THE EFFECT OF CALCIUM, MAGNESIUM, AND POTASSIUM ON THE GROWTH OF STRAWBERRY PLANTS IN SAND CULTURE

by
Albert A. Piringer Jr.

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INTRODUCTION

Despite considerable study, an understanding of the relationships of certain cations to the growth and fruiting responses of the strawberry remains incomplete. When it is attempted to reconcile the results from basic studies with performance in commercial production this becomes especially evident. For example, in the field, many contrary observations have been reported as to the response of the strawberry plant to lime applications. Generally these reports have attributed the effects of the lime to altered pH conditions of the soil. Also to be considered in this respect, however, is the magnesium content of the lime and its concommitant effect, if any, with calcium; and/or the effects of these two cations upon certain other mineral elements, especially potassium. Calcium in relation to total salt concentration holds interest in certain areas. Experimental work at various institutions has developed some of these relationships as well as the effect of calcium as a nutrient element but results and interpretations are somewhat inconsistent.

The desirability of determining more precisely the calcium requirement of the strawberry plant as well as the interrelationship of calcium and the other cations is therefore evident. Mineral nutrition experiments, as presented herein, were conducted in sand culture in the greenhouse to verify and augment existing information of this nature.

Specifically, the purpose of these experiments was threefold: to establish with cultivated strawberries a symptomology for conditions ranging from deficient to toxic amounts of calcium, magnesium, and potassium in the nutrient media; to correlate this symptomology with the mineral

content of the plant or its parts; and to study further the interrelationships of the effects of these cations in strawberry nutrition.

REVIEW OF LITERATURE

A portion of the literature reviewed herein is not necessarily pertinent to the immediate problem as outlined. However, it is presented partially for its historical interest and partially to indicate the general trends and nature of mineral nutrition studies made with the strawberry in the past. In this capacity it serves as a prologue.

Gardner (18) presented a discussion of results of seasonal applications of fertilizers that included an extensive bibliography of experiments prior to 1923. An inclusive review of fertilizer studies made with strawberries previous to 1936 accompanied the report of Whitehouse and Schrader (56) who considered the rate, time, and place of application of fertilizers on the growth, fruit bud formation, and size and yield of fruits of strawberry. Another of the comprehensive reviews was that of Wallace (53) who outlined in some detail the work that had been done in England with strawberry nutrition. The most recent general review of early and contemporary information regarding strawberry nutrition is that of Schowengerdt (46). He emphasized that the very earliest studies were simply fertilizer trials that involved a consideration of fertilizer versus no fertilizer. These studies were primarily concerned with the application of such natural materials as bone meal, kainit, dried blood, guano, and wood ashes as supplemental fertilizers but no recommendations were made as to the time or rates of application of these materials.

More recently, strawberry nutrition studies have taken two separate but allied, approaches: (1) an investigation of the general effect upon growth, yield, and fruit quality when fertilizers were applied to strawberries under field conditions; and (2) a study of the specific effects

of various nutritional elements upon development and performance of the strawberry plant. From the standpoint of field trials and generally speaking, investigators have recommended that soil fertility be maintained by plowing under green manure crops and by the addition of barnyard manure in the fall of the year preceding planting; in some cases the latter to be supplemented with nitrogen, phosphorus, and potassium. Supplemental fertilizers were recommended for fall application just before fruit bud differentiation, and again in the spring, just before anthesis. More recently, summer or early fall fertilization has been emphasized. The results obtained from the fertilizer studies have been variable and no definite recommendations can be made for the use of fertilizers on the strawberry plant for any considerable area. What recommendations can be made are perhaps best summarized by Shoemaker (47).

The studies under field conditions provide knowledge regarding the fertilizer requirement of the strawberry for a given soil. The number of controlled mineral nutrition studies, as opposed to field fertilizer trials, with strawberry is relatively small and somewhat varied in scope and experimental treatment.

The latter approach to strawberry mineral nutrition is more pertinent to the particular study herein reported. A review of the relevant literature of carefully conducted and controlled "nutrition" experiments is considered first chronologically and then again subjectively. The chronological presentation is a general survey to show the trends and development of the various phases and interests of the mineral nutrition problem with strawberries.

The earliest of the controlled nutrient studies in sand culture was that of Wallace, as reported in 1925 (51). He conducted pot experiments

with strawberry and certain bush fruits in the spring of 1921 at Long Ashton. The experiments were conducted to determine the following: the reaction of plants to different ratios of the essential elements of plant food; the behavior of the plants in nutrient media of widely different reaction; and the effect on growth of depriving the plants of "any one of the elements of plant food." In 1927, Morris and Crist reported an investigation of the behavior of strawberry plants as grown in media "with various lime requirements and pH values" (43). The works of Davis and Hill (13,14) that followed were concerned with nitrogen, phosphoric acid, and potash starvation at different stages of the growth of the strawberry. They attempted to establish optimum nutrient solutions for strawberry culture from the standpoint of salt concentrations and the ratios between component ions of the nutrient medium. Next was the work of Hoagland and Snyder (27), in 1934, who attempted to develop symptoms under controlled conditions similar to symptoms of disorder that were found in the field. Using water-culture techniques, they studied the effects of deficiencies of boron and the other "minor elements" as well as the susceptibility of strawberry plants to injury from sodium salts. Also, they were the first to specificially stress varietal differences of response to nutrient conditions. Davis, Hill, and Johnson (15) in 1934 published the results of a sand culture experiment in which they noted effects of deficient and excess amounts of potassium, phosphorus, magnesium, calcium, and sulfur. The experiments were designed primarily to provide information of diagnostic value, and extremes of ion concentrations in nutrient solutions were used to accomplish this purpose. About this same time, Waltman (54) became interested in the effect of hydrogen-ion concentration on the growth of strawberries in sand and soil and conducted

experiments concerning the problem. Somewhat later, 1941, Clark (6) expanded on Waltman's work and studied the growth and composition of the strawberry plant as affected by the source of nitrogen and also the pH value of the nutrient medium. In 1943, Lineberry and Burkhart (36) studied the effects on the leaf and the fruit of deficiencies of calcium, magnesium, potassium, and phosphorus and also stressed varietal differences in this respect. In 1944, Schowengerdt (46) using a "prepared soil" as a colloidal carrier of adsorbed mineral elements, investigated the mineral absorption by strawberry plants from the standpoint of variable concentrations of calcium, potassium, and phosphorus. He also considered the effects of these various ions on iron uptake and on the vitamin C content of the fruits. More recently, Gilbert (19) and Gilbert and Robbins (20) have reported the effects of varying the boron and calcium nutrient levels as well as the inter-relationship of boron and calcium in the nutrition of the strawberry. Iwakiri and Scott (29) have described the foliar symptomology and other growth responses of strawberry plants as grown in conditions deficient for calcium, magnesium, potassium, boron, and manganese. The most recent of the critical studies is that of Lineberry and Burkhart (38) in 1951 who, using the colloidal soil fractions as carriers for the nutrient ions, have studied the degree of calcium saturation of the soil in relation to the growth and calcium content of strawberry plants.

The above literature on strawberry nutrition will now be reconsidered in more detail and in the following categories and sequence: liming, its effect on plant growth per se, and on the resulting pH of the soil; the pH requirements of strawberry plants and the effect of pH on the source of nitrogen available to the plants; symptomology and other effects of deficiencies and/or toxicities for nitrogen, calcium, magnesium, potassium,

sodium, phosphorus, boron, sulfur, manganese, and aluminum; and the interrelationship effects between and among certain of the elements that have been found to occur in strawberry nutrition.

Lime. Strawberries require fairly abundant moisture and flourish where this condition exists. Soils that are formed under poor drainage conditions are likely to be high in organic matter and consequently such soils have been frequently planted to strawberries and some have produced abundant crops. These soils, being very acid, have been held responsible for the general conclusion that strawberries require acid soils (26). However, it has also been shown that strawberries respond favorably to lime applications and the resulting less acid conditions.

From experimental work it is sometimes difficult to separate one particular influence on plant growth and behavior and consider its effect individually and objectively. This is the situation with the studies on the liming of strawberries. As discussed by Clark (6), the beneficial effects of lime when applied to strawberry soils might be due to any one of several factors, including the correction of a calcium or magnesium deficiency, the precipitation of toxic materials, the promotion of the growth of certain soil organisms, an improvement in the physical condition of the soil, and the effecting of changes in the soil reaction which in turn provide more optimum conditions for the assimilation of nitrogen and minerals.

Liming studies with strawberries have been generally limited to a consideration of the value of lime applications as such on the resulting growth and yield of strawberry plants. Accompanying some of these investigations is a study of the effect of lime applications on pH and the resulting effect of the altered pH on the plant. Also considered in a

few cases is the relationship between pH and the source of nitrogen that is applied. A few critical studies of the pH requirements of strawberries have been made under controlled environmental conditions but most of the liming and pH studies have been conducted under field conditions.

In 1912 Cole (7), from observations in Virginia, stated that lime on many of the light sandy soils is often injurious to the strawberry crop. The same year in New York, Wright (59) indicated that lime hindered runner formation in most cases and on certain soils growth was reduced and yields were correspondingly smaller following lime applications. A year later Chandler (4) stated that since strawberry soils in Southwest Missouri were seldom acid, lime should never be used on a strawberry bed. It was further recommended that no form of nitrogen-bearing fertilizer be used. Darrow (11) in a cultural bulletin asserted that experiments have shown that lime has a harmful effect on the roots of strawberry plants but suggested that small quantities may be necessary to improve the physical condition of the soil, in which case lime should be applied considerably in advance of setting the plants. He also states that altering the pH value toward the neutral point eliminates the free aluminum which is toxic to strawberry plants. Waltman (54) in Kentucky felt that his results with growing strawberries in soil in the greenhouse indicated that liming may be harmful unless the initial reaction of the soil is so acid that the plants cannot grow. In Maryland, Whitehouse and Schrader (56) found lime to have a detrimental effect on early runner formation if used in amounts sufficient to bring the soil to neutrality. Their results were in accord with the studies of other investigators in that any attempt to grow strawberry plants in a neutral medium has resulted in less favorable response. They stress, however, that a very acid soil is defi-

nitely injurious to strawberry plant growth and sufficient lime should be used to correct high acidity. Shoemaker (47) has also cautioned that soils with a high lime content in the upper eight to ten inches, a condition common in the West, should be avoided. In these soils, a lime-induced chlorosis may result because of the effect of the "high lime" condition in making iron unavailable.

In contrast to the above workers who found a detrimental effect from lime applications, Wheeler and Tillinghast (57) working in Rhode Island, varied the soil reaction by applying lime and found that yields were increased. They concluded that lime is beneficial on a very acid soil. Later, Hartwell and Damon (25) from the same state also reported beneficial results from the use of hydrated lime. Also the yield was greater when ammonium sulfate was used as the source of nitrogen than when sodium nitrate was used. Morris and Crist (43) at Michigan obtained better growth after liming extremely acid muck soils but they found that plants survived within a range of pH 4.0 to 8.0. Application of fertilizers containing ammonium sulfate to the acid soil without the addition of lime caused the death of the plants. In Louisiana, Szymoniak (49) reported favorable effects of lime to the extent that liming a very acid soil produced much better plant growth although it did not increase fruit production. Clark (6) in New Jersey obtained best top growth by liming Keyport loamy sand to pH 5.2 and Sassafrass loam to pH 6.4 with hydrated lime. Also, in another test, he added lime immediately before the plants were set and produced no evidence of injury to the plants.

Lineberry and Collins (35) found that an application of 2000-4000 pounds of dolomitic limestone per acre increased the survival, growth, and yield of strawberry plants in Eastern North Carolina. In this same

area, Lineberry, Burkhart, and Collins (37) obtained an increase in yield from a broadcast application of 2000 pounds of dolomitic limestone per acre on newly cleared Coxville soil with a final pH of 4.75. Additional limestone had no effect. Clark (5) has stated that calcium, in the form of lime, has often been considered more important as a corrector of acidity than as an essential element. Apparently the first critical soil study to determine the effect of the degree of calcium saturation of soils on strawberry nutrition was the recent study of Lineberry and Burkhart (38). Under greenhouse conditions, and using soils with total base exchange capacities of 22 me. and 4 me. per 100 grams of soil respectively, they found that maximum growth occurred at 25 per cent calcium saturation in both soils for a first planting. In a succeeding planting, maximum growth occurred at 50 per cent and 100 per cent calcium saturation for the 22 me. and 4 me. soil respectively. From their results they concluded that both the degree of calcium saturation and the total calcium in the soils are factors affecting the growth and calcium content of strawberry plants.

pH. To determine the most favorable soil pH for strawberries, Morris and Crist (43) altered the pH by the addition of lime to extremely acid muck soils and found plant survival within the range of pH 4.0 to 8.0 with best growth between pH 5.0 and 7.0. In Florida, Brooks (3) found a soil reaction of pH 5.5 to pH 6.0 as the most favorable. Lineberry (34) found that on some of the North Carolina soils the best reaction for strawberries was from pH 5.8 to pH 6.5. From later experiments and observations, Lineberry and Collins (35) concluded that a pH of 6.0 was "about optimum" for strawberries and that plants would die at about pH 4.5. Meyer (41), in Louisiana, noted that season influenced the pH requirement of the

plants. His work indicated that during the cool part of the year strawberry plants grew well at pH 4.0 but during the hot months a more desirable reaction was pH 5.0 to pH 5.5. Whitehouse and Schrader (56) stated that Maryland soils have shown pH values of 5.0 or below to be accompanied by poor plant growth. They recommended that sufficient lime be used to correct this high acidity by raising the pH value of the soil to approximately 6.0. Hester et al. (26) in Virginia obtained maximum yields between pH 5.7 and pH 6.3, depending upon soil type, and stated that any reaction between pH 5.5 and pH 6.5 is satisfactory for strawberries on average field soils. Cooper and Vaile (9) in Arkansas reported that reactions at or slightly above pH 6.0 are optimum for production of the variety Klondike. Small (48) has indicated that the "ecological range" for Fragaria vesca is from below pH 4.8 to above pH 7.0 and stated that it is "amphi-tolerant."

Morris and Crist (43) growing strawberry plants in water culture found that the plants grew satisfactorily within the range of pH 5.0 to pH 7.0 with the optimum range being from pH 5.7 to 6.0. Waltman (54) growing an everbearer in sand culture found survival of plants within a range of pH 4.0 to pH 8.0 but stated that a reaction of pH 5.3 to pH 5.5 was optimum for the growth of strawberries. It was also stated that acidity at pH 4.0 was more harmful to the plant than alkalinity at pH 8.0. Clark (6) found that Premier plants grown in sand culture produced the greatest total growth when the nutrient solution was maintained at pH 4.6 or at 6.4 depending upon the source of nitrogen in the nutrient solution.

Source of Nitrogen. That the response of plants to different soil reactions may vary with the form of nitrogen supplied to the plant has also been shown. Hartwell and Damon (25) reported that the use of lime

greatly increased strawberry yields on ammonium sulfate plots but caused only small increases on sodium nitrate plots. Loree (40) reported that ammonium sulfate treatments gave much better growth and production than sodium nitrate on a soil which tested pH 7.5. Morris and Crist (43) found that applications of fertilizers containing ammonium sulfate to an acid soil without the addition of lime caused the death of the plants. Plants grown by them in water-culture where the only source of nitrogen was as the nitrate developed best at pH 5.7. Waltman (54) with plants in sand culture and where nitrogen was supplied as ammonium nitrate, found the optimum reaction to be in the range of pH 5.3 to pH 5.5. It should be noted that ammonium nitrate is 75 per cent nitrate nitrogen. Lineberry and Collins (35) found that strawberry plants died where nitrogen was supplied as ammonium sulfate on rather acid soils and plants survived where it was applied as sodium nitrate on the same soils. In sand culture experiments, Clark (6) found that where nitrogen was supplied as the nitrate, the optimum pH was 4.6; where it was supplied as the ammonium ion, the optimum reaction occurred at pH 6.4. The results of the above experiments would indicate that a somewhat higher pH value might be desirable in a medium receiving nitrogen as the ammonium ion. Nitrogen in the form of nitrate apparently would be more desirable with acid conditions.

Nitrogen. Wallace (52) noted that strawberry plants grown in sand culture without nitrogen were very small in size and with generally poor growth. There was scanty foliage development characterized by small leaflets having short petioles. The leaves were pale green and eventually developed yellow and red tints. Loree (40) grew strawberries in pots in a very light sandy soil and showed that nitrogen is the element most likely

to be deficient in such soils. Davis and Hill (14) report foliar deficiency symptoms as pale leaves smaller than normal with the leaves becoming dwarfed and developing yellow and red tints by fruiting time. Hambidge (23) describes nitrogen deficiency symptoms as follows:

> The beginning of nitrogen deficiency in strawberry plants is indicated by the yellow-green color of old leaves and by the small size of newly maturing ones. The plants thereafter form relatively few and weak runners. As the deficiency of nitrogen becomes acute, young leaves also acquire a yellow-green color, while mature foliage becomes yellower and at the same time becomes pigmented with red, especially toward the margins of blades. This stage is soon followed by the firing and withering of old leaves near the crowns.

Davis and Hill (13) state that in general, a relative excess accumulation of nitrogen is evidenced by abnormally green foliage, with a distinct tendency to curl upwards, and frequently accompanied by a bronzing and purpling on older leaves.

Davis and Hill (14) report that decreased yield accompanied deficient nitrogen and Whitehouse and Schrader (56) that the application of "large amounts of nitrogen in the fertilizer" to strawberry plants tends to increase the size of the berry and delay its maturity.

Calcium. It is again emphasized that calcium, in the form of lime, has often been considered more important as a corrector of acidity than as an essential element. Some sand-culture studies have been conducted that consider the effect of calcium as such and these supplement the observations of its effect on strawberry as lime. Most of the sand-culture studies of the effects of calcium on strawberry nutrition have emphasized foliar symptomology but other effects have also been noted.

From the standpoint of foliar symptoms under conditions of deficient calcium, Wallace (52) observes slightly paler color, larger leaflets, and longer petioles as compared to check plants. Davis et al. (15) reported

exceptional vigor, larger leaves with long petioles, no tints, but some blotching of the leaves by fall. Hambidge (23) states that red brown discolorations may develop around the base of the leaflet and that the entire leaf or parts of it may become necrotic. Lineberry and Burkhart (36) have shown an apparent varietal difference to calcium deficiency in that Klondike exhibited dwarfing and marginal scorching of young leaves followed by their death and with a lack of luster accompanied by mottling in mature leaves. Blakemore foliage developed a dwarfing and crinkling at the tips of young leaves with a loss of luster and a yellowing of the mature leaves. Gilbert and Robbins (20) report a marked chlorosis of older leaves accompanied by severe tip necrosis of younger leaves and death of some growing points. Gilbert (19) suggests that this tip burning may be a manifestation of boron toxicity. Iwakiri and Scott (29) showed similar tip burning of young unopened leaves which became deformed and crinkled when fully expanded as being definitely an expression of calcium deficiency. They also report as calcium deficiency a slight marginal necrosis and partial interveinal chlorosis with eventual death of the plant.

Davis et al. (15) found the effects of excess calcium in the nutrient solution to be reflected in the leaves by dull green foliage, by purpling of the older leaves, with both being accompanied by considerable scorch and blotch. At especially high concentrations they report a distinct curling inwards and upwards of the leaf blades with the undersides becoming "reddish purple" - a condition that resembles their low potassium and low phosphorus treatments.

Considering the effects of calcium on the roots, Hambidge (23) stated that under deficient calcium conditions the roots show considerable injury before the tops are seriously affected and the situation becomes progressively

worse as the deficiency continues. Roots die back from the tips after making relatively short growth and new rootlets develop behind the dead portion with the result that the entire root system consists of a small mass of short growths. Lineberry and Burkhart (36) working with Klondike and Blakemore grown with nutrient solutions in sand obtained little root growth without the addition of calcium.

In the crown, calcium deficiency affects the buds or growing points of the crown first and these are killed. Subsequent growth must take place from lateral buds and the young leaves may also be affected (23).

Davis et al. (15) reported that low calcium feeding is not apt to decrease fruit bud formation markedly. Schowengerdt (46) agreed with this essentially and stated that the per cent of strawberry flowers was not affected by variation of calcium in mineral nutrient concentrations. Gilbert and Robbins (20) reported that the yield of fruit increased with increasing concentrations of calcium in the substrate to a point but with a reduction in yield at concentrations above the optimum.

In addition to all of the above phenomena reflecting the effects of calcium, it has also been reported (15) that there was considerable winter killing of plants subjected to calcium deficient solutions.

Magnesium. Wallace (52) reported that strawberry plants "suffered badly" when receiving "a diet low in magnesium." Foliar symptoms of deficiency commenced with purple tints on the leaves and later developed a central patch and a marginal rim of purple on each leaflet. These purple tints later developed into various shades of red and yellow. Davis et al. (15) reported plants under deficient magnesium conditions to have large leaves and good vigor until late summer when patches of brown, confined mostly to the margins, developed, and fell out. Petioles were always

longer than normal. Hambidge (23) stated that magnesium deficient plants have abnormally thin leaves with bright green coloration. Blotching begins near the margins of old leaves and spreads until the whole surface is necrotic. The affected areas usually exhibited a purple or greyish brown color. Lineberry and Burkhart (36) report a chlorosis of the outer portion of mature leaves followed by a downward rolling of the leaf margin. In later stages the upper surface of the leaf blades between the veins become yellow orange in color except the region along the mid-rib. Brown necrotic areas appeared on the under surface of these leaves. Iwakiri and Scott (29) reported that magnesium deficiency appeared as interveinal chlorosis of older leaves. In addition there was development of marginal necrosis and a downward cupping of the leaf margins. In the later stages, a reddish brown coloration developed around the periphery of the leaflet.

The only information about the effect of excess magnesium conditions on strawberries is the work of Davis et al. (15) who reported that plants were normal in vigor but as the season progressed signs of marginal scorch developed and this was followed by chlorosis. Eventually older leaves showed considerable purpling "indicating lack of either potassium or phosphorus."

The effect of magnesium on yield was discussed by Davis et al. (15) who stated that the complete withdrawal of magnesium did not have as much effect on fruit bud formation as did the withdrawal of phosphorus or potassium although significant reduction did occur. Considering the effect of excess magnesium they stated that a significant reduction in yield did not occur until the magnesium in the medium was raised to four times the normal amount. These workers also reported marked winter injury

in treatments receiving deficient amounts of magnesium.

Potassium. Wallace (52) growing plants in sand culture in the absence of potassium stated that the plants had a normal appearance until fall when the younger foliage became a dull green color and lacked vigor. In succeeding seasons the plants developed slight leaf scorch by mid-summer and in the fall of the fourth season, the plants became dwarfed. Davis and Hill (14) reported as potassium deficient symptoms a gradual change in leaf color which was at first dark green but later lost luster and assumed a bronze-like tint, becoming violet, and finally purplish red. The leaves became curled by the end of the fruiting season. Hoagland and Snyder (27) stated that leaf blades on potassium deficient plants had no prominent marginal scorch but that the injury was first manifest by a bronzing and necrosis of the petiole and base of the leaf. Davis et al. (15) developed potassium deficient plants that exhibited abnormally dark leaves that were dull, drooping, and curled upward and inward. The under-side of the leaves were distinctly purpled with a "mosaic-like" mottling on many leaves. New leaves developed marginal burn which was followed by death of many of the leaves. Lineberry and Burkhart (36) found that plants in deficient nutrient solutions developed only about one-third of the foliage produced on plants in the complete nutrient solutions. As with calcium, there was a varietal difference in manifestation of potassium deficiency. In the matured leaves of Klondike the deficiency was characterized by progressive purpling of the mid-rib and petiole, followed by necrosis of the petiole. On the other hand, the mature leaves of Blakemore exhibited a scorching and upward rolling of the leaf margin. The potassium deficiency symptoms of Iwakiri and Scott (29) appeared on fully expanded leaves as a slight marginal necrosis which developed

progressively into interveinal chlorosis over the entire leaflet.

Davis and Hill (14) reported the effect of an excess of potassium on strawberry plants as producing plants of poor vigor bearing small leaves having considerable reddish tint on the margins. Later Davis et al. (15) reported that plants subjected to excess potassium had darker foliage and were more vigorous than plants grown in complete nutrient solutions. Also, all plants receiving excess potassium appeared slightly deficient for phosphorus or potassium on the basis of foliage tints.

Reports of the effect of potassium on yield indicated that a potassium deficiency caused a decreased yield (14). Davis et al. (15) stated that withdrawal of potassium caused an "almost significant" reduction in bloom and the reduction was greater than that due to an excess of potassium. Under high nitrogen, the absence of potassium reduced yield to a negligible amount and resulted in death of most plants. They also state that considering fruit bud formation there is little danger of "overfeeding" strawberry plants with potassium and that the plants appeared capable of reutilizing their original potassium to a marked degree. These workers also report that lack of winter hardiness was associated more markedly with deficient potassium than any other treatment.

Sodium. Hoagland and Snyder (27) investigated the tolerance of strawberry plants to sodium salts using water culture methods. The variety Nich Ohmer was highly sensitive to "moderate" concentrations of sodium salts - 100 to 500 ppm Na in solution - and the toxic effects were produced by both the sulfate and chloride form of sodium. Toxicity was manifested by a marginal burning which spread until the entire leaf became necrotic. Plants grown in solution containing small amounts of sodium bicarbonate showed marked root necrosis and some yellowing of foliage. The pH of the

toxic solutions was within the range of 7.3 to 8.2. Latimer (31) studied the response of Howard 17 plants to sodium salts and compared the effects of sodium, calcium, and ammonium cations when they were combined separately with the nitrate, phosphate and sulfate anions. The effect of sodium was pronounced and in the quantities used were highly injurious with respect to yield, leaf size, petiole length, and by causing a general dwarfing of the plant. This toxic effect occurred when sodium sulfate, sodium nitrate, and sodium acid phosphate were applied in the fall at the rate of 325 pounds, 400 pounds, and 600 pounds per acre respectively.

Phosphorus. Wallace (52) states that phosphorus deficiency is characterized by a dark greyish-green cast of the leaves and stems which is a "shade darker and duller" than a normal leaf. This is followed by a mottling and dying of the older leaves. Davis and Hill (14) found phosphorus deficient plants to have foliage of dark dull green blades with short petioles. At the end of the fruiting season these leaves exhibited a bronzing similar to potassium deficiency but reddish brown instead of purple. The leaf tissue was "thin and paper-like." Hoagland and Snyder (27) noted the development of purple tints in the leaves and these were "typical" of phosphorus deficient symptoms exhibited by many plants. Davis et al. (15) reported poor vigor and brownish green foliage in the early stages of deficiency symptoms with older leaves turning bronzed red and the leaves becoming reduced in size. Lineberry and Burkhart (36) found the same phosphorus deficiency symptoms for both Klondike and Blakemore in that the leaflets exhibit a blue-green coloration accompanying a reddening of the leaf blades which later became bronzed and had petioles that were bright red. The only phosphorus deficiency symptom noted by Iwakiri and Scott (20) was leaf blades of a darker green than normal.

Under conditions of excess phosphorus nutrition Davis and Hill (14) obtained plants having vigorous foliage lighter in color than normal. After the fruiting season, the leaves developed red tints accompanied by some curling of the blades. Davis et al. (15) observed that high concentrations of phosphorus caused a reduction in vigor along with a marked burning of the leaf margins as the season progressed. Also, the older leaves became light red in color.

Davis and Hill (14) stated that phosphorus deficiency decreased yield and a lack of phosphorus had more effect on set than a lack of nitrogen or potassium. In later experiments, Davis et al. (15) again reported that the withdrawal of phosphorus from the nutrient solution markedly reduced fruit bud formation. Waltman (54) believed his results indicated that strawberries need a relatively large amount of phosphorus and that the reaction of the soil may influence materially the availability of that element. He stated that an acid soil reaction is favorable to the utilization of phosphorus by the plants.

Boron. Hoagland and Snyder (27) showed that boron deficient plants grown in sand culture produced leaflets which developed necrosis of the apical portion of the leaf accompanied by upward cupping and crinkling, giving the leaf a puckered appearance. Latimer (32) under field conditions and Gilbert (19) in sand culture found boron deficiency foliar symptoms resembling those described by Hoagland and Snyder above. Iwakiri and Scott (29) reported no distinctive boron deficiency symptoms in sand culture other than poorer growth of the plants. They stated that the failure to produce definite boron deficiency symptoms reflects the low boron requirement of the strawberry plant, a fact that is also reported by Gilbert (19) and Hoagland and Snyder (27).

Purvis and Hanna (45) in a report on the tolerance of plants to the application of borax on a Norfolk sandy loam listed the strawberry as being sensitive, with 10 pounds of borax per acre causing injury. Latimer (32) found that the strawberry is very sensitive to boron and that applications of more than 25 pounds of borax per acre to Charlton sandy loam soil causes injury as manifested by marginal burning of the foliage and interior purple spots on the leaves. Eaton (16) 1944 found that 5 parts per million boron in nutrient solution caused the death of leaves in Klondike plants. Gilbert and Robbins (20) reported a marginal necrosis as being caused by toxic concentrations of boron in nutrient solution.

Hoagland and Snyder (27) stated that under conditions of boron deficiency roots are poor, runners are slow to develop, and the fruit is often fasciated. The prevention of fasciated strawberry fruits in the variety Fairfax was effected by Willis (58) in North Carolina with an application of 5 pounds of borax before the fruit buds were formed. Gilbert and Robbins (20) reported deformed strawberry fruits at deficient levels of boron and at excess levels the plants produced lower yields with fruit that was dull, unusually conic, and with some dead caps.

Sulfur. Under conditions of deficient sulfur, Davis et al. (15) reported plants of excellent vigor and no abnormal colors. Under excess sulfur conditions they obtained normal growth and vigor until mid-summer, at which time the plants exhibited a "certain amount of phosphorus deficiency symptoms."

Manganese. Lohnis (39) has reported strawberries as being resistant to manganese damage, either with deficient or excess amounts and Iwakiri (28) likewise could produce no manganese deficiency symptoms.

Aluminum. Darrow (11) suggested that aluminum is toxic to plants at low pH and Meyer (41) felt that the dying of plants in summer in Louisiana might be "due to less resistance to aluminum toxicity or else to a greater solubility of aluminum during the summer."

Minor Elements. Hoagland and Snyder (27) growing strawberry plants in water-culture established the necessity for certain of the minor elements and also reported favorable effects of chlorine. Lineberry and Burkhart (36) stated that the presence of chlorides was "objectionable" except at low concentrations.

Calcium and Magnesium. Davis et al. (15) reported that under conditions of excess calcium in treatment, the ash of strawberry plants contained a higher amount of calcium and a reduced amount of magnesium when compared to plants receiving normal amounts of calcium. When calcium was decreased from the normal amount in the nutrient solution, the plant ash contained decreased amounts of calcium and increased amounts of magnesium. Under conditions of increased magnesium in the nutrient solution, an increased amount of magnesium in the ash was accompanied by an increased calcium content. Decreasing the magnesium in nutrient solution resulted in a decreased magnesium and an increased calcium content of the ash. Schowengerdt (46) found that in the tops of strawberry plants, magnesium decreased as the calcium concentration in the treatment decreased. Iwakiri (28) found that the calcium concentration was higher in those plants that did not receive magnesium in the nutrient solution.

Calcium and Potassium. Knight and Wallace (30) reported a negative correlation between the potassium and calcium contents in strawberry plants. Davis et al. (15) found that an excess of potassium in nutrient solution

reduced the calcium accumulation but that an excess of calcium did not always cause a reduced potassium accumulation. They also reported that the effect of excess calcium feeding on fruit bud formation, presumably its reduction, was very marked when the amount of calcium fed was greater than three parts of calcium to one part of potassium fed. Lineberry and Burkhart (36) found that a lack of calcium in the nutrient medium resulted in a marked increase in potassium in the foliage and fruit. Schowengerdt (46) stated that when calcium in the media was decreased, its intake by the plant was also decreased and the absorption of potassium was increased. Also, total dry weight and the number of flowers setting fruit was greatest where the calcium and potassium concentrations in the nutrient media were between 20 and 60 milliequivalents and when these calcium and potassium concentrations were at the same level. The highest vitamin C content also occurred at this level. He stated further, that variations on phosphate concentration in the media do not appear to influence this calcium - potassium ratio. Iwakiri (28) has found that the calcium concentration was higher in plants that did not receive potassium in the nutrient solution.

Calcium and Boron. Gilbert and Robbins (20) reported that at the very low levels of boron in treatment there was a tendency for total boron in the tissues to decrease as calcium increased in the tissue. Generally, however, the ratio of calcium to boron in the tissue decreased with increasing boron in the tissue.

Calcium and Phosphorus. Davis et al. (15) reported that calcium accumulation decreases in the absence of phosphorus. When phosphorus is limiting, the plant does not take up as liberal amounts of calcium even

if the calcium feeding is increased as the phosphorus in the nutrient medium is decreased. Increased calcium did not necessarily increase phosphorus uptake but deficient calcium conditions increased phosphorus accumulation by the plant.

Magnesium and Potassium. Knight and Wallace (30) found "no discernible relationship" between the magnesium and potassium contents of strawberry plants. Davis et al. (15) reported that as magnesium in the plant ash increased the potassium decreased and vice versa. Also to obtain maximum fruit bud formation the amount of magnesium applied to the plants should be from one-third to one-fourth the amount of potassium applied. Lineberry and Burkhart (36) stated that a lack of magnesium in the nutrient media resulted in a marked increase in potassium in the foliage and fruit compared with the effects of the complete nutrient treatment. Schowengerdt (46) found that the magnesium content of strawberry tops decreased as potassium levels in the nutrient media were lowered. Iwakiri (28) found that the potassium concentration was higher in plants grown in nutrient solutions lacking in magnesium.

Magnesium and Phosphorus. Knight and Wallace (30) stated that the concentrations of magnesium and phosphorus in the strawberry plant showed "no discernible relationship" to each other. Davis et al. (15) found that excess magnesium conditions increased the concentration of magnesium in the ash of plants and this increase was accompanied by a corresponding increase in phosphorus. Excess phosphorus feeding had a similar effect. Deficient phosphorus levels in treatment decreased the phosphorus content of the ash from normal but caused no change in the magnesium content. Schowengerdt (46) stated that the magnesium content of strawberry plant

tops decreased as phosphorus levels were lowered. He also stated that magnesium absorption decreased when the calcium, potassium, and phosphorus levels were lowered simultaneously.

Potassium and Phosphorus. Davis et al. (15) stated that the complete withdrawal of potassium results in marked phosphorus accumulation and that the addition of potassium did not interfere with phosphorus accumulation until fed for a prolonged period. Increased phosphorus retarded potassium accumulation but potassium accumulation accompanied the withdrawal of phosphorus from the nutrient medium. Also, maximum fruit bud formation was obtained when the amount of potassium fed to the plants was three times the amount of phosphorus made available. Schowengerdt (46) has stated that variation in phosphorus concentration levels had little effect upon potassium absorption.

Potassium and Sodium. Knight and Wallace (30) reported a negative correlation between the potassium and the sodium contents of the strawberry plant.

