INFLUENCE OF NUTRIENT-ELEMENT SUPPLY ON LEAF COMPOSITION AND GROWTH OF HIGHBUSH BLUEBERRY (VACCINIUM CORYMBOSUM L.) WITH SPECIAL REFERENCE TO IMPORTANCE OF SAMPLING DATE ON LEAF AND FRUIT COMPOSITION OF FIELD GROWN BLUEBERRIES

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY

Harry James Amling

1958

This is to certify that the

thesis entitled

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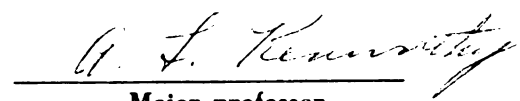
presented by

Harry James Amling

has been accepted towards fulfillment
of the requirements for

Doctor's degree in Horticulture



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Date November 17, 1958

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By

HARRY JAMES AMLING

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of Michigan State University of Agriculture and Applied Science
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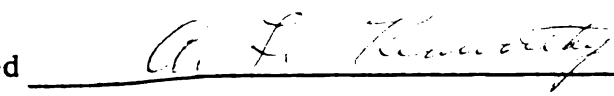
Approved 

One- and two-year-old rooted cuttings of the highbush blueberry Vaccinium corymbosum L., were grown in quartz sand and in vermiculite under varied levels of ten nutrient elements. Leaf analyses and plant response to treatment in terms of foliar expression, root development and growth were recorded and discussed. In addition, leaf and fruit samples were collected biweekly in the summer of 1957 to ascertain seasonal influence on leaf and fruit composition. Commercial blueberry fields were also surveyed for nutritional disorders. Leaf analyses, photographic and descriptive records were collected of the nutritional disorders observed.

In sand culture the leaf content of N, P, K, Mg, Ca, B and Mn increased as the supply of the element increased. Iron and copper increased in the leaf only when a high external supply existed. With vermiculite only, K and B increased in the leaf as the supply of the element increased. Mn, Fe and Cu leaf levels increased only when solutions containing high levels of the elements were used.

Numerous nutrient interrelations became apparent when the concentration of particular nutrient elements in solution were varied. The more prominent relationships are as follows: (1) As the supply of nitrogen increased, all elements except phosphorus decreased in the leaf. (2) A shortage or excess of phosphorus decreased the nitrogen level in the leaf. (3) As the supply of potassium or magnesium increased from 0 ppm to 30 ppm or 24 ppm,

respectively, the antagonistic influence of potassium on the uptake of magnesium was equal in severity to the reciptoval antagonism exerted by magnesium on potassium uptake. With further increases in the supply of these two elements, the antagonistic influence of potassium on magnesium uptake was less severe than the reciprocal antagonism of magnesium on potassium uptake. (4) Iron showed a strong antagonistic influence on the uptake of manganese. Manganese did not exhibit a reciprocal relationship on iron. (5) A low level of any one of the major elements in solution resulted in a high manganese leaf level. (6) A low level of calcium in solution promoted the accumulation of the heavy metal nutrient-elements, magnesium and potassium in the leaf. (7) The potassium level in the leaf increased with increased supply of boron.

Characteristic leaf pigmentation of N, P and Mg deficiencies appeared sooner and were more conspicuous under high amounts of solar radiation. Under low amounts, these same symptoms faded, or in the case of magnesium deficiency, developed completely different characteristics. A shortage of any one of the nutrient elements, except nitrogen and phosphorus, and an excess of all nutrient elements, except phosphorus, were associated with the occurrence of a chlorosis or necrosis, or both.

There appeared to be an increased requirement for most major nutrient elements, except potassium, as the amount of solar radiation increased. Correspondingly, there was an increased requirement for potassium when the

amount of solar radiation decreased. Under low solar radiation the high potassium treatment induced the greatest amount of growth, while under high solar radiation the high phosphorus treatment resulted in the greatest amount of growth.

Low nitrogen levels in solution stimulated root growth, while high N, B, Mn, Fe and Zn and low Ca, B, Mn solution levels noticeably reduced root development. The high phosphorus treatment induced the most desirable root system.

Blueberry plants were found to grow well in agricultural vermiculite if supplied with nitrogen and phosphorus. Plants growing in vermiculite showed noticeable reductions in growth when supplied with potassium or iron.

Definite seasonal trends existed for all nutrient elements in the leaves except boron. N, K, P, Cu decreased, while Mg, Ca, Fe, Mn and Zn increased in varying degrees as the season progressed. The biweekly leaf sampling study also indicated that the greatest consistency in the leaf content of all nutrient elements occurred during the three week period prior to, and including, the first week in which 35 percent of the crop could be harvested.

Considerably more manganese was found in leaves of the Jersey variety than in leaves of the Rubel variety. Foliar symptoms of magnesium deficiency were associated with a much higher medial leaf content of magnesium with Rubel than with Jersey. This was interpreted to mean that Rubel has a higher

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requirement for magnesium than Jersey. Rubel fruit contained higher amounts of K and N, and lower amounts of Ca and Mn than did Jersey fruit. Rubel fruit showed lower keeping quality than Jersey when N and K were higher, and Ca lower than average.

All nutrient elements in the fruit declined with increased maturity. There were, however, considerable differences in the magnitude of decline between elements. The percent decrease of these elements during the six weeks period prior to harvest were as follows: Mn - 73 percent; B - 61 percent; Ca - 59 percent; P - 55 percent; N - 54 percent; Mg - 41 percent; Fe - 29 percent; Cu - 24 percent; and K - 20 percent. During the harvest period N, K and Ca decreased significantly.

The nutritional disorder survey indicated the existence in 1957 of shortages of N, P, Mg and Ca, and excesses of N, K and Mn in commercial fields.

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INTRODUCTION

The highbush blueberry Vaccinium corymbosum L. differs from most other fruit crops by requiring an acid soil of high water-holding capacity. The availability of many nutrient-elements in such soils would be considered in short or in excess supply for most fruit crops. The adaptability of the blueberry to these soil conditions suggests that it differs fundamentally from other fruit crops in nutritional requirements.

The most reliable tool at present for diagnosing the nutritional status of woody plants is plant analyses. Its use, however, depends largely on a thorough understanding of the factors influencing plant composition. At present, little information is available on the factors influencing the leaf and fruit composition of the highbush blueberry.

The purpose of this investigation of the highbush blueberry was to evaluate the influence of nutrient-element shortages and excesses on leaf composition and growth, and to gain a better understanding of the seasonal changes in leaf and fruit composition.

REVIEW OF LITERATURE

Doehlert and Shive (1936) published one of the earliest reports in which sand culture techniques were employed to evaluate the nutrient requirements of the highbush blueberry. They studied the growth responses of the Rubel highbush blueberry in sand culture under varied amounts of monopotassium phosphate, calcium nitrate, ammonium sulfate, and magnesium sulfate. Although unable to segregate the influence of individual nutrients, their data showed that the best yield and tip growth was obtained from using solutions low in monopotassium phosphate and high in nitrogen which were supplied with boric acid and manganese sulfate. The authors suggested that the blueberry requirement for magnesium was slight and excesses of it may retard growth processes. They further implied that nitrate nitrogen was superior to ammoniacal nitrogen.

Kramer and Schroder (1942) reported a study on the effects of nutrient deficiencies, superimposed peat, and growth substances on rooted cuttings of the Cabot blueberry grown in sand culture. The authors used the nutrient solution proposed by Doehlert and Shive. Modifications of this nutrient solution were used to obtain solutions deficient in N, P, K, Mg, Ca, Fe, S, Mn and B. In the superimposed peat-on-sand cultures, no symptoms of calcium, iron or sulfur deficiency were observed during the course of the experiment, and

symptoms of boron deficiency were late in appearing. In straight sand cultures, iron deficiency sumptoms, also, were late in developing. With these exceptions, deficiency symptoms appeared after treatment initiation in both cultures in the following chronological order: N, K, S. Ca, B, Mg, P, Fe and Mn.

However, no chemical analyses were included in this paper to support the authors' contentions of having developed specific nutrient deficiency symptoms.

Fresh weight measurements indicated that only -N treatments resulted in significantly lower root weights, while -B, -P, -S, as well as -N treatments, resulted in a significantly reduced top weight when compared to the check treatment. The authors were of the opinion that the severe reduction in growth caused by anion deficiencies reflected a relatively high requirement for anion nutrients and a low requirement for cation nutrients.

Kramer and Schrader (1945) presented data which showed that the hydrogen ion concentration of blueberry leaf sap was much greater than in other plant species; that young leaves had a lower pH than the more mature leaves; and that the isoelectric point of the water soluble proteins in blueberry leaves was on the basic side of the plant sap pH.

They also found that deficiencies of P, K, Mg, Ca, Fe and B raised the pH and N deficiency lowered the pH of the leaf sap. These results were

interpreted to mean that a raise in the pH of leaf sap toward its isoelectric point was indicative of senescence or the occurrence of disease or injury. They further postulated that the soluble proteins may act amphoterically as cations, thus balancing the presence of excessive anions, which could result from plants growing in soils low in calcium and other exchangeable bases.

Minton, Hagler and Brightwell (1951) grew the rabbiteye blueberry by sand culture methods and reported that deficiency symptoms of N, P, K, Mg, Ca and S were similar to those reported by Kramer and Schrader (1942). Leaf analyses data presented by the authors substantiated the occurrence of these deficiencies. Significantly higher levels of P, K, Ca, Mg and S over that of the check nutrient solution were obtained in the leaves when nitrogen was lacking in the nutrient solution. Nutrient solutions lacking calcium increased significantly the nitrogen and sulfur content of the leaves, while solutions lacking magnesium decreased the calcium content and increased the sulfur content of leaves.

The concept that the sensitivity of the highbush blueberry to soil pH may be correlated with nutrient availability was stimulated by the report of Bailey (1936). He described a chlorosis of tip leaves which could be corrected by ammonium sulfate applications. White (1936) had attributed a similar chlorosis in gardenias to the use of nitrate nitrogen. He readily corrected the disorder with ammonium sulfate, and to a lesser degree with iron inoculations.

Bailey and Everson (1937) obtained a slight response with iron sulfate sprays and iron citrate injections in an attempt to correct the blueberry leaf chlorosis reported in 1936. Soil tests indicated lower ferrous iron levels under chlorotic plants than under non-chlorotic plants. Lime applications were found to induce the chlorosis. These workers concluded that a lack of soluble iron induced by too high a pH was responsible for the chlorosis.

According to Bailey (1940) the inducement of chlorosis by lime applications could be lessened by incorporating peat into the soil.

Stene (1939) found that the effects of pH on highbush blueberry growth was greatly influenced by rooting medium and by the manner in which nutrients were added. Plants grown in sand-oak leaf mold where the pH was maintained at 3.5, 5.2 and 7.0, showed no significant differences when supplied frequently with nutrient solution. Plants receiving dry fertilizer grew better at pH 3.5 and 5.2 than at pH 7.0. The author implied that these results threw doubt on generally accepted ideas that blueberries require a distinctly acid soil; that under certain conditions, where plant nutrients are available in adequate amounts throughout the growing period, the highbush blueberry would tolerate higher pH ranges than previously conceived.

Merrill (1939) and Harmer (1944) found lime applications beneficial to growth of blueberries in soils of pH 4.0 or lower. Harmer, in addition, recorded considerable decrease in growth if the pH was raised with lime

applications to above 5.2. No mention, however, was made in this report of inducing leaf chlorosis as was achieved by Bailey and Everson (1937). The author suggested that poor growth of blueberries in high pH soils may be the result of decreased manganese and possible boron availability due to large amounts of available calcium and magnesium. He also inferred that nitrates may exert an inhibiting effect.

Data presented by Cain (1952) indicated that the lack of ammoniacal nitrogen may be responsible for the appearance of iron deficiency chlorosis on highbush blueberry plants growing in relatively high pH soils. He was able to induce this chlorosis on plants grown in sand culture by substituting equivalent amounts of nitrogen in the form of calcium nitrate for ammonium nitrate in a complete nutrient solution in which the pH was maintained below 5.5. The chlorosis appeared only when complete substitution of the ammonium nitrate was achieved.

Cain maintained that this chlorosis was not necessarily related to soil pH or to the calcium and iron leaf content. He found that under field conditions blueberry plants grown in soil-sawdust mix at pH 7.0 made excellent growth and showed little chlorosis, if supplied with ammoniacal nitrogen. However, plants supplied with nitrate nitrogen developed severe chlorosis and suffered from nitrogen deficiency. Leaf analysis of chlorotic leaves showed, in some cases, lower calcium and a higher iron content than in non-chlorotic leaves.

Cain (1954) reported that chlorotic leaves contained a greater total amount of basic cations (Ca, Mg, K) on a dry weight basis than did non-chlorotic leaves. Correspondingly, he obtained higher pH values on expressed cell sap from chlorotic leaves than from non-chlorotic leaves. By injecting various materials into chlorotic shoots, Cain found that those materials which acidified the chlorotic tissue also caused a greening of that tissue. Although injections of basic materials did not induce a chlorosis in green tissue, heavy metal injections did. Cain concluded that the pattern of chlorosis caused by iron deficiency, nitrate nitrogen, calcareous soils, and heavy metal injections were visually indistinguishable.

In comparing nitrate nitrogen with ammoniacal nitrogen, Cain indicated that the latter was more readily absorbed and utilized. In addition, he observed that nitrate nitrogen had a detrimental effect on linear growth even when equivalent amounts of ammoniacal nitrogen were present in solutions being compared.

Subsequent work by Cain (1955) indicated that the amino acid content of chlorotic leaves was higher than in non-chlorotic leaves and increased with the severity of the chlorosis. This increase could be attributed primarily to an increase in the basic amino acid arginine. Correcting the chlorotic condition with Fe EDTA resulted in a sharp decrease in the total amino acid content. Ninety percent of this decrease could be attributed to a disappearance

of arginine. Cain suggested that some metabolic process, which controlled the reversible conversion of soluble nitrogen compounds into protein, was interfered with in chlorotic leaves regardless of the condition inducing the chlorosis.

The use of leaf analysis as a tool in determining the nutritional status of field grown highbush blueberries was stimulated by the identification of magnesium deficiency in Massachusetts (1949) and New Jersey (1950) blueberry fields.

Bailey, Smith, and Weatherby (1949) were unable to relate typical magnesium deficiency symptoms with lower leaf contents of magnesium. They were unable to increase the leaf content of magnesium with soil applications of magnesium sulfate applied the previous year. Leaf analyses did indicate that as the season progressed, calcium increased, phosphorus decreased, and magnesium and potassium varied inconsistently. Blueberry leaves, in comparison to apple leaves, had similar nitrogen levels, but much lower phosphorus, potassium, calcium and magnesium levels. They interpreted the low levels of basic cations as supporting evidence for the theory of Kramer and Schrader (1942) that the blueberry had low cation requirements. The low phosphorus level was considered to be indicative of a low requirement of this element, as was suggested by Doehlert and Shive (1936). The authors realized, however, that the apparent low phosphorus requirement conflicted with the

conception of high anion requirements put forth by Kramer and Schrader (1945). They inferred that anions, other than phosphorus, may fulfill this requirement.

Mikkelsen and Doehlert (1950) used leaf analyses to substantiate their diagnosis of magnesium deficiency in New Jersey blueberry fields. Leaf samples collected from plots treated the previous season with magnesium sulfate or dolomitic lime had higher levels of magnesium. This increase in magnesium leaf content corresponded with a disappearance of the magnesium deficiency symptom. These workers also found that no equivalent reciprocal replacement of potassium or calcium accompanied the increased magnesium level. On the contrary, they found that leaves accumulated more potassium, magnesium, and calcium when magnesium fertilizers were applied. Phosphorus, iron, and manganese levels in the leaves were unaltered by magnesium applications. Seasonal influences on leaf composition were apparent in the data presented. Calcium, magnesium, and potassium levels increased and phosphorus levels decreased as the season progressed.

Bailey and Drake (1954) continued the study of magnesium deficiency and found leaf magnesium to increase in both treated and untreated plots as a result of dry seasons. This increase was sufficient on untreated plots to greatly reduce the leaf expression of the deficiency. They reported that Epsom salts raised the leaf magnesium content more rapidly and to a higher level than did dolomitic limestone when both materials were applied at rates providing

equivalent amounts of MgO. This increase in leaf magnesium content reached its maximum level three years after treatment, and then leveled off. Applications of magnesium were found to have no effect on potassium, calcium and nitrogen content of leaves, regardless of the carrier used. Nitrogen, calcium and potassium were found to increase as the season progressed.

Studies by Popenoe (1952) on seasonal trends of the major nutrient element levels in Rancocus highbush blueberry leaves indicated similar responses as found by Bailey et al. (1949) and Mikkelsen and Doehlert (1950). However, his data showed reversed trends for calcium, phosphorus and magnesium from one year to the next. He theorized that the ratio of potassium to magnesium needed to create a deficient magnesium condition in Rancocus was lower than in other varieties of blueberries. In analyzing mature fruit, he found the potassium content to be higher than the potassium level in leaves sampled at the same time.

Ballinger (1957) concluded, upon completing a survey on the nutritional status of Michigan blueberry plantings, that soil moisture was one of the more important factors influencing growth and production. He found, in addition, that when calcium occupied more than eight percent of the soil cation exchange capacity, poor growth could be expected. Leaf analyses indicated that nitrogen was the most limiting factor on soils having less than eight percent calcium saturation of the exchange capacity. An increase in leaf nitrogen content was corre-

lated with an increase in yield, up to an apparent optimul level of 2.10 percent nitrogen. Although few instances of magnesium deficiency were found, he found some indications that the magnesium content of the leaves was directly related to yield. He suggested, in conclusion, that soil cation exchange determinations be coupled with leaf analyses for determination of the nutritional status of the highbush blueberry.

EXPERIMENTAL PROCEDURE

The program of experimentation was carried out from September, 1956 to November, 1957 as four separate experiments.

Experiment I was conducted primarily to study the influence of high and low levels of N, P, K, Mg and Ca on growth and leaf composition. It represented, in addition, an effort to evaluate various means of growing the highbush blueberry in sand culture for future studies.

Experiment II repeated the nutritional study of the initial experiment under conditions found to be more favorable for growth.

Experiment III was a study of the influence of high and low levels of B, Mn, Fe, Cu and Zn on growth and leaf composition.

Experiment IV was a study of seasonal changes in leaf and fruit composition of field-grown highbush blueberries. In conjunction with this study, commercial blueberry fields were also surveyed for nutritional disorders.

Experiment I

One-year-old rooted cuttings of the highbush blueberry Vaccinium corymbosum, variety Jersey, were used. These plants were removed from peat-filled propagation frames in late September of 1956. The leaves were removed, the plants then repacked in moist peat, and held in cold storage at 32 degrees F during October, and at 40 degrees F thereafter. During the first week of January, the plants were removed from cold storage and the roots washed free of peat. The plants were then sorted into eight groups on the basis of uniformity of size and root development. Plants within a group were designated as a replication. Differences between groups were thereby confounded into replications.

Seven-inch clay pots, coated interiorly with asphaltum paint, were used as containers. Drainage, in all cases, was provided by placing a two-inch watchglass over the drainage opening in the bottom of each pot. Coarse quartz sand (No. 7 Warsaw quarts) was used as the rooting medium. The eight replications were arranged on two greenhouse benches, four replications per bench. Two finer grades of sand (No. 1 silica sand and No. 4 Warsaw quarts) were used as an addition to each replication, so as to observe the effect of particle size on plant growth.

The nutrient solution designated as the check treatment was derived from solutions used by Kramer and Schrader (1942), Minton et al. (1951), and

Cain (1952). Appendix Table 1 shows the modification of this check solution used to formulate the minus series of treatments initiated at the time of planting. Plants designated to receive the plus series of treatments were supplied with check solution until February 17. Appendix Table 2 shows the formulation of the plus series of treatments and changes considered necessary in the check and minus series of treatments. One pint of nutrient solution was applied every third day. Supplementary watering was used on the intervening days as necessary. Plants grown in finer grades of sand received the check solution. As the experiment progressed, additional solution changes (Appendix Tables 3 and 4) were made to achieve more desirable results. C. P. chemicals and distilled or de-ionized water were used at all times in the preparation of the solutions.

To augment the short day lengths existing from January to May, supplementary lighting was used to provide a 16-hour day length. Fluorescent lighting was placed over one bench, and incandescent lighting over the second bench. The fluorescent lighting proved inadequate and was replaced by incandescent lighting. With the advent of warmer weather, a cheese cloth shade was placed over both benches during the second week in May. Supplementary lighting was discontinued at this time.

During the period June 27-28, the plants were transferred to the Horticulture farm. Nitrogen deficiency symptoms appeared on all plants, except

those receiving the high level of nitrogen. To counteract this, the nitrogen concentration of the solutions was doubled. The plants were placed in a newly constructed camouflage net shade house on July 9. At this time the nitrogen level of the solutions was decreased to the original concentration used. Also, at this time, de-ionized water was substituted for distilled water. At certain times, due to inclement weather, nutrient solutions were not applied. At no time, however, were two consecutive feedings missed.

During the third week of September, all the leaves from each plant were collected and total shoot length measurements recorded. The shoots and the original cutting stem were then removed and the roots separated from the sand by utilizing a forty mesh screen. After being oven-dried at 150 degrees F, dry weight measurements were recorded for all plant parts.

Because of a depressing growth interaction effect between fluorescent lighting and certain treatments, the leaves, after grinding, were composited by combining a replication originally under fluorescent lighting with one originally under incandescent lighting. When at all possible, equivalent proportions of each replication were used. This procedure provided four leaf samples per treatment, each having sufficient tissue for analyses of ten elements.

The leaf samples were analyzed in the Agricultural Chemistry laboratories. Total nitrogen was determined by use of the standard Kjeldahl method and potassium by use of the flame photometer. Magnesium, calcium, boron,

phosphorus, manganese, iron, copper and zinc were determined spectrographically.

Experiment II

Two-year-old Jersey highbush blueberry plants, grown one season in the cutting bed and one season in the nursery row, were used. The plants were pruned back to one or two vigorous shoots. The roots were washed free of soil and organic matter. The plants were then weighed and sorted into five groups on the basis of root development and shoot number. Four of the groups were used as replications in a sand culture experiment. The remaining group was planted in vermiculite*.

The plants were planted in 12-inch clay pots coated on the interior with asphaltum paint. A four-inch watchglass was placed over the drainage opening, the lower third of each pot filled with coarse quartz sand (No. 7 Warsaw quartz) prior to planting in a semi-fine sand (No. 4 Warsaw quartz). The two grades of sand were used, because semi-fine sand, although superior to coarser sand, retained excessive moisture at the bottom of the pot.

To avoid having the fibrous roots fold into a compact mass during planting, the roots were first dispersed in distilled water previously added to each pot. This dispersed condition was maintained by adding sufficient

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*Medium textured agricultural vermiculite distributed by the Zonolite Company, Chicago, Illinois, under the trade name of Terra-lite.

semi-fine sand to cover the roots. The pot was then drained and filled to capacity with additional semi-fine sand.

This planting procedure was used, also, in planting the plants in vermiculite. Due to the coarseness of the vermiculite, these plants were planted at a much deeper level than those planted in sand. This provided additional plant support and prevented dessication of the unestablished roots.

The plants, after planting, were placed on four greenhouse benches shaded with cheesecloth. Within each replication, treatments were assigned at random. The treatments, shown in Table II, were initiated one day after planting. One quart of nutrient solution was added every third day, and supplementary watering was provided on the intervening days as necessary.

During the first week of June, the vermiculite group was moved from the greenhouse to a site sheltered from the wind but not from other environmental influences. Due to the change of environmental conditions, apparent nitrogen deficiency symptoms appeared on all plants, except those receiving the high level of nitrogen. Later, these plants were transferred to the Horticulture farm with plants of Experiments I and II.

Until the third week of September, Experiment II was conducted simultaneously with, and in similar manner as Experiment I.

Experiment II plants, including the vermiculite group, were returned to the greenhouse during the third week of September, to obtain greater growth

differences between treatments and more distinct foliage disorders. The experiment was terminated on November 1. The procedure of termination was identical with that for Experiment I.

Experiment III

One-year-old rooted Jersey highbush blueberry cuttings, similar to those utilized in Experiment I, were used. These plants, however, were left in the cutting frame and transferred into the greenhouse during the third week of September to prevent the plants from going into dormancy.

During the third week of December, the plants were removed from the cutting frame, the roots washed free of peat, and each plant weighed and labeled accordingly. The plants were then sorted into three groups on a basis of top growth and root development. These three groups were then divided into six replications. The differences between groups were confounded with replication.

The plants were planted in the same manner as described for Experiment I. For the first two weeks after planting, the plants received only a nitrogen solution. By the end of this period the plants showed leaf colorations indicative of plants going into dormancy. During the first week of January the leaves were stripped off, the plants removed from pots and placed into polyethylene bags. These plants were then kept in cold storage at 40 degrees F until the last week of June.

Upon removal from cold storage, the plants were replanted in two-gallon glazed porcelain crocks. The interior of these crocks had been previously coated with silicone spray to seal off existing cracks. The drainage opening was covered with a two-inch watchglass. The planting procedure was identical to that used in Experiment II. Four of the replications were planted in sand; the remaining two replications were planted in vermiculite. Within each of the six replications, treatments were denoted at random. After planting, the plants were transferred to the shade house at the Horticulture Farm.

To provide high and low treatment levels of boron, manganese, iron, copper and zinc, modifications of the minor element solution, originated by Hoagland, were added to the check solution used in Experiments I and II.

The plants were returned to the greenhouse during the third week of September. Day lengths of 16 hours were imposed by supplementary incandescent lighting. The experiment was terminated on November 16 and 17, and the leaves, shoots, and original cutting pieces were removed for dry weight measurements. During the period November 18 to 28, the roots - one replication at a time - were washed free of sand and vermiculite for dry weight measurements.

The leaves were analyzed as in Experiments I and II.

Sand and vermiculite replications were treated separately in the statistical evaluation of the data.

