BULLETIN 611 JANUARY, 1940

Deficiency Symptoms of Greenhouse Flowering Crops

Alex Laurie and Arnold Wagner

OHIO
AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

CONTENTS

Introduction 3
Review of the Literature 3
Materials and Methods 4
Results 6
Deficiency Symptoms of *Begonia* 6
Deficiency Symptoms of *Calceolaria* 8
Deficiency Symptoms of Carnation 8
Deficiency Symptoms of *Chrysanthemum* 9
Deficiency Symptoms of *Cineraria* 11
Deficiency Symptoms of *Fuchsia* 12
Deficiency Symptoms of *Gardenia* 12
Deficiency Symptoms of Geranium 14
Deficiency Symptoms of *Hydrangea* 15
Deficiency Symptoms of *Poinsettia* 16
Deficiency Symptoms of *Primula* 17
Deficiency Symptoms of *Rosa* 18
Deficiency Symptoms of Snapdragons 19
Deficiency Symptoms of Sweet Pea 21
Key to Nutrient Deficiency Symptoms 22
Summary 23
Literature Cited 24

This page intentionally blank.

DEFICIENCY SYMPTOMS OF GREENHOUSE FLOWERING CROPS

ALEX LAURIE AND ARNOLD WAGNER

INTRODUCTION

The extensive use of commercial fertilizers in the greenhouse during recent years by men who have not always thoroughly understood their use, and the intensive system of cropping used in most commercial greenhouses have brought about many malnutritional troubles in greenhouse plants from excesses or deficiencies. These malnutritional disorders are of great importance to the florist because they are reflected in growth, foliage, and flower characteristics which definitely decrease the value of his product.

In addition to the studies of the effects of such elements as nitrogen, phosphorus, potassium, magnesium, and calcium, during the past few years there has been reawakened interest in trace elements as they affect plant growth and development and also in their relation to malnutrition and disease. Although research on this subject began several years ago, it is only comparatively recently that the relation of certain trace elements to the so-called physiological diseases of plants has been definitely recognized. Noteworthy results have been secured, for example, through the use of zinc and its compounds in the control of rosette and certain other troubles of fruit and nut trees in several localities (1, 7, 8, 9, 15, 21, 25, 27, 28, 29, 34, 35, 38, 40), and of iron and manganese in chlorosis (5, 12, 16, 17, 36, 37, 41). Further, the correction by boron and its compounds of certain troubles of fruit trees in the Northwest and elsewhere (11, 18, 26, 44, 45), and of turnips (11, 20), sugar beets (11, 32, 39), celery (2, 33), cauliflower (6, 10, 13), and other plants in other sections, has given results sufficiently spectacular to arrest the attention of the layman as well as the plant investigator.

It is the purpose of this bulletin to give the visual symptoms of nutritional deficiencies for the more important greenhouse crops to enable the grower to diagnose and correct these malnutritional disorders in time to save the affected crop.

Since these visual symptoms frequently develop long after retardation of growth has begun, it is very important that early diagnosis be made and corrective measures taken. Although it is true that these measures may have their desired effect after striking symptoms have developed, still it is advantageous to forestall serious stunting of growth by early observation.

REVIEW OF THE LITERATURE

The literature dealing with the nutrient deficiency symptoms of greenhouse crops is rather meager. The Division of Floriculture of the Ohio Agricultural Experiment Station pioneered in the nutrient deficiency work with greenhouse flowering crops. A series of tests was started in 1931 by Laurie (23) at Columbus, Ohio, to determine accurately the nutrient deficiency symptoms in the more important greenhouse crops to serve as a guide in diagnosing the physiological troubles of greenhouse crops. The latest results of this work were reported by Laurie (22) in 1936. This earlier work concerned itself mainly with the three major elements—nitrogen, phosphorus, and potassium. During 1937 and 1938, six additional deficiencies were studied, namely, boron, calcium, iron, magnesium, manganese, and sulfur. A progress report of this latter investigation was made by Laurie and Wagner (24) in 1937.

Brooks (3), Burkhart (4), Finch (14), Hill et al (19), Poesch (30, 31), and White (42, 43) give results which in general concur with those obtained in this investigation.

MATERIALS AND METHODS

Fourteen genera of greenhouse plants were used in these experiments: *Begonia* (*Begonia semperflorens*), *Calceolaria* (*Calceolaria rugosa*), Carnation (*Dianthus caryophyllus*), *Chrysanthemum* (*Chrysanthemum hortorum*—variety *Valencia*), *Cineraria* (*Cineraria cruenta*), *Fuchsia* (*Fuchsia hybrida*), *Gardenia* (*Gardenia veitchii*), Geranium (*Pelargonium hortorum*—variety *Mrs. Lawrence*), *Hydrangea* (*Hydrangea hortensis*—variety *Europa*), *Poinsettia* (*Euphorbia pulcherrima*—variety *Barbara Ecke*), *Primula* (*Primula obconica*), Rose (*Rosa hybrida*—variety *Talisman*), Snapdragon (*Antirrhinum majus*—variety *Talisman*), and Sweet Pea (*Lathyrus odoratus*—variety *Lady Gay*).

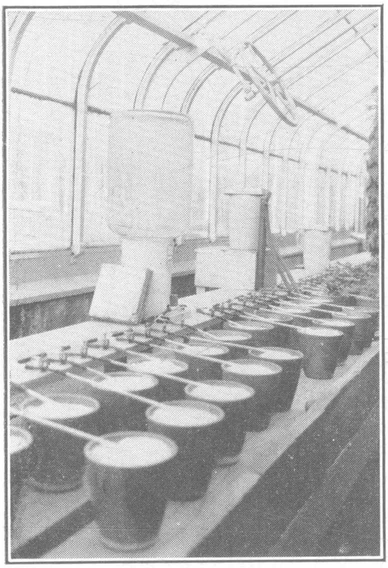

Fig. 1.—Drip-culture apparatus

The plants were grown in 5-inch glass pots in silica sand. The sand was soaked in a dilute nitric acid solution and washed well with tap water and then distilled water. All equipment was washed with hot water and soap. The drainage holes were covered with glass wool to prevent loss of sand.

The sand drip-culture method as shown in figure 1 was used. Six-millimeter glass and rubber tubing was used throughout the apparatus, and flow was regulated by a screw clamp at each individual outlet. This apparatus was adapted for conducting a large number of cultures on a large number of plants with a minimum of labor and attention, where normal growth of the plants and minimum care were more important than the addition of exactly the same amount of solution to each culture. A 3-quart glazed stone jar with a ¾-inch outlet was used as a reservoir. Seventeen liters of culture solution were used for 16 plants, and applications were made every second day. The sand cultures were leached periodically with distilled water to remove any excess ions that might accumulate.

The plants named were studied for visual symptoms of deficiency of nitrogen, phosphorus, potassium, boron, calcium, iron, magnesium, manganese, and sulfur.

Table 1 gives the composition of the complete nutrient solution. Analytical chemicals were used.

TABLE 1.—Complete nutrient solution

Salt	Molecular weight	Partial volume of molecular concentration in nutrient solution	Grams of salt per liter of stock solution M/2	Ml. of M/2* stock solution per liter of nutrient solution	Ml. of M/2 stock solution per 17 liters of nutrient solution
KH_2PO_4.......	136.14	0.00633	68.1	12.66*	215.22
$CaCl_2$.........	111.0	.00146	55.5	2.92	49.64
$Ca(NO_3)_2 \cdot 4H_2O$....	236.2	.00584	118.1	11.68	198.56
$MgSO_4 \cdot 7H_2O$.	246.5	.00237	123.25	4.74	80.58
$MnSO_4 \cdot 4H_2O$.	10 cc. of 0.5% stock solution per 17 liters of nutrient solution				
$FeSO_4 \cdot 7H_2O$.	25 cc. of 2% stock solution per 17 liters of nutrient solution				
H_3BO_3....	2 cc. of 1% stock solution per 17 liters of nutrient solution				

*This figure is obtained from the P. V. M. figure by multiplying 0.00633 by 2,000. Stock solutions should not be combined before diluting because precipitation may result if those respective M/2 stock solutions are mixed directly. This solution has an osmotic pressure of approximately three-fourths of an atmosphere.