Nitrogen and Minerals. With strawberry, Davis and Hill (13) did work that indicated the importance of a balance between nitrogen and the mineral elements in nutrient solutions. Their data showed a "danger" from an excess of nitrogen over minerals and indicated that a ratio of 1 part per million of nitrogen to 1 part per million of minerals was "about as close a ratio as could be brought about with safety." In later work, Davis et al. (15) stated that high nitrogen tended to increase the absorption of potassium and the absence of potassium under high nitrogen conditions reduced the yield to a negligible amount. High nitrogen also increased the absorption of phosphorus, and possibly magnesium, as well as decreased the absorption

of calcium from nutrient solution. Also, the withdrawal of calcium from the nutrient solution did not produce a "significant effect" on fruit bud formation until very large quantities of nitrogen were fed.

Accumulation in Plant Parts. Considering the accumulation of ions by the various plant parts of the strawberry, Hoagland and Snyder (27) found an accumulation of sodium by the leaves and roots. Lineberry and Burkhart (36) found in dormant strawberry plants of the variety Klondike a "considerable" accumulation of potassium in the roots as compared to leaves and crowns. Calcium, magnesium, and phosphorus were localized in the leaf blades. The crowns were low in calcium and sulfate. The nutrient content of the strawberry fruit was found to follow that of the leaves but was not as high.

MATERIALS AND METHODS

To accomplish the three-fold objective of this study it was conducted in two general phases that utilized different experimental techniques. The purpose of the first phase was to establish a symptomology for conditions ranging from deficient to toxic amounts of calcium, magnesium, and potassium in the nutrient media. The procedure involved a series of nutrient levels ranging from zero to toxic amounts of each of these cations. The growth manifestations at the various nutrient levels were then observed. The purpose of the second phase was to make manifest the interrelationship of the effects of these cations in strawberry nutrition. This phase was conducted as a factorial experiment involving three levels each of calcium, magnesium, and potassium in all combinations. The three levels selected for each of these cations - i.e. low, medium, and high - were based on the results obtained in the first phase. Each of the two phases contributed in part to the remaining objective of the study, namely to correlate symptomology with mineral content of the plant or its parts.

General Methods. The methods described here were used for both phases of the study. The experiments were conducted in sand culture in the greenhouse. The containers in which the plants were grown were 2-gallon crocks with basal holes for drainage. The supporting medium was #18 coarse white sand that had been thoroughly washed and leached with tap water before using. Salt concentrations in the nutrient solutions were considered on the basis of milliequivalents of cation per liter. Therefore, stock solutions were prepared as normal solutions of the salts with distilled water as

diluent. The chemicals used to prepare the stock solutions were "C.P.", "analyzed", or "analytical reagent" grade depending upon the proprietary designation of the manufacturer supplying the chemical. The nutrient solutions were applied using the "slop-culture" method. Minor elements were added as Hoagland's (27) minor element solution A; 1 ml. of the stock solution was added to a liter of the nutrient solution that was applied to the plants. Iron was added as 0.5 per cent ferric citrate and at the same rate as that for the minor element stock solution.

For chemical analyses, the plant material was washed free from sand, placed in a kraft-paper bag and dried in a forced air oven at 80°C.. After 48 hours, dry weights were taken and the dried plant material was pulverized in a Wiley mill fitted with a #40 mesh screen. Pulverized dried material, prepared as above, of a definite weight was placed in porcelain crucibles and ashed in a muffle furnace at 525°C.. The ash was taken up in 10 ml. of 1:1 HCl, evaporated to near dryness, and again taken up with 10 ml. of 1:1 HCl. This solution was then heated to boiling and filtered through Whatman #2 filter paper which was then washed free of the acid with hot water, all of the filtrate being collected. When cool, the filtrate was brought up to 100 ml. which then contained the ash of a measured amount of dried plant material. From this ash solution, calcium and potassium determinations were made by flame photometry using the Beckman instrument. Magnesium was determined by the Titan yellow method (21), the color comparisons involved being made with the Beckman spectrophotometer. The data were converted to terms of concentration and total content for statistical analyses.

Detailed Methods - Phase I. Rooted single-crowned primary and secondary runner plants of the variety Temple were obtained from the University

of Maryland Plant Research Farm on March 23, 1949. These plants were immediately cleaned, the roots being washed free from soil and each plant trimmed to three leaves. The plants were then graded and accordingly placed into one of five size groups based on the diameters of the crowns. The crown diameters of the five groups were as follows: (1) 5.0 - 7.5 mm.; (2) 7.6 - 10.0 mm.; (3) 10.1 - 12.5 mm.; (4) 12.6 -15.0 mm.; and (5) above 15.0 mm.. Each group was assigned respectively as one of the five replicates of the experiment. Three plants were placed in each crock and tap water was used to establish the plants until the beginning of treatments. To determine the mineral composition of the plants at the outset of the experiment, the mean dry weight of fifty plants comparable to those used in the experiment was determined as well as the concentration and content of calcium, magnesium, and potassium in the plants at that time (Appendix Table 4).

Nutrient treatments were started on May 5, 1949. On the basis of previous nutrient culture studies made with strawberry by others (Appendix Tables 1 and 2), apparent optimum levels of calcium, magnesium, and potassium were selected. The "best" or "normal" nutrient solutions of these workers were considered. The salt or ion concentration in these representative solutions were presented by various methods of expressing ion or salt concentration. To establish some degree of uniformity for comparison, these data were recalculated as parts per million and milliequivalents per liter (Appendix Table 3). Considering these data, the cation levels in the applied nutrient solution selected as optimum for this experiment were as follows: calcium, 4 me./l.; magnesium, 2 me./l.; and potassium, 2 me./l..

In all of the nutrient treatments herein, while any two of the three

cations were maintained at their selected optimum level, the third was varied through seven levels ranging from 0 to 25 me./l. as outlined in Table 1. This design involved a series of twenty-one treatments. However, it is to be noted that in the series, the optimum selected level occurs three times. For expediency and efficiency, only one group received this particular treatment. Thus, instead of the indicated twenty-one treatments, there were actually nineteen which were replicated five times, giving ninety-five crocks of plants for the entire experiment.

The following chemicals were used in Phase I: $Ca(NO_3)_2.4H_2O$, $CaCl_2.2H_2O$, $MgSO_4.7H_2O$, $MgCl_2.6H_2O$, $Mg(NO_3)_2$, KH_2PO_4, KNO_3, K_2SO_4, KCl, and H_3PO_4. The nutrient solutions to be applied were prepared in 18 liter quantities from the stock solutions, using distilled water as diluent, and 500 ml. of solution were applied to each crock every third day. See Table 2 for the ion composition, and Table 3 for the salt composition, of the nutrient solutions. The pH of these solutions was in the range 5.0 - 6.0.

Blossoms were removed from the plants as formed. The onset and appearance of symptoms of abnormality were noted as the experiment progressed. Dry weights of plants were obtained as a criterion of growth. Samples for analyses were taken at the following dates and intervals: May 5, the beginning of treatments; June 3, four weeks of treatment; June 17, 6 weeks of treatment; and July 3, when the experiment was terminated after eight weeks of treatment. The sample taken at each of the above times consisted of one plant per treatment from each of the five replicates. The entire plant was washed free from sand in distilled water, placed in a kraft-paper bag and processed as described in General Methods.

For statistical analyses, the data were separated into three groups according to the variable cation. Thus, there were three general units based on treatment: the calcium-variable group; the magnesium-variable

TABLE 1. Outline of Nutrient Treatments (Phase I).

Treatment No.	me./l. Ca	me./l. Mg	me./l. K
	(Calcium varied)		
1	0	2	2
2	0.5	2	2
3	1	2	2
4	2	2	2
*5	4	2	2
6	12	2	2
7	25	2	2
		(Magnesium varied)	
8	4	0	2
9	4	0.5	2
10	4	1	2
*11	4	2	2
12	4	4	2
13	4	12	2
14	4	25	2
			(Potassium varied)
15	4	2	0
16	4	2	0.1
17	4	2	0.25
18	4	2	0.5
*19	4	2	2
20	4	2	4
21	4	2	25

*Treatment selected as "optimum".

TABLE 2. Ion Composition of Applied Nutrient Solutions (Phase I).

Treatment	Concentration of Ions Expressed as me./l.										
	Cations						Anions				
	Ca	Mg	K	H	Na	Total	SO_4	H_2PO_4	NO_3	Cl	Total
1	-	2.0	2.0	-	-	4.0	1.0	1.0	2.0	-	4.0
2	0.5	2.0	2.0	-	-	4.5	1.0	1.0	2.0	0.5	4.5
3	1.0	2.0	2.0	-	-	5.0	1.0	1.0	2.0	1.0	5.0
4	2.0	2.0	2.0	-	-	6.0	1.0	1.0	2.0	2.0	6.0
5	4.0	2.0	2.0	-	-	8.0	1.0	1.0	2.0	4.0	8.0
6	12.0	2.0	2.0	-	-	16.0	1.0	1.0	2.0	12.0	16.0
7	25.0	2.0	2.0	-	-	29.0	1.0	1.0	2.0	25.0	29.0
8	4.0	2.0	-	1.0	-	7.0	1.0	1.0	2.0	3.0	7.0
9	4.0	2.0	0.1	1.0	-	7.1	1.0	1.0	2.0	3.1	7.1
10	4.0	2.0	0.25	1.0	-	7.25	1.0	1.0	2.0	3.25	7.25
11	4.0	2.0	0.5	1.0	-	7.5	1.0	1.0	2.0	3.5	7.5
12	4.0	2.0	2.0	-	-	8.0	1.0	1.0	2.0	4.0	8.0
13	4.0	2.0	4.0	-	-	10.0	1.0	1.0	2.0	6.0	10.0
14	4.0	2.0	25.0	-	-	31.0	1.0	1.0	2.0	27.0	31.0
15	4.0	-	2.0	-	-	6.0	1.0	1.0	2.0	2.0	6.0
16	4.0	0.5	2.0	-	-	6.5	1.0	1.0	2.0	2.5	6.5
17	4.0	1.0	2.0	-	-	7.0	1.0	1.0	2.0	3.0	7.0
18	4.0	2.0	2.0	-	-	8.0	1.0	1.0	2.0	4.0	8.0
19	4.0	4.0	2.0	-	-	10.0	1.0	1.0	2.0	6.0	10.0
20	4.0	12.0	2.0	-	-	18.0	1.0	1.0	2.0	14.0	18.0
21	4.0	25.0	2.0	-	-	31.0	1.0	1.0	2.0	27.0	31.0

TABLE 3. Salt Composition of Applied Nutrient Solution (Phase I).

Treatment				Concentration of Salts Expressed as me./l.										
	Levels me./l.													
No.	Ca	Mg	K	$Ca(NO_3)_2 \cdot 4H_2O$	$CaCl_2 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$	$MgCl_2 \cdot 6H_2O$	$Mg(NO_3)_2$	KH_2PO_4	KNO_3	K_2SO_4	KCl	H_3PO_4	Total
1	0.0	2.0	2.0	-	-	1.0	-	1.0	1.0	1.0	-	-	-	4.0
2	0.5	2.0	2.0	-	0.5	-	-	2.0	1.0	-	1.0	-	-	4.5
3	1.0	2.0	2.0	1.0	-	-	1.0	1.0	1.0	-	1.0	-	-	5.0
4	2.0	2.0	2.0	2.0	-	1.0	1.0	-	1.0	-	-	1.0	-	6.0
5	4.0	2.0	2.0	2.0	2.0	1.0	1.0	-	1.0	-	-	1.0	-	8.0
6	12.0	2.0	2.0	-	12.0	-	-	2.0	1.0	-	1.0	-	-	16.0
7	25.0	2.0	2.0	-	25.0	-	-	2.0	1.0	-	1.0	-	-	29.0
8	4.0	2.0	0.0	2.0	2.0	1.0	1.0	-	-	-	-	-	1.0	7.0
9	4.0	2.0	0.1	2.0	2.0	1.0	1.0	-	-	-	-	0.1	1.0	7.1
10	4.0	2.0	0.25	2.0	2.0	1.0	1.0	-	-	-	-	0.25	1.0	7.25
11	4.0	2.0	0.5	2.0	2.0	1.0	1.0	-	-	-	-	0.5	1.0	7.5
12	4.0	2.0	2.0	2.0	2.0	1.0	1.0	-	1.0	-	-	1.0	-	8.0
13	4.0	2.0	4.0	2.0	2.0	1.0	1.0	-	1.0	-	-	3.0	-	10.0
14	4.0	2.0	25.0	2.0	2.0	1.0	1.0	-	1.0	-	-	24.0	-	31.0
15	4.0	0.0	2.0	2.0	2.0	-	-	-	1.0	-	1.0	-	-	6.0
16	4.0	0.5	2.0	2.0	2.0	-	0.5	-	1.0	-	1.0	-	-	6.5
17	4.0	1.0	2.0	2.0	2.0	-	1.0	-	1.0	-	1.0	-	-	7.0
18	4.0	2.0	2.0	2.0	2.0	1.0	1.0	-	1.0	-	-	1.0	-	8.0
19	4.0	4.0	2.0	2.0	2.0	-	4.0	-	1.0	-	1.0	-	-	10.0
20	4.0	12.0	2.0	2.0	2.0	-	12.0	-	1.0	-	1.0	-	-	18.0
21	4.0	25.0	2.0	2.0	2.0	-	25.0	-	1.0	-	1.0	-	-	31.0

group; and the potassium-variable group. Data available included dry weight of plants and concentration and uptake of calcium, magnesium, and potassium. The effect of the rate of application (treatment), initial plant size (replicate), and time of sampling on each of these factors was considered in the analyses.

Detailed Methods - Phase II. A factorially designed experiment, based on the results of the study in Phase I above, was used to determine the effects and interrelationships of low, median, and high levels of calcium, magnesium, and potassium on the vegetative growth of strawberry plants. The execution of this experiment was more precise than the initial study (Phase I), in that the cations were varied without varying anions, the total salt concentration in each nutrient treatment was the same and all were within a narrow pH range.

A change in variety was necessitated for this phase of the experiment to take advantage of the availability of virus-free strawberry plants. Dormant stock plants of the variety Tennessee Beauty were obtained March 27, 1951, from the United States Department of Agriculture Plant Industry Station at Beltsville, Maryland.[1] These plants were immediately set into an isolated field plot at the University of Maryland Plant Research Farm for propagation. Weekly applications of parathion were made throughout the growing season to control the aphid vectors of the virus diseases. It is assumed that the test plants were maintained as virus-free since at the time plants were selected for the experiment, another group of ten plants was selected at random to be indexed for virus diseases by established

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[1]The author wishes to express appreciation to Mr. J. B. Demaree, from whom the plants were obtained.

techniques.[1] This latter group was found to be virus-free.

Primary and secondary runner plants were lifted from the field on November 9, 1951. Several nights of freezing temperatures had occurred by this date but to assure breaking of the rest period the plants were placed in cold storage at 32°F. for two weeks. After the cold storage treatment, the plants were washed free of soil, trimmed to three fully expanded leaves, and then graded into four size groups based on the diameter of the crowns. The crown diameters of these four groups were as follows: (1) 5.0 - 7.5 mm.; (2) 7.6 - 10.0 mm.; (3) 10.1 - 12.5 mm.; and (4) 12.6 - 15.0 mm.. Each group was assigned respectively to one of the four replicates of the experiment.

The plants were planted in the greenhouse on November 27, 1951. Three plants were placed in a crock and at planting time the roots of each plant were pruned to 2.5 inches from the crown base. From that date until the beginning of nutrient treatments on January 1, 1952, the plants were maintained with tap water. Figure 1 shows the root-trimmed plants at planting time as well as the subsequent root growth that occurred in the month between planting and the beginning of treatments. This same figure also illustrates the difference in crown diameter of the four groups selected. Figure 2 illustrates the general greenhouse arrangement of the experiment and Figure 3 shows a typical crock containing plants at the beginning of treatment. The cultural aspects of the experiment were terminated on March 8, 1952.

To maintain the plants in a vegetative condition, supplemental light

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[1]The author wishes to express appreciation to Mr. C. P. Marcus, by whom the plants were indexed for virus disease.

Figure 1. Appearance of Root-trimmed Plants at Planting Time and the Subsequent Root Growth by the Beginning of Treatments. The Arabic Numerals Designate Representative Plants From Each Replicate. Note the Difference in Crown Diameters.

Figure 2. General Arrangement of Experiment in the Greenhouse (Phase II).

Figure 3. Typical Plants at the Beginning of Treatments (Phase II).

providing a continuous 17-hour photoperiod was started on December 3 and continued for the duration of the experiment. Borthwick and Parker (1) employing the same virus-free strain of Tennessee Beauty plants as used in the present test found that maximum runner production was obtained, and lack of flower bud formation was most pronounced, with a 17-hour photoperiod. Hartman (24), studying several varieties, found that no flowers were formed under long days (15 hours) at temperatures of 70°F.. Subjection to the 17-hour photoperiod might also serve to break any rest that may not have been accomplished by cold treatment of the plants, since Darrow (12) found that exposure of plants to a temperature of 70°F. at a photoperiod of 14 to 16 hours broke the rest period of strawberry plants when lifted from the field in mid-November, 1936. The supplemental illumination was provided by 100-watt incandescent lamps hung at 4-foot intervals along the bench and at a distance of 4 feet above the level of the plants. This provided a light intensity of 30 to 40 foot candles at the plant level. The onset and termination of the supplemental light period (4:30 P.M. to 11:00 P.M.) was controlled by a G.E. model 3T27 time switch. The temperature of the greenhouse was maintained at 70-80°F. during the day and 60-70°F. at night.

As indicated previously, the experimental design involved the three cations calcium, magnesium, and potassium at three levels of concentration and in all possible combinations of these cations and levels. The resulting series of twenty-seven treatments was replicated four times making a total of 108 crocks of plants. It should be noted that the replications were confounded with the initial size of the plant as based on crown diameter. The three levels adopted were selected as a result of the preliminary experiment (Phase I) and were based primarily upon vegetative symptoms of

toxicity and deficiency. The three levels of cation concentration adopted for use in the nutrient solutions were the same for the three ions and were as follows: low, 0.5 me./l.; median, 2 me./l.; and high, 8 me./l..

While the cations were varied as above, the following anions were maintained as constant at the following levels: SO_4, 5 me./l.; H_2PO_4, 1 me./l.; NO_3, 5 me./l.; and Cl, 13 me./l.. The source of nitrogen for this experiment was from the nitrates of calcium, magnesium, potassium and sodium. The total concentration of ions in all of the treatments was placed at 24 me./l. which was the resulting concentration of the treatment that combines the three cations at the levels of their highest concentration. In order to maintain cations at this level, sodium was employed as a variable cation independent of the treatment levels of the other cations. The independent anion used to maintain the total anion concentration at 24 me./l. was chloride and this ion contributed 13 me./l. to the anion concentration of all treatments. These facts are outlined in Table 4 which presents the ion composition of the applied nutrient solutions. The salts utilized and the salt composition of the applied nutrient solutions are given in Table 5. The pH of these solutions ranged from pH 4.8 - pH 5.2. The nutrient solutions as applied were mixed in the greenhouse from the stock solutions immediately prior to application. Distilled water not being available in the greenhouse, a Barnstead Bantam Demineralizer was installed to provide the diluent with which to prepare the applied nutrient solutions. This instrument provided a demineralized water containing less than 5 ppm. of electrolyte expressed as NaCl. For the first month of treatments, the rate of application was 500 ml. of nutrient solution per crock applied every other day. After this time, applications every third day were made, and this interval was satisfactory for the duration of the experiment.

TABLE 4. Ion Composition of Applied Nutrient Solutions (Phase II).

Treatment	Concentration of Ions Expressed as me./l.									
	Cations					Anions				
	Ca	Mg	K	Na	Total	SO_4	H_2PO_4	NO_3	Cl	Total
1	0.5	0.5	0.5	22.5	24.0	5.0	1.0	5.0	13.0	24.0
2	0.5	0.5	2.0	21.0	24.0	5.0	1.0	5.0	13.0	24.0
3	0.5	0.5	8.0	15.0	24.0	5.0	1.0	5.0	13.0	24.0
4	0.5	2.0	0.5	21.0	24.0	5.0	1.0	5.0	13.0	24.0
5	0.5	2.0	2.0	19.5	24.0	5.0	1.0	5.0	13.0	24.0
6	0.5	2.0	8.0	13.5	24.0	5.0	1.0	5.0	13.0	24.0
7	0.5	8.0	0.5	15.0	24.0	5.0	1.0	5.0	13.0	24.0
8	0.5	8.0	2.0	13.5	24.0	5.0	1.0	5.0	13.0	24.0
9	0.5	8.0	8.0	7.5	24.0	5.0	1.0	5.0	13.0	24.0
10	2.0	0.5	0.5	21.0	24.0	5.0	1.0	5.0	13.0	24.0
11	2.0	0.5	2.0	19.5	24.0	5.0	1.0	5.0	13.0	24.0
12	2.0	0.5	8.0	13.5	24.0	5.0	1.0	5.0	13.0	24.0
13	2.0	2.0	0.5	19.5	24.0	5.0	1.0	5.0	13.0	24.0
14	2.0	2.0	2.0	18.0	24.0	5.0	1.0	5.0	13.0	24.0
15	2.0	2.0	8.0	12.0	24.0	5.0	1.0	5.0	13.0	24.0
16	2.0	8.0	0.5	13.5	24.0	5.0	1.0	5.0	13.0	24.0
17	2.0	8.0	2.0	12.0	24.0	5.0	1.0	5.0	13.0	24.0
18	2.0	8.0	8.0	6.0	24.0	5.0	1.0	5.0	13.0	24.0
19	8.0	0.5	0.5	15.0	24.0	5.0	1.0	5.0	13.0	24.0
20	8.0	0.5	2.0	13.5	24.0	5.0	1.0	5.0	13.0	24.0
21	8.0	0.5	8.0	7.5	24.0	5.0	1.0	5.0	13.0	24.0
22	8.0	2.0	0.5	14.5	24.0	5.0	1.0	5.0	13.0	24.0
23	8.0	2.0	2.0	12.0	24.0	5.0	1.0	5.0	13.0	24.0
24	8.0	2.0	8.0	6.0	24.0	5.0	1.0	5.0	13.0	24.0
25	8.0	8.0	0.5	7.5	24.0	5.0	1.0	5.0	13.0	24.0
26	8.0	8.0	2.0	6.0	24.0	5.0	1.0	5.0	13.0	24.0
27	8.0	8.0	8.0	--	24.0	5.0	1.0	5.0	13.0	24.0

TABLE 5. Salt Composition of Applied Nutrient Solutions (Phase II).

Treatment No.	Levels me./l. Ca	Mg	K	Concentration of salts expressed as me./l. $Ca(NO_3)_2$	$CaCl_2 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$	$Mg(NO_3)_2 \cdot 6H_2O$	$MgCl_2 \cdot 6H_2O$	KH_2PO_4	KNO_3	K_2SO_4	KCl	$Na_2SO_4 \cdot 10H_2O$	$NaH_2PO_4 \cdot 10H_2O$	$NaNO_3$	NaCl
1	0.5	0.5	0.5	0.5	-	0.5	-	-	0.5	-	-	-	4.5	0.5	4.5	13.0
2	0.5	0.5	2.0	0.5	-	0.5	-	-	-	2.0	-	-	4.5	1.0	2.5	13.0
3	0.5	0.5	8.0	0.5	-	-	0.5	-	-	-	5.0	3.0	-	1.0	4.0	10.0
4	0.5	2.0	0.5	0.5	-	2.0	-	-	-	0.5	-	-	3.0	1.0	4.0	13.0
5	0.5	2.0	2.0	0.5	-	2.0	-	-	-	2.0	-	-	3.0	1.0	2.5	13.0
6	0.5	2.0	8.0	-	0.5	2.0	-	-	-	5.0	3.0	-	-	1.0	-	12.5
7	0.5	8.0	0.5	0.5	-	5.0	-	3.0	-	0.5	-	-	-	1.0	4.0	10.0
8	0.5	8.0	2.0	-	0.5	3.0	5.0	-	-	-	2.0	-	-	1.0	-	12.5
9	0.5	8.0	8.0	-	0.5	3.0	-	5.0	-	5.0	2.0	-	-	1.0	-	7.5
10	2.0	0.5	0.5	-	2.0	-	-	0.5	-	-	-	0.5	5.0	1.0	5.0	10.0
11	2.0	0.5	2.0	-	2.0	-	-	0.5	1.0	1.0	-	-	5.0	-	4.0	10.5
12	2.0	0.5	8.0	-	2.0	-	-	0.5	1.0	5.0	2.0	-	3.0	-	-	10.5
13	2.0	2.0	0.5	-	2.0	-	2.0	-	-	0.5	-	-	5.0	1.0	2.5	11.0
14	2.0	2.0	2.0	2.0	-	2.0	-	-	1.0	1.0	-	-	3.0	-	2.0	13.0
15	2.0	2.0	8.0	-	2.0	-	2.0	-	1.0	3.0	3.0	1.0	2.0	-	-	10.0
16	2.0	8.0	0.5	-	2.0	3.0	5.0	-	-	-	-	0.5	2.0	1.0	-	10.5
17	2.0	8.0	2.0	-	2.0	3.0	3.0	2.0	-	2.0	-	-	2.0	1.0	-	9.0
18	2.0	8.0	8.0	-	2.0	3.0	5.0	-	1.0	-	-	7.0	2.0	-	-	4.0
19	8.0	0.5	0.5	-	8.0	-	0.5	-	-	0.5	-	-	5.0	1.0	4.0	5.0
20	8.0	0.5	2.0	-	8.0	-	0.5	-	1.0	1.0	-	-	5.0	-	3.5	5.0
21	8.0	0.5	8.0	5.0	3.0	-	-	0.5	1.0	-	-	7.0	5.0	-	-	2.5
22	8.0	2.0	0.5	5.0	3.0	2.0	-	-	-	-	-	0.5	3.0	1.0	-	9.5
23	8.0	2.0	2.0	4.0	4.0	2.0	-	-	-	1.0	-	-	3.0	1.0	-	9.0
24	8.0	2.0	8.0	-	8.0	2.0	-	-	1.0	5.0	-	2.0	3.0	-	-	3.0
25	8.0	8.0	0.5	5.0	3.0	5.0	-	3.0	-	-	-	0.5	-	1.0	-	6.5
26	8.0	8.0	2.0	4.0	4.0	5.0	-	3.0	1.0	1.0	-	-	-	-	-	6.0
27	8.0	8.0	8.0	-	8.0	5.0	-	3.0	1.0	5.0	-	2.0	-	-	-	-

Prior to beginning the treatments, the plants had been maintained for five weeks with tap water applications as the only source of nutrients. At the initiation of treatments on January 1, five groups of nine plants each, a group representating each replicate, were lifted for analyses to establish the mineral status of the plants at the outset of the experiment.

The onset and nature of unusual plant and foliar phenomena was observed and noted as treatments progressed. Visible flower clusters appeared from January 1 to March 1 and these were recorded and removed at weekly intervals. Runner formation was to be used as a criterion of response and runners were recorded and removed also at weekly intervals. The first runners appeared on February 10, 1952.

At the midpoint of the experiment severe foliar symptoms developed in certain of the treatment levels. Therefore, on February 13, all of the plants in the first replicate were lifted for analyses to provide an indication of the mineral status of the plants at that time. The greenhouse aspects of the experiment were terminated on March 8, 1952, and the remaining three replicates were removed on that date for dry weight determinations and chemical analyses for calcium, magnesium, potassium, and sodium.

After the plants were lifted for analyses, the sand in each crock was screened to salvage any roots that were severed as the plants were removed from the sand. All of the plant material was washed free from sand in demineralized water and each plant divided into the component parts, roots, crown, petiole, and leaf blade. Dry weights were determined for these component parts and chemical analyses of each plant part was made for calcium, magnesium, potassium, and sodium.

The plant parts were placed in kraft-paper bags and processed for

analysis as described in General Methods. Chemical determinations were also made in the same manner as previously described. In addition, determinations for sodium were made employing the Beckman flame photometer. Mineral status of the parts considered was presented in terms of both concentration and content.

The data were analyzed according to the statistical method prescribed for factorial designs by Brandt (2). For analysis by this method, the data were considered separately as follows: dry weight for each component part and calculated total dry weight of plant; concentration of each of the four cations in each of the four component parts and the calculated total in the plant; and the content of each of the four cations by each of the four component parts and the calculated total content by the plant.

RESULTS OF PHASE I

The results of the first phase of these experiments are discussed in several parts as follows: the onset and nature of the foliar symptomology; the resultant dry weights of the plants; the mineral concentration in the plant material; and the mineral content of the plants. For comparison with the final data of this experiment the status of the initial dormant plant material with respect to dry weights and mineral composition is given in Appendix Table 4. The data in this table are based on the composite of fifty representative plants selected for that purpose at the outset of the experiment.

The Onset And Nature Of Foliar Abnormalities

As the symptomology for each of the cations, namely calcium, magnesium, and potassium is subsequently presented it should be remembered that while the particular ion under discussion was varied through seven levels, the other two cations were applied at a constant level in all treatments of a series. Symptoms for each variable treatment series, whether due to high or low levels of the cation, are described in the order of their appearance.

Variable Calcium Series. Two weeks after the beginning of treatments the foliage of plants receiving 25 me./l. of calcium in nutrient solution showed a purplish discoloration of older leaves with some browning of the leaf margins followed by the drying of those margins within several days. After three weeks of treatment, similar symptoms appeared on leaves of plants receiving 12 me./l. of calcium. After four weeks of treatment, the

plants at these two high levels of calcium had leaves whose margins were brown, necrotic, and curled inwards. About this same time, those plants that received no calcium produced leaf blades characterized by small purple dot-like areas of variable size scattered throughout the inner leaf area. Within several days these small areas became necrotic and gave the inner leaf blade area a stippled appearance. Simultaneously the older leaves on plants receiving 0.5 me./l. of calcium developed small purplish dots along the veins of the leaf blade. Leaf blades on plants receiving 1 me./l., 2 me./l., and 4 me./l. of calcium in treatment were of normal appearance. All of the above described symptoms were well developed after six weeks of treatment and Figure 4 shows representative leaves from plants at that time showing the characteristic manifestations reflecting the treatment level of calcium. Continuing the treatments to eight weeks induced no additional symptoms other than to accentuate those that had already appeared, and this especially at the 0 me./l. calcium treatment level (Figure 5).

Variable Magnesium Series. The first suggestion of disorder occurred after three weeks of treatment when the plants receiving 25 me./l. of magnesium produced leaves having a purpling of the serrations. After another week of treatment similiar symptoms appeared on leaves of plants receiving 12 me./l. of magnesium and, on the older leaf blades of plants receiving the highest level, 25 me./l., the purple serrations developed into a marginal drying or scorch quite different from the dried inrolled margins that occurred at high calcium levels. About the same time, i.e. after four weeks of treatment, the older leaves on those plants receiving no magnesium showed a mottling of the interveinal area of the leaf blade which, a week later, became a multicolored region of red and orange hues. After six weeks of treatment, plants receiving 0.5 me./l. and 1 me./l. of

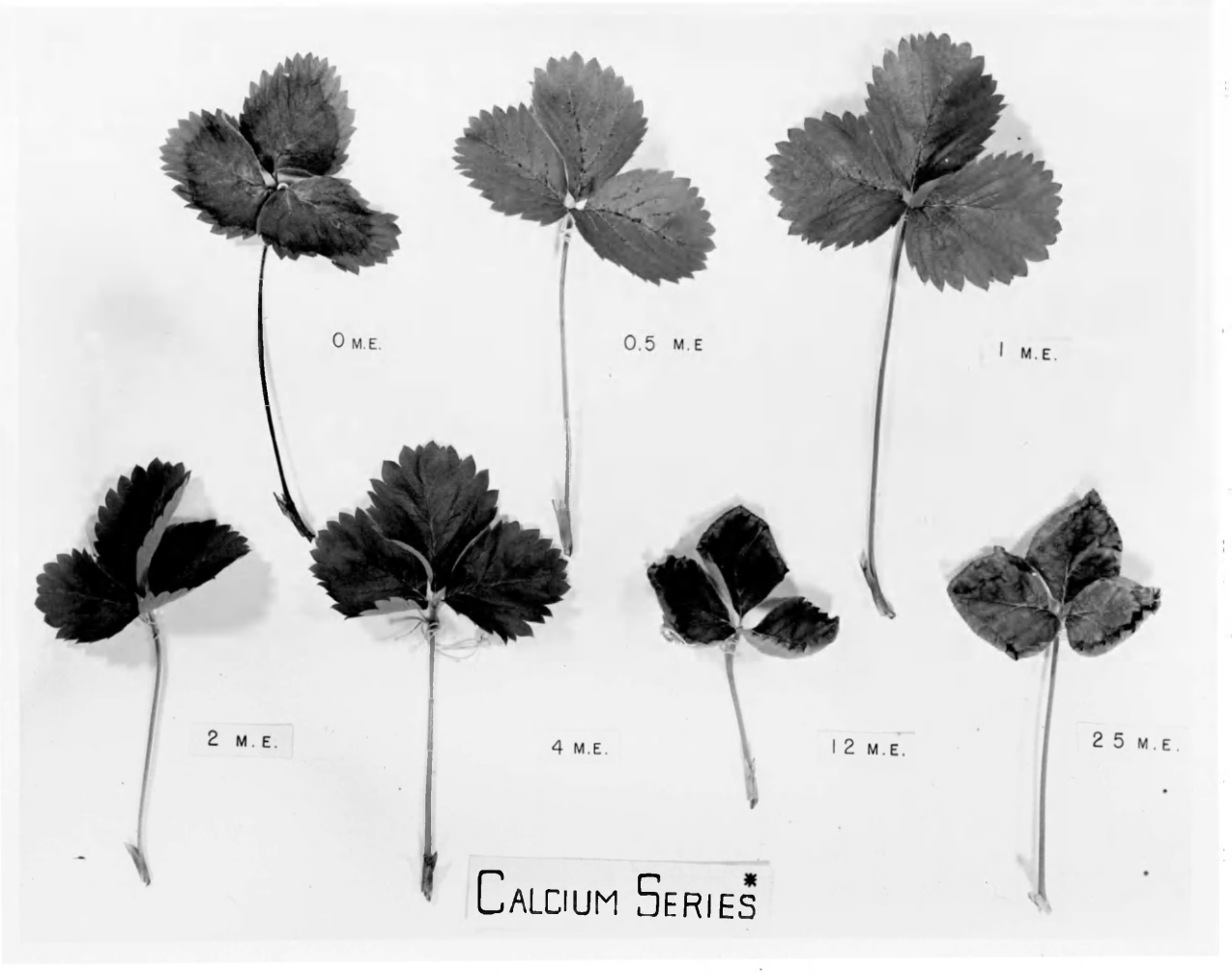

Figure 4. Characteristic Appearance of Strawberry Leaves at Various Levels of Calcium After Six Weeks of Treatment in Sand Culture (2 me./l. of Magnesium and Potassium Applied With All Levels of Calcium).