Experiment IV

Leaf samples were collected biweekly in 1957 from June 15 to September 5 from nine field plots considered to be free of any nutrient disorder. From adjacent plots fruit samples were also taken at the same time.

Each plot was composed of five to ten bushes. Five plots were of the Rubel variety, the remaining four were of the Jersey variety. The location of these plots provided excellent representation of the more important blueberry production areas in western Michigan.

Each leaf sample consisted of leaves taken from all sides of the particular plot sampled. Only those leaves from the middle of terminal and strong growing lateral shoots, which were expected to become fruitful the following year, were used. A survey of the fruitfulness of these shoots, as shown by the presence of fruit buds in September, indicated all to be fruitful. Yield records were also obtained from these plots.

Until the first picking by the grower, fruit samples were obtained by removing the berries from the apical portion of fruit clusters terminating, preferably vigorous shoots of the previous season. No cluster was sampled twice. After the first picking an attempt was made to collect a representative sample of the berries left on the bush.

Commercial fields, in addition, were surveyed for apparent nutrient disorders. Representative samples of leaves showing these disorders were collected.

All leaves were washed in a distilled water solution of Dreft* and rinsed with distilled water. They were then oven-dried at 150 degrees F.

The fruit samples were not washed. The procedure for analysis of both fruit and leaf samples followed that described for Experiment I.

The calcium level in the blueberry fruit was below that which could be determined accurately on the spectrograph. Because of this, the calcium content of the fruit was determined by using a Versenate method, as presented in the Appendix.

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*Trade name for a mild detergent.

RESULTS

Experiments I and II: Influence of N, P, K, Mg and Ca Levels in Solution

Growth in Experiment I, at least initially, occurred in a series of distinct flushes--each flush being terminated by a phenomenon in which the terminal bud aborted. This appeared to be the same "periodic bud abortion" reported by Kramer and Schrader (1942). As the experiment continued, the interval of time between flushes became progressively less. In addition, by late May, the tip bud aborting phenomenon ceased to occur.

In May and June shoot growth, arising from the basal portions of existing shoots and from the original stem, developed under most treatments. The vigor of these shoots was dependent upon the particular treatment imposed.

Growth response to treatment, particularly to that of the low and high potassium treatments, differed according to the environment. Early in the experiment under low light intensity, 0 ppm potassium in solution was not enough to sustain blueberry plant life, so small amounts of potassium (24 ppm) were added. At the same time an additional 58 ppm potassium was added to all but the low and high potassium treatment solutions. This is shown in Appendix Table 2. The 292 ppm potassium in solution, initially used as the high potassium treatment, appeared as the optimum treatment by the end of February. By the middle of April, however, the reverse was true. Ad-

justments as indicated in Appendix Table 3 were then made.

About the first of May it became readily noticeable that half strength solutions resulted in more growth. Subsequently, additional changes in solutions were made, as depicted in Appendix Table 4.

Plants used in Experiment II grew vigorously after planting and did not show the distinct flush pattern of growth observed in Experiment I. No permanent solution changes had to be made in the course of this experiment.

Leaf analyses of the two experiments indicated that a considerably lower leaf content of all nutrient-elements, except iron, was present in Experiment I than in Experiment II.

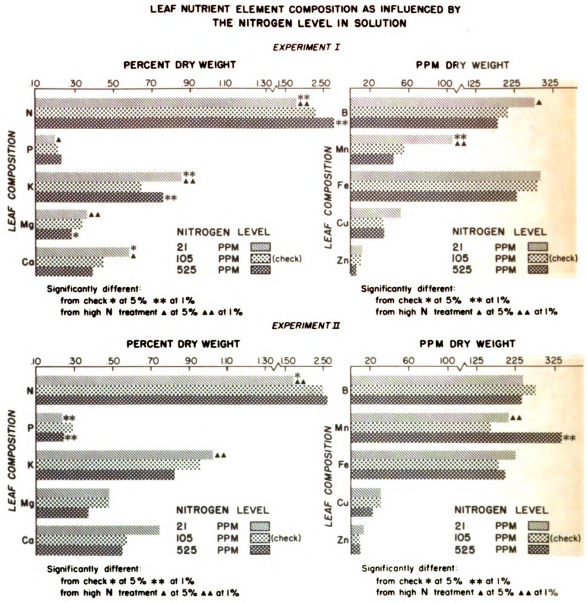
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY THE NITROGEN LEVEL IN SOLUTION
EXPERIMENT I
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
NITROGEN LEVEL
21 PPM
105 PPM (check)
525 PPM
Significantly different:
from check * at 5% ** at 1%
from high N treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
NITROGEN LEVEL
21 PPM
105 PPM (check)
525 PPM
Significantly different:
from check * at 5% ** at 1%
from high N treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT II
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
NITROGEN LEVEL
21 PPM
105 PPM (check)
525 PPM
Significantly different:
from check * at 5% ** at 1%
from high N treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
NITROGEN LEVEL
21 PPM
105 PPM (check)
525 PPM
Significantly different:
from check * at 5% ** at 1%
from high N treatment ▲ at 5% ▲▲ at 1%

Figure 1

Leaf Nutrient-Element Composition

Influence of the Nitrogen Level in Solution (See Figure 1)

Experiment I

When the nitrogen level in solution was raised from 21 ppm to 525 ppm the leaf content of nitrogen increased from 1.83 to 2.80 percent, and phosphorus from .20 to .24 percent. Subsequently, magnesium decreased from .38 to .29 percent, calcium from .60 to .51 percent, boron from 275 to 182 ppm, and manganese from 118 to 45 ppm. Iron, copper, and zinc leaf contents also decreased, but not significantly.

Plants receiving 105 ppm and 525 ppm nitrogen in solution were significantly lower in potassium content (.654 and .770 percent) than those receiving 21 ppm nitrogen (.865 percent K).

Experiment II

As the nitrogen supply (21-105-525 ppm) increased, significant increases in leaf content of nitrogen (1.71 to 2.60 percent) were obtained. Potassium, however, decreased from 1.022 to .826 percent. The manganese leaf level (339 ppm) induced by the high nitrogen treatment, was significantly higher than that occurring under the check treatment (159 ppm) and low nitrogen treatment (205 ppm).

Both the high and low nitrogen treatments resulted in significantly lower leaf phosphorus (.24 percent) than did the check treatment (.29 percent).

Magnesium, calcium, copper and zinc decreased, but not significantly, as nitrogen supply increased. Boron and iron levels showed non-significant variations.

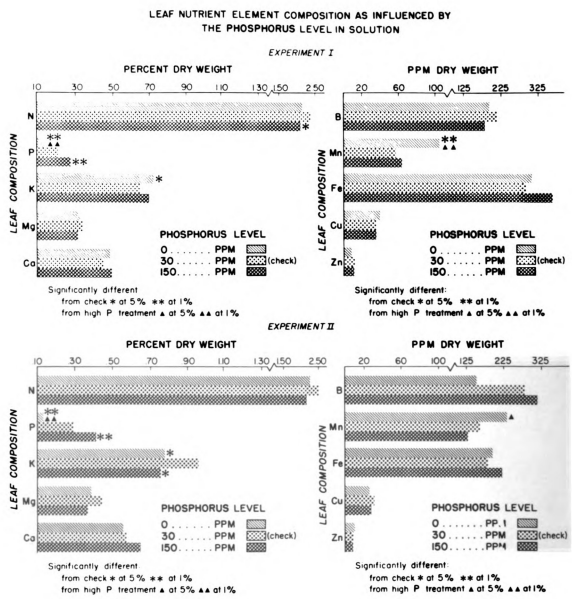
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY
THE PHOSPHORUS LEVEL IN SOLUTION
EXPERIMENT I
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
PHOSPHORUS LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different
from check * at 5% ** at 1%
from high P treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
PHOSPHORUS LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high P treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT II
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
PHOSPHORUS LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different
from check * at 5% ** at 1%
from high P treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
PHOSPHORUS LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high P treatment ▲ at 5% ▲▲ at 1%

Figure 2

Influence of the Phosphorus Level in Solution (See Figure 2)

Experiment I

When the phosphorus level in solution was increased (0-30-150 ppm), the phosphorus level in the leaf increased from .15 percent to .22 percent to .28 percent. High and low phosphorus levels resulted in larger amounts of potassium (.728 and .703 percent) than found for the check (.654 percent). Conversely, these same treatments resulted in lower amounts of nitrogen (2.11 and 2.06 percent) than that induced by the check (2.30 percent).

0 ppm phosphorus in solution significantly increased the manganese level (103 ppm) in the leaf over that level (55 and 62 ppm) found in plants receiving 30 and 150 ppm phosphorus.

The iron level (350 ppm) in the leaves of plants under the high phosphorus treatment was the highest obtained in this experiment under any treatment.

The magnesium, calcium, boron, copper and zinc levels in the leaf were not appreciably altered by changes in concentration of phosphorus in solution.

Experiment II

Raising the content of phosphorus in solution (0-30-150 ppm) increased the leaf content of phosphorus (.13 to .41 percent), calcium (.56 to .65 percent), and boron (150 to 310 ppm), but lowered the manganese content (230 to 127 ppm).

Nitrogen leaf contents were decreased from 2.46 percent in the check to 2.28 percent by the low phosphorus treatment, and 2.19 percent by the high phosphorus treatment. These results were in accord with that found in Experiment I, however, the differences were not significant in Experiment II.

Contrary to results obtained in Experiment I, 30 ppm phosphorus resulted in a higher potassium leaf content (.956 percent) than did 0 ppm or 150 ppm phosphorus (.783 and .769 percent K, respectively). Magnesium leaf levels were influenced in similar fashion, but differences were not significant.

Varying the phosphorus level in solution had little influence on iron, copper and zinc leaf levels.

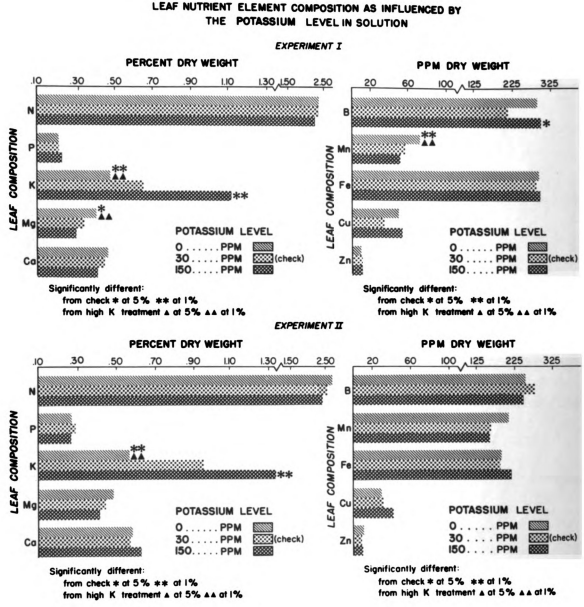
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY THE POTASSIUM LEVEL IN SOLUTION
EXPERIMENT I
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
POTASSIUM LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high K treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
POTASSIUM LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high K treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT II
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
POTASSIUM LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high K treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
POTASSIUM LEVEL
0 ..... PPM
30 ..... PPM (check)
150 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high K treatment ▲ at 5% ▲▲ at 1%

Figure 3

Influence of the Potassium Level in Solution (See Figure 3)

Experiment I

By increasing the potassium level in solution (0-30-150 ppm), an increase of potassium (.481 to 1.11 percent) coupled with decreases of magnesium (.41 to .31 percent), calcium (.47 to .42 percent), and manganese (71 to 51 ppm) was obtained in the leaf.

Boron and copper levels in the leaf were lower under the check treatment than under the high and low potassium treatments.

Nitrogen, phosphorus, iron and zinc levels in the leaf showed little change under varying levels of potassium in solution.

Experiment II

Potassium, magnesium and manganese leaf levels responded in similar fashion to Experiment I under the same treatment. As the potassium concentration in solution increased, the leaf content of potassium was raised significantly from .576 to 1.335 percent, while magnesium dropped from .49 to .42 percent, and manganese from 205 to 156 ppm. However, the influence upon magnesium and manganese was not significant.

Nitrogen leaf content showed a decreasing, but not significant, trend (2.65 to 2.46 to 2.39) as the potassium supply was increased.

The remaining nutrient-elements showed erratic or slight changes under the three levels of potassium in solution.

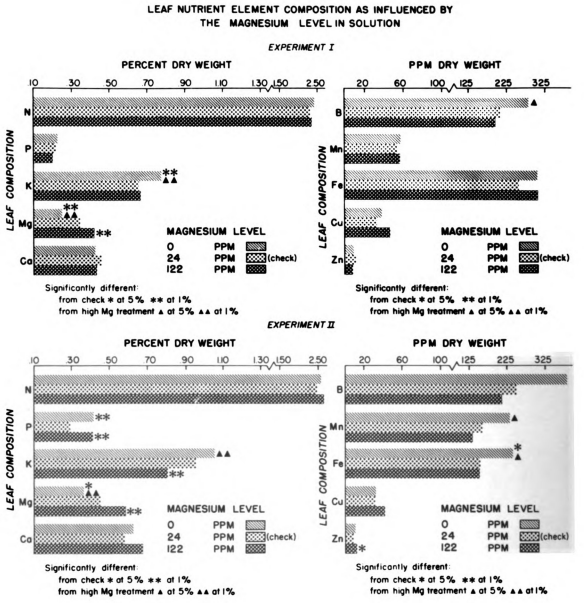
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY
THE MAGNESIUM LEVEL IN SOLUTION
EXPERIMENT I
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
MAGNESIUM LEVEL
0 PPM
24 PPM (check)
122 PPM
Significantly different:
from check * at 5% ** at 1%
from high Mg treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
MAGNESIUM LEVEL
0 PPM
24 PPM (check)
122 PPM
Significantly different:
from check * at 5% ** at 1%
from high Mg treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT II
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
MAGNESIUM LEVEL
0 PPM
24 PPM (check)
122 PPM
Significantly different:
from check * at 5% ** at 1%
from high Mg treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
MAGNESIUM LEVEL
0 PPM
24 PPM (check)
122 PPM
Significantly different:
from check * at 5% ** at 1%
from high Mg treatment ▲ at 5% ▲▲ at 1%

Figure 4

Influence of the Magnesium Level in Solution (See Figure 4)

Experiment I

An increase in the concentration of magnesium (0-24-122 ppm) in solution increased magnesium (. 25 to . 42 percent) and decreased phosphorus (. 23 to . 20 percent), potassium (. 776 to . 663 percent), and boron (282 to 196 ppm) levels in the leaf.

The high magnesium treatment promoted a non-significant increase in the copper level (48 ppm) in the leaf over that of the check (34 ppm).

Differences in leaf contents of nitrogen, calcium, manganese, iron and zinc were variable and not significant.

Experiment II

With an increase in the magnesium content (0-24-122 ppm) in solution, magnesium proportionately increased from . 36 to . 59 percent in the leaf. Subsequently, decreases of potassium (1. 054 to . 802), boron (382 to 211 ppm), manganese (232 to 134 ppm), and iron (238 to 178) also occurred. The reduction in leaf boron, however, was not significant.

Phosphorus and zinc levels in the leaf were lowest with the check treatment and increased with either increasing or decreasing levels of magnesium in solution.

The copper level in the leaf was increased from 32 ppm in the check to 42 ppm in the high magnesium treatment. This response was similar to that obtained in Experiment I, however, it still was not a significant response.

Nitrogen and calcium leaf levels were influenced only slightly by varying the magnesium concentration in solution.

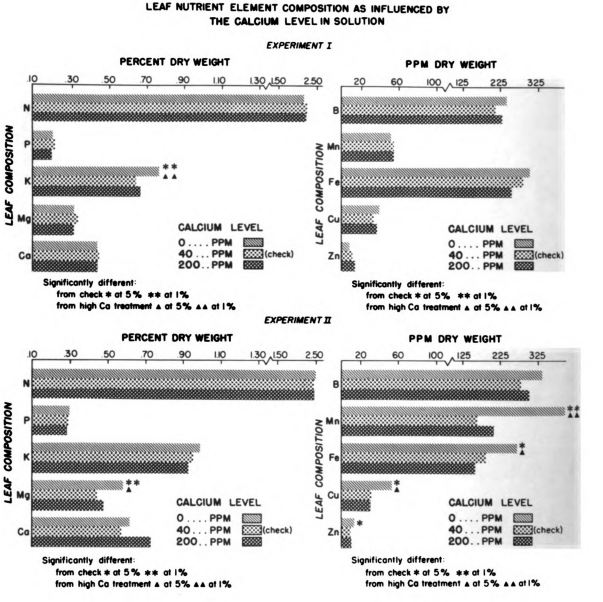
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY
THE CALCIUM LEVEL IN SOLUTION
EXPERIMENT I
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
CALCIUM LEVEL
0 . . . . PPM
40 . . . PPM (check)
200. . PPM
Significantly different:
from check * at 5% ** at 1%
from high Ca treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
CALCIUM LEVEL
0 . . . . PPM
40 . . . PPM (check)
200. . PPM
Significantly different:
from check * at 5% ** at 1%
from high Ca treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT II
PERCENT DRY WEIGHT
10 30 50 70 90 110 130 150 250
N
P
K
Mg
Ca
LEAF COMPOSITION
CALCIUM LEVEL
0 . . . . PPM
40 . . . PPM (check)
200. . PPM
Significantly different:
from check * at 5% ** at 1%
from high Ca treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
20 60 100 125 225 325
B
Mn
Fe
Cu
Zn
LEAF COMPOSITION
CALCIUM LEVEL
0 . . . . PPM
40 . . . PPM (check)
200. . PPM
Significantly different:
from check * at 5% ** at 1%
from high Ca treatment ▲ at 5% ▲▲ at 1%

Figure 5

Influence of the Calcium Level in Solution (See Figure 5)

Experiment I

The influence of the calcium level in solution on leaf composition was negligible with all nutrient elements, except potassium and iron. The 0 ppm calcium treatment resulted in a potassium level (. 775 percent) significantly above that induced by the check treatment (. 654 percent). As the calcium content increased in solution from 0 to 200 ppm, the iron content of the leaf decreased from 295 ppm to 248 ppm. This decrease was not significant.

Experiment II

Increasing the calcium concentration in solution from 0 ppm to 200 ppm decreased potassium (. 992 to . 931 percent), magnesium (. 59 to . 48 percent), manganese (391 to 202 ppm), iron (263 to 153 ppm), copper (53 to 31 ppm), and zinc (13 to 10 ppm), in the leaf. Of these elements, only potassium was not significantly lowered.

The calcium leaf content showed some indication of increasing with an increase in the calcium supply. This increase, however, was not significant.

Foliar Symptoms

The expression and rapidity of appearance of foliar symptoms depended to a large extent on solar radiation. Figure 6 shows the biweekly average solar radiation for the experimental period. Characteristic leaf pegmentation due to nitrogen, phosphorus, and magnesium deficiencies appeared sooner and were more conspicuous under high solar radiation. Under low solar radiation as encountered in late winter, under shading, or in the fall months, these same symptoms faded or developed completely different characteristics, as was the case with magnesium deficiency.

Descriptions of the various symptoms induced by the ten treatments used, are as follows:

Nitrogen deficiency: Under the prevailing low solar radiation available in the initial stages of Experiment I, the low nitrogen treatment, which originally contained 56 ppm nitrogen, provided sufficient nitrogen to maintain optimum growth. To induce foliar symptoms of nitrogen deficiency, the nitrogen level in solution was reduced to 21 ppm. With the advent of increased solar radiation, coupled with the use of only 21 ppm nitrogen in solution, deficiency symptoms rapidly developed.

In Experiment II, nitrogen deficiency symptoms appeared within two weeks after treatment initiation. The symptoms were further intensified when the plants were moved out of doors into full sunlight. The symptoms of nitrogen

Figure 6

Solar radiation available to blueberry plants used in the pot culture studies conducted in 1957.

The shading imposed by the shade house decreased the available solar radiation by 67 percent.

Data used to compile this chart are presented in Appendix Table 18*.

*Solar radiation data received through the courtesy of Mrs. Cottom, Hydrologic Research Project, U. S. D. A., Soil Conservation Service.

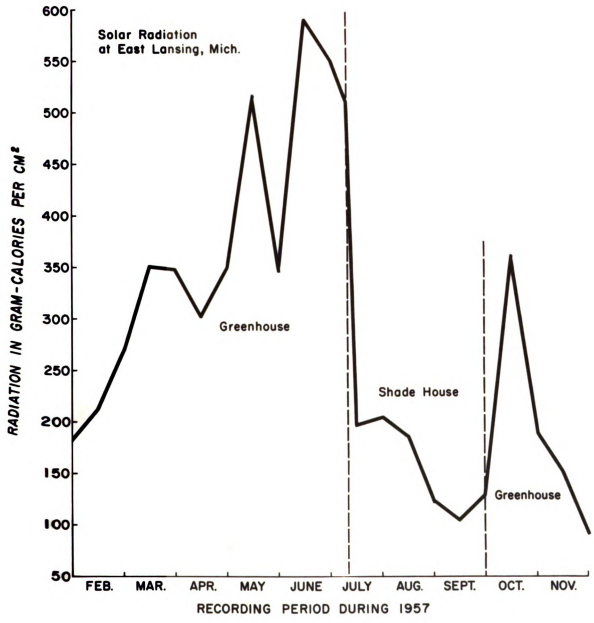
Solar Radiation
at East Lansing, Mich.
RADIATION IN GRAM-CALORIES PER CM²
600
550
500
450
400
350
300
250
200
150
100
50
Greenhouse
Shade House
Greenhouse
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
RECORDING PERIOD DURING 1957

Figure 6

deficiency, existing in both Experiments I and II, faded considerably when the plants were moved into the shade house.

Nitrogen deficiency became apparent when the leaves turned progressively more yellowish-green basipetally. With increased severity of the deficiency, the basal leaves exhibited minute reddish necrotic spots (Figure 7) over the entire leaf surface. Young shoots arising from the base of nitrogen deficient plants, were tinted a distinct pink. This coloration changed rapidly to a pale green upon cessation of growth.

In Experiment I, leaves deficient in nitrogen contained 1.83 percent nitrogen, as compared to 2.30 percent in check leaves. Wider differences between nitrogen deficient and check leaves (1.71 and 2.46 percent) were obtained in Experiment II.

Nitrogen excess: When the nitrogen concentration in solution was increased from 420 ppm to 525 ppm (Appendix Tables 3 and 4), tip leaves on high nitrogen treated plants developed an interveinal chlorosis followed by a rapid abscission, acropetally, of basal leaves (Figure 11). No foliar disorders were noted on the basal leaves prior to abscission. Upon moving the plants into shade and lowering the nitrogen content to 262 ppm in solution temporarily, the phenomenon ceased, shoot growth was renewed. Reverting back to 525 ppm nitrogen, however, did not result in a re-occurrence of the phenomenon.

Figure 7

Upper left - Nitrogen deficiency. Note pale greenish yellow basal leaves covered with minute red spots.

Upper right - Potassium deficiency. Note necrotic areas along margin of leaves.

Lower left - Phosphorus deficiency. Note purpling of basal leaves.

Lower right - Acute petiole angle, associated with phosphorus deficiency.


-N


-P

Leaf analyses showed 2.80 percent and 2.60 percent nitrogen, respectively, for the high nitrogen treated plants in Experiments I and II.

Phosphorus deficiency: In Experiment I the basal leaves of plants receiving 0 ppm phosphorus in solution became coriaceous in texture and turned a dark purple (Figure 7). Tip leaves exhibited, at the same time, a greenish-purple coloration. The greater the light intensity, the more intense the purple coloration. Decreasing the light intensity by shading rapidly eliminated the purplish coloration, but not the coriaceous leaf condition on basal leaves.

Only in direct sunlight did plants in Experiment II show purple pigmentation. This purple coloration disappeared rapidly after placing the plants in the shade house. No further foliar pigmentations developed on these plants for the duration of Experiment II.

In some instances the petiole angle of leaves on fast growing shoots in Experiment II became extremely acute. This condition resulted in the leaf being pressed against the stem (Figure 7).

Leaf analyses of the 0 ppm phosphorus treated plants indicated a phosphorus content of .15 percent and .13 percent, as opposed to .22 percent and .29 percent in the check leaves, respectively, for Experiments I and II.

Phosphorus excess: In Experiment II plants receiving 150 ppm phosphorus showed apparent nitrogen deficiency on basal leaves (Figure 8). Analyses of leaves taken from these plants indicated a nitrogen content of 2.19 per-

Figure 8

Marginal scorch of basal leaves due to excess potassium. Symptoms undistinguishable from that resulting from magnesium and calcium excess.

Top - Apparent nitrogen deficiency due to high phosphorus treatment.

Bottom - Potassium toxicity on basal leaves, indistinguishable from magnesium toxicity.

cent, while leaves taken from check plants contained 2.46 percent nitrogen.

Although 150 ppm phosphorus in solution depressed the nitrogen content below that found in check leaves in the first experiment, no distinguishable symptoms were present.

Potassium deficiency: Only in Experiment I did foliar symptoms of potassium deficiency become visible. Approximately six months after treatment initiation, small necrotic spots appeared on basal leaves just inside the leaf periphery (Figure 7). With increased severity of the condition, the necrotic spots coalesced into a necrotic area, which extended to the leaf margin.

Earlier in Experiment I, 26 ppm potassium had to be added to keep the minus potassium treated plants alive (Appendix Table 2). At this time, however, no foliar disorders were apparent. Analyses of leaves from these plants indicated the potassium content to be .48 percent; the check leaves in Experiment I had a potassium content of .65 percent.

Potassium excess: The foliar expression of potassium toxicity became evident only in Experiment II and only in the late stages of the experiment. Shortly after returning the plants to the greenhouse in September of 1957, a dark grayish-brown marginal burn developed on basal leaves of high potassium treated plants. Analyses of leaves from these plants showed the potassium level to be 1.3 percent.

Magnesium deficiency: The expression of magnesium deficiency was found to vary according to the amount of solar radiation the plant received. This is shown in Figure 9.