The minus nitrogen nutrient solution was prepared by omitting calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$, from the complete solution.

The minus phosphorus nutrient solution was prepared by omitting potassium phosphate, KH_2PO_4, from the solution and adding an equivalent of potassium from potassium chloride, KCl.

The minus potassium nutrient solution was prepared by omitting potassium phosphate, KH_2PO_4, from the solution and adding an equivalent of phosphorus from sodium phosphate, $NaH_2PO_4 \cdot H_2O$.

The minus boron nutrient solution was prepared by omitting boric acid, H_3BO_3, from the complete solution.

The minus calcium nutrient solution was prepared by omitting calcium chloride, $CaCl_2$, and calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$, and using an equivalent of nitrogen from ammonium sulfate, $(NH_4)_2SO_4$.

The minus iron nutrient solution was prepared by omitting ferrous sulfate, $FeSO_4 \cdot 7H_2O$.

In the minus magnesium solution, an equivalent of sulfur from sodium sulfate, Na_2SO_4, replaced the magnesium sulfate, $MgSO_4 \cdot 7H_2O$.

The manganous sulfate, $MnSO_4 \cdot 4H_2O$, was omitted from the minus manganese nutrient solution.

In the minus sulfur solution, magnesium sulfate, $MgSO_4 \cdot 7H_2O$, and manganous sulfate, $MnSO_4 \cdot 4H_2O$, were replaced by an equivalent amount of their respective chlorides, and ferrous sulfate, $FeSO_4 \cdot 7H_2O$, was replaced by soluble ferric phosphate, $FePO_4 \cdot 4H_2O$.

The pH of these solutions ranged from 4.5 to 5. After the solutions had drained through, the pH of the sand ranged from 5.5 to 6.

The plants were started from seed or cuttings. Some genera were rooted in the propagating bench and planted directly into the sand culture pots. Others were grown in 2½-inch pots until the proper size, and then the soil was washed from the roots. Four plants of each genus were used for each deficiency.

The deficiency symptoms were checked in three ways: (a) An identical setup of each genus was grown in a complete solution containing all elements. (b) The solutions and sand were tested to see that the element concerned was actually not present. (c) As soon as symptoms developed, the plant concerned was placed on complete solution to attempt its recovery. Microchemical tests of tissues were likewise used in determining deficiencies.

RESULTS

DEFICIENCY SYMPTOMS OF *BEGONIA SEMPERFLORENS*

Minus nitrogen.—Growth was stunted and the foliage was a brick red in color. There were very few flowers.

Minus phosphorus.—No side breaks developed and growth was stunted. The color of the plant was normal.

Minus potassium.—There was a very definite burning of the margins of older leaves, and these leaves turned brown and eventually dropped.

Minus magnesium.—Deficiency of magnesium was very marked in the case of *Begonia*. The plant soon stopped growth, and a very stunted condition resulted. The leaves were very small and the petioles exceedingly short. A chlorosis developed on the lower and middle leaves between the veins, but the veins remained a normal green. Soon after this chlorosis started, a puckering of the leaf was noticed, and not many days later, sometimes within a 24-hour period, there was a severe necrosis of the chlorotic leaves. These areas enlarged and dried to a crisp very soon thereafter. Some of these necrotic areas were darker colored than others. There was some leaf abscission. Figure 2 shows typical symptoms for the begonia leaf. In magnesium deficiency the lower part of the plant was affected first, and the symptoms progressed upward. The terminal bud was, therefore, the last part of the plant to become affected as the deficiency became more and more acute. When complete solution was added before the deficiency progressed too far, the plant recovered rapidly. Of course, the necrotized leaves never recovered, but new growth from the axils of the stem masked their bad appearance.

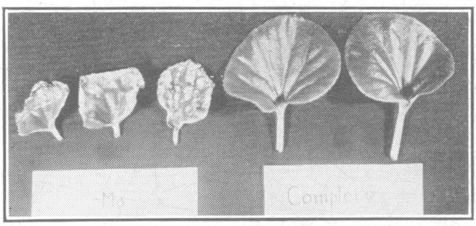

Fig. 2.—Leaf symptoms of magnesium deficiency of *Begonia*. Left—minus magnesium, Right—complete

(Note the necrotic areas and puckering of the leaf.)

Minus calcium.—The plants soon became stunted in growth. The leaves became a dull light green with reddish margins, very small, and had short petioles. Later the terminal bud and tip leaves died. Those plants that were grown in complete solution for a period and then transferred to minus calcium culture began wilting after 2 weeks and remained wilted until the plants dried entirely. Upon examination, it was found that the root system was brown and decomposed. Leaf symptoms are shown in figure 3.

Minus iron.—After 1 month, a chlorosis developed on the terminal leaves of each shoot. The veins remained normally green, but the areas between the veins became yellow.

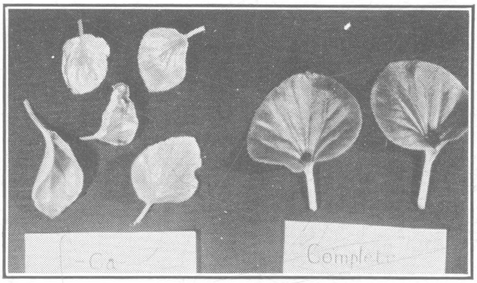

Fig. 3.—Leaf symptoms of calcium deficiency of *Begonia*. Left—minus calcium, Right—complete

(Note the light coloration of the leaf, as well as the softening of tissues near the tip and margin.)

Minus manganese.—Manganese deficient begonias did not become as severely stunted as magnesium deficient ones. There was, however, a chlorosis of the leaves between the veins, which appeared first on the terminal portions of the plant. The chlorotic areas later became necrotic, but these necrotic areas differed from those in magnesium deficiency in that they remained translucent and watery in appearance, not drying as rapidly. The remaining leaves were dull grayish-green in appearance. Necrosis due to manganese deficiency was never as severe as that due to magnesium deficiency. Figure 4 shows the leaf symptoms of manganese deficiency on *Begonia*.

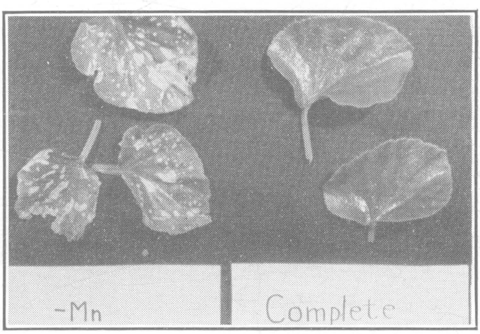

Fig. 4.—Leaf symptoms of manganese deficiency of *Begonia*

Minus sulfur.—The first symptom of sulfur deficiency on *Begonia* was a slower rate of growth. The plants were usually about one-half the size of plants grown with complete solution. The leaves were a dull, grayish, yellow green generally over the plant.

Minus boron.—After the plants had been growing 6 months in the same culture pots, the terminal bud and leaves exhibited a rosette condition with puckering of the tip leaves. In 2 weeks this condition was followed by a necrosis of the terminal bud and leaves which made further terminal elongation and growth impossible.

DEFICIENCY SYMPTOMS OF *CALCEOLARIA RUGOSA*

Minus nitrogen.—The plants were dwarfed with small flower clusters. Old leaves were almost white in color with light brown, dead margins. The young leaves were very pale yellowish-green in color.

Minus phosphorus.—Plants were small, of an unusually dark green color, and showed no indication of a flower cluster. The old leaves had some yellowing around the margins.

Minus potassium.—The plants were only slightly stunted, but the flower cluster was poorly developed and the flower color faded. The margins of the older leaves and the area around the petiole died and dried to a dark brown to black color. The leaf centers showed large spots with necrotic centers. The older leaves were brittle, crinkled between the veins, and of a normal green color except for the affected areas. The young leaves were light green to yellowish-green in color.

Minus magnesium.—Following a reduced rate of growth, chlorosis developed between the veins of the leaves on the lower part of the plant and progressed upward. Later, small reddish-brown necrotic spots covered the leaves and the leaves had a tendency to turn downward at the tip and margins. The plant became very stunted.