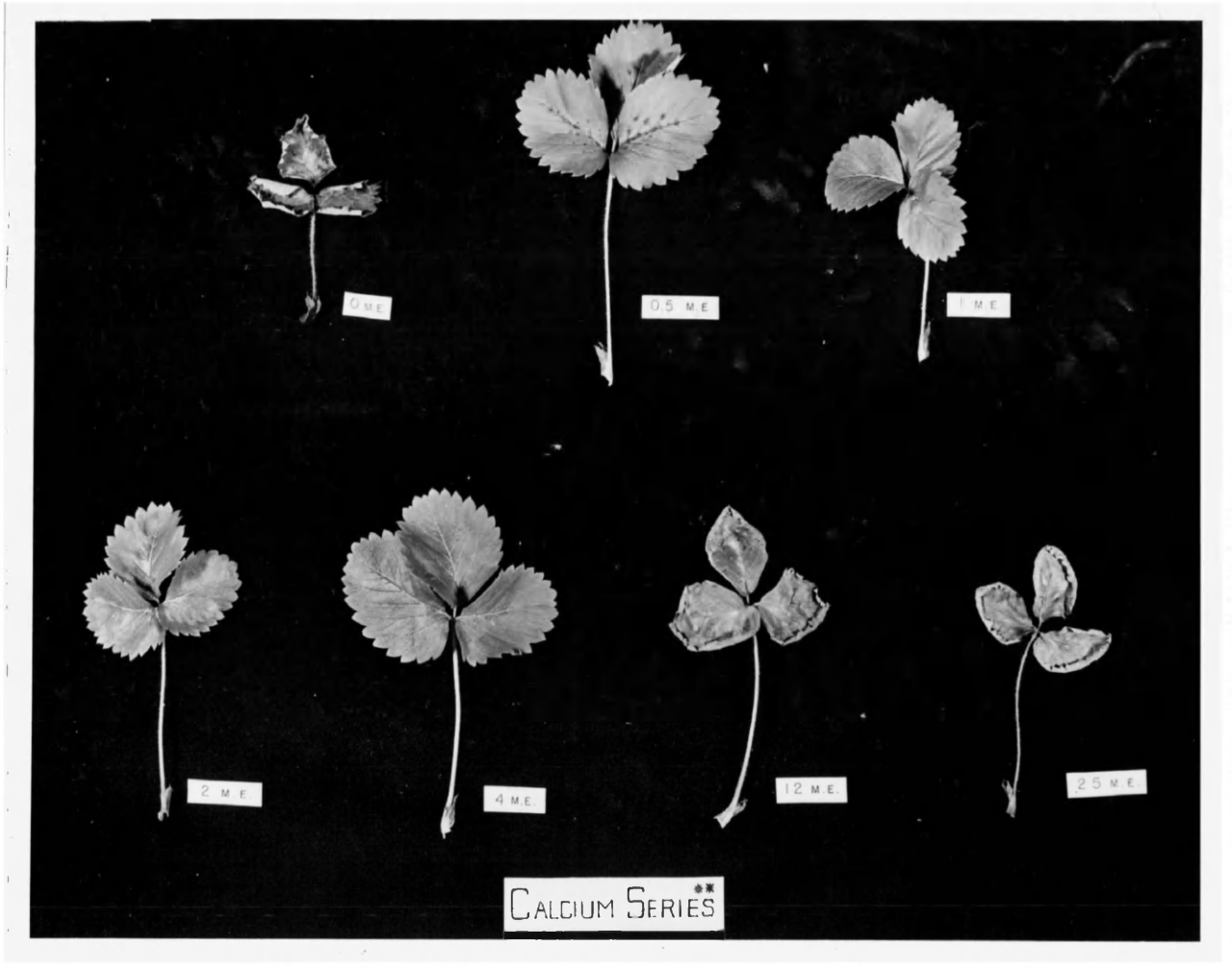

Figure 5. Characteristic Appearance of Strawberry Leaves at Various Levels of Calcium After Eight Weeks of Treatment in Sand Culture (2 me./l. of Magnesium and Potassium Were Applied With All Levels of Calcium).

magnesium developed little that was visually abnormal other than a slight browning of the serrations. Plants receiving 2 me./l. and 4 me./l. of magnesium in nutrient solution produced normal appearing foliage. Thus, leaf blades of plants receiving no magnesium or low levels of magnesium were characterized by interveinal bronzing and browning of the serrations. At high levels of magnesium the leaf blade margins were scorched. Figure 6 shows leaves of plants after six weeks of treatment. Continuing the treatments to eight weeks induced no additional symptoms of foliar disorder (Figure 7).

Variable Potassium Series. After three weeks of treatment the young leaves on all plants receiving no potassium in treatment developed inwardly cupped leaf blades. A week later these leaf blades were "burned" at the margins, the margins also becoming rolled inward. The leaves became mottled and chlorotic and gave the plants a small and shrivelled appearance. These same severe symptoms were exhibited by plants receiving 0.1 me./l. of potassium while marginal scorch was found on plants receiving 0.25 me./l. and 0.5 me./l. of potassium. During the course of the experiment those plants receiving 2 me./l. of potassium in treatment developed normal appearing foliage and those receiving larger amounts, that is 4 me./l. and 25 me./l., produced leaves with nothing more apparent than a slight purpling of the serrations. Figure 8 illustrates the extent of foliar disorder after six weeks of treatment. Continuing the treatments to eight weeks aggravated the foliar symptomology at levels of 0.5 me./l., and less, of potassium as well as at the 25 me./l. level. At this latter level there was a burning and rolling inward of the leaf margins (Figure 9).

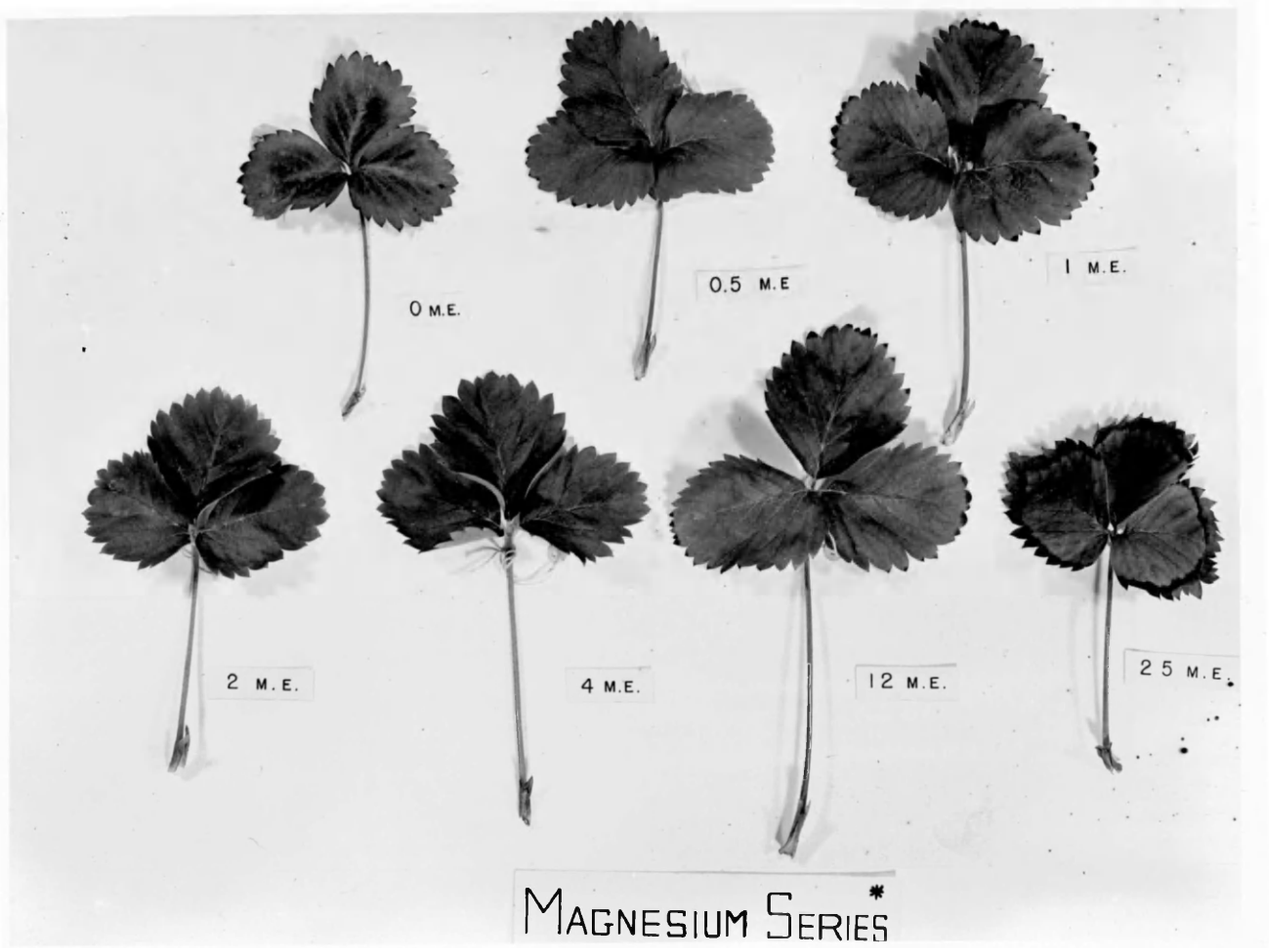

Figure 6. Characteristic Appearance of Strawberry Leaves at Various Levels of Magnesium After Six Weeks of Treatment in Sand Culture (4 me./l. of Calcium and 2 me./l. of Potassium Applied With All Levels of Magnesium).

Figure 7. Characteristic Appearance of Strawberry Leaves at Various Levels of Magnesium After Eight Weeks of Treatment in Sand Culture (4 me./l. of Calcium and 2 me./l. of Potassium Were Applied With All Levels of Magnesium).

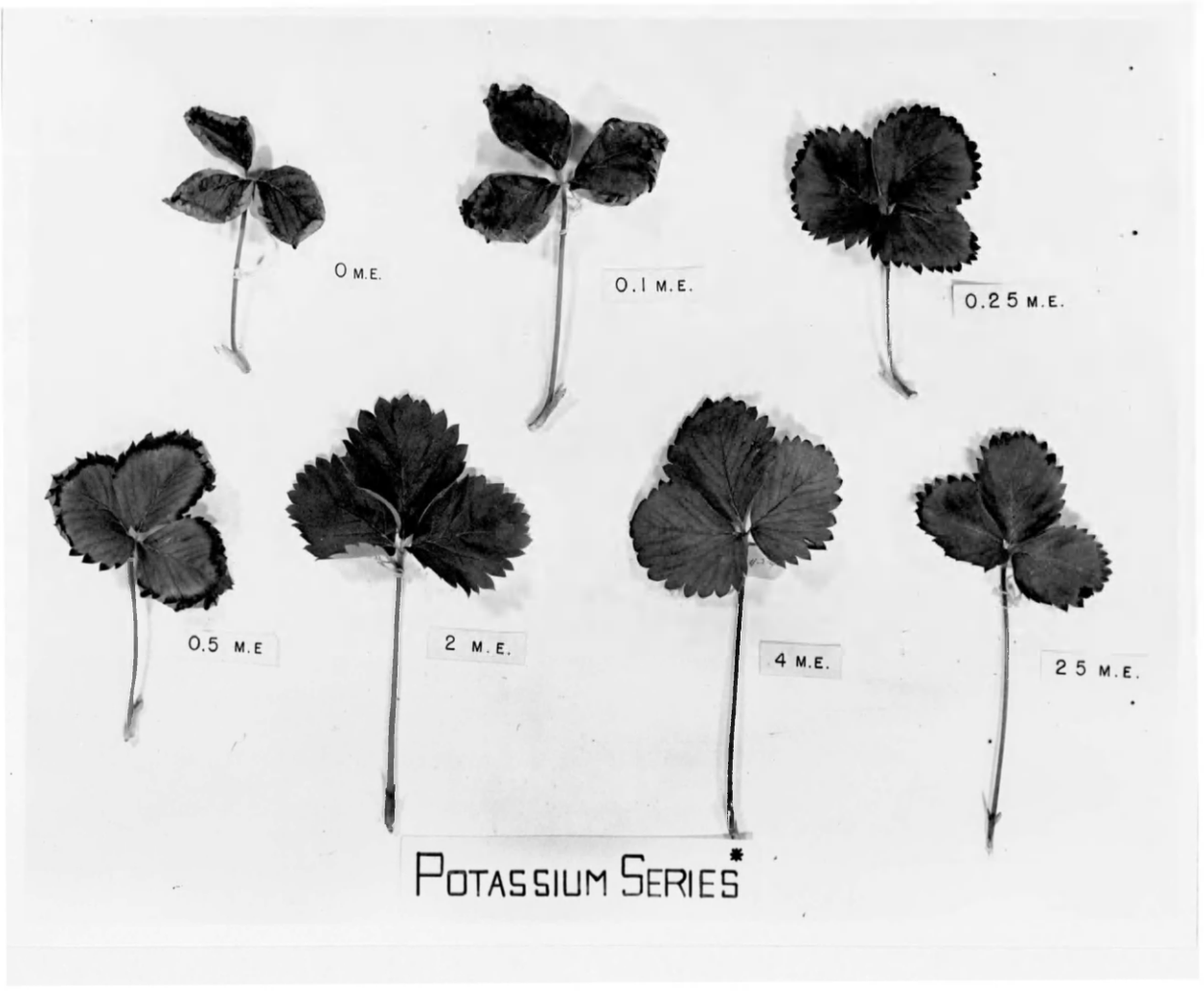

Figure 8. Characteristic Appearance of Strawberry Leaves at Various Levels of Potassium After Six Weeks of Treatment in Sand Culture (4 me./l. of Calcium and 2 me./l. of Magnesium Applied With All Levels of Potassium).

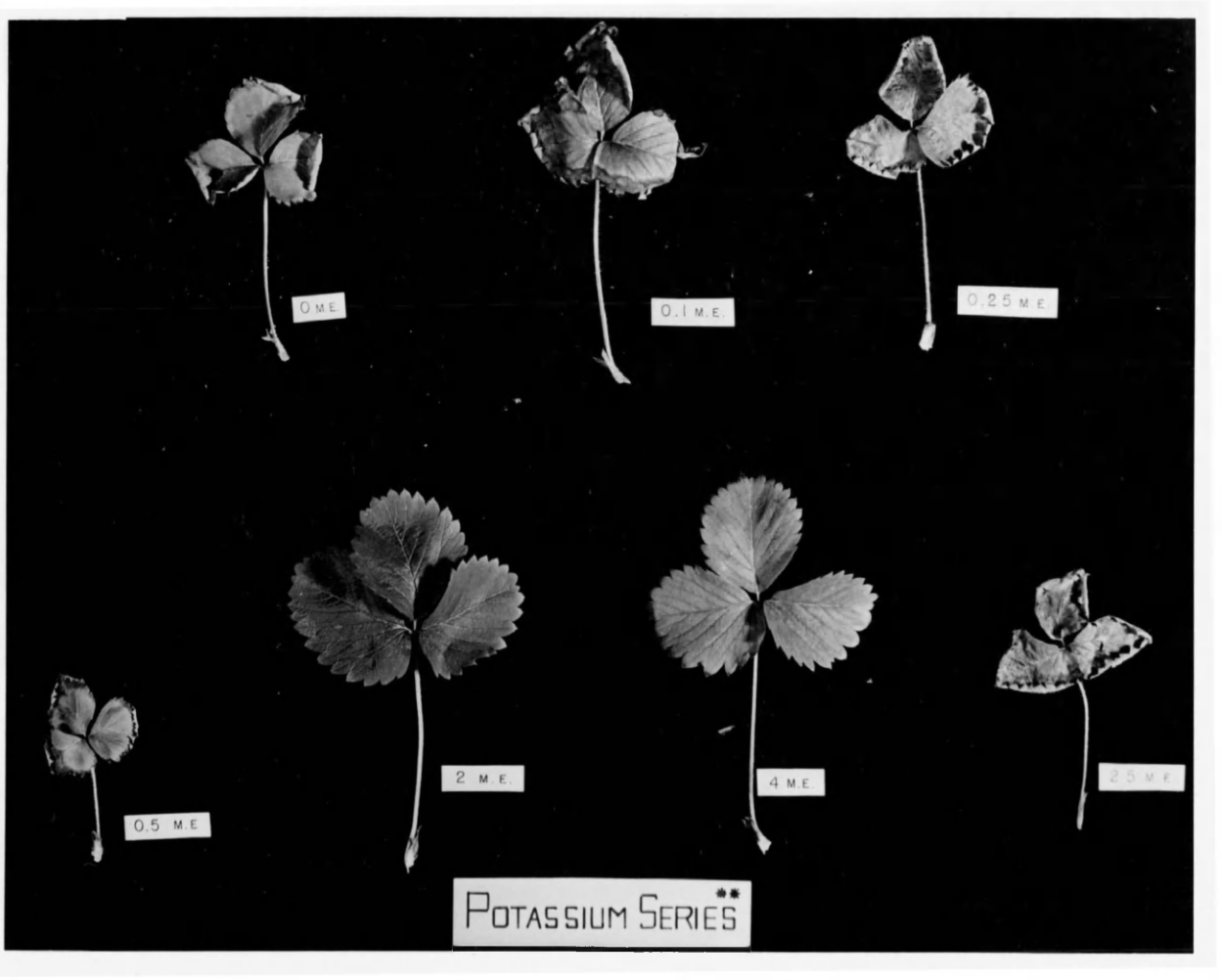

Figure 9. Characteristic Appearance of Strawberry Leaves at Various Levels of Potassium After Eight Weeks of Treatment in Sand Culture (4 me./l. of Calcium and 2 me./l. of Magnesium Were Applied With All Levels of Potassium.)

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Summarizing, plants which developed normal appearing foliage occurred at the following treatment levels: calcium, 2 me./l. and 4 me./l.; magnesium, 2 me./l. and 4 me./l.; and potassium, 2 me./l. of nutrient solution. This is in agreement with the selected optimum levels on which the treatments in this experiment were based. That selected optimum was 4 me./l., 2 me./l., and 2 me./l. respectively for calcium, magnesium and potassium.

The onset of abnormal foliar symptoms at the lower levels of the variable cation in treatment occurred first for potassium, then for magnesium, and finally for calcium. At the higher levels of the variable cation in treatment the high calcium treatments caused the earliest disturbance followed by magnesium and potassium in that order.

Of the three cations a deficiency of potassium in the nutrient solution produced the most severe foliar abnormality, followed in effect by calcium and magnesium. At the highest levels in the substrate potassium was the least severe and calcium the most severe in effect.

After six weeks of treatment there was a striking similarity between the appearance of abnormal foliage induced by high levels of calcium (12 me./l. and 25 me./l.) and those induced by low levels of potassium (0 me./l. and 0.1 me./l.). Also, abnormal foliage characteristic of certain low potassium levels (0.25 me./l. and 0.5 me./l.) showed a similarity to leaves produced under conditions of high magnesium (12 me./l. and 25 me./l.). After eight weeks of treatment the appearance of abnormal leaves at low potassium levels was similar to abnormal foliage of both the high magnesium and calcium levels.

The occurrence of normal and abnormal foliage has been incorporated

into the tables giving the cation concentrations in strawberry plant material. These are Tables 10, 11, and 12.

Dry Weights of Plants

The "F" values from analyses of variance of the dry weights of strawberry plants when calcium, magnesium, and potassium were varied in nutrient solution are given in Table 6.

It should be pointed out at this time that although the statistical analyses indicated significant effects due to replicate and/or replicate interactions, the replicate variance includes both location effects in the greenhouse and also effects due to original plant size. Thus it is impossible to ascertain causes of significant differences obtained where replicates are involved. For this reason, main effects due to replicate and replicate interactions indicated as significant in the statistical analyses of Phase I data are not considered in the discussion of results.

Dry weights of plants as affected by nutrient level of cation.

Variable Calcium Series. In the calcium series plants receiving from 0.5 me./l. to 4 me./l. of Ca were similar in mean dry weight and did not vary more than 0.12 grams within that range. The mean dry weight of plants receiving 12 me./l. of calcium in treatment, though somewhat lower, did not significantly differ from the above group. The mean dry weights of plants receiving the extremes of treatment, i.e., 0 me./l. and 25 me./l. of Ca were both significantly less than that of plants receiving from 0.5 me./l. to 4 me./l.. Generally speaking, with the exception of the treatment receiving no calcium, the larger mean dry weights occurred at the lower levels of calcium and decreased in a linear manner as the level

TABLE 6. F Values for Dry Weights of Strawberry Plants When Cations Were Varied in Nutrient Solution (Phase I).

Source	D/F	Cation Varied		
		Ca	Mg	K
Level	6	2.46*	4.58**	2.31*
Treatment Length	2	34.67**	23.62**	32.86**
Replicate	4	22.13**	25.20**	29.08**
Level x Length	12	1.15	0.76	1.18
Level x Replicate	24	1.09	0.77	1.41
Length x Replicate	8	1.01	2.49**	1.39
Error	48			
Total	104			

of calcium in treatment increased (Table 7).

Variable Magnesium Series. In this group of treatments the mean dry weight of plants receiving magnesium in the range of levels from 0.5 me./l. to 12 me./l. did not differ significantly. The mean dry weights of plants receiving the high and low treatments were both less than that of the above mentioned range. Thus, only at the lowest and highest levels of magnesium did plant dry weight significantly reflect the influences of treatment (Table 7).

Variable Potassium Series. Here the greatest mean dry weight of plants occurred at the level of 2 me./l. of potassium in treatment and there was a tendency to produce smaller plants at levels both lower and higher than that level (Table 7).

Dry weights of plants as affected
by length of treatment.

The mean dry weight after four, six, and eight weeks of treatment in which calcium, magnesium, and potassium were each varied separately in nutrient solution are given in Table 8. In all cases, the longer the treatment and therefore the longer the plants were grown, the greater was the mean dry weight of the plants. It is interesting that the greatest dry weights occurred where magnesium was varied in treatments and the lowest dry weights where potassium was so varied, reflecting the greater effect of potassium on plant growth.

* * * * * * * * * * * * *

Summarizing the effects of treatment on dry weight it may be said that varying the magnesium in treatment had the least apparent effect on

TABLE 7. Mean[a] Dry Weights of Strawberry Plants, in Grams, When Calcium, Magnesium, and Potassium Were Varied in Nutrient Solutions (Phase I).[b]

Treatment Level	Cation Varied		
me./l.	Ca	Mg	K
0.0	2.96	2.91	2.65
0.1	-	-	3.36
0.25	-	-	2.84
0.5	3.79	3.78	2.90
1.0	3.68	4.08	-
2.0	3.68	3.66	3.67
4.0	3.67	3.80	3.29
12.0	3.24	4.16	-
25.0	2.90	2.77	3.13
L.S.D. @5%	0.67	0.72	0.65
@1%	N.S.	0.96	N.S.

[a]Mean of 15 plants.

[b]At the beginning of the experiment the mean dry weight of 50 plants comparable to those used was 0.98 grams.

TABLE 8. Mean[a] Dry Weight Per Plant As Affected by Length of Treatment (Phase I).

Length of Treatment (weeks)	Cation Varied in Treatment Level		
	Ca	Mg	K
4	2.47	2.79	2.32
6	3.48	3.59	3.00
8	4.31	4.40	4.04
L.S.D. @5%	0.44	0.47	0.43
@1%	0.59	0.63	0.57

[a]Mean of 35 plants.

the resultant dry weight of the plants. It is noteworthy that the greatest dry weight values, as a group, occurred where magnesium was varied. Where calcium was the variable cation there was a tendency for the larger dry weights to occur at the higher levels of calcium in treatment. Where potassium was the variable cation in nutrient solution, the lower dry weight values occurred at the lower levels of treatment. In addition, potassium as the variable cation produced plants, as a group, with the smallest dry weights.

Mineral Concentration In Plants

When converting the results of the chemical analyses the data were calculated as milligrams of cation per gram of dried plant material as an expression of concentration. Statistical analyses of the data were made on this basis for ease of analysis. However, the experimental treatments were established on a milliequivalent per liter of nutrient solution basis and the data should be considered on the same basis. Therefore, the original data, expressed in terms of milligrams of cation per gram of dry weight, have been recalculated as milliequivalents per 100 grams of dry weight of plant material. Since the data are available in both forms of concentration expression, and since this experiment is somewhat transitional in the trend of reporting results, the data are presented in both ways. However, they are considered and discussed in the text only on the milliequivalent basis. Henceforth, concentration and content will be expressed simply as me. per unit for the sake of brevity. Plant weights given are always on an oven-dry basis.

The results of statistical analyses for the concentration of cations in strawberry plants as certain of the cations were varied in nutrient solution are summarized in Table 9.

TABLE 9. F Values For The Concentration of Cations in Strawberry Plants When Certain of The Cations Were Varied in Nutrient Solution (Phase I).

Source	D/F	Cation Varied								
		Calcium			Magnesium			Potassium		
		Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
Level	6	127.63**	15.00**	0.84	45.48**	340.33**	21.54**	28.30**	16.87**	283.67**
Treatment Length	2	5.50**	4.20*	12.82**	0.84	13.33**	11.79**	12.94**	21.87**	3.15
Replicate	4	1.82	6.00**	5.44**	1.20	1.66	0.85	3.46*	5.25**	2.05
Level x Length	12	1.40	1.40	1.49	1.48	5.33**	3.20**	1.98*	1.50	0.93
Level x Replicate	24	1.16	1.20	1.68	1.64	3.33**	1.08	1.38	0.62	1.39
Length x Replicate	8	1.65	4.20**	2.24*	0.57	2.66	1.09	2.92*	8.25**	1.64
Error	48									
Total	104									

Mineral concentration in plants as affected by nutrient level.

Variable Calcium Series. The cation concentration of strawberry plants when calcium was varied in nutrient solutions is shown in Table 10. As the level of calcium in treatment was increased the concentration of calcium in the plant material increased, the concentration of magnesium decreased, and the potassium concentration remained relatively constant.

The concentration of calcium ranged from 8.35 me./100g. at the lowest calcium level to 41.70 me./100g. at the highest level of calcium applied. Although the concentration of calcium in the plant material increased as the calcium in treatment was increased there was no significant difference of the concentrations in the plant material between successive levels up to 2 me. of Ca/l. of nutrient solution. It is interesting that the concentrations of calcium in the plant material in this same range are at, or below, the concentration of calcium in plants analysed at the outset of the experiment (Appendix Table 4).

As the calcium was increased, both in treatment level and concentration in plant material, the concentration of magnesium in the plant material progressively decreased. It should be kept in mind that the magnesium applied in treatment with this series was "constant" at 2 me./l. of nutrient solution as the calcium was varied through its seven levels of increasing amounts. The greatest concentration of magnesium, 4.11 me./100g., occurred at the 0 me. Ca level and the lowest concentration, 2.39 me./100g., occurred at the highest level of calcium in treatment. The concentration of magnesium at all levels was maintained higher than the magnesium concentration in plants analysed at the beginning of the experiment (Appendix Table 4).

TABLE 10. Final Mean Cation Concentration of Strawberry Plants When The Calcium Level Was Varied in Nutrient Solutions (Phase I).

Treatment me./l. Calcium	Unit	Mean[a] Concentration of Cation Ca	Mg	K	Foliar Response[b]
0	mgs./gm.	1.67	0.50	15.48	Abnormal
	me./100gms.	8.35	4.11	39.58	
0.5	mgs./gm.	2.14	0.43	15.44	Abnormal
	me./100gms.	10.70	3.54	39.48	
1	mgs./gm.	2.68	0.42	15.77	Normal
	me./100gms.	13.40	3.45	40.32	
2	mgs./gm.	3.18	0.39	15.84	Normal
	me./100gms.	15.90	3.21	40.50	
4	mgs./gm.	4.27	0.38	15.13	Normal
	me./100gms.	21.35	3.13	38.69	
12	mgs./gm.	6.78	0.31	16.36	Abnormal
	me./100gms.	33.90	2.55	41.83	
25	mgs./gm.	8.34	0.29	15.14	Abnormal
	me./100gms.	41.70	2.39	38.71	
L.S.D. @5%	mgs./gm.	0.63	0.07	N.S.	
	me./100gms.	3.15	0.58	N.S.	
L.S.D. @1%	mgs./gm.	0.84	0.09		
	me./100gms.	4.20	0.74		

[a]Mean of 15 plants.

[b]See Figures 4 and 5.

Potassium was also supplied at the constant rate of 2 me./l. of nutrient solution as the calcium was varied through seven levels. Varying the calcium in treatment produced no significant difference in the concentration of potassium in the plant material with the concentrations at all levels of treatment ranging between 38.69 me. and 41.83 me. K/100 grams. The potassium concentration in the initial plant material was 17.64 me./100 grams (Appendix Table 4).

Variable Magnesium Series. The cation concentrations of strawberry plants after eight weeks of treatment show that, as the magnesium was increased in the nutrient solution, the concentration of magnesium in the plant was increased while the calcium and potassium concentrations were decreased (Table 11).

Only at the 0.me Mg level of treatment was the magnesium concentration in the plant material less than that of the initial plants (Appendix Table 4). The concentration of magnesium in the plant increased progressively through the treatment levels from 1.07 me./100g. at the 0 me. Mg treatment level to 7.07 me. at the highest treatment level.

The decrease in calcium concentration from 30.30 me./100g. at the lowest level of magnesium in treatment to 12.95 me./100g. at the highest level was progressive through the treatment levels. Significant differences in calcium concentration occurred between treatments below 1 me. Mg and above 4 me. Mg per liter of nutrient solution. At the highest level of magnesium in treatment the calcium concentration was below that found in the plants initially (Appendix Table 4).

The potassium concentrations in the plant also decreased progressively as the magnesium concentration in both the treatment and the plant material increased. However, the decreasing differences in potassium concentration

TABLE 11. Final Mean Cation Concentration of Strawberry Plants When The Magnesium Level Was Varied in Nutrient Solutions (Phase I).

Treatment me./l. Magnesium	Unit	Mean[a] Concentration of Cation Ca	Mg	K	Foliar Response[b]
0	mgs./gm.	6.06	0.13	17.05	Abnormal
	me./100gms.	30.30	1.07	43.60	
0.5	mgs./gm.	5.29	0.17	16.14	Abnormal
	me./100gms.	26.45	1.40	41.27	
1	mgs./gm.	4.60	0.22	15.18	Abnormal
	me./100gms.	23.00	1.81	38.82	
2	mgs./gm.	4.28	0.36	15.35	Normal
	me./100gms.	21.40	2.96	39.25	
4	mgs./gm.	3.94	0.40	14.83	Normal
	me./100gms.	19.70	3.29	37.92	
12	mgs./gm.	3.32	0.61	14.16	Abnormal
	me./100gms.	16.60	5.02	36.21	
25	mgs./gm.	2.59	0.86	10.22	Abnormal
	me./100gms.	12.95	7.07	26.13	
L.S.D. @5%	mgs./gm.	0.47	0.05	1.34	
	me./100gms.	2.35	0.41	3.42	
L.S.D. @1%	mgs./gm.	0.63	0.07	1.78	
	me./100gms.	3.15	0.58	4.55	

[a]Mean of 15 plants.

[b]See Figures 6 and 7.

between successive treatment levels were not significant until the highest level of magnesium, 25 me./l. of nutrient solution, was reached.

Variable Potassium Series. The data in Table 12 indicate that as potassium was increased in the nutrient solutions the potassium concentration in the plant likewise increased and the calcium and magnesium concentrations decreased. The progressive increase in potassium concentration from 4.81 me./100g. at the 0 me. K level, to 62.49 me./100g. at the 25 me. K level showed significant differences between concentrations at each successive level with the one exception, namely, the difference between the levels at 0.1 and 0.25 me. of K in the nutrient solution. The potassium concentrations of plant material grown at the three lowest levels of treatment were less than that of the plants at the outset of the experiment (Appendix Table 4).

As the potassium level was increased in the substrate the calcium concentration of the plant material at the three lowest treatment levels increased successively from 27.10 me. to 31.00 me. of calcium. At higher levels of treatment, 0.25 me. K and above, the calcium concentration at successive levels dropped from 31.0 me. to 16.5 me. per 100 g. at the highest level. Never was the calcium concentration less than that of the initial plant material although that level was approached at the highest potassium treatment level.

The magnesium concentration of the plant material showed no differences between succeeding treatments as potassium was increased in treatment. The higher magnesium concentrations, 3.62 me. to 4.03 me. of magnesium per 100 g. occurred at the lower levels of potassium in the nutrient treatment. As the potassium increases to 25 me./l. in nutrient solution the trend in magnesium concentration in the plant material was downward to

TABLE 12. Final Mean Cation Concentration of Strawberry Plants When The Potassium Level Was Varied in Nutrient Solutions (Phase I).

Treatment me./l. Potassium	Unit	Mean[a] Concentration of Cation Ca	Mg	K	Foliar Response[b]
0	mgs./gm.	5.42	0.49	3.72	Abnormal
	me./100gms.	27.10	4.03	9.51	
0.1	mgs./gm.	5.69	0.46	5.60	Abnormal
	me./100gms.	28.45	3.78	14.32	
0.25	mgs./gm.	6.20	0.49	5.88	Abnormal
	me./100gms.	31.00	4.03	15.04	
0.5	mgs./gm.	4.61	0.44	8.02	Abnormal
	me./100gms.	23.05	3.62	20.51	
2	mgs./gm.	4.28	0.37	15.13	Normal
	me./100gms.	21.40	3.04	38.69	
4	mgs./gm.	4.40	0.32	17.36	Abnormal
	me./100gms.	22.00	2.63	44.39	
25	mgs./gm.	3.30	0.24	24.44	Abnormal
	me./100gms.	16.50	1.97	62.49	
L.S.D. @5%	mgs./gm.	0.53	0.09	1.29	
	me./100gms.	2.65	0.74	3.30	
L.S.D. @1%	mgs./gm.	0.70	0.12	1.73	
	me./100gms.	3.50	0.98	4.42	

[a]Mean of 15 plants.

[b]See Figures 8 and 9.

1.97 me./100 grams. Significant differences do occur when comparing magnesium concentration at high levels of potassium with those at low levels of potassium. As with calcium, the final magnesium concentration of the plant material for all treatment levels was greater than that of the initial plant material.

Mineral concentration in plants as affected by length of treatment.

When the calcium level was varied in the nutrient solution the concentration of the three cations, Ca, Mg, and K was higher at six weeks of treatment than at either the four or eight week period (Table 13). A similar situation was found when the magnesium level was varied in the nutrient solution as shown in Table 14. In the potassium series of treatments, however, the Ca concentration decreased during the course of the experiment, the concentration of Mg was highest at the six week period, and the K concentration remained unchanged (Table 15).

Mineral concentration in plants as affected by certain interactions of nutrient level and length of treatment.

The statistical summary in Table 9 indicated certain significant interactions other than those involving replicate. While these interactions are statistically significant no important trends are shown. The tables of means for these interactions are given in Appendix Tables 6, 7, and 8.

* * * * * * * * * * * * *

Summarizing briefly, the concentrations of Ca, Mg and K found in the strawberry plant have shown that increasing K or Mg in the nutrient solution resulted in decreased concentration of the other two cations.

TABLE 13. Mean Cation Concentration of Plants As Influenced by Length of Treatment When Calcium Level Was Varied in Nutrient Solution (Phase I).

Length of Treatment (weeks)	Unit	Mean[a] Concentration of Cation					
		Ca		Mg		K	
4	mgs./gm.	4.24		0.33		14.42	
	me./100gm.		21.20		2.71		36.87
6	mgs./gm.	4.44		0.48		16.62	
	me./100gm.		22.20		3.95		42.50
8	mgs./gm.	3.77		0.36		15.71	
	me./100gm.		18.85		2.96		40.17
L.S.D. @5%	mgs./gm.	0.41		0.03		0.87	
	me./100gm.		2.05		0.25		2.22
L.S.D. @1%	mgs./gm.	0.54		0.04		1.16	
	me./100gm.		2.70		0.33		2.97

[a]Mean of 35 plants.

