	
LSD Calcium levels		5%	20		
		1%	26		
Magnesium levels		NS			

in petioles (Table 13). With 100 ppm (1x) calcium in the solution there was no significant influence of the magnesium levels upon the iron content of the petioles. However, the lowest iron content was found in combination with 73 ppm (3x) magnesium. With 200 ppm (2x) calcium in the solution the use of 24 ppm (1x) magnesium resulted in iron being significantly below that found for either 49 or 73 ppm (2x and 3x) magnesium. With 301 ppm (3x) calcium in the solution and 73 ppm (3K) magnesium, the lowest iron content of petioles resulted, while with 24 ppm (1x) magnesium the highest content occurred. The various magnesium levels were of no influence upon the iron petiole content when combined with 401 ppm (4x) calcium.

Boron: A decrease in potassium from 117 ppm (treatment 1) to 23 ppm (treatment 3) resulted in an incrrase in the boron content of the petioles. However, with higher levels of calcium and magnesium reduced potassium levels did not affect the amount of boron in the petioles.

Statistical analysis of the factorial design showed that the levels of calcium and the calcium-magnesium interaction had a significant influence upon the boron content of the petioles (Table 15) and stems (Table 16). The level of magnesium on the other hand, significantly affected boron only in the stems.

The interaction of magnesium with calcium showed that the influence of calcium upon the boron content of the petioles was reduced with higher

TABLE 15

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON BORON CONTENT (PPM-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	92	49	58	49	62
200	29	32	30	31	31
301	12	24	32	34	25
401	31	42	27	32	33
Means for Mg levels	41	37	37	37	

LSD Calcium levels	5%	6		
	1%	8		
Magnesium levels	NS			
Calcium-magnesium interaction	5%		12	
	1%		16	

TABLE 16

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON BORON CONTENT (PPM-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	11	25	25	36	24
200	13	11	21	17	16
301	10	14	19	20	16
401	16	20	12	13	15
Means for Mg levels	12	17	19	22	

LSD Calcium and magnesium levels	5%	3		
	1%	4		
Calcium-magnesium interaction	5%		6	
	1%		9	

levels of magnesium. The low level of calcium resulted in a greater amount of boron in the petioles than found for the other levels of calcium regardless of mangesium supply. Conversely the influence of magnesium upon boron content of the stems was reduced with higher levels of calcium. An increase in the magnesium supply resulted in an increase in stem boron only when in combination with 100 ppm (1x) of calcium.

Copper: The use of 117 ppm of potassium resulted in a significantly higher value for copper in the petioles than found with 23 ppm of potassium when the level of calcium and magnesium in the solution was low (1x).

Increasing the level of calcium or magnesium in the nutrient solution had a significant depressing effect on copper in the petioles (Table 17). The influence of calcium was associated mainly with the low level (1x).

Furthermore, the F value for the interaction calcium-magnesium of the factorial design indicated that a significant influence was exerted on the copper content of both petioles and stems. The use of 24 and 49 ppm (1x and 2x) magnesium depressed copper in petioles significantly more when combined with 200, 301 and 401 ppm (2x, 3x and 4x) of calcium than when combined with 100 ppm (1x) calcium in solution. The combination of 73 ppm (3x) magnesium with 200 and 401 ppm (2x and 4x) of calcium in the solution depressed copper more than when combined with 100 or 301 ppm (1x and 3x) in the solution. All four calcium levels in combination with

TABLE 17

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON COPPER CONTENT (PPM-DRY WEIGHT) OF PETIOLES (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	37	29	27	25	29
200	23	23	20	23	22
301	23	24	27	23	24
401	25	26	21	24	24
Means for Mg levels	27	25	23	23	

LSD	Calcium and magnesium levels	5%	2	
		1%	3	
	Calcium-magnesium interaction	5%		4
		1%		6

TABLE 18

INFLUENCE OF VARIABLE CALCIUM AND MAGNESIUM LEVELS ON COPPER CONTENT (PPM-DRY WEIGHT) OF STEMS (MEANS OF 4 REPLICATIONS).

Calcium Conc. (Ppm)	Magnesium Concentration (Ppm) 24	49	73	97	Means for Ca Levels
100	20	21	23	20	21
200	21	20	21	17	19
301	16	19	23	23	20
401	19	22	18	20	20
Means for Mg levels	18	20	21	20	

LSD	Calcium and magnesium levels		NS	
	Calcium-magnesium interaction	5%		3
		1%		4

97 ppm (4x) magnesium resulted in almost the same copper values for petioles.

In stem analysis it was found that the 1x level of magnesium when combined with the 1x level of calcium in the solution depressed copper significantly more than when combined with the other three calcium levels (Table 18). With 49 and 73 ppm (2x and 3x) magnesium there was a significant difference between the 3x and 4x levels of calcium. 97 ppm (4x) magnesium combined with 200 ppm (2x) calcium in the solution depressed copper uptake more than when combined with the other three calcium levels.

Zinc: The treatments (1 and 2) that contained 117 ppm potassium resulted in significantly more zinc in the petioles than the corresponding treatments (3 and 13) that contained only 23 ppm potassium in the solution. An increase in the supply of calcium and magnesium significantly reduced the amount of petiole zinc associated with the use of 117 ppm of potassium.

No significant influence of calcium or magnesium supply upon zinc content of either petioles or stems was found in the factorial experiment.

DISCUSSION

A variation in the appearance of potassium symptoms occurs not only on labrusca type grape plants, but also on vinifera varieties.

Harding (1957) observed only purple symptoms in an experiment on Concord grapes with nutrient culture. Stellwaag (1955), in nutrient culture experiments with Riesling, Sylvaner, and Burgunder vines, was able to produce brown symptoms by using Van der Crone, Hellriegel, and Merkenschlager solutions. He was, however, unable to obtain them with Hoagland solution because iron chlorosis appeared and masked the symptoms of potassium deficiency. The statement of Gärtel (1955) that with potassium deficiency symptoms the ratio of K_2O:Mg in leaves is below 1, held true for petioles in this experiment.

Knotte and Ritschl (1931) gave a description of nutrient culture results obtained under potassium deficient conditions. They mentioned that "greasy looking spots" appeared first on the leaf epidermis between the veins. These spots later turned yellow and then brown, with the tissue dying off. Preliminary experiments by the author (Bergman and Kenworthy, 1956) showed similar symptoms under combined molybdenum and potassium deficient conditions. Inasmuch as in 1931 not much was known of the essentiality of molybdenum for plant growth, it might well be worth while to further investigate these possible connections.

The composition of the nutrient solutions in this experiment was designed to study various $\frac{Ca+Mg}{K}$ ratios in relation to the various potassium deficiency symptoms described in literature. Since in Experiment I the potassium content of the petioles was far above the usual field potassium content, it was felt that 1/2x modified Hoagland solution would be a justified basis. However, it became evident from the stem and petiole analysis at the end of the experiment that 23 ppm potassium in the solutions for treatments 3 to 18 was too low in comparison with the calcium and magnesium levels and that potassium may have been the limiting factor in all treatments. On the other hand, if higher levels of potassium would have been used, the calcium and magnesium should have been increased to provide the desired ratios and potassium may still have been the limiting factor.

The higher $\frac{Ca+Mg}{K}$ ratios obtained by increasing the calcium and magnesium supply had no direct influence on the stem or petiole composition for any specific element. Increasing ratios of treatments 1, 2 and 3 (ratios 1.6 to 5.3) resulted in a decrease in potassium, calcium and zinc and an increase in nitrogen, phosphorus, boron and copper content of the petioles. Furthermore, there was an increase in total dry weight and an increase in total linear growth and in the shoot/root ratios. Since treatments 1 and 2 had the same potassium content in the solution, with 2 having higher calcium and magnesium levels, and treatment 3 having lower potassium content than 1,

the effect seemed to be due to potassium rather than the ratios. Otherwise, treatments 3 to 18 should have shown similar response.