Minus calcium.—The first noticeable effect was a reduced rate of growth followed by a wilting and yellowing of the plant. In later stages the terminal bud died. The roots were brown and decomposed. The entire plant died in the last stages.

Minus iron.—The terminal leaves exhibited a chlorosis between the veins.

Minus manganese.—The first symptom of manganese deficiency in this plant was a very pronounced chlorosis of the terminal leaves extending from the margins back to the midrib between the veins while the veins remained green. This condition gave a very streaked appearance to the leaf. The plants never became stunted in appearance until small necrotic spots developed in the chlorotic areas of the leaves.

Minus sulfur.—A greatly reduced rate of growth and chlorosis of young leaves were the two symptoms noted in this deficiency.

DEFICIENCY SYMPTOMS OF CARNATION *(DIANTHUS CARYOPHYLLUS)*

Minus nitrogen.—The leaves were short and did not exhibit their usual healthy bloom. Internodes, as well as the entire stem, were short. Flowers were small.

Minus phosphorus and potassium.—It was difficult to distinguish between phosphorus and potassium deficiency, but lack of either of these elements produced limber stems. The lower foliage turned brown and died. There was a greater susceptibility to disease.

Minus calcium.—Weak stems occurred.

Minus iron and manganese.—Symptoms of deficiencies of these elements were difficult to observe.

DEFICIENCY SYMPTOMS OF *CHRYSANTHEMUM HORTORUM*

Minus nitrogen.—Yellow foliage (general over the entire plant), small leaves, woody stems, and short internodes characterized this deficiency. There was no drop of foliage. Leaf symptoms are shown in figure 5.

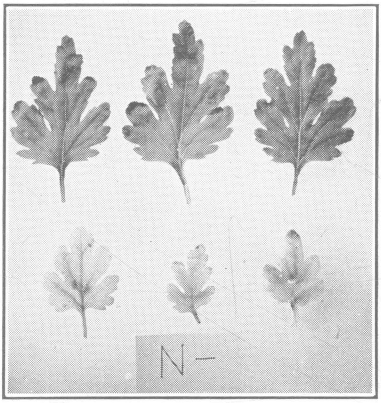

Fig. 5.—Leaf symptoms for nitrogen deficiency of *Chrysanthemum*

(Note the general yellowing of the leaf.)

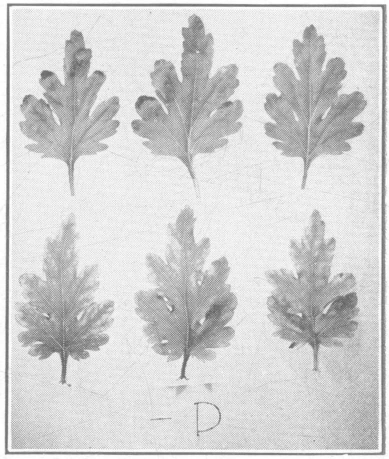

Fig. 6.—Leaf symptoms of phosphorus deficiency of *Chrysanthemum*

Minus phosphorus.—Gray-green foliage which was darker near the petiole and pale green near the edges dropped gradually from the base up. The growth was stunted throughout. Leaf symptoms of phosphorus deficiency are given in figure 6.

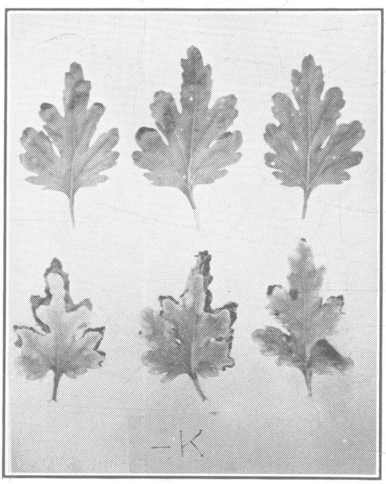

Fig. 7.—Leaf symptoms of potassium deficiency of *Chrysanthemum*

(Note the marginal browning.)

Minus potassium.—Small leaves, gray-green foliage, and slight mottling were typical of this deficiency, as shown in figure 7. There was a characteristic browning of the edges of the leaves, eventually spreading farther back.

Minus magnesium.—The effect of deficiency of magnesium on the growth of *Chrysanthemum* was marked. A greatly decreased rate of growth was noted. A chlorosis developed between the veins, but the veins themselves remained a normal green. This chlorosis appeared first on the lower and middle parts of the plant, later progressed upward. The leaves curled upward at the tips and margins, giving a dishlike appearance. Leaves were very small and the petioles short. In severe cases of deficiency, the leaf petiole shriveled and the leaf hung down against the stalk. A purple coloration developed on the leaves in blotches after the plant had become stunted. If complete solution was added before the deficiency became acute, almost complete recovery of the plant could be expected. The blooming period was delayed 2 weeks and the blooms were smaller. Some of them were aborted. Roots were few in number with few lateral branches. They were slimy in appearance. A comparison of root systems is given in figure 8.

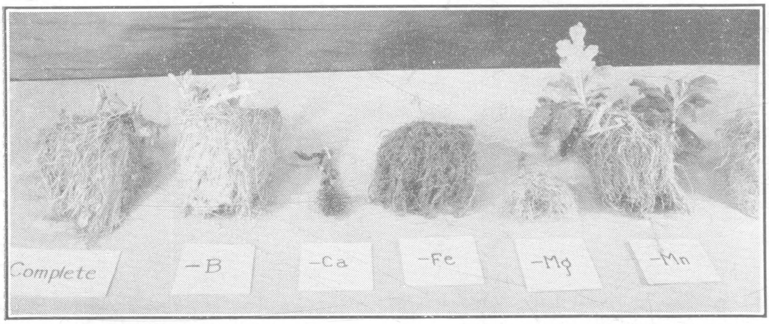

Fig. 8.—Comparative root systems of various deficiencies of *Chrysanthemum*

Minus calcium.—With this deficiency, nearly all the root hairs died within 2 or 3 weeks' time. The roots were short and thick, dirty brown in color, and appeared decomposed. The top ceased to grow and the plant remained stunted, finally dying after several weeks. Leaves were small and had short petioles. Terminal buds and leaves died. Some chlorosis of leaves occurred. After plants had been severely stunted they recovered very slowly when grown in a complete solution. The stems were very stiff, and the plants did not produce flowers.

Minus iron.—With a deficiency of iron, there was a very severe chlorosis which developed by degrees from a mild chlorosis, first becoming evident on the young leaves at the tip of the plant and later progressing downward. The first casual glance gave the impression of dark green veins with chlorosis occurring between the veins. Upon closer examination, however, (see fig. 9) it was seen that the veins were yellow and that there were narrow strips of green tissue on each side. This condition accounted for the general impression of dark green veins. With a severe deficiency of iron the leaves turned completely white or cream in color. Soon after this stage was reached, a severe burning or necrosis of the chlorotic leaves developed. The burned area was small at first, but increased in size until a large part of the leaf was desiccated. This burning may begin any place on the leaf, but it usually occurred on the tip or margins, increasing inward.

If severely deficient plants were given complete solution, all new growth was normal, but some of the more chlorotic leaves never regained their green color. The roots on minus iron plants were relatively short and had many short branches. They were intense reddish-brown in color and appeared partly decomposed. Blooming was delayed.

Minus manganese.—Manganese deficiency also stunted *Chrysanthemum*, but not as severely as magnesium deficiency. There was an orange-yellow chlorosis between the veins of the leaves, starting on the tip of the plant. The veins remained a normal green. The leaf margins and tip curled under until the leaf was almost folded double. There was a slight purple coloration of the leaf which was noticed more prominently in the case of magnesium deficiency. When complete solution was added, recovery was rapid. Blooming was delayed.

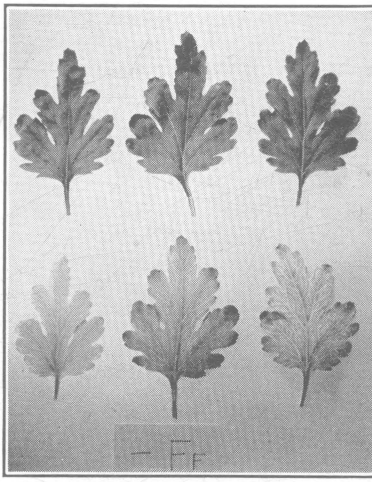

Fig. 9.—Leaf symptoms of iron deficiency of *Chrysanthemum*

(Note the prominent light veins.)