TABLE 14. Mean Cation Concentration of Plants As Influenced by Length of Treatment When Magnesium Level Was Varied in Nutrient Solution (Phase I).

Length of Treatment (weeks)	Unit	Mean[a] Concentration of Cation					
		Ca		Mg		K	
4	mgs./gm.	4.30		0.39		13.55	
	me./100gm.		21.50		3.21		34.65
6	mgs./gm.	4.40		0.43		15.63	
	me./100gm.		22.00		3.54		39.96
8	mgs./gm.	4.19		0.36		14.93	
	me./100gm.		20.95		2.96		38.17
L.S.D. @5%	mgs./gm.	N.S.		0.02		0.87	
	me./100gm.				0.16		2.22
L.S.D. @1%	mgs./gm.			0.03		0.96	
	me./100gm.				0.25		2.41

[a]Mean of 35 plants.

TABLE 15. Mean Cation Concentration of Plants As Influenced by Length of Treatment When Potassium Level Was Varied in Nutrient Solution (Phase I).

Length of Treatment (weeks)	Unit	Mean[a] Concentration of Cation					
		Ca		Mg		K	
4	mgs./gm.	5.34		0.38		10.97	
	me./100gm.		26.70		3.13		28.05
6	mgs./gm.	5.01		0.48		12.02	
	me./100gm.		25.05		3.95		30.73
8	mgs./gm.	4.47		0.34		11.37	
	me./100gm.		22.35		2.79		29.07
L.S.D. @5%	mgs./gm.	0.34		0.05		N.S.	
	me./100gm.		1.70		0.41		
L.S.D. @1%	mgs./gm.	0.45		0.07			
	me./100gm.		2.25		0.57		

[a]Mean of 35 plants.

Similarly increasing Ca in the nutrient solution decreased the Mg concentration in the plant. However, little or no effect on the K concentration was obtained by increasing levels of Ca in the substrate. The extent of the depressive effect varied greatly with the ion considered.

The Ca concentration of plants with normal foliage after treatment was relatively close to that of the dormant plants at the outset of the experiment. The Mg and K concentrations of normal plants after treatment exceeded the initial concentration of the plants by 100 per cent or more.

Mineral Content Of Strawberry Plants

The total content of Ca, Mg, and K of the plant is a calculated value derived by multiplying the total dry weight of the plant by the concentration of the ion found.

The "F" values obtained by variance analyses of the cation content in strawberry plants of the several treatments are given in Table 16.

Mineral content of plants as affected by nutrient level.

As the calcium in treatment was increased, the calcium content of the plant likewise increased (Table 17). Under the same conditions of increasing calcium in treatment the content of magnesium was the same for the five lower treatment levels, up to 4 me. of Ca per liter of nutrient solution, and decreased at the higher levels of treatment. The content of K showed no significant differences due to changing levels of calcium. These are essentially the same trends exhibited by the concentration of these cations in the plant material as affected by treatment level of calcium.

Where magnesium was varied in nutrient solution the content of Mg in

TABLE 16. F Values For The Cation Content of Strawberry Plants When Certain of The Cations Are Varied in Nutrient Solution (Phase I).

Source	D/F	Cation Varied								
		Calcium			Magnesium			Potassium		
		Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
Level	6	3.14**	4.64**	1.27	15.14**	55.05**	6.12**	6.54**	6.04**	38.70**
Treatment Length	2	9.37**	26.67**	20.79**	19.41**	12.27**	15.49**	21.01**	22.71**	13.21**
Replicate	4	14.12**	14.35**	8.60**	21.61**	17.22**	11.32**	34.57**	26.38**	9.82**
Level x Length	12	15.51**	1.09·	0.38	1.27	1.11	1.44	1.91	2.04*	1.20
Level x Replicate	24	2.59*	0.82	1.08	1.11	1.55	0.83	1.62	2.09*	1.49
Length x Replicate	8	0.61	3.06**	0.98	1.28	1.44	2.19*	1.90	4.80**	1.05
Error	48									
Total	104									

TABLE 17. Final Mean Cation Content of Strawberry Plants When The Calcium Level Was Varied in Nutrient Solutions (Phase I).

Treatment me./l. Calcium	Unit	Mean[a] Content of Cation Per Plant		
		Ca	Mg	K
0	mgs.	4.84	1.51	45.94
	me.	0.25	0.12	1.17
0.5	mgs.	7.66	1.72	59.33
	me.	0.38	0.14	1.51
1	mgs.	9.05	1.62	58.88
	me.	0.45	0.13	1.50
2	mgs.	11.23	1.52	58.88
	me.	0.56	0.12	1.50
4	mgs.	15.48	1.37	56.86
	me.	0.77	0.11	1.45
12	mgs.	22.53	1.06	54.66
	me.	1.12	0.08	1.39
25	mgs.	21.78	0.86	44.75
	me.	1.08	0.07	1.14
L.S.D. @5%	mgs.	3.50	0.41	N.S.
	me.	0.18	0.03	N.S.
L.S.D. @1%	mgs.	N.S.	0.54	N.S.
	me.	N.S.	0.04	N.S.

[a]Mean of 15 plants.

the plant increased steadily as Mg in the nutrient substrate was increased (Table 18). Plants of the 25 me. Mg treatment contained 0.19 me. of Mg as contrasted to 0.03 me. of Mg for the 0 me. treatment. The calcium content indicated a steady and generally significant decline as the magnesium level in treatment, and its content in the plant material, was increased. Potassium showed a decrease only at the highest and lowest levels of Mg in treatment. In general, the content of calcium, magnesium, and potassium follow the same trends as those of the concentration of these three cations in the plant material when magnesium is varied in nutrient solution.

The data of Table 19 show that when the concentration of potassium in the treatment was increased the potassium content of the plant also increased. The differences between the increased content values are not significant until the 0.5 me./l. treatment level, above which the increase is almost three-fold and the differences highly significant. The calcium content showed a significant increase from the 0 me. K level to the next treatment level, 0.1 me. K/l. of nutrient solution. At this level the calcium content was greatest and from this point the Ca content decreased, with the smallest content at the highest potassium treatment level. Under the same conditions of increasing potassium in nutrient solution, the five lowest levels of treatment, up to 2 me./l. of potassium, produced no significant differences in the content of magnesium. The magnesium content at the 4 me./l. of K treatment level showed a significant difference with the content at certain of the lower treatment levels; but the lowest magnesium uptake, occurring at the highest potassium level, differed significantly with the content values of magnesium at all of the other treatment levels. Variation in content of the three cations when potassium is varied

TABLE 18. Final Mean Cation Content of Strawberry Plants When The Magnesium Level Was Varied in Nutrient Solutions (Phase I).

Treatment me./l. Magnesium	Unit	Mean[a] Content of Cation Per Plant		
		Ca	Mg	K
0	mgs.	17.81	0.36	50.85
	me.	0.88	0.03	1.30
0.5	mgs.	19.46	0.66	57.17
	me.	0.97	0.05	1.46
1	mgs.	18.41	0.92	64.64
	me.	0.91	0.07	1.65
2	mgs.	15.53	1.29	58.22
	me.	0.77	0.11	1.48
4	mgs.	14.52	1.46	54.51
	me.	0.72	0.12	1.39
12	mgs.	13.59	2.45	54.06
	me.	0.67	0.20	1.38
25	mgs.	7.14	2.40	27.15
	me.	0.36	0.19	0.69
L.S.D. @5%	mgs.	3.03	0.31	13.67
	me.	0.15	0.02	0.34
L.S.D. @1%	mgs.	4.04	0.42	18.24
	me.	0.20	0.03	0.46

[a]Mean of 15 plants.

TABLE 19. Final Mean Cation Content of Strawberry Plants When The Potassium Level Was Varied in Nutrient Solutions (Phase I).

Treatment me./l. Potassium	Unit	Mean[a] Content of Cation Per Plant					
		Ca		Mg		K	
0	mgs.	14.22		1.28		10.18	
	me.		0.71		0.11		0.25
0.1	mgs.	18.75		1.61		18.95	
	me.		0.93		0.13		0.48
0.25	mgs.	16.61		1.48		17.07	
	me.		0.83		0.12		0.43
0.5	mgs.	15.07		1.36		23.33	
	me.		0.75		0.11		0.59
2	mgs.	15.49		1.35		56.86	
	me.		0.77		0.11		1.45
4	mgs.	13.55		1.00		56.39	
	me.		0.67		0.08		1.44
25	mgs.	10.31		0.77		76.58	
	me.		0.52		0.06		1.96
L.S.D. @5%	mgs.	2.92		0.34		11.74	
	me.		0.15		0.03		0.30
L.S.D. @1%	mgs.	3.88		0.45		15.65	
	me.		0.19		0.04		0.40

[a]Mean of 15 plants.

in nutrient solution again showed essentially the same trends that were apparent for the concentrations of the cations in the plant material.

Mineral content of plants as affected by length of treatment.

The content of Ca, Mg, and K in plants as influenced by length of treatment when each of the cations was varied in nutrient solution is shown in Tables 20, 21, and 22.

As the length of treatment was increased, the dry weights of the plants were increased, and concommitantly, the content of each of the cations was increased. Thus, the longer the plants were grown in this experiment, the greater was the content of each cation. The content of a particular cation for any given period was relatively the same regardless of the cation varied in nutrient solution - with one exception. Where potassium was the cation varied in nutrient solution, the content of K in the plants was considerably lower than it was where calcium or magnesium were varied. The explanation for this may be the fact that where calcium and magnesium were the varied cations in treatment, potassium was applied at the same rate of 2 me./l. in all treatment levels. Where potassium was the variable cation in nutrient treatment it was applied at relatively lower levels than were calcium and magnesium when they were the variable cations.

Mineral content of plants as affected by certain interactions of nutrient level and length of treatment.

The statistical summary in Table 16 indicated certain interactions that were significantly variable. The tables of means for these interactions are given as Appendix Tables 9 and 10. A detailed consideration of these interactions is not presented.

TABLE 20. Mean Cation Content And Dry Weights of Plants As Influenced by Length of Treatment When Calcium Level Was Varied in Nutrient Solution (Phase I).

Length of Treatment (weeks)	Unit	Mean[a] Content of Cations Per Plant						Mean[a] Dry Weight Per Plant(gms.)
		Ca		Mg		K		
4	mgs.	10.47		0.83		35.83		2.47
	me.		0.52		0.07		0.91	
6	mgs.	13.95		1.75		58.65		3.48
	me.		0.69		0.14		1.50	
8	mgs.	15.26		1.56		68.07		4.31
	me.		0.76		0.13		1.73	
L.S.D. @5%	mgs.	2.29		0.26		10.33		0.44
	me.		0.11		0.02		0.26	
L.S.D. @1%	mgs.	3.06		0.35		13.77		0.59
	me.		0.15		0.03		0.35	

[a]Mean of 35 plants.

TABLE 21. Mean Cation Content and Dry Weights of Plants As Influenced by Length of Treatment When Magnesium Level Was Varied in Nutrient Solution (Phase I).

Length of Treatment (weeks)	Unit	Mean[a] Content of Cations Per Plant						Mean[a] Dry Weight Per Plant(gms.)
		Ca		Mg		K		
4	mgs.	11.84		1.07		38.36		2.79
	me.		0.59		0.09		0.98	
6	mgs.	15.90		1.50		56.76		3.59
	me.		0.79		0.12		1.45	
8	mgs.	17.88		1.52		61.99		4.40
	me.		0.89		0.12		1.58	
L.S.D. @5%	mgs.	1.98		0.20		8.95		0.47
	me.		0.10		0.01		0.23	
L.S.D. @1%	mgs.	2.64		0.27		11.94		0.63
	me.		0.13		0.02		0.30	

[a]Mean of 35 plants.

TABLE 22. Mean Cation Content And Dry Weight of Plants As Influenced by Length of Treatment When Potassium Level Was Varied in Nutrient Solution (Phase I).

Length of Treatment (weeks)	Unit	Mean[a] Content of Cations Per Plant						Mean[a] Dry Weight Per Plant(gms.)
		Ca		Mg		K		
4	mgs.	11.73		0.84		27.29		2.32
	me.		0.58		0.07		0.69	
6	mgs.	14.93		1.52		36.90		3.00
	me.		0.75		0.12		0.94	
8	mgs.	17.90		1.43		46.95		4.04
	me.		0.89		0.11		1.20	
L.S.D. @5%	mgs.	1.91		0.22		7.68		0.43
	me.		0.10		0.018		0.19	
L.S.D. @1%	mgs.	2.55		0.29		10.25		0.57
	me.		0.13		0.024		0.26	

[a]Mean of 35 plants.

* * * * * * * * * * * * *

In summary, the content of the three cations follows essentially the same resultant trends as were indicated for concentration of the ions in plant material. However, the content values were perhaps less sensitive in reflecting variations in treatment than were the corresponding concentration values.

RESULTS OF PHASE II

Flower clusters appeared on the plants from January 1 to February 15. As would be expected, treatment had no influence upon the time or extent of their occurrence since this was predetermined by the initial plant size and the previous conditions of environment. However, certain abnormalities appeared on the flower clusters and these will be described later.

The plants had been placed on a 17-hour photoperiod with the expectation that runner-plant formation would be induced and this runner formation was to be used as a criterion of effect. Atually, the 324 plants in the experiment produced only 8 runner plants and these without relation to treatment. When it was apparent that runners were not being formed, a close examination of the plants showed the presence of branched crowns. At the termination of the experiment each plant had produced from one to five branched crowns. An effect of treatment on crown formation was not evident and the number of crowns per plant was closely associated with plant size. Thus, the use of supplemental light to induce and maintain the plants in a vegetative condition accomplished this purpose but in a manner different from that anticipated.

Treatment was found to have an effect on the foliar condition of the plants; on the vigor and growth of the plants as reflected in dry weight; and on the mineral composition, both concentration and content, in the strawberry plant.

For comparison with the final data of this phase of the experiment, plants representative of those used were analyzed in the dormant condition

and others after five weeks of culture with tap water prior to treatment (Figure 1). These data are presented with respect to dry weight and mineral composition of the plant material and accompany data tables where pertinent.

The Onset And Nature Of Foliar Disorders

The assignment of certain symptoms of foliar abnormality as being peculiar to any one treatment combination in this experiment is difficult. Perhaps the simplest approach is to describe the salient features of foliar change chronologically and then in summary.

The first indication of foliar abnormality appeared after 17 days of treatment when it was noted that the youngest expanding leaves of plants receiving the low level of Ca with high levels of Mg and K were necrotic at the tips. The following day flower buds were observed to have brown and drying sepals in the treatment where Ca and Mg were low and K was high. Two days later the necrosis of young flower buds was noted in additional low Ca treatments. On this same date necrotic tips on young unexpanded leaves were also observed at low Ca levels. As these leaves expanded they showed a crimped effect at the tips (Figure 10). About this same time extensive marginal burning of the older leaves became apparent on all treatment combinations having low and median Ca levels. This burning was followed by the eventual senescence of the leaves.

After 25 days of treatment, plants at all low Ca levels of treatment developed a purple blotching along the veins of the older leaves (Figure 11). On February 8, after 39 days of treatment, petioles on these leaves showed a dark or purplish blotching and streaking which, a week later, became black and necrotic at the distal end (Figure 12). Meanwhile the leaf blade deteriorated and eventually dried when the petiole collapsed at the

Figure 10. Young Expanding Leaf Blades With Necrosis of the Blade Tips: A, Treatment $Ca_LMg_MK_H$; B, Treatment $Ca_LMg_HK_H$; C, Treatment $Ca_MMg_HK_L$.

Figure 11. Leaves With Blotching Along the Veins and Petiole: A, Treatment $Ca_LMg_HK_L$; B and C, Treatment $Ca_LMg_HK_M$.

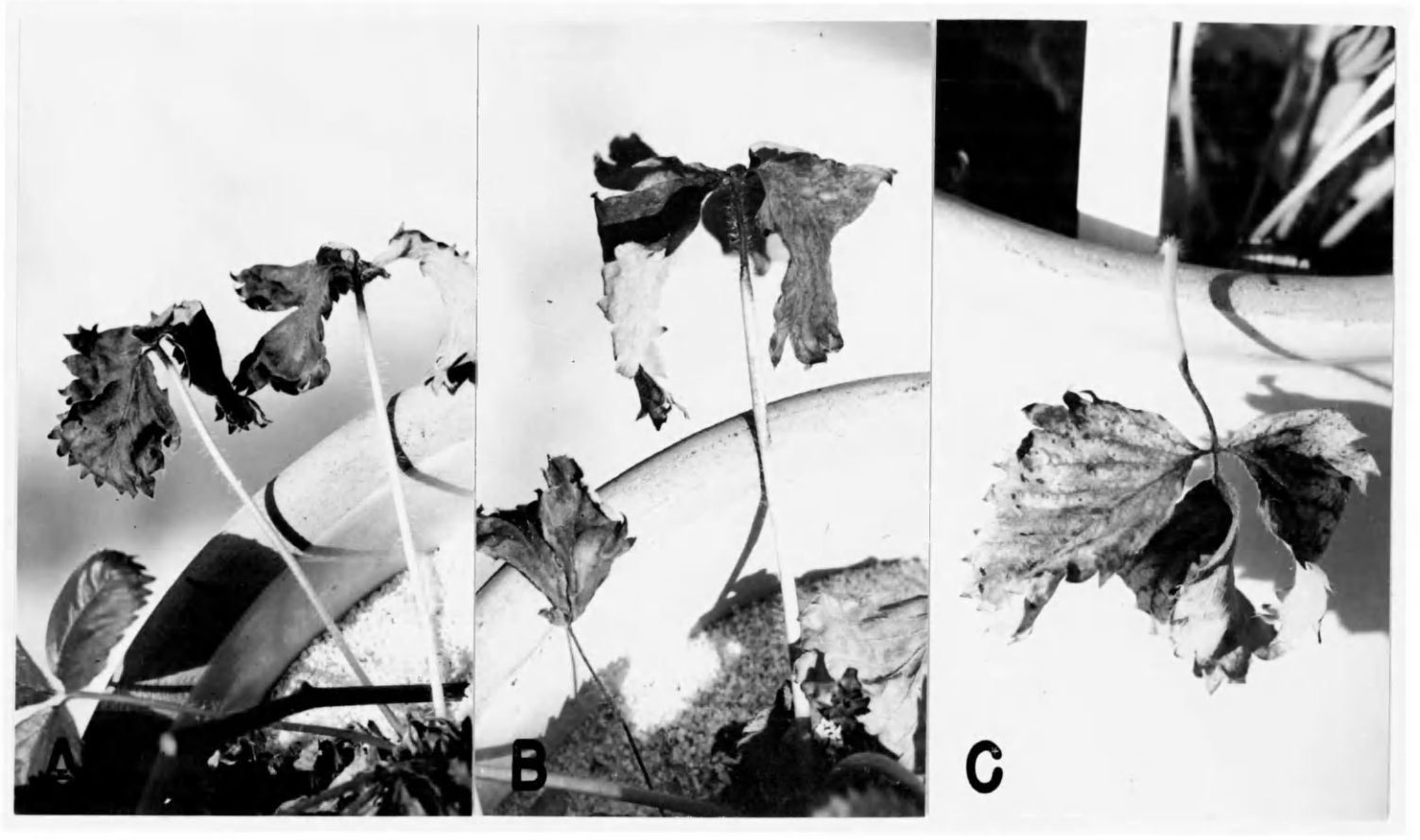

Figure 12. Leaves With Necrotic Petiole at Base of Leaflets: A, Treatment $Ca_LMg_LK_M$; B, Treatment $Ca_LMg_MK_L$; C, Treatment $Ca_MMg_HK_H$.

base of the leaf blade. The dried leaf blade remained attached to the living petiole (Figure 12). It is interesting that on February 10 a condition similar to the petiolar blotching and deterioration was noted on the peduncle of inflorescences at several low Ca levels.

At the termination of the experiment, after ten weeks of treatment, the following abnormal foliar or flower conditions had become apparent and in this order: necrosis of the tips of young unexpanded leaf blades with the result that as these leaves developed they had a crimped appearance; necrosis of flower buds accompanied by occasional blotching of the peduncle; senescence of older foliage; purple blotching along the veins of the leaf blades; and purple blotching and streaking of the petiole with the eventual necrosis of the petiole at the distal end accompanied by the deterioration and collapse of the leaf blade at that point. The occurrence of these phenomena is summarized in Table 23. If the disorder occurred on any one of twelve plants receiving the treatment it was designated as being positive for that treatment. Thus, this tabular summary indicates only occurrence and not degree.

From the data of this table it was apparent that the occurrence of all of the observed disorders was associated with low Ca levels regardless of the Mg and K levels in treatment. At median Ca levels the necrotic leaf tip condition occurred at all levels of Mg and K in treatment except where both of these cations were at their low level in the same treatment. This is also the only median Ca level where necrosis of the flower buds did not occur. The veinal blotching on the leaf blade occurred at all median Ca levels except where the Mg levels were low. Petiolar symptoms were notably absent at all median Ca levels. Senescent foliage was apparent at low and median calcium treatments. At high Ca levels the only foliar dis-

TABLE 23. Summary of Occurrence of Foliar Phenomena of Strawberry Plants During Ten Weeks of Treatment (Phase II).[a]

Treatment					Foliar abnormality[b]				
	Level me./l.								
No.	Ca	Mg	K	Na	Necrotic leaf tips	Foliar senescence	Purple blotching of leaf veins	Blotching and necrosis of petiole	Browning and necrosis of flower buds
1	.5	.5	.5	22.5	x	x	x	x	x
2	.5	.5	2	21.0	x	x	x	x	x
3	.5	.5	8	15.0	x	x	x	x	x
4	.5	2	.5	21.0	x	x	x	x	x
5	.5	2	2	19.5	x	x	x	x	x
6	.5	2	8	13.5	x	x	x	x	x
7	.5	8	.5	15.0	x	x	x	x	x
8	.5	8	2	13.5	x	x	x	x	x
9	.5	8	8	7.5	x	x	x	x	x
10	2	.5	.5	21.0	-	x	-	-	-
11	2	.5	2	19.5	x	x	-	-	x
12	2	.5	8	13.5	x	x	-	-	x
13	2	2	.5	19.5	x	x	x	-	x
14	2	2	2	18.0	x	x	x	-	x
15	2	2	8	12.0	x	x	x	-	x
16	2	8	.5	13.5	x	x	x	-	x
17	2	8	2	12.0	x	x	x	-	x
18	2	8	8	6.0	x	x	x	-	x
19	8	.5	.5	15.0	-	-	-	-	-
20	8	.5	2	13.5	x[c]	-	-	-	-
21	8	.5	8	7.5	-	-	-	-	x
22	8	2	.5	13.5	-	-	-	-	x
23	8	2	2	12.0	-	-	-	-	x
24	8	2	8	6.0	x	-	-	-	-
25	8	8	.5	7.5	-	-	-	-	x
26	8	8	2	6.0	x	-	-	-	x
27	8	8	8	0.0	x	-	-	-	x

[a]"x" designates a positive effect.
[b]In order of appearance from left to right.
[c]Symptom occurred on only one of nine plants.

order to occur was the one that appeared first chronologically - the necrotic leaf tips. It is interesting that the last symptom to appear, the abnormal petiolar conditions, occurred only at the low calcium treatment levels. It is also noteworthy that at one treatment level no foliar or flower disorder appeared; this was the treatment where the Ca level was sixteen-fold greater than the Mg and K levels. Where Ca was four-fold greater than either, or both, Mg and K in treatment the absence of foliar abnormality generally is also noteworthy.

No foliar symptoms of Mg deficiency appeared as such. With low Mg in association with median Ca, regardless of K level, the veinal blotching which occurred at other median Ca levels was lacking. Similarly, low Mg in relation to high Ca in treatment is associated with the general absence of foliar abnormalities. Figure 13 illustrates a series of three treatments with high Ca and K levels but with low, median, and high levels of magnesium. No foliar disorder attributable to Mg was apparent where Mg was so low in relation to the high levels of the other cations.

There were no characteristic symptoms of deficiency disorder attributable to K treatment. Figure 14 illustrates plants of a series in which K was varied through three levels while the Ca level was median and the Mg level was high. Figure 15 illustrates a similar series of treatments but with Ca and Mg both supplied at high levels. No foliar disorder was apparent that could be assigned to low levels of K although potassium deficiency symptoms had been expected at least where the K level was low in relation to high levels of the other two cations (Figure 14, A). The cupping of leaf blades seen in these photographs, and sometimes associated with a K deficiency, had occurred in all treatments and was not considered as diagnostic. In addition to illustrating the lack of a potassium deficiency

Figure 13. Plants From a Series of Treatments, After 10 Weeks, in Which Ca and K Levels Were High and Magnesium was Waried Through Three Levels: A, Low; B, Median; and C, High.

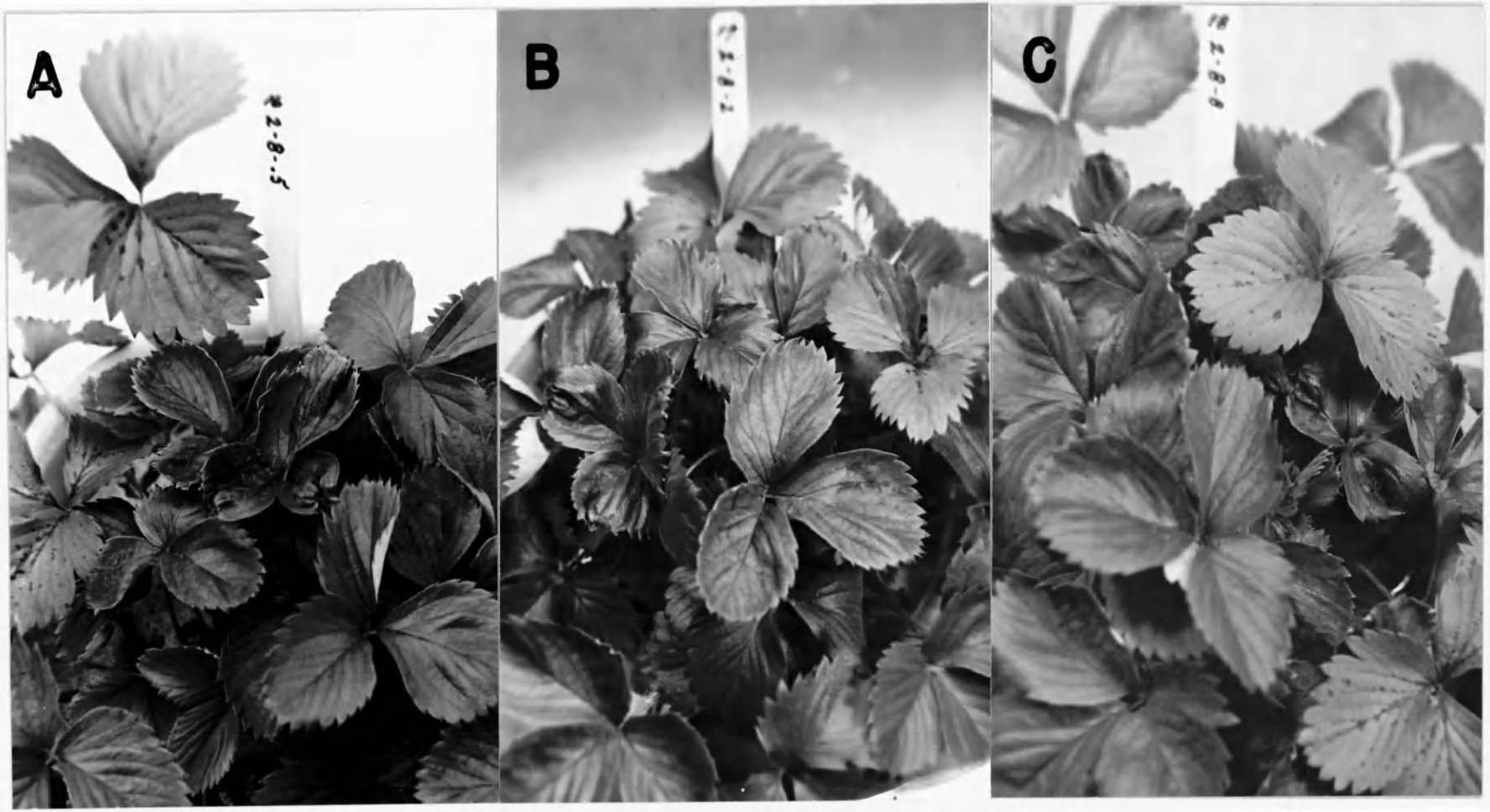

Figure 14. Plants From a Series of Treatments, After 10 Weeks, in Which Ca Level Was Median and Mg Level High While Potassium Was Varied Through Three Levels: A, Low; B, Median; and C, High.

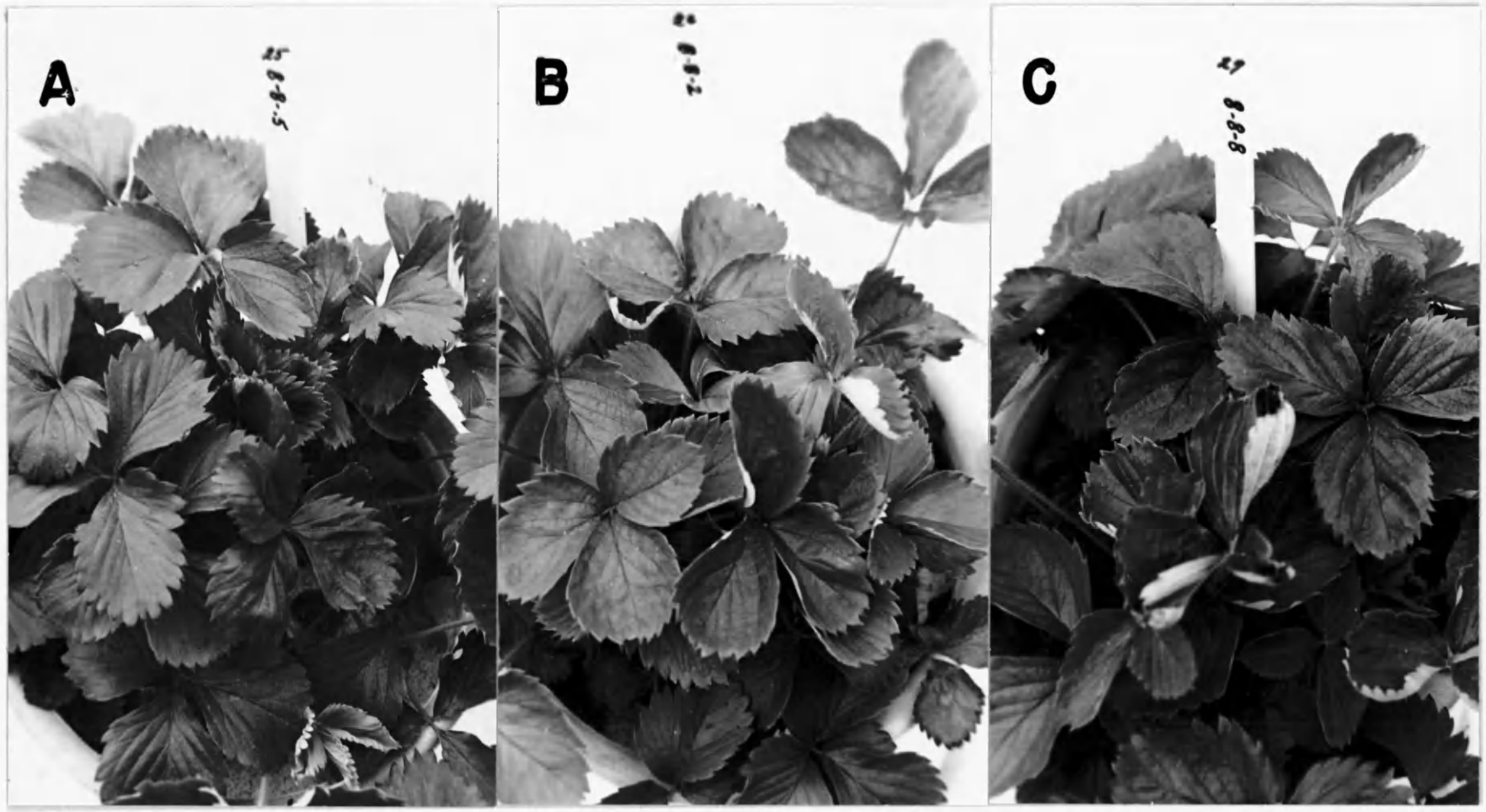

Figure 15. Plants From a Series of Treatments, After 10 Weeks, in Which Ca and Mg Levels Were High and Potassium Was Varied Through Three Levels: A, Low; B, Median; and C, High.

effect, Figure 14 illustrates another interesting development. This was the occurrence, in the three groups of plants, of the blotched veins and the crimped leaves characteristic of low Ca levels. Note that the Ca level is median and the Mg level is high and that the disorders appear at the three K levels.

Nothing has been presented concerning "toxic" effects, as such, on foliar conditions. If toxicities existed they were apparently associated with high levels of Mg and/or K in relation to calcium, and these have been interpreted as Ca deficiency symptoms.

Dry Weights Of Plants

Dry weight determinations were made at the termination of the experiment on March 8, 1952. The plants were fractioned into the component parts: root, crown, petiole, and leaf blade. These were then processed as described in General Methods.

The "F" values from analyses of variance of the dry weights of the strawberry plant fractions are given in Table 24.

In the tables that follow which give the effects of nutrient level on the dry weight values and the chemical composition of the plant and its parts, the values are given on the basis of three plants which constituted a single plot. In the text that follows, the term level refers to the cation in the nutrient solution. The terms concentration and content refer to the cation in the plant material.

Effect of nutrition on the dry weight of roots.

The data of Table 25 show a linear increase in root dry weight with increased levels of Calcium. Increased dry weights also occurred from the low to the high level of K in treatment but there was a deviation from

TABLE 24. F Values From Analyses of Variance of Dry Weights of Strawberry Plant Material (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	14.18**	60.55**	58.45**	30.41**	32.00**
Ca(r)	1	100.17**	61.62**	264.28**	266.29**	200.93**
Ca(d)	1	1.57	2.80	5.76*	1.54	0.09
Mg(r)	1	1.21	32.09**	86.12**	32.33**	27.56**
Mg(d)	1	1.04	0.79	6.45*	0.97	1.56
K(r)	1	14.84**	27.22**	71.93**	31.85**	33.75**
K(d)	1	7.26**	2.78	4.01*	5.22*	5.82*
Ca(r) x Mg(r)	1	4.19*	5.69*	9.96**	0.25	2.62
Ca(r) x Mg(d)	1	2.16	0.47	0.00	0.03	0.13
Ca(d) x Mg(r)	1	2.13	0.34	7.88**	2.16	1.50
Ca(d) x Mg(d)	1	2.97	0.27	1.72	0.11	0.51
Ca(r) x K(r)	1	5.10**	10.24**	23.61**	8.84**	10.56**
Ca(r) x K(d)	1	0.99	0.06	4.22*	1.34	1.30
Ca(d) x K(r)	1	0.88	0.06	0.87	1.31	0.96
Ca(d) x K(d)	1	0.16	0.27	0.74	0.00	0.00
Mg(r) x K(r)	1	0.01	1.64	2.18	0.78	0.77
Mg(r) x K(d)	1	1.83	4.75**	2.29	1.67	2.49
Mg(d) x K(r)	1	0.00	1.31	0.28	0.29	0.03
Mg(d) x K(d)	1	1.63	0.13	2.70	0.64	1.00
Error	60					
Total	80					

TABLE 25. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Final Dry Weight of Roots, in Grams, of Strawberry Plants[a] (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		3.89	3.83	4.53	3.31	3.96	4.98
Mg-L	4.04	3.88	3.86	4.38	3.15	3.91	5.06
Mg-M	3.99	3.72	3.56	4.68	3.16	3.63	5.17
Mg-H	4.23	4.08	4.06	4.54	3.63	4.35	4.70
Ca-L	3.31	2.99	3.69	5.00			
Ca-M	3.96	2.97	3.65	4.86			
Ca-H	4.98	3.98	4.55	5.07			

[a]Each value represents a 3 plant sample.

linearity of response in that no appreciable increase in dry weight occurred at the median K level.

