

A STUDY OF THE INFLUENCE OF CERTAIN NUTRIENTS
ON THE GROWTH AND FLOWERING OF
HYACINTHUS ORIENTALIS LINN.

By

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DEDICATION

"It is a knowledge to know that you
do not know what you do not know."

To the Arabian philosopher who said this thoughtful proverb, the author dedicates this work.

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INTRODUCTION

The name of the genus Hyacinthus was derived from the Greek mythology. Apollo killed his beloved youth Hyacinthus by an unlucky throw of the discus. In another version it is stated that Hyacinthus was killed by Zyphyrus, God of the west wind, because of jealousy (Thayer, 1928). Actually there is no proof that this was the hyacinth of today.

The hyacinth is a native of the Eurasian region, but particularly in the vicinity of Aleppo and Baghdad. It has been cultivated as an ornamental plant since Grecian times (Thayer, 1928), and is planted in temperate regions as well as in countries where the temperature can be controlled to favor its growth. It is frequently called the Dutch hyacinth, probably because the Netherlands is leading in the production of this bulb. Since 1944, the acreage of hyacinths grown in the Netherlands has steadily increased to 1,027 acres in the 1950-1951 season. It had reached 1,302 acres in 1938, but dropped severely between 1939 and 1944 (Agriculture Attaché of the Netherlands Embassy, Washington, D. C.). Since 1946, an average of approximately twenty-one million hyacinth bulbs have been imported by the United States of America from

the Netherlands. During 1950, the number of hyacinth bulbs imported by the United States of America was approximately twenty-four million--a total expenditure of \$1,470,000 (Bureau of Agricultural Economics, USDA).

The growth of the hyacinth is grouped into three phases of development, each of which is controlled by temperature and light: heat treatment after the bulbs are dug from the soil, growth under dark conditions, and growth under normal light.

When the bulbs are dug from the soil in the field, no florets are present. The initiation of the floral parts, quality of the raceme, and the number of the florets on each raceme are controlled by the temperature during the first phase (Beijer, 1936).

The second phase of growth to be considered occurs when the bulbs are planted and light is withheld. The growth during this phase is governed by conditions of temperature and light. Increasing this phase to excess results in increasing the length of the peduncle and leaves; while decreasing this phase reduces the growth of the roots, leaves, peduncle, and the plant becomes short and produces flowers of poor quality (Biekart, 1928).

During the third phase, when the bulbs are exposed to normal light conditions, an increase in temperature shortens the time

required for flowering, but results in flowers of lighter color (Biekart, 1928).

Although initiation and elongation processes of growth are governed by temperature and light conditions, they could not proceed favorably unless the nutritional content of the bulb provided the necessary elements. Assuming that a bulb was planted in a soil deficient in one nutritional element, the most favorable time to supply this element would seem to be during the second phase when the bulb is first planted and placed in the dark. To continue the addition of nutrients as long as the bulb is growing and increasing in size would possibly prevent any further deficiency. This would enable the nutritional status of the bulb to be more favorable for the initiation of the raceme and the florets at the time the bulb is subjected to the heat treatment for stimulation of the floral axis.

Very little information is available concerning the importance of various soil nutrients upon the growth and flowering of the hyacinth. The purpose of this study was to learn the effect of some nutrient elements on the growth of the hyacinth bulb, the quality of the raceme, the period required for flowering, and the period of flowering. The macroelements used were nitrogen,

phosphorus, potassium, calcium, and magnesium; the microelements were iron, copper, zinc, manganese, and boron.

REVIEW OF LITERATURE

Few research reports were found that related directly to the influence of soil nutrients on the growth of bulbs. No detailed experiments have been located where the influence of nutrients on the growth of the hyacinth was studied.

Biekart (1928) recommended the addition of ammonium sulphate or ammonium nitrate early in the spring, because it was found to be noticeably helpful to hyacinths grown in most soils. He maintained that since the florets were in the bulb before planting, the soil did not need to be highly rich, but that the flowers would be larger and stronger under better nutrient conditions. Griffiths (1930) suggested a crop of Vigna catjang followed by a crop of Secale, to be turned over a month before planting hyacinth bulbs. Such treatment, supplemented by a complete fertilizer at the rate of 1,000 to 1,200 pounds per acre at planting time with a top dressing of 150 to 200 pounds of ammonium sulphate per acre in the spring when the leaves appear above the soil, should produce good hyacinths. He advised, for greenhouse purposes, a good loam soil preferably of sod, and composted for a year with sod and fertilizer. Volkersz (1938) stated that the best soils were composed

of 94.1 percent sand, 4 percent calcium carbonate, 1 percent clay, and 0.1 percent humus, with a pH of 7.7. With such soils in the Netherlands, he said the phosphorus content was normally good, but addition of potassium in commercial fertilizers was very important. Generally phosphorus was applied in the autumn before planting, either as basic slag or as superphosphate. Other mineral fertilizers were given as top dressings, usually one-third in the late autumn before mulching, and two-thirds in the spring, with much care to avoid leaching resulting from rainfall. He continued to report that organic nitrogen in manure might be incorporated during the autumn, and mineral sources were usually necessary in addition. Mineral nitrogen was supplied as ammonium sulphate or ammonium-nitro-chalk at a total rate of 700 to 1,050 kilograms per hectare (638 to 957 pounds per acre). Volkersz said that granulated 6-18-30 fertilizer had been widely used at a rate of 1,000 to 1,400 kilograms per hectare (911 to 1,275 pounds per acre), supplemented with nitrogen and usually potassium. Inorganic nitrogen appeared to induce earlier flowering than organic nitrogen. He also stated that different varieties of hyacinth varied in fertilizer requirements. Hargrave and Thompson (1939) studied the influence of bulb size on the dry matter, nitrogen, and mineral

content. They chemically analyzed hyacinth bulbs, ranging from 6 to 16 centimeters in circumference, for nitrogen, phosphorus, potassium, ash, and dry matter. Nitrogen, phosphorus, potassium, and ash contents were less in the 6- than in the 8-centimeter bulbs, but they increased with increasing the size of the bulb from 10 to 16 centimeters in circumference. They explained the rise in mineral content of a larger bulb by increasing capacity of the bulb for flower formation, root development, and foliage production. The importance of producing well-developed roots for better growth and quality of hyacinth bulbs was emphasized by Bailey (1947), and Biekart (1928).

More nutritional studies have been conducted on Narcissus and Tulipa. Stuart (1947) found that potassium increased the yields of Narcissus bulbs and flowers. Bould (1939) observed that the omission of potassium resulted in reduction in Narcissus "bulb weight increase," while omission of nitrogen reduced the general growth, quality of flowers, and flower stem length. Bould (1939), working with Tulipa, found that omitting potassium had a small effect on the general appearance, although it reduced the "bulb weight increase." He also found that omitting nitrogen reduced "bulb weight increase" and flower stem length, especially the

second year. Emsweller (1938) indicated that addition of boron increased the number of Narcissus flowers during the first year of growth.

EXPERIMENTAL PROCEDURE

First Experiment

Preparation of the nutrient solution. Twenty-five 20-liter pyrex bottles were cleaned by using hydrochloric acid, detergent solution, and distilled water. Rubber and glass tubes cleaned in the same way were connected to the bottles.

The aim of the following procedure was to prepare three levels of nutrient solutions: a high, moderate, and low level. Nitrogen, potassium, calcium, and magnesium stock salt solutions, as well as orthophosphoric acid stock solution, were prepared in the 20-liter pyrex bottles. The chemically pure chemicals used as sources for each element were: ammonium nitrate, orthophosphoric acid, potassium chloride, calcium chloride, and magnesium sulphate. The three levels of nutrient solutions were prepared, one of the elements being omitted from each combination, so that there would be a series of five solutions, in each one of which an element was lacking. A sixth solution was made in which all the nutrients were included (Table I).

TABLE I
NUTRIENT ELEMENTS AND CONCENTRATIONS OF THE
NUTRIENT SOLUTIONS

Element	Nutrient Levels in Parts per Million		
	High	Moderate	Low
N	200	100	50
P	200	100	50
K	200	100	50
Ca	200	100	50
Mg	100	50	25
B	1.0	0.5	0.25
Zn	0.2	0.1	0.05
Cu	0.2	0.1	0.05
Mn	1.0	0.5	0.25
Fe	4.0	2.0	1.00

Chemically pure zinc sulphate, copper sulphate, manganese sulphate, and boric acid used as sources of microelements were added to distilled water, making a stock solution a thousand times the concentration used for the high level of the microelements (Table I). A dilute solution of the microelements was made which served as the high level of the nutrient solution containing only the microelements. The moderate level of the microelements was prepared by adding an equal volume of distilled water, and a low level, by adding three volumes of distilled water to one volume of the high level solution.

Chemically pure iron lactate was dissolved in distilled water to make a solution five hundred times the concentration used in the high level (Table I). Iron lactate solution was not added to the other solutions until they were used.

In order to supply the bulbs with only the desired nutrients, eight 2,000-milliliter Erlenmeyer pyrex flasks and eight 200-milliliter pyrex beakers were cleaned, and a separate flask and beaker were labeled and used for each treatment.

The treatments were arranged as follows:

- (a) Complete, containing all nutrients.
- (b) Minus nitrogen.

- (c) Minus phosphorus.
- (d) Minus potassium.
- (e) Minus calcium.
- (f) Minus magnesium.
- (g) Microelements.
- (h) Distilled water.

Planting. One hundred and sixty-eight flower pots, 6 inches in diameter, were thoroughly cleaned and painted with asphalt paint on the inside walls to reduce the possible accumulation of the nutrients. Each pot was labeled indicating the level of the nutrient added, treatment, and pot number. A piece of glass wool was placed in the bottom of each pot to maintain the level of the 3-1/2 pounds of clean silica sand that were placed in each pot. The weights were recorded for each of the 504 bulbs of the variety Gertrude, 17 centimeters in circumference. Each three bulbs of closely the same weight were planted in a 6-inch pot on December 30, 1950. Bulbs of the various weights were distributed among all the treatments, and the pots were randomized to subject all the bulbs to the same possible variations of environment. All the plants were grown in the greenhouse. In order to prevent any foreign nutrients flowing through the hole in the bottom of a pot

and entering another pot, the planted pots were placed inside new 4-inch pots; and thus the experimental pots were prevented from touching the surface of the tables on which they were placed. The nutrients were supplied immediately after planting by adding 200 milliliters of the previously prepared solutions to produce the three levels of all the treatments, making seven pots for each level of each treatment. Later, 200 milliliters of the various solutions were added every five to six days. Shortly before the bulbs were brought into the daylight, the solutions were supplied every two to three days. Two hundred milliliters of distilled water were supplied to each pot of the control treatment at the time of each application of nutrients to the other treatment. To prevent the increase of the nutrient concentrations, after every second addition of nutrients 200 milliliters of distilled water were added to each pot instead of the usual nutrient supply.