Minus sulfur.—The lack of sulfur resulted in a decided reduction in height of plant. The younger leaves of the plant, as well as those of medium age, were lighter green than those of the normal plants. Chlorosis due to lack of sulfur was very characteristic in that the veins were characteristically lighter in color than the areas between the veins. In the later stages there was a characteristic dying of the leaf veins just at the base of the leaf blade, as shown in figure 10. This dead area was purplish-brown in color. It remained soft and moist, not drying readily. It proceeded along the veins until the leaf tip was reached. Along with this development, the remainder of the leaf died. Plants recovered if they were given complete solution before this necrosis at the base of the leaf blade became evident. Blooming was delayed. Roots on minus sulfur plants were abundant and much branched.

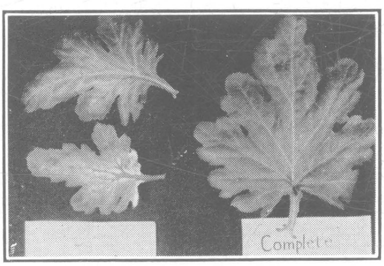

Fig. 10.—Leaf symptoms of the sulfur deficiency of *Chrysanthemum*. Left—minus sulfur Right—complete

(Note the dying of the midrib and veins near the base of the leaf blade.)

DEFICIENCY SYMPTOMS OF *CINERARIA CRUENTA*

Minus nitrogen.—The plants became stunted in growth soon after they were deprived of nitrogen. The flower buds were small and poorly developed. All the leaves were rusty-yellow in color and remained attached to the plant for a long time after dying

Minus phosphorus.—The plants were partially stunted and had small leaves of an abnormally dark green color. The older leaves began to turn yellow and died but usually dropped before becoming completely yellow.

Minus potassium.—The plants were slightly stunted in growth. The older leaves were mottled with whitish-yellow markings between the veins and along the margins of the leaf. The margins later turned brown.

Minus magnesium.—These plants were severely dwarfed. A chlorosis appeared between the veins of the older leaves. Necrotic areas appeared on the margins and between the veins. These increased in size until the entire leaf was dead. The leaves were very crinkled, and the leaf margins curled upward, giving a revolute appearance. Growth was very stunted.

Minus calcium.—These plants were stunted very early in their growth, became necrotized, and finally died completely. Roots were brown and decomposed. Plants that had been started on complete solution for 2 months and had then been transferred to minus calcium started wilting after 1 week and finally died, primarily because of the root injury caused by a lack of calcium.

Minus iron.—There were chlorosis of the young leaves, normal green veins, and yellow between the veins. The plants were stunted.

Minus manganese.—The plants grown on minus manganese exhibited poor growth the entire period of the experiment. There was a slight chlorosis followed by the appearance of necrotic areas on the young leaves, which finally died.

Minus sulfur.—A light foliage and poor growth were the only symptoms note

DEFICIENCY SYMPTOMS OF *FUCHSIA HYBRIDA*

Minus nitrogen.—The plants were very stunted and produced few side shoots. All the leaves gradually turned yellowish-green, and the older leaves finally turned to an orange color and dropped before dying completely. The plants flowered prematurely with malformed flowers.

Minus phosphorus.—The plants were very stunted in growth. The older leaves were an unusually dark green color, the young leaves, a bronze-purple color, crinkled, and cup shaped.

Minus potassium.—The plants were only slightly stunted. The older leaves were dark green in color and showed some browning in spots between the veins and along the margin of the leaf. The young leaves were slightly yellowish-green in color and rolled inward along the margins.

DEFICIENCY SYMPTOMS OF *GARDENIA VEITCHII*

Minus nitrogen.—There were a stunting of growth and a general yellowing of the foliage over the entire plant.

Minus phosphorus.—There was a general stunting with darker foliage than usual.

Minus potassium.—Marginal dying of the older leaves was characteristic.

Minus magnesium.—The plant became very stunted early in the experiment and died completely after 3 or 4 months. The leaves abscised very easily and the plant became defoliated gradually, from the bottom to the top. Necrotic areas appeared on the margin of the leaves and enlarged inward. After this condition had been reached, recovery was exceedingly slow when complete solution was added regularly. The roots were very poorly developed and slimy in appearance.

Minus calcium.—The first evidence of the deficiency was very slow growth. A chlorosis developed on the leaves. Later the terminal bud died and necrotic areas appeared on the leaf margins and tip at the top of the plant. This necrosis caused a crinkling of the terminal leaves. Root injury was apparent after 2 weeks, and in a short time the entire plant died. After root injury had taken place, recovery was exceedingly slow when complete nutrient solution was added.

Minus iron.—With a deficiency of iron, there was a very severe chlorosis, which first became evident on the young leaves at the tip of the plant and later progressed downward. In the early stages the veins remained a normal green, but as the deficiency became acute, the leaves turned completely white or cream in color. Soon after this stage was reached, a severe burning of the chlorotic leaves developed. The burned area was small at first, increasing in size until a large part of the leaf was desiccated. This burning might begin any place on the leaf, but it frequently occurred on the tip or margins, increasing inward. Progressive stages of leaf symptoms are illustrated in figure 11. Plants became very stunted. If severely chlorotic plants were given complete solution, all new growth was normal, but some of the older and more chlorotic leaves never regained their green color.

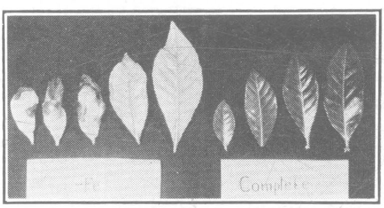

Fig. 11.—Progressive stages (from right to left) of the iron deficiency of *Gardenia*. Left—minus iron, Right—complete

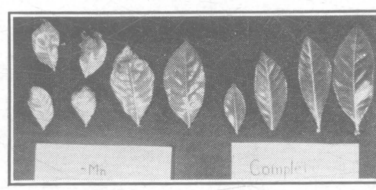

Fig. 12.—Leaf symptoms of manganese deficiency of *Gardenia*. Left—minus manganese, Right—complete

(Note the crinkling of the leaf, as well as the necrotized areas.)

Minus manganese.—Manganese deficiency stunted *Gardenia* but not as severely as magnesium deficiency. The first evidence was a chlorosis of the top leaves of each shoot; the yellowing came between the veins. This chlorosis later progressed downward on the plant. Even the most minute veins remained green, and there was the appearance of a very fine network over the leaf. Shortly after the chlorosis had appeared there was a severe necrosis of these yellowed areas followed by abscission of the youngest of these leaves. This necrosis frequently took place on the leaf tip. It was very characteristic in that it was reddish-brown in color, whereas that due to iron deficiency was a true brown. Also, the necrotic spots were much smaller in the case of manganese deficiency. The necrotized leaves became very crinkled and deformed (see fig. 12). In some cases, on smaller, younger leaves particularly, the entire leaf became necrotized and abscised. When complete solution was added before the deficiency became acute, partial recovery took place.

Minus sulfur.—The foliage was of a lighter green, and the amount of growth was about one-half that of plants given complete solution.

Minus boron.—After 6 months, chlorosis was evident on the tip leaves. Soon after, these areas became necrotic and the terminal growth ceased. The leaves became very crinkled and deformed.

DEFICIENCY SYMPTOMS OF GERANIUM *(PELARGONIUM HORTORUM)*

Minus nitrogen.—Plants were very stunted in growth, with only a central stem and no flower clusters. The young leaves were very light green in color with a definite reddish-bronze ring around the center. The older leaves turned a brilliant red except for a yellowish-red area around the petiole, dried up, and remained attached to the plant for some time.

Minus phosphorus.—The plants were stunted almost as much as those in the treatment without nitrogen, but showed a well-developed flower cluster of good color. The young leaves were dark green in color and showed a distinct chocolate-brown ring around the center. The older leaves turned dull, dark red, from the margin toward the petiole, dried, and dropped from the plant early.