Statistical analysis of the factorial design (treatments 3 to 18), in which only the calcium and magnesium level of the solution was varied, gave some indications of how the various elements in petioles and stems were affected by these two elements or their interaction (Appendix Table 15). Increasing levels of calcium in the solution resulted in a significant increase in calcium and a decrease in phosphorus, potassium, boron and copper in petioles. Increasing levels of magnesium brought a significant increase of phosphorus and magnesium, but a decrease in calcium and copper. The stems followed the same trend. The effect of calcium and magnesium in the solution upon these elements in petioles or stems, agreed with the results of Experiment I.

It is interesting to note that when the potassium level in the solution was reduced from 117 ppm to 23 ppm, there was a slight increase in the magnesium content of the petioles and the calcium content of the petioles decreased from 2.40 to .64% (treatments 1 and 3) while with a higher level of calcium in the solution a further decrease from 1.64 to 1.13% (treatments 2 and 13) was observed. This could be interpreted that a certain level of potassium in the substrate may be necessary for an adequate absorption of calcium.

In the chapter on deficiency and toxicity symptoms of leaves, it was stated that treatments 4 and 6 were chlorotic and iron chlorosis was expected to be the cause. Both treatments, however, had the highest iron content (131 ppm) of the stems. Gouny and Mazoyer (1953) felt that there are two different kinds of iron chlorosis: one, where the iron is tied up in the soil due to high pH, and the other due to metabolic actions within the plant. In the latter case, very low levels or very high levels of potassium might be responsible. Lindner and Harley (1944) found very high potassium concentrations in leaves of Bartlett pear trees showing iron chlorosis. The data of Experiment II show that the above mentioned first reason could not be responsible for the observed chlorosis because the pH of the solution was 5.0 and, furthermore, actually more iron was found in the stems of the chlorotic plants than in the other stems.

However, one striking factor is the high level of iron found in the stems, as compared to the lower levels found in petioles. This phenomena could not be associated with any specific ratio of calcium/potassium, magnesium/potassium, calcium/magnesium or $\frac{\text{calcium + magnesium}}{\text{potassium}}$. Experiment I produced the highest iron stem value under potassium deficient conditions (100 ppm versus 80 ppm in petioles), while the high calcium treatment had slightly more iron in the petioles than in the stems (50 ppm versus 45 ppm). Furthermore, in this experiment, the highest phosphorus petiole and stem contents coincided with the highest iron stem contents.

Based on these data, it is suggested that under low or potassium deficient conditions the metabolic process in the plant is slowed down. Since this slower process needs less energy, derived from the organic phosphate which, in turn, is present within the plant in higher concentration, any excess would combine with the iron and form an insoluble iron-phosphate complex which would prevent any further iron translocation to the petioles.

To the author's knowledge nobody has been able to explain the various potassium deficiency symptoms on grape vines from a nutritional viewpoint. The results of this experiment suggest that this problem may not be solved on the basis of mineral nutrition. The occurrence of necrotic tissues in the event of potassium deficiency may be considered as the normal symptom. An investigation of the various leaf colors associated with potassium deficiency may best be approached on a biochemical basis to establish what pigments are involved and to study the quantities present, as well as to investigate the origin of the pigments. An approach similar to that employed by Burghardt (1956) could be used as basis for tests in this respect.

EXPERIMENT III

EFFECT OF THREE LEVELS OF MANGANESE ON GROWTH, PETIOLE AND STEM COMPOSITION

The petiole manganese content of the check treatment in Experiment I was very low, compared to the average of field samples collected in late July. It was also found that the manganese content of petioles from plants grown under field conditions increased throughout the season (Bergman and Kenworthy, 1957), and reached a value as high as 2700 ppm in late fall without any specific leaf symptoms. Therefore, Experiment III was designed to find out how high the manganese content in the solution had to be in order to reproduce the values for manganese found in average field samples and to observe the effects of very high levels of manganese in the solution upon the plants and absorption of nutrients.

EXPERIMENTAL PROCEDURE

This experiment was conducted simultaneously with Experiment II. The experimental methods were the same as for Experiment II. Furthermore, the check of Experiment II (1/2x modified Hoagland solution with 1.0 ppm (2x) manganese) served also as a check for this experiment (Appendix Table 9).

The other treatments had 12.5 and 25 ppm (25x and 50x Hoagland) manganese in the 1/2x Hoagland solution.

RESULTS

GENERAL OBSERVATIONS

Since the experiment was carried out at the same time and with plants like those of Experiment II, the general behavior of the plants, including spray injury, was the same. Here too, the flower clusters were left on the plants and the berries were allowed to develop. On warm, sunny days, the plants supplied with 12.5 and 25 ppm manganese seemed to need more sulution because wilting occurred more quickly. This may have been associated with the rather fine texture of the young leaves. Plants receiving the high levels of manganese grew very well, but the berries did not seem to ripen evenly on each cluster, while they ripened well on the plants of the check treatments.

VISUAL SYMPTOMS

During 15 weeks, the high manganese plants grew normally like the check plants. At this time the youngest leaves of the high (25 ppm) manganese treatment began to show interveinal chlorosis with the veins staying green (Figure 11). After a week, the green veination disappeared too, and the entire leaf took on a greenish-brown color with darker brown edges not wider than the depth of the dentation. The older leaves kept their normal green color and did not turn brownish. Leaf enlargement was slightly hampered. No similar symptom was observed throughout these investigations. The roots were judged as good, and actually nothing specific was observed on either stem or roots.

Figure 11. Symptom on grape leaves observed when plants were supplied with the high level (25 ppm) of manganese in the nutrient solution, after 15 weeks of growth.