Exposing the bulbs to the daylight. All the bulbs were grown in a dark room at a controlled 50° Fahrenheit temperature. As soon as at least two of the bulbs in each pot had produced leaves 6 centimeters in height, the pot was placed in another greenhouse in the same randomized pattern and exposed to natural light where the night temperature was 50° Fahrenheit. In instances

when the vegetative growth had not reached 6 centimeters in height, the bulbs were removed to the daylight as soon as at least two of them began to flower.

Method of recording data. Since some of the bulbs were found to be rooting when they were received and some of them had already grown vegetatively at the time of planting, it was not possible to record accurately the data for the time required for the appearance of vegetative growth. The following records were made: time required during the dark period, the period from the blooming of the first flower until the death of the last flower, the number of the florets on each raceme, the number of the florets on the secondary stems, the length and width of the three outer leaves, and the length of the raceme.

On February 9--forty-one days after planting--one bulb of approximately the same weight representing each level of each treatment was carefully washed from the sand to allow photographing the root growth.

After the vegetative growth had been allowed to dry, five bulbs representing each level of each treatment were chosen at random for quantitative analysis of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, ash content, and moisture content.

Second Experiment

Preparation of the nutrient solutions. As a result of the first experiment, it was necessary to modify the procedure slightly for the second experiment. The second year's work was somewhat a repetition of the previous work, with the addition of another treatment. The preliminary experiment showed that phosphorus was necessary for better growth and development of the bulb. At the same time, an excess of that element seemed to retard almost any phase of growth and development. Consequently, an extra treatment was included, using the same nutrients at the same three levels as before, but the concentrations of the phosphorus were reduced to forty, twenty, and ten parts per million for the high, moderate, and low nutrient levels respectively. This was done to attempt to maintain a better nutrient balance and thereby produce better growth.

Methods of dilution were identical with those described previously. Dilute solutions of microelements were prepared, as in the first experiment, for the treatment using microelements alone. For all other treatments containing microelements, the microelements were not mixed until immediately prior to feeding the bulbs.

Planting. Four hundred and five bulbs, 19 centimeters in circumference, of the variety Gertrude were selected for planting. The planting date was December 15--fifteen days earlier than that for the first experiment. This made it possible to record the time required for the vegetative growth to begin. It was also possible to study the effect of the time of planting on the time of flowering. Because it was found that there was a lack of uniformity of growth among the bulbs of the same circumference during the first experiment, each bulb was planted separately in a 4-inch pot in the same manner as before and using a pound of clean silica sand. A 2.5-inch pot was placed below each of the planted pots to prevent contamination of nutrients. One hundred milliliters of solution or of distilled water were added to each pot when the nutrients were supplied. Planting of the bulbs, one per pot, enabled accurate recording of all data for each bulb.

As a relatively high percentage of bulbs (approximately 25%) was infected by the pathogenic bacteria identified to be Erwinia carotovora and Xanthomonas hyacinthi, this separate planting prevented the spread of the pathogen which could enter any bulb readily through wounds on the scales.

Method of recording data. The number of flowers produced by each bulb in the first experiment was sufficient to conduct a correlation analysis with the weight of the bulb. These data were not collected during the second experiment.

The following records were made: time required from planting until the appearance of the vegetative growth, time from the appearance of vegetative growth until exposing the bulbs to normal light, time elapsing from blooming of the first flower on each raceme until death of the last flower on each raceme, the length and width of the three outer leaves, and the length of the raceme.

RESULTS

The following stages of growth were segregated to facilitate in the discussion of the results: from planting to appearance of vegetative growth, from beginning of vegetative growth until normal light conditions, from beginning of exposing the bulb to normal light conditions until flowering, and the flower period (Fig. 1). Results for Experiments One and Two were similar. More emphasis is placed on the results of the second experiment, and those of the first experiment are included only where important deviations are found.

Time Required for the Various Stages of Growth

From planting until the appearance of vegetative parts. The bulbs supplied with high, moderate, and low nutrient levels, and either phosphorus or calcium lacking, required on the average 5.7 days longer to produce vegetative parts than the bulbs supplied with distilled water (Table II). Treatments where high nutrient levels were added and phosphorus concentration was 40 parts per million, as well as treatment where nitrogen was lacking, did not

FIGURE 1

Time Required for Flowering

TIME REQUIRED FOR FLOWERING

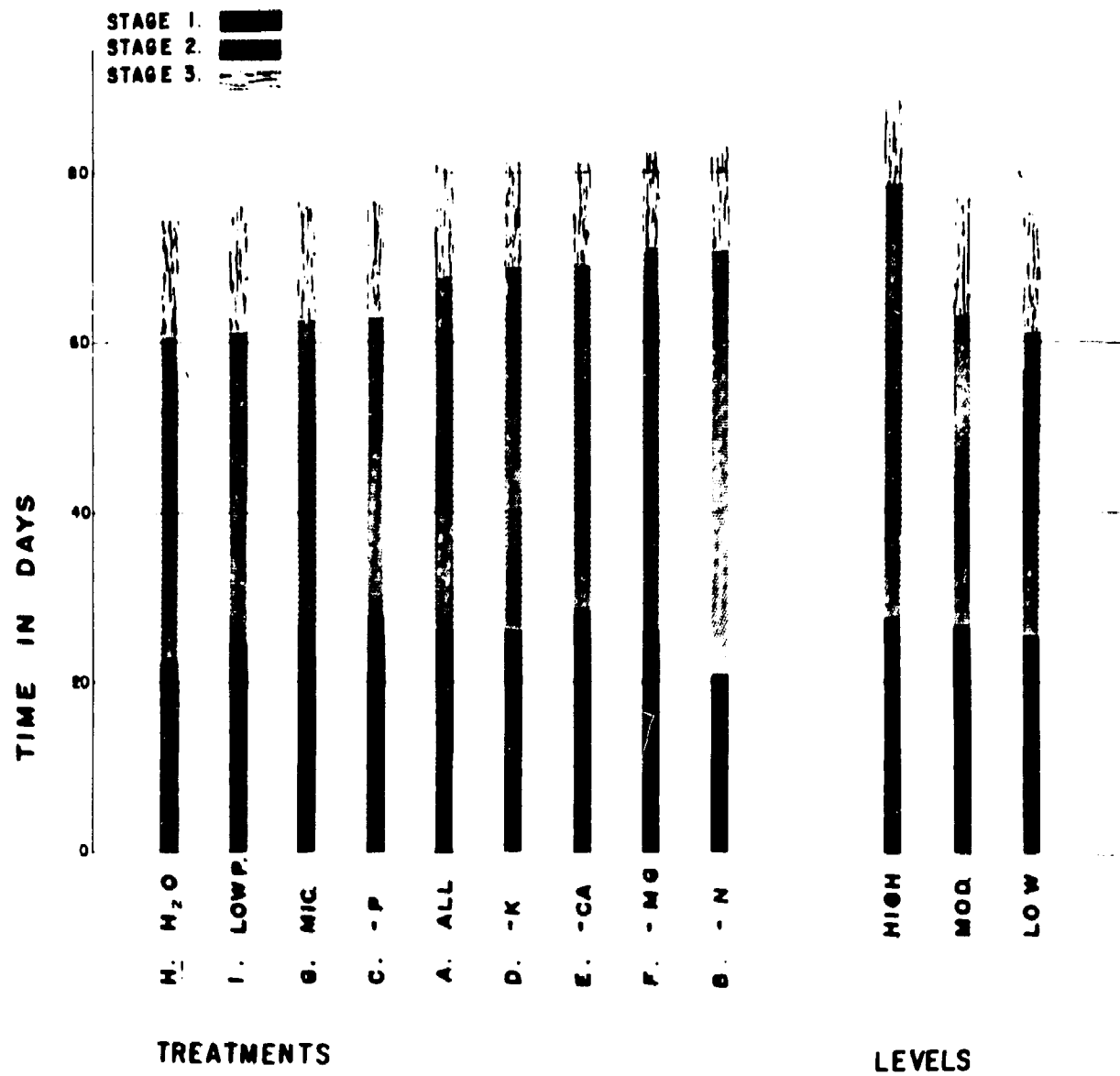


TABLE II

AVERAGE NUMBER OF DAYS REQUIRED FROM PLANTING
UNTIL THE APPEARANCE OF VEGETATIVE PARTS
"STAGE I"

Treatment	Number of Days			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	29.6	26.8	22.9	26.4
(b) Minus nitro- gen	24.2	24.6	26.8	25.2
(c) Minus phos- phorus	28.7	27.2	28.0	28.0
(d) Minus potas- sium	27.3	25.8	23.9	25.7
(e) Minus cal- cium	31.3	27.3	25.4	28.0
(f) Minus mag- nesium	25.7	28.7	24.4	26.3
(g) Microele- ments	25.8	26.2	25.8	25.9
(h) Distilled water				22.3
(i) All nutrients and low phos- phorus	24.1	23.7	25.6	24.5
Average	27.1	26.3	25.4	

significantly increase the time as did the high level in the other treatments, including the treatment where only microelements were supplied.

At all levels where no phosphorus was added, the retardation of rate of growth was significant. Addition of 10 parts per million phosphorus with low levels of the other elements also retarded the growth.

From the appearance of vegetative parts until normal light.

During this stage, the treatments may be segregated into two groups. In the first group, as is conspicuous in Table III, the growth is much less rapid in treatments at the high concentration as a result of the presence of phosphorus at the rate of 200 parts per million. This retardation effect of phosphorus was significant at the 1-percent level when compared to the treatment supplied with distilled water. All other treatments fall in the second group where there is no retardation from all concentrations of phosphorus employed (100, 50, 40, 20, 10, 0 ppm.).

The bulbs in the treatment where no phosphorus was used in combination with other nutrients required an average of 2.8 days less than the average time required by the bulbs where distilled water was added. The bulbs supplied with low phosphorus

TABLE III
AVERAGE NUMBER OF DAYS REQUIRED FROM THE
APPEARANCE OF THE VEGETATIVE GROWTH
UNTIL LIGHT PERIOD
"STAGE II"

Treatment	Number of Days			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	51.9	35.8	36.3	41.0
(b) Minus nitro- gen	58.6	40.4	36.4	45.1
(c) Minus phos- phorus	35.6	35.8	33.2	34.9
(d) Minus potas- sium	56.4	37.8	33.9	42.7
(e) Minus cal- cium	52.3	36.1	35.0	41.1
(f) Minus mag- nesium	62.1	36.5	35.2	44.6
(g) Microele- ments	38.0	34.6	36.9	36.5
(h) Distilled water				37.7
(i) All nutrients and low phos- phorus	37.6	34.8	36.7	36.4
Average	49.1	36.5	35.5	

concentrations of 40, 20, and 10 parts per million required 1.3 days less than the bulbs supplied with distilled water. Even with such a low phosphorus concentration, the time required increased over that where no phosphorus was added.

Where no phosphorus was added and where nitrogen was lacking, the results were contrary to those obtained during the stage of the vegetative growth. The bulbs supplied with high, moderate, and low nutrient levels, but without phosphorus, grew more rapidly than those in any of the other treatments (Table III). The significance over the treatments a, b, d, e, and f, where all the nutrients were added and where nitrogen, potassium, calcium, or magnesium respectively, were lacking, was at the 1-percent level. Where all the nutrients were added and nitrogen was lacking, the bulbs required an average of 10.2 days more than where nutrients were supplied but phosphorus was omitted. Obviously absence of nitrogen increased the delaying effect of phosphorus. This effect was more pronounced with the high level of phosphorus where the time required was on the average 20.9 days more than that required by the bulbs supplied with distilled water.