Minus potassium.—The plants were only slightly smaller than those in the complete treatment and produced several side branches and flower clusters. The young leaves were a pale, yellowish-green color with dark green veins. The older leaves were grayish-yellow between the veins and along the margins, with some yellow and brown spotting between the veins, and showed a distinct rusty-brown ring around the center. There were some yellowing and brown spotting between the veins of the old leaves.

Minus magnesium.—A chlorosis on the lower part of the plant was the first evidence of magnesium deficiency of *Geranium*. This chlorosis began on the margins and progressed inward between the margins until a large part of the leaf was yellow. The only green portion remaining was a fan-shaped area at the base of the leaf blade extending out along the palmate veins for a short distance. This chlorosis progressed upward on the plant as the deficiency became more acute. The leaves of middle age and younger exhibited a puckering effect. The plants were very stunted, leaf petioles were short, and roots were very few in number.

Minus calcium.—The plant became very stunted and failed to put forth any new growth after being placed in minus calcium solution. Roots soon became brown and decomposed in appearance. Figure 13 illustrates magnesium and calcium deficiencies of the geranium.

Minus iron.—A general chlorosis between the veins was noted on the tip leaves of the plant.

Minus manganese.—A chlorosis appeared on the tip of the plant. The areas between the veins were yellowed, but even the most minute veins retained their normal green color. This coloring gave a very finely netted appearance to the leaf. Although growth was somewhat poorer than on plants in the complete solution, the plants did bloom; but the flower color was poor and faded.

Minus sulfur.—Lighter green foliage and decreased growth were the only symptoms noted.

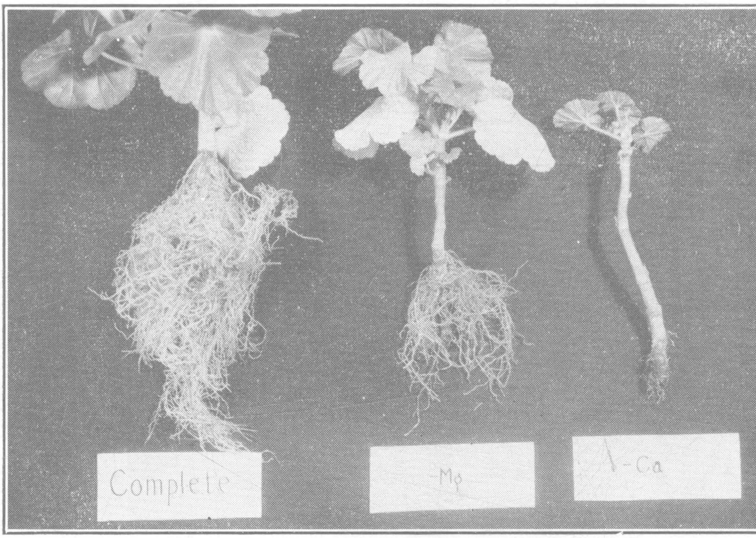

Fig. 13.—Magnesium and calcium deficiency of geraniums

(Note the dwarfed condition of the tops as well as the roots.)

DEFICIENCY SYMPTOMS OF *HYDRANGEA HORTENSIS*

Minus nitrogen.—Light foliage, light-colored veins, short growth, and small leaves characterized this deficiency.

Minus phosphorus.—The plant failed to develop flowering buds.

Minus potassium.—The plant failed to develop flowering buds, and there was a browning of edges of older leaves.

Minus magnesium.—Magnesium deficiency was particularly destructive to *Hydrangea.* There was a chlorosis of the older leaves (dark veins, yellow between) followed by death of the entire plant after it had been on the deficient solution for 1 month.

Minus calcium.—Hydrangeas grown with minus calcium solution died within 4 weeks. The terminal growth was killed first. Roots were brown and decomposed.

Minus iron.—Iron chlorosis was exhibited. The interveinal areas became yellow while the veins remained a normal green. This chlorosis appeared on the terminal leaves of the plant.

Minus manganese.—After a period of 1 month the usual symptoms for manganese deficiency gradually became apparent. There was a chlorosis of the terminal leaves between the veins.

Minus sulfur.—Hydrangeas in minus sulfur solution produced about one-half the growth that the plants in complete solution did. The young leaves were a lighter green. In the later stages a bad infection of mildew caused the plants to be completely defoliated. Since the minus sulfur plants were the only treatment to be thus affected and since sulfur dust is used to combat mildew, it is suggested that there may be some correlation between sulfur deficiency of a plant and its susceptibility to mildew.

DEFICIENCY SYMPTOMS OF *POINSETTIA (EUPHORBIA PULCHERRIMA)*

Minus nitrogen.—The plants showed a uniform yellowing of all leaves, beginning at the bottom of the plant and progressing to the top. The older leaves turned pale yellow and dropped (see fig. 14).

Minus phosphorus.—The plants made very little growth. The older leaves began yellowing from the margins toward the center of the leaf and dropped before becoming completely yellow (see fig. 15). All leaves dropped in succession until only the topmost leaves, which were very dark green in color, remained

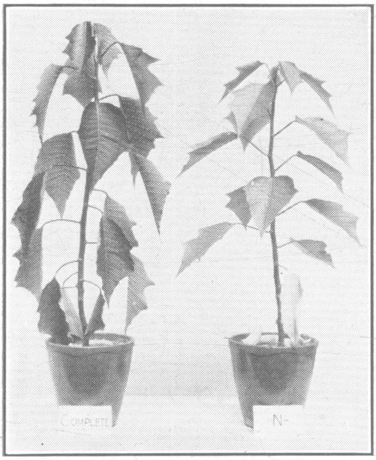

Fig. 14.—Nitrogen deficiency of *Poinsettia*. Left—complete Right—minus nitrogen

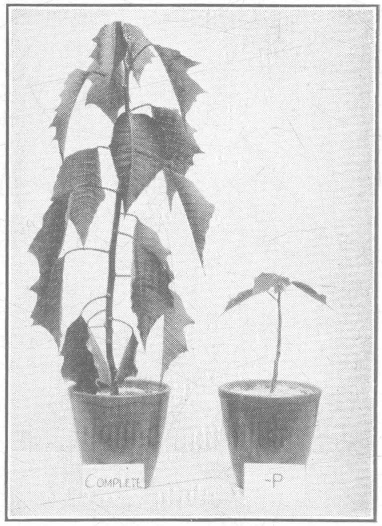

Fig. 15.—Phosphorus deficiency of *Poinsettia*. Left—complete Right—minus phosphorus

Minus potassium.—The plants were only partially stunted in growth. The older leaves began to turn yellow along the margins and finally turned completely yellow except for the veins, which remained dark green in color. Browning along the margin began after the leaves had become completely yellow. The leaves remained attached to the plant for some time after dying. All the leaves were finally affected except the young bud leaves at the tip. These remained dark green. The plants produced several side branches that developed normally for a short time and then began to turn yellow and later brown along the margins, as shown in figure 16.

Minus magnesium.—Magnesium deficiency resulted in a severe stunting of the plant. There was the characteristic chlorosis, dark veins with the yellowing, occurring on the lower part of the plant. This chlorosis was accompanied by a puckering of the leaf. Necrotic spots occurred on the margins and between the veins. These areas increased in size until the entire leaf was desiccated. Leaf margins generally curled under. The bracts were extremely small and imperfect.

Minus calcium.—The tip leaves became abnormally dark green with a reddish tint and exhibited wilting. Stems were very stiff. The terminal bud died and complete defoliation occurred. Root injury was severe.

Minus iron.—No symptoms were observed.

Minus manganese.—A chlorosis developed on the tip of the plant. It was not as severe as magnesium chlorosis, but gave a more or less netted appearance to the leaf. Manganese deficient poinsettias were about one-half the size of those grown in complete solution. Bracts were also smaller.

Minus sulfur.—The foliage color was a light dull green. Yellowing, followed by necrosis of the tissue at the base of the leaf blade, was evident in the later stages of deficiency. This necrosis extended along the midrib. The sulfur deficient plants were much smaller than those grown in complete solution.

Fig. 16.—Potassium deficiency of *Poinsettia*. Left—complete Right—minus potassium

(Note the multiple branching of the plants.)