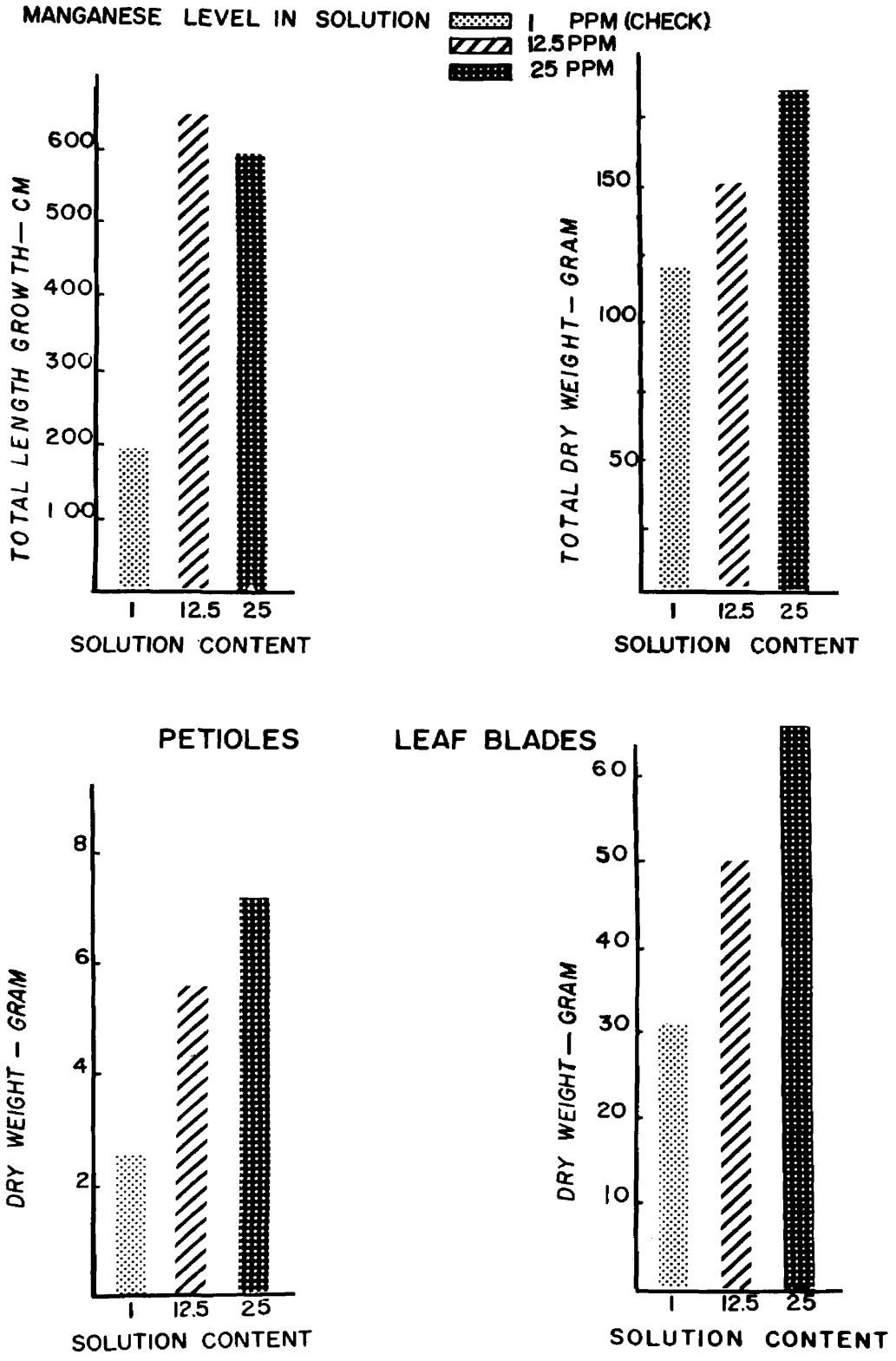


Figure 12. Effect of three levels of manganese in the solution on total linear growth, total dry weight, petiole and leaf blade dry weight accumulation.

GROWTH

Data pertaining to total linear growth and total dry weight accumulation of roots, stems, berries, petioles and leaf blades can be found in Appendix Table 16. Dry weight accumulation of roots, stems and berries, petioles and leaf blades converted into per cent of total dry weight accumulation are recorded in Appendix Table 17.

Total Linear Growth (Figure 12)

There was a significant increase in total linear growth from 192 cm to 658 cm when the manganese content in the solution was increased from 1.0 ppm to 12.5 ppm. However, further increases in manganese brought a slight depression to 610 cm which, however, was still significantly larger than the check.

Total Dry Weight Accumulation (Figure 12)

The total dry weight accumulation increased with increasing manganese content in the solution. The treatment containing 25 ppm manganese in the solution produced significantly more total dry weight than the check (1.0 ppm Mn) treatment. The 12.5 ppm treatment resulted in 150.36 grams of dry matter. This was 31 grams more than found for the check, and 37 grams less than for the treatment containing 25 ppm manganese.

Dry Weight Accumulation of Roots, Stems, Berries, Petioles and Leaf Blades

Statistical analysis for dry weights of the above mentioned plant parts showed no significant difference between the treatments for roots, stems and berries. The dry weight of stems, however, increased with increasing levels of manganese in the solution. The 12.5 ppm treatment produced twice as much stem dry weight and the 25 ppm treatment three times as much as the check.

This same trend held true for the petioles. Here both the 12.5 and 25 ppm treatments were significantly higher in petiole dry weight than the check (Figure 12). Although the 25 ppm manganese level produced more petiole dry weight than the 12.5 ppm manganese level, the difference was not significant.

Dry weight accumulation of leaf blades increased with increasing levels of manganese in the solution. The use of 12.5 ppm of manganese resulted in significantly greater production of leaf blades than 1.0 ppm of manganese (check). Also, the use of 25 ppm of manganese in the solution resulted in significantly greater dry weight of leaf blades than 12.5 ppm (Figure 12).

Accumulation of Dry Weight Expressed in Per Cent of Total Dry Weight by Roots, Stems and Berries, Petioles, and Leaf Blades

Converting the dry weight measurements into per cent of total dry weight showed that stems and berries, petioles, and leaf blades increased

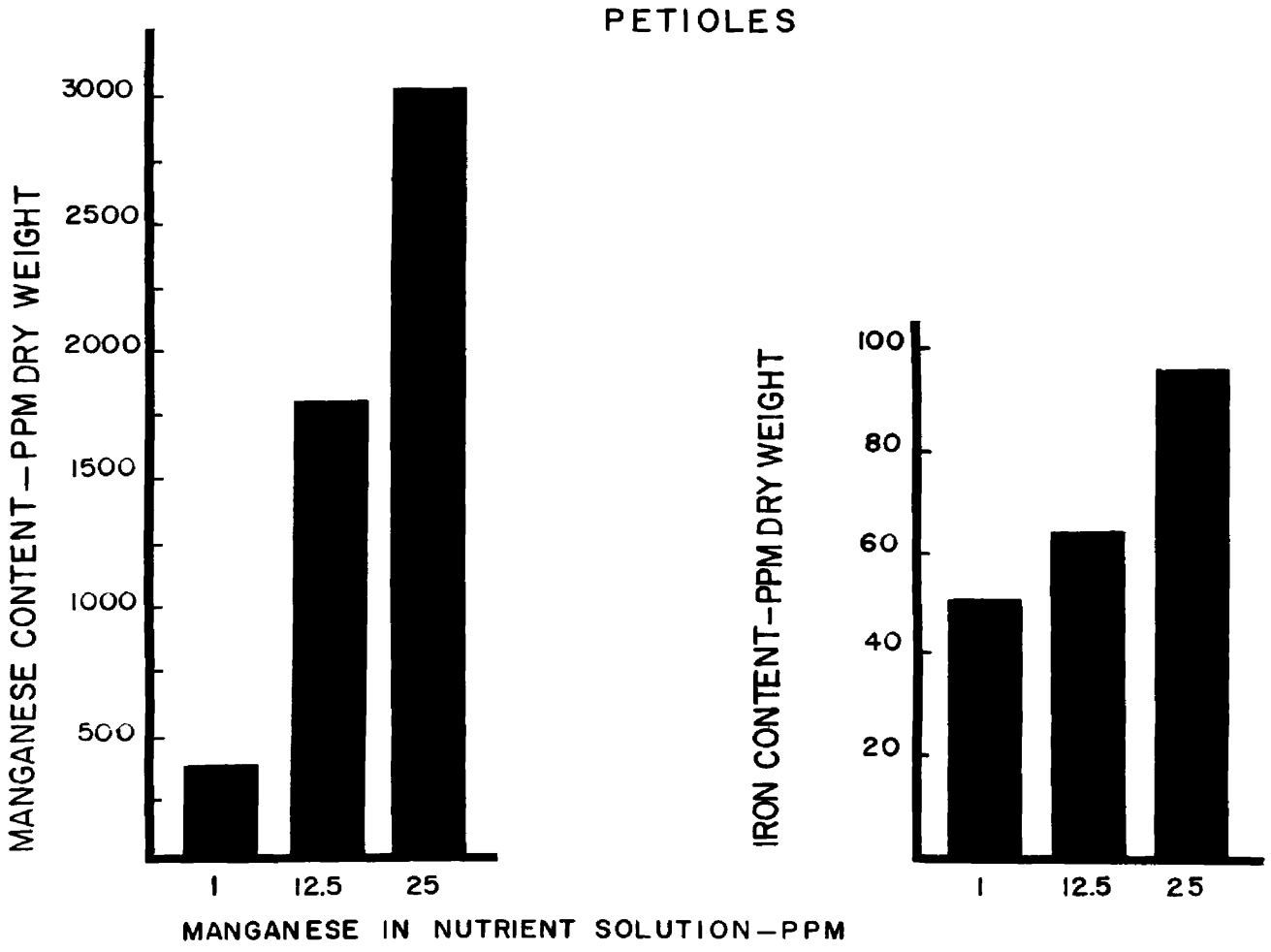


Figure 13. Effect of three levels of manganese in the solution of manganese and iron in the petioles.

with increasing levels of manganese in the solution, while the roots decreased. Since shoot growth increased, and root growth decreased, there was an increase in the shoot/root ratios as the manganese level was increased. The differences in the per cent of total dry weight for the different plant parts was always greater for the increase from the 1.0 to 12.5 ppm manganese level than for the increase from the 12.5 to 25 ppm manganese.