Although a main effect of Mg level on resultant dry weights was not indicated, a Ca(r) x Mg(r) interaction occurred. Thus at low Ca levels, increased Mg in the substrate increased dry weight while at the high Ca level the dry weight was decreased by an increased Mg level.

An additional interaction, Ca(r) x K(r), indicated a greater response when Ca was varied at the lower K level.

Effect of nutrition on the dry weight of crowns.

The data of Table 26 show that for each of the three cations, an increasing level increased the dry weight of the crown with a linear response through the three levels. The close approximation of dry weight values for the three cation series and especially Mg and K, at a given level is striking.

Certain interactions were significant. For example, the Ca(r) x Mg(r) interaction which indicated that the response to Mg was greater at the low Ca level than at the high Ca level. An analogous situation existed in the relative response to Ca at low and high Mg levels.

Another linear interaction, Ca(r) x K(r) was also significant, indicating that increased levels of K were more effective in increasing dry weight at the low Ca level.

The only significant Mg and K interaction was the Mg(r) x K(d) interaction. Here, the median K level produced the lowest dry weight at the high Mg level.

Effect of nutrition on the dry weight of petioles.

A significant linear effect of treatment was indicated for each of the

TABLE 26. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Dry Weight of Crowns, in Grams, of Strawberry Plants[a] (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		2.66	2.78	3.23	2.51	2.78	3.37
Mg-L	2.61	2.32	2.61	2.90	2.03	2.52	3.27
Mg-M	2.83	2.45	2.69	3.36	2.49	2.77	3.24
Mg-H	3.23	3.20	3.05	3.43	3.02	3.05	3.62
Ca-L	2.51	2.09	2.51	3.37			
Ca-M	2.78	2.36	2.72	3.26			
Ca-H	3.37	3.08	3.12	3.49			

[a]Each value represents a 3 plant sample.

three cations. The data of Table 27 show that in each case the largest dry weight occurred at the highest level of each cation. Also indicated for all three cations were slight deviations at the median level but the effects were largely linear. It is noteworthy that the response at each of the three levels of Mg and K is similar within 0.05 gram of dry weight.

Two important Ca x Mg interactions on petiole dry weight were found. The first was a Ca(r) x Mg(r) interaction where increased Ca at the low Mg level had a greater effect than it did at high magnesium. The other interaction, Ca(d) x Mg(r), indicated that at the high Mg level there was no additional increase in dry weight from the median to the high Ca level.

Two Ca x K interactions were also found to be significant. In the Ca (r) x K(r) interaction the most striking relationship was the higher increased dry weight that accompanied higher levels of K at the low Ca level. The Ca(r) x K(d) interaction indicated less response to median K at the high level of Ca than at the low level of calcium.

Effect of nutrition on the dry weight of leaf blades.

The general response, as shown in Table 28, is the same for the three cations in that the larger dry weights occurred at the high levels of each ion. There was a close approximation in the response at each level of Mg and K as reflected in the dry weight values. A departure from linearity occurred only at the median K level where the effect of the additional K was not significantly more effective than that at the lower level.

A significant Ca(r) x K(r) interaction showed two responses. First, there was little or no response to the addition of potassium at the high Ca level. Secondly, there was a greater response to varied potassium at Ca levels than there was to varied calcium at the K levels.

TABLE 27. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Dry Weight of Petioles, in Grams, of Strawberry Plants[a] (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		2.37	2.56	3.02	1.97	2.76	3.23
Mg-L	2.35	2.03	2.28	2.74	1.57	2.34	3.13
Mg-M	2.54	2.22	2.34	3.05	1.89	2.56	3.16
Mg-H	3.07	2.86	3.06	3.29	2.44	3.37	3.40
Ca-L	1.97	1.55	2.40	3.16			
Ca-M	2.76	1.74	2.72	3.22			
Ca-H	3.23	2.62	3.16	3.30			

[a]Each value represents a 3 plant sample.

TABLE 28. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Levels on the Dry Weight of Leaf Blades, in Grams, of Strawberry Plants[a] (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		9.29	9.55	11.01	7.35	10.17	12.33
Mg-L	9.17	8.41	8.90	10.19	6.63	9.11	11.77
Mg-M	9.78	8.94	9.17	11.22	7.18	9.91	12.24
Mg-H	10.91	10.52	10.57	11.63	8.24	11.49	13.00
Ca-L	7.35	6.38	9.26	12.23			
Ca-M	10.17	6.70	9.76	12.18			
Ca-H	12.33	8.97	11.48	12.59			

[a]Each value represents a 3 plant sample.

Effect of nutrition on the total dry weight of the plant.

The total dry weight values on which the means in Table 29 are based were derived by summating the dry weight values of the plant fractions for any one given treatment level. Significance of main effects and interactions of treatment levels indicated the same variances for both leaf blade dry weight and total dry weight (Table 24). Except for the fact that the dry weight of the entire plant is represented by larger values, the trends that have been stated about the main effects of Ca, Mg, and K levels, as well as the Ca(r) x K(r) interaction, for leaf blades is precisely the same for the total dry weight.

It should be noted that the leaf blade fraction in the experiment contributed approximately 50 per cent to the total dry weight, the actual percentage varying somewhat with treatment level.

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Summarizing, from the standpoint of main effects there were the same trends of linear response as increased dry weights accompanying increased levels of each of the cations for each plant fraction with but one exception. This was the lack of response in the roots to varied levels of magnesium. In every plant fraction the magnitude of response was greatest with the varied Ca levels. The response to varied Mg and K levels showed almost identical trends, as well as actual values, within a plant fraction and, as a pair, between fractions; again with the exception of the lack of a response to Mg in the roots.

Of the interactions, the most notable was at the high Ca level where increasing the Mg level to high decreased the dry weight of the roots.

The most striking similarity of effect in these data occurred between

TABLE 29. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Total Dry Weight[a], in Grams, of Strawberry Plants[b] (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		18.23	18.73	21.82	15.16	19.71	23.93
Mg-L	18.20	16.67	17.67	20.24	13.40	17.95	23.24
Mg-M	19.15	17.34	17.78	22.32	14.73	18.90	23.82
Mg-H	21.44	20.67	20.75	22.91	17.34	22.27	24.72
Ca-L	15.16	13.03	13.78	18.66			
Ca-M	19.71	17.89	18.88	22.35			
Ca-H	23.93	23.77	23.53	24.47			

[a]Calculated from plant fractions.
[b]Each value represents a 3 plant sample.

the trends of leaf blade response compared to the response of the plants as a whole with the main difference being only in the magnitude of the dry weight values.

Mineral Composition of Plants

The effect of nutrient level on the mineral composition of the plants will be presented first as it affected concentration and then again as it affected content. The concentration and content of Ca, Mg, and K, and Na will be presented for roots, crowns, petioles, leaf blades, and the plant as a whole. This latter value has been calculated from the plant fractions.

Mineral concentration in plants

Effect of nutrition on the calcium concentration of the plant fractions.

The results of the statistical analyses for the calcium concentration of each of the plant fractions is given in Table 30. The mean values for the main effects and first-order interactions giving the effects of nutrient level on the calcium concentration of the five plant fractions are given in Tables 31 to 35.

From the data in these tables it is seen that in each, and all, of the plant fractions there was a considerable increase in the Ca concentration from the low to the high level of calcium. Increasing the Ca level from low to medium did not greatly increase the Ca concentration in the tissue.

The leaf blade was the only fraction of plant tissue in which the Ca concentration was not affected by the Mg level. In the other plant parts, increased Mg in treatment decreased the Ca concentration in the plant part with the median Mg level causing only a slight decrease from

TABLE 30. F Values From Analyses of Variance of the Calcium Concentration of Strawberry Plant Tissue (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	4.35*	6.48**	1.71**	3.99*	4.34*
Ca(r)	1	779.29**	997.92**	580.82**	1136.03**	1867.44**
Ca(d)	1	154.34**	73.83**	58.93**	121.26**	207.72**
Mg(r)	1	26.48**	132.23**	110.27**	0.51	29.10**
Mg(d)	1	8.05**	14.90**	18.27**	1.75	10.93**
K(r)	1	0.08	73.81**	82.64**	38.86**	80.10**
K(d)	1	0.05	14.44**	4.20**	0.00	1.34
Ca(r) x Mg(r)	1	0.07	0.15	12.69**	0.00	1.37
Ca(r) x Mg(d)	1	13.69**	5.72*	14.18**	1.15	15.90**
Ca(d) x Mg(r)	1	1.84	6.59*	0.05	0.38	0.06
Ca(d) x Mg(d)	1	1.95	1.96	3.03	1.19	2.24
Ca(r) x K(r)	1	3.16	1.51	8.76**	8.80**	7.82**
Ca(r) x K(d)	1	2.19	0.00	0.48	0.18	0.17
Ca(d) x K(r)	1	0.20	0.03	1.68	0.50	1.65
Ca(d) x K(d)	1	0.43	3.36	0.06	0.52	1.34
Mg(r) x K(r)	1	0.12	1.59	21.40**	2.56	5.51*
Mg(r) x K(d)	1	0.10	0.98	0.03	1.84	0.17
Mg(d) x K(r)	1	0.97	0.00	0.82	0.00	0.41
Mg(d) x K(d)	1	0.15	0.21	1.37	1.51	2.03
Error	60					
Total	80					

the value at the low Mg level. In all of the plant portions except roots, increasing K levels decreased the Ca concentration. In the leaf and in the plant as a whole, the decrease was linear, while in the crown and petiole, the first increment of K was not as effective in decreasing the Ca concentration.

Certain first-order interactions of treatment level were indicated for the Ca concentration of the various plant portions. A Ca(r) x Mg(r) interaction for the petiole showed that the Ca concentration decreased with increasing levels of Ca at the low Mg level; but increased when the Mg level was high. The Ca(r) x Mg(d) interaction indicated that at the median Mg level the Ca concentration in the tissue increased with increased Ca in the treatment to a much greater degree than when the Mg level was high. From another viewpoint, this same interaction indicated a linear response of decreased Ca concentration from low to high Mg levels when the Ca in the substrate was also low. When the Ca level in the substrate was high, the Ca concentration decreased from the high to the low level of Mg but with a quadratic response at the median Mg level. Here the Ca concentration increased slightly over that at the low Mg level before being decreased by the high Mg level. Except for differences in values, these same trends for the Ca(r) x Mg(d) interaction were apparent also for the root, crown, and the plant as a whole. An additional Ca x Mg interaction was indicated for crowns. This interaction, Ca(d) x Mg(r), showed that at the high Mg level with increasing Ca also in the treatment the increased Ca concentration in the tissues was linear. At the high Mg level, the first increment of Ca in treatment had little additional effect over the low Ca level.

One Ca x K interaction was evident. This was the Ca(r) x K(r) inter-

action for petioles, leaf blades, and the entire plant. In all three cases the decrease in the Ca concentration due to increased K level in treatment was more pronounced when the Ca level in the substrate was high.

Mg(r) x K(r) interactions were found to be important for two plant portions. In the whole plant the decrease in Ca concentration with increasing K levels was more pronounced at the low Mg level. In the case of the petiole, the interaction was more striking. Here the Ca concentration increased with increased K at the low Mg level but decreased with increased K at the high Mg level.

The supplementary data of Table 36 present the relative concentrations of calcium in the various plant fractions as the ratio of the mean concentration of Ca in the fractions to the mean concentration in the root. It is seen that with two exceptions the relative Ca concentrations in the other plant fractions were all greater than that of the root. The two exceptions were with the leaf blades where Ca level was low and the K level was median and high respectively. It is also noteworthy that, as a rule, the relative concentrations of Ca in the crown and petiole were very similar. Where it varied greatly it was due to an apparent increased concentration in the petiole that was usually associated with a high level of Ca in relation to the Mg or K level in treatment.

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In summarizing the main effects, the following responses to nutrient level were apparent: identical trends of increased Ca concentration, quadratic at the median treatment level, for all of the plant fractions; identical trends of decreased Ca concentration from low to high Mg level, quadratic at the median level, in all plant portions except the leaf

blades where there was no effect of Mg level; identical linear trends of decreased Ca concentration with increased K in treatment for all plant portions except the root which showed no response to increased K in treatment. A quadratic effect of the K level on the Ca concentration was also shown in the crown and the petiole. It is noteworthy that the crown and petiole were the only two fractions to show similar trends of response for the main effects of Ca levels by all three of the cations.

Of the significant interactions only two were really striking and both of these occurred in the petiole. In the one case, the Ca(r) x Mg(r) interaction, as the Ca level in treatment increased the Ca concentration in the tissue increased at the high Mg level but decreased at the low Mg level. In the other case, the Mg(r) x K(r) interaction, as the K level in treatment increased the Ca concentration in the petiole decreased at the high Mg level and increased when the Mg in treatment was low.

At any one treatment level the relative Ca concentrations in the crown and petiole were greatest and generally tended to be similar. The lowest relative concentration occurred in the roots.

Effect of nutrition on the magnesium concentration of the plant fractions.

The results of the statistical analyses for the magnesium concentration of each of the plant fractions is given in Table 37. The mean values for the main effects and first-order interactions giving the effects of nutrient level on the magnesium concentration of the various plant fractions are given in Tables 38 to 42.

From the data in these tables it is seen that increasing the Mg in the substrate increased the Mg concentration for all plant fractions. However, the response was not linear in that the median Mg level did not greatly increase the Mg concentration over that at the low Mg level.

TABLE 31. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Roots (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		22.35	22.00	22.00	15.45	17.50	33.15
Mg-L	23.20	23.00	23.65	22.90	17.40	18.35	33.75
Mg-M	23.10	23.20	22.80	23.30	15.20	17.80	36.30
Mg-H	19.90	20.40	19.50	19.80	13.75	16.30	29.65
Ca-L	15.45	16.15	15.85	14.35			
Ca-M	17.50	17.25	17.75	17.50			
Ca-H	33.15	33.20	32.30	34.20			

TABLE 32. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Crowns (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		34.35	33.75	28.35	22.80	28.65	44.95
Mg-L	35.40	37.80	37.15	31.20	25.70	33.50	47.00
Mg-M	33.70	36.55	35.05	29.55	23.60	29.40	48.10
Mg-H	27.35	28.70	29.05	24.25	19.15	23.10	39.75
Ca-L	22.80	25.85	23.85	18.70			
Ca-M	28.65	30.25	31.30	24.40			
Ca-H	44.95	46.90	46.05	41.85			

TABLE 33. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Petioles (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		43.65	39.60	30.30	23.40	31.35	58.85
Mg-L	43.75	52.80	97.15	81.30	77.65	88.05	65.60
Mg-M	41.50	48.20	41.80	34.40	24.15	32.85	67.40
Mg-H	28.30	30.00	29.80	25.15	18.35	23.10	43.50
Ca-L	23.40	27.65	24.25	18.25			
Ca-M	31.35	35.65	33.35	25.00			
Ca-H	58.85	67.70	61.15	47.65			

TABLE 34. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Leaf Blades (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		36.00	32.25	28.85	16.75	25.10	54.10
Mg-L	32.30	37.30	32.80	28.80	17.10	25.05	54.80
Mg-M	33.30	36.35	32.10	31.40	17.25	25.00	57.65
Mg-H	31.65	34.35	32.20	28.35	15.85	25.35	53.70
Ca-L	16.75	18.55	16.70	15.00			
Ca-M	25.10	27.80	25.75	21.80			
Ca-H	54.10	61.70	54.65	49.80			

TABLE 35. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Combined Plant Fractions (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		34.10	31.55	27.50	18.25	24.85	49.85
Mg-L	32.30	36.10	33.55	27.20	19.70	26.50	50.70
Mg-M	32.40	35.65	32.05	29.55	18.35	25.40	53.45
Mg-H	28.40	30.45	29.00	25.80	16.75	22.90	45.60
Ca-L	18.25	20.45	18.65	15.70			
Ca-M	24.85	26.95	26.15	21.75			
Ca-H	49.95	54.85	49.85	45.10			

TABLE 36. Mean[a] Concentration of Calcium in Strawberry Plant Fractions And the Ratio of the Mean Concentration of These Fractions to the Concentration of Calcium in the root (Phase II).

Treatment me./l.				Concentration (me./100g.)				Ratio (part:root)			
No.	Ca	Mg	K	Root	Crown	Petiole	Leaf	Root	Crown	Petiole	Leaf
1	.5	.5	.5	16.30	28.50	34.00	20.15	1	1.74	2.08	1.23
2	.5	.5	2	19.30	27.50	27.30	17.15	1	1.42	1.41	0.88
3	.5	.5	8	16.65	21.15	21.65	14.00	1	1.27	1.30	0.84
4	.5	2	.5	17.50	28.00	28.30	18.15	1	1.66	1.61	1.03
5	.5	2	2	14.65	25.15	26.15	17.00	1	1.71	1.78	1.16
6	.5	2	8	13.50	17.65	18.00	16.65	1	1.30	1.33	1.23
7	.5	8	.5	14.65	21.15	20.65	17.30	1	1.44	1.40	1.18
8	.5	8	2	13.65	19.00	19.30	16.00	1	1.39	1.41	1.17
9	.5	8	8	13.00	17.30	15.15	14.30	1	1.33	1.16	1.10
10	2	.5	.5	17.80	35.65	44.50	27.80	1	2.00	2.50	1.56
11	2	.5	2	18.00	36.65	41.15	25.80	1	2.03	2.28	1.43
12	2	.5	8	19.30	28.15	28.50	21.50	1	1.45	1.47	1.11
13	2	2	.5	18.15	33.00	39.80	30.50	1	1.81	2.19	1.68
14	2	2	2	18.50	31.60	33.65	23.80	1	1.70	1.81	1.28
15	2	2	8	16.80	23.65	25.15	20.65	1	1.40	1.49	1.22
16	2	8	.5	15.80	22.15	22.65	25.20	1	1.40	1.43	1.59
17	2	8	2	16.80	25.65	25.30	27.65	1	1.52	1.50	1.64
18	2	8	8	16.30	21.50	21.30	23.30	1	1.31	1.30	1.42
19	8	.5	.5	34.80	49.30	80.00	64.00	1	1.41	2.21	1.83
20	8	.5	2	33.65	47.30	73.00	55.50	1	1.40	2.16	1.64
21	8	.5	8	32.80	44.30	43.80	45.00	1	1.35	1.33	1.37
22	8	2	.5	34.00	48.65	76.50	60.50	1	1.43	2.25	1.77
23	8	2	2	35.25	48.30	65.65	55.50	1	1.37	1.86	1.57
24	8	2	8	39.65	47.30	60.15	57.00	1	1.19	1.51	1.43
25	8	8	2	28.00	42.50	44.80	53.00	1	1.51	1.60	1.89
26	8	8	.5	30.80	42.80	46.65	60.65	1	1.38	1.51	1.96
27	8	8	8	30.15	34.00	39.00	47.50	1	1.12	1.29	1.57
Dormant				12.3	25.6	37.0	24.7	1	2.08	3.00	2.00
Pretreatment				14.3	30.6	33.6	25.2	1	2.13	2.34	1.76

[a]Mean of 9 plants
[b]Mean of 36 plants

TABLE 37. F Values From Analyses of Variance of the Magnesium Concentration of Strawberry Plant Tissue (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	3.81*	12.41**	11.13**	4.12*	13.55**
Ca(r)	1	24.30**	5.34*	0.00	18.92**	24.11**
Ca(d)	1	0.44	0.41	0.00	1.97	0.22
Mg(r)	1	741.68**	228.33**	239.76**	1177.29**	1961.55**
Mg(d)	1	107.07**	20.35**	14.05**	141.27**	220.55**
K(r)	1	23.50**	4.43*	18.03**	32.02**	41.11**
K(d)	1	0.68	0.15	0.12	0.05	0.55
Ca(r) x Mg(r)	1	5.86*	0.02	0.53	23.54**	7.22**
Ca(r) x Mg(d)	1	4.00*	1.06	0.51	2.72	1.77
Ca(d) x Mg(r)	1	4.72*	0.00	0.74	6.00*	3.11
Ca(d) x Mg(d)	1	0.01	0.49	0.76	0.47	0.33
Ca(r) x K(r)	1	0.35	0.03	0.13	0.27	0.11
Ca(r) x K(d)	1	0.26	0.64	0.01	2.72	1.66
Ca(d) x K(r)	1	0.26	0.00	0.00	1.31	0.55
Ca(d) x K(d)	1	1.54	1.48	0.00	0.11	0.44
Mg(r) x K(r)	1	0.50	0.12	0.36	0.14	0.00
Mg(r) x K(d)	1	0.33	0.56	0.00	0.10	0.00
Mg(d) x K(r)	1	0.38	1.89	0.20	7.16*	2.77
Mg(d) x K(d)	1	1.57	0.04	0.27	2.56	1.11
Error	60					
Total	80					

Increasing the Ca in the nutrient solution decreased the Mg concentration in roots, leaf blades, and the plant as a unit, and increased it in the crowns. In all of the plant parts but the crown, increasing K in substrate decreased the Mg concentration. In the crown, however, increased K level increased the Mg concentration in the tissue.

The root, leaf blade, and whole plant showed a significant Ca(r) x Mg(r) interaction. In all three cases the trends were the same; increased Mg concentrations due to increased levels of Mg were more pronounced at low Ca levels. A Ca(r) x Mg(d) interaction for roots indicated response to the first increment of Mg at either Ca level. A Ca(d) x Mg(r) interaction, also for roots, showed that at the high Mg level the first increment of Ca produced the greatest Mg concentration. The reverse situation was true in the leaf blades where the same effect of median Ca occurred at the low Mg level.

The interaction of Mg(d) x K(r) on the Mg concentration for the leaf blade indicated that the first increment of Mg level in treatment was not overly effective when compared to the low Mg level.

The supplementary data of Table 43 present the relative concentrations of magnesium in the various plant fractions as the ratio of the mean concentration of Mg in the fractions to the concentration in the root. As a rule, relative Mg concentrations were greater in the crown and petiole than in the root. In a few cases, however, the relative concentration was lower or similar to that of the roots. It would appear that where the Ca and Mg levels were constant in treatment and K was varied from high to low, the relative Mg concentration increased in the crown and decreased in the petiole. It is also noteworthy that the relative Mg concentration in the leaf blades were lower than those in the roots.

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In summary, the Mg concentration in all plant parts, except the crown, increased with increased Mg in treatment and Mg concentration decreased when the Ca and K levels in the substrate were increased. Exceptions to this generality were the petiole fraction where the Mg concentration was not affected by the Ca level; and the crown portion where the Mg concentration was increased with increased levels of all three cations in treatment.

The majority of significant interactions were Ca x Mg interactions which were generally characteristic of the root and leaf blade tissues.

At any one treatment level the relative Mg concentration was lowest in the leaf blades. It was highest in either the crown or petiole depending upon treatment.

Effect of nutrition on the potassium concentration of the plant fractions.

The results of the statistical analyses for the K concentration of each of the plant fractions are given in Table 44. The mean values for the main effects and first-order interactions giving the effects of nutrient level on the K concentration of the plant fractions are given in Tables 45 to 49.

Considering the main effects of varied levels of the three cations on the resultant K concentration in the respective plant parts, a varied K level was the only one consistent in its effect on all plant parts; that is, increased K in the substrate increased the K concentration in the plant tissue.

A varied magnesium level had no effect on the K concentration in the petiole and entire plant. The remaining parts showed two different types

TABLE 38. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Roots (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		33.80	32.73	30.27	34.54	32.65	29.61
Mg-L	21.63	23.36	22.20	19.33	26.81	20.56	17.52
Mg-M	26.32	28.78	25.74	24.34	27.22	26.56	25.08
Mg-H	48.85	49.35	50.33	47.04	49.59	50.83	46.22
Ca-L	34.54	37.09	34.13	32.40			
Ca-M	32.65	33.31	34.13	30.51			
Ca-H	29.61	31.00	29.94	27.80			

TABLE 39. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Crowns (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		36.84	38.24	40.96	37.17	38.32	41.70
Mg-L	26.56	23.60	28.21	27.96	26.32	26.98	29.77
Mg-M	33.64	33.06	32.90	35.03	30.27	33.06	37.58
Mg-H	55.85	53.95	57.71	59.88	54.94	54.94	57.65
Ca-L	37.17	35.86	36.27	39.48			
Ca-M	38.32	38.32	35.61	41.12			
Ca-H	41.70	39.72	42.93	42.36			

TABLE 40. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Petioles (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		43.42	38.98	32.98	38.49	38.32	38.49
Mg-L	22.12	26.15	22.37	17.76	20.15	22.61	23.52
Mg-M	33.14	38.82	32.57	28.04	33.55	34.79	31.01
Mg-H	60.12	65.22	61.93	53.13	61.85	57.65	60.28
Ca-L	38.49	42.93	39.23	33.39			
Ca-M	38.32	43.09	38.90	33.06			
Ca-H	38.49	44.16	38.73	32.48			

TABLE 41. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Concentration, Expressed as me./100 Grams of Dry Plant Tissue of Strawberry Leaf Blades (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		27.55	25.25	22.61	26.64	25.82	22.94
Mg-L	13.32	16.12	12.41	11.51	13.65	12.33	14.06
Mg-M	19.24	21.96	18.25	17.51	19.49	20.39	17.76
Mg-H	42.85	44.49	45.23	38.98	46.88	44.82	37.01
Ca-L	26.64	28.54	27.96	23.52			
Ca-M	25.82	27.63	25.74	24.18			
Ca-H	22.94	26.40	22.20	20.23			

TABLE 42. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Combined Plant Fractions (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		32.65	31.01	28.37	32.24	30.84	28.95
Mg-L	18.67	21.05	18.50	16.45	19.98	17.84	18.25
Mg-M	24.92	27.06	24.67	23.03	25.66	25.41	23.68
Mg-H	48.44	50.09	49.92	45.56	51.07	49.35	44.91
Ca-L	32.24	33.88	33.39	29.44			
Ca-M	30.84	32.73	30.76	29.11			
Ca-H	28.95	31.50	28.78	26.48			

TABLE 43. Mean[a] Concentration of Magnesium in Strawberry Plant Fractions And the Ratio of These Concentrations to the Magnesium Concentration of the Roots (Phase II).

Treatment me./l.				Concentration (me./100g.)				Ratio (part:root)			
No.	Ca	Mg	K	Root	Crown	Petiole	Leaf	Root	Crown	Petiole	Leaf
1	.5	.5	.5	29.61	25.99	24.92	16.45	1	0.87	0.84	0.55
2	.5	.5	2	26.81	26.56	19.16	12.33	1	0.99	0.71	0.46
3	.5	.5	8	24.09	26.32	16.45	12.33	1	1.09	0.68	0.51
10	2	.5	.5	21.38	27.38	26.32	15.05	1	1.28	1.23	0.70
11	2	.5	2	23.27	26.32	23.85	11.51	1	1.13	1.02	0.49
12	2	.5	8	17.76	27.38	17.76	10.36	1	1.54	1.00	0.58
19	8	.5	.5	19.16	27.38	27.38	16.94	1	1.42	1.42	0.88
20	8	.5	2	16.45	31.35	24.09	13.40	1	1.93	1.46	0.81
21	8	.5	8	16.94	30.10	19.16	11.76	1	1.77	1.13	0.69
4	.5	2	.5	30.68	30.67	36.68	21.63	1	1.00	1.19	0.70
5	.5	2	2	26.56	29.61	34.21	20.23	1	1.11	1.28	0.76
6	.5	2	8	24.34	30.67	29.85	16.69	1	1.26	1.22	0.68
13	2	2	.5	28.45	31.25	43.01	24.09	1	1.09	1.51	0.84
14	2	2	2	25.16	31.74	32.90	17.76	1	1.26	1.30	0.70
15	2	2	8	25.99	36.19	28.45	19.41	1	1.39	1.09	0.74
22	8	2	.5	27.14	37.25	36.68	20.23	1	1.37	1.35	0.74
23	8	2	2	25.49	37.25	30.67	16.69	1	1.46	1.20	0.65
24	8	2	8	22.70	38.32	25.74	16.45	1	1.68	1.13	0.72
7	.5	8	.5	51.81	50.99	67.11	47.70	1	0.98	1.29	0.92
8	.5	8	2	49.02	52.64	64.64	51.24	1	1.07	1.31	1.04
9	.5	8	8	48.77	61.35	53.95	41.61	1	1.25	1.10	0.85
16	2	8	.5	50.17	56.42	60.04	43.83	1	1.12	1.19	0.87
17	2	8	2	53.95	48.77	60.04	47.95	1	0.90	1.11	0.88
18	2	8	8	48.52	59.71	52.88	42.77	1	1.23	1.08	0.88
25	8	8	.5	46.88	54.53	68.51	41.94	1	1.16	1.46	0.89
26	8	8	2	47.95	59.71	61.35	36.43	1	1.24	1.27	0.75
27	8	8	8	43.83	58.64	52.64	32.57	1	1.33	1.20	0.74
Dormant				30.4	30.4	35.4	23.0	1	1.00	1.16	0.75
Pretreatment[b]				24.7	46.0	27.0	20.5	1	1.86	1.09	0.82

[a]Mean of 9 plants
[b]Mean of 36 plants

TABLE 44. F Values From Analyses of Variance of the Potassium Concentration of Strawberry Plant Tissue (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	5.53**	9.47**	0.53	2.18	1.61
Ca(r)	1	39.01**	4.87*	4.52*	7.17**	3.35
Ca(d)	1	0.02	0.47	4.00*	3.26	0.03
Mg(r)	1	16.81**	9.93**	0.03	5.39*	1.59
Mg(d)	1	2.49	0.38	0.69	0.77	0.61
K(r)	1	823.73**	679.47**	241.76**	810.14**	386.97**
K(d)	1	81.61**	74.21**	4.40*	48.31**	16.68**
Ca(r) x Mg(r)	1	0.20	0.23	0.41	1.29	0.27
Ca(r) x Mg(d)	1	0.00	2.09	0.01	0.63	0.17
Ca(d) x Mg(r)	1	9.72**	3.25	2.01	9.08**	10.26**
Ca(d) x Mg(d)	1	3.67	2.11	0.03	7.53**	10.27**
Ca(r) x K(r)	1	12.91**	1.01	0.02	28.42**	3.75
Ca(r) x K(d)	1	1.17	3.82	0.00	4.87*	2.31
Ca(d) x K(r)	1	9.57**	4.75*	5.76*	6.85*	19.15**
Ca(d) x K(d)	1	4.20*	6.51*	3.29	9.55**	0.60
Mg(r) x K(r)	1	2.40	0.03	3.66	11.75**	1.21
Mg(r) x K(d)	1	0.08	7.03*	0.06	6.92	0.90
Mg(d) x K(r)	1	4.25*	0.91	1.26	1.58	1.62
Mg(d) x K(d)	1	0.80	1.42	0.39	0.59	0.93
Error	60					
Total	80					

of linear response to varied Mg in treatment: in the leaf blades and increased Mg level decreased the K concentration, whereas in the roots and crowns, increased Mg increased the K concentration.

In the plant, as a unit, there was no effect of varied Ca in treatment on the K concentration. Except for the petiole, the remaining plant fractions showed that increased Ca levels were accompanied by linear increases in K concentration. In the petiole, the largest K concentration occurred at the median Ca level and the smallest concentration at the high Ca level.

Two Ca x Mg interactions were indicated. One of these, the Ca(d) x Mg(r) interaction, was the same for roots, leaf blades, and the entire plant. For these plant parts, when the Mg level in treatment was high, the greatest K concentration occurred at the median Ca level. The Ca(d) x Mg(d) interaction, indicated for leaf blades and the whole plant, showed that the lowest K concentration at the median Mg level occurred when the Ca level was also median.

Several Ca x K interactions were apparent. The first of these was a Ca(r) x K(r) interaction for roots and leaf blades. For the leaf blades it indicated that when the Ca in treatment was increased, the K concentration also increased at the low K level but decreased at the high K level. In the roots, the K concentration increased considerably at high K and only slightly at low K as Ca was varied from low to high in treatment. A Ca(r) x K(d) interaction, also for leaves, showed a greater response to the second increment of K at low Ca in treatment compared to the high Ca level.

A Ca(d) x K(r) interaction was indicated for all plant parts. Here, the greatest K concentration at the low K level in treatment occurred when

the Ca level was median. At the high K level, there was a downward trend in K concentration as Ca level increased for all fractions but the roots. For roots, at the high K level the response of K concentration to increased Ca was upward. A Ca(d) x K(d) response was indicated for roots, crowns, and leaf blades. The trend was similar for the three parts and showed that only a small additional increase in K concentration was due to the first increment of Ca at the median of K level in treatment.

Several Mg x K interactions were also designated as significant. The first of these, an Mg(r) x K(r) interaction for leaf blades, indicated that as the K level in treatment was increased from low to high, the K concentration was increased at low Mg and decreased at high Mg in treatment. An Mg(r) x K(d) interaction for this same plant fraction indicated further that at the low Mg level, the first increment of K in treatment was not greatly effective in raising the K concentration. In the crown, this situation was true at both the high and low Mg levels. An Mg(d) x K(r) interaction for roots showed, at both high and low levels of K in treatment, a relatively small additive effect on K concentration due to the first increment of Mg in treatment.

The supplementary data of Table 50 show that for any one treatment the greatest K concentration occurred in the petiole followed in order by the leaf, crown, and root. As K was increased in treatment, the crown:root ratio showed a continued decrease through the three K levels. A striking decrease in the petiole:root and leaf:root ratios occurred at the high K level.

Thus, from these data, it appeared that increased K in treatment tended to increase the K concentration most in the root as compared to the other plant parts.

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Summarizing the response of K concentration in the plant parts to treatment levels of the various cations, it was found that similar trends of response to a varied K level in treatment were the most uniform and also true for all of the plant fractions. The magnitude of response between high and low levels of cation in treatment was also greatest where K was the variable cation. The close approximation of both trends and actual values at varied Ca and Mg levels in any one plant fraction was striking.

Irrespective of treatment combination, the greatest K concentration occurred in the petiole and to a considerably less degree in the leaf, crown, and root in that order.

Mineral content of plants

Effect of nutrition on the calcium content of the plant and its fractions.

The results of the statistical analyses for the calcium content of each plant fraction are given in Table 51. The mean values for main effects and first-order interactions giving the effects of nutrient level on the Ca content of the plant fractions are given in Tables 52 to 56.

It is seen that as the Ca level in treatment was increased, the Ca content of all plant parts increased. However, the median Ca level did not, as a rule, increase the Ca content greatly over that at the low Ca level. The trends of response were similar for all plant parts.

The Ca content in the crown, leaf blade, and entire plant showed no significant response to varied Mg in treatment. In the root and petiole increased Mg in treatment decreased the Ca content slightly.