Minus boron.—The first injury occurred about 3 months after plants were placed on this deficient solution. The buds ceased to grow and had a somewhat drawn, stunted appearance. This stunting caused the side buds near the tip to develop. The terminal leaves thickened and had a tendency to roll in a half-circle from the tip toward the base. On some leaves the midrib on the underside of the leaf cracked. The bracts developed slowly and abnormally.

DEFICIENCY SYMPTOMS OF *PRIMULA OBCONICA*

Minus nitrogen.—The plants were very stunted in growth and all the leaves were small and light yellowish-green in color. There was no indication of flowering.

Minus phosphorus.—The leaves were an unusually dark green color, deeply crimped, and yellow along the margins. No flower clusters developed.

Minus potassium.—The young leaves were of normal color, but the older leaves were yellow in spots and along the margins. The veins of the affected leaves remained green until the leaf died. Flower clusters were faded.

Minus magnesium.—Chlorosis developed between the veins, but the veins remained normal green. Previous to the development of this chlorosis, however, a chlorotic band had formed around the margin of the leaf. Following the chlorosis, a very puckered condition of the leaf developed. In the later stages, a severe necrosis appeared between the veins and on the margins. The plants were stunted severely. The plants flowered, but the clusters were very poor in size, color, and quality.

Minus calcium.—Plants in the calcium deficient solution died after 1 month's treatment. Root injury was apparent. When plants which had been started in complete solution were transferred to minus calcium solution, wilting took place within a week, and after 1 month the plants were completely dead.

Minus iron.—The characteristic chlorosis developed. The veins remained normal green while the areas between became chlorotic.

Minus manganese.—There was a reduced rate of growth, as well as the typical manganese chlorosis. The chlorosis came between the veins while the most minute of the veins remained green, and the leaf had a very netted appearance.

Minus sulfur.—This deficiency was characterized by chlorosis; however, in the case of minus sulfur, the veins were lighter than the rest of the leaf. Growth was reduced.

DEFICIENCY SYMPTOMS OF *ROSA HYBRIDA*

Minus nitrogen.—The foliage turned yellow and remained on the plant (see fig. 19). Shortening of growth, failure to develop buds properly, and small flowers of light color were also characteristic.

Minus phosphorus.—The older foliage dropped without turning yellow. This type of drop should not be confused with foliage drop due to overwatering, for the latter is accompanied by yellowing first. Weakness of stems, slow development of buds, and poor production due to smaller root systems were also characteristic.

Minus potassium.—Marginal browning of lower foliage, occasional purpling of leaves, poor color, and weak stems typified this deficiency.

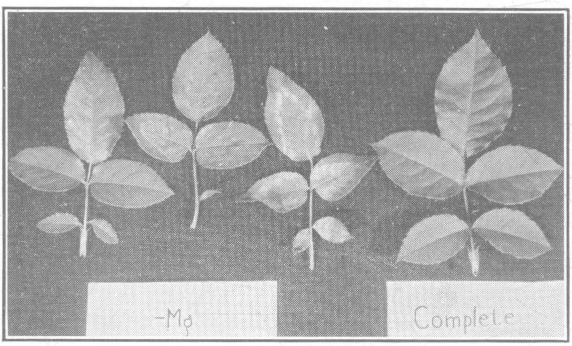

Fig. 17.—Progressive stages (from left to right) of magnesium deficiency symptoms of the rose leaf

(Note the regular oval arrangement of necrotic spots.)

Minus magnesium.—The plants were very stunted in growth and produced few breaks. The first stage was a chlorosis appearing on the lower part of the plant, dark veins, yellow between. After 2 months of treatment, dry necrotic areas, small at first, and interveinal, appeared. These formed a row of necrotic spots halfway between the veins and the midrib, following the outline of the margin of the leaf and giving an oval-shaped ring of dead tissue. These spots enlarged until most of the leaf was dead (see fig. 17). Flowers were smaller and of poor color. Roots were thickened and had few laterals.

Minus calcium.—Roots died in a short time. Concurrently with the death of roots, the terminal bud died and the plant became entirely defoliated.

Minus iron.—The first symptom was a light chlorosis developing on the tip leaves of the plant. This chlorosis increased gradually until it could be noted very markedly. The veins remained dark green while the interveinal areas became chlorotic (see fig. 18). As the deficiency became more acute, the chlorosis progressed downward on the plant. Small necrotic areas appeared on some of the more chlorotic leaves. The minus iron plants bloomed, but the flowers were very light colored in comparison with the flowers of the plants in complete solution. It was noted that the roots of minus iron plants were nearly white in color. There was only a slight browning of the cortex of the older roots, and it was probably due to natural maturation of the tissues.

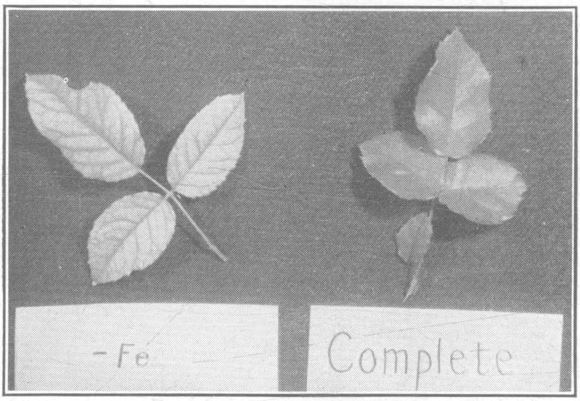

Fig. 18.—Leaf symptoms of iron deficiency for the rose

Minus manganese.—A chlorosis appeared between the veins of the top leaves. Manganese chlorosis was very difficult to distinguish from iron chlorosis, but as a general rule, in the case of manganese chlorosis even the most minute vein remained green while the areas between were yellowed. This type of chlorosis gave a very netted or checkered appearance to the leaf, as is shown in figure 19. Manganese chlorosis appeared on the top of the plant.

DEFICIENCY SYMPTOMS OF SNAPDRAGONS *(ANTIRRHINUM MAJUS)*

Minus nitrogen.—The plants were very stunted in growth and produced few shoots. The young leaves were light green in color with some yellowing along the margins and between the veins. The old leaves were rusty-yellow to rusty-yellowish-green in color. After dying, the old leaves remained a rusty color and stayed on the plant for some time.

Minus phosphorus.—The growth was stunted and the young leaves became an unusual dark green color. The old leaves were bronzy dark green in color and showed a definite purple cast beneath, later shriveling and dying.

Minus potassium.—The plants were only slightly stunted in growth. The young leaves were yellowish-green in color with dark green veins and a reddish tinge along the margin. The older leaves turned purplish-green in color on the upper surface but not purplish beneath as had those in the treatment without phosphorus. These leaves began to die first along the margin and in spots over the entire leaf.

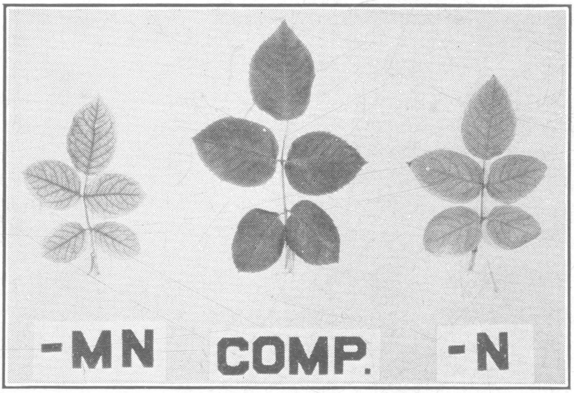

Fig. 19.—Leaf symptoms of nitrogen and manganese deficiencies for the rose

Minus magnesium.—The first evidence of magnesium deficiency was a chlorosis between the veins of the leaves on the lower part of the plant. Later, white necrotic areas developed on the leaves between the veins. This necrosis

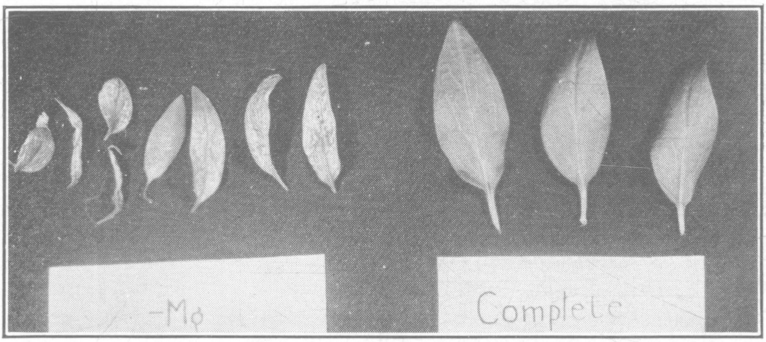

Fig. 20.—Leaf symptoms of magnesium deficiency of snapdragons

(Note the crinkling and puckering of the leaves, as well as the necrotized veins.)

gave the leaf a crinkled effect. The tips of the leaves hooked down and the margins curled upward. The growth of the plant became very stunted. The petiole and leaf blade shriveled and dried, and the leaf drooped along the axis of the plant. Leaf symptoms are given in figure 20. One or two flowers per spike appeared, but the color faded almost to a white. After some time the plant died entirely. If complete solution was added before the deficiency became acute, recovery took place in a short time. It is to be understood, however, that any necrotized areas that had appeared previous to the time of application of complete solution never did recover, but all the new growth was normal.