ELEMENTAL COMPOSITION OF PETIOLES AND STEMS

Data pertaining to petiole and stem composition are given in Appendix Tables 18 and 19, respectively. Statistical analysis showed a significant effect of the treatments on uptake of iron and manganese in petioles without any significant influence on the other elements. The elemental composition of the stems was not significantly affected.

Although the differences were not significant the increase in manganese supply seemed to decrease the petiole concentration of nitrogen, phosphorus, potassium, calcium and magnesium. Stem analysis for nitrogen showed a decrease, while phosphorus, potassium and calcium showed an increase with increasing levels of manganese in the solution.

Iron (Figure 13) in the petioles was significantly increased as the manganese content of the solution was increased. The increase in iron of stems associated with increasing levels of manganese in the solution was

however not significant. Iron in the petioles of the 25 ppm manganese treatment was significantly higher than in the 12.5 ppm treatment and in the check (1.0 ppm Mn). In all three treatments the stem iron content was lower than the petiole iron content.

Manganese (Figure 13) in petioles was increased five fold when manganese in the solution was increased from 1.0 to 12.5 ppm. There was about eight times as much manganese in the petioles from the 25 ppm treatment than in the petioles from the check treatment (1.0 ppm Mn). The stems had three times more manganese when the solution manganese level was raised from 1.0 to 12.5 ppm, and seven times more when increased to 25 ppm. Also, the petioles contained four times more manganese than the stems for the check treatment, the difference increased to seven fold when manganese was increased to 12.5 ppm, and to 4.7 fold with 25 ppm manganese in the solution. The value of 3067 ppm of manganese in the petioles from the 25 ppm manganese treatment was comparable to the high values found under field conditions in late summer. However, the use of 12.5 ppm of manganese in the solutions resulted in values for petiole manganese in excess of the values found for average field samples in midsummer.

DISCUSSION

Manganese in the solution strongly influenced the manganese concentration in the plant, and seemed to be taken up in solution to its amount present in the substrate. Maume and DuLac (1952) reported, after investigating various grape varieties grown in different locations, that the specificity of a variety or species was not responsible for the manganese content of the various plant parts, but primarily the location. Large differences of manganese in grape petioles were found by Bergman and Kenworthy (1957) under Michigan conditions which coincided with highly variable manganese levels in Michigan soils (Lawton, 1957). Therefore, the reaction of grapes to manganese in nutrient culture is understandable. Furthermore, the pH of the nutrient solution used in this experiment was about equal to the pH of the soil in which grapes are grown in Michigan.

It is interesting to note that apples, containing over 500 ppm manganese in the leaves, normally show internal bark necrosis (measles) on the stems (Kenworthy, 1957) while under field conditions the grape vine with 2800 ppm in the petioles produced no observed symptoms. The leaf symptoms present in Experiment III with 3067 ppm manganese in the petioles may have been the beginning of a deficiency induced by the high levels of manganese or an expression of manganese excess.

In stems of the 25 ppm manganese treatment plants, the phosphorus

was higher than in the petioles which would indicate, if interpreted on the basis of findings in Experiment I, that the plants were low or deficient in phosphorus. Extremely high manganese leaf values were found under field conditions by Gärtel (1956) and were associated with phosphorus deficiency symptoms. However, the symptoms observed on the plants of the 25 ppm treatment were not similar to symptoms of phosphorus deficiency found in Experiment I.

The potassium content of petioles and stems decreased with increasing manganese levels in the solution. The data from Experiment I suggest that with high levels of potassium in the solution the manganese was depressed more than the potassium was with high manganese levels.

There are many reports in literature indicating high levels of heavy metals in the solution which induce iron chlorosis (Goodall and Gregory, 1947; DeKock, 1956). Weinstein and Robbins (1955) noted that under high manganese and low iron levels true iron deficiency is induced. On the other hand, Burghardt (1956) was unable to find any indications of iron/manganese antagonism in spinach plants. He based his statement on results obtained on the rate of CO_2 assimilation and respiration as well as the amount of chlorophyll and xanthophyll present under low and high iron or manganese levels. In Experiment III the iron in petioles increased with increasing manganese in the solutions. Furthermore, the difference between stem and petiole iron increased with higher manganese levels. In treatments 4 and 6 of Experiment II, the

petiole iron content was far below that in stems and the visible symptoms (iron chlorosis) did not match the symptoms obtained under high manganese levels or symptoms found in Experiment I.

The correlation coefficient between iron and manganese in petioles was calculated separately for treatments varied in iron and manganese (Experiments I and III), calcium and magnesium (Experiment II), and for all the treatments of Experiment I where every element was varied and the following results were obtained:

only iron and manganese varied	+ .826
all elements varied	+ .718
calcium and magnesium varied	+ .461

The first two correlation coefficients were significant at the 1% level and the third at the 5% level. This suggests that iron and manganese are acting independently; otherwise, a negative correlation should have been found.

Since the correlation between iron and manganese in the calcium and magnesium treatments is comparatively low, a possible direct or indirect relation could exist with these elements. It, therefore, appears that the visual symptoms observed with the 25 ppm treatment are manganese toxicity symptoms, based on spectrographic analysis for total iron in petioles and stems. Since the leaves were not analyzed and no comparison was made between "active" and total iron present (Samish, 1954) it is felt that the symptoms observed were not connected with low levels of total iron.

SUMMARY

The response of Concord grape vines to high and low levels of eleven nutrient elements was studied in the greenhouse in three experiments. In each case, the plants were grown for 16 weeks with nutrient solutions and using quartz sand as growing media.

In Experiment I one-year-old rooted cuttings were used and the check treatment was supplied with standard Hoagland solution No. 1 (Hoagland and Arnon, 1950). The high and low levels of eleven nutrient elements were obtained by adjusting the composition of the standard solution to the specific levels. High calcium and potassium were tested in combination with sulfate and chloride as anions. This provided 25 treatments which were arranged in a randomized block with three replicates per treatment.

In Experiments II and III two-year-old rooted cuttings were used. The check solution was modified by doubling the manganese and increasing the copper content by 50%. Ratios from 1.6 to 21.2 of $\frac{Ca+Mg}{K}$ in the nutrient solution, based on 1/2x modified Hoagland solution, were used to test the influence on growth and the visible expression of potassium deficiency arranged in a randomized block, 18 treatments with four replicates per treatment, were the basis for Experiment II. Sixteen of these 18 treatments were set up as a 4 x 4 factorial design containing four levels each of calcium and magnesium, with all other elements constant. The other two treatments were varied in the potassium content.

In Experiment III the effect of three levels of manganese in the nutrient solution was tested with three treatments having four replicates each. Petioles and stems of each plant were analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, copper, zinc, and partially for chloride.

Total linear growth, total dry weight accumulation, as well as dry weight accumulation by roots, stems, berries, petioles, and leaf blades were taken.

Low levels of nutrients depressed dry weight accumulation in the following decreasing order: potassium,>nitrogen,>calcium,>phosphorus, >boron,>magnesium,>zinc,>manganese>molybdenum. High levels of nutrients were of depressing effect in the following decreasing order: potassium with chloride,>magnesium,>calcium with sulfate,>calcium with chloride,>nitrogen, >phosphorus,>potassium with sulfate,>iron,>boron,>manganese. The high molybdenum treatment resulted in the greatest dry weight accumulation.

Linear growth was depressed by deficient levels of nutrients in the following decreasing order: nitrogen,>potassium,>phosphorus,>calcium, >boron,>copper,>zinc,>molybdenum,>iron,>manganese,>magnesium. High levels of nutrients depressed in the following decreasing order: magnesium, >calcium and potassium with chloride,>calcium with sulfate,>nitrogen,>iron, >manganese,>molybdenum,>zinc,>potassium with sulfate,>copper,>boron. The check treatment resulted in the greatest linear growth with the high phosphorus treatment close second.