TABLE 45. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Roots (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		11.50	16.67	34.23	18.38	20.86	23.14
Mg-L	19.53	10.48	16.26	31.86	18.41	18.48	21.73
Mg-M	20.07	10.63	16.51	33.06	18.23	18.92	23.08
Mg-H	22.78	13.37	17.20	37.76	18.51	25.21	24.59
Ca-L	18.38	9.87	14.31	30.96			
Ca-M	20.86	13.96	15.41	33.24			
Ca-H	23.14	10.63	20.27	38.48			

TABLE 46. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Crowns (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		16.44	20.30	34.90	22.93	24.13	24.59
Mg-L	22.85	15.93	19.43	33.24	21.81	23.60	23.16
Mg-M	23.70	14.57	20.81	35.69	21.58	24.80	24.70
Mg-H	25.10	18.82	20.71	35.79	25.39	24.03	25.90
Ca-L	22.93	14.57	19.10	35.10			
Ca-M	24.13	18.48	19.07	34.85			
Ca-H	24.59	16.26	22.75	34.77			

TABLE 47. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Petioles (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		56.79	79.47	116.03	86.77	89.65	78.58
Mg-L	84.91	51.52	81.41	121.84	90.21	85.81	77.47
Mg-M	86.01	56.10	82.41	119.56	87.88	89.87	80.54
Mg-H	84.17	62.74	74.61	115.19	83.23	93.28	77.75
Ca-L	86.77	54.84	84.50	121.99			
Ca-M	89.65	71.13	78.24	119.61			
Ca-H	78.58	46.33	75.71	114.98			

TABLE 48. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Strawberry Leaf Blades (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		32.32	41.93	65.63	44.44	47.84	47.58
Mg-L	48.27	32.26	44.26	68.32	47.17	48.32	49.35
Mg-M	46.02	29.17	42.06	66.83	50.42	44.62	47.63
Mg-H	45.56	35.49	39.45	61.72	40.32	50.57	45.77
Ca-L	44.44	25.39	39.40	68.55			
Ca-M	47.84	37.20	40.19	66.12			
Ca-H	47.58	34.34	46.18	62.21			

TABLE 49. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Concentration, Expressed as me./100 Grams of Dry Plant Tissue, of Combined Plant Fractions (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		28.79	38.53	59.19	40.68	42.34	43.52
Mg-L	41.55	27.25	38.68	58.70	41.50	39.37	43.77
Mg-M	41.47	26.43	39.04	58.91	41.60	39.30	43.52
Mg-H	43.49	32.70	37.84	59.96	38.94	48.32	43.23
Ca-L	40.68	23.65	35.87	62.56			
Ca-M	42.34	34.23	37.71	55.07			
Ca-H	43.52	28.51	42.01	60.01			

TABLE 50. Mean[a] Concentration of Potassium in Strawberry Plant Fractions And the Ratio of the Mean Concentration of These Fractions to the Concentration in the Roots (Phase II).

Treatment me./l.				Concentration (me./100g.)				Ratio (part:root)			
No.	Ca	Mg	K	Root	Crown	Petiole	Leaf	Root	Crown	Petiole	Leaf
1	.5	.5	.5	9.97	14.31	56.25	29.22	1	1.43	5.69	2.93
4	.5	2	.5	10.74	13.04	57.68	26.15	1	1.21	5.37	2.43
7	.5	8	.5	8.94	16.36	50.11	20.78	1	1.82	5.60	2.32
10	2	.5	.5	10.48	15.59	55.48	33.31	1	1.48	5.29	3.17
13	2	2	.5	10.48	15.59	65.35	27.61	1	1.48	6.23	2.63
16	2	8	.5	20.96	24.29	92.56	50.70	1	1.15	4.41	2.41
19	8	.5	.5	10.99	17.89	42.34	34.26	1	1.62	3.85	3.11
22	8	2	.5	10.99	15.08	45.92	33.75	1	1.37	4.17	3.06
25	8	8	.5	10.22	15.85	50.70	35.03	1	1.55	4.95	3.42
2	.5	.5	2	14.32	17.64	82.48	41.50	1	1.23	5.76	2.89
5	.5	2	2	15.59	18.66	87.60	40.65	1	1.20	5.61	2.60
8	.5	8	2	13.04	21.73	81.13	36.05	1	1.66	6.22	2.76
11	2	.5	2	14.32	22.24	83.10	42.95	1	1.55	5.80	3.00
14	2	2	2	14.57	21.22	82.07	38.50	1	1.45	5.63	2.64
17	2	8	2	17.38	14.06	69.55	39.12	1	0.80	4.00	2.25
20	8	.5	2	20.20	18.41	76.35	48.32	1	0.91	3.77	2.39
23	8	2	2	19.43	23.52	77.55	47.04	1	1.21	3.99	2.42
26	8	8	2	21.22	26.33	81.72	43.21	1	1.24	3.85	2.03
3	.5	.5	8	30.93	33.49	129.12	70.82	1	1.08	4.33	2.28
6	.5	2	8	28.12	33.75	118.38	70.64	1	1.18	4.17	2.48
9	.5	8	8	27.61	38.09	118.46	64.18	1	1.37	4.28	2.32
12	2	.5	8	30.68	32.98	118.90	68.68	1	1.07	3.87	2.23
15	2	2	8	31.70	37.84	122.22	67.76	1	1.19	3.85	2.13
18	2	8	8	37.33	33.75	117.77	61.95	1	0.90	3.15	1.65
21	8	.5	8	34.00	33.24	117.51	65.45	1	0.97	3.45	1.92
23	8	2	8	39.12	35.54	118.13	62.13	1	0.90	3.01	1.58
27	8	8	8	42.44	35.54	109.33	59.06	1	0.83	2.57	1.39
Dormant				39.9	16.1	76.7	39.9	1	0.40	1.92	1.00
Pretreatment[b]				21.9	14.6	55.2	37.1	1	0.66	2.52	1.69

[a]Mean of 9 plants
[b]Mean of 36 plants

TABLE 51. F Values From Analyses of Variance of the Calcium Content by Strawberry Plant Tissue (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	2.66	30.47**	14.11**	1.97	12.04**
Ca(r)	1	531.45**	671.19**	569.68**	501.74**	1596.27**
Ca(d)	1	81.21**	55.34**	43.87**	49.29**	159.04**
Mg(r)	1	7.04*	3.80	14.61**	2.69	0.00
Mg(d)	1	2.42	2.56	7.28**	0.05	2.39
K(r)	1	5.61*	0.52	9.60**	2.49	4.55*
K(d)	1	3.41	1.45	1.68	0.25	0.35
Ca(r) x Mg(r)	1	4.52*	2.77	19.70**	0.18	2.24
Ca(r) x Mg(d)	1	12.50**	0.51	8.94**	0.40	6.06*
Ca(d) x Mg(r)	1	2.65	2.48	1.76	0.17	0.90
Ca(d) x Mg(d)	1	5.44*	0.30	2.60	0.37	2.99
Ca(r) x K(r)	1	0.00	1.84	18.07**	4.94*	15.63**
Ca(r) x K(d)	1	0.19	0.10	2.40	0.07	0.00
Ca(d) x K(r)	1	0.32	0.37	2.21	0.94	3.18
Ca(d) x K(d)	1	0.01	0.99	0.09	0.23	0.74
Mg(r) x K(r)	1	0.16	1.67	4.91*	0.32	1.32
Mg(r) x K(d)	1	3.19	3.94	0.20	1.64	4.51
Mg(d) x K(r)	1	0.15	1.15	1.89	0.23	1.22
Mg(d) x K(d)	1	0.37	0.00	2.59	0.41	1.96
Error	60					
Total	80					

The Ca content in the crown and leaf blade showed no significant response to varied K in treatment. This was similar to the response to varied Mg levels. In the petiole and plant as a whole there was a linear decrease of Ca content with increased K in the substrate. In the root, however, increased K in treatment increased the Ca content.

In roots and petioles a significant Ca(r) x Mg(r) interaction indicated that in these plant fractions the depression of Ca content by Mg in the substrate was greater when the Ca level was high. A Ca(r) x Mg(d) interaction also for roots and petioles showed that at median Mg and high Ca levels in treatment, the Ca content was higher than that at the other two Mg levels.

A significant Ca(r) x K(r) interaction was shown for petiole, leaf blade, and the entire plant. The response was the same for all three fractions; with increasing K levels the Ca content increased slightly at the low Ca level but decreased at the high Ca level.

The comparative supplementary data of Table 57 show, in addition to the relationships previously described, that for any one treatment level the largest Ca content was in the leaf blades. As the Ca in treatment was increased the Ca content in the plant and its parts increased. However, the greatest increase occurred in the leaf blades as indicated by the increased percentage content at higher Ca levels. This increased content tended to be associated with decreases of the other plant fractions, the relative contents of these remaining static or decreasing.

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In summary, the trends of increased Ca content at increased levels of Ca in treatment were similar for all plant fractions. The crowns and leaf blade fractions were notable in that their Ca contents were not

influenced by varied Mg and K levels. Of the other fractions, the petiole and entire plant showed only slight linear response of decreased Ca content to increased K in treatment. Increased K in treatment had the reverse effect in the roots. Varied Mg in treatment had an effect only for roots and petioles. Here, increased Mg levels decreased the Ca content slightly in the plant part.

The interactions tended to show a more marked decrease in Ca content as one cation was varied from low to high level at the high level of another cation.

The leaf blade had the largest Ca content and appeared to be the plant fraction most sensitive in response to varied Ca level in treatment.

Effect of nutrition on the magnesium content of the plant fractions.

The results of the statistical analyses for the Mg content of the plant fractions are given in Table 58. The mean values for the main effects and first-order interactions giving the effects of nutrient level on the Mg content of the plant fractions are given in Tables 59 to 63.

These data show that the Mg content of the plant part increased as the concentration of Mg in the substrate was increased. This response was not linear in that the median Mg level was nearer in its effect to the low Mg level.

Similarly it is also shown that the Mg content of all plant parts increased as the Ca in the nutrient was increased. This response was linear in all cases except the leaf blade where the median level of Ca in treatment approached the high level in effectiveness.

Potassium nutrition showed less effect on the Mg content. The Mg content of the crown increased with increased K in treatment. In the entire

TABLE 52. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Content, Expressed as Milliequivalents, by Strawberry Roots (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		0.91	0.89	1.03	0.50	0.69	1.65
Mg-L	0.99	0.99	0.96	1.02	0.55	0.72	1.70
Mg-M	0.99	0.91	0.91	1.15	0.47	0.64	1.87
Mg-H	0.86	0.84	0.80	0.92	0.49	0.70	1.38
Ca-L	0.50	0.47	0.46	0.57			
Ca-M	0.69	0.63	0.64	0.72			
Ca-H	1.65	1.64	1.58	1.74			

TABLE 53. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Content, Expressed as Milliequivalents, by Strawberry Crowns (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		0.94	0.96	0.91	0.53	0.77	1.50
Mg-L	0.95	0.94	1.01	0.92	0.49	0.84	1.52
Mg-M	0.97	0.92	1.00	1.00	0.55	0.79	1.56
Mg-H	0.88	0.95	0.88	0.81	0.54	0.69	1.42
Ca-L	0.53	0.52	0.53	0.54			
Ca-M	0.77	0.74	0.83	0.75			
Ca-H	1.50	1.55	1.52	1.44			

TABLE 54. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Content, Expressed as Milliequivalents, by Strawberry Petioles (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		1.10	1.08	0.95	0.44	0.81	1.88
Mg-L	1.10	1.20	1.24	0.87	0.41	0.85	2.05
Mg-M	1.13	1.20	1.08	1.09	0.43	0.81	2.13
Mg-H	0.91	0.90	0.92	0.89	0.48	0.77	1.47
Ca-L	0.44	0.41	0.40	0.51			
Ca-M	0.81	0.80	0.86	0.78			
Ca-H	1.88	2.10	1.98	1.57			

TABLE 55. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Content, Expressed as Milliequivalents, by Strawberry Leaf Blades (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		3.73	3.42	3.34	1.22	2.48	6.83
Mg-L	3.27	3.63	3.36	2.83	1.10	2.24	6.48
Mg-M	3.53	3.62	3.31	3.67	1.18	2.39	7.03
Mg-H	3.69	3.95	3.60	3.51	1.30	2.81	6.95
Ca-L	1.22	1.18	1.16	1.32			
Ca-M	2.48	2.42	2.51	2.44			
Ca-H	6.83	7.53	6.65	6.28			

TABLE 56. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Calcium Content, Expressed as Milliequivalents, by Combined Plant Fractions (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		6.74	6.37	6.24	2.68	4.77	11.91
Mg-L	6.35	6.82	6.59	5.65	2.56	4.68	11.83
Mg-M	6.66	6.73	6.31	6.93	2.64	4.65	12.68
Mg-H	6.34	6.67	6.22	6.15	2.82	4.98	11.18
Ca-L	2.68	2.59	2.52	2.92			
Ca-M	4.77	4.68	4.85	4.77			
Ca-H	11.91	12.95	11.74	11.04			

TABLE 57. Mean[a] Content of Calcium, As Milliequivalents, by Strawberry Plant Fractions and the Per Cent of the Total Content by Each Tissue Fraction (Phase II).

Treatment				Plant Tissue Fraction								
	Level			Root		Crown		Petiole		Leaf		Total
No.	Ca	Mg	K	Content	%	Content	%	Content	%	Content	%	Content
1	.5	.5	.5	0.13	17.8	0.13	18.0	0.13	16.8	0.36	47.4	0.75
2	.5	.5	2	0.18	23.4	0.17	22.1	0.11	13.9	0.32	40.6	0.78
3	.5	.5	8	0.22	19.9	0.18	16.1	0.16	15.0	0.41	38.9	0.97
4	.5	2	.5	0.18	19.9	0.18	20.8	0.14	15.7	0.39	43.5	0.89
5	.5	2	2	0.11	14.7	0.17	22.6	0.13	17.0	0.35	45.6	0.76
6	.5	2	8	0.17	18.3	0.19	20.0	0.16	16.6	0.44	45.1	0.96
7	.5	8	.5	0.15	17.2	0.19	21.4	0.13	15.3	0.42	46.2	0.89
8	.5	8	2	0.16	16.9	0.18	19.2	0.16	17.0	0.44	46.8	0.94
9	.5	8	8	0.17	17.8	0.16	12.1	0.18	19.0	0.44	45.9	0.95
10	2	.5	.5	0.20	13.5	0.27	18.5	0.28	18.8	0.74	49.2	1.49
11	2	.5	2	0.22	14.3	0.29	18.7	0.30	19.3	0.75	47.6	1.56
12	2	.5	8	0.29	18.4	0.27	17.1	0.26	17.0	0.74	47.4	1.56
13	2	2	.5	0.19	12.5	0.25	16.0	0.27	17.7	0.85	53.7	1.56
14	2	2	2	0.18	12.7	0.28	19.5	0.26	18.5	0.71	49.2	1.43
15	2	2	8	0.25	15.9	0.25	15.9	0.26	16.7	0.82	51.3	1.58
16	2	8	.5	0.23	14.6	0.21	13.4	0.24	15.1	0.90	56.8	1.58
17	2	8	2	0.22	12.7	0.25	13.9	0.29	16.1	1.03	57.2	1.79
18	2	8	8	0.24	15.5	0.22	14.2	0.24	15.3	0.87	54.9	1.57
19	8	.5	.5	0.65	14.5	0.52	11.6	0.79	17.6	2.52	56.2	4.48
20	8	.5	2	0.54	13.1	0.53	12.8	0.82	19.6	2.28	54.45	4.17
21	8	.5	8	0.50	16.4	0.46	15.2	0.43	14.1	1.67	54.2	3.06
22	8	2	.5	0.53	12.8	0.47	11.5	0.78	18.8	2.37	56.9	4.15
23	8	2	2	0.61	15.1	0.54	13.6	0.68	16.7	2.24	54.9	4.07
24	8	2	8	0.72	16.6	0.54	12.6	0.66	15.3	2.41	55.5	4.33
25	8	8	.5	0.45	11.0	0.54	13.1	0.52	12.6	2.63	63.2	4.14
26	8	8	2	0.41	12.0	0.44	12.9	0.47	13.6	2.12	61.4	3.44
27	8	8	8	0.51	14.2	0.42	11.7	0.47	13.1	2.19	60.9	3.59
Dormant				0.09	23.6	0.08	21.0	0.05	13.1	0.15	39.4	0.38
Pretreatment[b]				0.15	26.3	0.20	35.0	0.08	14.0	0.13	22.8	0.57

[a]Mean of 9 plants
[b]Mean of 36 plants

TABLE 58. F Values From Analyses of Variance of the Magnesium Content by Strawberry Plant Tissue (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	11.71**	6.96**	10.02**	17.35**	39.59**
Ca(r)	1	9.49**	10.55**	16.26**	28.59**	63.09**
Ca(d)	1	0.00	0.71	0.34	5.31*	2.14
Mg(r)	1	223.54**	22.71**	202.83**	447.89**	819.45**
Mg(d)	1	30.24**	7.02*	17.89**	57.95**	100.69**
K(r)	1	0.74	4.82*	0.25	0.41	0.50
K(d)	1	0.55	1.05	0.04	0.78	31.73**
Ca(r) x Mg(r)	1	2.90	0.01	0.18	0.38	1.10
Ca(r) x Mg(d)	1	0.75	0.03	0.60	0.05	0.00
Ca(d) x Mg(r)	1	3.44	0.19	0.66	2.97	6.54*
Ca(d) x Mg(d)	1	2.69	0.10	0.01	0.18	0.45
Ca(r) x K(r)	1	1.82	0.91	4.33*	5.10*	10.00**
Ca(r) x K(d)	1	0.03	0.04	0.05	0.92	0.23
Ca(d) x K(r)	1	0.11	0.01	0.00	1.25	0.74
Ca(d) x K(d)	1	0.00	0.17	0.09	0.00	0.00
Mg(r) x K(r)	1	0.38	0.13	0.16	0.00	0.23
Mg(r) x K(d)	1	0.00	0.14	0.00	0.31	0.53
Mg(d) x K(r)	1	0.02	1.10	0.33	0.67	0.06
Mg(d) x K(d)	1	0.22	0.01	0.40	1.09	1.30
Error	60					
Total	80					

plant the Mg content at the median K level was significantly below that at the median K level was significantly below that at the other two K levels.

The only significant interaction was the Ca(r) x K(r) interaction which occurred for petioles, leaf blades, and the entire plant. The trend of response in these plant fractions was the same, namely that as K in treatment increased the Mg content in the tissue increased at the low Ca level but decreased at the high Ca level.

The supplementary data in Table 64 show that the greatest Mg content occurred in the leaf blades with the smallest relative content being in the petiole. As Mg in treatment was increased there was a tendency toward a slight relative decrease in Mg content of the roots, crown, and petiole, and a slight increase in the leaf blades.

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To summarize, an increased Mg content of all plant parts accompanied increased levels of Ca and Mg in treatment with the greatest response when the latter was varied. The varied K level had no effect in changing the Mg content of the root, petiole, and leaf blade. In the crown a linearly increased Mg content accompanied an increased K level. In the total of plant parts, there was a decreased Mg content at the median K level.

A Ca(r) x K(r) interaction for petioles, leaf blades, and the entire plant showed that K nutrition increased the Mg content at the low Ca level but decreased it at the high Ca level.

The greatest Mg content, as per cent of total content, occurred in the leaf blades. The lowest Mg content was in the petioles.

TABLE 59. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Content, Expressed as Milliequivalents, by Strawberry Roots (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		1.31	1.25	1.32	1.20	1.33	1.45
Mg-L	0.84	0.85	0.81	0.86	0.85	0.79	0.88
Mg-M	1.06	1.06	1.00	1.13	0.94	0.96	1.29
Mg-H	2.07	2.00	2.06	2.14	1.80	2.23	2.17
Ca-L	1.20	1.13	1.15	1.31			
Ca-M	1.33	1.29	1.29	1.40			
Ca-H	1.45	1.50	1.42	1.42			

TABLE 60. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Content, Expressed as Milliequivalents, by Strawberry Crowns (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		1.06	1.08	1.34	0.98	1.10	1.40
Mg-L	0.73	0.81	0.91	1.23	0.54	0.69	0.96
Mg-M	1.00	1.00	0.98	1.31	0.75	0.93	1.21
Mg-H	1.79	1.36	1.37	1.48	1.66	1.67	2.04
Ca-L	0.98	0.63	0.74	0.88			
Ca-M	1.10	0.82	0.90	1.17			
Ca-H	1.40	1.73	1.61	2.03			

TABLE 61. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Content, Expressed as Milliequivalents, by Strawberry Petioles (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		1.10	1.09	1.05	0.87	1.11	1.25
Mg-L	0.53	0.53	0.53	0.53	0.35	0.51	0.73
Mg-M	0.85	0.89	0.81	0.85	0.70	0.87	0.98
Mg-H	1.85	1.86	1.93	1.77	1.57	1.94	2.05
Ca-L	0.87	0.77	0.89	0.96			
Ca-M	1.11	1.11	1.15	1.07			
Ca-H	1.25	1.40	1.23	1.11			

TABLE 62. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Content, Expressed as Milliequivalents, by Strawberry Leaf Blades (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		2.67	2.49	2.57	2.04	2.79	2.90
Mg-L	1.23	1.38	1.13	1.20	0.90	1.14	1.66
Mg-M	1.87	1.97	1.65	1.99	1.39	2.03	2.20
Mg-H	4.62	4.66	4.70	4.51	3.83	5.20	4.84
Ca-L	2.04	1.92	2.06	2.14			
Ca-M	2.79	2.75	2.72	2.90			
Ca-H	2.90	3.33	2.70	2.66			

TABLE 63. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Magnesium Content, Expressed as Milliequivalents, by Combined Plant Fractions (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		6.23	5.96	6.34	5.08	6.36	7.02
Mg-L	3.37	3.48	3.24	3.38	2.65	3.20	4.25
Mg-M	4.74	4.74	4.32	5.16	3.72	4.81	5.69
Mg-H	10.35	10.27	10.31	10.46	8.88	11.06	11.11
Ca-L	5.08	4.65	4.98	5.62			
Ca-M	6.36	6.23	6.15	6.70			
Ca-H	7.02	7.61	6.75	6.69			

TABLE 64. Mean[a] Content of Magnesium, As Milliequivalents, by Strawberry Plant Fractions and the Per Cent of the Total Content by Each Tissue Fraction (Phase II).

Treatment No.	Level Ca	Mg	K	Root Content	%	Crown Content	%	Petiole Content	%	Leaf Content	%	Total Content
1	.5	.5	.5	0.25	32.3	0.12	16.6	0.09	12.3	0.35	38.7	0.76
2	.5	.5	2	0.26	34.9	0.17	23.3	0.07	10.6	0.23	31.2	0.73
3	.5	.5	8	0.34	31.7	0.23	15.2	0.12	11.9	0.37	34.2	1.06
10	2	.5	.5	0.24	23.7	0.21	20.5	0.16	16.2	0.40	39.5	1.01
11	2	.5	2	0.29	28.3	0.21	21.0	0.17	17.4	0.34	33.2	1.01
12	2	.5	8	0.26	24.0	0.26	24.3	0.17	15.6	0.39	36.1	1.08
19	8	.5	.5	0.36	22.6	0.29	18.2	0.27	16.9	0.67	42.3	1.59
20	8	.5	2	0.26	18.4	0.35	24.5	0.27	18.7	0.55	38.4	1.43
21	8	.5	8	0.25	20.2	0.31	24.7	0.19	14.9	0.43	33.8	1.18
4	.5	2	.5	0.32	27.5	0.20	17.5	0.18	15.4	0.46	39.6	1.16
5	.5	2	2	0.29	27.3	0.20	19.0	0.17	15.5	0.41	38.1	1.07
6	.5	2	8	0.32	22.4	0.34	23.6	0.26	18.6	0.51	35.4	1.43
13	2	2	.5	0.30	19.7	0.24	15.8	0.31	19.9	0.69	44.5	1.54
14	2	2	2	0.25	18.6	0.29	21.4	0.26	19.3	0.55	40.6	1.35
15	2	2	8	0.39	21.1	0.39	21.1	0.30	16.1	0.78	41.6	1.86
22	8	2	.5	0.43	21.8	0.36	18.5	0.37	18.9	0.80	40.6	1.96
23	8	2	2	0.44	24.2	0.40	21.7	0.31	17.2	0.68	36.8	1.83
24	8	2	8	0.41	22.5	0.43	23.7	0.28	15.4	0.70	38.3	1.82
7	.5	8	.5	0.55	20.9	0.47	17.94	0.46	17.6	1.16	43.6	2.64
8	.5	8	2	0.59	19.1	0.53	17.0	0.57	18.5	1.41	45.4	3.10
9	.5	8	8	0.65	19.0	0.65	19.2	0.52	15.3	1.58	46.4	3.40
16	2	8	.5	0.74	20.6	0.54	15.3	0.63	17.8	1.65	46.2	3.56
17	2	8	2	0.75	20.0	0.47	12.6	0.70	18.7	1.82	48.6	3.74
18	2	8	8	0.74	21.4	0.65	18.8	0.60	17.4	1.46	42.3	3.45
25	8	8	.5	0.71	17.7	0.70	17.5	0.75	18.8	1.85	46.0	4.01
26	8	8	2	0.71	20.7	0.61	17.8	0.64	18.8	1.46	42.6	3.42
27	8	8	8	0.65	18.5	0.73	20.5	0.64	18.1	1.52	42.8	3.54
Dormant				0.23	44.2	0.10	19.2	0.05	9.6	0.14	26.9	0.52
Pretreatment[b]				0.26	46.4	0.14	25.0	0.05	8.9	0.10	17.8	0.56

[a]Mean of 9 plants
[b]Mean of 36 plants

Effect of nutrition on the potassium content of the plant fractions.

The results of the statistical analyses for the K content of the plant fractions are given in Table 65. The mean values for the main effects and first-order interactions giving the effects of nutrient level on the K content of the plant fractions are given in Tables 66 to 70.

Increased K content accompanied increased K in treatment with a deviation from linearity at the median level. At this level, the increased K content was closer to that at the lowest level. The greatest magnitude of response occurred where K was varied and the response was generally similar for all plant parts.

An increased K content occurred with an increased Ca level that showed a significant linear response for all plant portions. A quadratic response was indicated for the petioles and leaf blades. In the petiole, the median Ca level was as efficacious as the high level in increasing the K content. In the leaf blade, the K content deviated only slightly from linearity.

An increased K content accompanied an increased Mg treatment level. The response was linear for all plant parts with no deviations from that linearity.

The Ca(d) x Mg(r) interaction for root, leaf, and entire portion showed that the K content at the median Ca level was similar to that at the high Ca level when the Mg level was high. In the petiole, under the same conditions of Ca and Mg levels, the K content reached its peak at the median Ca level. A Ca(d) x Mg(d) interaction for roots and leaf blades showed that at the median Ca level the K content was about the same at low and median levels of Mg in treatment.

A Ca(r) x K(r) interaction for roots and leaf blades was similar in

TABLE 65. F Values From Analyses of Variance of the Potassium Content by Strawberry Plant Material (Phase II).

Source	D/F	Plant Fraction				
		Root	Crown	Petiole	Leaf Blade	Entire Plant
Replicate	2	10.36**	35.50**	43.31**	20.59**	7.32**
Ca(r)	1	86.80**	61.03**	33.00**	441.38**	57.86**
Ca(d)	1	0.37	2.58	10.35**	11.77**	0.21
Mg(r)	1	11.10**	50.24**	22.60**	17.04**	10.54**
Mg(d)	1	0.97	0.08	0.43	2.08	0.86
K(r)	1	385.47**	622.05**	332.21**	1079.81**	218.92**
K(d)	1	52.20**	75.07**	20.56**	105.05**	17.67**
Ca(r) x Mg(r)	1	0.23	3.38	1.32	0.16	0.02
Ca(r) x Mg(d)	1	1.65	0.22	0.00	0.09	0.00
Ca(d) x Mg(r)	1	4.62*	3.57	6.42*	19.96**	5.85*
Ca(d) x Mg(d)	1	4.30*	2.07	1.17	6.16*	2.22
Ca(r) x K(r)	1	13.08**	2.01	0.02	9.50**	0.22
Ca(r) x K(d)	1	0.27	3.11	2.41	12.02**	2.10
Ca(d) x K(r)	1	3.45	3.32	1.73	0.09	3.47
Ca(d) x K(d)	1	2.15	2.88	1.97	14.66**	0.78
Mg(r) x K(r)	1	2.28	0.90	1.80	8.82	0.21
Mg(r) x K(d)	1	0.89	14.68**	2.30	15.51**	1.71
Mg(d) x K(r)	1	2.56	4.04*	0.82	3.42	1.16
Mg(d) x K(d)	1	0.09	0.07	0.16	0.05	0.00
Error	60					
Total	80					

that K content increased at either low or high levels when Ca was varied from low to high; or at either low or high levels of Ca when K was varied from low to high. Also for leaf blades, the Ca(r) x K(d) interaction indicated that, at the high level of Ca, the K content at the median K level approached that at the high level.

An Mg(r) x K(r) interaction for leaf blades showed a greater K content when Mg level was increased at the low K level. Another Mg x K interaction, Mg(r) x K(d), for leaf blades and roots showed that the effect of Mg level in increasing K content was not as great at the median as it was at the other two K levels.

The supplementary data of Table 71 show that the largest relative K content occurred in the leaf blades and was two-fold to three-fold that of the petioles which showed the next largest content. The K content of roots and crowns tended to be similar in many cases.

* * * * * * * * * * * * *

Summarizing the effects of varied levels of the cations on the K content, the following generalization was true for all plant portions: an increased K content accompanied the increased level of a given cation with the greatest response between levels when K was the cation in treatment. The effects of interactions were variable and no generalization can be made except that the leaf blade fraction showed the most interaction of cation levels on K content. Approximately 75 per cent of the K content of the plant occurred in the leaf blades and petioles.

TABLE 66. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Content, Expressed as Milliequivalents, by Strawberry Roots (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		0.48	0.66	1.56	0.64	0.87	1.16
Mg-L	0.81	0.41	0.65	1.38	0.62	0.76	1.06
Mg-M	0.86	0.39	0.61	1.57	0.60	0.74	1.23
Mg-H	1.00	0.56	0.71	1.73	0.69	1.11	1.20
Ca-L	0.64	0.29	0.42	1.21			
Ca-M	0.87	0.54	0.57	0.98			
Ca-H	1.16	1.21	1.50	1.97			

TABLE 67. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Content, Expressed as Milliequivalents, by Strawberry Crowns (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		0.44	0.56	1.12	0.61	0.68	0.83
Mg-L	0.61	0.38	0.50	0.95	0.47	0.60	0.75
Mg-M	0.70	0.35	0.57	1.19	0.58	0.71	0.82
Mg-H	0.81	0.59	0.62	1.22	0.78	0.73	0.93
Ca-L	0.61	0.30	0.45	1.07			
Ca-M	0.68	0.47	0.49	1.08			
Ca-H	0.83	0.54	0.74	1.21			

TABLE 68. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Content, Expressed as Milliequivalents, by Strawberry Petioles (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		1.35	1.99	3.61	1.84	2.55	2.56
Mg-L	2.04	0.99	1.82	3.32	1.57	2.11	2.46
Mg-M	2.27	1.19	1.90	3.71	1.85	2.39	2.56
Mg-H	2.63	1.86	2.25	3.79	2.11	3.14	2.65
Ca-L	1.84	0.84	1.45	3.24			
Ca-M	2.55	1.76	2.08	3.79			
Ca-H	2.56	1.44	2.44	3.79			

TABLE 69. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Content, Expressed as Milliequivalents, by Strawberry Leaf Blades (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		3.11	4.05	7.44	3.45	5.03	5.87
Mg-L	4.58	2.77	4.02	6.94	3.18	4.56	5.78
Mg-M	4.68	2.68	3.92	7.44	3.50	4.67	5.87
Mg-H	5.09	3.89	4.20	7.17	3.45	5.85	5.96
Ca-L	3.45	1.59	2.60	4.17			
Ca-M	5.03	3.58	3.91	5.63			
Ca-H	5.87	4.17	7.59	7.80			

TABLE 70. Mean Values for the Main Effects and First-Order Interactions, Giving the Effects of Nutrient Level on the Potassium Content, Expressed as Milliequivalents, by Combined Plant Fractions (Phase II).

		K-L	K-M	K-H	Ca-L	Ca-M	Ca-H
		5.37	7.30	12.98	6.53	8.68	10.44
Mg-L	7.85	4.56	7.00	11.99	6.07	7.42	10.07
Mg-M	8.27	4.62	7.01	13.18	6.54	7.78	10.49
Mg-H	9.52	6.92	7.89	13.76	6.97	10.85	10.75
Ca-L	6.53	3.03	4.94	11.61			
Ca-M	8.68	6.37	7.06	12.62			
Ca-H	10.44	6.71	9.90	14.70			

TABLE 71. Mean[a] Content of Potassium, As Milliequivalents, by Strawberry Plant Fractions and the Per Cent of Total Content by Each Tissue Fraction (Phase II).

Treatment No.	Level Ca	Mg	K	Root Content	%	Crown Content	%	Petiole Content	%	Leaf Content	%	Total Content
1	.5	.5	.5	0.07	9.1	0.07	7.8	0.21	24.2	0.52	58.8	0.87
4	.5	2	.5	0.10	10.0	0.08	8.0	0.28	28.0	0.54	54.0	1.00
7	.5	8	.5	0.09	8.9	0.15	13.7	0.33	30.7	0.50	46.6	1.07
10	2	.5	.5	0.11	8.2	0.11	7.9	0.35	23.9	0.89	59.9	1.46
13	2	2	.5	0.11	7.9	0.11	8.2	0.42	29.1	0.80	54.8	1.44
16	2	8	.5	0.30	9.1	0.23	6.9	0.98	28.8	1.89	55.2	3.40
19	8	.5	.5	0.21	9.8	0.19	9.0	0.42	19.3	1.35	61.9	2.17
22	8	2	.5	0.17	8.1	0.15	7.0	0.47	22.4	1.32	62.4	2.11
25	8	8	.5	0.15	6.5	0.20	8.5	0.54	22.7	1.49	62.2	2.38
2	.5	.5	2	0.14	10.3	0.11	8.4	0.34	24.7	0.77	56.5	1.36
5	.5	2	2	0.12	8.0	0.11	7.8	0.43	29.1	0.82	55.0	1.48
8	.5	8	2	0.15	7.7	0.21	10.6	0.67	33.0	0.99	48.6	2.02
11	2	.5	2	0.18	8.2	0.17	7.9	0.61	27.6	1.25	56.2	2.21
14	2	2	2	0.14	6.8	0.18	8.6	0.66	30.4	1.18	54.1	2.16
17	2	8	2	0.24	9.0	0.13	5.1	0.80	30.2	1.47	55.6	2.64
20	8	.5	2	0.32	9.6	0.21	6.2	0.86	25.5	1.99	58.6	3.38
23	8	2	2	0.34	10.3	0.26	7.9	0.80	24.2	1.91	57.5	3.31
26	8	8	2	0.31	10.2	0.27	8.9	0.77	24.9	1.73	55.9	3.08
3	.5	.5	8	0.40	10.6	0.28	7.6	1.01	26.7	2.08	55.0	3.77
6	.5	2	8	0.37	9.4	0.37	9.4	1.12	28.2	2.12	53.0	3.98
9	.5	8	8	0.36	9.4	0.41	10.8	1.10	28.8	1.94	50.9	3.81
12	2	.5	8	0.45	10.5	0.31	7.2	1.13	26.3	2.41	55.9	4.30
15	2	2	8	0.48	9.9	0.40	8.3	1.30	26.7	2.69	55.1	4.87
18	2	8	8	0.56	11.9	0.36	7.6	1.35	28.4	2.48	52.1	4.75
21	8	.5	8	0.52	11.6	0.35	7.8	1.17	26.1	2.44	54.3	4.48
24	8	2	8	0.71	14.2	0.41	8.2	1.28	25.5	2.62	52.1	5.02
27	8	8	8	0.72	13.9	0.45	8.6	1.33	25.4	2.74	52.1	5.24
Dormant				0.30	42.2	0.05	7.0	0.11	15.4	0.24	33.8	0.71
Pretreatment[b]				0.23	35.9	0.10	15.6	0.13	20.3	0.19	29.6	0.64

[a]Mean of 9 plants

[b]Mean of 36 plants

DISCUSSION

The cultural demands of strawberries under the conditions of the experiments herein were generally anticipated by a consideration of the mineral nutrition and cultural studies conducted by others. Especially considered were the sand culture studies outlined in Appendix Tables 1 to 3. For example, Morris and Crist (43) found the optimum pH in water culture to be in the range of pH 5 to pH 7. In sand culture, Waltman (54) reported the optimum pH to be from pH 5.3 to 5.5 and Clark (6) reported an optimum pH of 4.6 when the source of nitrogen was in the nitrate form. In the experiments reported herein the pH ranges of the nutrient solutions were pH 5.0 - 6.0 in Phase I and pH 4.8 - 5.2 in Phase II. In both phases nitrogen was supplied only as nitrate which evidence indicates to be the more desirable source of nitrogen for strawberry plants under acid conditions (6, 25, 36, 40, 43, 54).