Minus calcium.—Plants were killed almost immediately in the young seedling stage after being placed on calcium deficiency. Plants that were first grown on complete solution for a while and then transferred to calcium deficiency began to wilt after 1 week. The wilted condition became more severe until the entire plant became brown and dried. Root injury was apparent.

Minus iron.—A chlorosis developed between the veins of the terminal leaves of the plant. Plants were stunted. Flower color was much lighter than normal.

Minus manganese.—A chlorosis developed between the veins on the tip leaves of the plant, arranged in such a manner as to give a somewhat mottled effect. In later stages the small leaves just emerging from the terminal bud became very chlorotic. Later, small necrotic spots appeared on the upper leaves, the margins curled under, and the tips turned down.

Minus sulfur.—The typical sulfur chlorosis developed; the veins were lighter than the rest of the leaf. Symptoms of chlorosis were found on the terminal leaves of the plant in the early stages and later progressed downward. The plants bloomed, but they were somewhat smaller than normal.

DEFICIENCY SYMPTOMS OF SWEET PEA *(LATHYRUS ODORATUS)*

Minus nitrogen.—The plants were very stunted in growth, and all the leaves were very light yellow, almost white, in color. The old leaves dried to a grayish-white, papery color and remained on the plant for some time before dropping.

Minus potassium.—The plants were stunted in growth, and the older leaves showed a progressive yellowing from the margins to the center. The veins of the yellowing leaves remained green until the entire leaf had turned yellow. The yellowing progressed upward until only the young leaves at the tip remained green. The dead leaves dropped from the plant early.

Minus magnesium.—The first symptom was a decreased rate of growth. The deficiency symptoms began on the lower part of the plant but quickly progressed to the top. Chlorosis soon appeared between the veins. Not long after this, the leaf exhibited large white necrotic areas between the veins. No puckering of the leaf was noticed. Needless to say, the plants were very stunted, and the root system was very small.

Minus calcium.—The earliest symptom was a dying back of the root tips. The roots were very short, and stunted. Death of the root tips was followed shortly by death of the terminal bud and yellowing and necrosis of the leaves. In the last stage the plant was entirely necrotized, and the leaves were almost white in color.

Minus manganese.—A chlorosis appeared on the terminal leaves between the veins. Puckering of the leaf was evident, and later necrotic spots appeared. These spots resembled raised welts about the size of a pinhead and were distributed evenly over the leaf.

Minus boron.—These plants never grew over 6 inches high. The terminal bud was killed and the leaves of the entire plant turned yellow. Root injury was severe.

KEY TO NUTRIENT DEFICIENCY SYMPTOMS

1. *Effects general on whole plant* or *localized on older, lower leaves.*
   2. *Effects usually general on whole plant,* although often manifested by yellowing and dying of older leaves.
      3. *Foliage light green.* Growth stunted, stalks slender, and few new breaks. Leaves small, lower ones lighter yellow than upper. Yellowing followed by a drying to a light brown color, usually little dropping. *Minus nitrogen.*
      3. *Foliage dark green.* Retarded growth. Lower leaves sometimes yellow between veins but more often purplish, particularly on petiole. Leaves dropping early. *Minus phosphorus.*
   2. *Effects usually local on older, lower leaves.*
      4. *Lower leaves mottled, usually with necrotic areas near tip and margins.* Yellowing beginning at margin and continuing toward center. Margins later becoming brown and curving under and older leaves dropping. *Minus potassium.*
      4. *Lower leaves chlorotic and usually necrotic in late stages.* Chlorosis between the veins, veins normal green. Leaf margins curling upward or downward or developing a puckering effect. Necrosis developing between the veins very suddenly, usually within 24 hours. *Minus magnesium.*
1. *Effects localized on new leaves.*
5. *Terminal bud remaining alive.*
   6. *Leaves chlorotic between the veins; veins remaining green.*
      7. *Necrotic spots usually absent.* In extreme cases necrosis of margins and tip of leaf, sometimes extending inward, developing large areas. Larger veins only remaining green. *Minus iron.* Note: Certain cultural factors, such as high pH, overwatering, low temperature, and nematodes on roots, may cause identical symptoms. However, the symptoms are still probably of iron deficiency in the plant due to unavailability of iron caused by these factors.
      7. *Necrotic spots usually present* and scattered over the leaf surface. Checkered or finely netted effect produced by even the smallest veins remaining green. Poor bloom, both size and color. *Minus manganese.*
   6. *Leaves light green, veins lighter than adjoining interveinal areas.* Some necrotic spots. Little or no drying of older leaves. *Minus sulfur.*
5. *Terminal bud usually dead.*
      8. *Necrosis at tip and margin of young leaves.* Young leaves often definitely hooked at tip. Death of roots actually preceding all the above symptoms. *Minus calcium.*
      8. *Breakdown at base of young leaves.* Stems and petioles brittle. Death of roots, particularly the meristematic tips. *Minus boron.*

SUMMARY

The following greenhouse crops: *Begonia, Calceolaria,* Carnation, *Chrysanthemum, Cineraria, Fuchsia, Gardenia,* Geranium, *Hydrangea, Poinsettia, Primula,* Rose, Snapdragon, and Sweet Pea were grown in sand drip cultures, and the visual nutrient deficiency symptoms for nitrogen, phosphorus, potassium, boron, calcium, iron, magnesium, manganese, and sulfur were studied.

The symptoms exhibited by the crops studied agreed in general with each other and with the symptoms noted by other investigators on other crops. The symptoms, however, varied in degree or intensity with each crop studied, and there were some exceptions to the ordinary symptoms.

The general nutrient deficiency symptoms for the nine elements studied were:

Nitrogen deficiency.—There were a severe dwarfing of the plant and a uniform yellowing of all the leaves. The yellowing started on the old growth and soon spread to include even the young leaves. The affected leaves tended to dry slowly and remain on the plant for some time.

Phosphorus deficiency.—The plant was severely dwarfed and the foliage was an unusually dark green color which sometimes took on a greenish-purple cast. There was a marginal leaf yellowing followed by dropping of foliage.

Potassium deficiency.—Potassium deficiency was shown by a mottling of foliage and a marginal browning and dying of lower leaves.

Magnesium deficiency.—The earliest symptom was a greatly reduced rate of growth. A chlorosis appeared on the lower part of the plant. The yellowing came between the veins, and the veins remained normal green. Petioles were short, and the entire plant became severely stunted. Frequently necrotic areas appeared very suddenly (within 24 hours) between the veins. On some types puckering of leaves was evident. Leaf abscission was prevalent with some types. Roots were few in number. Blooming was delayed and flower color was poor.

Calcium deficiency.—Nearly all of the feeding roots died within 2 to 4 weeks. Death of the terminal bud followed. Severe stunting of the plant resulted, and finally the plant died entirely.

Iron deficiency.—The first symptom was a chlorosis between the veins of the top leaves of the plant. On some plants this chlorosis became so severe that necrotic areas appeared on the leaf. These necrotic areas were usually larger than those due to manganese deficiency, and appeared more generally on the margins and tip of the leaf.