Treatments deficient in nitrogen and phosphorus or high in magnesium and molybdenum produced the lowest shoot/root ratios. High levels of phosphorus, nitrogen and low levels of magnesium resulted in highest shoot/root ratios.

Based on dry weight accumulation, low potassium, high calcium with chloride, and high magnesium produced least petioles percentage-wise. Most leaf blades (per cent of total dry weight) were caused by high nitrogen levels.

A positive relationship between the specific nutrient element in the solution and the petiole content was observed for all elements with the exception of iron and zinc. Petioles seemed to be the better indicators of normal and above normal levels of nutrition than the stems. The stems, on the other hand, were better indicators of low and deficient levels. The stem content was always equal to, or higher than, the petiole content under low or deficient nutrient conditions.

The $\frac{Ca+Mg}{K}$ ratios in the nutrient solution were of no direct influence on total linear growth, total dry weight accumulation, or the appearance of the potassium deficiency symptoms. Indirectly, however, potassium, calcium or magnesium exerted varied influences.

Chronological appearance of visible deficiency or toxicity symptoms did not correlate with the depressive elemental effects on total linear growth and dry weight accumulation. These symptoms appeared on plants of the

mentioned treatments in the following order: - N after 4 weeks, 5 N and 5 P after 6 weeks, - K and 5 $K(SO_4)$ after 9 weeks, 5 K(Cl) and - Fe after 10 weeks, - Mg, - Mn, - B and - Cu after 11 weeks, - P, - Ca, - Zn after 12 weeks, and - Mo after 14 weeks.

It was impossible to grow plants without any nitrogen for longer than three weeks. Magnesium deficiency symptoms appeared more quickly on plants with high potassium treatments than on those treated with magnesium deficient solution.

Visible deficiency symptoms on plants, as described, were associated with the following nutrient levels in the petioles: nitrogen .51%, phosphorus .10%, potassium .47%, calcium .26%, magnesium .14%, manganese 18 ppm, boron 14 ppm, copper 28 ppm, and zinc 11 ppm.

Many significant interactions between nutrient elements were found. In general, major elements influenced the concentration of minor elements in petioles and stems more than minor elements influenced major elements. High levels of major elements in solution induced deficiency symptoms of other elements.

Some of the more striking interactions between elements were as follows: (1) Low nitrogen in the solution resulted in low phosphorus, low boron, and high calcium in petioles. (2) High nitrogen produced high phosphorus and high boron petiole contents. (3) Low phosphorus in petioles coincided with high manganese and high iron. (4) Very low levels of copper and

zinc were found under deficient potassium conditions. (5) A specific amount of potassium was needed to get adequate calcium and manganese uptake. (6) More potassium was taken up when associated with the sulfate anion than in combination with chloride. In the latter case, more calcium was found in petioles. (7) High nitrogen, phosphorus, potassium, manganese and boron in petioles appeared under calcium deficient conditions. (8) A significant positive correlation between total iron and manganese in the petioles was established. (9) Low phosphorus, potassium, calcium, and high magnesium were associated with high manganese values in petioles. (10) More boron was observed in petioles of plants treated with high levels of nitrogen, phosphorus, potassium, and low levels of calcium than in those plants treated with high levels of boron in the solution.

With extreme high manganese concentrations, manganese toxicity symptoms appeared on leaves. The transition point from non-toxic levels to toxic levels seemed to be with 2900 ppm manganese present in the petioles.

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APPENDIX

APPENDIX TABLE 1

NUTRIENT SOLUTION COMPOSITION, MAJOR ELEMENTS, USED IN EXPERIMENT I

Treatment	Ppm per 1 Liter*							
	N	P	K	Ca	Mg	SO_4	CO_3	Cl
Check	210	31	235	200	49	192	-	-
- N	**	31	235	200	49	480	360	-
5 N	1050	31	235	200	49	192	-	-
- P	210	-	235	200	49	192	60	-
5 P	210	155	235	200	49	192	60	-
- K	210	31	-	200	49	192	-	-
5 K (SO_4)	210	31	1171	200	49	1342	-	-
5 K (Cl)	210	31	1171	200	49	192	-	849
- Ca	210	31	235	-	49	192	-	-
5 Ca (SO_4)	210	31	235	1002	49	960	300	532
5 Ca (Cl)	210	31	235	1002	49	192	-	1418
- Mg	210	31	235	200	-	192	60	-
5 Mg	210	31	235	200	243	576	-	284

*Minor elements as recommended by Hoagland and Arnon (1950).

**Originally no nitrogen, but 42 ppm added after 4 weeks in order to save the plants.

APPENDIX TABLE 2

NUTRIENT SOLUTION COMPOSITION, MINOR ELEMENTS, USED IN EXPERIMENT I

Treatment	Ppm per 1 Liter*					
	Fe	Mn	B	Cu	Zn	Mo
- Fe	-	.5	.5	.02	.05	.01
5 Fe	25	.5	.5	.02	.05	.01
- Mn	5	-	.5	.02	.05	.01
5 Mn	5	2.5	.5	.02	.05	.01
- B	5	.5	-	.02	.05	.01
5 B	5	.5	2.5	.02	.05	.01
- Cu	5	.5	.5	-	.05	.01
5 Cu	5	.5	.5	.10	.05	.01
- Zn	5	.5	.5	.02	-	.01
5 Zn	5	.5	.5	.02	.25	.01
- Mo	5	.5	.5	.02	.05	-
5 Mo	5	.5	.5	.02	.05	.05

*Major elements used in the same amount as for check; see Appendix Table 1.

APPENDIX TABLE 3

MILLILITERS OF STOCK SOLUTIONS REQUIRED TO MAKE ONE LITER OF NUTRIENT SOLUTION FOR MAJOR ELEMENTS IN EXPERIMENT I

Treatment	KNO_3 1M	KCl 2M	KOH 1M	KH_2PO_4 .2M	K_2SO_4 .5M	$KHCO_3$ .5M	$Ca(NO_3)_2$ 1M	$CaCl_2$ 2M	$CaSO_4$ .01M	$Ca(H_2PO_4)_2$ .025M	$MgSO_4$ .4M	$MgCl_2$ .4M	NH_4NO_3 1M	H_3PO_4 .5M	Minors*
Check	5			5			5				5				2
All minors	5			5			5				5				2
- N						12	1.5		300	20	5				2
5 N	5			5			5				5		30		2
- P	5					2	5				5				2
5 P			5	5			5				5		2.5	8	2
- K							4.27			20	5		3		2
5 K (SO_4)	5			5	24		5				5				2
5 K (Cl)	5	12		5		10	5				5				2
- Ca	5			5							5		5		2
5 Ca (SO_4)				5			7.5	3.25	**		5				2
5 Ca (Cl)	5			5			5	10			5				2
- Mg				5	4	2	5								2
5 Mg	5			5			5				15	10	2.5		2

*Minor elements stock solution see Appendix Table 4.

**30.9 grams $CaSO_4$ added directly to nutrient solution.

APPENDIX TABLE 4

STOCK SOLUTION COMPOSITION, MINOR ELEMENTS, USED IN PREPARING NUTRIENT SOLUTIONS FOR EXPERIMENT I

Treatment	Grams per 1 Liter*				
	$MnCl_2 \cdot H_2O$	H_3BO_4	$CuSO_4 \cdot 5H_2O$	$ZnSO_4$	$H_2MoO_4 \cdot 2H_2O$
All majors) - Fe) 5 Fe)	.900	1.430	.040	.108	.02
- Mn	--	1.430	.040	.108	.02
5 Mn	4.500	1.430	.040	.108	.02
- B	.900	--	.040	.108	.02
5 B	.900	7.150	.040	.108	.02
- Cu	.900	1.430	--	.108	.02
5 Cu	.900	1.430	.200	.108	.02
- Zn	.900	1.430	.040	--	.02
5 Zn	.900	1.430	.040	.540	.02
- Mo	.900	1.430	.040	.108	--
5 Mo	.900	1.430	.040	.108	.10

*Ferrous lactate, $Fe(C_3H_5O_3)_2 \cdot 3H_2O$, 12.956 grams per liter made up as a separate stock solution.