Bulbs supplied with high nutrient levels, but from which magnesium was omitted, required 24.4 days more than the bulbs

supplied with distilled water. Where moderate and low levels of nutrients lacking magnesium were used, the time required was closely similar to the time required by the other treatments of the same levels.

Generally, the bulbs supplied with high nutrient levels required more time to develop than those bulbs supplied with moderate or low nutrient levels (significant at 1% level; Fig. 1).

From planting until exposure to normal light. Considering the first stages together, the results are very similar to those of the second stage (Table IV and Fig. 1).

The least time required was that of the treatment where 40, 20, and 10 parts per million phosphorus were added to the high, moderate, and low levels of the other nutrients.

Omitting magnesium from the nutrient supply resulted in increasing the time required more than in any other treatment. The difference averaged 10.0 days more than the time required in the treatment where 40, 20, and 10 parts per million phosphorus were added to the three levels.

Lack of nitrogen resulted in increasing the time on the average by 9.4 more days than the time required by treatment where 40, 20, and 10 parts per million phosphorus were supplied.

TABLE IV

AVERAGE TIME IN DAYS REQUIRED IN THE DARK PERIOD

Treatment	Number of Days			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	81.4	62.6	59.2	67.7
(b) Minus nitro- gen	82.8	65.0	63.2	70.3
(c) Minus phos- phorus	64.4	63.0	61.2	62.9
(d) Minus potas- sium	83.8	63.6	57.8	68.4
(e) Minus cal- cium	83.6	63.4	60.4	69.1
(f) Minus mag- nesium	87.8	65.2	59.7	70.9
(g) Microele- ments	63.8	60.8	62.7	62.4
(h) Distilled water				60.7
(i) All nutrients and low phos- phorus	61.7	58.5	62.4	60.9
Average	78.2	62.8	60.8	

The following conclusions in summary of the two stages are of interest. Absence of phosphorus or calcium increased the time during the first period. Even a low phosphorus concentration of 10 parts per million was below the minimum required for optimum growth. At the same time, increasing the phosphorus concentration to 200 parts per million, or even 100 parts per million, resulted in increasing the time of growth in any stage.

The most favorable concentration of phosphorus that resulted in the shortest time was 20 parts per million in combination with the moderate level of the other nutrients.

It is possible that additional nitrogen was not needed during the first stage, while its need was apparent during the second stage, since its absence with addition of high phosphorus concentration resulted in delaying the time more than any other nutrient element. Considering the nutrient levels, there was no significant difference between the time required for the moderate and low levels during the first or the second stage, while during the whole period the significance was over the 1-percent level.

During the normal light. During this stage the time recorded was from the beginning of exposure to normal light until the first floret opened. Contrary to the results obtained during the

dark period, the bulbs supplied with the various high nutrient levels containing phosphorus required the least time to develop after they were placed in the light: average from 6.3 to 10.0 days (Table V). The time required by the bulbs supplied with distilled water averaged 14.6 days. Meanwhile, the bulbs treated with high nutrient levels, but without phosphorus or with a low concentration of 40 parts per million phosphorus, required almost the same time to flower as the bulbs grown in distilled water. In general, the treatments, where moderate or low nutrient levels were supplied, increased this time over the treatments with high nutrient levels (significant at 1% level).

From planting until flowering. The treatments, where high phosphorus concentrations of 200 parts per million were supplied with the other high nutrient levels, resulted in an increase in time required for flowering over that where distilled water was supplied (Table VI). The increase ranged on the average from 15.5 to 19.3 days, where all the nutrients were added, and where all the nutrients were added and magnesium was lacking, respectively.

Among the treatments supplied with moderate nutrient levels (phosphorus concentration of 100 ppm.), there was great similarity. The difference on the average was 2.4 to 4.1 days more

TABLE V
AVERAGE NUMBER OF DAYS REQUIRED DURING
THE NORMAL LIGHT
"STAGE III"

Treatment	Number of Days			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	8.8	15.8	15.8	13.5
(b) Minus nitro- gen	10.0	13.6	14.1	12.6
(c) Minus phos- phorus	14.8	14.8	14.6	14.7
(d) Minus potas- sium	7.6	14.1	15.6	12.4
(e) Minus cal- cium	8.1	14.0	14.5	12.2
(f) Minus mag- nesium	6.3	13.5	14.6	11.5
(g) Microele- ments	14.0	14.2	14.3	14.2
(h) Distilled water				14.6
(i) All nutrients and low phos- phorus	15.2	16.4	13.9	15.2
Average	10.6	14.6	14.7	

TABLE VI
 AVERAGE TIME IN DAYS REQUIRED FROM
 PLANTING UNTIL FLOWERING
 "STAGES I, II, AND III"
 1952

Treatment	Number of Days .			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	90.2	77.1	75.0	80.8
(b) Minus nitro- gen	92.8	78.6	77.3	82.9
(c) Minus phos- phorus	79.2	77.8	75.8	77.6
(d) Minus potas- sium	91.3	77.7	73.3	80.8
(e) Minus cal- cium	91.7	77.4	74.8	81.3
(f) Minus mag- nesium	94.0	78.8	74.2	82.3
(g) Microele- ments	77.8	75.0	76.9	76.6
(h) Distilled water				74.7
(i) All nutrients and low phos- phorus	76.9	74.8	76.3	76.0
Average	86.7	77.2	75.5	

than the time required where only distilled water was added. A difference of 2.4 days resulted from the addition of all the nutrients. A difference of 4.1 days resulted from treatments where all the nutrients were supplied and magnesium was lacking. The range between the average time required for flowering where low nutrient levels were supplied was more than that where moderate nutrients were added. Omitting potassium from the low nutrient levels resulted in decreasing the time required for flowering over that where distilled water was supplied by an average of 1.4 days. The longest time required was where nitrogen was lacking from the low nutrient level solution, differing by 2.6 days more than the time where distilled water was used.

In the treatment where phosphorus concentrations of 40, 20, and 10 parts per million were added to the high, moderate, and low nutrient levels, respectively, the difference was slight: an average maximum difference of 2.2 days and minimum difference of 0.1 days over that where distilled water was supplied. Using moderate nutrient levels and phosphorus at a rate of 20 parts per million resulted in increasing the time by 0.1 days over that where distilled water was used.

Regarding the levels in general, there was a direct relation between the time required for flowering and the increase of the levels. The significance for low or moderate levels in relation to high levels was over the 1-percent level, while the significance in time where low nutrient levels were used in relation to moderate levels was only at the 5-percent level.

It is interesting to observe that omitting phosphorus while using high levels of the other nutrients resulted in an increase in the time required for flowering over that where phosphorus was supplied in low concentrations of 40, 20, or 10 parts per million.

Comparison of results for two years. In general, the results for both experiments were similar. The most outstanding differences were found in the time elapsing between planting and flowering (1951 in Table VII, and 1952 in Table VI). It was thought that reporting some of these comparisons would aid in the discussion to follow. Where high nutrient levels combined with phosphorus concentrations of 200 parts per million were added, the time required for flowering was longer than that where moderate nutrient levels with phosphorus concentrations of 100 parts per million were used. Both the high and moderate levels resulted in longer time required for flowering than the addition of low nutrient levels with

TABLE VII
AVERAGE TIME IN DAYS REQUIRED FROM PLANTING
UNTIL FLOWERING
1951

Treatment	Number of Days			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	68.0	60.3	52.6	60.3
(b) Minus nitro- gen	84.8	60.5	55.4	66.9
(c) Minus phos- phorus	51.9	53.1	54.9	53.3
(d) Minus potas- sium	63.9	55.3	54.5	57.9
(e) Minus cal- cium	65.4	61.6	53.8	60.3
(f) Minus mag- nesium	67.6	54.0	54.3	58.6
(g) Microele- ments	55.2	51.8	58.2	55.0
(h) Distilled water				53.9
Average	65.3	56.7	54.8	

phosphorus concentration of 50 parts per million. These results were similar both years. When phosphorus was omitted during the first year's work, the time required for the high, moderate, and low levels averaged 53.3 days, which was a 0.6 days less than the time required when distilled water was used. During the second year, the time required by the same treatment was 2.9 days more than the time required when distilled water was supplied.

Using high nutrient levels and omitting nitrogen during the first year resulted in maximum delay in flowering: 30.9 days more than that where distilled water was used. The same treatment during the second year also resulted in increasing the time required for flowering; the difference was 18.1 days more than the time required when distilled water was used. Omitting magnesium while using high nutrient levels resulted during the first year in increasing the time required for flowering by only 13.7 days more than that required when supplying distilled water, compared to 19.3 days in the second year.

The difference in the average time required for flowering between the high and moderate levels was 8.6 days for the first year, while it was 9.5 days for the second year (Table VIII).

TABLE VIII
TIME IN DAYS REQUIRED FROM PLANTING
UNTIL FLOWERING

Year	Number of Days		
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level
1951	65.3	56.7	54.8
1952	86.7	77.2	75.5

Differences of 1.9 and 1.7 days were obtained between the time required for flowering between the moderate and low levels during the first and the second year, respectively.

It is conspicuous in Table VIII that the difference in time required for flowering between the two years for each nutrient level was twenty-one days. This delay in flowering resulted from planting the bulbs fifteen days earlier in 1952.

Flowering period. The second stage in the normal light is the time from the opening of the first floret until fading of all the florets. The florets of the bulbs in the treatment where distilled water was supplied required an average of 13.4 days (Table IX).

TABLE IX
AVERAGE TIME IN DAYS OF THE FLOWERING PERIOD
"STAGE IV"

Treatment	Number of Days			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	13.7	14.6	15.6	14.6
(b) Minus nitro- gen	12.3	14.6	15.9	14.3
(c) Minus phos- phorus	15.9	14.4	14.0	14.8
(d) Minus potas- sium	12.4	13.9	14.6	13.6
(e) Minus cal- cium	12.1	14.5	13.6	13.4
(f) Minus mag- nesium	13.0	15.1	15.0	14.4
(g) Microele- ments	13.7	15.0	12.7	13.8
(h) Distilled water				13.4
(i) All nutrients and low phos- phorus	14.9	16.5	15.5	15.6
Average	13.5	14.5	14.6	

Where moderate nutrient level was added with phosphorus concentration of 20 parts per million, the average time was 3.1 days more than that where distilled water was supplied. Adding the high nutrient level with phosphorus lacking resulted in an increase of an average time of 2.5 days more than that of the control treatment, while addition of low nutrient level and omitting nitrogen resulted in an increase of 2.5 days with a significance over the 1-percent level in every case. Other treatments resulting in a significant difference over the 5-percent level above that where distilled water was supplied were: low level of all the nutrients, low nutrient level with a phosphorus concentration of 10 parts per million, moderate level of nutrient and magnesium lacking, and moderate microelements level.

In general, the low levels of the nutrients resulted in increasing the time over that where the high nutrient levels were supplied (significant at 1% level).

Quality of Plants

Length of racemes. Where high nutrient levels were supplied and phosphorus was lacking or added at low concentrations of 40, 20, and 10 parts per million, the average length of the

flower stem was greater than for any other treatment (Table X and Fig. 2). An average flower stem length of 21.0 centimeters was obtained where all the nutrients were added and phosphorus concentrations were 40, 20, and 10 parts per million. This was the highest average among all treatments--1.4 centimeters more than the average length resulting from distilled water alone. Phosphorus concentration of 20 parts per million, combined with the moderate level of the other nutrients, produced, on the average, stems that were 2.6 centimeters--longer than the average resulting from distilled water. In this treatment, the uniformity of the lengths of the stems was very apparent. Excluding two infected bulbs, the difference between the longest and the shortest stems was 1.7 centimeters, while the difference between the extremes of the stem length of the bulbs grown in distilled water was 10.3 centimeters. Similar uniformity was observed where all the nutrients were added and phosphorus concentrations were 40 or 20 parts per million.

The shortest average length was obtained in the treatment where high, moderate, and low nutrient levels were supplied and potassium was omitted; this difference was 3.6 centimeters less than in distilled water.

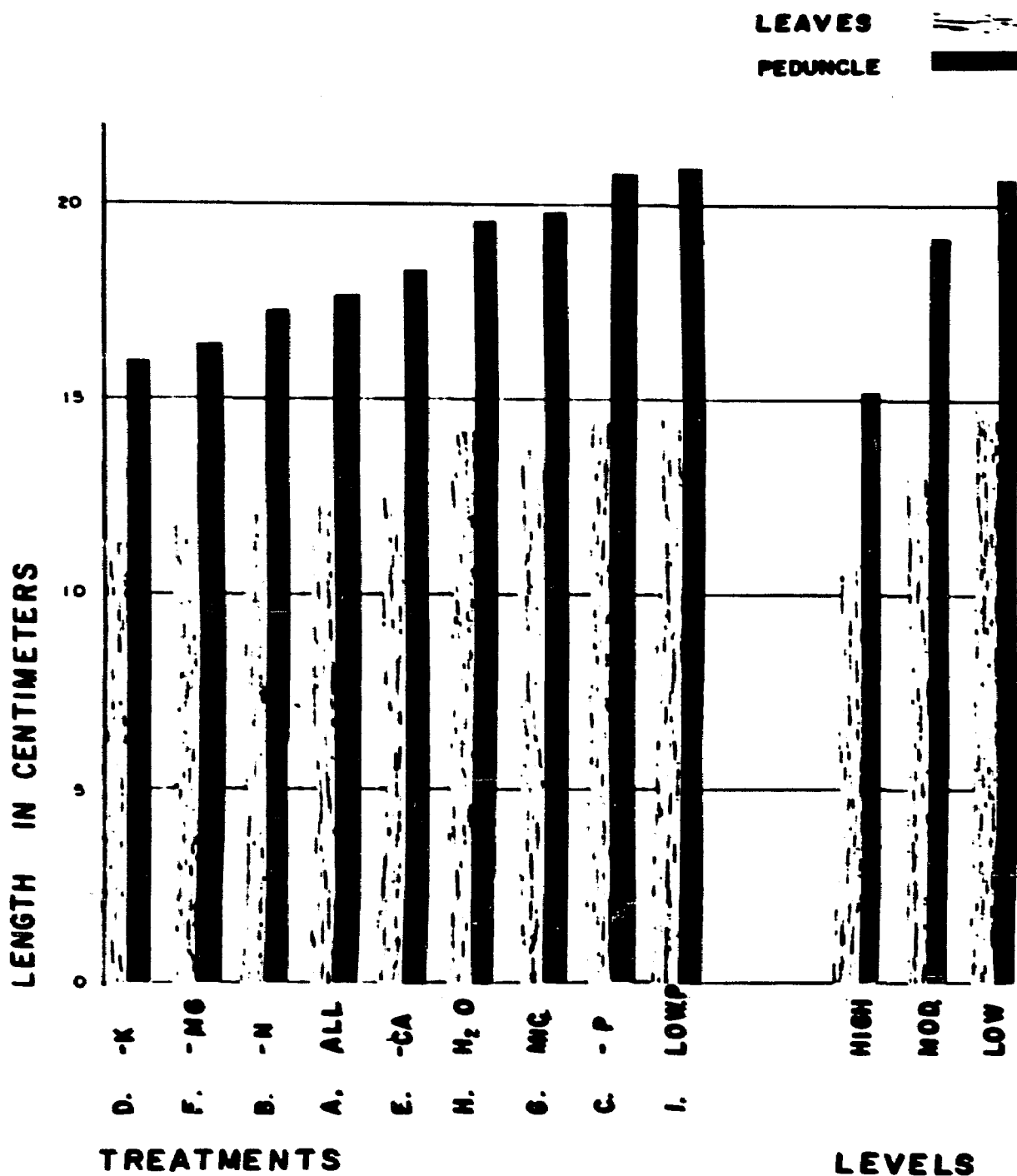
TABLE X
RACEME LENGTH

Treatment	Length in Centimeters			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	14.5	17.4	21.3	17.7
(b) Minus nitro- gen	12.2	18.4	21.2	17.3
(c) Minus phos- phorus	20.2	20.8	21.5	20.8
(d) Minus potas- sium	10.4	16.4	21.1	16.0
(e) Minus cal- cium	14.4	19.5	20.9	18.3
(f) Minus mag- nesium	11.5	18.5	19.3	16.4
(g) Microele- ments	20.2	20.1	19.1	19.8
(h) Distilled water				19.6
(i) All nutrients and low phos- phorus	20.0	22.2	20.9	21.0
Average	15.4	19.4	20.7	

FIGURE 2

Height of Plants

HEIGHT OF PLANTS



The average stem length increases directly with a decrease in levels of nutrients, from high to moderate (significant at 1% level), and moderate to low (significant at 5% level).

Length of leaves. Using distilled water for comparison, there was an increase in the average length of the three outer leaves in the treatment where phosphorus was added at 40, 20, and 10 parts per million, and the treatment where phosphorus was not added to the usual three levels (Table XI and Fig. 2). The increase over that where distilled water was used was 1.2 centimeters for both treatments. The moderate nutrient level with phosphorus concentration of 20 parts per million, produced an average increase of 1.7 centimeters.

The shortest average length was obtained where any of the three nutrient levels were added and potassium was lacking. This length was 2.9 centimeters less than in distilled water.

A marked uniformity between the lengths of the leaves where the moderate nutrient level was used with 20 parts per million phosphorus contrasted a lack of uniformity between the lengths of the leaves when using distilled water.

TABLE XI
AVERAGE LENGTH OF THE THREE OUTER LEAVES

Treatment	Length in Centimeters			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	8.6	12.9	15.3	12.3
(b) Minus nitro- gen	7.9	12.8	15.5	12.1
(c) Minus phos- phorus	15.2	15.1	15.9	15.4
(d) Minus potas- sium	7.8	12.0	14.0	11.3
(e) Minus cal- cium	9.9	13.6	14.0	12.5
(f) Minus mag- nesium	8.3	12.7	14.6	11.9
(g) Microele- ments	13.9	13.9	13.2	13.7
(h) Distilled water				14.2
(i) All nutrients and low phos- phorus	14.6	15.9	15.6	15.4
Average	10.8	13.6	14.8	

The average lengths of the three outer leaves increase directly with a decrease in levels of nutrients, from high to moderate (significant at 1%), and moderate to low (significant at 5%).

Width of leaves. In the treatment supplied with all nutrients and phosphorus concentrations of 40, 20, and 10 parts per million, and where no phosphorus was added, the widest leaves were produced (Table XII). The significance of the increase of both these treatments over that where no potassium was added to the three levels was at the 1-percent level, while it was significant over all the other treatments each containing the high, moderate, and low levels, at the 5-percent level.

The average length of the flower stem, and the average length and width of the three outer leaves were found to be increased to the same extent. The treatment producing the longest flower stems produced on the average the longest and widest leaves. Each treatment ranked in the same order for flower stem length, length and width of the three outer leaves, and, in descending order, it was the same treatment that produced the same decrease in flower stem length, and length and width of the leaves.

The treatment which was supplied with all nutrients and phosphorus concentrations of 40, 20, and 10 parts per million

TABLE XII

AVERAGE WIDTH OF THE THREE OUTER LEAVES

Treatment	Width in Centimeters			Average
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level	
(a) Complete, containing all nutrient ele- ments	2.0	2.2	2.3	2.17
(b) Minus nitro- gen	1.9	2.2	2.3	2.13
(c) Minus phos- phorus	2.3	2.4	2.3	2.33
(d) Minus potas- sium	1.9	2.2	2.1	2.07
(e) Minus cal- cium	2.1	2.2	2.3	2.20
(f) Minus mag- nesium	1.9	2.2	2.3	2.13
(g) Microele- ments	2.3	2.1	2.2	2.20
(h) Distilled water				2.20
(i) All nutrients and low phos- phorus	2.3	2.3	2.4	2.33
Average	2.09	2.23	2.28	

resulted in longer flower stem average than the treatment where phosphorus was omitted; yet, both treatments gave the same results for the length and width of the three outer leaves.

Root growth. Figures 3 and 4 show one representative bulb from each treatment where moderate nutrient levels were supplied for the first and second year, respectively. Figures 5, 6, 7, 8, 9, 10, and 11 show representative samples for the high, moderate, and low nutrient levels, forty-one days after planting, each treatment during the first experiment. Figure 12 shows the differences in root growth for representative samples of the treatment where all the nutrients were added at the usual three levels (Table I) with phosphorus concentrations of 40, 20, and 10 parts per million for the high, moderate, and low nutrient levels, respectively. This photograph was also made from the second experiment during 1952, forty-two days after planting. These bulbs show the pernicious effect of high phosphorus concentrations. Roots produced on the bulbs supplied with high nutrient levels did not show this harmful effect unless phosphorus concentrations were 200 parts per million. Omitting any of the other elements did not result in such a marked increase of root growth. Figures 5 to 12 show also that by decreasing the phosphorus

FIGURE 3

Effect of moderate nutrient levels, forty-one days after
planting; first experiment, 1951.



COMP



H₂O



MICRO



-N



-P



-K



-CA



-MB

FIGURE 4

Effect of moderate nutrient levels, forty-two days after planting; second experiment, 1952.



ALL



—N



—P



—K



LOW P



—CA



—MG



MICRO



H₂O

MODERATE

FIGURE 5

Growth of bulbs forty-one days after planting, showing effect of high, moderate, and low levels of complete solutions, 1951.

FIGURE 6

Growth of bulbs forty-one days after planting, showing effect of high, moderate, and low nutrient levels with the omission of nitrogen, 1951.

H M L
COMPLETE

H

M

L

—

M

FIGURE 7

Growth of bulbs forty-one days after planting, showing effect of high, moderate, and low nutrient levels with the omission of phosphorus, 1951.

FIGURE 8

Growth of bulbs forty-one days after planting, showing effect of high, moderate, and low nutrient levels with the omission of potassium, 1951.

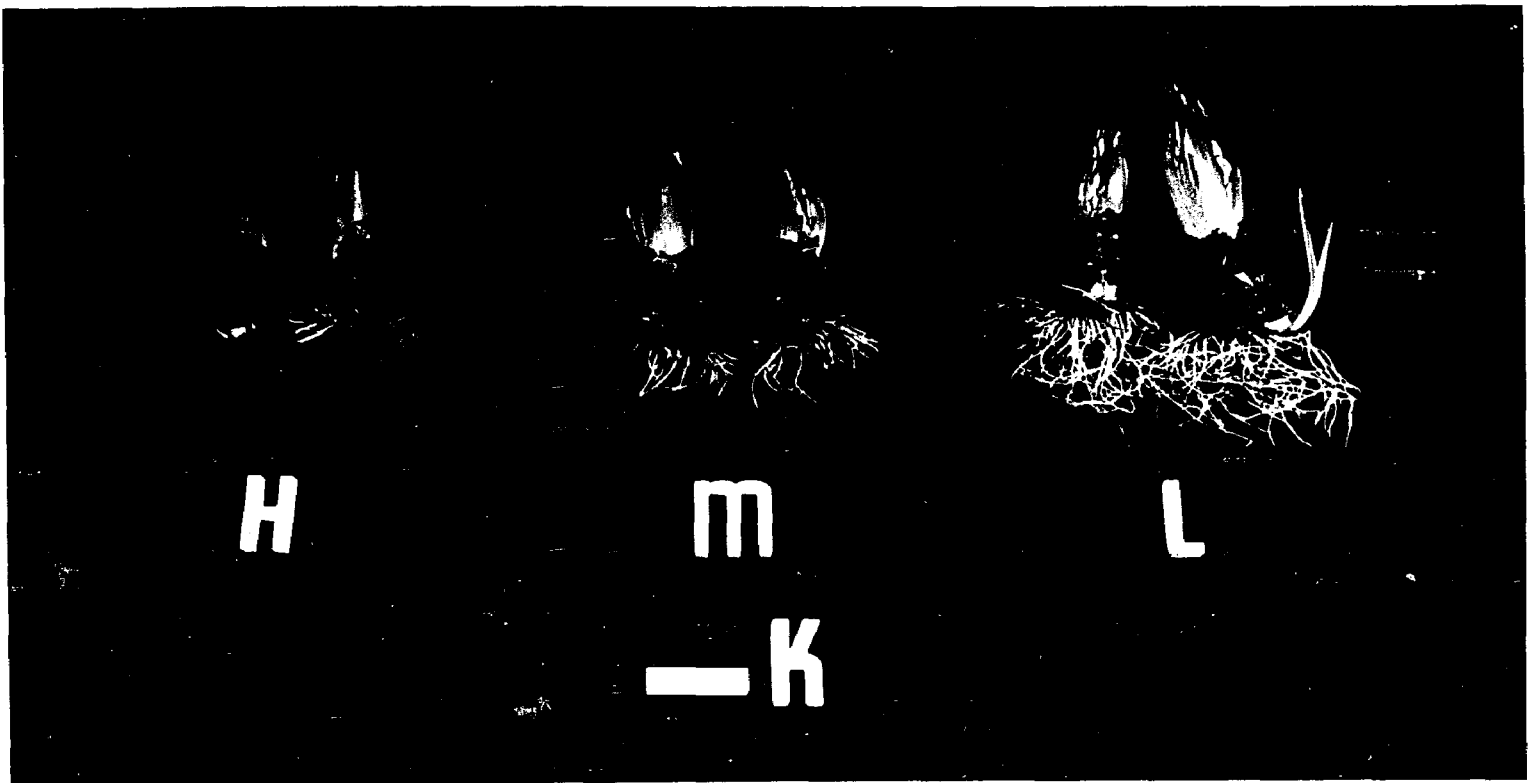


FIGURE 9

Growth of bulbs forty-one days after planting, showing effect of high, moderate, and low nutrient levels with the omission of calcium, 1951.

FIGURE 10

Growth of bulbs forty-one days after planting, showing effect of high, moderate, and low nutrient levels with the omission of magnesium, 1951.

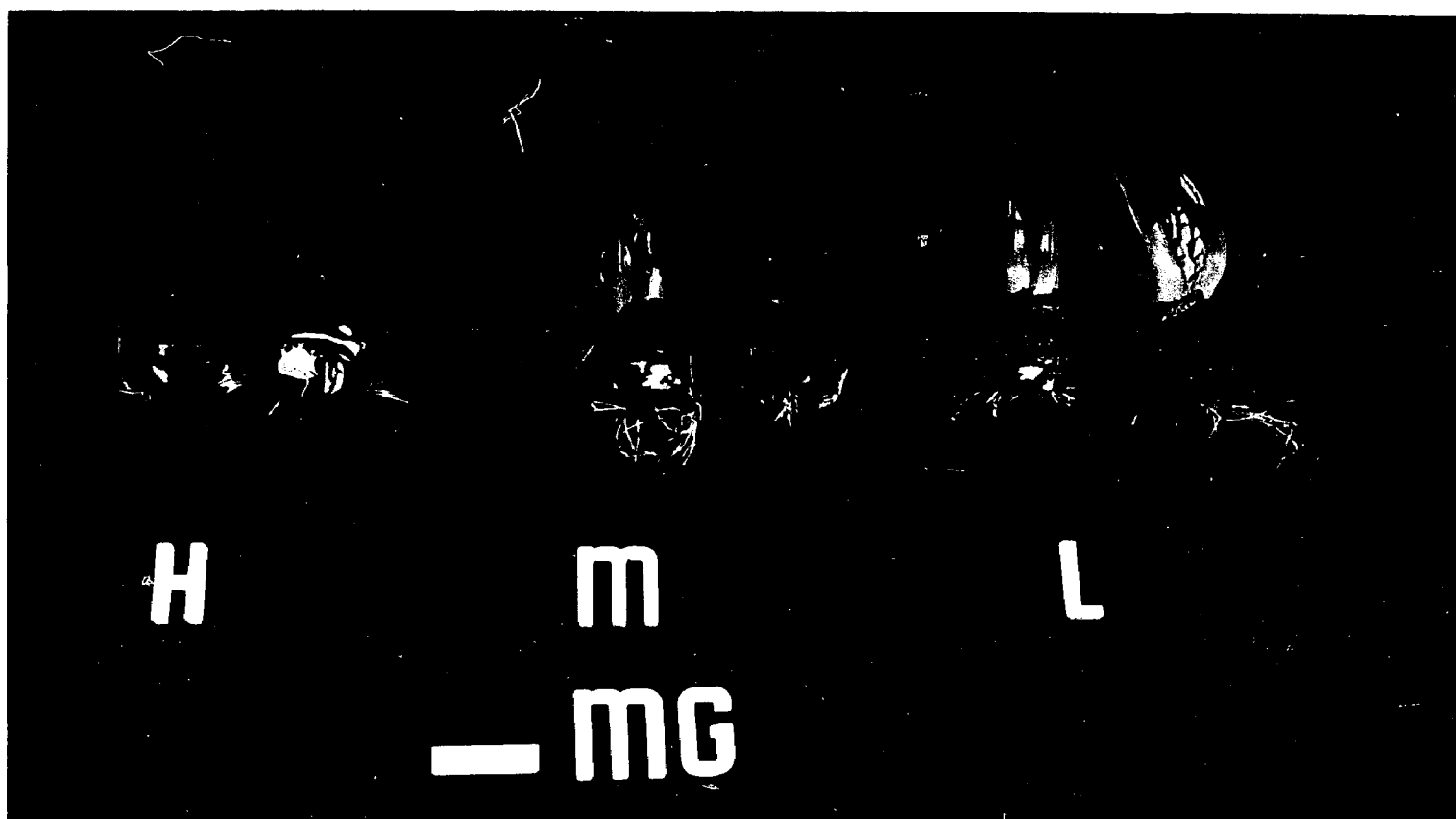
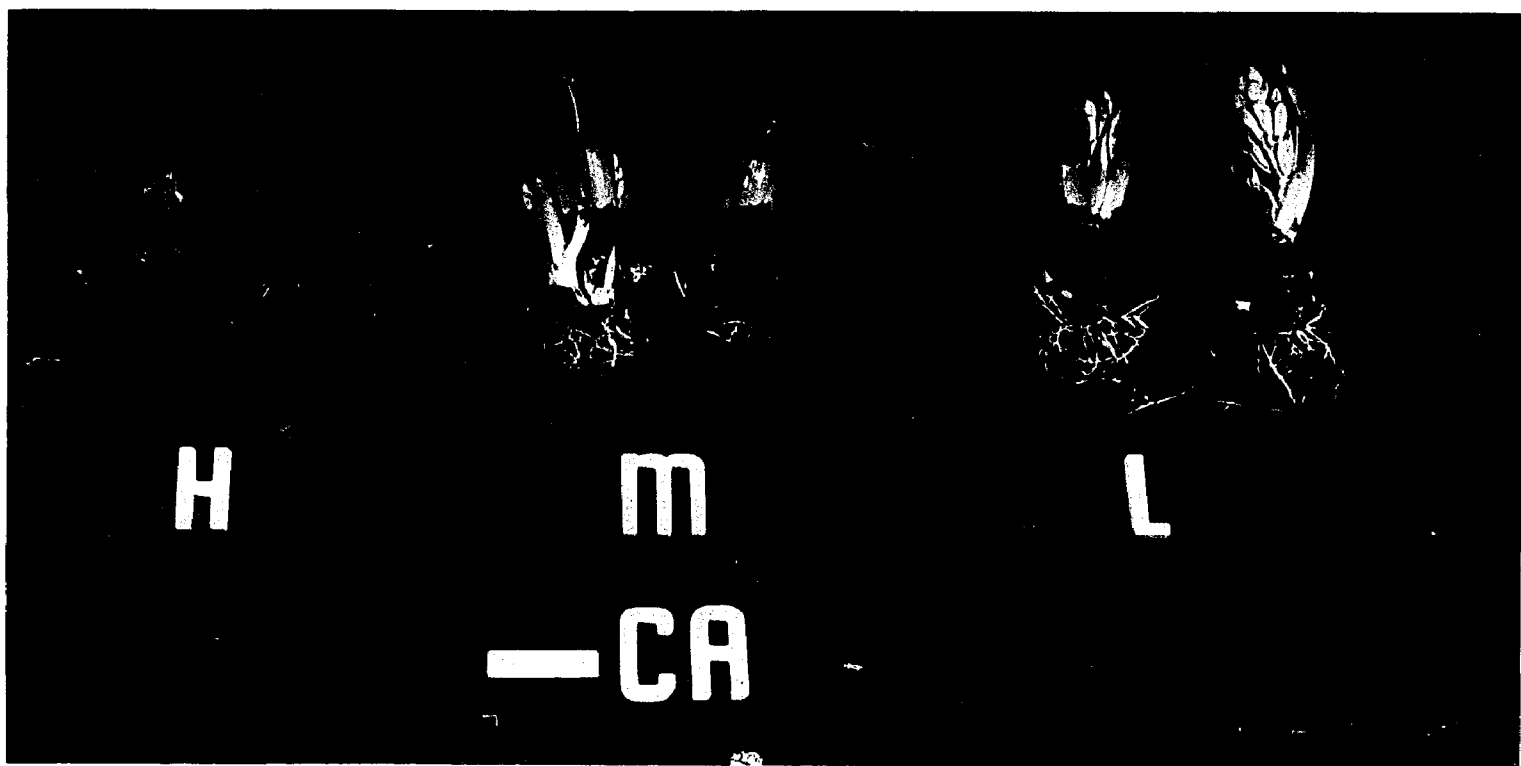


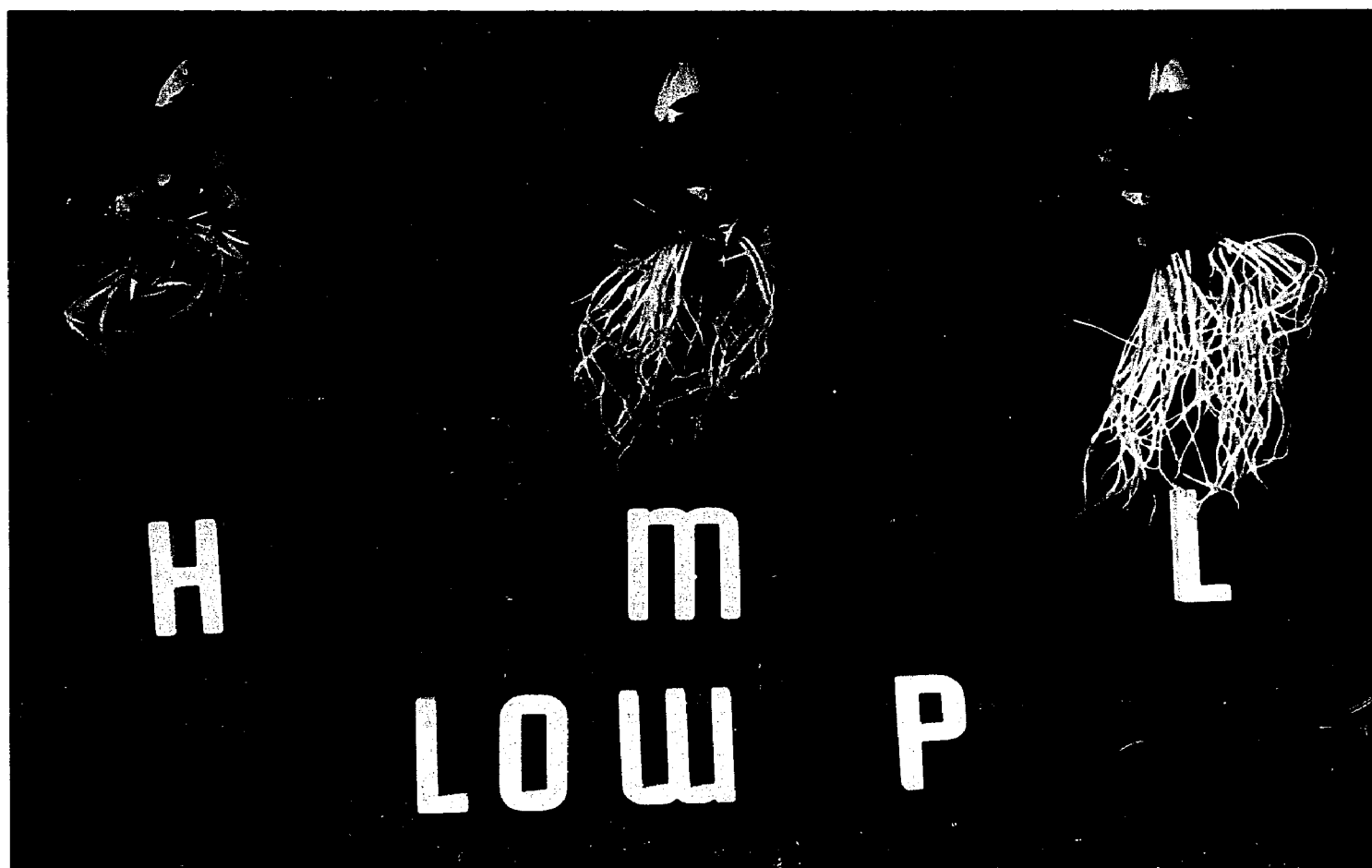
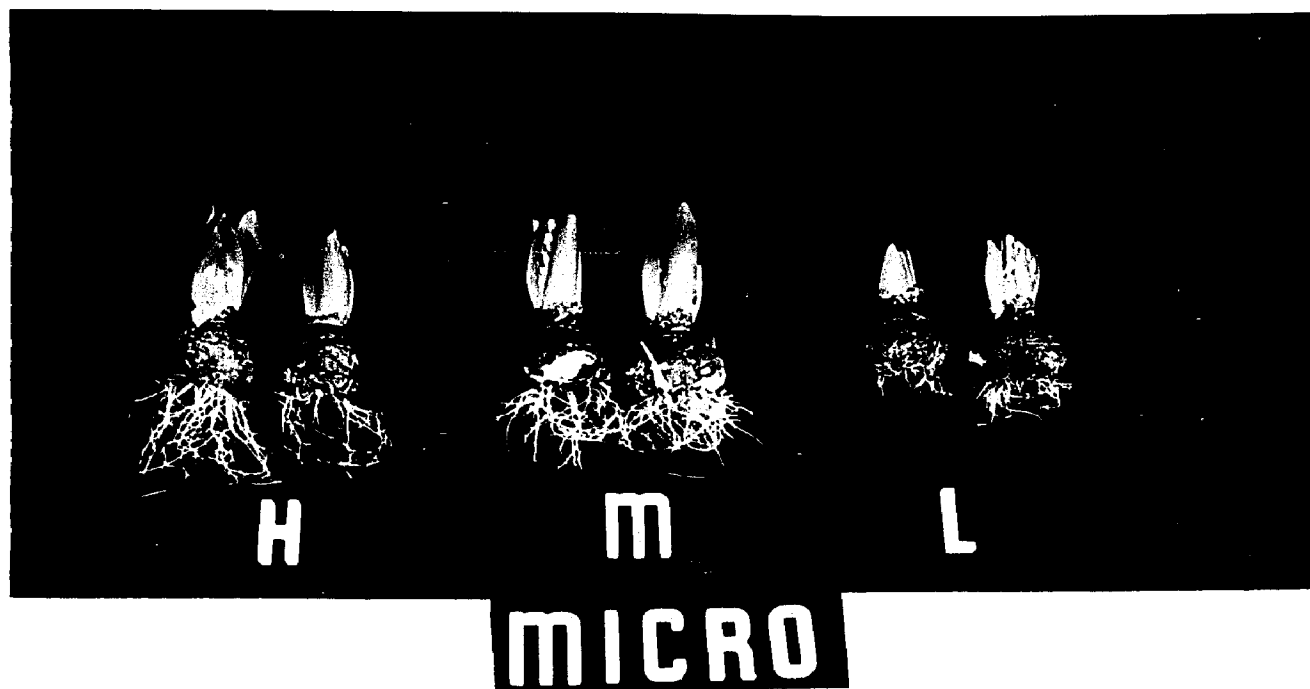
FIGURE 11

Microelements supplied at high, moderate, and low levels,

1951.

FIGURE 12

Growth of bulbs forty-two days after planting, showing effect of low phosphorus concentrations added to the high, moderate, and low nutrient levels, 1952.



concentrations to 100 parts per million, a better growth of roots occurred, while the best root growth resulted from addition of 50 parts per million of phosphorus. Figure 12 shows a rather interesting observation which could not be observed in any of the other treatments. Higher nutrient levels with phosphorus concentration of 40 parts per million resulted in decreasing root growth compared to the growth in the moderate and low nutrient levels of the same treatment with phosphorus concentrations of 20 and 10 parts per million, respectively. Such a decrease in root growth was not observed even from addition of low nutrient levels with phosphorus concentration of 50 parts per million.

Figures 13, 14, and 15, taken during the second experiment, eighty days after planting, show representative bulbs of about the same weight. They represent mature plants and illustrate the relation between growth and phosphorus concentrations. Figure 13 shows the effect of adding all the nutrients at the high, moderate, and low levels, while Figure 14 shows the effect of omitting phosphorus from the high, moderate, and low nutrient levels. Figure 15 shows the differences in growth resulting from adding phosphorus concentrations of 40, 20, and 10 parts per million to the usual high, moderate, and low levels.

FIGURE 13

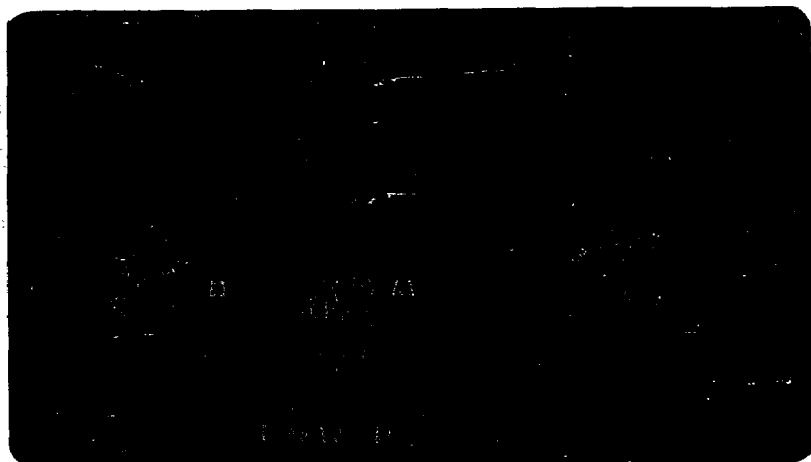
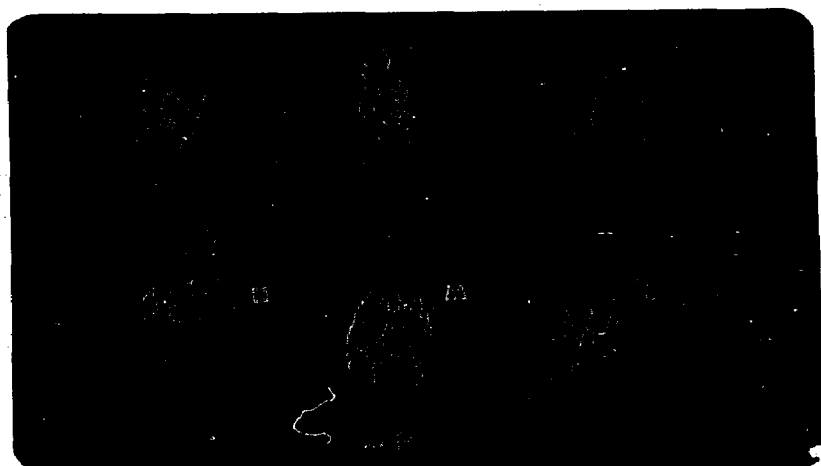
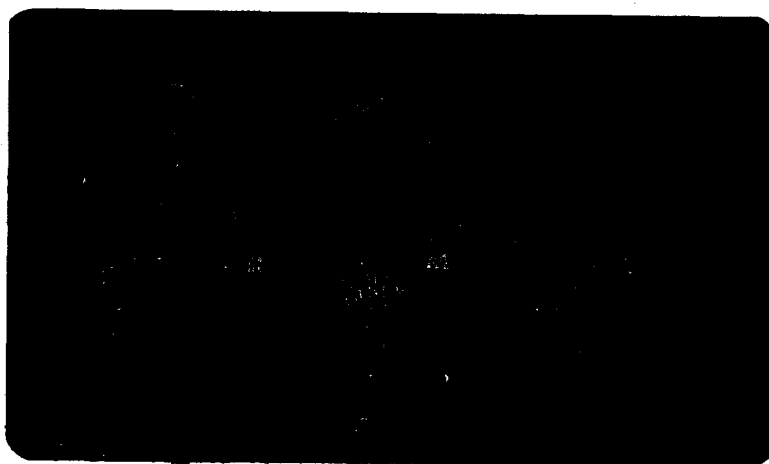
Growth of bulbs at full bloom, showing effect of high, moderate, and low nutrient levels of complete solutions, 1952.

FIGURE 14

Growth of bulbs at full bloom, showing effect of high, moderate, and low nutrient levels with the omission of phosphorus, 1952.

FIGURE 15

Growth of bulbs at full bloom, showing effect of low phosphorus concentrations added to the high, moderate, and low nutrient levels, 1952.



From close observation of the treatment where phosphorus was added at a concentration of 40 parts per million to the high nutrient level (Fig. 15), it is noticed that the root growth was equal to or better than where lower phosphorus concentrations were added in the same treatment. This is contrary to the same treatment made forty-two days after planting (Fig. 12).

Chemical Analysis

Tissue content. After the plants of the first experiment had flowered, and were thoroughly dried, five bulbs of each level of each treatment were chosen at random. Quantitative analyses were made to determine nitrogen, phosphorus, potassium, calcium, magnesium, manganese, ash, and moisture contents (Table XIII).

The bulbs from the second experiment were dried, and five bulbs were chosen at random from each of the following treatments: no phosphorus added to the high, moderate, and low nutrient levels; 40, 20, and 10 parts per million phosphorus included in the high, moderate, and low nutrient levels; and distilled water. They were chemically analyzed to determine the previously mentioned elements, as well as iron. Five bulbs representing the

TABLE XIII
CHEMICAL CONTENT OF HYACINTH BULBS
FIVE BULBS FOR EACH TREATMENT
1951

Treatment	Level	H ₂ O
(a) Complete, containing all nutrient elements	H	66.23
	M	67.40
	L	68.59
(b) Minus nitrogen	H	65.29
	M	68.70
	L	69.91
(c) Minus phosphorus	H	73.19
	M	69.37
	L	70.38
(d) Minus potassium	H	67.78
	M	70.58
	L	68.00
(e) Minus calcium	H	66.99
	M	69.11
	L	70.92
(f) Minus magnesium	H	66.93
	M	68.21
	L	67.89
(g) Microelements	H	69.92
	M	68.68
	L	67.82
(h) Distilled water		69.53

TABLE XIII (Continued)

Percentage on Fresh Weight Bases						
Ash	Ca	K	Mg	Mn	N	P
1.04	0.027	0.383	0.033	0.00021	0.790	0.103
1.11	0.015	0.424	0.035	0.00023	0.904	0.137
1.13	0.026	0.434	0.034	0.00022	0.801	0.125
1.04	0.025	0.403	0.032	0.00014	0.820	0.109
1.14	0.026	0.445	0.035	0.00016	0.880	0.122
1.07	0.017	0.446	0.033	0.00021	0.939	0.141
1.35	0.038	0.483	0.051	0.00022	1.01	0.137
1.08	0.027	0.428	0.035	0.00037	0.732	0.090
1.07	0.003	0.431	0.033	0.00018	0.814	0.090
1.11	0.026	0.410	0.044	0.00017	1.06	0.133
1.09	0.023	0.424	0.043	0.00018	0.840	0.122
1.04	0.019	0.408	0.052	0.00026	0.659	0.101
1.25	0.003	0.435	0.027	0.00017	1.01	0.140
1.23	0.029	0.464	0.041	0.00014	1.08	0.146
1.05	0.020	0.379	0.032	0.00018	0.855	0.110
1.25	0.031	0.420	0.015	0.00013	0.844	0.121
1.24	0.028	0.484	0.018	0.00026	0.967	0.137
1.30	0.028	0.478	0.018	0.00023	0.767	0.110
1.21	0.011	0.418	0.028	0.00063	0.877	0.120
1.20	0.023	0.429	0.027	0.00035	0.806	0.125
1.26	0.024	0.437	0.016	0.00013	0.927	0.139
1.14	0.021	0.401	0.014	0.00006	0.842	0.107

treatment where all the nutrients were supplied at the high level were chosen at random for iron determination.

Tables XIII and XIV summarize these data and show that there was no consistent trend in the results of this analysis. They could not be related to the variation in the rate or time of growth. High iron content was conspicuous in the bulbs supplied with all the nutrients at the high level. It was twice as great as the highest iron content in any bulbs that were supplied with either 40, 20, or 10 parts per million in combination with the high, moderate, and low nutrient levels, where phosphorus was omitted from the high, moderate, or low levels, or where distilled water was supplied.

The pH of the culture medium. During the first experiment when the flowers were in full bloom, the leachate of one pot of every treatment was collected following the second application of the nutrients to determine the pH values. From Table XV it was observed that the pH value of the leachate of the treatment where no phosphorus was supplied to the high concentration of the other elements was 4.24, and this treatment produced the best growth most rapidly during the first year. In the other treatments supplied with high nutrient levels, the rate of growth was less

TABLE XIV
CHEMICAL CONTENT OF HYACINTH BULBS
FIVE BULBS FOR EACH TREATMENT
1952

Treatment	Level			
		H ₂ O	Ash	Ca
All nutrients and low phosphorus	H	66.46	1.31	0.047
	M	67.67	1.19	0.052
	L	69.58	1.26	0.035
Minus phosphorus	H	69.66	1.25	0.047
	M	69.24	1.13	0.051
	L	66.99	1.13	0.044
Distilled water		68.02	1.04	0.036
All nutrients	H			

TABLE XIV (Continued)

Percentage on Fresh Weight Bases					
Fe	K	Mg	Mn	N	P
0.0011	0.533	0.008	0.00018	1.09	0.163
0.0012	0.442	0.024	0.00015	0.950	0.152
0.0013	0.472	0.021	0.00014	0.976	0.152
0.0017	0.482	0.016	0.00024	0.998	0.125
0.0014	0.448	0.036	0.00014	0.985	0.119
0.0013	0.418	0.030	0.00014	0.917	0.125
0.0011	0.413	0.020	0.00010	0.918	0.132
0.0034					

TABLE XV
pH VALUES OF THE LEACHATE

Treatment	pH Values		
	High Nutrient Level	Moderate Nutrient Level	Low Nutrient Level
(a) Complete, containing all nutrient elements .	5.45	6.23	6.02
(b) Minus nitrogen	3.60	5.14	5.41
(c) Minus phosphorus	4.24	5.14	6.31
(d) Minus potassium	5.11	6.49	6.72
(e) Minus calcium	4.08	5.80	6.67
(f) Minus magnesium	6.07	6.37	7.26
(g) Microelements	7.26	6.22	7.35
(h) Distilled water	7.22		

rapid and the time of flowering was later. There was less growth, and the pH values ranged from a low of 3.60, where nitrogen was omitted, to a high of 6.07, where magnesium was omitted.

By comparing the time required for growth as an example of a growth process, it was found that where the macroelements were used, there was no correlation between the pH value and bulb growth within any of the levels, although such correlation existed between the levels. Decreasing the nutrient levels increased the pH value and improved the growth.

DISCUSSION

It was observed that weights of bulbs of a shipment of hyacinth bulbs of the same variety and from the same exporter, in the same year, varied greatly. Bulbs of the same circumference from one lot ranged from 40 to 81 grams in weight, while the bulbs of the same circumference and the same weight produced from forty-five to ninety-five florets. It was noticed also that bulbs of the same weight and circumference varied as much as 8 days in the various phases of growth.

The difference in number of florets from bulbs of the same circumference and weight might be attributed to the difference in temperature to which the bulbs had been subjected (Beijer, 1936). Since, in spite of the uniformity in exposing these bulbs to the heat treatment, such differences occur, it was thought that differences in the nutritional status of the bulbs (carbohydrates, proteins, auxins, vitamins, mineral elements, or other substances that are either absorbed by the plant or synthesized in it) could be related indirectly to the environment of the bulb. Since all the bulbs were imported from the Netherlands at the same time, the probability of relating these differences to the availability of the soil nutrients

is more likely than differences in postharvest environmental conditions. References to work done for Hyacinthus and other genera of bulbs tend to suggest that there is a marked relation between the supply of nutrients and the growth of the bulb.

The Depression of Growth By High Concentrations of Phosphorus

It has been reported by many research workers that soil applications of phosphorus depressed the growth of certain plants. During 1944, Woodman found that high concentrations of phosphorus resulted in depression in yield of tops and roots of certain vegetables, Brassica Rapa roots being particularly susceptible. Lilleland, Omund, and Brown (1942), studying the phosphate nutrition of Prunus persica trees, observed that poor growth could frequently be associated with high phosphorus. Loustalat and Winters (1948) stated that a high level of phosphorus (25 ppm.) greatly depressed growth of Cinchona ledgeriana in the presence of a low supply of nitrogen, and depressed growth to a lesser extent with a medium level of nitrogen. In Florida, Reuther, Gardner, Smith, and Roy (1949) indicated that a depression in growth of orange trees was associated with a heavy superphosphate application. Chapman and

Fulmor (1951) reported that excess phosphate tended to decrease citrus fruit size.

In agreement with the results of the present work, Howard (1951) reported that the height of Gossypium thirty days after emergence was significantly less in a low phosphorus solution, while sixty days after emergence, the height of the plants was still short, but not significantly lower than where relatively higher phosphorus concentrations were applied. Ninety days after emergence, the plants began to grow more rapidly; and finally, 145 days after emergence, they were higher than plants with a high supply of phosphorus. Shanks and Link (1951) reported that the addition of phosphorus, in order to maintain it at high levels, reduced the number of flowering shoots of Hydrangea, as well as reduced the growth. Other research workers either reported the depression effect of growth resulting from high phosphorus applications, or such an effect could be observed from their data. A thorough investigation of the type of culture medium, its reaction, availability of phosphorus, other elements present, and the microbiological activity of the soil, would influence the effect of high phosphorus applications. If the calcium ion is prevalent in a soil, phosphorus may become an unavailable calcium phosphate compound. Under such conditions, additional phosphorus would be beneficial to the plant. In soils

tending to have an acid reaction, iron and aluminum would form unavailable phosphate compounds. Sideris and Kraus (1934) stated that moderate to high applications of phosphate to soils with an initial pH value of between 6.0 and 7.0 might result in depression of Ananas sativus growth as well as decrease yields. Where they applied the same quantities of phosphate to soils with an initial pH value of between 3.5 and 5.8, stimulation of plant growth and increase in yields was suggested. Swenson, Cole, and Sieling (1949) reported that maximum fixation of phosphate was found to occur at pH 2.5 to 3.5 with iron, and at pH 3.5 to 4.0 with aluminum, but approximately 90 percent of the phosphorus was still fixed by iron and aluminum at pH 6.5. To release 50 percent of the phosphate chemically combined with iron or aluminum would necessitate raising the pH of the soil to 7.0 or 8.0 for iron and even higher for aluminum. Even in the plant, Wright (1943) reported that high phosphorus concentrations were found in the roots, and a lower percentage of water-soluble phosphorus was found in the top resulting from an excess of aluminum. Pierre and Stuart (1933) stated that phosphorus concentrations of the sap of the plants receiving aluminum were in some cases one-fifth to one-seventh as

high as from those which did not receive aluminum. Under similar conditions, additional phosphorus would benefit the plant.

When the phosphorus status is observed in soils, and especially sand or solution culture medium, excess of phosphorus could be easily obtained and harmful effects could be expected. Forsee and Young (1948) reported that heavy applications of superphosphate to soil decreased the assimilation of copper by the Citrus sinensis tree and resulted in copper deficiency symptoms. Pierre and Stuart (1933) observed that superphosphate reduced the concentration of aluminum in the soil without affecting the pH of the soil. Marsh and Shive (1925) planted Glicine Soja in water culture supplied with iron, phosphorus, and other elements. They found a slight iron precipitation on the outside of the roots. They also stated that the plants showing chlorotic or toxic conditions contained higher total iron than the normal plants. Explaining further, they showed abnormally high iron content in the stem, but relatively low iron concentrations in the leaves. Olsen (1935) reported that iron was precipitated as iron phosphate in the leaf tissue, particularly along the vascular bundles. She also found that chlorotic leaves contained as much or more iron than green leaves. Other investigators have observed this effect of phosphorus

on iron. Recently Biddulph (1950), using radioactive iron in nutrient solution for feeding Glycine Soja plants, found larger amounts of precipitated iron on the root surfaces. Such precipitation inhibited the uptake of additional iron. This precipitate was found to be ferric phosphate at pH's below 6.0. At pH 6.0, some calcium was present, and at pH 7.0, calcium was predominant. He also found that at pH 4.0 and with medium phosphorus concentration, equal distribution of iron occurred throughout the plant, while at a pH 7.0 and with medium phosphorus concentration, little or no distribution of iron occurred in the mesophyll. It was accumulated in the veins indicating complete immobility. He also found that at pH 7.0 and with high phosphorus concentration, radioactive iron failed to enter the xylem as it precipitated at the root surfaces, and very little of it was found either in the veins or in the mesophyll.

Besides the possible precipitation of iron by high phosphorus concentrations, increase of calcium concentration, decrease of potassium, increase of magnesium would accentuate such precipitation, either directly or indirectly, through the interaction between the elements (Holmes and Crowley, 1944; Lindner and Harley, 1944; Wallace and Bear, 1949; Troug, Goate, and Gerloff, 1947).

In the present investigation, although chlorosis extended from the tip and margins of the hyacinth leaf to the base of the leaf, it appeared on almost all of the plants several days after exposure to normal light. It was impossible to relate this chlorosis to either deficiency or excess of any element. It appeared on the bulbs supplied with distilled water.

The Effect of Nutrients

It was shown in Table VI that the nutrients had little influence on the time required for flowering. There was a retardation of the various stages of growth as a result of adding high phosphorus concentrations. In general, it was observed that when phosphorus was added at low concentrations of 40, 20, and 10 parts per million, the least time was required for the various stages of growth. Omitting phosphorus resulted in reducing the time for growth, but not as much reduction was produced as when phosphorus was added at low concentrations of 40, 20, and 10 parts per million. The most rapid and most vigorous growth resulted from the addition of a moderate concentration of all nutrients combined with a phosphorus concentration of 20 parts per million. This was not true for every stage of growth, but the over-all

growth rate was most rapid, and the longest raceme, largest leaves, and the most roots were produced by this treatment. Such a condition is preferred for the production of larger bulbs. Producing larger bulbs containing more nutrient elements is important for production of more florets.

Jenkins and Stuart (1949) found that larger applications of nutrients resulted in increasing the rate of growth of Narcissus bulbs the second year after supplying them with the nutrients. Parker (1935) also found that heavier Narcissus mother bulbs were produced as a result of heavier fertilization. He stated that bulbs fertilized when planted produced fewer flowers the second year, with no difference in size, although the flower stalks and foliage were significantly longer. Working with Narcissus bulbs (paper white), Dickey (1940) observed that larger bulbs produced a greater number of saleable bulbs. Larger sizes of Narcissus bulbs (paper white) in each of their categories produced more flowers. Wóycicki, in Poland (1945-46), calculated a ratio of nitrogen: phosphorus: potassium contents of Tulipa to be 5.5:1:2.5 during the vegetative period, and 3.5:1:2.5 during dormancy. He calculated the amounts of nitrogen, phosphorus, and potassium absorbed by one hundred bulbs and found them to be 14.41, 3.89, and 14.92 grams, respectively

This ratio is very close to the ratio of nitrogen, phosphorus, and potassium (5:1:5) that was found to be the most favorable for optimum growth of the hyacinth.

A correlation coefficient analysis was made between the weight of the bulbs and the number of the florets produced by each bulb, and was found to be highly significant at the 1-percent level. Hargrave and Thompson (1939) stated that nitrogen, phosphorus, and potassium contents in hyacinth bulbs variety L'Innocense increased with increasing the size of the bulbs from 8 to 16 centimeters in circumference. Although this tendency of increase in nitrogen, ^{phosphorus} phosphate, and potassium content was observed on the bulbs of 17 to 18 centimeters in circumference planted the first year, the change of variety and possible change in past history made a comparison illogical. It should be mentioned that relating the increase in number of florets to the circumferences of the bulbs would not be of the same accuracy as relating this increase to the weight of the bulbs either of the same or different circumferences.

The effect of omitting the various nutrient elements was observed during the first and second stage, time required from planting until the vegetative growth appeared, and time required

from the appearance of vegetative growth until exposing the bulbs to normal light. Such an effect was not of great importance in changing the time required from planting until flowering. Omitting phosphorus, calcium, and magnesium increased the time required from planting until the appearance of the vegetative growth. Omission of nitrogen, potassium, as well as calcium and magnesium, increased the time required from the appearance of vegetative parts until exposing the bulbs to normal light. Accordingly, the addition of all the nutrients at the time of planting is favored to decrease the over-all time required for the first two stages. Although it is clearly shown that addition of all the nutrients did not reduce the time for the first two stages, the retarding effect of high phosphorus concentrations should be taken into consideration. Recommendation of the addition of all the elements with phosphorus concentration of 20 parts per million can be emphasized, therefore, as the best treatment for most rapid growth.

Since the bulbs were planted late in the season (December 30 and 15, for the first and second year, respectively), it is possible that if they are to be planted earlier, a probable variation in the time required from planting until flowering might occur. Such

variation might be in favor of adding all the nutrient elements at moderate concentrations with 20 parts per million of phosphorus.

The addition of nutrients resulted in the uniformity between the lengths of racemes. This uniformity was very apparent where low phosphorus concentrations of 40, 20, and 10 parts per million were added to the high, moderate, and low level of nutrients, respectively. Excluding two infected bulbs from those supplied with moderate nutrient level and 20 parts per million phosphorus, the difference between the longest and shortest racemes was 1.7 centimeters. This uniformity was also noticed, but to a lesser extent where phosphorus was not included with the other nutrient elements. Such uniformity could be observed to a much lesser extent where low levels of nutrients were added and any one of the other elements was omitted. Uniformity was not so marked between the bulbs supplied with all the nutrients except phosphorus or where the low nutrient levels were supplied and nitrogen, potassium, calcium, or magnesium were omitted. The variation in the nutrient content resulting from the past history of the bulbs might be suggested as a reason for this lack of uniformity.

Considering the treatment, each containing the high, moderate, and low levels, it was observed that the lack of potassium

resulted in the least growth, followed by omitting magnesium, nitrogen, and calcium, respectively. Stuart (1947) and Bould (1939) indicated the importance of potassium for producing better yield of bulbs and flowers of Narcissus, and increase in "bulb weight increase." Seely (1950) observed smaller flowers and leaves and shorter shoots of Rosa (Peter's Briarcliff) grown in pure quartz sand deficient in potassium. Post and Fischer (1951) found that Rosa (Better Times) produced significantly less flowers with low potassium during their second- and third-year growth. The stem length was also significantly reduced during the second year. Twigg and Link (1951) found that growth of Azalea was greatly restricted as a result of omitting potassium.

Additional microelements at the high and moderate concentrations resulted also in increasing the raceme length and leaf size of hyacinths over that resulting from addition of distilled water. Emsweller (1938) indicated that increase in number of Narcissus flowers resulted from addition of boron during the first period of growth.

SUMMARY

Hyacinth bulbs, variety Gertrude, were planted in silica sand. They were supplied with the following nutrient solutions: complete, containing all nutrient elements; all nutrient elements minus nitrogen; all nutrient elements minus phosphorus; all nutrient elements minus potassium; all nutrient elements minus calcium; all nutrient elements minus magnesium; microelements; distilled water; and all nutrients with a low concentration of phosphorus. For each treatment, three levels were supplied; high, which was twice the moderate level, and moderate, which was twice the low level.

Data were recorded for the time required from planting until the vegetative growth appeared, from the appearance of vegetative growth until exposing the bulbs to normal light, from exposing the bulbs to normal light until beginning of blooming, period of flowering, length of raceme, length and width of the three outer leaves. Photographs were made to compare the effect of the nutrients on root, shoot, and raceme growth.

The addition of nutrients favored rapid and better quality growth of plants.

The best time for adding the nutrients is immediately after planting.

High phosphorus concentration of 200 parts per million greatly retarded the time required for the various processes of growth, as well as impaired the quality of the plants.

Optimum uniformity of growth resulted from the addition of a complete nutrient solution combined with a phosphorus concentration of 20 parts per million. This uniformity was reduced with either decreasing or increasing the phosphorus concentrations. There was a marked lack of uniformity of growth where a high phosphorus concentration of 200 parts per million was used, or where only distilled water was supplied.

Optimum quality of plants was produced from bulbs grown in sand supplied with a complete nutrient solution containing 100 parts per million of nitrogen, potassium, calcium; 50 parts per million magnesium; moderate concentrations of microelements; and 20 parts per million of phosphorus.

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