The Phase I study was conducted to establish a symptomology for conditions ranging from deficient to toxic amounts of Ca, Mg, and K in the nutrient media. To accomplish this two of the cations were maintained at a constant optimum level while the third was varied through seven levels to opposite extremes. In an attempt to establish optimum levels on which to base such an experiment the complete or "best" solutions of other workers were considered. Since the salt or ion concentrations in their solutions were presented in several methods of expression (Appendix Table 1), their nutrient solutions were all recalculated in terms of parts per million and milliequivalents in order to establish some degree of uniformity for comparison (Appendix Table 3). Considering these data, the cation

levels in the applied nutrient solution selected as optimum for Phase I treatments were as follows: calcium, 4 me./l.; magnesium, 2 me./l.; and potassium, 2 me./liter. Evidence that these levels approached the optimum for this experiment is provided by the fact that no foliar disorders occurred in the treatment having the three cations in these concentrations. The data on mean dry weights (Table 7) would suggest that these levels were also optimum for Ca and K although a higher level of Mg might have been desirable.

The results of Phase I satisfied the intended objective to establish a symptomology for varying amounts of cations in the nutrient media ranging from deficient to toxic. These results will be considered in more detail presently. The foliar symptomology of Phase I facilitated the selection of three levels of each cation for the factorial experiment in Phase II.

As was indicated earlier in Methods, the three levels of cation concentration adopted for use in the nutrient solutions were the same for the three ions and were as follows: low, 0.5 md./l.; median, 2 me./l.; and high, 8 me./liter. The selection of these three levels was based primarily upon the vegetative symptoms of toxicity and deficiency. In Phase I, no attempt was made to control the total ion content of the nutrient solutions. However, in Phase II the total concentration of the three variable cations was 1.5 me. at the lowest level in treatment and 24 me. at the highest level. To overcome this wide difference in total concentration, sodium was employed as a neutral cation to bring all treatment levels to a total concentration of 24 me./l. which was the concentration of the highest level.

Hoagland and Snyder (27) had reported deleterious effects to straw-

berries due to sodium but these were reported as having occurred at a pH of 7.3 to 8.2. Collander (8) had reported that Na was one of the cations most notably excluded by many plants. Considering these reports on the effects of Na, it was assumed that Hoagland and Snyder's results were due more to an effect of high pH than to sodium. It was also considered that any effects that might be due to sodium would be more easily accounted for than osmotic pressure effects due to widely varied concentrations in the nutrient solutions. Thus, sodium was used. During the course of the experiment profound effects due to sodium became apparent, or were at least suspected, and chemical analyses for sodium in the plant material were made to supplement the data for the other cations. A consideration of the effects of sodium will be made in a later part of this discussion.

Although not an effect of nutrient treatments, the failure of the plants to produce runners as anticipated is noteworthy. The plants were maintained in the vegetative condition by photoperiod control. However, the fact that branch crowns were formed where runners were expected was surprising but not unaccountable. Darrow (11) has stated that branch crowns, runners, and inflorescences are different stem structures, any one of which may be produced by any one of the growing points in leaf axils depending upon the genetic constitution of the variety and/or the environment. Prolific runner formation in Tennessee Beauty plants was obtained by Borthwick and Parker (1) at the higher light intensities and temperatures of mid-summer and early fall. The response differed however, under the same photoperiod but at cooler temperatures and lower light intensities of winter, as in this experiment.

In the discussion that follows, certain aspects of the results will be compared with the results of other workers. The methods of others, as

summarized in Appendix Tables 1 and 2 indicate a diversity of materials and methods and any comparisons made will be qualified by this diversity.

The nutrient solutions in these experiments were considered on the basis of milliequivalents for ease in conceiving and preparing the solutions. For consistency the chemical composition of the plant material was reported on the same basis. However, since the results being presented are somewhat transitional in the trends of reporting data as mgs./unit or me./unit, the data of Phase I have been presented in both ways. For an immediate comparison of the two methods of expressing concentration some of the data of Phase II has been similarly summarized in Table 76. A consideration of these data by the two methods would indicate different conclusions. For example, when comparing the cation concentration at the 0.5 me. Ca level in treatment on a mg./gm. basis (Table 76) it appears that the Ca and Mg concentrations are similar and that the K concentration is four-fold greater than either. The same data converted to a me. basis present a different picture. Here the concentration of Mg and K are more nearly similar and both are at most only twice as great as the Ca concentration. Thus it is apparent that quite different conclusions can be drawn from the two methods. It is possible to consider that ions are absorbed and used by the plant function on a basis of chemical equality rather than actual weights. Since expressing ion concentration in terms of milliequivalents places it on a basis of equal chemical reactivity it would appear that this method of expression may be the more desirable.

Considering the effect of treatment on foliar condition, varied Ca levels appeared to be most prominent in effect. One of the most notable of the calcium deficiency symptoms was the purple blotching of the leaf veins. This condition appeared in Phase I at both the 0.5 me. and 1.0

me. Ca level in treatment. In Phase II this symptom again was observed and this time at the 0.5 me. and 2 me. of Ca in treatment. Since this symptom occurred at similar low Ca levels in the two experiments, it is considered to be a definite calcium deficiency manifestation. It is possible that this was also the blotching of leaves reported by Davis et al. (15) and/or the red-brown discoloration around the base of the leaflet as described by Hambidge (23). This was the only foliar disorder to occur that was common to both experiments and it was the third to appear chronologically in Phase II.

The first symptom of disorder in the latter experiment (Phase II) was the necrosis at the tips of young leaves followed by the crinkling of these leaves as they developed. This response was characteristic of all low Ca levels, all median Ca levels with one notable exception, and at certain of the high Ca levels. The exceptions will be reconsidered presently. This same condition of necrotic leaf tips was also reported as Ca deficiency by Lineberry and Burkhart (36), Gilbert and Robbins (20), and Iwakiri and Scott (29). The fact that this was the first Ca deficiency symptom to appear is in agreement with the consensus of investigators, as pointed out by Gourley and Howlett (22), that a Ca deficiency is expressed in fruit plants in pot culture rather quickly. They state that since very little Ca is translocated from the older portions of the plant, the deficiency symptoms first appear in the young growing tips and leaves. It should be stressed that although the necrotic leaf tips were characteristic of the Ca deficiency treatments, this same condition has been observed under different circumstances to be due also to low temperature or chemical spray injury. Thus, although this condition is characteristic of Ca deficiency in this experiment it is not necessarily a specific

calcium deficiency symptom.

The second symptom to develop was the general senescence of older foliage and by the termination of the experiment this condition was characteristic of all low and median Ca levels irrespective of levels of the other cations. As a symptom it was considered as calcium deficiency although it contributed little that was diagnostic. There was no foliar senescence at high Ca levels in treatment.

The petiolar blotching and necrosis of the petiole at the base of the leaf blade (Figure 11, 12) occurred only at the low Ca levels and was the last disorder to appear. Both Hoagland and Snyder (27) and Lineberry and Burkhart (36) have reported, and illustrated, this same condition and designated it to be a potassium deficiency symptom. In the experiments of both of these workers K was omitted from the nutrient solutions, the Ca level was 8.0 - 10.0 me./l. and the Mg level was 4 me./liter. Under these conditions their interpretation would appear to be correct. However, in this experiment, the symptom in question appeared at all low calcium levels regardless of K level (Table 23); and in three instances the K level (8.0 me.) was sixteen-fold greater than the Ca level (0.5 me.). At low levels of K (0.5 me.) in relation to high levels of Ca and/or Mg (8.0 me.) where this condition would be expected to occur, it was notably absent. Thus the assignment of a cause for this condition is in conflict unless one assumes that the low level of K (0.5 me.) used in this experiment provided enough K to prevent the manifestation of this symptom. This would appear to be true since Eckstein et al. (17) have stated that K has a high degree of efficiency in plants and typical K starvation occurs only after an extreme degree of K deficiency is reached. This would also explain the absence of the condition at median and high

Ca levels (Table 23). However, it contributes nothing to an explanation for the occurrence of the condition at all K levels when the Ca level was low. There appears no alternative but to consider it a Ca deficient disorder under the conditions of this experiment.

The several abnormal foliar phenomena just discussed are all considered to be due to deficient amounts of Ca in treatment. They have all occurred at low levels of Ca in treatment regardless of the level of the other cations. As was pointed out previously, all of the symptoms occur at low calcium levels. At the median Ca levels, the last Ca deficiency that occurred at the low Ca level did not appear. Also, where Mg was low at the median Ca level, the third chronological symptom was not apparent. At the high Ca level, the only symptom to occur was that which appeared first - the necrosis of the young leaf tip. Thus it would seem that the necrotic leaf tip was the most sensitive, and the blotching and necrosis of the petiole the least sensitive symptom of deficient Ca in treatment. If one notes in Table 23 the levels at which symptoms of disorder are absent, it is apparent that this situation occurred where the Ca level in treatment was generally four to sixteen-fold greater than the Mg or K level.

From the same data, the fact that no foliar disorders occurred at treatment levels of 8.0 me., 0.5 me., and 0.5 me. for Ca, Mg, and K respectively, and did occur where the level was 8.0 me. for all three cations, would indicate that cation balance in the nutrient solution and not absolute amounts was the critical feature from the standpoint of foliar symptomology.

The only magnesium deficiency as found in Phase I was the vari-colored inner leaf area which developed at the 0 me. Mg level. This was in partial

agreement with other workers who reported various shades of red and yellow, as well as chlorosis of interveinal areas (15, 29, 36, 52). No symptoms of Mg deficiency were apparent as such in Phase II even though their appearance was expected at least where the low Mg level accompanied the high Ca and K levels (Figure 13, A). The marginal scorch that developed at the highest Mg level in the first experiment is apparently similar to that reported by Davis et al. (15) as a condition of Mg toxicity.

In the first experiment reported herein, plants at 0 me. and 0.1 me. of K produced leaves that were necrotic at the margins and inwardly rolled; while at levels of 0.25 me. and 0.5 me. of K scorching and rolling of the margins occurred. These symptoms appear to be in agreement with those found by others (13, 15, 29, 36, 52). Davis et al. (15) reported, as a Ca excess symptom, a curling upwards and inwards of the leaf blades that resembled low K treatments. Comparison of the foliage at low K levels (Figure 8) with those at high Ca levels (Figure 4) would imply a similar situation. Thus, from the standpoint of foliar symptomology, disorders due to excess Ca in treatment greatly resemble disorders due to low K in treatment.

In the second of the experiments no foliar disorder occurred which could be attributed to K deficiency; even at low K levels relative to high levels of calcium and/or magnesium (Figures 14, 15). A possible explanation might be revealed in a comparison of the results of Iwakiri and Scott (29) with those of these experiments. They found the onset of deficiency symptoms to be in the following order of cations: Ca first, followed by Mg and then K. The foliar deficiency symptoms under Phase I of the present experiments occurred in the following order: K first, followed by Ca and Mg in that order. In the second phase of the experiment,

Ca deficiency symptoms occurred but no Mg or K deficiencies appeared during the course of the test. In their experiments where Ca was the first to show its deficiency effect, and K the last, Iwakiri and Scott (29) had used sodium in the nutrient solutions (Appendix Table 2). In the first experiment herein where a K deficiency disorder was the first to appear, no sodium had been used in the treatments. In the second experiment where Na was used to adjust the total concentration of cations, Ca deficiency symptoms were the first, and only, disorder to appear. Thus it would appear that sodium had an effect in either delaying or masking the foliar effects due to a K deficiency in the nutrient solution. This would suggest that the presence of Na in the nutrient solutions and in the plant material might have been responsible for the absence of K deficiency symptoms. It has been proposed that Na can replace K to a certain extent (17, 44, 50) and Lehr (33) has cautioned:

> It should be borne in mind that, for the estimation of sodium, it is necessary to work with a standard which differs from that used for most other nutritional elements. As far as we know, there are no distinct symptoms of sodium deficiency in plants unless certain symptoms considered up to now as exclusively due to potassium deficiency, are wholly or partially identical with symptoms of sodium deficiency.

Knight and Wallace (30) have reported a negative correlation between the K and Na content of the strawberry plant. The data of this experiment would indicate the same correlation. However, this has not been considered an effect of Na:K as such but rather an effect of the relative amounts available in the nutrient solution. That is, the strawberry plant is a sodium "accumulator." This situation will be discussed in more detail presently.

The dry weight data of Phase I (Table 7) is based on entire plants and there is little that is striking or unexpected about the effect of

nutrient level on the total dry weight of the plants. In all cases lowered dry weight values tended to occur at the extremes of treatment indicating that an excess or deficient amount of a cation was detrimental when compared to more median nutrient levels. It would appear that greater dry weight values as a group occurred where Mg was varied and this series also showed the greatest magnitude of response.

More specific comparison of the dry weight response of the three series of varied cations is complicated by the different K levels compared to the Mg and Ca levels. In Phase II where the levels were the same for the three cations such comparisons are more reliable. In addition to the total dry weight of the plant, the dry weight values of certain component parts are also available. These data are available for dormant plants at planting; plants after five weeks of conditioning prior to treatment; and plants at the termination of the experiment after ten weeks of treatment. The summarization in Appendix Table 5 is a simplified accounting of the data in Phase II RESULTS.

It can be seen that the mean dry weight of the plant and/or any of its component parts increased with an increase of the cation level (Appendix Table 5). Where Mg and K were the varied cations, the similarity between the dry weight values of a given plant fraction at a given level is striking. Also for both of these cations the response to the first increment of the cation was relatively small and in the case of the root fraction was ineffective in increasing the dry weight. The lowest and highest mean dry weights occurred respectively at the lowest and highest Ca levels. Thus the magnitude of the response was greatest where Ca was the cation varied in the nutrient solution. This was true for all plant fractions. It is also interesting to note that the increase in dry

weight of leaf blades at the low Ca level was five-fold greater than the dry weight of leaf blades of comparable plants at the beginning of treatments. The dry weight of roots at this same level showed an almost negligible increase. This latter situation is in agreement with Lineberry and Burkhart (36) who reported litle root growth at low Ca levels.

When comparing the dry weight data of Phase I (Table 7) with that of Phase II (Appendix Table 5) it is apparent that the values in the first experiment are noticeably lower than those in the second. Interesting comparisons between the two sets of final dry weight data might be made but these are avoided because their validity is qualified by the following facts: a difference in varieties for the two experiments; a difference in the initial size of plant before treatment; and a difference in the season and length of experiments (Appendix Table 1,2). Thus, the larger dry weight values of Phase II plants were due, disregarding any varietal differences, to several features of the experiment. First, larger plants were used initially and these plants were assumed to be more vigorous by virtue of their being virus-free. Secondly, these plants were given a longer recovery period between planting and the beginning of treatments and were maintained on the treatments for a two weeks' longer period. Thirdly, the plants were grown during the winter season when temperatures in the greenhouse were more easily maintained at favorable growing temperatures. Finally, the photoperiod treatment induced branched crown formation which conserved the growth of the plant rather than expending it in runner formation. These differences in experimental procedure and resultant effects on growth also complicate any comparisons of the mineral composition of the plants in the two experiments.

A comparison of the effect of treatment on the chemical composition of plants in the two experiments is complicated by experimental differences already outlined. Nevertheless, certain trends of response were similar to both experiments when these comparisons are on the basis of whole plants (Tables 10, 11, 12, 17, 18, 19, 74, 75). First, for all of the cations considered there was a significant response, as increased concentration and content, of a given cation when that cation was varied in treatment. Within similar ranges of varied cation in treatment for the two experiments, that is between 0.5 and 12 me./l., certain trends of response, expressed as concentration, in the plants are apparent. As the Ca level increased, the Ca concentration increased and the Mg concentration decreased. As the Mg level increased the Mg concentration increased and the Ca concentration decreased. As the K level in treatment increased, the K concentration increased and both the Ca and Mg concentrations decreased. The trends of K concentration where the Ca and Mg levels were varied were inconsistent in the two experiments (Tables 10, 11, 12, 74).

When comparing the effect of treatment on the cation content of the plants in Phases I and II (Tables 17, 18, 19, 75), in only one case does a similar response occur and that is a decreased Ca content when the K level, and content, increased. The results of other workers along these lines have already been presented in some detail in the LITERATURE REVIEW.

It is noteworthy that Iwakiri and Scott (29), stated that since the concentration of a nutrient element in the plant was closely related with the growth of the plant, the differences found among treatments were more widely apparent when measured by total uptake of an element than when measured by the concentration of the element. The data of this experiment are in partial agreement with this in that concentration of an element was

closely related with growth. However, for these experiments, the differences found among treatments were more apparent when measured in terms of concentration.

Certain of the cation composition data have been presented as content, in lieu of uptake, of the plant material because the latter term implies the total amount of cation taken up by the plant as a result of treatment. Even though the cation composition of initial plant material was available, final uptake values could not be accurately determined from this information since it would be based on comparable plant material and not the actual plant material on which final analyses were made. Thus the data on dormant and pretreatment plants is of interest only in that they serve as general reference points.

The effect of nutrient level on the cation composition of strawberry plant fractions has been summarized in Tables 74 and 75. These data reflect in a general way the trends of treatment already presented and are combined here to facilitate comparison and discussion of results within Phase II.

In Phase II the plants had been fractioned into component parts in an attempt to determine differences in the accumulation of a given cation by those parts. The possible diagnostic value of a pronounced accumulation of a given cation by a plant part was considered.

Comparing the final cation content of the various fractions, the greatest contents of Ca, Mg, and K all occurred in the leaf blade (Table 75). This is not surprising in view of the fact that the leaf blades also showed the greatest resultant dry weight (Appendix Table 5).

A consideration of concentration values presents a somewhat different picture. The data of Table 74 and the data giving the relative ratios of

the mean concentration of the cations in the plant parts (Tables 36, 43, and 50) indicated that the concentration of each of the cations was highest in the petiole. In general all of the plant parts showed the same trends of response already discussed for entire plants. Since the data (Table 74) showed that in general all of the plant fractions indicate the same trends of concentration, with the exception of the petiole in certain cases, any plant part could serve for analyses to indicate the mineral status of the plant with respect to trends of response. The petiole with its highest cation concentration might be the most desirable to analyze because of the greater amount of cation present. However, because of the discrepancies in agreement of trends exhibited by the petiole, this would make it undesirable. The next possibility would be the leaf blade, the concentration values of which are relatively high and the trends of which clearly approximate the results obtained with whole plants. However, to determine the mineral status of strawberry plants the more desirable approach would appear to be an analysis of entire plants. In situations when the plant cannot be expended, foliar analysis would be acceptable. This is in agreement with the conclusions of Lineberry and Burkhart (36).

In these experiments, if one accepts good vigor, absence foliar abnormalities, and greater dry weight as the criteria of good growth then the best level of treatment in Phase I was the one in which Ca-Mg-K were supplied at 4-2-2 me./l. respectively. In Phase II the better treatments levels, in general, were those in which Ca was supplied at 8 me./l. regardless of the levels of the other cations. In Phase II also, from the standpoint of the absence of foliar abnormalities, the two best nutrient solutions were those in which Ca-Mg-K were supplied at 2-.5-.5 and 8-.5-.5

me.1/. respectively (Table 23). Thus a high level of Ca in treatment appeared to be best for growth and a high level of Ca in treatment in relation to lower levels of Mg and K also appears to be desirable from the standpoint of foliar condition. Although the strawberry plants generally indicated a high calcium requirement, it is suggested that the requirement, as absolute amounts of Ca, is not necessarily high but is variable and depends upon the concommitant amounts of Mg and K that are also available. That is, strawberry plants can produce satisfactory growth with small amounts of available Ca if the accompanying levels of Mg and K are substantially lower. This would also reconcile the high Ca requirement as found in these tests with the low pH requirement in the field.

When the analyses of the plant material were considered in an attempt to associate plant condition with mineral content (Tables 36, 43, 50, 74) it is seen that the plant has taken up the cations in much different proportions than supplied. Balanced relationships, as concentration values, are difficult to detect and are confusing especially when attempting to correlate the data of both experimental phases with regard to the mineral status and plant condition.

It has been stressed previously that sodium was used as a neutral cation to provide a similar total cation level for all treatments. Although sodium was considered as neutral in its effect upon plants, its possible effect on foliar conditions in strawberry should be considered. No foliar disorder as found in this experiment was attributed to sodium since reference to Table 23 shows similar foliar abnormalities occurred regardless of sodium levels. The possible effect of sodium level in treatment on the dry weights of the plants presents a different aspect.

The design of this experiment was such that Na effects could not be

determined statistically. To illustrate certain trends that were suspected to be due to sodium level, mean dry weights for entire plants at each treatment level were summarized in Table 72.

The data show that the largest mean dry weight, 8.83 grams, occurred where there was no sodium in treatment; and the smallest dry weight, 3.35 grams, occurred at the highest Na level (22.5 me./liter). In general, the greater dry weights occurred where the Na levels were lower. There appears to be a "positive correlation" between the mean dry weight and the levels of Ca-Mg-K; and a "negative correlation" between Ca-Mg-K level, and therefore, mean dry weight, and the Na level. The Na to Ca-Mg-K relationship of treatment levels is artificial. However, the response of dry weight to this relationship is not. Stated more simply, the greater dry weights tended to occur at the higher concentration of the three cations (individually or in combination) and concomitantly at the lower concentrations of Na in treatment. This might suggest an effect of sodium level. However, referring again to Table 23 and selecting several Ca-Mg-K levels where the Na concentration was the same, e.g. at 13.5 me. Na/l., it appears that the increased dry weights were also closely associated with increased Ca levels. There is no one level of Na where a break in effect occurs and the general trend of increased dry weights accompanying decreased Na levels is a gradual transition. Although it is impossible to assign the above effects on the dry weight to a definite causal factor it would appear that any treatment condition that increased the Ca-Mg-K levels in treatment reduced the Na level and increased the resultant dry weight of the plants. It is again stressed that these were trends for which statistical analyses are not available.

The data of Table 72 give the mean concentrations of sodium in the

plant parts and the ratio of these concentrations to the concentration in the roots at the different nutrient levels. These data have been arranged in order of decreasing Na levels in treatment. It is seen that in general for all plant parts, the Na concentration tends to decrease gradually as the Na in the substrate is decreased. The highest relative Na concentration occurs in the root as indicated by the generally lower part:root ratio values of the other fractions. With decreasing Na in treatment the relative concentrations in the leaf blades and petioles decreased markedly. It is also seen that at the very highest Na levels a higher relative Na concentration occurred in the leaf blades and petioles than occurred in the roots; and at lower Na levels the higher relative concentrations occurred in the roots. This could be interpreted as meaning that, although sodium will be found in the leaves, most of the Na is accumulated in the roots and moves to the leaves in quantity only when the Na in the substrate is at a relatively high level. This is in agreement with the results of Hoagland and Snyder (27) who reported an accumulation of Na by leaves and roots with a marked accumulation of Na in injured strawberry leaves that had been grown at high Na levels.

Table 73 presents the mean content of sodium in the plant parts, and the per cent of the total content that it represents in that part. These data have been arranged in order of decreasing Na levels in treatment. It is seen that the total Na content and the Na content in each plant part decreased more or less progressively with decreased Na in treatment. However, the relative Na content, expressed as the per cent of total content, in the root tended to increase and that in the leaf blade to decrease as the Na in the treatment was decreased. The highest relative Na content occurred in the leaves when the Na level was high and the

highest relative content was in the roots when the Na content was low. The relative Na content of the crowns and petioles tended to remain fairly constant. This is essentially the same relationship that was found for the relative Na concentration in the plant parts. In its briefest sense this implied a sodium accumulation, expressed either as content or concentration, for the plant as a whole with the leaves receiving relatively greater quantities under conditions of excess sodium in the substrate. Thus it would appear that, under conditions of this experiment at least, the strawberry plant is a sodium "accumulator."

TABLE 72. Mean[a] Concentration of Sodium in Strawberry Plant Fractions and the Ratio of the Mean Concentration of These Fractions to the Mean Concentration in the Roots at the Different Nutrient Levels (PhaseII).

Treatment						Concentration (me./100g.)				Ratio (part:root)			
	Level (me./l.)												
No.	Na	Ca	Mg	K	Total[b]	Root	Crown	Petiole	Leaf	Root	Crown	Petiole	Leaf
1	22.5	.5	.5	.5	1.5	58.95	50.56	85.65	63.30	1	0.85	1.45	1.07
2	21.0	.5	.5	2	3.0	55.04	46.08	73.74	57.39	1	0.83	1.33	1.04
4	21.0	.5	2	.5	3.0	51.30	47.09	75.35	55.65	1	0.91	1.46	1.08
10	21.0	2	.5	.5	3.0	60.00	40.69	53.74	49.56	1	0.67	0.89	0.82
5	19.5	.5	2	2	4.5	50.87	43.17	52.74	47.39	1	0.84	1.03	0.93
11	19,5	2	.5	2	4.5	60.87	35.04	40.13	39.39	1	0.57	0.65	0.64
13	19.5	2	2	.5	4.5	60.13	42.61	37.52	41.43	1	0.70	0.62	0.68
14	18.0	2	2	2	6.0	54.13	38.39	43.61	39.82	1	0.64	0.73	0.67
3	15.0	.5	.5	8	9.0	50.56	28.82	35.65	22.08	1	0.57	0.70	0.53
7	15.0	.5	8	.5	9.0	42.61	38.39	44.17	38.95	1	0.90	1.03	0.91
19	15.0	8	.5	.5	9.0	53.04	31.56	34.78	26.34	1	0.59	0.65	0.49
6	13.5	.5	2	8	10.5	48.82	21.87	20.56	20.69	1	0.44	0.42	0.42
8	13.5	.5	8	2	10.5	41.30	30.56	28.69	28.08	1	0.74	0.69	0.68
12	13.5	2	.5	8	10.5	55.78	24.35	20.00	20.56	1	0.43	0.35	0.36
16	13.5	2	8	.5	10.5	50.43	24.04	15.91	14.17	1	0.47	0.31	0.28
20	13.5	8	.5	2	10.5	46.22	24.78	20.26	18.39	1	0.53	0.43	0.39
22	13.5	8	2	.5	10.5	54.35	30.56	28.82	17.65	1	0.56	0.53	0.32
15	12.0	2	2	8	12.0	51.30	21.13	14.78	15.78	1	0.41	0.28	0.30
17	12.0	2	8	2	12.0	44.78	30.00	24.61	18.26	1	0.60	0.54	0.40
23	12.0	8	2	2	12.0	44.78	19.69	19.13	13.16	1	0.43	0.42	0.30
9	7.5	.5	8	8	16.5	32.87	14.04	9.69	10.69	1	0.42	0.29	0.32
21	7.5	8	.5	8	16.5	22.00	10.87	6.95	8.52	1	0.49	0.31	0.38
25	7.5	8	8	.5	16.5	32.87	18.52	14.04	9.26	1	0.50	0.42	0.28
18	6.0	2	8	8	18.0	34.61	10.43	6.52	8.08	1	0.30	0.18	0.23
24	6.0	8	2	8	18.0	20.56	9.56	7.53	7.21	1	0.46	0.36	0.35
26	6.0	8	8	2	18.0	22.74	11.56	11.13	7.82	1	0.50	0.48	0.34
27	-	8	8	8	24.0	5.78	3.60	7.39	3.30	1	0.62	1.27	0.51
Dormant						6.1	6.1	6.9	6.5	1	1.00	1.13	1.06
Pretreatment[c]						21.3	6.9	6.9	4.7	1	0.03	0.03	0.02

[a]Mean of 9 plants

[b]Total of cations other than sodium

[c]Mean of 36 plants

TABLE 73. Mean[a] Dry Weight and Final Mean Content of Sodium, As Milliequivalents, in Strawberry Plants and the Per Cent of the Total Content Found in Each Plant Part (Phase II).

Treatment Level me./l.						Mean Dry Weight In	Plant Fraction								
							Root		Crown		Petiole		Leaf		Total
No.	Na	Ca	Mg	K	Total[b]	Grams	Content	%	Content	%	Content	%	Content	%	Content
1	22.5	.5	.5	.5	1.5	3.35	0.49	22.3	0.24	11.1	0.32	14.8	1.14	51.7	2.19
2	21.0	.5	.5	2	3.0	3.91	0.53	24.1	0.29	13.5	0.29	13.5	1.08	48.9	2.19
4	21.0	.5	2	.5	3.0	4.36	0.53	22.1	0.31	13.1	0.37	15.6	1.18	49.2	2.39
10	21.0	2	.5	.5	3.0	5.23	0.68	26.1	0.22	8.7	0.36	13.8	1.34	51.3	2.60
5	19.5	.5	2	2	4.5	4.03	0.39	20.4	0.29	15.5	0.26	13.6	0.97	50.4	1.91
11	19.5	2	.5	2	4.5	5.75	0.77	30.8	0.28	11.3	0.30	11.9	1.15	45.9	2.50
13	19.5	2	2	.5	4.5	5.41	0.65	26.6	0.32	13.5	0.29	12.1	1.16	47.8	2.42
14	18.0	2	2	2	6.0	5.79	0.59	23.8	0.34	13.8	0.35	14.1	1.21	48.3	2.49
3	15.0	.5	.5	8	9.0	5.95	0.68	34.5	0.24	12.4	0.25	13.1	0.79	40.1	1.93
7	15.0	.5	8	.5	9.0	5.13	0.46	22.4	0.35	17.1	0.29	14.1	0.96	46.4	2.06
19	15.0	8	.5	.5	9.0	7.90	0.99	36.3	0.34	12.5	0.35	12.9	1.04	38.2	2.72
6	13.5	.5	2	8	10.5	6.33	0.64	38.2	0.24	14.3	0.18	10.9	0.61	36.4	1.67
8	13.5	.5	8	2	10.5	6.37	0.49	27.3	0.29	19.1	0.24	13.3	0.78	43.2	1.80
12	13.5	2	.5	8	10.5	6.95	0.86	42.8	0.23	11.6	0.19	9.4	0.72	36.2	2.0
16	13.5	2	8	.5	10.5	7.24	0.72	43.4	0.23	13.7	0.19	10.9	0.55	31.9	1.71
20	13.5	8	.5	2	10.5	8.0	0.92	43.0	0.28	13.0	0.19	8.9	0.75	34.9	2.14
22	13.5	8	2	.5	10.5	7.57	0.64	32.7	0.30	15.6	0.30	15.7	0.69	35.8	1.93
15	12.0	2	2	8	12.0	7.68	0.78	43.6	0.22	12.4	0.15	8.8	0.63	35.4	1.78
17	12.0	2	8	2	12.0	7.32	0.61	32.3	0.29	15.4	0.29	15.3	0.70	36.8	1.89
23	12.0	8	2	2	12.0	7.94	0.79	44.8	0.22	12.5	0.20	11.5	0.54	31.1	1.75
9	7.5	.5	8	8	16.5	6.37	0.44	43.6	0.15	14.9	0.09	9.3	0.32	32.2	1.0
21	7.5	8	.5	8	16.5	7.33	0.34	40.5	0.11	13.7	0.06	8.1	0.31	36.7	0.82
25	7.5	8	8	.5	16.5	8.29	0.49	38.3	0.24	18.5	0.16	12.5	0.39	30.7	1.28
18	6.0	2	8	8	18.0	7.70	0.51	54.7	0.10	11.5	0.07	7.9	0.24	25.7	0.92
24	6.0	8	2	8	18.0	8.34	0.37	43.0	0.11	12.9	0.08	9.4	0.30	34.6	0.86
26	6.0	8	8	2	18.0	7.60	0.33	39.3	0.12	13.9	0.08	10.3	0.31	36.4	0.84
27	0.0	8	8	8	24.0	8.83	0.09	28.2	0.04	12.8	0.05	15.4	0.15	43.5	0.33
Dormant							0.04	36.3	0.02	18.1	0.02	18.1	0.03	27.2	0.11
Pretreatment[c]							0.22	75.8	0.04	13.7	0.01	3.4	0.02	6.8	0.29

[a]Mean of 9 plants
[b]Total of cations other than sodium
[c]Mean of 36 plants

TABLE 74. Final Mean[a] Cation Concentration in Strawberry Plant Fractions, As Main Effects, of Three Levels of Calcium, Magnesium, and Potassium (Phase II).

Treatment		Milliequivalents Per 100 Grams of Dry Weight																			
		Calcium Concentration					Magnesium Concentration					Potassium Concentration					Sodium Concentration				
Cation	me./l.	Root	Crown	Petiole	Leaf	Whole	Root	Crown	Petiole	Leaf	Whole	Root	Crown	Petiole	Leaf	Whole	Root	Crown	Petiole	Leaf	Whole
	0.5	15.45	22.80	23.40	16.75	18.25	34.54	37.17	38.49	26.64	32.24	18.38	22.93	86.77	44.44	40.68	48.04	35.61	47.34	38.78	41.13
Ca	2	17.50	28.65	31.35	25.10	24.85	32.65	38.32	38.32	25.82	30.84	20.86	24.13	89.65	47.84	42.34	53.04	29.61	29.65	27.43	32.91
	8	33.15	44.95	58.85	54.10	49.95	29.61	41.70	38.49	22.94	28.95	23.14	24.59	78.58	47.58	43.52	33.56	17.87	16.65	12.47	18.52
	0.5	23.20	35.40	43.75	32.30	32.30	21.63	26.56	22.12	13.32	18.67	19.53	22.85	84.91	48.27	41.55	51.39	32.52	41.22	34.52	38.34
Mg	2	23.10	33.70	41.50	33.30	32.40	26.32	33.64	33.14	19.24	24.92	20.07	23.70	86.01	46.02	41.47	49.00	30.43	34.30	28.78	33.74
	8	19.90	27.35	28.30	31.65	28.40	48.85	55.85	60.12	42.85	48.44	22.78	25.10	84.17	45.56	43.49	34.26	20.13	18.17	15.39	27.69
	0.5	22.35	34.35	43.65	36.00	34.10	33.80	36.84	43.42	27.55	32.65	11.50	16.44	56.79	32.32	28.79	51.52	36.06	43.00	35.13	38.91
K	2	22.00	33.75	39.60	37.30	31.55	32.73	38.24	38.98	25.25	31.01	16.67	20.30	79.47	41.93	38.53	47.30	31.04	34.87	30.00	34.39
	8	22.00	28.35	30.30	36.35	27.50	30.27	40.96	32.98	22.61	28.37	34.23	34.90	116.03	65.63	59.19	35.82	16.08	14.34	13.56	19.26
Dormant		12.3	25.6	37.0	24.7	20.2	30.4	30.4	35.4	23.0	27.9	39.9	16.1	76.7	39.9	38.1	6.1	6.1	6.9	6.5	6.5
Pretreatment[b]		14.3	30.6	33.6	25.2	22.7	24.7	46.0	27.1	28.5	23.0	21.9	14.6	55.2	37.1	25.8	21.3	6.9	6.9	4.7	10.8

[a]Mean of 9 plants

[b]Mean of 36 plants

TABLE 75. Final Mean[a] Cation Content Per Plant in Strawberry Plant Fractions, As Main Effects, of Three Levels of Calcium, Magnesium, and Potassium (Phase II).

Treatment		Milliequivalents Per Plant																				
		Calcium Content					Magnesium Content			Potassium Content							Sodium Content				
Cation	me./l.	Root	Crown	Petiole	Leaf	Whole	Root	Crown	Petiole	Leaf	Whole	Root	Crown	Petiole	Leaf	Whole	Root	Crown	Petiole	Leaf	Whole
Ca	0.5	0.16	0.17	0.14	0.40	0.89	0.40	0.33	0.29	0.68	1.69	0.31	0.20	0.61	1.15	2.17	0.52	0.27	0.26	0.87	1.92
	2	0.23	0.25	0.27	0.82	1.59	0.43	0.36	0.37	0.93	2.12	0.29	0.22	0.85	1.67	2.89	0.69	0.26	0.25	0.85	2.04
	8	0.55	0.50	0.62	2.27	3.97	0.48	0.46	0.41	0.96	2.34	0.38	0.27	0.85	1.95	3.48	0.58	0.19	0.17	0.50	1.46
Mg	0.5	0.33	0.31	0.36	1.09	2.11	0.28	0.24	0.17	0.41	1.12	0.27	0.20	0.68	1.52	2.61	0.69	0.26	0.26	0.93	2.12
	2	0.33	0.32	0.37	1.17	2.22	0.35	0.33	0.28	0.62	1.58	0.28	0.23	0.75	1.56	2.75	0.62	0.27	0.25	0.81	1.95
	8	0.28	0.29	0.30	1.23	2.11	0.69	0.59	0.61	1.54	3.45	0.33	0.27	0.87	1.69	3.17	0.46	0.20	0.17	0.50	1.36
K	0.5	0.30	0.31	0.36	1.24	2.24	0.43	0.35	0.36	0.89	2.07	0.16	0.14	0.45	1.03	1.79	0.65	0.30	0.29	0.94	2.13
	2	0.29	0.32	0.36	1.14	2.12	0.41	0.36	0.36	0.83	1.98	0.22	0.18	0.66	1.35	2.43	0.60	0.27	0.25	0.83	1.97
	8	0.34	0.30	0.31	1.11	2.08	0.44	0.44	0.35	0.85	2.11	0.52	0.37	1.20	2.48	4.32	0.52	0.16	0.13	0.45	1.33
Dormant		0.09	0.08	0.05	0.15	0.38	0.23	0.10	0.05	0.14	0.52	0.30	0.05	0.11	0.24	0.71	0.04	0.02	0.01	0.03	0.11
Pretreatment[b]		0.15	0.20	0.08	0.13	0.57	0.26	0.14	0.05	0.10	0.56	0.23	0.10	0.13	0.19	0.64	0.22	0.04	0.01	0.02	0.23

[a]Mean of 9 plants

[b]Mean of 36 plants

TABLE 76. Final Mean[a] Cation Concentration in Strawberry Plants, As Main Effects, of Three Levels of Calcium, Magnesium, and Potassium (Phase II).

Treatment			Concentration		
Cation	me./l.	Unit	Ca	Mg	K
	0.5	mgs./gm.	3.65	3.92	15.91
		me./100gms.	18.25	32.24	40.68
Ca	2	mgs./gm.	4.97	3.75	16.56
		me./100gms.	24.85	30.84	42.34
	8	mgs./gm.	9.99	3.52	17.02
		me./100gms.	49.95	28.95	43.52
	0.5	mgs./gm.	6.46	2.27	16.25
		me./100gms.	32.30	18.67	41.55
Mg	2	mgs./gm.	6.48	3.03	16.22
		me./100gms.	32.40	24.92	41.47
	8	mgs./gm.	5.68	5.89	17.01
		me./100gms.	28.40	48.44	43.49
	0.5	mgs./gm.	6.82	3.97	11.26
		me./100gms.	34.10	32.65	28.79
K	2	mgs./gm.	6.31	3.77	15.07
		me./100gms.	31.55	31.01	38.53
	8	mgs./gm.	5.50	3.45	23.15
		me./100gms.	27.50	28.37	59.19

[a]Mean of 9 plants

SUMMARY AND CONCLUSIONS

Strawberry plants were grown in sand culture to (a) establish a symptomology for conditions ranging from deficient to toxic amounts of calcium, magnesium and potassium in the nutrient media; (b) correlate this symptomology with the mineral content of the plant or its parts; and (c) study the interrelationships of the effects of these cations. To accomplish these objectives, experiments were conducted in two phases utilizing different experimental techniques.

Phase I. The variety Temple was used. This experiment was conducted to establish a symptomology for conditions ranging from deficient to toxic amounts of Ca, Mg, and K in the nutrient media. To accomplish this two of these cations were maintained at a constant optimum level while the third was varied through seven levels from o me./l. to 25 me./liter. The optimum cation levels selected were as follows: calcium, 4 me./l.; magnesium, 2 me./l.; and potassium, 2 me./liter.

1. Plants developed normal appearing foliage at the following treatment levels: calcium, 2 me./l. and 4 me./l.; magnesium, 2 me./l. and 4 me./l.; and potassium, 2 me./liter. This is in agreement with the selected optimum levels on which the treatments in this experiment were based.
2. The onset of abnormal foliar symptoms at the lower levels of the variable cation in treatment occurred for potassium, magnesium, and calcium, in that order. At high levels, calcium caused the earliest disturbance followed by magnesium and potassium in that order.

3. Low levels of calcium produced plants with leaf blades having small purple dot-like areas along the veins. At the toxic levels, the leaf margins were dried and curled inward. Plant analyses showed that as the calcium in the treatment increased the calcium concentration in the plant increased; the magnesium concentration decreased; and the potassium concentration remained relatively constant. With the exception of the treatment receiving no calcium, the larger dry weights occurred at the lower nutrient levels of calcium.
4. Leaf blades of plants receiving low magnesium showed interveinal bronzing and browning of the serrations. At high levels of magnesium the leaf margins were scorched. Plant analyses showed that as magnesium was increased in the treatment the concentration of magnesium in the plant increased but the calcium and potassium concentrations decreased. At the extreme levels of treatment lowered dry weights reflected the influence of treatment.
5. Low nutrient levels of potassium produced plants having leaf blades that were scorched and rolled inward at the margins. Leaf blades at the higher levels showed only a slight purpling of the serrations. Plant analyses showed that as potassium increased in the nutrient solutions the potassium concentration in the plant increased and the calcium and magnesium concentrations decreased. Dry weights were lower at the extreme levels of K in treatment.
6. The content of the three cations in the plant resulted in essentially the same trends as were indicated for concentrations of the ions in the plant material. However, the content values were less

sensitive in reflecting variations in treatment than were the corresponding concentration values.

7. The results of Phase I satisfied the intended objective to establish a symptomology for conditions ranging from deficient to toxic amounts of the cations in the nutrient media and facilitated the selection of the levels of each cation for the factorial experiment in Phase II.

Phase II. The purpose of this experiment was to determine the effects and interrelationships of low, median, and high levels of Ca, Mg, and K on the vegetative growth of strawberry plants. Virus-free plants of the variety Tennessee Beauty were used and maintained as vegetative by photoperiod control. A 3 x 3 x 3 factorially designed experiment was used with 3 replications. The concentration levels adopted were the same for the three ions and were as follows: low, 0.5 me./l.; median, 2 me./l.; and high, 8 me./l. of nutrient solution. The selection of these three levels was based primarily upon the vegetative symptoms of deficiency and toxicity found in Phase I.

By employing sodium as a neutral cation, the total cation concentration level in treatment was maintained at 24 me./l. which was the solution concentration when all of the cations were supplied simultaneously at their high levels. Anions used were each supplied at a constant level for all treatments.

To determine any effects of treatment on the dry weight and mineral composition of certain plant parts, the plants were fractioned into roots, crowns, petioles, and leaf blades for analyses.

1. The following foliar disorders were associated with low Ca levels regardless of Mg and K levels in treatment; necrosis of the tips

of young unexpanded leaf blades which became crimped at later stages; purple blotching of the veins of the leaf blade; and purple blotching and streaking of the petiole followed by the eventual necrosis and collapse of the petiole at the base of the leaf blade. The above foliar conditions were considered to be calcium deficiency symptoms. The blotching of the veins was the only Ca deficiency symptom common to both experiments.

2. No foliar symptoms attributable to Mg or K deficiency were observed.

3. No effect due to toxic cation levels as such is given. Toxicities if present were associated with high treatment levels of Mg and/or K in relation to Ca levels and these have been interpreted as Ca deficiency symptoms.

4. The mean dry weight of the plant and/or any of its component parts increased with an increase of the cation level. Where Mg and K were the varied cations, there was a striking similarity between dry weight values for a given plant fraction at a given Mg and K level. For both of these cations the response to the first increment of the cation in treatment was relatively small. The magnitude of response in all plant fractions was greatest where Ca was the cation varied.

5. There was a significant response reflected as increased concentration and content, for each of the cations when the given cation was varied in treatment. Nutrient interrelationships were evident as follows: as the Ca level in treatment increased, K concentration increased and the Mg concentration decreased; as the Mg level in treatment increased the Ca concentration decreased; and

as the K level in treatment increased, both the Ca and Mg concentrations decreased. The trends of K concentration at different Ca and Mg levels varied somewhat with the plant part considered.

6. Attempts to associate plant condition with mineral content remains unestablished, and balanced relationships in terms of concentration values were difficult to detect.
7. The greatest contents of Ca, Mg, and K occurred in the leaf blade which also produced the greatest dry weight values. The greatest concentration of each of these cations occurred in the petioles. In general, all of the plant parts showed the same trends of response found for entire plants. The results indicate that to determine the mineral status of strawberry plants analysis of entire plants proved desirable but in situations when the plant cannot be expended, foliar analysis would be acceptable.
8. A high level of Ca in treatment appeared to be best for growth and a high level of Ca in treatment in relation to lower levels of Mg and K also appeared to be desirable from the standpoint of foliar condition. The best treatment levels with respect to plant vigor, foliar conditions, and greater dry weights occurred at the high Ca level regardless of the levels of the other cations. From the standpoint of the absence of foliar abnormalities, the two best nutrient solutions were those in which Ca-Mg-K were supplied at 2-.5-.5 and 8-.5-.5 me./l. respectively.
9. The possibility that sodium, used as a neutral cation, might have an effect on plant condition was considered. No foliar disorder as occurring in this experiment was attributed to sodium. The

effect of Na on dry weight remains uncertain. At the high levels of sodium in treatment the Na concentration in the plant material approached the levels of the other cations. Evidently under the conditions of this experiment the strawberry plant is a sodium "accumulator."

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APPENDIX

APPENDIX TABLE I. CHRONOLOGICAL REVIEW OF SAND CULTURE STUDIES WITH STRAWBERRIES: EXPERIMENTAL FEATURES

INVESTIGATOR	DATE[a]	NATURE OF EXPERIMENT[b]	VARIETY	FACILITIES	CULTURAL MEDIUM	LENGTH OF EXPERIMENT	SEASON	GIVEN APPLIED NUTRIENT SOLUTION		
								CONCENTRATION	pH	RATE OF APPLICATION
WALLACE	1925	A	ROYAL SOVEREIGN	LEAN-TO SHED	QUARTZ SAND	4 YEARS	ALL	P. P. M.	6.4-6.6	MAINTAIN MOISTURE AT 20% OF DRY WT. OF SAND IN 6" POT
MORRIS-CRIST	1927	B	PREMIER	GREENHOUSE	WATER CULTURE	a) 5 WEEKS b) 4 WEEKS	SUMMER	MOLAR	a) 3.6-7.5 b) 3.0-9.0	CHANGED WEEKLY (QUART JARS & 3-GALLON JARS)
DAVIS-HILL	1928	A	.....	COLD FRAME	GROUND SANDSTONE	1 YEAR	ALL	PER CENT	.....	400 C.C. / 5" POT / WEEK
DAVIS-HILL	1928	A	.....	.....	GROUND SANDSTONE	1 YEAR	ALL	GRAMS SALT / 4000 C.C. H_2O	.....	200 C.C. / 5" POT / WEEK
WALTMAN	1931	B	MASTODON	GREENHOUSE	GLASS SAND	a) 8 WEEKS b) 10 WEEKS	a) SUMMER b) WINTER	P. P. M.	3.0-9.0	150 C.C. / DAY PERCOLATED THROUGH INVERTED ORDINARY ACID BOTTLES
CLARK	1933	B	HOWARD 17	GREENHOUSE	QUARTZ SAND	6 WEEKS	FALL	MOLAR	3.0-9.0	6 LITERS THROUGH 3-GALLON CROCK EVERY 12 HRS.
HOAGLAND-SNYDER	1933	A	KLONDIKE BANNER NICH OHMER	GREENHOUSE	WATER CULTURE.	a) 6-8 WEEKS b)	a) ..... b)	MOLAR	a) ..... b) 7.3-8.2	SOLUTION IN 45-LITER TANK "CHANGED ONCE OR TWICE DURING THE EXPERIMENT"
DAVIS et al	1934	A	PARSONS' BEAUTY	.....	GROUND SANDSTONE	3 YEARS	ALL	P.P.M.	.....	200 C.C. / 6" POT / WEEK
CLARK	1941	A, B	HOWARD 17	GREENHOUSE	QUARTZ SAND	a) 14 WEEKS b) 5 WEEKS	a) FALL b) FALL	MOLAR	a) ..... b) 3.4-6.4	a) 1 LITER THROUGH 12" POT EVERY 20 HRS. b) 12 LITERS THROUGH 3-GALLON JAR EVERY 24 HRS.
LINEBERRY-BURKHART	1943	A	KLONDIKE BLAKEMORE	GREENHOUSE	QUARTZ SAND	8 WEEKS	WINTER	MOLAR	5.6	"APPLIED DAILY" TO 2-GALLON CROCK
GILBERT	1950	A	SPARKLE	GREENHOUSE	QUARTZ SAND	a) 10 WEEKS b) 10 WEEKS	a) WINTER b) SPRING	MOLAR AND P.P.M.	.....	2-GALLON CROCK FLUSHED DAILY WITH 600 C.C.
IWAKIRI-SCOTT	1951	A	TEMPLE	GREENHOUSE	QUARTZ SAND	12 WEEKS	FALL-WINTER	P. P. M.	5.0-6.0	1 PINT / 2-GALLON CROCK DAILY
PIRINGER	1949[c]	A	TEMPLE	GREENHOUSE	QUARTZ SAND	8 WEEKS	SPRING-SUMMER	M.E. / L.	5.0-6.0	500 ML. / 2-GALLON CROCK EVERY 3 RD. DAY
PIRINGER	1952[c]	A	TENNESSEE BEAUTY	GREENHOUSE	QUARTZ SAND	10 WEEKS	WINTER	M.E. / L.	4.8-5.2	500 ML. / 2-GALLON CROCK EVERY 3 RD. DAY

a DATE OF PUBLICATION - SEE BIBLIOGRAPHY

b A indicates a mineral nutrition study
B indicates a p^H study

c UNPUBLISHED CURRENT RESEARCH

APPENDIX TABLE 2 - CHRONOLOGICAL REVIEW OF SAND CULTURE STUDIES WITH STRAWBERRY: CHEMICAL COMPOUNDS UTILIZED IN NUTRIENT SOLUTIONS IN ALL PHASES OF EXPERIMENTS

INVESTIGATOR	DATE[a]	SALTS							MISCELLANEOUS[b]
		CALCIUM	MAGNESIUM	POTASSIUM	AMMONIUM	SODIUM	IRON	MICROELEMENTS	
WALLACE	1925	$CaSO_4$	$MgSO_4 \cdot 7H_2O$	KNO_3 K_2HPO_4	.....	$NaNO_3$ $NaCl$	$FeCl_3$	.....	.....
MORRIS-CRIST	1927	$Ca(NO_3)_2$	$MgSO_4$	KH_2PO_4 K_2HPO_4	.....	$NaCl$	FERRIC CITRATE FERRIC TARTRATE	.....	$NaOH$ H_3PO_4 HCl
DAVIS-HILL	1928 A	$Ca(NO_3)_2 \cdot 4H_2O$ $CaSO_4 \cdot 2H_2O$ $Ca(OH)$	$Mg(NO_3)_2 \cdot 6H_2O$ $MgSO_4 \cdot 7H_2O$	KNO_3 KCl KH_2PO_4	NH_4NO_3	$NaCl$	.....	.....	.....
DAVIS-HILL	1928 B	$Ca(OH)$ $Ca(H_2PO_4)_2$	$MgSO_4 \cdot 7H_2O$	KH_2PO_4 KCl	NH_4NO_3	$NaCl$	.....	.....	.. ..
WALTMAN	1931	$CaCl_2 \cdot H_2O$	$MgSO_4 \cdot 7H_2O$	KH_2PO_4 KCl	NH_4NO_3	.....	FERRIC CITRATE FERRIC TARTRATE $FeCl_3$	.....	$NaOH$ ACETIC ACID
CLARK	1933	$CaCl_2$ $Ca(NO_3)_2$	$MgSO_4 \cdot 7H_2O$	KH_2PO_4	$(NH_4)_2SO_4$	.....	$FeSO_4 \cdot 7H_2O$	$MnSO_4$ H_3BO_3	KOH H_2SO_4
HOAGLAND-SNYDER	1933	$Ca(NO_3)_2$	$MgSO_4$	KNO_3 KH_2PO_4	.....	$NaCl$ Na_2SO_4	FERRIC TARTRATE	SUPPLEMENTARY SOLUTION[d]	.....
DAVIS ET AL	1934	$CaCl_2$	$MgSO_4 \cdot 7H_2O$ $Mg(NO_3)_2 \cdot 6H_2O$	KCl KNO_3 $KH\ PO$	NH_4NO_3 $NH_4H_2PO_4$	.....	.....	.....	.....
CLARK	1941	$CaCl_2$ $Ca(NO_3)_2$	$MgSO_4 \cdot 7H_2O$	KH_2PO_4	$(NH_4)_2SO_4$	.....	$FeSO_4 \cdot 7H_2O$	$MnSO_4$ H_3BO_3	KOH H_2SO_4
LINEBERRY-BURKHART	1943	$Ca(NO_3)_2$ $CaSO_4$	$MgSO_4$ $Mg(NO_3)_2$	KH_2PO_4 K_2SO_4	NH_4NO_3	Na_2SO_4 NaH_2PO_4 $NaNO_3$	Fe[c]	Mn, Zn, Cu, AND B	.....
GILBERT	1948	$Ca(NO_3)_2$ $CaCl_2$	$MgSO_4$ $Mg(NO_3)_2$	KH_2PO_4 KNO_3	.....	.....	$FeSO_4 \cdot 7H_2O$	$MnSO_4$ $ZnSO_4$	.....
IWAKIRI-SCOTT	1951	$CaCl_2$	$MgSO_4$	KH_2PO_4 KNO_3	$(NH_4)_2SO_4$ NH_4NO_3 $NH_4H_2PO_4$	$NaNO_3$	FERRIC CITRATE	HOAGLAND SOLUTION A[d]	.....
PIRINGER	1949*	$Ca(NO_3)_2 \cdot 4H_2O$ $CaCl_2 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$ $MgCl_2 \cdot 6H_2O$ $Mg(NO_3)_2 \cdot 6H_2O$	KH_2PO_4 KNO_3 K_2SO_4 KCl	.....	.....	FERRIC CITRATE	HOAGLAND SOLUTION A[d]	.....
PIRINGER	1952*	DO	DO	DO	.....	$Na_2SO_4 \cdot 10H_2O$ $NaH_2PO_4 \cdot 12H_2O$ $NaNO_3$ $NaCl$	DO	DO	.....

[a] DATE OF PUBLICATION: SEE BIBLIOGRAPHY
[b] TO CONTROL pH
[c] SALTS NOT GIVEN
[d] A GENERAL SUPPLEMENTARY SOLUTION CONTAINING $Al, I, Br, Ti, Sn, Li, Mn, B, Zn, Cu, Ni$, AND Co
* UNPUBLISHED CURRENT RESEARCH

APPENDIX TABLE 3 - CHRONOLOGICAL REVIEW OF SAND CULTURE STUDIES WITH STRAWBERRY THE COMPLETE NUTRIENT SOLUTIONS[a]

INVESTIGATOR	DATE[b]	ION CONCENTRATION OF APPLIED NUTRIENT SOLUTIONS EXPRESSED AS PARTS PER MILLION													
		CATIONS							ANIONS						
		C_A	M_G	K	NH_4	N_A	F_E	TOTAL	NO_3	H_2PO_4	HPO_4	SO_4	C_L	OH	TOTAL
WALLACE	1925	29	10	122	.....	175	14	350	487	.....	55	109	87	.....	738
MORRIS-GRIST	1927	40	7	391	.....	7	c	445	124	776	96	28	11	.....	1035
DAVIS-HILL	1928 A	49	6	25	.....	.....	.....	80	181	41	.....	12	.....	.....	234
DAVIS-HILL	1928 B	98	14	50	19	.....	.....	181	50	82	.....	56	15	83	286
WALTMAN	1931	97	14	61	155	.....	c	327	534	111	.....	56	187	.....	888
CLARK	1933	433	104	86	.....	.....	c,d	623	1339	213	.....	413	.....	.....	1965
HOAGLAND-SNYDER	1933	201	49	235	.....	.....	c,d	485	931	97	.....	191	.....	.....	1219
DAVIS ET AL	1934	97	14	50	146	.....	.....	307	503	82	.....	56	187	.....	828
CLARK	1941	433	104	86	.....	.....	c,d	623	1339	213	.....	413	.....	.....	1965
LINEBERRY-BURKHART	1943	160	49	78	18	.....	c,d	305	558	194	.....	191	.....	.....	943
GILBERT	1948	100	48	194	.....	.....	c,d	342	496	49	.....	192	53	.....	790
IWAKIRI-SCOTT	1951	97	14	63	125	74	c,d	373	631	156	.....	55	172	.....	1014
PIRINGER	1949[f]	80	24	78	.....	.....	c,d	182	124	97	.....	48	142	.....	411
PIRINGER	1952[f]	40[e]	24[e]	78[e]	.....	414	c,d	556	310	97	.....	240	462	.....	1109

a VALUES RECALCULATED IN WHOLE OR IN PART FROM ORIGINAL INFORMATION
b DATE OF PUBLICATION AND REPERENCE
c IRON ADDED: SEE APPERDIX TABLE 2
d MINOR ELEMENTS ADDED: SEE APPENDIX TABLE 2
e MEDIAN LEVEL IN A 3X3X3 FACTORIAL EXPERIMENT
f UNPUBLISHED CURRENT RESEARCH

APPENDIX TABLE 3 (CON'T.) CHRONOLOGICAL REVIEW OF SAND CULTURE STUDIES WITH STRAWBERRY THE COMPLETE NUTRIENT SOLUTIONS[a]

INVESTIGATOR	DATE[b]	ION CONCENTRATION OF APPLIED NUTRIENT SOLUTIONS EXPRESSED AS MILLIEQUIVALENTS PER LITER													
		CATIONS							ANIONS						
		C_A	M_G	K	NH_4	N_A	F_E	TOTAL	NO_3	H_2PO_4	HPO_4	SO_4	C_L	OH	TOTAL
WALLACE	1925	1.5	0.8	3.1	.....	7.6	0.7	13.7	7.9	.....	1.1	2.3	2.4	.....	13.7
MORRIS-GRIST	1927	2.0	0.6	10.0	.....	0.3	c	12.9	2.0	8.0	2.0	0.6	0.3	.....	12.9
DAVIS-HILL	1928 A	2.5	0.5	0.6	.....	.....	.....	3.6	2.9	0.4	.....	0.3	.....	.....	3.6
DAVIS-HILL	1928 B	4.9	1.2	1.3	1.0	.....	.....	8.4	1.0	0.8	.....	1.2	0.4	4.9	8.3
WALTMAN	1931	4.8	1.2	1.6	8.6	.....	c	16.2	8.6	1.1	.....	1.2	5.3	.....	16.2
CLARK	1933	21.6	8.6	2.2	.....	.....	c,d	32.4	21.6	2.2	.....	8.6	.....	.....	32.4
HOAGLAND-SNYDER	1933	10.0	4.0	6.0	.....	.....	c,d	20.0	15.0	1.0	.....	4.0	.....	.....	20.0
DAVIS ET AL	1934	4.8	1.2	1.3	8.1	.....	.....	15.4	8.1	0.8	.....	1.2	5.3	.....	15.4
CLARK	1941	21.6	8.6	2.2	.....	.....	c,d	32.4	21.6	2.2	.....	8.6	.....	.....	32.4
LINEBERRY-BURKHART	1943	8.0	4.0	2.0	1.0	.....	c,d	15.0	9.0	2.0	.....	4.0	.....	.....	15.0
GILBERT	1948	5.0	4.0	5.0	.....	.....	c,d	14.0	8.0	0.5	.....	4.0	1.5	.....	14.0
IWAKIRI-SCOTT	1951	4.8	1.2	1.6	7.0	3.2	c,d	17.8	10.2	1.6	.....	1.2	4.8	.....	17.8
PIRINGER	1949[f]	4.0	2.0	2.0	.....	.....	c,d	8.0	2.0	1.0	.....	1.0	4.0	.....	8.0
PIRINGER	1952[f]	2.0[e]	2.0[e]	2.0[e]	.....	18.0	c,d	24.0	5.0	1.0	.....	5.0	13.0	.....	24.0

a VALUES RECALCULATED IN WHOLE OR IN PART FROM ORIGINAL INFORMATION
b DATE OF PUBLICATION AND REFERENCE
c IRON ADDED: SEE APPENDIX TABLE 2
d MINOR ELEMENTS ADDED: SEE APPENDIX TABLE 2
e MEDIAN LEVEL IN A 3X3X3 FACTORIAL EXPERIMENT
f UNPUBLISHED CURRENT RESEARCH

APPENDIX TABLE 4. The Mean[a] Dry Weight and Cation Composition of Dormant Strawberry Plants at the Beginning of Experimentation (Phase I).

	Mineral Composition							
	Concentration				Total Content			
Dry Weight	Unit	Ca	Mg	K	Unit	Ca	Mg	K
0.98 gms.	mgs./gm.	3.2	0.21	6.9	mgs.	3.13	0.20	6.7
	me./100gm.	15.9	1.72	17.64	me.	0.15	.017	0.17

[a]Mean of fifty plants

APPENDIX TABLE 5. Initial and Final Mean[a] Dry Weight of Strawberry Plant Fractions, in Grams, at Different Levels of Cation in Treatment (Phase II).

Treatment		Plant Fraction				
Cation	me./l.	Roots	Crown	Petiole	Leaf	Entire
	0.5	1.10	0.83	0.65	2.45	5.03
	2	1.32	0.92	0.92	3.39	6.55
Ca	8	1.66	1.12	1.07	4.11	7.96
	0.5	1.34	0.87	0.78	3.05	6.04
Mg	2	1.33	0.94	0.84	3.26	6.37
	8	1.41	1.06	1.02	3.63	7.12
	0.5	1.29	0.88	0.79	3.09	6.05
K	2	1.27	0.92	0.85	3.18	6.22
	8	1.51	1.07	1.00	3.67	7.25
Dormant		0.77	0.34	0.14	0.62	1.87
Pretreatment[b]		1.05	0.66	0.24	0.53	2.48

[a]Mean of 9 plants
[b]Mean of 36 plants

APPENDIX TABLE 6. Interaction of Treatment Level and Length of Treatment on Mean[a] Concentration of Calcium When Potassium Was Varied in Nutrient Solution (Phase I).

Treatment me./l. Potassium	Unit	Length of Treatment in Weeks 4	6	8
0	mgs./gm.	5.56	5.66	5.04
	me./100gm.	27.80	28.30	25.20
0.1	mgs./gm.	5.90	5.92	5.26
	me./100gm.	29.50	29.60	26.30
0.25	mgs./gm.	7.54	5.88	5.18
	me./100gm.	37.70	29.40	25.90
0.5	mgs./gm.	5.22	5.70	4.92
	me./100gm.	26.10	28.50	24.60
2	mgs./gm.	4.38	4.50	3.96
	me./100gm.	21.90	22.50	19.80
4	mgs./gm.	5.25	4.06	3.88
	me./100gm.	26.25	20.30	19.40
25	mgs./gm.	3.50	3.36	3.06
	me./100gm.	17.50	16.80	15.30
L.S.D. @5%	mgs./gm.	1.29		
	me./100gm.	6.45		
L.S.D. @1%	mgs./gm.	N.S.		
	me./100gm.			

[a]Mean of 5 plants

APPENDIX TABLE 7. Interaction of Treatment Level and Length of Treatment on Mean[a] Concentration of Magnesium When Magnesium Was Varied in Nutrient Solution (Phase I).

Treatment me./l. Magnesium	Unit	Length of Treatment in Weeks 4	6	8
0	mgs./gm.	0.13	0.11	0.14
	me./100gm.	1.07	0.90	1.15
0.5	mgs./gm.	0.18	0.17	0.17
	me./100gm.	1.48	1.39	1.39
1	mgs./gm.	0.22	0.23	0.22
	me./100gm.	1.81	1.89	1.81
2	mgs./gm.	0.37	0.44	0.26
	me./100gm.	3.04	3.62	2.13
4	mgs./gm.	0.45	0.39	0.37
	me./100gm.	3.70	3.21	3.04
12	mgs./gm.	0.54	0.75	0.54
	me./100gm.	4.44	6.17	4.44
25	mgs./gm.	0.83	0.92	0.82
	me./100gm.	6.82	7.57	6.74
L.S.D. @5%	mgs./gm.	0.13		
	me./100gm.	1.07		
L.S.D. @1%	mgs./gm.	0.17		
	me./100gm.	1.40		

[a]Mean of 5 plants

APPENDIX TABLE 8. Interaction of Treatment Level and Length of Treatment on Mean[a] Concentration of Potassium When Magnesium Was Varied in Nutrient Solution (Phase I).

Treatment me./l. Magnesium	Unit	Length of Treatment in Weeks 4	6	8
0	mgs./gm.	13.66	19.76	17.74
	me./100gms.	34.93	50.53	45.36
0.5	mgs./gm.	14.70	16.98	16.76
	me./100gms.	37.59	43.42	42.85
1	mgs./gm.	13.08	15.56	16.92
	me./100gm.	33.44	39.78	43.26
2	mgs./gm.	14.38	15.36	16.32
	me./100gm.	36.77	39.27	41.75
4	mgs./gm.	14.04	16.14	14.32
	me./100gm.	35.90	41.27	36.62
12	mgs./gm.	14.32	13.92	14.24
	me./100gm.	36.62	35.59	36.41
25	mgs./gm.	10.72	11.74	8.22
	me./100gm.	27.41	30.02	21.02
L.S.D. @5%	mgs./gm.	3.27		
	me./100gm.	8.36		
L.S.D. @1%	mgs./gm.	4.36		
	me./100gm.	11.15		

[a]Mean of 5 plants

APPENDIX TABLE 9. Interaction of Treatment Level and Length of Treatment on Mean[a] Content of Calcium When Calcium Was Varied in Nutrient Solution (Phase I).

Treatment me./l. Calcium	Unit	Length of Treatment in Weeks 4	6	8
0	mgs.	4.90	5.16	4.47
	me.	0.24	0.26	0.22
0.5	mgs.	5.50	8.54	8.94
	me.	0.27	0.43	0.44
1	mgs.	8.06	7.92	11.17
	me.	0.40	0.39	0.55
2	mgs.	8.58	13.53	11.60
	me.	0.42	0.67	0.57
4	mgs.	11.16	15.65	19.64
	me.	0.55	0.78	0.98
12	mgs.	14.74	25.62	27.24
	me.	0.73	1.28	1.35
25	mgs.	20.35	21.26	23.74
	me.	1.02	1.06	1.18
L.S.D. @5%	mgs.	8.59		
	me.	0.43		
L.S.D. @1%	mgs.	11.45		
	me.	0.57		

[a]Mean of 5 plants

APPENDIX TABLE 10. Interaction of Treatment Level and Length of Treatment on Mean[a] Content of Magnesium When Potassium Was Varied in Nutrient Solution (Phase I).

Treatment me./l. Potassium	Unit	Length of Treatment in Weeks 4		6		8	
0	mgs.	1.03		1.26		1.55	
	me.		0.08		0.10		0.12
0.1	mgs.	0.78		1.96		2.15	
	me.		0.06		0.16		0.17
0.25	mgs.	0.73		2.04		1.66	
	me.		0.06		0.17		0.13
0.5	mgs.	0.79		1.74		1.54	
	me.		0.06		0.14		0.12
2	mgs.	1.06		1.74		1.25	
	me.		0.09		0.14		0.10
4	mgs.	0.88		1.04		1.08	
	me.		0.07		0.08		0.08
25	mgs.	0.64		0.88		0.79	
	me.		0.05		0.07		0.06
L.S.D. @5%	mgs.	0.82					
	me.		0.07				
L.S.D. @1%	mgs.	N.S.					
	me.						

[a]Mean of 5 plants

VITA

Name: Albert A. Piringer Jr.

Permanent Address: 284 East Page Street
Saint Paul 7, Minnesota

Degree: Doctor of Philosophy, 1953

Date of Birth: April 24, 1921

Place of Birth: Saint Paul, Minnesota

Secondary Education: Cretin High School
Saint Paul, Minnesota, 1935-1939

College Institutions Attended:

University of Minnesota 1939-1942, 1946-1947
B.S. Degree in Horticulture 1947

University of Minnesota 1947-1948
M.S. Degree in Horticulture 1948

University of Maryland 1948-1953
Ph.D. Degree in Horticulture 1953

Positions Held:

U.S. Armed Forces 1942-1946

Teaching Assistant
University of Minnesota 1947-1948

Teaching Assistant
University of Maryland 1948-1950

Research Assistant
University of Maryland 1950-1952

Assistant Horticulturist
USDA Bureau of Plant Industry
Beltsville, Maryland 1952-