APPENDIX TABLE 5

INFLUENCE OF TREATMENTS OF EXPERIMENT I ON DRY WEIGHT ACCUMULATION AND TOTAL LENGTH GROWTH

Treatment	Dry Weight (Grams)					Linear Growth (Cm)
	Roots	Stems	Petioles	Leaf Blades	Total	
Check	23.65	25.60	4.30	37.15	90.70	625
- N	16.45	7.15	1.50	13.20	38.30	109
5 N	11.85	13.95	2.65	27.40	55.85	336
- P	26.55	12.90	2.60	23.00	65.05	212
5 P	12.45	18.90	3.20	27.75	61.40	623
- K	11.45	7.00	1.10	15.90	35.45	186
5 K (SO_4)	19.55	19.20	3.70	31.05	73.50	490
5 K (Cl)	9.85	8.85	2.00	18.50	39.20	229
- Ca	21.65	12.40	2.25	25.20	61.50	223
5 Ca (SO_4)	15.80	10.45	1.75	18.50	46.50	315
5 Ca (Cl)	19.40	11.20	1.75	21.00	53.35	229
- Mg	15.80	22.15	3.30	36.50	77.75	518
5 Mg	21.35	7.15	1.25	16.40	46.15	178
- Fe	35.05	28.75	5.11	37.65	106.55	458
5 Fe	24.45	17.70	3.40	29.55	75.10	354
- Mn	27.65	19.50	3.80	29.15	80.10	464
5 Mn	32.35	20.80	3.60	31.25	88.00	468
- B	24.70	17.75	3.15	23.00	68.60	362
5 B	28.25	24.10	4.15	30.45	86.95	516
- Cu	39.60	20.05	3.05	29.25	91.95	372
5 Cu	34.90	24.30	4.90	36.95	101.05	506
- Zn	29.25	18.10	2.80	28.45	78.60	390
5 Zn	36.05	24.85	3.70	35.05	99.65	482
- Mo	33.20	18.85	3.35	29.45	84.85	420
5 Mo	49.35	26.65	4.25	37.50	117.75	472
LSD 5%	14.11	14.07	2.57	17.24	21.07	252
LSD 1%	19.17	19.12	3.48	23.41	28.64	343

APPENDIX TABLE 6

INFLUENCE OF TREATMENTS OF EXPERIMENT I ON DRY WEIGHT ACCUMULATION CONVERTED INTO PER CENT OF TOTAL DRY WEIGHT

Treatment	Per Cent of Total Dry Weight				Shoot/Root Ratio
	Roots	Stems	Petioles	Leaf Blades	
Check	26.29	28.05	4.71	40.95	2.8
- N	43.86	18.29	3.80	34.05	1.3
5 N	21.32	24.96	4.74	49.98	3.7
- P	43.77	17.98	3.84	34.41	1.3
5 P	20.38	29.33	5.20	45.09	3.9
- K	32.25	19.75	3.11	44.89	2.1
5 K (SO_4)	28.10	25.00	4.68	42.22	2.6
5 K (Cl)	24.38	23.07	5.16	47.39	3.1
- Ca	35.29	19.97	3.57	41.17	1.8
5 Ca (SO_4)	32.54	23.03	4.10	40.33	2.1
5 Ca (Cl)	36.78	20.31	3.13	39.78	1.7
- Mg	20.35	28.45	4.24	46.96	3.9
5 Mg	46.35	15.43	2.70	35.52	1.2
- Fe	31.59	27.43	4.96	36.02	2.2
5 Fe	32.76	23.48	4.56	39.20	2.1
- Mn	33.91	22.03	4.30	30.26	1.7
5 Mn	36.62	23.64	4.09	35.65	1.7
- B	35.47	25.84	4.60	34.09	1.8
5 B	34.60	26.10	4.54	34.76	1.9
- Cu	43.08	21.82	3.31	31.79	1.3
5 Cu	36.42	23.32	4.54	35.72	1.7
- Zn	37.20	22.89	3.59	36.32	1.7
5 Zn	37.86	23.94	3.57	34.63	1.6
- Mo	41.04	21.04	3.75	34.17	1.4
5 Mo	44.80	21.96	3.28	30.96	1.3
LSD 5%	11.80	6.80	1.53	8.55	
LSD 1%	16.03	9.24	2.08	11.62	

APPENDIX TABLE 7

INFLUENCE OF TREATMENTS OF EXPERIMENT I ON PETIOLE COMPOSITION

Treatment	Per Cent of Dry Weight					Ppm of Dry Weight				
	N	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn
Check	1.06	.37	5.72	.99	.45	35	63	56	24	46
- N	.51	.21	2.24	1.41	.31	40	116	47	18	37
5 N	5.19	.66	1.57	.46	.37	55	159	195	26	44
- P	.62	.10	4.65	1.48	.30	45	247	16	18	46
5 P	1.41	1.02	4.18	.46	.37	35	83	242	28	49
- K	-*	.75	.12	.86	.99	70	268	45	11	25
5 K (SO_4)	1.14	.68	9.86	.64	.14	35	44	229	23	42
5 K (Cl)	1.18	.52	8.88	.76	.14	45	52	198	20	56
- Ca	2.37	1.04	6.80	.26	.52	50	201	196	22	36
5 Ca (SO_4)	1.09	.37	4.51	.96	.42	45	76	67	21	42
5 Ca (Cl)	1.18	.42	2.82	2.55	.37	55	131	37	15	62
- Mg	1.31	.42	4.92	1.67	.06	60	85	48	30	56
5 Mg	-*	.70	4.62	.58	.74	40	174	152	22	32
- Fe	.95	.29	5.13	1.48	.65	35	75	42	29	59
5 Fe	1.01	.29	4.71	1.62	.49	40	89	55	23	49
- Mn	1.12	.32	5.77	1.24	.50	35	18	26	23	46
5 Mn	1.04	.37	5.59	1.21	.50	90	323	59	23	53
- B	1.25	.42	5.50	.85	.46	45	102	14	26	46
5 B	1.08	.35	5.32	1.54	.46	50	77	174	23	57
- Cu	1.03	.33	5.35	1.43	.48	50	63	24	29	42
5 Cu	1.12	.29	5.33	1.53	.54	35	42	38	30	49
- Zn	1.01	.43	5.24	1.10	.55	45	82	33	24	48
5 Zn	1.05	.45	6.33	.96	.46	50	46	118	28	42
- Mo	1.06	.28	4.85	1.79	.53	35	84	21	22	64
5 Mo	1.01	.33	5.15	1.78	.54	50	94	58	22	47
LSD 5%	**	.14	**	.42	.13	N.S.	83	48	N.S.	N.S.
LSD 1%		.19		.57	.18	N.S.	113	65	N.S.	N.S.

*Nitrogen analysis omitted due to shortage of plant material.