Manganese deficiency.—The top leaves became chlorotic between the veins. This type of chlorosis could be distinguished from iron chlorosis in several ways. First, manganese deficiency was usually not as severe as iron deficiency. Second, necrotic areas due to manganese deficiency were smaller in size and were located in the middle of the leaf. Third, even the most minute veins remained green in manganese deficiency, and the leaf had a very netted appearance.

Sulfur deficiency.—As a general rule, the veins of sulfur deficient leaves were lighter than the rest of the leaf. This condition was exactly opposite to that found in all other deficiencies. Plants had a much slower rate of growth. The top leaves of the plant were affected first.

Boron deficiency.—Death of the terminal bud was characteristic. This caused the development of the lateral buds. The leaves on the top of the plant became thick and brittle and tended to roll in a half-circle from the tip toward the base.

LITERATURE CITED

1. Ark, P. A. 1937. Little-leaf or rosette of fruit trees, VII. Soil microflora and little-leaf or rosette disease. Proc. Amer. Soc. Hort. Sci. 34: 216-221

2. Bouquet, A. G. B., and W. L. Powers. 1939. Celery stem crack and the use of boron in its control. Oreg. Agr. Exp. Sta. Cir. of Information 194.

3. Brooks, J. H., 3d. 1932. The effect of a deficiency of nitrogen, phosphorus and potassium upon the growth of chrysanthemums (abstract). Proc. Amer. Soc. Hort. Sci. 29: 544.

4. Burkhart, L. 1937. Deficiency symptoms of the rose. Proc. Amer. Soc. Hort. Sci. 35: 758.

5. Chadwick, L. C. 1935. Chlorosis of pin oaks. Proc. Amer. Soc. Hort. Sci. 33: 669-673.

6. Chandler, F. B., J. A. Chucka, and I. C. Mason. 1937. Boron deficiency in cauliflower and related plants. Maine Agr. Exp. Sta. Bull. 387.

7. Chandler, W. H., D. R. Hoagland, and P. L. Hibbard. 1934. Little-leaf or rosette of fruit trees, III. Proc. Amer. Soc. Hort. Sci. 30: 70-86.

8. ————, ————, and ————. 1934. Little-leaf or rosette of fruit trees, IV. Proc. Amer. Soc. Hort. Sci. 32: 11-19.

9. Chapman, H. D., A. P. Vanselow, and G. F. Liebig, Jr. 1937. The production of citrus mottle-leaf in controlled nutrient cultures. Jour. Agr. Res. 55: 365-379.

10. Dearborn, C. H., et al. 1937. Cauliflower browning resulting from a deficiency of boron. Proc. Amer. Soc. Hort. Sci. 34: 483-487.

11. Dennis, R. W. G., and D. G. O'Brien. 1937. Boron in agriculture. West Scot. Agr. Col. Plant Husbandry Dept. Res. Bull. 5.

12. Dickey, R. D., and Walter Reuther. 1938. Manganese sulfate as a corrective for a chlorosis of certain ornamental plants. Fla. Agr. Exp. Sta. Bull. 319.

13. Ferguson, Wm. 1938. Boron deficiency in cauliflower. Sci. Agr. 18: 7.

14. Finch, A. H., D. W. Albert, and A. F. Kinnison. 1933. A chlorotic condition of plants in Arizona related to iron deficiency. Proc. Amer. Soc. Hort. Sci. 30: 431-434.

15. ———— and A. F. Kinnison. 1933. Pecan rosette: Soil, chemical and physiological studies. Ariz. Agr. Exp. Sta. Tech. Bull. 47.

16. Gilbert, B. E., and F. L. McLean. 1928. A "Deficiency disease": The lack of available manganese in a lime-induced chlorosis. Soil Sci. 26: 27-31.

17. Haas, A. R. C. 1932. Injurious effects of manganese and iron deficiencies on the growth of citrus. Hilgardia 7: 181-206.

18. ———— and L. J. Klotz. 1931. Some anatomical and physiological changes in citrus produced by boron deficiency. Hilgardia 5: 175-186.

19. Hill, H., M. B. Davis, and F. B. Johnson. 1934. Nutritional studies with chrysanthemums. Sci. Agr. 15: 2.

20. ———— and E. P. Grant. 1935. The growth of turnips in artificial cultures. Sci. Agr. 15: 9.

21. Jones, H. W., O. E. Gall, and R. M. Barnette. 1936. The reaction of zinc sulfate with the soil. Fla. Agr. Exp. Sta. Bull. 298.

22. Laurie, Alex. 1936. Deficiency studies. Ohio Agr. Exp. Sta. Spec. Cir. 48: 38-41.

23. ———— and E. W. McElwee. 1934. A method for studying nutrient deficiencies in greenhouse crops. Proc. Amer. Soc. Hort. Sci. 32: 617-619.

24. ———— and Arnold Wagner. 1937. Nutritional deficiencies in greenhouse flowering plants. Proc. Amer. Soc. Hort. Sci. 35: 759-761.

25. McMurran, S. M. 1919. Pecan rosette in relation to soil deficiencies. U. S. D. A. Bull. 756.

26. Magness, J. R., et al. 1937. Effect of nutritional treatments of internal cork of apples. Proc. Amer. Soc. Hort. Sci. 34: 206-209.

27. Mowry, H., and A. F. Camp. 1934. A preliminary report on zinc sulphate as a corrective for bronzing of tung trees. Fla. Agr. Exp. Sta. Bull. 273.

28. Parker, E. R. 1937. Effect of zinc applications on the crop of grapefruit trees affected with mottle-leaf. Hilgardia 11: 35-53.

29. ————. 1938. Experiment on the treatment of mottle-leaf of citrus trees. Proc. Amer. Soc. Hort. Sci. 35: 217-226.

30. Poesch, G. H. 1935. Chlorosis of *Hydrangea hortensis*. Ohio Agr. Exp. Sta. Bimo. Bull. 20: 175: 142-143.

31. ————. 1935. (Soil) Acidity studies. Ohio Agr. Exp. Sta. Bull. 548: 56.

32. Powers, W. L., and A. G. B. Bouquet. 1939. Use of boron in controlling canker of table beets. Oreg. Agr. Exp. Sta. Cir. of Information 195.

33. Purvis, E. R., and R. W. Ruprecht. 1937. Cracked stem of celery. Fla. Agr. Exp. Sta. Bull. 307.

34. Reed, H. S. 1938. Cytology of leaves affected with little-leaf. Amer. Jour. Bot. 25: 174-186.

35. ———— and J. Dufrenoy. 1935. Effects of zinc and iron salts on the cell structure of mottled orange leaves. Hilgardia 9: 113-141.

36. Reuther, W., and R. D. Dickey. 1937. A preliminary report on frenching of tung trees. Fla. Agr. Exp. Sta. Bull. 318.

37. ———— and ————. 1938. Preliminary report of frenching of tung trees. Proc. Amer. Soc. Hort. Sci. 35: 230.

38. Ridgway, H. W. 1938. Case of rosette on apple in Virginia. Proc. Amer. Soc. Hort. Sci. 35: 227-229.

39. Row, E. A. 1936. Study of heart-rot of young sugar-beet plants grown in culture solutions. Ann. Bot. 50: 735-746.

40. Skinner, J. J., and J. B. Demaree. 1926. Relation of soil conditions and orchard management to the rosette of pecan trees. U. S. D. A. Dept. Bull. 1378.

41. Townsend, G. R., and H. H. Wedgworth. 1936. A manganese deficiency affecting beans. Fla. Agr. Exp. Sta. Bull. 300.

42. White, H. E. 1935. Effect of plant nutrients, soil reaction and light on gardenias. Mass. Agr. Exp. Sta. Bull. 315: 58-59.

43. ———. 1938. Factors affecting iron chlorosis in gardenias. Proc. Amer. Soc. Hort. Sci. 35: 774-780.

44. Woodbridge, C. G. 1937. Boron content of apple tissues as related to drought spot and corky core. Sci. Agr. 18: 41-48.

45. Young, H. C., and H. F. Winter. 1937. The effect of boron, manganese, and zinc on the control of apple measles. Ohio Agr. Exp. Sta. Bimo. Bull. 22: 147-152.