In February under low solar radiation (biweekly average of 250 gram-calories per cm^2), magnesium deficiency appeared as an arc of necrotic oval areas close to the midrib on basal leaves. Abscission of these leaves occurred within three weeks after the initial appearance of the symptom. When the solar radiation increased to a biweekly average of 350 gram-calories per cm^2 in March, necrotic oval areas began appearing along the leaf margin. By May, with solar radiation reaching a biweekly average of 450 gram-calories per cm^2, necrotic areas ceased to form.

The symptoms now appeared as a mottled yellowish-red submarginal interveinal chlorosis. Associated with the cessation of necrotic area development was a decrease in leaf abscission of afflicted leaves. By the end of June, under strong solar radiation (biweekly average of 550 gram-calories per cm^2), the expression of magnesium deficiency changed to a bright red submarginal interveinal chlorosis. Accompanying the development of red pigmentation was a tendency of the leaf margin to curl abaxially.

In July, by moving the plants from the greenhouse to an outdoor shade house, the average biweekly solar radiation was reduced to 100 to 200 gram-calories per cm^2. Consequently, the bright red coloration of magnesium

deficiency achieved under strong solar radiation faded to a dull red. Newly afflicted basal leaves began showing necrotic areas close to the midrib at the base of the leaf blade. Abscission of such leaves occurred very rapidly.

Transferring Experiment II back into the greenhouse did not result in the formation of pigments. Chemical analyses showed the level of magnesium to be .25 percent and .36 percent in leaves from deficient plants, and .34 percent and .44 percent in leaves from check plants for Experiments I and II, respectively.

Magnessium excess: Apparent toxicity symptoms from the 122 ppm magnesium treatment were present only in Experiment II. These symptoms appeared on basal leaves, and were indistinguishable from those described for potassium toxicity. Leaves from plants in Experiment II under high magnesium treatment had a .58 percent magnesium content, as compared to .45 percent in check leaves. It was interesting to note that under 0 ppm calcium treatment, plants also accumulated .58 percent magnesium.

Calcium deficiency: The appearance of foliar disorders that could be attributed to a deficient level of available calcium did not manifest themselves until de-ionized water was substituted for distilled water. In Experiment I, terminal leaves of plants receiving 0 ppm calcium showed a slight yellowish-green blotchiness. Plants in Experiment II, under the same treatment, developed a marginal chlorosis on tip leaves, and a tendency toward

rosetting. Basal leaves, in addition, developed tip and marginal scorching. These basal leaves later abscissed. Chemical analyses of the calcium content in these leaves did not indicate what could be considered a deficient level of calcium in comparison to other treatments. It did indicate in Experiment II leaves an extremely high level of magnesium, comparable to that resulting from the high magnesium treatment.

Calcium excess: In Experiment II basal leaves on plants supplied with 200 ppm calcium developed tip and marginal burning, identical to that found on plants receiving high levels of potassium and magnesium.

Plant Growth

Considerable differences in growth response between Experiments I and II were obtained, using the same treatment. These differences may reflect an interaction between environmental conditions existing during the course of each experiment and the nutrient treatment.

Much of the growth in Experiment I was made during periods of low solar radiation; whereas, in Experiment II the initial flush and part of the second flush growth were made under relatively high solar radiation. Figures 10 and 11 show representative plants from Experiment II for the different treatments.

The growth responses encountered in Experiments I and II are recorded

Figure 10

Influence of low levels of N, P, K, Mg and Ca in solution on top growth as compared to check in Experiment II.

Top left - check
Top right - 21 ppm nitrogen
Middle left - 0 ppm phosphorus
Middle right - 0 ppm potassium
Bottom left - 0 ppm magnesium
Bottom right - 0 ppm calcium

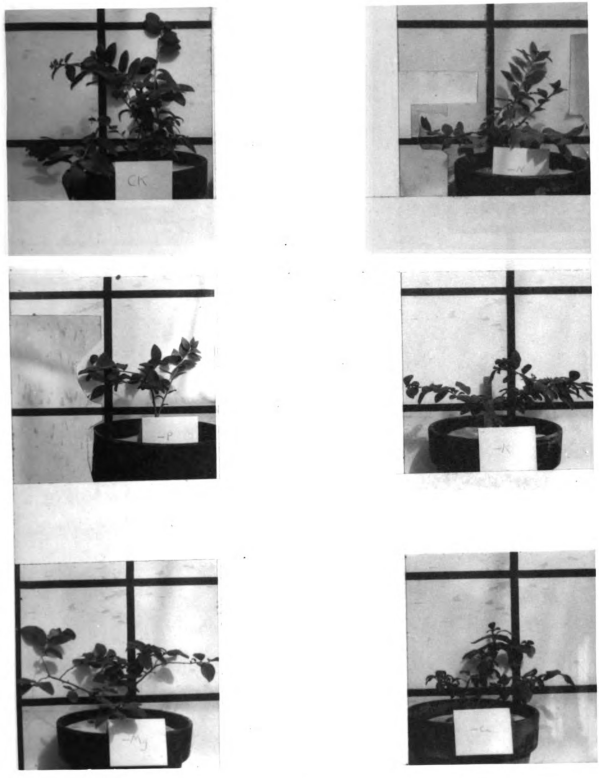

Figure 10

Figure 11

Influence of high levels of N, P, K, Mg and Ca in solution on top growth as compared to check in Experiment II.

Top left - check
Top right - 525 ppm nitrogen
Middle left - 150 ppm phosphorus
Middle right - 150 ppm potassium
Bottom left - 121 ppm magnesium
Bottom right - 200 ppm calcium

Figure 11

Growth as influenced by the N, P, K, Mg and Ca level in solution

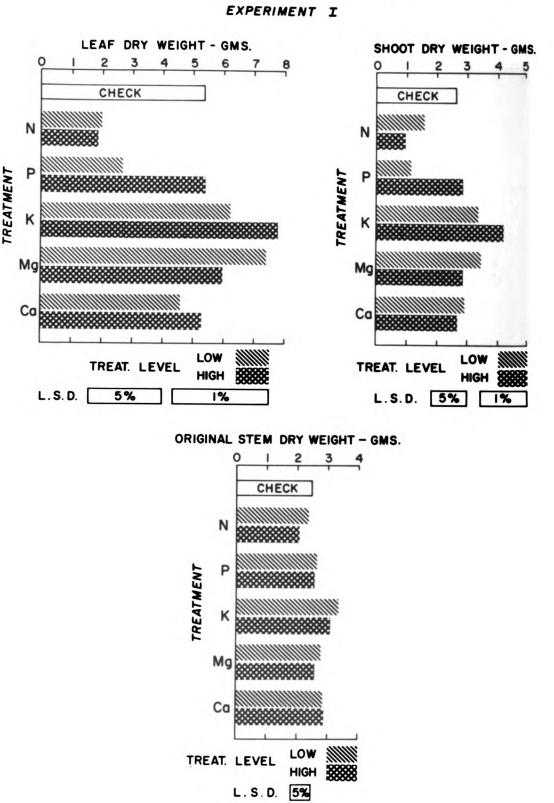

Figure 12

in Appendix Tables 7 and 9. Graphic illustrations of these data are presented in the following dissertation:

Experiment I

Leaf dry weight (See Figure 12): A decrease in leaf dry weight below that of the check occurred when 21 ppm or 525 ppm nitrogen, 0 ppm phosphorus, and 0 ppm calcium treatments were employed. The effect of the low calcium treatment, however, was slight and not significant.

Increases in leaf dry weight over that obtained with the check resulted with the 0 or 150 ppm potassium and the 0 ppm magnesium treatment. These increases, however, were not significant. The 150 ppm potassium treatment resulted in the highest leaf dry weight.

Shoot dry weight (See Figure 12): Only those plants receiving 150 ppm potassium made significantly more shoot dry weight than the check. Substantial but non-significant increase over that of the check did occur with solutions devoid of magnesium and potassium.

Significant decreases in shoot dry weight below that of the check resulted only under 525 ppm nitrogen and 0 ppm phosphorus treatments.

Although the 21 ppm nitrogen treatment was not significantly lower in shoot dry weight than the check, the resulting decrease induced by it was considerable.

The remaining treatments resulted in shoot dry weight approximating that of the check.

Original stem dry weight (See Figure 12): The original stem refers primarily to the cutting piece and subsequent shoot growth existing at the end of the first season in the cutting bed.

The only significant increase over the check treatment was induced by the 0 ppm potassium treatment. The 150 ppm potassium treatment also showed an increase which approached significance.

The 525 ppm nitrogen in solution depressed the dry weight of the original stem, but not significantly.

Top dry weight (See Figure 13): Treatments fell into three groups on a basis of plant response in the form of top growth -- those treatments that severely reduced top growth, those that had little effect on it, and those that substantially increased top growth over that of the check.

The 0 and 525 ppm nitrogen and 0 ppm phosphorus treatments comprise the first group. The second group of treatments consisted of the 150 ppm phosphorus, 122 ppm magnesium, and both the 0 and 200 ppm calcium treatments. The last group, which increased top growth, consisted of the 0 and 150 ppm potassium and 0 ppm magnesium treatments.

Root dry weight (See Figure 13): Substantial decreases in root dry weight below that of the check were induced by the 525 ppm nitrogen and 0 ppm phosphorus in solution. Only the former treatment, however, resulted in a significant decrease.

Figure 13

Top dry weight, root dry weight, total dry weight and total shoot length in Experiment I, as influenced by the N, P, K, Mg and Ca level in solution.

Growth as influenced by the N, P, K, Mg, and Ca level in solution

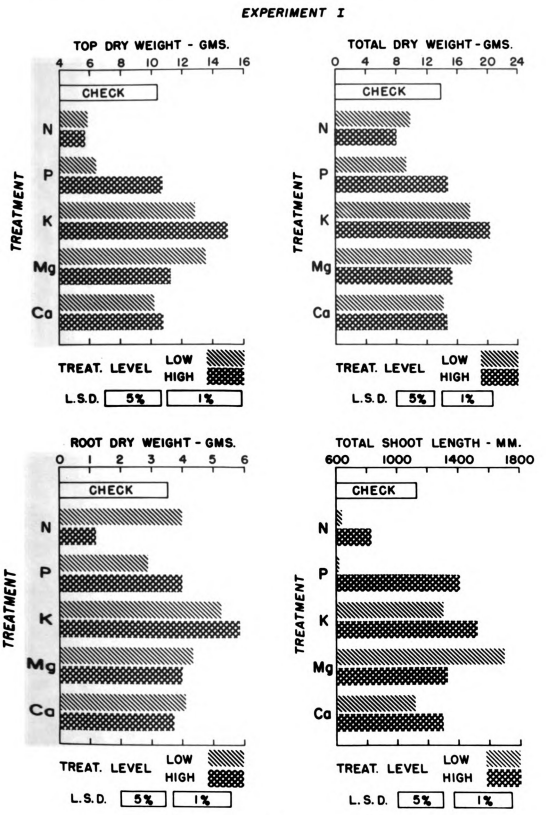

Figure 13

Highly significant increases in root dry weight were achieved by 0 and 150 ppm potassium in solution.

Noticeable, but non-significant, increases were obtained when using the 0 ppm nitrogen, 150 ppm phosphorus, 0 and 122 ppm magnesium, and 0 ppm calcium treatments.

Total dry weight (See Figure 13): Significant differences from the check were recorded only for the decrease induced by the 525 ppm nitrogen treatment and the increase induced by the 150 ppm potassium treatment. In addition, however, non-significant decreases resulted from the 0 ppm nitrogen and phosphorus treatments, and increases from the 0 ppm potassium and magnesium treatments.

Total shoot length (See Figure 13): Greatest total shoot length was achieved with 0 ppm magnesium in solution with 150 ppm potassium in solution resulting in the next greatest shoot length. Both treatments induced highly significant increases in shoot growth over that of the check. A similar but non-significant increase was induced also by the 150 ppm phosphorus treatment.

A severe depression of total shoot length occurred with the 0 and 525 ppm nitrogen and the 0 ppm phosphorus treatments.

The response to the remaining treatments paralleled that of the check or were slightly higher in shoot length.

Experiment II

Leaf dry weight (See Figure 14): Only the 150 ppm phosphorus treatment resulted in significantly greater leaf weight than the check.

Similar responses to that of the check were obtained by using the 0 and 150 ppm potassium and 0 and 122 ppm magnesium treatments.

Leaf dry weight was depressed by solutions containing 21 ppm and 525 ppm nitrogen, 0 ppm phosphorus, and 0 and 200 ppm calcium. A significant depression below the check, however, was only obtained with the high nitrogen and low phosphorus and calcium treatments.

Shoot dry weight (See Figure 14): There were no significant differences in shoot dry weight between treatments. A positive, but non-significant, response was evident when plants were given solutions containing 150 ppm phosphorus. Negative non-significant responses were achieved with the 525 ppm nitrogen and 0 ppm phosphorus and calcium treatments.

Total shoot length (See Figure 14): Severe reductions in shoot length were caused by the 21 ppm nitrogen, 525 ppm nitrogen, 0 ppm phosphorus, and 0 ppm calcium treatments. Only the decrease due to the low nitrogen treatment was not significant.

The 150 ppm phosphorus treatment increased shoot growth over that of the check, but not significantly.

Little difference in total shoot length was recorded between the check and remaining treatments.

Figure 14

Leaf dry weight, total shoot length, shoot dry weight and original stem dry weight in Experiment II, as influenced by N, P, K, Mg and Ca level in solution.

Growth as influenced by the N, P, K, Mg and Ca level in solution

EXPERIMENT II

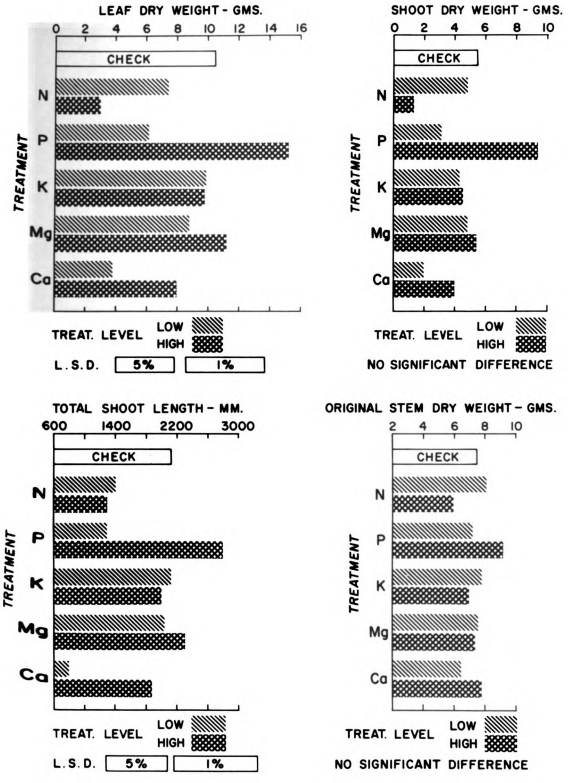

Figure 14

Original stem dry weight (See Figure 14): No significant differences existed between treatments. The high phosphorus treatment, however, did increase and the high nitrogen decrease stem weight.

Top dry weight (See Figure 15): Plant top growth response to treatment, as indicated by top dry weight, reflected three categories of treatment influence.

Detrimental influences were exerted by the high nitrogen and low phosphorus, magnesium and calcium treatments.

Slight influences on top growth were registered by the low nitrogen and potassium treatments, and by high potassium, magnesium and calcium treatments.

A beneficial influence on top growth was achieved only with the high phosphorus treatment.

Root dry weight (See Figure 15): Only the low nitrogen treatment resulted in a significantly greater root dry weight than the check. All other treatments reduced root growth, with the exception of the 150 ppm phosphorus treatment. Significant reduction in root growth below that of the check, however, were induced only by the low calcium and high nitrogen treatments.

Total dry weight (See Figure 15): Total dry weight was significantly reduced by high nitrogen and low calcium treatments, and increased by the high phosphorus treatment. A non-significant reduction trend was noted also

Figure 15

Top dry weight, root dry weight, total dry weight, and dry weight accumulation in Experiment II as influenced by the N, P, K, Mg and Ca level in solution.

Growth as influenced by the N, P, K, Mg and Ca level in solution

EXPERIMENT II

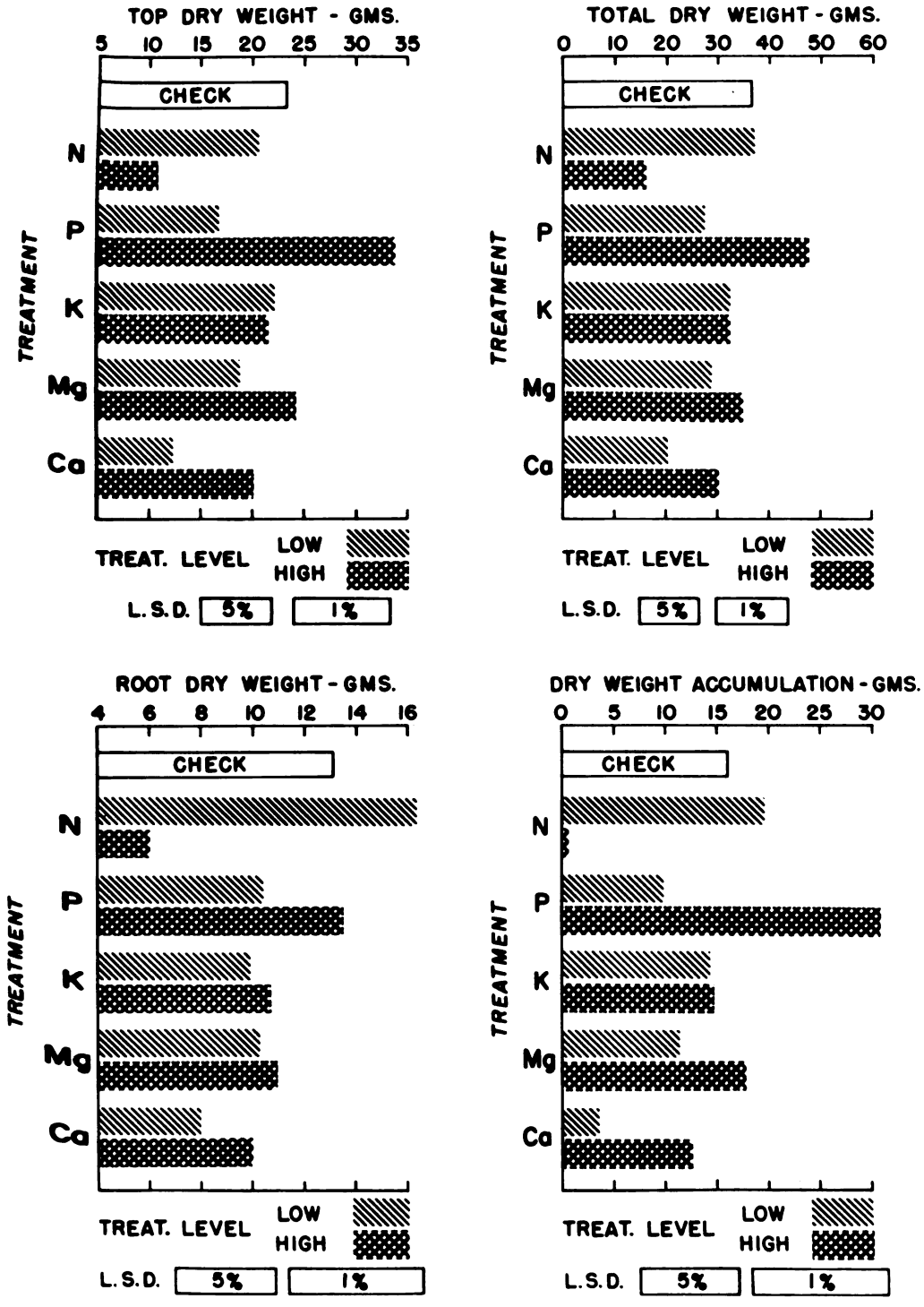

Figure 15

with the low magnesium, low phosphorus, and high calcium treatments.

Remaining treatments showed only slight variations from that of the check.

Dry weight accumulation (See Figure 15): Only those plants receiving 150 ppm phosphorus in solution accumulated significantly more dry weight than the check.

Dry weight accumulation was severely reduced by solutions containing 525 ppm nitrogen and 0 ppm calcium.

The remaining treatments, except 21 ppm nitrogen and the 122 ppm magnesium, induced the accumulation of lower dry weights in varying degrees than check. The two exceptions produced slightly more dry weight than the check.

Root Systems

Root systems were found to reflect a deficiency or toxicity level of the nutrients studied in Experiment II. Although similar differences were observed in Experiment I, they were not as outstanding.

Figure 16 illustrates the typical color associated with certain root systems. The influence of the various nutrient levels on the root systems of plants grown in sand culture is shown in Figures 17 to 21.

Figure 16

Typical color of root systems under various treatments.

Figure 17

Low nitrogen level - Root growth was stimulated by the low nitrogen treatment. The lateral roots, however, were considerably coarser in texture and fewer in number than those induced by the check treatment. These roots had a blackish-brown coloration as compared to the reddish-brown check roots.

High nitrogen level - Lateral root development was inhibited severely by solution levels of 525 ppm N. Correspondingly, the entire root system was stunted. A considerable number of dead roots were present, and the remaining roots were dark brown to black in coloration.

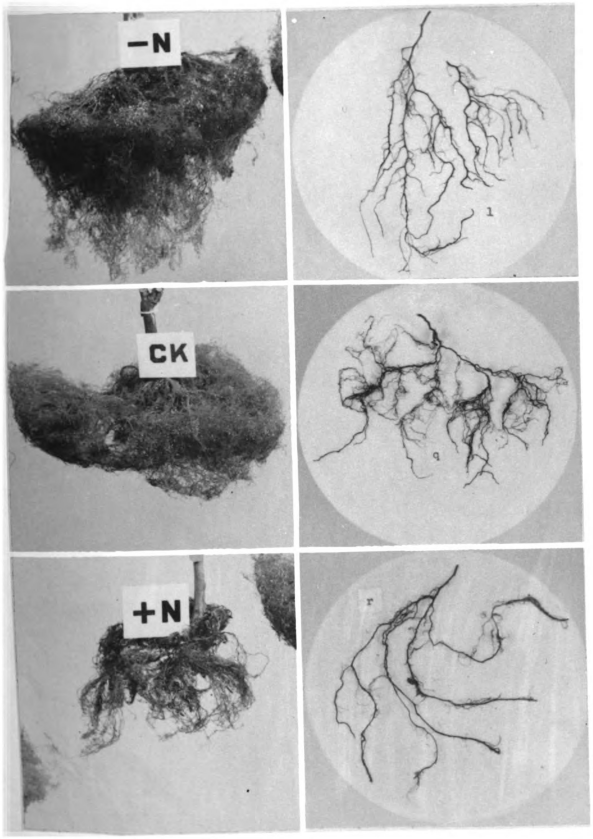

Figure 17

Figure 18

Low phosphorus level - The 0 ppm phosphorus level stunted root growth considerably. The fibrous root system was characterized by being dark in color and having very fine lateral roots.

High phosphorus level - Plants receiving 150 ppm phosphorus developed a root system comparable on a dry weight basis to that of the check. This root system, however, was considerably lighter in color and finer in texture.

Lateral roots under high phosphorus treatment were abundant from the base of the stem to the periphery of the root system; whereas, the majority of lateral roots of the check occurred close to the periphery of the root system.

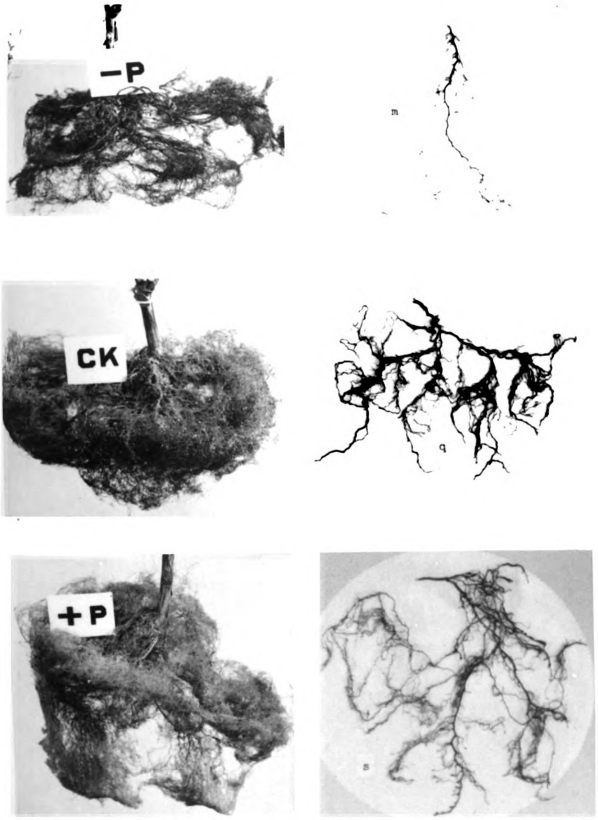

Figure 18

Figure 19

Low potassium level - Plants given a solution devoid of potassium developed a considerably smaller root system than the check. The fibrous roots were characterized by being coarse textured and dark brown. The few lateral roots present showed considerable dieback.

High potassium level - Maintaining 150 ppm potassium in solution resulted in a root system about the size developed under the low potassium treatment. Root texture, color, and lateral root growth, however, approximated that obtained with the check solution.

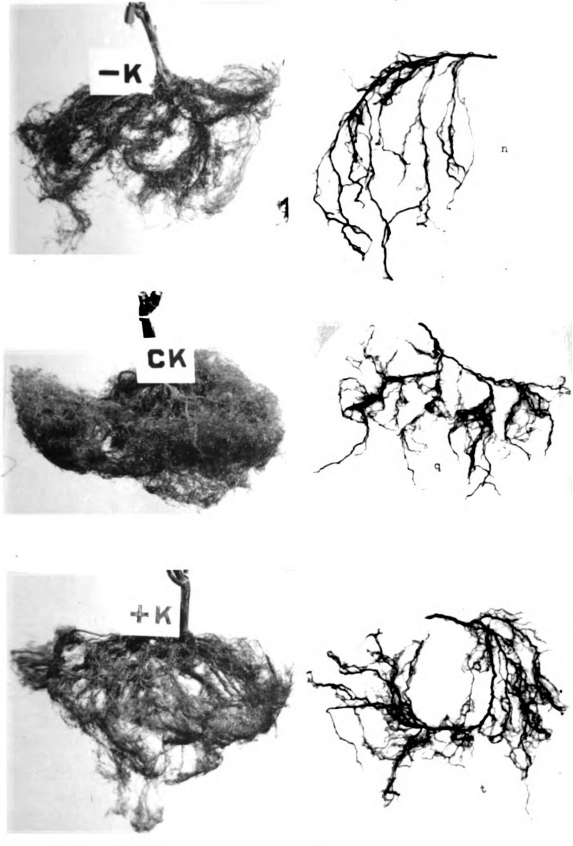

Figure 19

Figure 20

Low magnesium level - Leaving magnesium out of the nutrient solution resulted in a coarse fibrous root system having only a few lateral roots near the periphery of the root system. The color of these roots tended to be dark brown. The lateral roots may have developed as a result of using impure de-ionized water in late August.

High magnesium level - Increasing the magnesium level in solution to 122 ppm caused the development of a dark brown, very coarse, brittle root system. Lateral root growth was definitely less than the check.

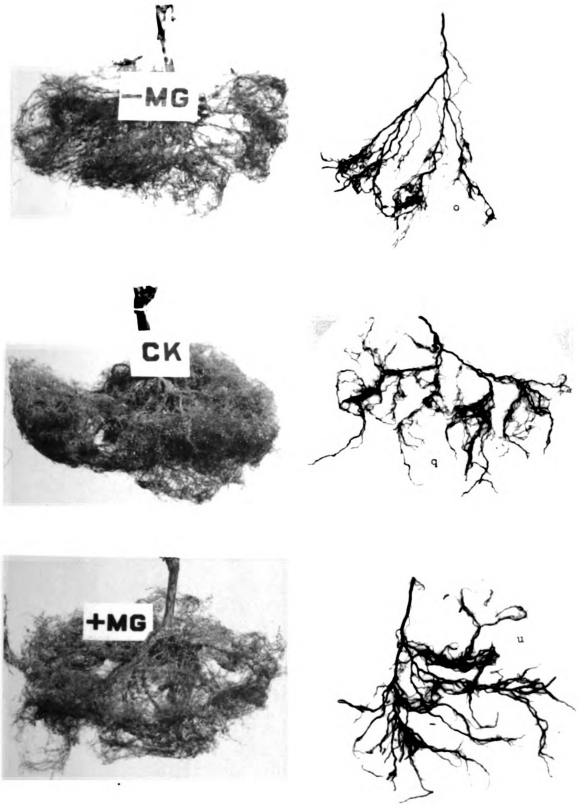

Figure 20

Figure 21

Low calcium level - The fibrous root system of plants receiving a solution devoid of calcium, although severely stunted, showed considerable root development at the terminal ends. This root growth presumably occurred after contamination with impure de-ionized water in August, 1957. The remaining portion of the root system was dark in color, very coarse, and showed little lateral branching.

High calcium level - Root growth was reduced below that of the check by using 200 ppm calcium in solution. Also lateral branching was reduced, and the root system was considerably coarser in texture. In both Experiments I and II root color under this treatment was considerably lighter than the check.

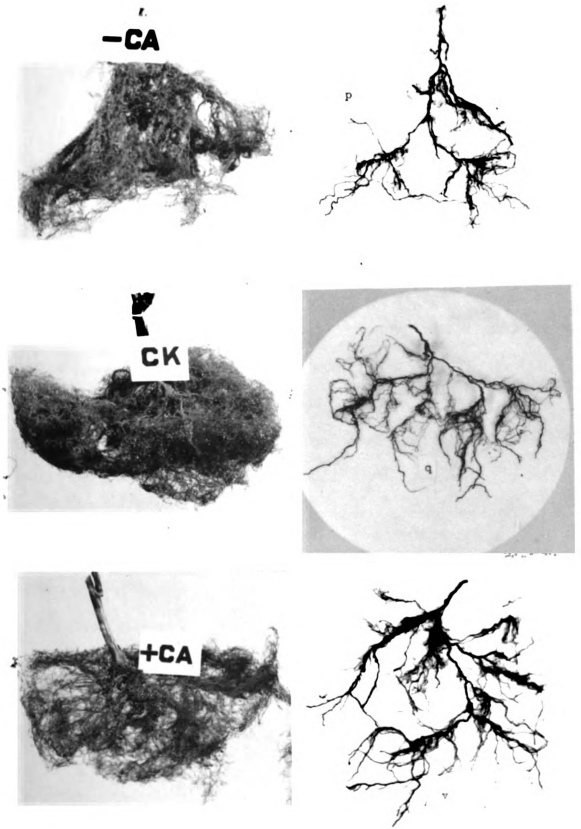

Figure 21

Vermiculite as a Growing Media

Blueberry plants were found to grow extremely well in vermiculite if supplied with sufficient nitrogen and phosphorus. Plants not receiving nitrogen or phosphorus made very little growth in comparison to plants under the remaining treatments (Figure 22). The plants, however, still had a greater dry weight accumulation than plants grown in sand under all treatments, except the 0 ppm nitrogen and 150 ppm phosphorus (Appendix Table 11). Greatest growth response was achieved when the plants received solutions devoid of potassium (Appendix Table 11 and Figure 22).

Although only one replication of plants growing in vermiculite was used for comparison with sand grown plants, there were obvious indications that leaf composition was influenced by treatment (Appendix Table 10). By increasing the nitrogen supply from 21 ppm to 525 ppm in solution, the leaf content of potassium was raised from .778 percent to 1.11 percent and boron lowered from 241 ppm to 51 ppm. Increasing the nitrogen supply from 105 to 525 ppm did not alter the leaf content of nitrogen appreciably.

Raising the phosphorus concentration in solution did not increase the phosphorus content of the leaf, but high levels did result in the lowest iron leaf content under any treatment.

Increasing potassium from 0 ppm to 150 ppm did increase the leaf

Figure 22

Growth response of plants growing in vermiculite as influenced by -N, -P, +K and check treatments*.

Top: 21 ppm nitrogen treatment in comparison to check treatment.

Middle: 0 ppm phosphorus treatment in comparison to check treatment.

Bottom: 0 ppm potassium treatment in comparison to check treatment.

*NOTE: Plants under the remaining treatments in Experiment II responded in similar fashion to that of the check.

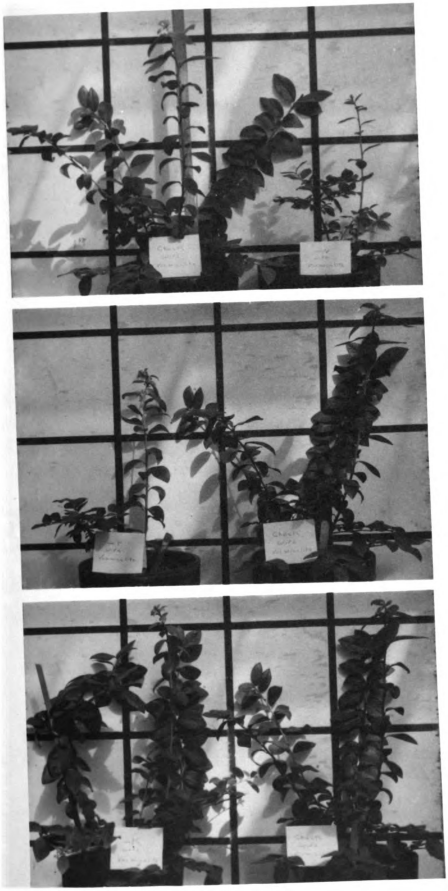

Figure 22

content of potassium from .819 percent to 1.13 percent and the manganese leaf content from 164 ppm to 226 ppm.

When the concentration of magnesium in solution was raised from 0 ppm to 121 ppm, nitrogen was decreased from 2.52 percent to 2.31 percent and boron from 280 ppm to 81 ppm. Magnesium, however, only showed a slight raise.

By increasing the calcium content in solution the leaf content of nitrogen was reduced from 2.53 percent to 2.28 percent, magnesium from .36 percent to .30 percent, and potassium from 1.09 percent to .894 percent. Iron, on the other hand, increased from 357 ppm to 511 ppm. No appreciable increase in the calcium content of the leaf resulted when the calcium supply was increased.

The only foliar symptoms indicative of a deficency to appear were those of nitrogen and phosphorus. These were observed shortly after initiation of the low level treatments of these respective elements. No foliar toxicity symptoms resulted from the high levels of the nutrients studied.

Experiment III: Influence of the B, Mn, Fe, Cu and Zn Levels in Solution

The growth of plants in sand in Experiment III was not sufficient to obtain significant differences between treatments. Definite trends, however, in growth response to treatment did exist. This lack of growth of these plants may have been due to the depletion of carbohydrate reserves during the forced growth period in the fall of 1957. This apparent lack of reserve carbohydrates was further intensified by initiating Experiment III in the shade house.

The use of vermiculite as a rooting media resulted in greater growth than that achieved in sand. The use of only two replications of these media, however, proved inadequate to overcome experimental error. Consequently, statistical evaluations of growth response to treatment showed no significant differences, even though distinct trends were apparent.

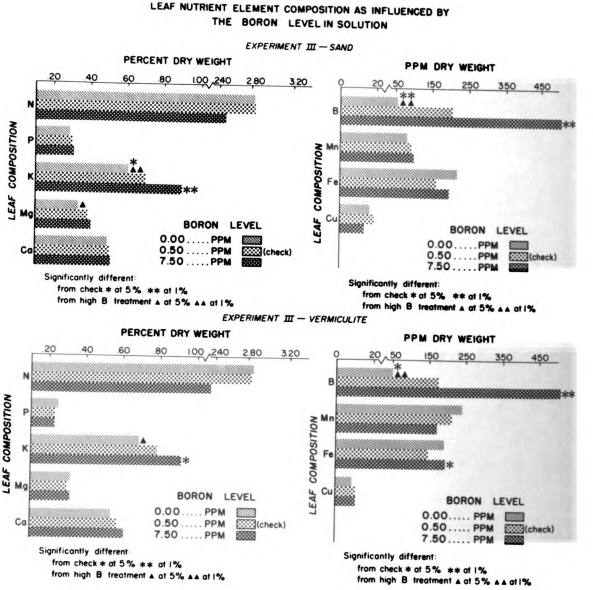
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY THE BORON LEVEL IN SOLUTION
EXPERIMENT III — SAND
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
N
P
K
Mg
Ca
LEAF COMPOSITION
BORON LEVEL
0.00 ..... PPM
0.50 ..... PPM (check)
7.50 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high B treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
LEAF COMPOSITION
BORON LEVEL
0.00 ..... PPM
0.50 ..... PPM (check)
7.50 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high B treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT III — VERMICULITE
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
N
P
K
Mg
Ca
LEAF COMPOSITION
BORON LEVEL
0.00 ..... PPM
0.50 ..... PPM (check)
7.50 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high B treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
LEAF COMPOSITION
BORON LEVEL
0.00 ..... PPM
0.50 ..... PPM (check)
7.50 ..... PPM
Significantly different:
from check * at 5% ** at 1%
from high B treatment ▲ at 5% ▲▲ at 1%

Figure 23

Leaf Nutrient Element Composition

Influence of the Boron Level in Solution (See Figure 23)

Sand Medium

By increasing the boron supply (0 to 7.5 ppm) significant increases in leaf content were obtained for boron (54 to 500 ppm), magnesium (.35 to .42 percent), and potassium (.619 to .906 percent).

Under the high boron treatment, notable but nonsignificant, decreases below that found in check leaves were obtained for nitrogen (2.78 to 2.47 percent) and copper (24 to 19 ppm).

Iron leaf levels increased nonsignificantly with either increasing or decreasing boron supply. Only slight changes were noted in the leaf content of manganese, phosphorus, and calcium.

Vermiculite Medium

With increased boron supply significant increases in leaf content of boron (52 to 500 ppm) and potassium (.688 to .911 percent), similar to that observed in the sand medium, were obtained.. Subsequently the calcium leaf level, in contrast to sand medium, increased (.54 to .61 percent) and manganese decreased (236 to 170 ppm). These changes, however, were not significant.

Leaf levels of iron and nitrogen were in accord with that obtained

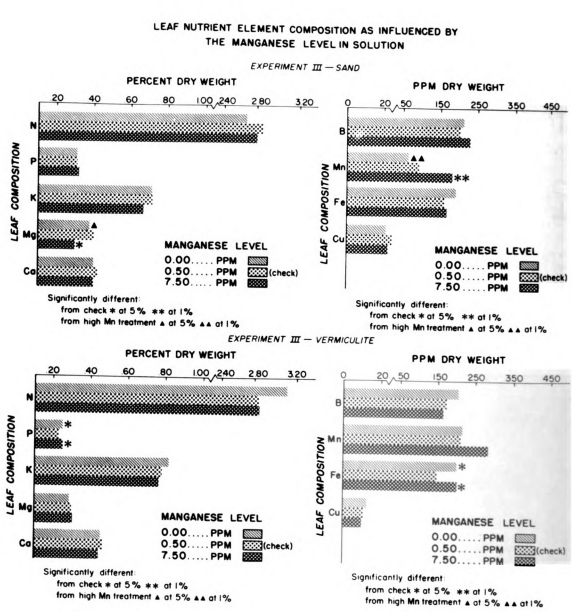
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY THE MANGANESE LEVEL IN SOLUTION
EXPERIMENT III — SAND
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
N
P
K
Mg
Ca
LEAF COMPOSITION
MANGANESE LEVEL
0.00..... PPM
0.50..... PPM (check)
7.50..... PPM
Significantly different:
from check * at 5% ** at 1%
from high Mn treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
LEAF COMPOSITION
MANGANESE LEVEL
0.00..... PPM
0.50..... PPM (check)
7.50..... PPM
Significantly different:
from check * at 5% ** at 1%
from high Mn treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT III — VERMICULITE
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
N
P
K
Mg
Ca
LEAF COMPOSITION
MANGANESE LEVEL
0.00..... PPM
0.50..... PPM (check)
7.50..... PPM
Significantly different:
from check * at 5% ** at 1%
from high Mn treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
LEAF COMPOSITION
MANGANESE LEVEL
0.00..... PPM
0.50..... PPM (check)
7.50..... PPM
Significantly different:
from check * at 5% ** at 1%
from high Mn treatment ▲ at 5% ▲▲ at 1%

Figure 24

in the sand medium under the same treatment.

Copper phosphorus and magnesium leaf levels were not appreciably influenced by varying the boron supply.

Influence of the Manganese Level in Solution (See Figure 24)

Sand Medium

As the manganese level in solution increased (0 ppm to .5 ppm to 7.5 ppm), the leaf content of manganese increased significantly from 65 ppm to 182 ppm.

A sharp decrease in the leaf content of magnesium (.40 to .30 percent) was induced by 7.5 ppm manganese in comparison with .5 ppm manganese in solution.

The remaining elements changed only slightly under the various levels of manganese in solution.

Vermiculite Medium

Phosphorus and iron significantly increased when the solution content of manganese was raised or lowered.

By increasing the manganese level in solution, nonsignificant decreasing trends existed for nitrogen, potassium, boron and copper; while an increasing trend existed for manganese. Magnesium and calcium leaf levels showed little change as the solution content of manganese was altered.

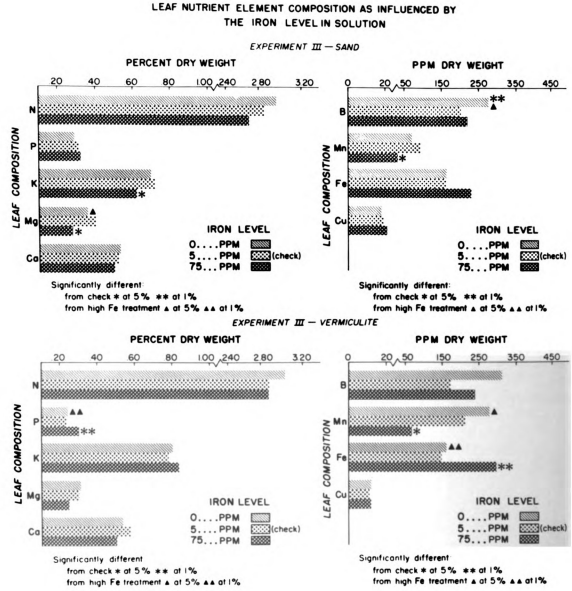
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY
THE IRON LEVEL IN SOLUTION
EXPERIMENT III — SAND
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
N
P
K
Mg
Ca
LEAF COMPOSITION
IRON LEVEL
0....PPM
5....PPM (check)
75...PPM
Significantly different:
from check * at 5% ** at 1%
from high Fe treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
LEAF COMPOSITION
IRON LEVEL
0....PPM
5....PPM (check)
75...PPM
Significantly different:
from check * at 5% ** at 1%
from high Fe treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT III — VERMICULITE
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
N
P
K
Mg
Ca
LEAF COMPOSITION
IRON LEVEL
0....PPM
5....PPM (check)
75...PPM
Significantly different
from check * at 5% ** at 1%
from high Fe treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
LEAF COMPOSITION
IRON LEVEL
0....PPM
5....PPM (check)
75...PPM
Significantly different
from check * at 5% ** at 1%
from high Fe treatment ▲ at 5% ▲▲ at 1%

Figure 25

Influence of the Iron Level in Solution (See Figure 25)

Sand Medium

With increasing iron content in solution (0 - 5 - 75 ppm), nitrogen decreased progressively from 3.02 to 2.62 percent, while phosphorus increased from .29 to .32 percent. Neither element, however, changed significantly.

The 75 ppm iron treatment, in contrast to check, depressed significantly the leaf content of potassium (.710 to .622 percent) and magnesium (92 to 43 ppm). The iron leaf level was not decreased with 0 ppm, but subsequently increased from 160 to 227 ppm when 75 ppm iron was used. This increase was not significant.

Boron levels were significantly higher in leaves under the 0 ppm than under 5 or 75 ppm iron treatment.

Vermiculite Medium

The depressing effect of increasing iron availability on leaf manganese (274 to 67 ppm) was more pronounced in vermiculite than in sand. As in sand medium, nitrogen leaf content was higher (3.02 percent) with 0 ppm iron than with 5 ppm (2.76 percent) or 75 ppm iron (2.82 percent).

The 75 ppm iron content in solution, as compared to the 5 ppm iron solution content, lowered the leaf content of magnesium (.30 to .25 percent) and calcium (.57 to .50 percent), but raised the iron (147 to 291 ppm) and phosphorus (.23 to .30 percent), as well as potassium (.780 to .803 percent)

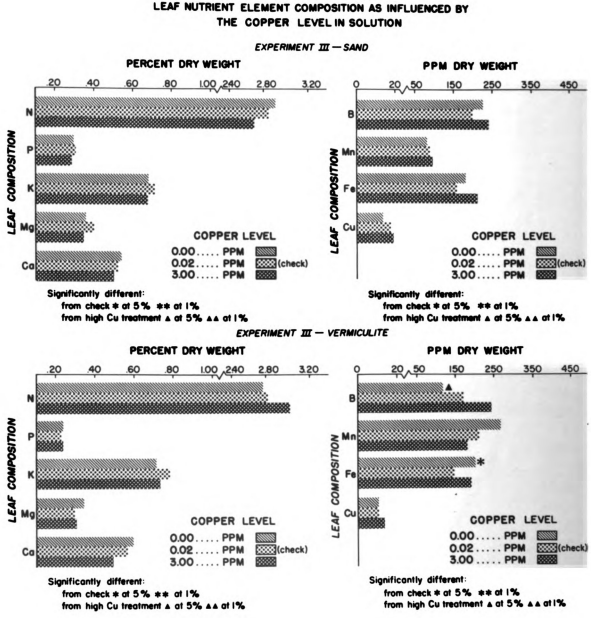
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY THE COPPER LEVEL IN SOLUTION
EXPERIMENT III — SAND
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
PPM DRY WEIGHT
0 20 50 150 250 350 450
LEAF COMPOSITION
N
P
K
Mg
Ca
B
Mn
Fe
Cu
COPPER LEVEL
0.00..... PPM
0.02..... PPM (check)
3.00..... PPM
Significantly different:
from check * at 5% ** at 1%
from high Cu treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT III — VERMICULITE
PERCENT DRY WEIGHT
PPM DRY WEIGHT
LEAF COMPOSITION
COPPER LEVEL
0.00..... PPM
0.02..... PPM (check)
3.00..... PPM
Significantly different:
from check * at 5% ** at 1%
from high Cu treatment ▲ at 5% ▲▲ at 1%

Figure 26

content. The influence upon phosphorus and iron were significant.

Boron increased nonsignificantly, with either increasing or decreasing iron supply.

Influence of the Copper Level in Solution (See Figure 26)

Sand Medium

Varying the copper content in solution resulted in no significant changes in leaf composition. There was, however, some indications that nitrogen and calcium decreased and copper increased with increasing levels of copper in solution.

Vermiculite Medium

Increasing the copper level in solution resulted in an increase in the leaf content of nitrogen (2.70 to 2.99 percent), copper (16 to 19 ppm), and boron (119 to 241 ppm), and decrease of calcium (.60 to .50 percent), and manganese (265 to 182 ppm). Only boron, however, changed significantly.

The leaf level of iron increased as the solution content of copper increased or decreased. The increase of iron that occurred when the copper supply decreased from .02 ppm to 0 ppm was significant.

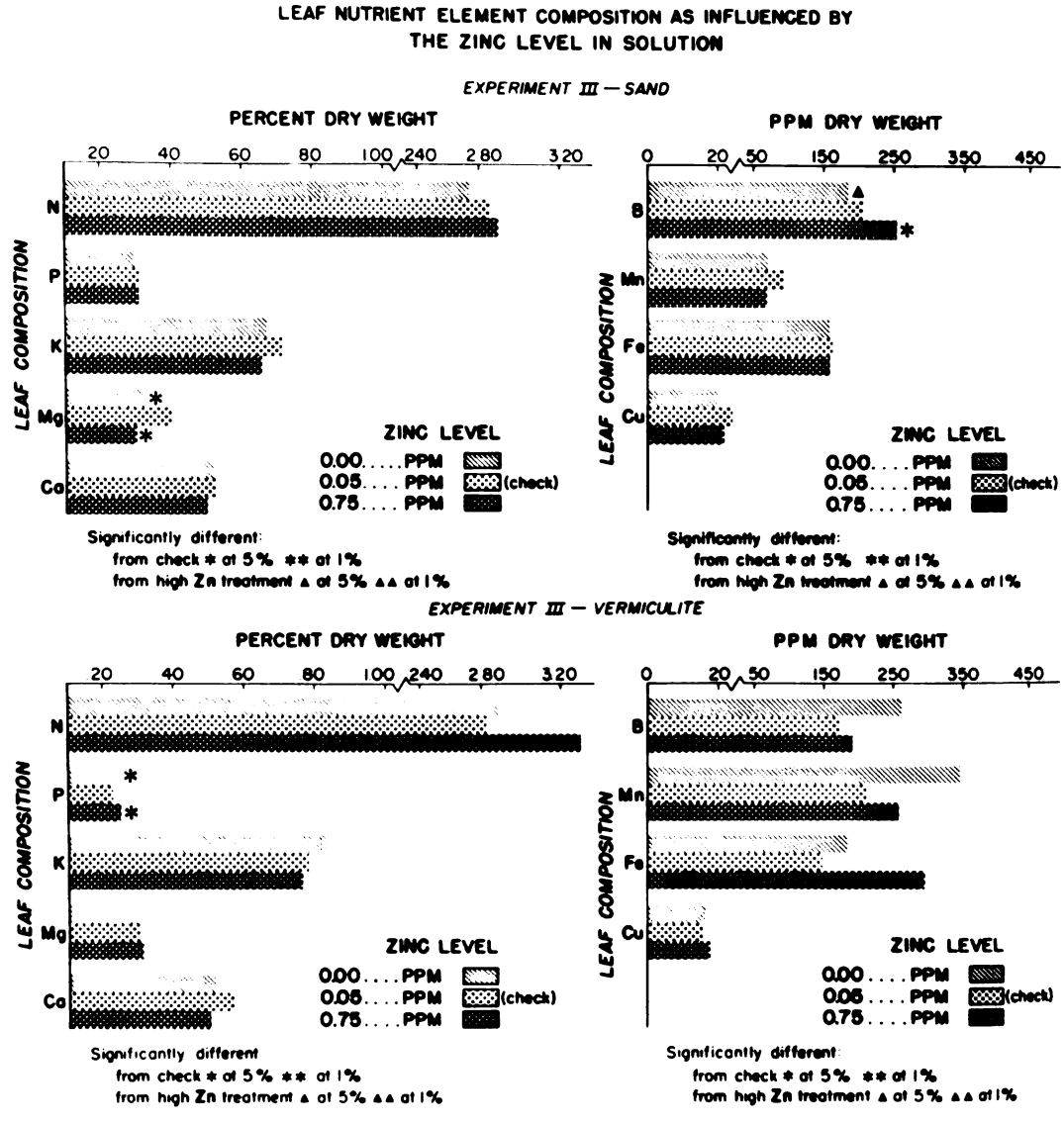
LEAF NUTRIENT ELEMENT COMPOSITION AS INFLUENCED BY THE ZINC LEVEL IN SOLUTION
EXPERIMENT III — SAND
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
LEAF COMPOSITION
N
P
K
Mg
Ca
ZINC LEVEL
0.00.....PPM
0.05.....PPM (check)
0.75.....PPM
Significantly different:
from check * at 5% ** at 1%
from high Zn treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
ZINC LEVEL
0.00....PPM
0.05....PPM (check)
0.75....PPM
Significantly different:
from check * at 5% ** at 1%
from high Zn treatment ▲ at 5% ▲▲ at 1%
EXPERIMENT III — VERMICULITE
PERCENT DRY WEIGHT
20 40 60 80 100 240 280 320
LEAF COMPOSITION
N
P
K
Mg
Ca
ZINC LEVEL
0.00....PPM
0.05....PPM (check)
0.75....PPM
Significantly different
from check * at 5% ** at 1%
from high Zn treatment ▲ at 5% ▲▲ at 1%
PPM DRY WEIGHT
0 20 50 150 250 350 450
B
Mn
Fe
Cu
ZINC LEVEL
0.00....PPM
0.05....PPM (check)
0.75....PPM
Significantly different:
from check * at 5% ** at 1%
from high Zn treatment ▲ at 5% ▲▲ at 1%

Figure 27

Influence of the Zinc Level in Solution (See Figure 27)

Sand Medium

A significant increase in the leaf content of boron (181 to 248 ppm) resulted when the zinc level in solution was increased. The increase in leaf nitrogen (2.67 to 2.83 percent) that occurred with increased zinc levels in the solution was not significant.

Magnesium leaf levels were lowered significantly by increasing or decreasing the zinc supply.

Only slight variations in leaf concentrates were exhibited by the remaining elements that were analyzed.

Vermiculite Medium

Nitrogen increased, but not significantly, when the zinc content in solution was increased from .05 ppm to 7.5 ppm. Phosphorus, however, increased significantly with increasing or decreasing zinc supply.

Other nutrients showed nonsignificant variations. However, leaf levels of boron and manganese were lowered and iron raised by the addition of zinc to the nutrient solution.

Foliar Symptoms

Plants growing in sand developed a considerable number of foliar disorders of a chlorotic nature that were not confined to any one treatment. They were also not apparent in the vermiculite medium or in preceding experiments. Characteristic foliar disorders were induced by the 0 ppm boron, 7.5 ppm manganese, and the 7.5 ppm zinc treatments.

Plants growing in vermiculite developed only boron toxicity symptoms, although they were considerably more vigorous and contained less boron and more manganese in their leaves than similarly treated plants in sand.

Descriptions of the treatment induced are as follows:

Boron Deficiency (See Figure 28): Tip leaves of actively growing shoots suddenly ceased to enlarge. This cessation of leaf expansion was followed by a slight interveinal chlorosis localized along the leaf margin. Accompanying the leaf disorder was a dying of the terminal growing point.

The boron level in leaves of plants exhibiting these symptoms was 54 ppm. Check leaves, in comparison, registered a boron content of 199 ppm.

Although plants growing in vermiculite under the 0 ppm boron treatment did not show foliar symptoms, their leaf content of boron was 52 ppm. Check plants in vermiculite had a leaf content of 170 ppm boron.

Boron Toxicity (See Figure 28): Boron toxicity appeared initially on basal leaves and developed acropetally. The disorder appeared as a mottled

Figure 28

Top - Boron deficiency

Bottom left - Boron toxicity

Bottom right - Boron toxicity

interveinal chlorosis followed by a light brown marginal scorch. This scorch proceeded to envelop the entire leaf blade with increased severity of the toxicity. Leaf drop did not occur until the entire leaf was scorched.

Leaves from affected plants contained 500 ppm boron regardless of rooting medium.

Copper Toxicity (See Figure 29): Tip leaves of plants which were receiving 3 ppm copper in solution developed a blanched appearance. This chlorotic condition extended from the leaf margin to the midrib. The basal portions of the primary lateral veins and the midrib, however, remained green. At the time the experiment was terminated, the leaves of these plants were exceptionally easy to detach.

Chemical analyses of leaves from these plants indicated a copper content of 25 ppm as opposed to 24 ppm in the check, and 20 ppm in the leaves of plants receiving solutions devoid of copper.

Manganese and Zinc Toxicity (See Figure 29): The interveinal chlorosis resulting from high levels of these two elements were indistinguishable. The disorder only appeared on those plants growing in sand. Terminal leaves were affected initially, and the condition progressed basipetally. The midrib and, contrary to copper toxicity, nearly the entire length of the lateral veins remained green. As the condition increased in severity, a few small red necrotic spots appeared. A faint marginal reddening accompanied the development of these spots.

Figure 29

Top - Copper toxicity

Bottom left - Manganese toxicity

Bottom right - Zinc toxicity

A manganese leaf content of 182 ppm was associated with the chlorotic leaf condition induced by the high manganese treatment. Check leaves contained 92 ppm manganese.

Although higher manganese leaf levels were obtained in Experiment II, only a manganese leaf content of 339 ppm induced a chlorotic leaf condition.

Plants in Experiment III growing in vermiculite also did not develop foliar symptoms of manganese toxicity, even though their leaf content of manganese was considerably higher than that found in sand. Those plants receiving the high manganese treatment had a leaf content of 280 ppm manganese, in contrast to check leaves containing 210 ppm manganese.

No zinc analyses were performed.

Plant Growth

Rooting medium did not appreciably influence growth responses to treatment. Greater growth of the plants in vermiculite, however, resulted in a considerable increase in magnitude of response. Growth data are presented in Figures 30 and 33, and in Appendix Tables 13 and 15.

Sand Medium

Top dry weight (See Figure 30): Moderate to severe retardation of top growth resulted when boron was left out of the nutrient solution, or when excessive amounts of manganese, iron and zinc were added to it. Response to the remaining treatments was not appreciably different from the check.

Root dry weight (See Figure 30): All treatments resulted in a lower root dry weight than the check. The 0 ppm iron and 3 ppm copper treatments exerted the least inhibiting effect, while 0 ppm boron and 7.5 ppm zinc resulted in the greatest decrease in root dry weight.

Treatment influence on root dry weight did not coincide exactly, however, with its influence on root texture. As shown in Figure 31, few differences can be observed between the minus treatments and the check. In Figure 32, the coarse root texture induced by high levels of iron, manganese and zinc is readily discernible.

Figure 30

Growth of plants in sand as influenced by the B, Mn, Fe, Cu and Zn level in solution.

Growth as influenced by the B, Mn, Fe, Cu and Zn level in solution

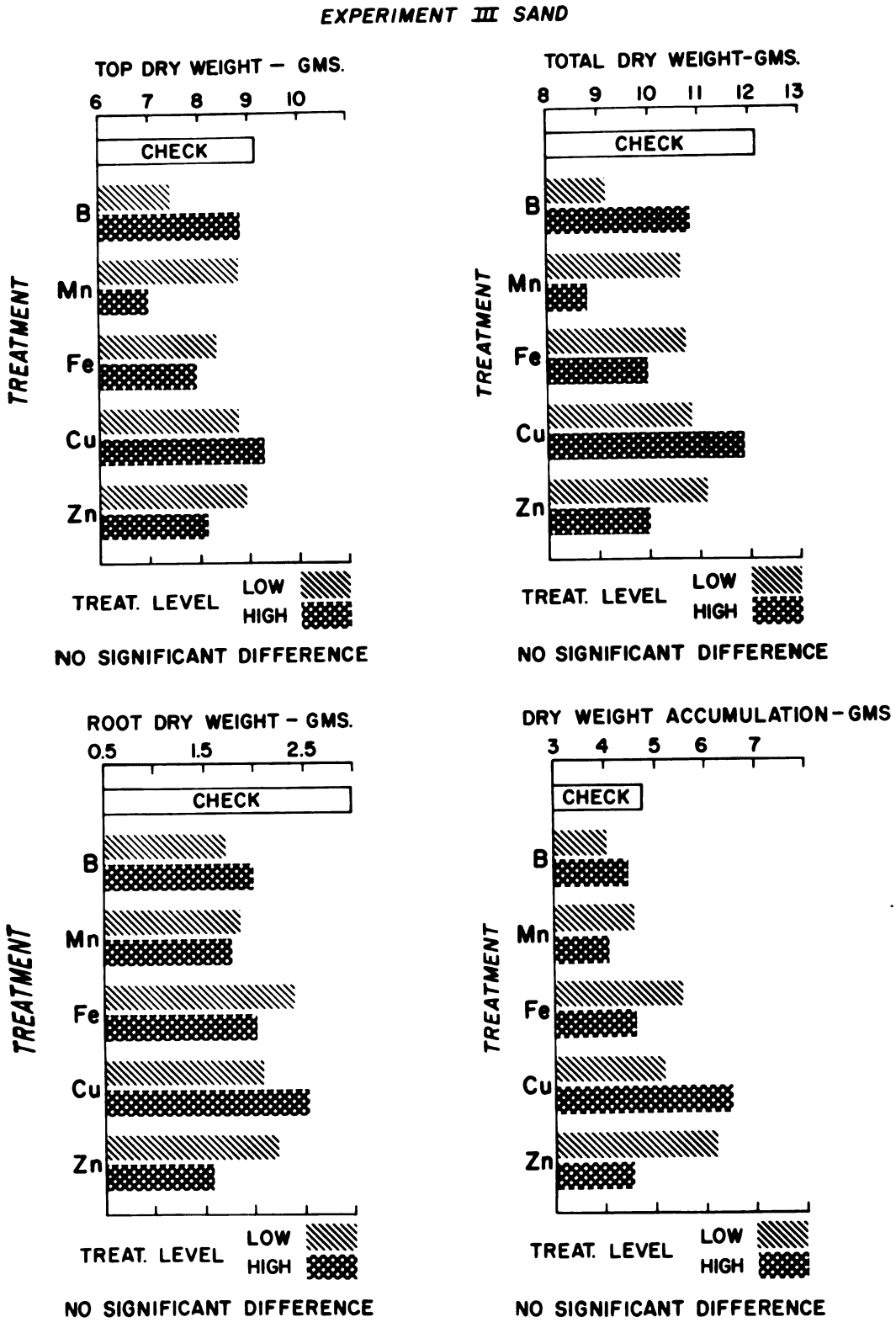

Figure 30

Figure 31

Influence of the low B, Mn, Fe, Cu, Zn and check treatments on root development in sand culture.

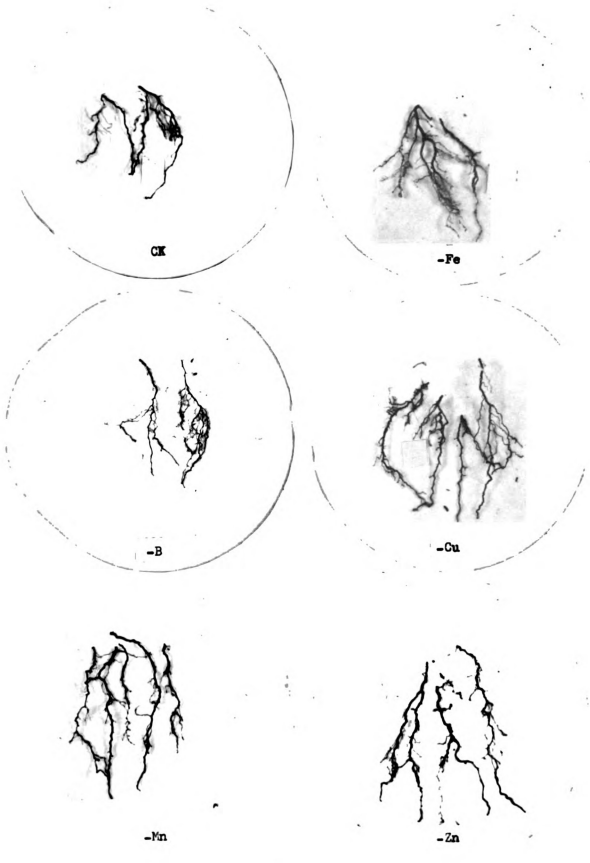

Figure 31

Figure 32

Influence of the high B, Mn, Fe, Cu, Zn and check treatments on root development in sand culture.

Note coarse texture of the high Fe, Mn and Zn treatments in comparison to the check treatments.

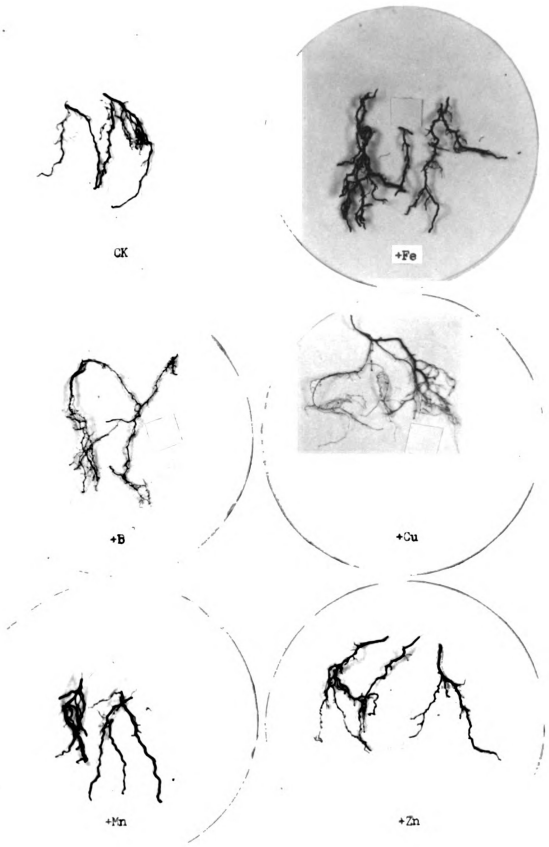

Figure 32

Total dry weight (See Figure 30): All treatments, except 3 ppm copper, reduced total dry weight noticeably below the check. The low boron and high manganese, iron, and zinc treatments resulted in the most severe reduction of weight.

Dry weight accumulation (See Figure 30): Plants receiving solutions devoid of iron or zinc, or high in copper, accumulated appreciably more dry matter than the check; while those plants receiving no boron or excessive manganese accumulated less dry matter than the check.

Vermiculite Rooting Medium

The growth response to treatment of plants growing in vermiculite was of the same magnitude for all growth measurements (Figure 33).

Severe reductions in growth were induced by high levels of manganese, iron and zinc. Less severe reductions resulted from the high and low boron and the low manganese, copper and zinc treatments.

Similar growth responses to that of the check were obtained with solutions high in copper. Only plants receiving the 0 ppm iron solution made greater growth than the check.

Figure 33

Growth of plants in vermiculite as influenced by the B, Mn, Fe, Cu and Zn level in solution.

Growth as influenced by the B, Mn, Fe, Cu and Zn level in solution

EXPERIMENT III VERMICULITE

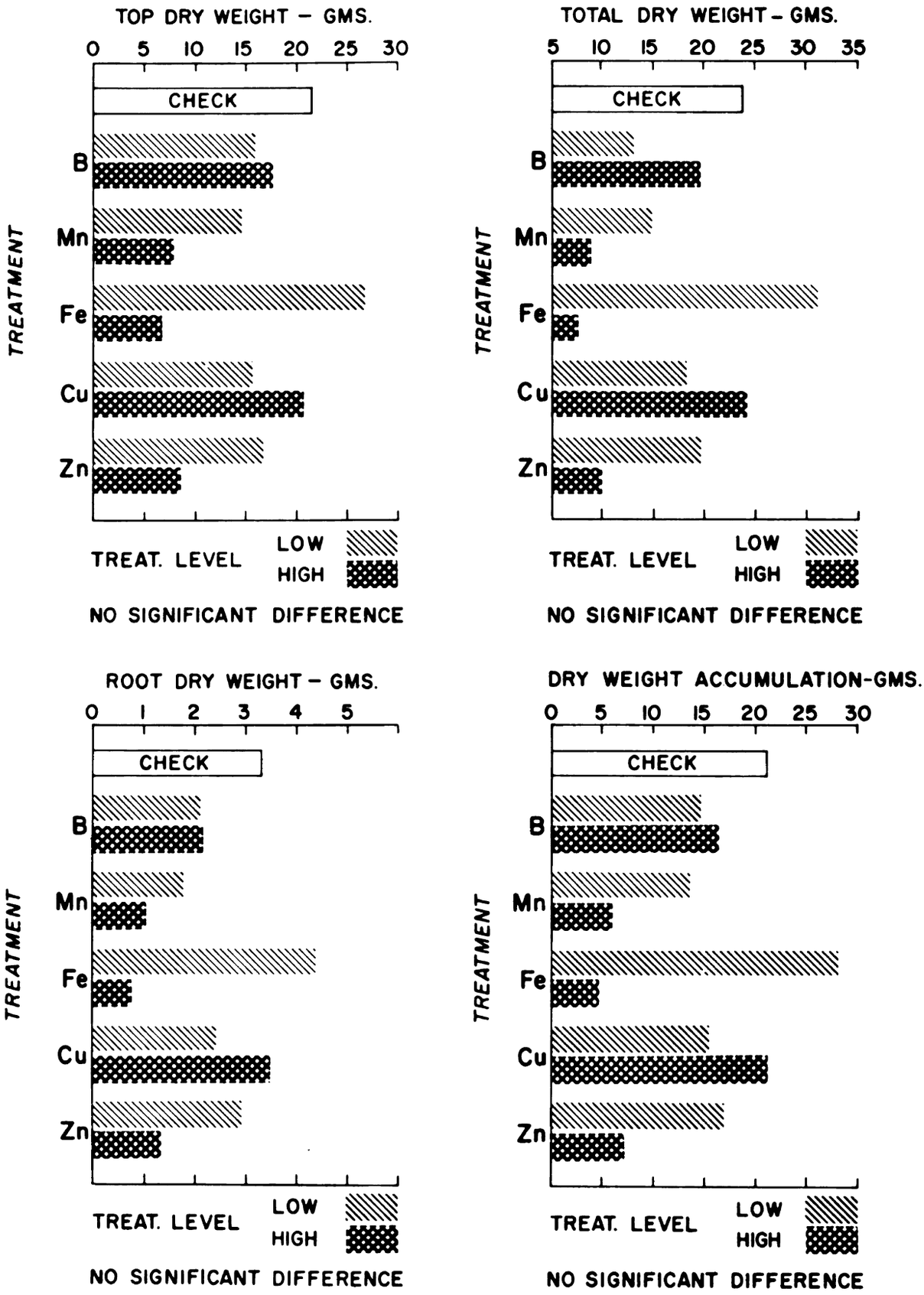

Figure 33

Experiment IV: Seasonal and Field Nutrient Disorder Studies

General Observations

During the late spring and early summer portion of the 1957 growing season considerable rainfall occurred in the blueberry producing areas of Michigan. As a result, excellent growth was made in the majority of the blueberry fields.

Consequently, the vigorous growth and the accompanying high soil moisture aggrevated a potential, but at the time unknown, shortage of magnesium in all but a few blueberry fields. Subsequently, foliar expression of magnesium deficency occurred in two Rubel plots (plots 35 and 49) previously considered free of nutrient disorders.

The Rubel bushes constituting plot 35, in addition, were of lower vigor and had considerably smaller leaves than other Rubel plots in the seasonal survey. The keeping quality of fruit harvested from this plot was extremely poor.*

Seasonal Influence on Leaf Composition

Definite seasonal trends existed for all nutrient elements in blueberry leaves, except boron. The data pertaining to these results are presented in Figures 34 and 35, and in Table I. Additional information is presented in Appendix Table 16.

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*Evaluation of fruit from this plot was made by Richard Woodruff during a cooperative shelf life experiment.

Nitrogen decreased in the leaf as the season progressed from 2.86 percent to 1.96 percent. The greatest decrease (2.86 to 2.17) occurred from June 15 to July 12. From July 12 to August 9 little change in leaf nitrogen occurred. During the period August 9 to September 5, nitrogen decreased from 2.21 percent to 1.96 percent.

Phosphorus decreased in the leaf from .21 percent on June 15 to .16 percent on July 12. No further significant changes occurred during the remaining portion of the season.

Potassium in the leaf showed a significant biweekly decrease (.712 to .507 percent) from June 15 to July 27. Thereafter, only small nonsignificant decreases occurred until September 5, at which time potassium increased to a level significantly above that of the previous sampling date, August 22.

Magnesium increased in the leaf from .19 percent to .33 percent during the period June 15 to August 22. The largest increase (.24 to .33 percent) occurred during, and immediately following, the harvest period (July 27 to August 22).

The leaf content of calcium remained at about .38 percent from June 15 to July 12. Subsequently, it increased biweekly to a high of .60 percent on September 5.

Although manganese tended to increase as the season progressed, it

Figure 34

Seasonal influence on leaf content of N, P, K, Mg and Ca (percent dry weight).

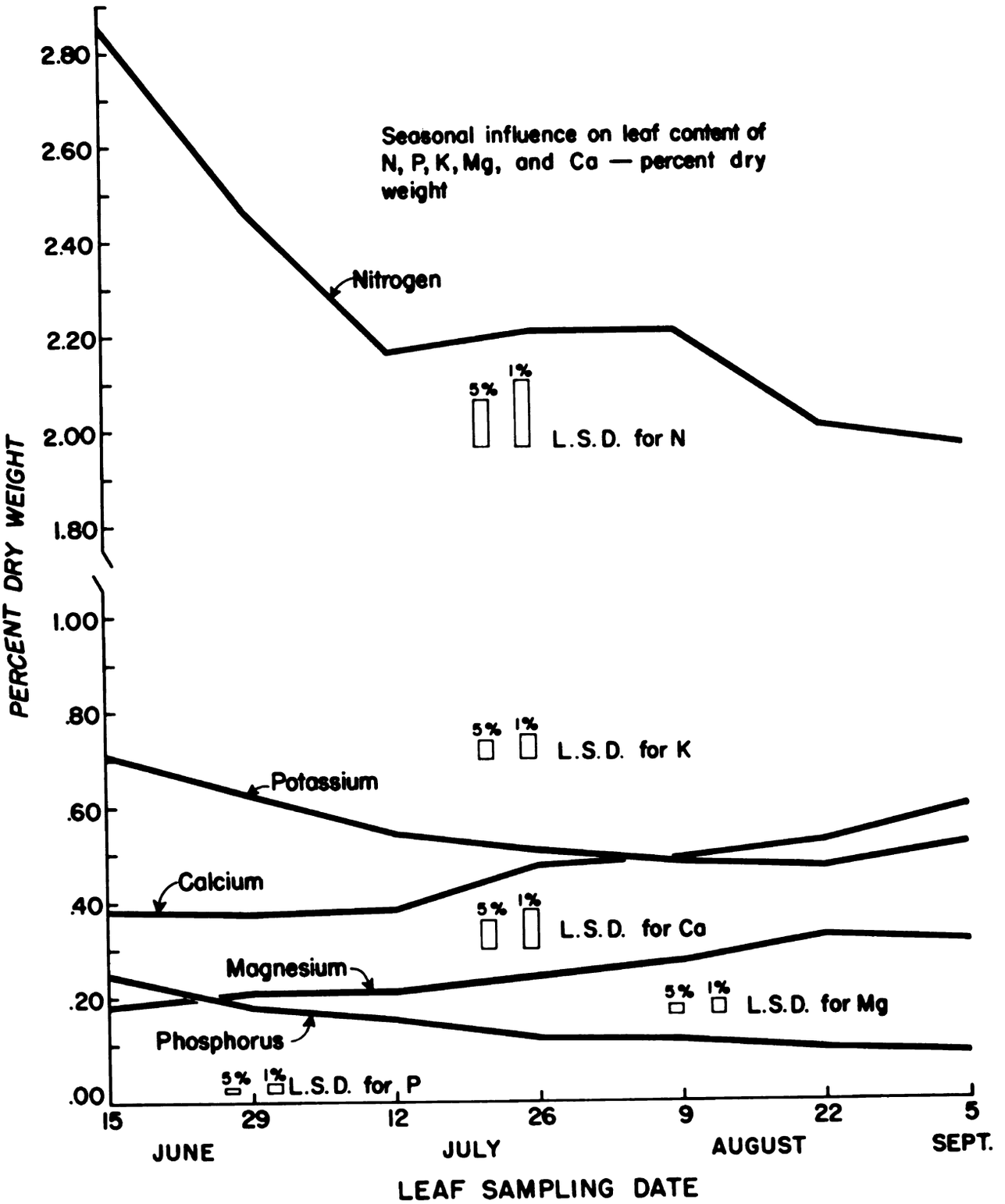

Seasonal influence on leaf content of N, P, K, Mg, and Ca — percent dry weight
Nitrogen
5%
1%
L.S.D. for N
Potassium
L.S.D. for K
Calcium
L.S.D. for Ca
Magnesium
L.S.D. for Mg
Phosphorus
L.S.D. for P
PERCENT DRY WEIGHT
2.80
2.60
2.40
2.20
2.00
1.80
1.00
.80
.60
.40
.20
.00
15
29
12
26
9
22
5
JUNE
JULY
AUGUST
SEPT.
LEAF SAMPLING DATE

Figure 34

Figure 35

Seasonal influence on leaf content of Mn, Fe, B, Cu and Zn (parts per million of dry weight).

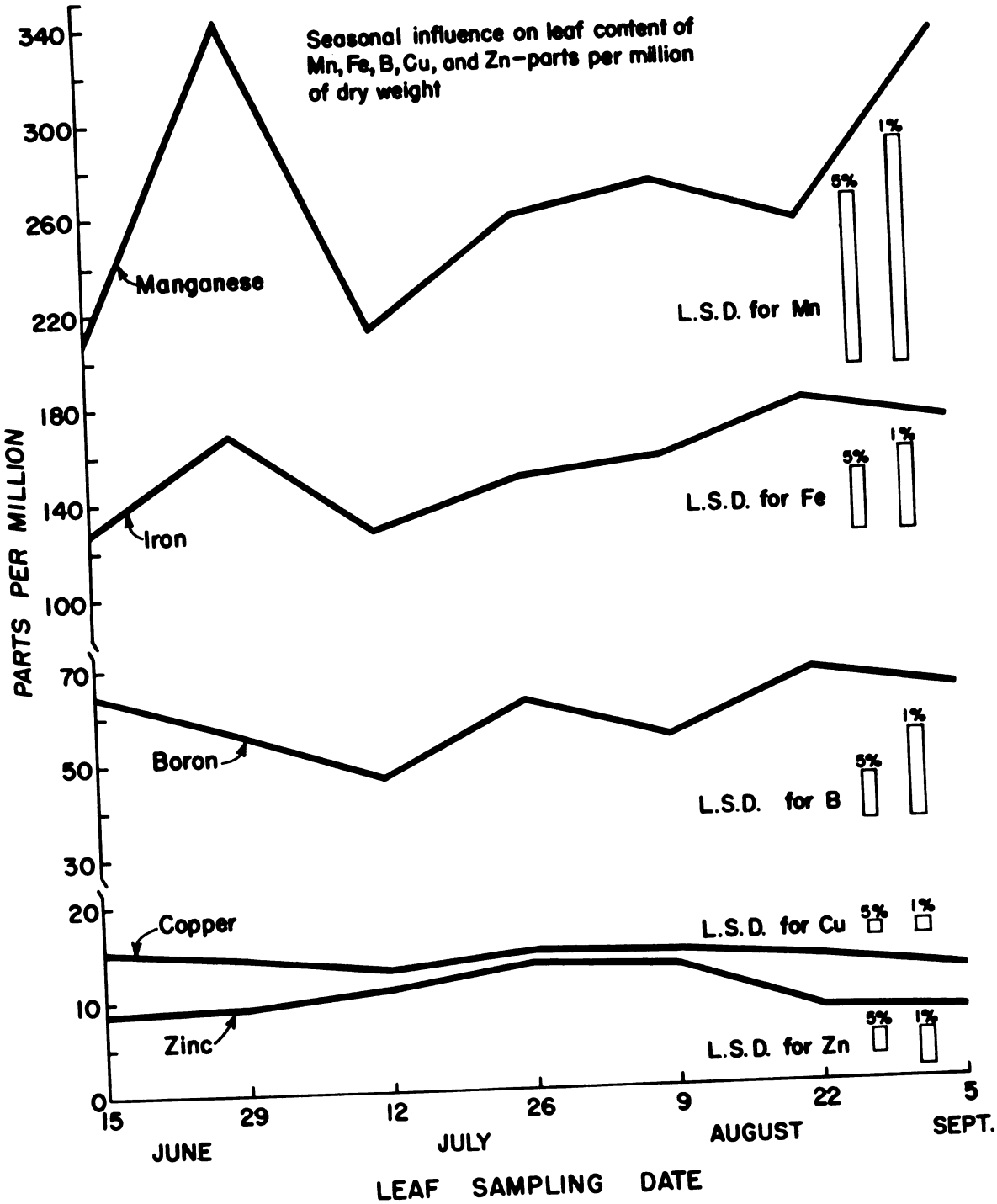

Seasonal influence on leaf content of Mn, Fe, B, Cu, and Zn—parts per million of dry weight
PARTS PER MILLION
340
300
260
220
180
140
100
70
50
30
20
10
0
Manganese
Iron
Boron
Copper
Zinc
L.S.D. for Mn
L.S.D. for Fe
L.S.D. for B
L.S.D. for Cu
L.S.D. for Zn
5%
1%
15
29
12
26
9
22
5
JUNE
JULY
AUGUST
SEPT.
LEAF SAMPLING DATE

Figure 35

appeared that leaf levels of this element were affected more by soil moisture than by seasonal effects. During dry periods manganese decreased to as low as 207 ppm, and increased to as high as 341 ppm in wet periods. This was particularly true with the Jersey variety of blueberry, which accumulated far greater amounts of manganese in the leaf than did the Rubel variety. A comparison between the manganese leaf content of these two varieties is presented in Table I.

The leaf content of iron, with the exception of the June 30 sampling, increased gradually from 128 ppm on June 15 to 177 ppm on August 22.

Boron leaf levels varied significantly during the season, but showed no explainable trends. The leaf content of boron was considerably higher, regardless of date or variety, than that found in previous years on the same plots (Appendix Table 23).

Copper levels in the leaf decreased slightly as the season progressed. A high of 15 ppm copper was obtained in leaves sampled June 15 and a low of 12 ppm was obtained on September 5. The decrease, although small, was significant.

The zinc content of blueberry leaves increased from 9 ppm on June 15 to 13 ppm on July 26. Subsequently, it decreased to a final level of 7 ppm on September 5.

TABLE I

Nutrient Element Composition of Blueberry Leaves as Influenced by Variety - Percent Dry Weight

Variety	Leaf Composition									
	N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
Rubel	2.30	.17	.546	.25	.45	.0064	.0210	.0152	.0014	.0010
Jersey	2.23	.18	.562	.26	.49	.0053	.0342	.0153	.0014	.0010
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**	N.S.	N.S.	N.S.

**Jersey significantly higher at the 1 percent level of significance.

Seasonal Influence on Fruit Composition

Although the concentrations of all nutrient elements declined as the fruit matured, considerable differences in the magnitude of decline existed between elements. Data pertaining to this survey are present in Figures 36 and 37, Table II, and Appendix Table 17.

Greatest decline of all elements occurred from June 15 to July 26 (Figures 36 and 37). July 26 marked the beginning of the harvest period, after which fruit composition showed only slight changes in composition.

The most rapid decline during this period was registered by the manganese level which decreased 73 percent. Slightly less rapid declines prevailed for boron (61 percent), calcium (59 percent), phosphorus (55 percent) and nitrogen (54 percent). Magnesium decreased moderately, while slow declines were evident for iron (29 percent), copper (24 percent), and potassium (20 percent). These decreases were all significant.

From July 26 to August 22, slow declines were apparent for all elements, except iron and copper. During this period, iron levels showed significant, but unexplainable fluctuation, whereas copper levels remained steady.

Samples collected on August 22 and September 5 consisted only of mature fruit and showed no change in nutrient composition except for potassium. Potassium showed a definite, but nonsignificant, increase from August 22 to September 5.

Figure 36

Seasonal influence on fruit content of N, P, K, Mg and Ca (percent of dry weight).

Mg and

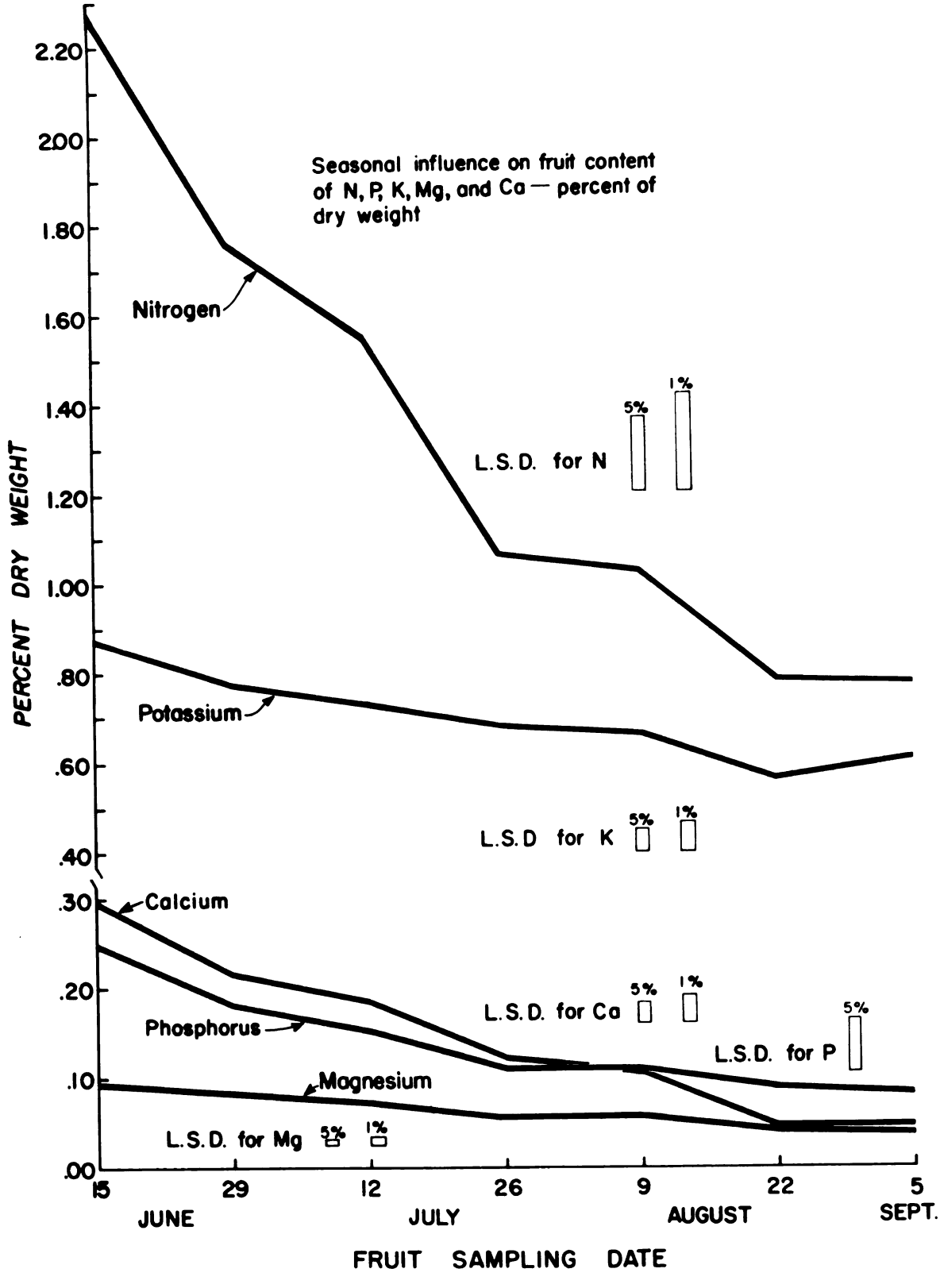


Figure 36

Figure 37

Seasonal influence on fruit content of Mn, Cu, Fe and B (parts per million of dry weight).

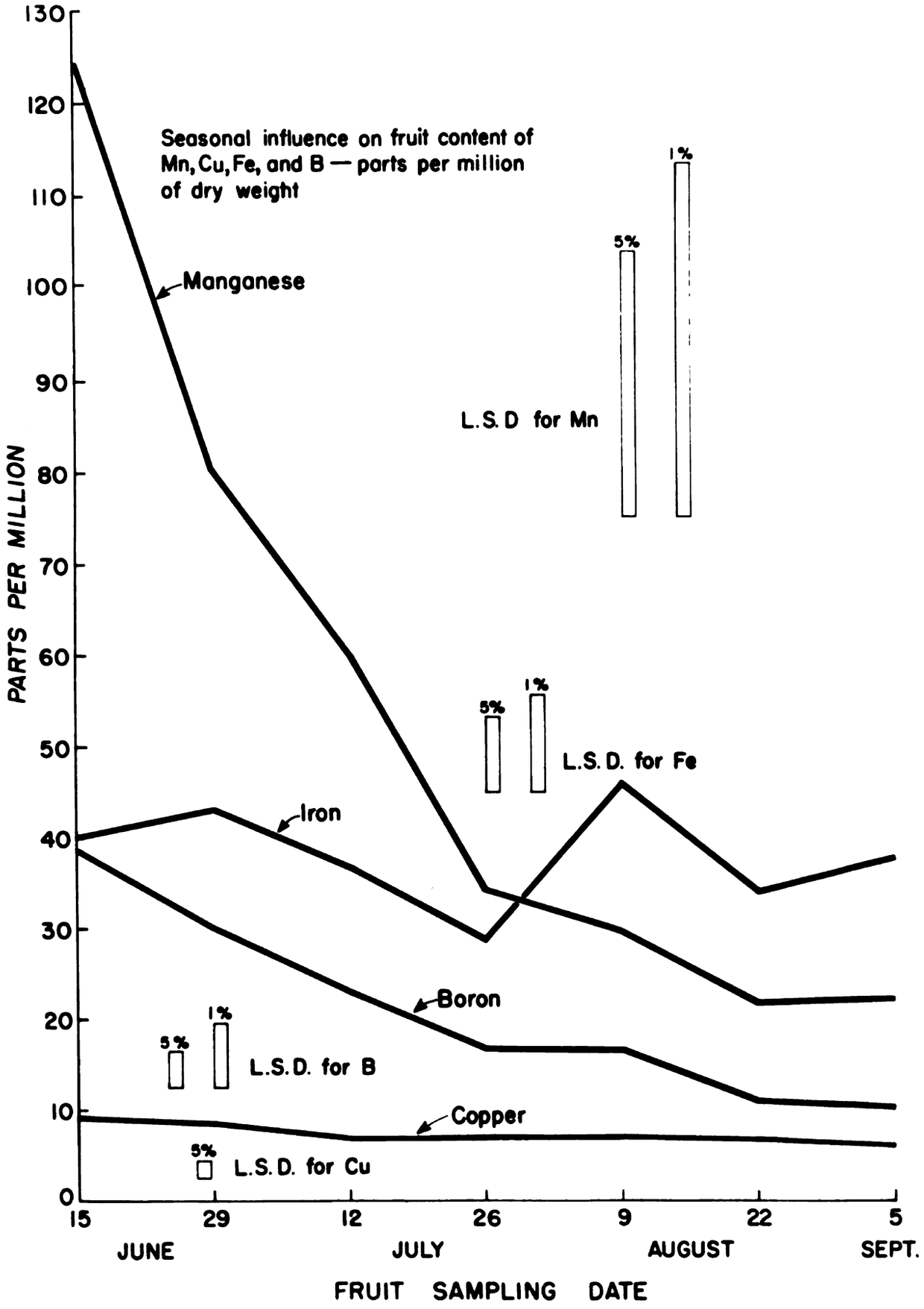

Seasonal influence on fruit content of Mn, Cu, Fe, and B — parts per million of dry weight
Manganese
Iron
Boron
Copper
L.S.D for Mn
L.S.D. for Fe
L.S.D. for B
L.S.D. for Cu
5%
1%
PARTS PER MILLION
130
120
110
100
90
80
70
60
50
40
30
20
10
0
15
29
12
26
9
22
5
JUNE
JULY
AUGUST
SEPT.
FRUIT SAMPLING DATE

Figure 37

Variety, in addition to date of sampling, exerted considerable influence on fruit composition. There were higher levels of potassium and nitrogen and lower levels of calcium, magnesium, and manganese in Rubel fruit than in Jersey fruit. This is shown in Table II.

Nutritional Disorder Survey

The environmental conditions that promoted the vigorous growth of blueberry plantings in 1957 may have stimulated the occurrence of nutrient disorders other than magnesium deficiency. Foliar symptoms ascertained to be the result of nutrient disorders are illustrated in Figures 38 to 42. Chemical analyses of leaf and fruit samples associated with the particular nutritional are presented in Appendix Table 20.

Magnesium deficiency: This disorder was the most prevalent nutrient disorder observed in 1957. Noticeable differences in the foliar expressions of the deficiency existed between varieties Rancocus, Rubel and Jersey. These differences are illustrated in Figure 38.

Coupled with these foliar differences were noticeable distinctions in the degree of susceptibility of these varieties to magensium deficiency.

In plantings known to be low in magnesium, Rancocus was found to be most severely affected, Rubel less so, and only in a few cases did Jersey exhibit foliar symptoms.

TABLE II

Nutrient Element Composition of Blueberry Fruit as Influenced by Variety - Percent Dry Weight

Variety	Nutrient Element Composition								
	N	P	K	Mg	Ca	B	Mn	Fe	Cu
Rubel	1.36	.14	.731	.061	.123	.0021	.0036	.0038	.0007
Jersey	1.29	.14	.664	.069	.174	.0021	.0075	.0039	.0008
	N.S.	N.S.	**	N.S.	**	N.S.	**	N.S.	N.S.

**Jersey variety significantly different in fruit composition from Rubel variety.

Figure 38

Top left - Magnesium deficency symptoms on the Rubel variety of blueberry. Chemical analyses of the normal medial leaves (BL 54) and basal leaves (BL 56) exhibiting symptoms of the same shoots are presented in Appendix Table 20.

Top right - Magnesium deficiency on partially shaded leaves of the Jersey variety of blueberry. Chemical analyses of these leaves (BL 132) are given in Appendix Table 20.

Bottom left - Magnesium deficiency symptoms on blueberry bushes of the Rancocus variety that were interplanted with the Rubel bushes described above.

Bottom right - Extreme case of magnesium deficiency on Pemberton blueberry bushes.

The expression of magnesium deficiency on the Jersey variety also differed according to shoot vigor. These differences are presented in Figure 39.

As previously noted in greenhouse studies, the foliar expression of magnesium was altered by the amount of solar radiation received by the leaf prior to the appearance of the symptom. As shown in Figure 39, the change from red to yellow to necrotic areas correspond to the amount of shade imposed on these leaves by their position on the shoot which arose from the center of the bush. Figure 39 illustrates the effect of extreme shade.

Chemical analyses of green leaves (BL 130), red leaves (BL 131) and yellow and necrotic leaves (BL 132) are presented in Appendix Table 20.

With leaves low in phosphorus (. 12 percent) and low in magnesium (. 07 percent), the expression of magnesium deficiency was considerably different but still recognizable as such. Figure 39 shows this complex condition.

Temporary flooding effects: In fields flooded more than five to seven days by late spring and early summer rains, foliar patterns, illustrated in Figure 40, were observed. Leaf analyses of these leaves indicated extremely low nitrogen and phosphorus (BL 55).

Manganese toxicity: Jersey plants grown in excessively wet areas developed foliar symptoms which, on the basis of leaf analyses (BL 153),

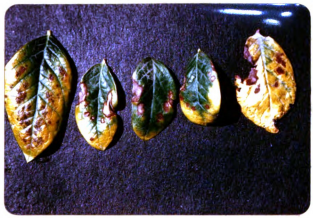
Figure 39

Top left - Magnesium deficiency on leaves taken from a slow growing shoot arising from within the bush.

Top right - Magnesium deficiency on leaves taken from a rapidly growing sucker shoot arising from the base of the plant.

Bottom left - Magnesium deficiency on shaded basal leaves of shoots arising from within the bush.

Bottom right - Magnesium deficiency symptoms complicated by phosphorus deficiency.



appeared to be the result of excessive accumulations of manganese. Figure 41 shows this phenomenon.

Phosphorus deficiency: Symptoms closely resembling phosphorus deficiency as developed in pot culture were observed in a four-year-old planting on virgin ground in the Fruitport area (Figure 40). Leaf analyses (BL 58) of these leaves indicated a phosphorus content of .12 percent.

General fertilizer toxicity on light soils: In one field the apical portion of the leaf blade showed an interveinal chlorosis (Figure 41). As the condition increased in severity, dark brown necrosis developed on the leaf margin. The symptom appeared initially on basal leaves and progressed acropetally. Toxicity symptoms of the basic cations developed in pot culture bore a resemblance to these field symptoms. Chemical analyses of these leaves (BL 61) registered a nitrogen content of 3.62 percent and a potassium content of 1.79 percent, which was much above the average values.

Potassium accumulation in tip leaves: The accumulation of potassium in tip leaves resulted in an interveinal chlorosis. This accumulation apparently can be stimulated by more than one factor.

In several fields, terminal leaves of shoots growing under dense shade exhibited the chlorosis illustrated in Figure 41. The potassium content of these leaves (BL 82) registered 1.28 percent, while exposed tip leaves (BL 81) on the same plants registered .313 percent.

Potassium accumulation in tip leaves also was found to take place when an apparent shortage of calcium existed. An illustration is presented in Figure 42.

Figure 40

Top left - Leaf showing phosphorus deficiency.

Top right - Young plant exhibiting phosphorus deficiency symptoms. Leaf analyses presented in Appendix Table 20 as sample BL 80-57.

Bottom left - Note acute petiole angle that was apparently associated with phosphorus deficiency.

Bottom right - Leaf symptoms induced by temporary flooding. Leaf analyses indicate low nitrogen and phosphorus. Leaf analyses presented in Appendix Table 20 as sample BL 55-57.

Figure 41

Top left - Apparent manganese toxicity resulting from prolonged exposure to excess soil moisture. Leaf composition presented as sample BL 50 in Appendix Table 20.

Top right - Apparent toxicity resulting from over fertilization on a dry sandy planting site. Leaf composition given as sample Bl 61-57 in Appendix Table 20.

Bottom - Interveinal net chlorosis apparently resulting from the accumulation of basic cations in tip leaves subjected to extreme shade. Chemical composition given in Appendix Table 20. See sample BL 82-57.

Figure 42

Sensitivity of the Rubel Highbush Blueberry to Apparent Excessive Fertilization when grown in a soil of low pH.

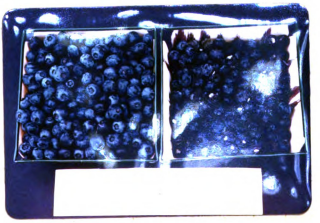
Top left - Bushes appeared excessively vigorous. Analyses of medial leaves from these bushes are presented as sample Bl 58 of Appendix Table 20. Soil tests indicated a ph of 3. 5 (Ballinger 1957, personal correspondence).

Top right - Considerable tip dieback or previous season's terminal shoot growth was apparent.

Middle left - Excessive lateral shoot growth was stimulated by dieback of the previous season's shoot tips.

Middle right - Light yellowish-green tip leaves showed a faint net chlorosis. Scorching of the apical portion of the leaf blade was evident in many cases. Leaf analyses of these tip leaves are given as BL 84 in Appendix Table 20.

Bottom - Poor keeping quality fruit on right taken from bushes described above. Illustration represents state of fruit 72 hours after harvest. Chemical analyses of poor keeping quality fruit (BF 64) and good keeping quality of fruit (BF 70) are presented in Appendix Table 20. Good keeping quality fruit taken from bushes growing in soil of pH 4. 7 (Ballinger 1957, personal correspondence).



DISCUSSION

Only small differences in leaf composition of N, P, K, Mg, Ca, Cu and Zn, under a given set of environmental conditions, may separate that level which can be considered deficient from that which is in excess. This narrow range appears to reflect the stringent nutritional requirements characteristic of the blueberry.

The leaf content of manganese, boron and iron, however, does not fall into a narrow concentration range. The leaf levels of these elements appeared to be proportional to the external supply. This was clearly illustrated for manganese and boron in Experiment III. Plants deficient in boron registered 54 ppm boron in the leaf. In the same experiment, a six fold increase in leaf content of boron induced no apparent toxicity symptoms, while a ten fold increase proved toxic. Manganese appeared toxic when leaf concentrations were double that found in check leaves. Whereas, an iron content of 162 ppm in leaves was associated with excellent growth, plants having an iron leaf content of 227 ppm were stunted. As to how low an iron leaf content may be before a shortage of iron exists was indicated by Cain (1954). He associated iron deficiency with a leaf content of 60 ppm iron or less with the Jersey variety in sand culture.

Although foliar analyses may be used successfully as a measure of determining the nutritional status of the highbush blueberry, the existence of

only a narrow nutrient composition range between that which would be considered normal and that indicative of a shortage or excess necessitates a high degree of care in the collection and analyses of leaf samples.

Differences of intensity and balance in leaf composition and growth due to treatment between Experiments I and II may reflect the cumulative effects of difference in age of plant, influence of sand medium on vigor, and the environmental conditions associated with each experiment. Of all these influences, however, light may have exerted the greatest effect. This assertion is based on the apparent sensitivity of the blueberry to light as indicated by its response to quality of light and amount of solar radiation in these studies, and by the definite day length required by the blueberry, as shown by Perlmutter and Darrow (1942).

The sensitivity of the blueberry to light was apparent in the concurrent studies in several ways. Early in Experiment I, under the same fluorescent lighting, which was adequate for good strawberry growth, blueberry plants failed to grow. A change to incandescent lighting resulted in a marked growth response. The occurrence of foliar deficiency symptoms of nitrogen and phosphorus and the characteristic expression of magnesium deficiency also showed marked dependence on the amount of solar radiation received. Growth response to varied levels of potassium, in addition, were apparently altered by the prevailing amount of solar radiation. These particular plant responses to light

may indicate that there is an increased requirement for most nutrient elements, except potassium, as the amount of solar radiation increases. Correspondingly, there is an increased requirement for potassium when the amount of solar radiation decreases. The need of changing the nutrient-element balance in solution with changes in solar radiation to maintain a suitable nutrient-element balance in the plant was over emphasized by Proebsting and Kenworthy (1954). These workers inferred that the plant's requirement for nitrogen decreased with decrease in solar radiation.

The light conditions that existed during the period in which Experiments I and II were conducted differed widely. In Experiment I, in contrast to Experiment II, most of the growth occurred under low light periods. In addition, extreme shade prevailed for an extended period of time prior to leaf sampling. Therefore, the results obtained in Experiment I may reflect the nutritional requirements of the blueberry under low light intensity, such as would be found in propagating beds and houses, while Experiment II probably reflects the nutritional requirements of field grown plants.

In sand culture the leaf content of all nutrient elements, except iron and copper, increased as the supply of the element increased. Iron and copper only increased when the external concentration was extremely high.

With the vermiculite medium only potassium and boron increased in the leaf as the external concentration of these elements increased. Substantial increases over that found in check leaves were achieved also for manganese,

iron, and copper when solutions containing the high level of these elements was used.

The lower intensity of nutrient elements in leaves from plants growing in vermiculite and the greater disruption in these leaves of the nutrient-element balance due to treatment in Experiment III probably was due to dilution because of the increased growth of plants in this medium as compared to those plants in sand.

The influence of the nitrogen level in solution on leaf composition, as determined in Experiments I and II suggests that if a lower than optimum level of another nutrient-element is available to the blueberry plant, the addition of nitrogen may induce a deficiency of that nutrient-element. Reuther, Embleton and Jones (1958) in reviewing the literature, found this to be generally true in most fruit crops, particularly in regard to phosphorus, potassium, boron, zinc and copper.

Phosphorus shortage, as well as phosphorus excess, decreased the nitrogen level in the leaf. The influence of excess phosphorus on reducing the nitrogen level in the leaf has been reported by Brown (1945) on peach. Most reports on fruit crops, however, either indicate no effect on nitrogen or an increase in nitrogen in the leaf when phosphorus is in excess supply.

When the supply of potassium or magnesium was increased from 0 ppm to 30 ppm or 24 ppm, respectively, the antagonistic influence of potassium

on the uptake of magnesium was equal in severity to the reciprocal antagonism exerted by magnesium on potassium uptake.

A further increase in supply of these two elements, however, indicated that the antagonistic influence of potassium on magnesium uptake was less severe than the reciprocal antagonism of magnesium on potassium uptake. These results were only achieved in Experiment II. In Experiment I high levels of magnesium showed no antagonism toward the leaf content of potassium. In the same experiment, high levels of potassium induced only a 10 percent decrease of magnesium in the leaf below that found in the check leaves.

These findings are contrary to what has been found in other fruit crops. Cain (1951), Shear, Crane and Meyers (1951), Lagasse and Drosdoff (1948) and others have all stressed the marked antagonism of potassium on reducing the leaf content of magnesium.

Foliar symptoms of magnesium deficiency were not induced by the 150 ppm potassium treatment. This prevailed even though the leaf content of potassium in these leaves was considerably higher than in the leaves of the 0 ppm magnesium treated plants, and sufficiently high enough to cause marginal scorching of the basal leaves. This indicated that the critical level of magnesium in blueberry leaves below which foliar expressions of magnesium deficiency will develop may be independent of the potassium concentration in the leaf. Thus, a blueberry plant provided with sufficient magnesium to

maintain the leaf content of magnesium above this critical level may not exhibit symptoms when supplied with an excess of potassium.

These findings are not in accord with the conception put forth by Shear, Crane and Meyers (1946) that magnesium deficiency may be the result of potassium excess. Granted that high levels of potassium are associated with magnesium deficiency, the content of magnesium, however, must be below a critical level for the expression of magnesium deficiency to appear.

The 0 ppm calcium treatment in Experiments I and II promoted the accumulation of heavy metals, magnesium, and potassium in the leaf. A similar balance of nutrient elements occurred in leaves taken from field plants growing in soil of pH 3. 5 and thought to be calcium deficient (BL58 - Appendix Table

The reduction in growth, development of foliar patterns on both basal and tip leaves, and the tendency toward rosetting that characterized these plants receiving 0 ppm calcium may not have been due entirely to an actual calcium shortage. It is conceivable that these responses of the plant resulted from the toxic accumulation and subsequent antagonisms of those elements that were accumulated readily in the leaf as a result of the low calcium treatment. The influence of the low pH of the 0 ppm calcium can not be segregated from that of the 0 ppm level of calcium in this study. In the field, however, low calcium is associated generally with soils having a pH below 4. 0.

The potassium-boron relationship observed in Experiment III does not reflect the findings of other investigators with other plants. Reeve and Shive (1944) demonstrated that when the boron supply was increased from a deficient level of .001 ppm up to .1 ppm, there was an increase in potassium in tomato leaves. An additional increase, however, up to 5 ppm boron resulted in a definite decrease in leaf content of potassium. The depression of potassium leaf levels by excess boron supply has also been found by Hernandez and Childers (1956) on peach and by Bergman (1957) on grape.

It is theoretically conceivable that at the pH of 4.0 to 4.2 maintained in Experiment III, a disruption of the potassium-boron relationship as found in leaves of plants adapted to a higher pH could occur. This disruption may further be intensified by the ease in which the blueberry apparently absorbed monovalent cations, such as potassium.

The difference in the leaf levels of manganese between Experiment I and II may be attributed to differences in light intensity that prevailed during each experiment. This contention is supported by the investigations of McCool (1935), which indicated that manganese toxicity and corresponding leaf levels of manganese decreased with decreasing light intensity. Morris and Pierre (1947) implied that this interaction of light and manganese leaf concentration may have influenced in similar fashion their results on the effects of manganese toxicity on Lespedeza.

These workers also observed that manganese toxicity symptoms were

less pronounced at a high iron level than at lower iron levels. Subsequently, they found that this was due to an antagonistic relationship of iron on the uptake of manganese. This same antagonism of iron on the uptake of manganese was found in Experiment III, particularly in plants grown in vermiculite.

The reverse relationship of manganese impeding the uptake of iron was not apparent in Experiment III. In Experiment II, however, the general increase in leaf content of manganese was accompanied by a decrease in the leaf content of iron below that found in Experiment I. This implies that the possibility of manganese impeding the uptake of iron as proposed by Somers and Shive (1942) may occur, depending upon environmental conditions.

It is also noteworthy that a high manganese leaf content was associated with a deficient level of every major nutrient element. The significance of this phenomenon cannot be explained at present.

The high copper level in solution did not inhibit root or top growth in Experiment III, although copper is usually more available at a low pH. This lack of toxicity may be explained by the fact that copper did not increase appreciably in the leaves with increased copper supply. Smith and Specht (1953), however, demonstrated with orange trees that lethal quantities of copper will be absorbed by the roots, but will not be transported to the leaf.

Smith (1956) reported that in addition to copper, high levels of manganese and zinc in solution also supressed root development without appreciably

altering the above ground portions of orange trees. In this present study on blueberry plants, however, solutions high in manganese, zinc and iron depressed both top and root growth to a considerable extent.

Magnesium levels in the blueberry leaf decreased with increasing or decreasing supply of the heavy metal nutrient elements studied. Similar decreases in the magnesium level of orange trees was achieved by Smith (1956) using high levels of copper, zinc and manganese. The antagonistic effects of high iron on the accumulation of magnesium in the leaf has not been reported for other crops.

A reciprocal antagonistic relationship of magnesium on the leaf content of boron, iron and manganese was apparent in Experiment II.

The seasonal leaf sampling survey showed that the greatest consistency in the leaf content of all nutrient elements occurred during the three week period prior to and including the first week in which 35 percent of the crop could be harvested. This period of the season, therefore, may be considered as the optimum time to collect blueberry leaf samples, if an accurate diagnosis of the nutritional status of a blueberry plant is to be made.

Variety differences, in respect to leaf composition and nutrient requirement of manganese and magnesium should be taken into consideration when evaluating the nutritional status of the blueberry by foliar analyses.

As indicated in the results, considerably more manganese may be found in the leaves of the Jersey variety than in the Rubel variety. This same

phenomenon was evident upon re-evaluation of data collected by Ballinger (1957, unpublished data) in 1955 and 1956. This is presented in Table III.

The inability of the Rubel variety to accumulate as much manganese as the Jersey variety on a given site may explain why Rubel is more adapted to fertile soils of greater moisture content than is Jersey. Blueberry bushes of the Jersey variety planted in the wetter portions of blueberry fields showed foliar disorders and shoot dieback in 1957 that were later associated with high manganese leaf levels. Correspondingly, no Rubel bushes were found that showed evidence of manganese toxicity even though planted in close proximity to the Jersey variety.

Although manganese toxicity has not been previously reported affecting blueberries, it has been shown by many workers as a limiting factor in the production of such crops as potatoes (Berger and Gerloff, 1948), tobacco (Bortner, 1935), Lespedeza (Morris and Pierre, 1948) on acid soils.

Field leaf samples of 1957 also indicated that with the Rubel variety magnesium deficiency may be associated with a much higher leaf level of magnesium than with the Jersey variety. Hence, it may be assumed that the Rubel variety has a greater requirement for magnesium. Similar differences in magnesium requirements between varieties have also been found in celery (Pope and Munger, 1951).

Chemical analyses of blueberry leaves, sampled as described in the

methods of Experiment IV, can be expected to indicate low or high levels of a particular nutrient, if a shortage or excess exists for that nutrient. It will not, however, show these conditions in the same magnitude nor will it show associated nutrient interrelationships to the same extent as would analyses of the tip or basal leaves that are exhibiting the particular symptom.

Medial leaves, for example, on a shoot whose basal leaves are exhibiting magnesium deficiency symptoms, will indicate upon analyses a shortage of magnesium. The potassium content of these medial leaves, however, will not be abnormally high. Yet, analyses of the basal leaves will show an extreme shortage of magnesium accompanied by a definite excess of potassium.

Hence, the identification of questionable nutrient disorders may be enhanced greatly if analyses of affected leaves could be compared to a corresponding tip or basal leaf standard composition range. Further research along these lines should provide valuable information.

Tentative standard leaf composition values, as established by a survey reported by Ballinger (1957) do not reflect necessarily optimum levels of nutrients. They represent the average nutrient-element composition of leaves collected from bushes in plots of high productivity. The fact that two of nine plots, which were designated as free of nutrient disorders, exhibiting magnesium deficiency symptoms in 1957, illustrate the fallacy of considering leaf composition values obtained by survey methods as the optimum.

Based upon the occurrence of magnesium deficiency in the field and results of this study, the suggested standard values have been reassigned. A tentative standard range for the nutrient-elements in the leaf is proposed. This range is presented in Table IV.

Plants, whose leaf composition compares favorably to this range of nutrients, may be expected to be of good vigor and to be productive, providing, however, that proper climatic conditions and cultural practices prevail.

The magnesium deficiency condition that existed in many blueberry plantings in 1957 probably was the cumulative effect of a number of influential factors, such as greater soil moisture, generally low magnesium supply, and an increased availability of nitrogen as manifested by higher nitrogen leaf levels.

The antagonistic influence of potassium, which would ordinarily be suspected as a causative agent in magnesium deficiency conditions, probably exerted only a minor influence in 1957. This assertion is made on the basis that the leaf level of potassium was lower in seven of nine standard plots in 1957 than in the two years previous (see Appendix Table 19).

This decrease in leaf potassium levels appeared even in plots showing magnesium deficiency. The two plots in which potassium did increase showed also the highest nitrogen levels. A relationship similar to that found in Experiments I and II.

TABLE IV

Tentative Standard Range for Optimum Blueberry Leaf Composition (Percent Dry Weight) as Compared to the Tentative Standards Established by Ballinger (1957)

Nutrient	Percent Composition	
	Standard Range	Standard Established by Ballinger
Nitrogen	1.95 - 2.15	1.98
Phosphorus	.15 - ?	0.16
Potassium	.450 - .550	0.527
Magnesium	.25 - .30	0.28
Calcium	.50 - .80	0.74
Boron	.0050 - .0150	0.0049
Manganese	.0050 - .0350	0.0168
Iron	.0070 - .0200	0.0150
Copper	.0010 - .0020	0.0015
Zinc	.0008 - .0020	0.0020

The antagonistic relationship between an increasing nitrogen supply and leaf content of magnesium was illustrated in Experiments I and II. This same relationship appeared in the field. A planting showing mild to moderate magnesium deficiency, was given supplemental ammonium sulfate (one-quarter pound per bush) during the early part of July 1957. Within two to three weeks most of the planting appeared as illustrated by Figure 38.

Although the foliar expressions of magnesium deficiency have been previously described by Bailey et al. (1947) and Mikkelson and Doehlert (1947), and Kramer and Schrader (1942) for the highbush blueberry, the relationship between light and the development of these symptoms as observed in the present studies has not been reported.

The differences between varieties in nutrient-element composition of fruit (Table II) may be related to the generally observed differences between varieties in keeping quality. The Rubel fruit, which accumulated more nitrogen and potassium and less calcium, magnesium and manganese than the Jersey fruit, often has poorer keeping quality. The keeping quality of Rubel appeared to be reduced if nitrogen and potassium were higher and calcium lower than average.

In re-evaluating the data collected by Ballinger in 1956, similar varietal differences in fruit composition were noted. This is presented in Table III.

TABLE III

Nutrient Element Composition of Blueberry Leaves and Fruit as Influenced by Variety - Percent Dry Weight (Re-evaluation of Unpublished Data Collected by W. E. Ballinger in 1956)

Variety	Nutrient Element Composition									
	N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
					Leaf					
Rubel	1.73	.14	.480	.22	.62	.0037	.0102	.0127	.0018	.0017
Jersey	1.71	.14	.479	.23	.72	.0034	.0195	.0152	.0017	.0021
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**		N.S.	N.S.
					Fruit					
Rubel	.613	.074	.531	.037	.32	.0070	.0011	.0023	.0005	
Jersey	.532	.062	.445	.037	.31	.0069	.0019	.0025	.0005	
	**	N.S.	*	N.S.	N.S.	N.S.	**	N.S.	N.S.	

* or **Jersey variety significantly different in fruit composition from Rubel variety.

Leaf composition did not reflect the significant varietal difference found in fruit composition in respect to potassium and calcium. It did, however, reflect the greater manganese content of the Jersey fruit. Consequently, leaf analyses should be accompanied by fruit analyses if nutrient disorders involving fruit are to be accurately diagnosed.

The foliar symptoms associated with shortages of particular nutrient elements in the current study differed in several respects to that reported by Minton, Hagler and Brightwell (1951) for the rabbiteye blueberry, and by Kramer and Schrader (1942) for the highbush blueberry. In both of these reports potassium deficiency developed as an interveinal chlorosis on young leaves and was accompanied by a severe necrosis of older leaves. In the current study, foliar symptoms of potassium deficiency were confined to a slight submarginal necrosis on older leaves. These symptoms did not appear until five months after treatment initiation, and then only in Experiment I. These workers also reported that foliar symptoms of phosphorus deficiency were slow to appear. The time of appearance of foliar symptoms of phosphorus shortage in the current study depended on the amount of solar radiation received. This probably was an indirect relationship with carbohydrate accumulation in these leaves. This relationship was not considered in the previous studies.

Kramer and Schrader (1942) observed that terminal leaves of boron

deficient plants were misshapen. This condition was not observed in Experiment III. The lack of misshapen leaves, however, may represent a difference in severity of boron deficiency.

A shortage of any one of the nutrient elements, except nitrogen and phosphorus, and an excess of any one of the nutrient elements, except phosphorus, in the current pot and field studies was associated with the occurrence of a chlorosis or a necrosis, or both. In light of the reports of Kramer and Schrader (1945) and Cain (1952, 1954, 1955), these results suggest that any disturbance of the metabolic processes within the blueberry leaf that causes the cell sap to have a higher pH value will be manifested by the appearance of a chlorosis or necrosis. The patterns of this chlorosis or necrosis will depend on the particular element or elements that cause the nutrient disorder.

Excess potassium accumulations may occur in both tip and basal leaves. Potassium appeared to accumulate in tip leaves when these leaves were subjected to extreme shade, or when calcium was in short supply. The accumulation of potassium in basal leaves occurred when magnesium was in short supply, or when excessive N-P-K fertilizers were applied. These accumulations may be explained on the basis that a shortage of an antagonizer exists at the time of accumulation of potassium in these leaves. Based on the appearance of deficiency symptoms, calcium may assume this role in tip leaves while magnesium may assume it in basal leaves. A shortage of either one of

these elements may result in an accumulation of potassium in those leaves affected most severely by the shortage. It appears, however, that calcium cannot substitute for magnesium and vice versa in this antagonistic function in the blueberry plant.

This explanation is in accord with some of the ideas expressed by Cain (1951) to the effect that the accumulation of basic cations in the leaves of such plants as the apple are the result of a shortage of an antagonizer. Cain, however, contended that basic cations could substitute for each other in this function.

SUMMARY

One- and two-year-old rooted cuttings of the highbush blueberry Vaccinium corymbosum L. were grown in quartz sand and in vermiculite under varied levels of ten nutrient elements. Leaf analysis and plant response to treatment in terms of foliar expressions, root development and growth were recorded and discussed. In addition, leaf and fruit samples were collected biweekly in the summer of 1957 to ascertain seasonal influences on leaf and fruit composition. Commercial blueberry fields were also surveyed for nutritional disorders. Leaf analyses, photographic and descriptive records were collected of the nutritional disorders observed.

In sand culture the leaf content of N, P, K, Mg, Ca, B and Mn increased as the supply of the element increased. Iron and copper increased in the leaf only when a high external supply existed. With the vermiculite rooting media only potassium and boron increased in the leaf as the supply of the element increased. Manganese, iron and copper leaf levels increased substantially only when solutions containing high levels of these elements were used.

In varying the concentration of particular nutrient elements in solution, numerous nutrient interrelations became apparent. Some of these relationships are as follows:

1. As the supply of nitrogen increased, all elements except phosphorus decreased in the leaf.

2. A shortage or excess of phosphorus decreased the nitrogen level in the leaf.

3. As the supply of potassium or magnesium increased from 0 ppm to 30 ppm or 24 ppm, respectively, the antagonistic influence of potassium on the uptake of magnesium was equal in severity to the reciprocal antagonism exerted by magnesium on potassium uptake. With further increases in the supply of these two elements, the antagonistic influence of potassium on magnesium uptake was less severe than the reciprocal antagonism of magnesium on potassium uptake.

4. Iron showed a strong antagonistic influence on the uptake of manganese. Manganese did not exhibit a reciprocal relationship on iron.

5. A low level of any one of the major elements in solution resulted in a high manganese leaf level.

6. A low level of calcium in solution promoted the accumulation of the heavy metal nutrient-elements, magnesium and potassium in the leaf.

7. The potassium level in the leaf increased with increased supply of boron.

The expression and rapidity of appearance of foliar symptoms depended to a large extent on solar radiation. Characteristic leaf pigmentation of N, P and Mg deficiencies appeared sooner and were more conspicuous under high amounts of solar radiation. Under low amounts, these same symptoms faded, or in the case of magnesium deficiency, developed completely different characteristics.

A shortage of any one of the nutrient elements, except nitrogen and phosphorus, and an excess of all nutrient elements, except phosphorus, were associated with the occurrence of a chlorosis or necrosis, or both. It was suggested that any disturbance of the metabolic processes within the blueberry leaf that increases the cell sap pH value will be manifested by the appearance of a chlorosis or necrosis.

Growth response to treatment differed according to available solar radiation. There appeared to be an increased requirement for most major nutrient elements, except potassium, as the amount of solar radiation increased. Correspondingly, there was an increased requirement for potassium when the amount of solar radiation decreased. Under low solar radiation the high potassium treatment induced the greatest amount of growth, while under high solar radiation the high phosphorus treatment stimulated the greatest amount of growth.

Root systems were found to be more indicative of a deficiency or toxicity than were foliar symptoms in sand culture. Low nitrogen levels in solution stimulated root growth, while high N, B, Mn, Fe and Zn and low Ca, B, Mn solution levels noticeably reduced root development. The high phosphorus treatment induced the most desirable root system.

Blueberry plants were found to grow extremely well in vermiculite if supplied with nitrogen and phosphorus. Plants growing in vermiculite showed

noticeable reductions in growth when supplied with potassium or iron.

Definite seasonal trends existed for all nutrient elements in the leaves except boron. Nitrogen, potassium, phosphorus and copper decreased, while magnesium, calcium, iron, manganese and zinc increased in varying degrees as the season progressed. Late in the season potassium increased and zinc decreased in the leaf.

The biweekly leaf sampling study indicated that the greatest consistency in the leaf content of all nutrient elements occurred during the three week period prior to, and including, the first week in which 35 percent of the crop could be harvested.

Marked varietal differences were apparent in respect to leaf and fruit composition and nutrient requirements. Considerably more manganese was generally found in the leaves of the Jersey variety than in leaves of the Rubel variety. Subsequently, the Jersey variety was found to accumulate toxic amounts of manganese, while the Rubel variety did not, even though both were grown on the same or on similar excessive wet sites. Foliar symptoms of magnesium deficiency were associated with a much higher medial leaf content of magnesium with Rubel than with Jersey. This was interpreted to mean that Rubel has a higher requirement for magnesium than Jersey. Rubel fruit usually contained higher levels of potassium and lower levels of calcium than did Jersey fruit. These differences in fruit composition were associated with differences

in keeping quality. Rubel fruit showed lower keeping quality than Jersey when nitrogen and potassium were higher and calcium lower than average.

Although the concentration of all nutrient elements in the fruit declined with increased maturity, considerable differences in the magnitude of decline existed between elements. The percent decrease of these elements during the six week period prior to harvest was as follows: manganese - 73 percent; boron - 61 percent; calcium - 59 percent; phosphorus - 55 percent; nitrogen - 54 percent; magnesium - 41 percent; iron - 29 percent; copper - 24 percent; and potassium - 20 percent. Slow declines of all nutrient elements except iron and copper occurred during the harvest period.

The nutritional disorder survey indicated the existence in 1957 of shortages of nitrogen, phosphorus, magnesium and calcium, excesses of nitrogen, potassium and manganese in commercial blueberry fields.

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A P P E N D I X

Appendix Table 1

Nutrient-Element Composition of Treatment Solution Used from January 15 to February 16, 1957[†]

Chemical Used	Nutrient Supplied	Nutrient Composition of Treatment Solution** (ppm)					
		Check	-N	-P	-K	-Mg*	-Ca***
$(NH_4)_2SO_4$	(N)	140	0	140	140	140	140
NH_4Cl	(N)	56	56	56	56	56	56
$NH_4C_2H_3O_2$	(N)	0	0	0	0	0	28
H_3PO_4	(P)	0	0	0	0	0	0
$K_2H\,PO_4$	(P)	47	47	0	0	47	47
	(K)	117	117	0	0	117	117
K_2SO_4	(K)	0	0	117	0	0	0
$MgCl_2$	(Mg)	49	49	49	49	0	49
$Ca(C_2H_3O_2)_2$	(Ca)	160	160	160	160	160	0

*Hydrochloric acid added to -Mg solution to maintain constant Cl concentration in all treatments.

**Sulfuric acid used in all solutions to adjust pH at 4.0.

***Minus calcium solution contained an additional 28 ppm nitrogen.

[†]Plants designated to receive plus treatments were given check solution until February 17, 1957.

Appendix Table 2

Nutrient-Element Composition of Treatment Solutions Used February 17 to April 24, 1957

Chemical Used	Nutrient Supplied	Nutrient Composition of Treatment Solutions (ppm)										
		Check	-N	-P	-K	-Mg*	-Ca*	+N	+P	+K	+Mg	+Ca
$(NH_4)_2SO_4$	(N)	140	0	140	140	140	140	280	140	140	140	196
NH_4Cl	(N)	56	21	56	56	56	28	56	56	56	56	0
$(NH_4)(C_2H_3O_2)$	(N)	0	0	0	0	0	28**	0	0	0	0	0
H_3PO_4	(P)	0	0	0	0	0	0	0	47	0	0	0
K_2HPO_4	(P)	47	47	0	0	47	47	47	47	47	47	47
	(K)	117	117	117	0	117	117	117	117	117	117	117
K_2SO_4	(K)	58	58	58	24***	58	58	58	58	175	58	58
$MgCl_2$	(Mg)	49	49	49	49	0	49	49	49	49	98	0
$MgSO_4$	(Mg)	0	0	0	0	0	0	0	0	0	0	49
$Ca(C_2H_3O_2)$	(Ca)	160	160	160	160	160	0	160	160	160	160	160
$CaCl_2$	(Ca)	0	0	0	0	0	0	0	0	0	0	180

*Hydrochloric acid added to -Mg and -Ca solutions to maintain constant Cl concentration in all treatments.

**$NH_4C_2H_3O_2$ proved toxic (caused excessive wilting) and was replaced by $HC_2H_3O_2$ after one application.

***24 ppm potassium was added to prevent complete loss of -K solution treated plants. Its use was discontinued after four weeks.

Appendix Table 4

Nutrient-Element Composition of Treatment Solutions Used After May 10, 1957

Chemical Used	Nutrient Supplied	Nutrient Composition of Treatment Solutions (ppm)**										
		Check	-N	-P	-K	-Mg	-Ca*	+N	+P	+K	+Mg	+Ca
$(NH_4)_2SO_4$	(N)	105	21	105	105	105	105	525	52	105	105	105
$(NH_4)H_2PO_4$	(N)	0	0	0	0	0	0	0	53	0	0	0
	(P)	0	0	0	0	0	0	0	120	0	0	0
H_3PO_4	(P)	30	30	0	30	30	30	30	30	30-	30	30
K_2SO_4	(K)	30	30	30	0	30	30	30	30	150	30	30
$MgSO_4$	(Mg)	24	24	24	24	0	24	24	24	24	122	24
$Ca(C_2H_3O_2)_2$	(Ca)	40	40	40	40	40	0	40	40	40	40	40
$CaSO_4$	(Ca)	0	0	0	0	0	0	0	0	0	0	160
Solution	pH	4.0	4.0	4.0	4.3	4.0	3.0	4.0	4.2	4.2	3.5	4.0

*Acetic acid used in -Ca solutions to maintain constant acetate level in all treatments.

**Sulfuric acid used in -P, -K, -Mg, +N and +Ca solutions to maintain pH below 4.3.

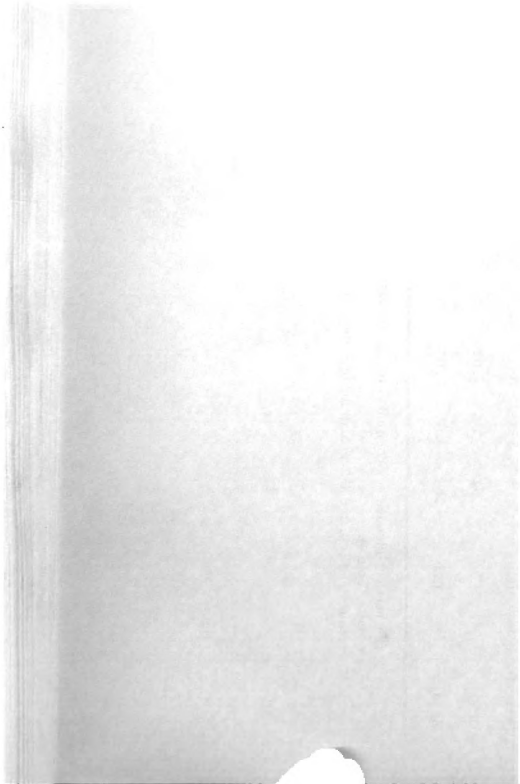
Appendix Table 5

Nutrient-Element Composition of Treatment Solutions Used in Experiment III*

Chemical Used	Nutrient Supplied	Nutrient Composition of Treatment Solutions (ppm)**										
		Check	-B	-Mn	-Fe	-Cu	-Zn	+B	+Mn	+Fe	+Cu	+Zn
H_3PO_4	(B)	.50	0	.5	.5	.5	.5	7.5	.5	.5	.5	.5
$MnSO_4$	(Mn)	.50	.5	0	.5	.5	.5	.5	7.5	.5	.5	.5
Sequestrene 300	(Fe)	5	5	5	0	5	5	5	5	75	5	5
$CuSO_4$	(Cu)	.02	.02	.02	.02	0	.02	.02	.02	.02	3	.02
$ZnSO_4$	(Zn)	.05	.05	.05	.05	.05	0	.05	.05	.05	.05	.75

*Major nutrient-element composition of these solutions identical to that of the check in Experiment III (see Appendix Table 4).

**pH maintained at 4.0 to 4.2 by addition of sulfuric acid.



Appendix Table 6

Leaf Composition of Blueberry Plants in Experiment I as Influenced by Various Levels of N, P, K, Mg and Ca

Treatment	Nutrient Content - Percent Dry Weight									
	N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
CK	2.30	.22	.654	.35	.46	.0207	.0055	.0281	.0034	.0012
-N	1.83	.20	.866	.38	.60	.0275	.0118	.0289	.0053	.0014
+N	2.80	.24	.770	.29	.51	.0182	.0045	.0229	.0036	.0008
-P	2.11	.15	.728	.34	.49	.0187	.0103	.0293	.0039	.0009
+P	2.06	.28	.703	.32	.51	.0174	.0062	.0356	.0035	.0011
-K	2.29	.21	.481	.41	.47	.0284	.0072	.0289	.0049	.0010
+K	2.23	.23	1.110	.31	.42	.0293	.0051	.0291	.0053	.0012
-Mg	2.39	.23	.776	.25	.43	.0282	.0059	.0305	.0039	.0010
+Mg	2.31	.20	.663	.42	.44	.0196	.0058	.0307	.0048	.0009
-Ca	2.20	.21	.775	.33	.45	.0236	.0053	.0295	.0040	.0009
+Ca	2.28	.20	.673	.32	.45	.0221	.0055	.0248	.0037	.0011
L. S. D. 5%	.20	.03	.065	.05	.09	.0082	.0013	N. S.	N. S.	N. S.
1%	.27	.04	.088	.06	N. S.	N. S.	.0017	N. S.	N. S.	N. S.

Appendix Table 7

Growth Measurements of Blueberry Plants in Experiment I as Influenced by Various Levels of N, P, K, Mg and Ca

Treatment	Dry Weight (gms)						Shoot Length (mm)
	Leaf	Shoot	Stem	Top	Root	Total	
CK	5.34	2.60	2.47	10.41	3.51	13.91	1136
-N	1.97	1.55	2.37	5.89	4.01	9.90	640
+N	1.83	.91	2.04	4.77	1.22	6.00	838
-P	2.64	1.10	2.64	6.37	2.92	9.29	622
+P	5.35	2.83	2.53	10.71	3.98	14.69	1406
-K	6.19	3.34	3.31	12.84	4.76	17.60	1315
+K	7.72	4.15	3.08	14.94	5.36	20.31	1539
-Mg	7.38	3.41	2.78	13.57	4.37	17.93	1714
+Mg	5.94	2.84	2.54	11.32	4.00	15.32	1331
-Ca	4.53	2.87	2.81	10.20	3.97	14.17	1118
+Ca	5.27	2.65	2.88	10.80	3.75	14.54	1299
L. S. D. 5%	2.40	1.18	.66	3.62	1.41	4.95	285
1%	3.18	1.55	N. S.	4.80	1.86	6.56	377

Appendix Table 8

Leaf Composition of Blueberry Plants in Experiment II as Influenced by Various Levels of N, P, K, Mg and Ca

Treatment	Nutrient Content - Percent Dry Weight									
	N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
CK	2.46	.29	.956	.45	.58	.0274	.0159	.0179	.0032	.0009
-N	1.71	.24	1.022	.45	.75	.0241	.0205	.0225	.0031	.0013
+N	2.60	.24	.826	.38	.55	.0238	.0339	.0196	.0023	.0009
-P	2.28	.13	.783	.39	.56	.0150	.0230	.0193	.0026	.0011
+P	2.19	.41	.769	.37	.65	.0310	.0127	.0218	.0028	.0009
-K	2.65	.28	.576	.49	.63	.0250	.0205	.0185	.0030	.0012
+K	2.39	.27	1.335	.42	.63	.0244	.0156	.0212	.0042	.0010
-Mg	2.57	.42	1.054	.36	.62	.0382	.0232	.0238	.0032	.0011
+Mg	2.64	.23	.802	.59	.68	.0211	.0134	.0178	.0041	.0012
-Ca	2.53	.30	.992	.59	.55	.0328	.0391	.0263	.0053	.0013
+Ca	2.47	.29	.931	.48	.73	.0296	.0202	.0153	.0031	.0010
L. S. D. 5%	.31	.04	.142	.09	.10	N. S.	.0092	.0055	.0015	.0003
1%	.41	.05	.191	.12	.14	N. S.	.0124	N. S.	N. S.	N. S.

Appendix Table 9

Growth Measurements of Blueberry Plants in Experiment II as Influenced by Various Levels of N, P, K, Mg and Ca

Treatment	Dry Weight (gms)							Shoot Length (mm)
	Leaf	Shoot	Stem	Top	Root	Total	Accumulation	
CK	10.44	5.50	7.48	23.42	13.11	36.53	16.13	2111
-N	7.55	4.84	8.12	20.51	16.35	36.86	19.56	1420
+N	3.11	1.30	5.99	10.64	5.99	15.46	.48	1271
-P	6.21	3.17	7.21	16.59	10.40	26.99	9.92	1293
+P	15.22	9.41	9.19	33.64	13.46	47.28	30.69	2795
-K	9.90	4.29	7.81	22.00	9.95	31.95	14.37	2137
+K	9.84	4.51	7.08	21.43	10.76	32.20	14.62	1997
-Mg	8.83	4.77	7.61	18.70	10.26	28.81	11.29	2061
+Mg	11.23	5.37	7.40	24.00	10.93	34.93	17.78	2307
-Ca	3.77	2.01	6.48	12.26	7.99	20.25	3.40	805
+Ca	8.06	4.08	7.81	19.95	10.01	29.96	12.46	1880
L.S.D. 5%	3.77	N.S.	N.S.	6.94	3.86	10.17	9.72	808
1%	5.08	N.S.	N.S.	9.36	5.20	13.70	13.10	1089

Appendix Table 10

Leaf Composition of Blueberry Plants in Experiment II Grown in Vermiculite and Subjected to Various Levels of N, P, K, Mg and Ca

Treatment	Nutrient Content - Percent Dry Weight									
	N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
-N	1.59	.17	.778	.37	.70	.0241	.0229	.0222	.0021	.0007
CK	2.44	.20	.881	.33	.55	.0155	.0172	.0393	.0017	.0011
+N	2.41	.21	1.11	.23	.37*	.0051	.0352	.0231	.0013	.0008
-P	2.36	.16	.860	.30	.54	.0212	.0235	.0314	.0019	.0012
CK	2.44	.20	.881	.33	.55	.0155	.0172	.0393	.0017	.0011
+P	2.25	.20	.955	.28	.59	.0314	.0203	.0139	.0028	.0011
-K	2.46	.19	.819	.33	.61	.0202	.0164	.0347	.0017	.0013
CK	2.44	.20	.881	.33	.55	.0155	.0172	.0393	.0017	.0011
+K	2.41	.18	1.13	.26	.54	.0200	.0226	.0250	.0021	.0006
-Mg	2.52	.19	.851	.31	.47*	.0286	.0219	.0282	.0016	.0007
CK	2.44	.20	.881	.33	.55	.0155	.0172	.0393	.0017	.0011
+Mg	2.31	.17	.885	.34	.72	.0081	.0175	.0195	.0016	.0014
-Ca	2.53	.19	1.09	.36	.46*	.0257	.0223	.0357	.0015	.0009
CK	2.44	.20	.881	.33	.55	.0155	.0172	.0393	.0017	.0011
+Ca	2.28	.20	.894	.30	.56	.0150	.0231	.0511	.0019	.0012

*Obtained by extending the standard curve; hence, the values should be regarded as relative rather than absolute.

Appendix Table 11

Growth of Blueberry Plants In Experiment II Grown in Vermiculite when Subjected to Various Levels of N, P, K, Mg and Ca

Treatments	Growth Measurements			
	Top Growth (gms)	Root Growth (gms)	Dry Weight Accumulation (gms)	Shoot Growth (mm)
-N	22.95	10.91	19.08	2005
CK	70.19	17.44	70.16	4592
+N	52.22	16.64	54.68	3014
-P	23.45	8.50	21.74	1650
CK	70.19	17.44	70.16	4592
+P	48.49	14.58	50.60	3058
-K	85.08	21.65	95.39	5054
CK	70.19	17.44	70.16	4592
+K	71.00	16.03	74.56	3049
-Mg	66.07	14.55	68.15	4967
CK	70.19	17.44	70.16	4592
+Mg	59.57	12.18	60.41	3008
-Ca	66.70	19.89	72.41	2818
CK	70.19	17.44	70.16	4592
+Ca	68.57	17.78	73.88	5424

Appendix Table 12

Leaf Composition of Blueberry Plants in Experiment III Grown in Sand and Subjected to Various Levels of B, Mn, Fe, Cu and Zn

Treatment	Nutrient Content - Percent Dry Weight								
	N	P	K	Mg	Ca	B	Mn	Fe	Cu
CK	2.78	.31	.710	.40	.52	.0199	.0092	.0160	.0024
-B	2.77	.30	.619	.35	.51	.0054	.0082	.0216	.0022
+B	2.47	.32	.906	.42	.53	.0500	.0100	.0195	.0019
-Mn	2.60	.31	.710	.38	.50	.0208	.0065	.0193	.0021
+Mn	2.73	.32	.662	.30	.50	.0225	.0182	.0167	.0022
-Fe	3.02	.29	.693	.36	.53	.0271	.0070	.0162	.0023
+Fe	2.62	.32	.622	.28	.50	.0215	.0043	.0227	.0026
-Cu	2.85	.30	.688	.36	.54	.0224	.0084	.0183	.0020
+Cu	2.64	.29	.675	.35	.50	.0239	.0097	.0214	.0025
-Zn	2.67	.30	.671	.33	.52	.0181	.0070	.0158	.0020
+Zn	2.83	.31	.656	.30	.50	.0248	.0068	.0158	.0022
L.S.D. 5%	N.S.	N.S.	.082	.07	N.S.	.0051	.0042	.0056	N.S.
1%	N.S.	N.S.	.110	N.S.	N.S.	.0068	.0056	N.S.	N.S.

Appendix Table 13

Growth Measurements of Blueberry Plants in Experiment III Grown in Sand and Subjected to Various Levels of B, Mn, Fe, Cu and Zn

Treatment	Dry Weight (gms)			
	Top	Root	Total	Accumulation
CK	9.18	2.98	12.15	4.78
-B	7.49	1.71	9.19	4.09
+B	8.87	1.99	10.86	4.48
-Mn	8.82	1.86	10.68	4.58
+Mn	7.03	1.77	8.80	4.05
-Fe	8.39	2.40	10.79	5.55
+Fe	7.97	2.02	9.99	4.60
-Cu	8.68	2.17	10.85	5.18
+Cu	9.30	2.59	11.89	6.50
-Zn	8.93	2.23	11.16	6.20
+Zn	8.19	1.59	9.78	4.53
L. S. D.	N. S.	N. S.	N. S.	N. S.

Appendix Table 14

Leaf Composition of Blueberry Plants in Experiment III Grown in Vermiculite and Subjected to Various Levels of B, Mn, Fe, Cu and Zn

Treatment	Nutrient Content - Percent Dry Weight								
	N	P	K	Mg	Ca	B	Mn	Fe	Cu
CK	2.76	.23	.780	.30	.57	.0170	.0209	.0147	.0016
-B	2.79	.25	.688	.32	.54	.0052	.0236	.0190	.0014
+B	2.33	.23	.911	.32	.61	.0500	.0170	.0192	.0016
-Mn	3.07	.25	.813	.29	.56	.0200	.0210	.0199	.0018
+Mn	2.78	.25	.768	.31	.50	.0162	.0280	.0200	.0015
-Fe	3.02	.24	.800	.31	.53	.0306	.0274	.0162	.0017
+Fe	2.82	.30	.803	.25	.50	.0235	.0067	.0291	.0017
-Cu	2.70	.24	.714	.35	.60	.0119	.0265	.0202	.0016
+Cu	2.99	.24	.734	.31	.50	.0241	.0182	.0190	.0019
-Zn	2.83	.25	.830	.32	.52	.0257	.0343	.0184	.0017
+Zn	3.29	.25	.768	.31	.50	.0189	.0254	.0183	.0018
L. S. D. 5%	N. S.	.02	.109	N. S.	N. S.	.0108	.0138	.0045	N. S.
1%	N. S.	.03	N. S.	N. S.	N. S.	.0153	N. S.	.0065	N. S.

Appendix Table 15

Growth Measurements of Blueberry Plants in Experiment III Grown in Vermiculite and Subjected to Various Levels of B, Mn, Fe, Cu and Zn

Treatment	Dry Weight (gms)			
	Top	Root	Total	Accumulation
CK	20.61	3.31	23.92	21.08
-B	16.01	2.14	18.16	14.82
+B	17.59	2.16	19.75	16.41
-Mn	14.77	1.79	16.75	13.73
+Mn	8.00	1.01	9.00	6.16
-Fe	26.72	4.39	31.10	28.26
+Fe	6.94	.78	7.72	4.88
-Cu	15.82	2.44	18.25	15.41
+Cu	20.82	3.33	24.15	21.31
-Zn	16.90	2.92	19.82	16.98
+Zn	8.66	1.35	10.01	7.17
L. S. D.	N. S.	N. S.	N. S.	N. S.

Appendix Table 16

Nutrient-Element Composition of Blueberry Leaves Collected Biweekly from June 15 to September 5 - Percent Dry Weight*

Element	Sampling Date							L. S. D.	
	June 15	June 30	July 12	July 26	Aug. 9	Aug. 22	Sept. 5	5%	1%
N	2.86	2.47	2.17	2.20	2.21	2.02	1.96	.11	.14
P	.21	.20	.16	.16	.16	.17	.17	.01	.02
K	.712	.626	.546	.507	.486	.476	.514	.037	.048
Mg	.19	.21	.22	.24	.27	.33	.31	.02	.03
Ca	.39	.38	.39	.47	.49	.53	.60	.06	.08
B	.0065	.0056	.0046	.0062	.0053	.0067	.0063	.0015	.0019
Mn	.0208	.0341	.0211	.0257	.0271	.0253	.0341	.0072	.0095
Fe	.0128	.0168	.0126	.0147	.0154	.0177	.0168	.0026	.0035
Cu	.0015	.0014	.0013	.0014	.0014	.0013	.0012	.0001	.0002
Zn	.0009	.0009	.0011	.0013	.0013	.0008	.0007	.0003	.0004

*Each value represents the mean of nine plots, four of which were of the Jersey variety and five of the Rubel variety.

Appendix Table 17

Nutrient-Element Composition of Blueberry Fruit Sampled Biweekly Throughout the Growing Season - Percent Dry Weight*

Element	Sampling Date							L. S. D.	
	June 15	June 30	July 12	July 26	Aug. 9	Aug. 22	Sept. 5	5%	1%
N	2.27	1.76	1.55	1.06	1.03	.78	.78	.17	.22
P	.25	.18	.15	.11	.11	.09	.08	.06	N.S.
K	.873	.776	.734	.690	.665	.561	.609	.049	.0o5
Mg	.096	.085	.074	.057	.057	.041	.040	.007	.010
Ca	.295	.216	.187	.123	.107	.045	.046	.046	.061
B	.0039	.0030	.0023	.0016	.0016	.0010	.0010	.0004	.0005
Mn	.0125	.0081	.0061	.0034	.0030	.0022	.0022	.0029	.0039
Fe	.0040	.0043	.0037	.0029	.0046	.0034	.0038	.0008	.0011
Cu	.0009	.0009	.0007	.0007	.0007	.0007	.0006	.0002	N.S.

*Each value represents the mean of nine plots, four of which were of the Jersey variety and five of the Rubel variety.

Appendix Table 18

Weekly Average of Phyrheliometer Readings of Solar and Sky Radiation in 1957 (Radiation in Gr. -Cal. per cm^2 of Horizontal Surface)

Week Ending	Radiation	Week Ending	Radiation
February 4	182.3	July 1	493.1
11	167.0	8	509.8
18	258.2	15	558.9
25	218.6	22	625.0
March 4	318.6	29	625.0
11	319.5	Aug. 5	598.0
18	382.9	12	594.0
25	368.0	19	520.0
April 1	326.3	26	463.8
8	187.6	Sept. 2	266.0
15	417.9	9	335.8
22	306.8	16	296.0
29	392.9	23	319.0
May 6	643.2	30	475.2
13	384.2	Oct. 7	412.2
20	271.2	14	314.0
27	422.1	21	206.0
June 3	620.8	28	147.6
10	593.7	Nov. 4	146.7
17	553.2	11	170.0
24	607.1	18	89.0

Appendix Table 19

Comparison of the Nutrient-Element Content of Blueberry Leaves Sampled Three Years in Succession from Nine Field Plots During the Same Physiological Growth Period (Date Pertaining to the Years 1955 and 1956 Reported by Ballinger, 1957).

Plot	Year	Nutrient Content - Percent Dry Weight									
		N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
14	1955	2.11	.17	.558	.33	.77	121	186	190	20	27
	1956	1.85	.10	.539	.17	.59	64	172	130	18	17
	1957	2.27	.16	.532	.23	.44	80	452	209	16	15
17	1955	2.20	.15	.520	.30	.69	46	88	180	10	22
	1956	1.97	.13	.440	.23	.57	31	143	140	18	15
	1957	2.30	.15	.544	.26	.65	55	153	143	17	15
18	1955	1.98	.19	.636	.39	.59	69	139	140	11	29
	1956	1.81	.14	.590	.26	.57	42	120	130	18	12
	1957	2.26	.17	.520	.28	.42	93	153	130	14	15
19	1955	1.94	.20	.559	.46	.78	44	176	200	8	21
	1956	1.68	.14	.552	.25	.50	27	180	120	16	14
	1957	2.12	.16	.518	.27	.44	63	211	157	16	10
35	1955	2.25	.19	.522	.28	.74	38	117	200	11	22
	1956	1.85	.14	.560	.18	.65	22	80	90	12	21
	1957	2.04	.15	.518	.19	.44	36	107	141	12	13
41	1955	2.18	.15	.511	.27	.65	45	245	160	9	22
	1956	1.91	.15	.551	.19	.95	32	167	110	6	19
	1957	1.97	.15	.511	.20	.51	41	174	128	12	14
44	1955	2.19	.16	.491	.30	.70	68	275	180	11	20
	1956	1.81	.13	.504	.25	1.29	43	305	150	20	28
	1957	2.14	.18	.416	.25	.61	60	478	141	15	15
49	1955	2.16	.15	.467	.27	.55	46	133	150	13	20
	1956	1.92	.17	.494	.27	.94	45	116	160	28	8
	1957	2.27	.16	.460	.25	.40	62	152	139	16	9
51	1955	2.16	.20	.528	.33	.57	61	206	180	12	15
	1956	1.74	.13	.458	.25	1.13	41	169	130	23	20
	1957	2.47	.18	.547	.25	.35	64	430	135	12	11

Appendix Table 20

Nutrient-Element Composition of Leaves and Fruit Collected from Commercial Blueberry Plantings Surveyed for Nutritional Disorders in 1957

Sample No.	Date of Sampling	Nutrient Content - Percent Dry Weight									
		N	P	K	Mg	Ca	B	Mn	Fe	Cu	Zn
BL 24	July 11	1.99	17	.544	.19	.38	.0038	.0183	.0115	.0011	.0006
BL 53	July 11	2.61	.21	.866	.19	.38	.0048	.0411	.0191	.0013	.0012
BL 54	July 11	2.15	.16	.636	.18	.36	.0046	.0137	.0116	.0014	.0009
BL 55	July 11	1.04	.14	.514	.16	.37	.0046	.0167	.0175	.0012	.0006
BL 56	July 11	2.21	.16	.766	.11	.36	.0068	.0553	.0200	.0015	.0011
BL 58	Aug. 9	2.04	.17	.558	.35	.33	.0052	.0210	.0195	.0026	.0012
BL 61	Aug. 9	3.62	.15	1.79	.13	.62	.0036	.0920	.0420	.0040	.0011
BL 80	Aug. 21	2.03	.12	.669	.16	.59	.0021	.0249	.0352	.0016	.0013
BL 83	Aug. 21	2.62	.12	1.76	.07	.53	.0018	.0299	.0178	.0016	.0006
BL 84	Aug. 18	2.08	.22	.872	.20	.38	.0017	.0030	.0124	.0015	.0005
BL 130	Aug. 23	2.02	.15	.538	.13	.47	.0021	.0146	.0177	.0017	.0007
BL 131	Aug. 23	1.77	.14	1.11	.06	.47	.0016	.0083	.0166	.0019	.0008
BL 132	Aug. 23	2.22	.17	1.32	.06	.56	.0016	.0126	.0219	.0019	.0009
BF 64	Aug. 18	.969	.09	.750	.043	.052	.0008	.0025	.0034	.0004	----
BF 70	July 29	.681	.07	.478	.039	.105	.0008	.0015	.0019	.0007	----
BL 81	Aug. 21	1.64	.16	.313	.28	.55	.0030	.0069	.0277	.0015	.0009
BL 82	Aug. 21	2.32	.18	1.280	.30	.52	.0074	.0243	.0294	.0032	.0011

The determination of calcium in fruit by a combination of the EDTA ("Versenate") method and spectrographic determination of magnesium.

Information collected and written up by Gerhard Bunemann, M. S. U., March 1958. modified by the present author for blueberry fruit.

Introduction

The complexometric titration is based upon the property of EDTA (Ethylene diamine tetraacetic acid) to complex selectively the ions of Calcium and Magnesium.

The amount of divalent ions present in one gram of dry matter is found by dissolving the ash in acid solution and subsequently titrating at a buffered pH of 10.0 to 10.5. At first the EDTA complexes all the calcium ions present, and then all the magnesium ions, and finally the magnesium which is part of the indicator. This exchange of the Mg from the indicator for Na from the EDTA causes the color change of the indicator from pink or purple to pure blue.

The titration must be carried to an endpoint which does not retain the slightest purple tinge. Practice on both standards and fruit samples may be necessary. The calcium value is obtained by subtracting the meq Mg^{++} from the total meq cations.

Method

Materials: 1. EDTA ("Versenate" or "Versene") = Ethylene diamine tetraacetic acid (disodium-dihydrogen salt): 2 g in 1 liter H_2O (approx.).

2. Indicator: Mix 0.5 g. Eriochrome Black T (Baker, F. 241) with 4.5 g. Hydroxylamine · HCl ($NH_2OH \cdot HCl$) and dissolve in 120 ml ethanol. Make up new solution at least every four weeks.

3. Calcium oxalate standard. Dry 1 g of Ca-ox overnight at 80°C, and then store in a desiccator. Dissolve in H_2O, with the addition of approx. 10 ml HCl (1:1) and approx. 5 ml HNO_3 (conc.) and make up to 500 ml in volumetric flask. This standard contains 3.12 mg or .1557 meq Ca in 5 ml solution.

At the time of titration for standardization of the EDTA add 1 mg (= .0822 meq) of Mg* to the 5 ml aliquot of the Ca solution, giving

.1557 meq Ca
+.0822 meq of Mg
.2379 meq of Ca + Mg in Standard

* (as $MgCl_2$ solution, calculate amount according to normality of solution).

Calculate the equivalence of the EDTA solution from the number of ml EDTA used to titrate the above mixture as a pH of 10.0 - 10.5; e.g. ave. 21.94 ml EDTA used: $\frac{.2379}{21.94}$ meq = .0109 meq cations per ml of EDTA.

Diehl et al. suggest adding the Mg to the standard EDTA solution. In work with fruit samples, which always contain some Mg, the method described above seems simpler and therefore more adequate.

Note: Always add water to make a total volume of approx. 125 ml before adding the buffer. Indicator degenerates in water, titrate quickly.

4. Buffer: Dissolve 135 g of C.P. Ammonium Chloride in 1140 ml conc. NH_4OH and dilute to 2000 ml with distilled and de-ionized water. This buffer solution can be expected to give a pH of 10.5 or higher.

5. Magnetic stirring equipment.
Let the stirrer run fast enough to produce a whirlpool of 1-2 inch depth. This will ease the accurate observation of the color change.

6. Fluorescent light and background against which the color change can be observed conveniently.

Procedure

Ash 1 g of carefully dried and ground fruit sample in a small porcelain crucible at 550° overnight. Transfer the ash into a 250 ml beaker. Rinse crucible quantitatively with 0.5 ml 1:1 HCl into the beaker and wash quantitatively with distilled and deionized water. Add about 100-125 ml distilled and deionized water. Then add sufficient ammonium buffer solution to bring the pH up to 10.0-10.1 (10 ml buffer should do). Make sure the water is added before the buffer to avoid undesirable precipitations. Use about 6 drops of Eriochrome Black T indicator and titrate quickly, to reach clear blue endpoint exactly like the one achieved on the standard solution. Run two parallel samples and check agreement. The detection of the endpoint is difficult and one should practice on the standard solutions before attempting to run any actual fruit samples.

Calculation examples:

.0109 (meq/ml) x 6.6 (ml used) = .0719 meq Mg + Ca
.0719 - .0452 (meq Mg, spectrograph determination) = .0267 meq Ca
.0267 meq Ca x 20.04 = .5150 mg Ca in 1 g dry wt.
= .052% Ca in fruit sample.

Modification by present author: To obtain meq of Ca + Mg, the number of ml of EDTA used was plotted graphically against a standard concentration gradient.

Special considerations:

Interferences may be expected from any divalent ions; therefore, the quality of the distilled water is of utmost importance. The metal ions which might interfere with the endpoint, are present in the fruit in such small amounts that they may be neglected in the calculation.

This method is also suitable to determine the Ca + Mg in immature fruit samples. Because of the higher concentration of these elements as well as of interfering substances, and because of the possibility of precipitations it is advisable to reduce the weighed amount to .250 g in order to work with the same concentration of EDTA as in the determination of mature fruit contents.