**Analysis of variance omitted due to many missing values.

APPENDIX TABLE 8

INFLUENCE OF TREATMENTS OF EXPERIMENT I ON STEM COMPOSITION

Treatment	Per Cent of Dry Weight					Ppm of Dry Weight				
	N	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn
Check	1.05	.26	2.37	.62	.27	40	36	45	22	34
- N	.63	.16	1.00	.80	.21	50	79	19	20	19
5 N	2.10	.30	1.87	.37	.19	70	104	53	29	32
- P	.62	.11	.97	.77	.23	60	137	11	22	29
5 P	.99	.40	2.52	.36	.19	50	41	64	36	25
- K	1.23	.26	.27	.43	.33	100	122	26	28	33
5 K (SO_4)	.91	.26	2.61	.44	.18	40	28	41	22	28
5 K (Cl)	1.07	.26	2.68	.49	.19	40	31	29	22	31
- Ca	1.50	.25	1.67	.25	.38	80	154	45	32	33
5 Ca (SO_4)	1.10	.24	1.86	.91	.28	45	63	32	19	23
5 Ca (Cl)	.95	.24	1.00	1.56	.22	45	68	25	21	22
- Mg	.91	.25	1.53	.97	.07	55	83	17	22	50
5 Mg	1.11	.32	1.70	.45	.45	45	95	47	24	31
- Fe	.83	.19	1.65	.72	.27	40	44	18	24	39
5 Fe	.96	.23	2.04	.79	.26	45	40	26	24	35
- Mn	.91	.21	1.98	.72	.27	35	23	36	20	28
5 Mn	1.04	.22	1.99	.61	.25	50	94	20	24	44
- B	1.12	.23	1.56	.52	.24	45	59	11	23	20
5 B	1.00	.22	1.86	.63	.24	50	47	55	30	41
- Cu	.86	.21	1.42	.79	.26	45	44	50	20	38
5 Cu	.89	.24	1.97	.69	.32	45	34	24	22	31
- Zn	.92	.22	1.57	.66	.28	35	49	21	24	45
5 Zn	.93	.23	1.69	.53	.26	60	39	21	24	37
- Mo	.89	.21	1.69	.67	.25	45	50	26	31	36
5 Mo	.90	.23	1.75	.85	.39	55	56	28	38	48
LSD 5%	.24	.11	.58	.28	.06	N. S.	34	31	N. S.	17
LSD 1%	.33	.15	.79	.38	.09	N. S.	47	35	N. S.	24

APPENDIX TABLE 9

NUTRIENT SOLUTION COMPOSITION OF EXPERIMENT II

Treatment	$\frac{Ca+Mg}{K}$	Ppm per 1 Liter*				
		K	Ca	Mg	SO_4	Cl
1	1.6	117	100	24	96	--
2	3.2	117	301	73	288	--
3	5.3	23	100	24	96	--
4	6.3	23	100	49	192	--
5	7.4	23	100	73	288	--
6	8.4	23	100	97	384	--
7	9.6	23	200	24	96	--
8	10.6	23	200	49	192	--
9	11.7	23	200	73	288	--
10	12.7	23	200	97	384	--
11	13.8	23	301	24	120	--
12	14.9	23	301	49	216	--
13	15.9	23	301	73	312	--
14	17.0	23	301	97	408	--
15	18.1	23	401	24	120	177
16	19.2	23	401	49	216	177
17	20.2	23	401	73	312	177
18	21.2	23	401	97	408	177

*Nitrogen, phosphorus, iron, boron, zinc and molybdenum was the same as for the check treatment of Appendix Table 1 with the exception for manganese 1 ppm and copper .03 ppm.

APPENDIX TABLE 10

MILLILITERS OF STOCK SOLUTION REQUIRED TO MAKE ONE LITER OF NUTRIENT SOLUTION FOR EXPERIMENT II

Treatment	KNO_3 .5M	KH_2PO_4 .2M	$Ca(NO_3)_2$ 1M	$CaSO_4$ .01M	$CaCl_2$ .5M	$MgSO_4$ .4M	NH_4NO_3 1M	$NH_4H_2PO_4$ .5M	Minors*
1 Check	5	2.5	2.5	-	-	2.5	-	-	1
2	5	2.5	5	-	-	7.5	1.25	-	2
3	1.2	-	2.5	-	-	2.5	4.18	5	2
4	1.2	-	2.5	-	-	5.0	4.18	5	2
5	1.2	-	2.5	-	-	7.5	4.18	5	2
6	1.2	-	2.5	-	-	10.0	4.18	5	2
7	1.2	-	5	-	-	2.5	1.70	5	2
8	1.2	-	5	-	-	5.0	1.70	5	2
9	1.2	-	5	-	-	7.5	1.70	5	2
10	1.2	-	5	-	-	10.0	1.70	5	2
11	1.2	-	5	24.55	-	2.5	1.70	5	2
12	1.2	-	5	24.55	-	5.0	1.70	5	2
13	1.2	-	5	24.55	-	7.5	1.70	5	2
14	1.2	-	5	24.55	-	10.0	1.70	5	2
15	1.2	-	5	24.55	5	2.5	1.70	5	2
16	1.2	-	5	24.55	5	5.0	1.70	5	2
17	1.2	-	5	24.55	5	7.5	1.70	5	2
18	1.2	-	5	24.55	5	10.0	1.70	5	2

*$MnCl_2$ 1.8 gr; H_3BO_4 1.43 gr; $CuSO_4$ .06 gr; $ZnSO_4$ .108 gr; H_2MoO_4 .02 gr; Sequestrine 12% Fe 41.6 gr.

APPENDIX TABLE 11

INFLUENCE OF TREATMENTS OF EXPERIMENT II ON DRY WEIGHT ACCUMULATION AND TOTAL LENGTH GROWTH

Treatment	Ca+Mg / K	Dry Weight (Grams)						Linear Growth (Cm)
		Roots	Stems	Berries	Petioles	Leaf Blades	Total	
1	1.6	60.23	12.85	12.43	2.55	31.33	119.39	192
2	3.2	48.10	13.97	15.76	2.85	36.20	116.88	294
3	5.3	21.88	14.57	8.38	2.55	37.70	85.08	326
4	6.3	18.40	10.15	11.90	1.98	26.93	69.36	259
5	7.4	26.23	13.86	5.47	2.45	34.03	82.04	308
6	8.4	23.93	8.38	9.69	1.75	26.15	69.90	253
7	9.6	25.53	18.83	5.42	3.13	39.43	92.34	397
8	10.6	16.83	10.35	13.45	1.93	27.20	69.76	319
9	11.7	16.40	11.38	12.97	2.08	29.50	72.33	292
10	12.7	27.60	13.35	13.30	2.50	33.60	90.35	330
11	13.8	16.53	12.68	12.20	2.35	31.48	75.24	327
12	14.9	20.00	12.35	13.87	2.30	30.40	78.92	306
13	15.9	13.93	12.18	6.77	2.00	26.20	61.08	283
14	17.0	24.10	12.03	12.45	2.50	31.50	82.58	336
15	18.1	18.65	10.58	10.00	2.05	27.55	68.83	298
16	19.2	20.50	13.53	10.27	2.18	29.45	75.93	278
17	20.2	18.33	13.90	9.13	2.03	25.98	69.37	230
18	21.2	21.40	13.18	7.75	2.20	29.93	74.46	275
LSD 5%		13.93	NS	*	NS	NS	29.54	NS
LSD 1%		18.57	NS		NS	NS	42.59	NS

*Analysis of variance omitted due to many missing values.

APPENDIX TABLE 12

INFLUENCE OF TREATMENTS OF EXPERIMENT II ON DRY WEIGHT ACCUMULATION CONVERTED INTO PER CENT OF TOTAL DRY WEIGHT

Treatment	Per Cent of Total Dry Weight				
	Roots	Stems and Berries	Petioles	Leaf Blades	Shoot/Root Ratio
1	50.45	21.17	2.14	26.24	.98
2	41.15	25.44	2.44	30.97	1.4
3	25.72	26.97	3.00	44.31	2.9
4	26.53	31.79	2.85	38.83	2.8
5	31.97	23.56	2.99	41.48	2.1
6	34.24	25.85	2.50	37.41	1.9
7	27.65	27.26	3.39	42.70	2.7
8	24.12	34.12	2.77	38.99	3.2
9	22.67	33.67	2.88	40.78	3.4
10	30.55	29.50	2.77	37.18	2.3
11	21.97	33.07	3.12	41.84	3.6
12	25.34	33.22	2.92	38.52	3.0
13	22.81	31.02	3.28	42.89	3.4
14	29.18	29.64	3.03	38.15	2.4
15	27.10	29.90	2.98	40.02	2.7
16	27.00	31.34	2.87	38.79	2.7
17	26.42	33.20	2.93	37.45	2.8
18	28.74	28.11	2.95	40.20	2.5
LSD 5%	N.S.	N.S.	N.S.	N.S.	

APPENDIX TABLE 13

INFLUENCE OF TREATMENTS OF EXPERIMENT II ON PETIOLE COMPOSITION

Treatment	Ratio $\frac{Ca+Mg}{K}$	Per Cent of Dry Weight					Ppm of Dry Weight				
		N	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn
1	1.6	2.18	.31	5.86	2.40	.65	52	371	22	22	50
2	3.2	2.38	.42	3.21	1.64	1.05	61	329	28	26	39
3	5.3	3.72	.73	.76	.64	.74	81	560	92	37	17
4	6.3	2.66	.74	.80	.45	.88	107	604	49	29	18
5	7.4	3.62	.75	.66	.44	.88	94	630	58	27	18
6	8.4	3.15	.77	.76	.44	1.29	83	890	49	25	16
7	9.6	2.12	.50	.68	.95	.78	75	589	29	23	28
8	10.6	3.01	.62	.72	.85	1.10	108	679	32	23	29
9	11.7	2.68	.66	.64	.88	1.24	106	542	30	20	25
10	12.7	2.62	.71	.45	.83	1.71	103	703	30	23	26
11	13.8	3.01	.57	.51	1.05	.88	124	600	12	23	35
12	14.9	2.42	.58	.45	.85	1.29	108	649	24	23	26
13	15.9	2.17	.58	.52	.62	1.13	72	476	32	27	17
14	17.0	2.52	.58	.54	.71	1.25	85	707	34	23	21
15	18.1	2.79	.52	.79	1.05	.69	86	428	31	25	24
16	19.2	3.31	.56	.98	1.05	.84	90	667	42	26	26
17	20.2	2.72	.53	.64	.84	1.08	95	458	27	21	22
18	21.2	2.43	.59	.60	.78	1.14	98	538	32	24	19
LSD 5%		*	.07	.46	.25	.34	29	NS	12	6	9
LSD 1%			.09	.61	.33	.46	38	NS	16	8	12

*Analysis of variance omitted due to many missing values.

APPENDIX TABLE 14

INFLUENCE OF TREATMENTS OF EXPERIMENT II ON STEM COMPOSITION

Treatment	Ratio $\frac{Ca+Mg}{K}$	Per Cent of Dry Weight					Ppm of Dry Weight				
		N	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn
1	1.6	1.24	.19	.74	.57	.18	34	91	9	21	15
2	3.2	1.32	.24	.80	.65	.25	44	117	9	21	19
3	5.3	1.60	.26	.48	.39	.15	105	128	11	20	14
4	6.3	1.89	.35	.45	.42	.26	131	210	25	21	15
5	7.4	1.60	.30	.53	.43	.23	104	69	25	23	16
6	8.4	1.64	.35	.58	.42	.32	131	236	36	20	11
7	9.6	1.30	.26	.53	.57	.22	85	111	13	21	12
8	10.6	1.49	.27	.50	.50	.26	89	208	11	20	15
9	11.7	1.49	.29	.47	.44	.29	97	165	21	20	15
10	12.7	1.37	.27	.45	.42	.31	85	186	17	17	13
11	13.8	1.41	.27	.51	.55	.24	86	172	10	18	19
12	14.9	1.32	.28	.48	.55	.27	93	152	14	19	16
13	15.9	1.41	.30	.52	.48	.29	91	139	16	23	16
14	17.0	1.32	.29	.56	.52	.35	104	189	20	23	16
15	18.1	1.33	.29	.54	.64	.25	99	142	16	19	15
16	19.2	1.26	.30	.65	.68	.25	98	132	20	22	16
17	20.2	1.33	.28	.55	.59	.27	94	111	12	18	16
18	21.2	1.27	.29	.48	.64	.29	101	132	13	20	15
LSD 5%		.24	.05	.20	.10	.07	37	74	6	3	NS
LSD 1%		.32	.07	.27	.14	.09	50	99	8	4	NS

APPENDIX TABLE 15

SIGNIFICANCE OF F VALUES IN 4x4 FACTORIAL PORTION OF EXPERIMENT II

Element	Plant Parts	F - Values for		
		Calcium	Magnesium	Interaction Calcium/Magnesium
Nitrogen	Petioles	--	--	--
	Stems	*	NS	NS
Phosphorus	Petioles	**	**	NS
	Stems	**	*	NS
Potassium	Petioles	*	NS	NS
	Stems	NS	NS	NS
Calcium	Petioles	**	**	NS
	Stems	*	NS	NS
Magnesium	Petioles	*	**	NS
	Stems	NS	NS	NS
Iron	Petioles	NS	NS	**
	Stems	**	NS	NS
Manganese	Petioles	NS	NS	NS
	Stems	*	*	NS
Boron	Petioles	**	NS	**
	Stems	*	*	*
Copper	Petioles	**	*	*
	Stems	NS	NS	*
Zinc	Petioles	NS	NS	NS
	Stems	NS	NS	NS

-- Not determined

* Significant 5% level

** Significant 1% level

APPENDIX TABLE 16

INFLUENCE OF MANGANESE LEVELS OF EXPERIMENT III ON DRY WEIGHT ACCUMULATION AND TOTAL LENGTH GROWTH

Treatment	Dry Weight (Grams)						Linear Growth (Cm)
	Roots	Stems	Berries	Petioles	Leaf Blades	Total	
Check (1.0 ppm Mn)	60.23	12.85	12.43	2.55	31.33	119.39	192
12.5 ppm Mn	56.25	29.90	8.46	5.65	50.10	150.36	658
25 ppm Mn	63.10	38.80	12.86	7.25	65.60	187.61	610
LSD 5%	NS	NS	NS	2.90	15.35	40.36	182.83

APPENDIX TABLE 17

INFLUENCE OF THE MANGANESE LEVELS OF EXPERIMENT III ON DRY WEIGHT ACCUMULATION CONVERTED INTO PER CENT OF TOTAL DRY WEIGHT

Treatment	Per Cent of Total Dry Weight				Shoot/Root Ratio
	Roots	Stems and Berries	Petioles	Leaf Blades	
Check (1.0 ppm Mn)	50.45	21.17	2.14	26.24	.98
12.5 ppm Mn	37.41	25.51	3.76	33.32	1.7
25 ppm Mn	33.63	27.54	3.86	34.97	2.0
LSD 5%	NS	NS	NS	NS	

APPENDIX TABLE 18

INFLUENCE OF MANGANESE LEVELS OF EXPERIMENT III ON PETIOLE COMPOSITION

Treatment	Per Cent of Dry Weight					Ppm of Dry Weight				
	N	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn
Check (1.0 ppm Mn)	2.18	.31	5.86	2.40	.65	52	371	22	22	50
12.5 ppm Mn	1.33	.29	3.41	1.72	.41	65	1840*	22	21	36
25 ppm Mn	1.45	.26	3.14	1.72	.43	97	3067*	13	21	34
LSD 5%	NS	NS	NS	NS	NS	28	965	NS	NS	NS

*Accuracy of spectrographical analysis for manganese at these levels may be questionable.

APPENDIX TABLE 19

INFLUENCE OF MANGANESE LEVELS OF EXPERIMENT III ON STEM COMPOSITION

Treatment	Per Cent of Dry Weight					Ppm of Dry Weight				
	N	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn
Check (1.0 ppm Mn)	1.24	.19	.74	.57	.18	34	91	9	21	15
12.5 ppm Mn	1.17	.25	1.45	.84	.17	46	265	15	17	17
25 ppm Mn	1.13	.27	1.28	.98	.20	62	658	12	17	21
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS