THE INFLUENCE OF LIGHT, TEMPERATURE AND NUTRITION ON THE GROWTH RESPONSE OF SNAPDRAGON *ANTIRRHINUM MAJUS L.*

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Donald Daniel Juchartz

1958

This is to certify that the

thesis entitled

The Influence of Light, Temperature, and
Nutrition on the Growth Response
of Snapdragon *Antirrhinum majus* L.

presented by

Donald Daniel Juchartz

has been accepted towards fulfillment
of the requirements for

M. S. degree in Hort.

Walter J. Carey
Major professor

Date Feb 24, 1959

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THE INFLUENCE OF LIGHT, TEMPERATURE AND NUTRITION ON THE GROWTH RESPONSE OF SNAPDRAGON *ANTIRRHINUM MAJUS L.*

By

DONALD DANIEL JUCHARTZ

AN ABSTRACT

Submitted to the College of Agriculture of Michigan State University
of Agriculture and Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Horticulture

1958

Approved ____________________

DONALD DANIEL JUCHARTZ

ABSTRACT

The interaction of three light intensities, three minimum night temperatures, and four fertility levels on the growth rate of hybrid snapdragons (*Antirrhinum majus L.*) by the criteria of fresh weight, dry weight, and leaf area, was determined at five time intervals.

Growth rate by each criterion was significantly influenced by light intensity, temperature and fertility. Although the interactions lacked significance, optimum fertility levels at low light intensity increased leaf area and minimized differences in dry weight due to low light intensity.

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However, the greatest debt of appreciation and thanks belongs to the author's wife, Doris, whose constant encouragement and patience meant much to the author. The many hours she spent assisting in obtaining measurement data and keeping records will always be gratefully remembered.

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I. INTRODUCTION

The relationship of a plant to its environment is a complex system, with mutually influencing interdependent factors affecting the photosynthetic process of the plant as well as the other functions involved in its physiological processes. Hoagland and Arnon (19) felt that the most complex biological process known is the nutrition of a plant in soil, with three factors being taken into account: the plant, the soil system, and the above ground environment. Under natural conditions of environment, the external appearance of plants is determined by genetic and physiological factors, as they are modified and influenced by the prevailing ecological conditions. According to Thomas (55), some of the principal ecological factors to be evaluated are: light intensity, temperature, soil moisture, age of the leaves, general nutritional level, and concentration of particular nutrients, such as nitrogen, phosphorus, or potassium.

The variation of individuals within one species is set within certain limits by genetic factors. Physiological factors determine the morphological and formative expressions within these limits. Investigations by Wassink and Stolwijk (60) have indicated that the boundaries set by these genetical limits are not as confining as formerly believed, and can be altered provided the physiological treatment is adequately differentiated.

Since one of the principal functions of plants is that of photosynthesis, any condition influencing this process is important. The photosynthetic rate influences the growth rate and ultimate fresh and dry weights of the plant. Thomas (56), has demonstrated that the growth rate and weight of a plant provide indirect and approximate measures of the photosynthetic rate.

Spurway (53) has shown that optimum plant nutrition depends on the supply of available plant nutrients in the soil, in conjunction with the environmental and soil conditions which control the utilization of the nutrients in the growth of plants.

In order to compare soil fertility or fertility level with quantitative crop yield, a standard measure of plant nutrients as required by crops or plants is necessary. The classical work of Mitscherlich and his co-workers (34, 35), who discovered certain plant-nutrition relationships, has had a great influence on yield predictions and soil fertility diagnosis.

The purpose of this investigation was to determine the influence of light, temperature, and nutrition levels on the growth response of plants, using for this study, the snapdragon (*Antirrhinum majus L.*).

II. REVIEW OF LITERATURE

The growth of plants in a natural condition is one that is ever-changing as the development of the plant is influenced by its variable environmental surroundings. When a plant is taken out of its natural habitat and subjected to varying cultures, the interactions brought about assume significant proportions.

Many areas of influence on plant growth have been investigated, some of which are: plant nutrition, effect of light, soil moisture, and temperature. One of the earliest attempts to relate the interaction of plant nutrients and other factors affecting plant growth and the growth or yield of a plant was expressed by Liebig with his "Law of the Minimum" (46, 62), which states that the amount of plant growth is regulated by that growth factor present in minimum amount and varies according to whether this minimum factor is increased or decreased. Growth will increase with additions of the limiting factor until it no longer is limiting, at which point plant growth becomes independent of this factor. With a further increase, a point is reached when it becomes toxic and causes plant growth to decrease. It was upon this foundation that all future work was based. Unfortunately, this law has a limited validity, for if several factors are low, increasing any one will increase the yield.

Beginning work with this premise, Mitscherlich (35) undertook to express the exactness of the experimental curves in mathematical terms, and the formula he derived is widely known. He assumed that a plant should produce a maximum yield if all conditions were ideal, but with any essential factor limiting growth there would be a corresponding shortage in the yield. Also, the unit increase in the plant produced by a unit increment of the limiting factor is proportional to the deduction from the maximum, or expressed mathematically: $\frac{dy}{dx} = (A - y)\,C$, where y is the yield obtained when x is the amount of the limiting factor present, A is the maximum yield obtainable if x were present in an optimum amount, and C is a constant. Mitscherlich claimed that the proportionality factor C was a constant for each nutrient, independent of the crop, the soil, or other conditions. He used this formula to predict yields (35) and in other ways (33), such as estimating the amount of available nutrients in a soil through direct pot experiments.

Many workers have tried to improve on this equation, as may be seen in the work of Baule (4), Bondorff (8, 9), Balmukand (3) and Spurway (53). However, the interest in a more exact equation has abated, as shown by Gregory (15) in his review of the work of plant physiologists on this subject, inasmuch as the response of a plant or crop to a nutrient depends on many factors, such as the environmental conditions and the levels of the other nutrients present.

The necessity for an adequate water supply with fertilizer applications was shown by von Seelhorst (50) in 1898 at Gottingen. Lundegardh (25) reviewing work of Mitscherlich on the influence of soil-moisture percentage in terms of moisture capacity, indicates that the yield of potatoes varies from 16 percent with 20 percent saturation to 100 percent with 80 percent saturation, and is decreased to 62.5 percent yield with 100 percent saturation.

Under favorable growing conditions, the period of rapid vegetative enlargement is often characterized by increasing increments of total amounts of inorganic elements, carbohydrates, and proteins. Boresch (7), Maksimov (26) and White (61) have shown that many annual type plants have a tendency toward absorption of the major portion of their total mineral supply in early stages of growth.

Gregory (16) has drawn attention to the fact that over 90 percent of the nitrogen and phosphorus taken up by a developing cereal plant had been accumulated when the dry weight was only 25 percent of the final value. This store of accumulated nutrient was the reserve on which all later growth and development depended, and its level determined the final yield. Loehwing (24) has stated that the early absorption of these minerals is generally in excess of actual needs when the external supply is adequate. Anderson and others (1) have shown that with balanced conditions or constant supply, nitrogen, phosphorus and potassium increase faster in the plant than calcium, iron, magnesium and sulfur.

Goodall and Gregory (14) have demonstrated that the rate of absorption of a particular ion is determined not only by its availability in the substrate but by the concentration present in the plant. Blackman and Rutter (5) have concluded, as a result of their investigations, that the beneficial effects of fertilizer applications are due primarily to an increase in foliar area and of assimilative tissue rather than to an increase in the efficiency of assimilative processes.

The three elements needed in largest amounts in plant nutrition are nitrogen, phosphorus and potassium. Many investigations have been made on the influence of these elements on plant physiological processes. Ballard and Petrie (2) studied the effects of varying nitrogen supply on the ontogeny of plants. Mason and Phillis (30) observed the influence of boll formation on the redistribution of nitrogen in cotton plants after the external nitrogen supply was removed, showing that nitrogen migrated from vegetative areas to the reproductive tissues. Williams (64) has presented data for amounts of protein, nitrogen and for total and nucleic acid phosphorus in Phalaria tuberosa leaves, suggesting that unduly rapid, short growth can accelerate the senescence of more mature tissues by inducing the hydrolysis of the nucleic acids.

Nightingale (37) has shown that certain plants can utilize ammonium-nitrogen equally well or better than nitrate-nitrogen. For many plants, provided the growing conditions are optimum, ammonium ions may be a better source of nitrogen than nitrate ions. If the relative efficiencies of the two forms of nitrogen depended solely on the conservation of energy by the plant, ammonium-nitrogen would be the preferred form, since nitrate absorbed by plants must go through a reduction process prior to being assimilated into organic nitrogen compounds. This reduction process requires energy. Nitrogen in the ammonium form is already in a highly reduced form and immediately available for assimilation. The energy necessary for nitrate reduction appears to be obtained at the expense of carbohydrates which have been synthesized and stored by the plant.

According to Nightingale, plants do not grow nearly as well on nitrogen in the ammonium form at low as at high light intensities, which may be the result of forced utilization of carbohydrates for protein synthesis. With low light intensities carbohydrate synthesis and reserve storage are low. Forced utilization may deplete the reserves markedly and derange the growth pattern of the plant. Ammonium-nitrogen can be utilized for protein synthesis and growth at a rapid rate with high light intensities and the maintaining of carbohydrate reserves.

Hewitt (18) cites evidence to indicate that plants grow as well or better on a mixture of ammonium and nitrate nitrogen than on either form alone. In a general statement, Miller (32) indicates that young plants may more effectively utilize ammonium-nitrogen and older plants nitrate-nitrogen, although this is not true for all plants.

Wagner (57) has shown that in oats the amount of phosphorus rose to an early maximum in the leaves, later in the stems, and still later in the inflorescence, with over 70 percent of the leaf phosphorus translocated. Sommer (52) indicates that limited supplies of both nitrogen and phosphorus will hasten senescence when other nutrients are in adequate supply. Williams (63) found that the net movement of nitrogen from the leaves was delayed by phosphorus deficiency. He also found the rate of intake of nitrogen and phosphorus to be governed by the external concentration or supply of the nutrient, and by the demand for the nutrient set up by the growth and normal functioning of various plant parts, including the roots. However, he considered nutrient intake to be most often subject to the controlling influence of growth factors other than concentration.

Eaton (12) has demonstrated the interference of potassium with nitrogen metabolism. The inhibitory effect of potassium deficiency upon the formation of cell walls has been shown by Mulder (36). Investigations by Rathje (43) have shown that the potassium level of the cell controls the processes of photosynthesis and respiration to a high degree, and that conversely, the extent of these metabolic processes is important for the uptake of potassium. Pirson *et al.* (40) worked with algae of the *Chlorella* type to demonstrate the effect of potassium deficiency and the influence of light on reversibility and recovery. O'Rourke and Marshall (38) investigated the stimulation of inhibited growth in tung trees caused by a lack of potassium. Schwabe (49) demonstrated an increased sensitivity to strong light in bracken, with the effective range of light intensity considerably narrowed by potassium deficiency. Russell (45), working at the Rothamsted Experiment Station, found that applications of potassium fertilizers were particularly effective in weak light.

Blackman and Wilson (6) grew sunflowers with and without shade and later transferred them to other light intensities. They found that regardless of early lighting conditions, the net assimilation (grams of dry matter per 100 square centimeters of leaf surface per week) in the second period was the same linear function of the logarithm of the light intensity during the second period, even though some of the plant characters, like leaf area, were modified by the early lighting. Previous exposure did not appreciably modify the subsequent response of the plants to light. Pirson (39) has collected evidence on the recovery of plants from a mineral deficiency and its effect on photosynthesis and respiration, which shows that an adequate level of potassium in the plant allows utilization of the shorter wave lengths of light.

Withrow (68), in his review article, sums up the known influences of light on the mineral nutrition of plants, as do Wadleigh and Richards (56) on the relation of soil moisture to the mineral nutrition of plants. The effect of light intensity and light duration on woody plants has been reviewed by Wareing (59), and the further effect of light quality on plant growth by Wassink and Stolwijk (60).

Of more particular interest to snapdragon culture, is the work of Flint and Asen (13), in which they conclude that the snapdragon was injured by a high nutrient intensity. Earlier work by Post and Bell (42) in 1936, showed that an excess of a single salt could also be injurious.

A summation of all the interactions of the many growth factors on a plant, can be depicted in a growth curve, similar to that of Kreusler, Prehn and Hornberger (21), whose slope can be modified by adequately differentiated physiological treatment.

III. OBJECTIVES

In setting up this study, three main objectives were in mind. Inasmuch as light intensity, temperature and fertility rates can be somewhat manipulated in the average greenhouse range, it was desirable to determine the effect of the interactions of light, temperature, and fertility upon the growth rate of plants and to plot the results as growth curves. The effect of light, temperature, and the interaction of light and temperature on optimum fertility level, are the three main sections of investigation undertaken.

The original study was to carry through a snapdragon crop for each of the three main growing seasons, summer, fall and spring. We were not able to maintain the crop in the fall, giving only a summer and early spring crop. The summer crop, using MSC No. 16 snapdragon seed, was used as a crop for investigation purposes.

During the summer months, the solar radiation reaches its highest intensity and is accompanied by higher temperatures than at other times of the year. Snapdragon crops grown at this time have often produced poor quality while demonstrating a capacity for rapid growth. These characteristics might indicate inadequate fertility. The first investigation was designed to determine levels of fertilizer application snapdragon plants would tolerate. The second investigation utilized these results in conjunction with varying light and temperature.

IV. MATERIALS

A. Plant Material

The plant material chosen for this study was the snapdragon hybrid, designated experimental MSC No. 16, produced by crossing a true breeding early deep bronze F_6 from the cross Scarlet O'Hara x Lady Dorothy times a homozygous pink F_6 from the cross Helen Tobin x Armstrong's White. For the purposes of this experiment, plants exhibiting uniformity, reproducibility, and maximum genetic growth potential were desirable. In repeated bench trials this hybrid had been consistently excellent in vigor and uniformity (17). The snapdragon plants used in this study were grown from seed. Cuttings were not utilized, nor considered, from this or other plants because of the lack of uniformity in the resulting plants. Robbins (44) has stated that "any increase in the genetic uniformity of plants permits the use of a smaller number of replicates of cultural treatments without loss of statistical significance of the data than is possible with plants produced from the seeds of parents of markedly dissimilar genetic constitution." An ample source of seed, produced under controlled conditions, was available from the Department of Horticulture, Michigan State University.

B. Soil Mixture

The soil mixture utilized in these experiments was of the following composition by volume: (1) three parts of Miami loam soil, (2) two parts of local, fine sand, and (3) one part of German peat*. .This soil was thoroughly mixed, shredded and steamed for approximately three hours, with the equipment in use at the Michigan State University Plant Science greenhouses. The three-inch pots utilized in this study were filled with approximately equal weights of this soil mixture, to equalize the moisture-holding capacities of the pots, seven days after steam sterilization of the soil mixture, at which time the 15-day-old snapdragon seedlings were transplanted into the pots.

Preliminary investigations indicated that seedlings transplanted within 24 hours of steaming into "sterilized" soils were apparently benefitted greatly by the amount of nitrogenous nutrients immediately available. Russell and Hutchinson (47) have found that a primary cause of this stimulation comes from the ability of microorganisms in the soil, surviving this partial sterilization, to produce more ammonia and nitrates than did the original population, and also to increase to greater numbers due to the reduced number of antagonistic or competitive organisms.

Chemical tests run by the Spurway method (54) indicate that im-

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* Purchased from Cottage Gardens, Lansing, Michigan.

immediately after steaming, high ammonia values were found coupled with high nitrites. This was to be expected, as was the fact that the presence of nitrates was not apparent until most of the nitrites had been oxidized. It has been shown by Schloesing and Muntz (48, 58) that the transformation of ammonia to nitrates is largely biological in nature, and is accomplished in two steps. Winogradsky (65, 66, 67) isolated an ammonia oxidizing and nitrite producing bacterium, which he called Nitrosomonas, and a nitrite oxidizing and nitrate producing bacterium, which he called Nitrobacter. Martin et al. (28, 29) have produced direct evidence to show that nitrate formation in soils occurs through the nitrite stage. Therefore, with steaming, the ammonia released is oxidized to nitrites by Nitrosomonas bacteria, and this nitrite is further oxidized to nitrates by Nitrobacter bacteria. The immediate effect of steam sterilization on soils appears to be similar to that of an addition of nitrogen fertilizer.

For this reason, the soil was leached twice daily for seven days with distilled water before using, thus removing much of the additional nitrates produced as a result of steaming.

By actual test, the weighing of 256 soil-filled 3-inch pots, it was determined that the weight of soil in these pots varied less than one percent. By assuring constant weight of soil and complete mixing, it was possible to assume that the moisture-holding capacity and the soil moisture would be relatively equal in all units of the experiment.

The soil volume had been so adjusted in each pot that, with the addition of a seedling, there were approximately 50 cubic centimeters of volume remaining after the soil had been settled. This allowed the same amount of water to be applied to each plant at each watering.

C. Greenhouse and Physical Equipment

1. Pots

The pots used in these experiments were new 3-inch porous clay pots, not painted or treated.* Before being used they were steamed with the potting soil and were set aside for seven days before the seedlings were transplanted into them. To assure that all water and nutrient solution applied to the pots would remain in the soil, aluminum foil cups were made and placed over the bottom of each pot. After each application of nutrient solution, allowing time for percolation and drainage, these cups were inspected for any liquid and if present it was placed on the top of the pot again to be absorbed by the soil. Generally speaking, it was not necessary to do this because all of the 50 milliliters of solution applied remained within the pot in the soil.

2. Benches

The three benches employed were cement sided and bottomed, with a tile drain extending down the center of the V-bottom, set approximately two and one-half feet above ground level. The benches were filled to an approximate depth of six inches with fine, sharp, white silica sand. Four

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* Purchased from F. W. Ritter and Sons, South Rockwood, Michigan

lines of steam heating pipe ran directly beneath the benches and the south glass walls of the greenhouses extended below the level of the benches. Access could be gained to the plots only from the north side.

3. Temperature

For purposes of this study it was desirable to grow plants at various temperatures to affect the structural development and physiological reactions of the plant. According to Meyer and Anderson (31) the optimum temperature for the elongation or enlargement phase of growth is seldom the optimum for other portions of the growth cycle. Each stage in the plant's development usually has a different optimum temperature. In many instances, the optimum temperature for seed germination is higher than that for vegetative growth which may be lower than that required for flowering or fruiting.

In the case of the snapdragon, it has been commercial practice to grow this crop at a temperature of 48 to 50° F, night temperature, as advocated by Post (41).

Snapdragon seedlings, grown at 55° F until they were 29 days old, were placed into three greenhouse compartments, each completely separated, where the temperatures were governed by means of Minneapolis-Honeywell thermostats controlling the flow of steam through the four lines of pipe beneath the benches.

Temperatures employed were 50, 60 and 70° F, night temperatures. During the day the temperature varied in accordance with commercial practice for bright and cloudy days. Close control was maintained of the night temperatures.

Each greenhouse was ventilated by two rows of manually operated continuous roof ventilators running the entire length of the roof on both sides of the ridge. No side ventilation was available.

4. Light Intensity

An extremely important part of the environment necessary for plant growth is light, including its quality, duration and intensity. Various manipulations have been made of all three to determine the effect on plant development. The light source used in the majority of instances for crop growth is that of the naturally occurring solar radiation. This radiation varies in quantity daily and with the time of the year, as shown by Crabb (10).

It is this variation in light conditions that makes it possible for a grower in one section of the country to have a cultural advantage over another in many cases. In an attempt to define the interaction of fertility level and temperature with light intensity, three levels of light intensity were employed with each temperature and fertility level.

For purposes of controlling the light intensity, each bench used was divided into thirds, with one section left unshaded and one section covered with approximately twice as much shading material as the third section. Those portions shaded were completely enclosed with the shading material.

The shading material used was No. 240 bleached-white cheesecloth. An average of about 100 light readings, using a Model 756 Weston light meter, indicates that, compared with unrestricted solar radiation through the greenhouse glass, the nonshaded portion had 100 percent light, one section had 30. 8 percent shade - 69. 2 percent light, and the remaining section had 59. 6 percent shade - 40. 4 percent light, or approximately 0 shade, 1/3 shade, and 2/3 shade, at plant height.

D. Nutrient Solutions

1. Basis for Nutrient Solution Composition

On the basis of the Mitscherlich-Baule theory, the ultimate yield of any croup would be realized, all other growth factors being at the optimum, with the following amounts of N, P_20_5 and K_20 per acre: N - 2250 pounds; K_20 - 820 pounds. This would be equivalent to about a 5-1-2 formulation.

However, while agreeing in theory with the ideas of Mitscherlich and Baule, Spurway (53) disagrees with the amounts of the three important nutrients. According to him they become: N - 1, 000 pounds; P_20_5 - 200 pounds; K_20 - 370 pounds. For purposes of this study the values of Mitscherlich were used. In Mitscherlich and Baule's thinking, these values were considered to be the maximum amount of fertility required and are referred to as ten Baule units of fertilizer, with one Baule unit being equal to one-tenth of these values. Soil fertility is balanced then, quantitatively, when the same number of Baule units of all plant nutrients are available to a crop.

In calculating possible yields on the basis of these Baule units, Mitscherlich devised a universal yield formula: $Y = 100-(0.1 \times 2^{(10 - X)})$, in which Y is the percent of maximum crop yield, and X is the plant nutrient in Baule units per acre. Using this formula, the following values are apparent as taken from Spurway (53):

TABLE I

Potency of a Single Plant Nutrient in Terms of Baule Units and Percent of Maximum Crop Yield, all other Plant Growth Factors at the Optimum

Baule Units	Percent of Maximum Crop Yield
1.0	48.8
2.0	74.4
3.0	87.2
4.0	93.6
5.0	96.8
6.0	98.4
7.0	99.2
8.0	99.6
9.0	99.8
10.0	100.0

Inasmuch as the unit volume of soil concerned here was that contained in a 3-inch pot, the N-P-K values of Mitscherlich were converted from pounds per acre to grams per 3-inch pot. To reduce the number of variables, superphosphate was added, in a dry form, to the soil mixture prior to planting, in an amount equivalent to at least ten Baule units of phosphorus. The levels of nitrogen and potassium were varied. To introduce continuity with standard commercial practices of fertilizer applications, the basic unit of commercial fertilizer recommendations was converted to grams per 3-inch pot, and this used in making up the fertility levels.

Preliminary investigations showed that with the following rates of application, the solution concentration for further studies could be selected, inasmuch as the No. 1, 2, 6 and 7 levels were definitely not optimal, under the environmental conditions imposed.

TABLE II

Equivalency of Fertility Levels with Baule Units

Baule Units	Calculated		Applied		
	Mg. per 3-Inch Pot		Fertility Level	Mg. of Nutrients	
	N	K_2O		N	K_2O
1	47	17	1	-	-
2	95	35	2	22.8	8.5
3	142	52	3	45.7	17.0
4	189	69	4	91.3	33.9
5	236	86	5	182.6	67.9
6	283	103	6	365.2	135.7
7	330	120	7	730.5	271.4
8	377	137			
9	424	154			
10	471	171			

Employing the concept of a 5-1-2 formulation it was determined that the Baule unit of nitrogen would be equal to 47.0 mg of nitrogen per 3-inch pot. Post (41), and Laurie and Kiplinger (22) recommend that ammonium nitrate be applied at the rate of one-half pound per 100 square feet. Upon converting to a nitrogen value, for purposes of this study, the unit application of nitrogen was considered to be one-half pound per 100 square feet or 45.7 mg per 3-inch pot. The amount of K_20 to be applied was adjusted to this value with the Baulic ratio recommended by Mitscherlich. The unit application of K_20 is equal to 0.19 pounds per 100 square feet or 17.0 mg per 3-inch pot.

Upon this basis the solution composition for the actual experiment was formulated.

2. Solution Composition

In making up a nutrient solution to use in these studies, it was necessary to include only two nutrients, nitrogen and potassium. To obtain a solution such as this, ammonium nitrate (NH_4NO_3), and potassium nitrate (KNO_3) were employed. The ammonium salt was Baker's Analyzed and the potassium salt Fisher Reagent grade. Distilled water was used throughout.

These two chemical compounds were chosen because of the absence of other nutrients and because of the high amounts of nitrogen and potassium contained therein: NH_4NO_3 - 35.0 percent nitrogen; KNO_3 - 13.9 percent nitrogen and 46.6 percent K_2O. In addition, the fact that NH_4NO_3 contains ammonium ions may have an important effect as far as a continuous supply of nitrogen is concerned. The results of many experiments have shown that with autotrophically fed green algae, nitrate and ammonium salts can serve as practically equivalent sources of nitrogen, as has been demonstrated by Pirson, Tichy and Wilhelmi (40). It is very difficult to establish the biochemical equivalence of ammonium and nitrate nutrition even if indications can be obtained from the visual appearance of plants; as determined by Pirson (39), the plants used for comparison can show differences within the range of physiological tolerances.

The work of Lees and Quastel (23) has demonstrated that the site of soil nitrification is on the adsorption surface of the soil complex. Relatively little nitrification takes place in the soil solution compared to that on the soil where the ammonium ions are adsorbed. The nitrifying bacteria in the soil preferentially oxidize the adsorbed ammonium ions as opposed to those in solution. Thus, by supplying a source of ammonium ions, a continuous source of nitrogen was assured, even after the initially added nitrates were taken up.

As a result of the findings of the preliminary investigations, the range of solution concentrations was reduced so as to consist of only four fertility levels, (1) 0, (2) .5X, (3) 1X, and (4) 2X.

The basic stock solution was made up to 10 liters of a one-fifth strength solution and applied to the plants in five weekly 50 milliliter increments. This was done so as to make the nutrients available in less quantity to reduce the chance of injury to the plant, and allowed the plant to utilize a portion of the total nutrient supply over weekly portions of the experimental period. Fertility level "1" received 50 milliliters of distilled water at nutrient application time.

E. Measuring Instruments

During the course of these studies various types of measuring instruments were employed for which descriptions and nomenclature follow:

Thermo-Humidigraph: Continuous temperature readings were taken in each greenhouse through the use of Bristol Thermo-Humidigraphs, Model 4069TH.[1] These instruments, through a 24-hour period, recorded the temperature and humidity.

Area-Photometer: The measurement of leaf area, in square centimeters, was made while the leaves were in a fully turgid condition, by means of an Area Photometer,[2] which, when calibrated with a Keuffel and Esser compensating planimeter, gave area in square centimeters. The area photometer is sensitive to the optical density of the plant material being measured, and it is necessary to make individual calibrations for each type of material. The wiring diagram is shown in Figure 1. The D. C. circuit is actuated through light from the lumiline bulbs passing through an aperture and striking the photronic cell. Plant material being measured is placed on a glass tray over the aperture and the amount of light prevented from passing through to the photronic cell is a measure of the area of the material.

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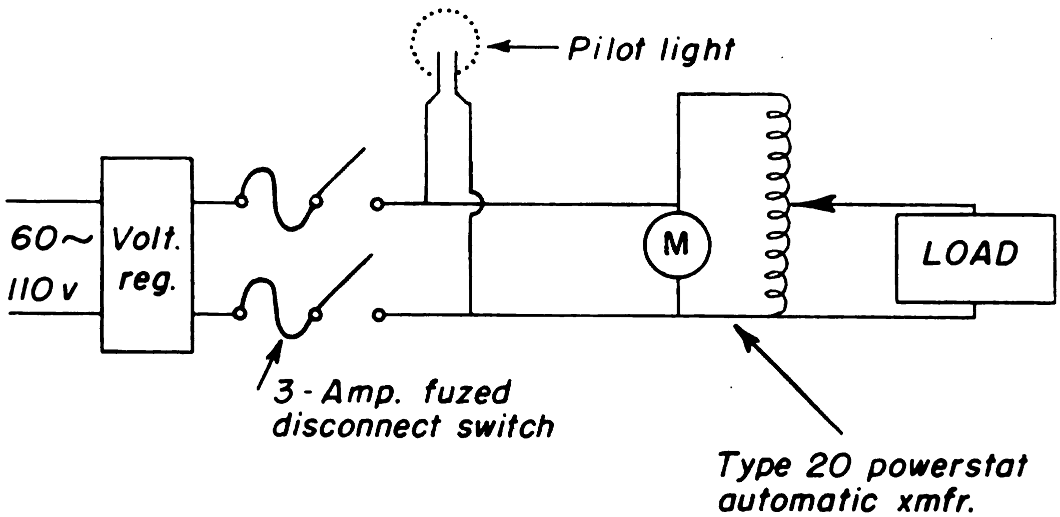
[1]Purchased from the Bristol Company, Waterbury, Connecticut.

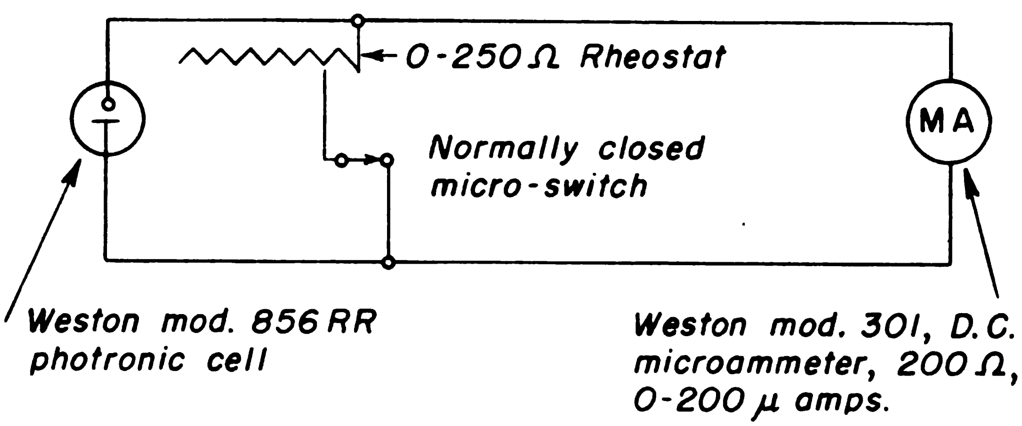
[2]Manufactured by the Agricultural Instrument Company, R. D. 1, State College, Pennsylvania.



LOAD: Eight 40-watt GE lumiline bulbs

VOLT. REG.: Sorenson regulator, mod. 500 S, KVA 0-5,
freq. 50-60.

A. C. CIRCUIT



D. C. CIRCUIT

AREA-PHOTOMETER
WIRING DIAGRAM

Figure 1

Scales: Two types of balances were used to obtain the fresh and dry weights of the plants. Fresh weight was determined on all plants harvested by means of a Shadowgraph, Model 4104-A,[1] calibrated to tenths of grams. Weights of individual plants were estimated to hundredths of grams. Dry weight was obtained through the use of a Torsion Balance,[2] calibrated in grams with estimation to tenths of grams.

Solu-Bridge: In some soils, such as greenhouse or truck garden soils and in some alkali areas in the western United States, the concentration of soluble salts may be so great as to injure plants or prohibit germination or growth, which has been shown by Markle and Dunkle (27). The concentration of soluble salts in a soil, resulting from a given application, is determined, to a large extent, by the exchange-capacity of the soil involved. The greater the exchange-capacity of the soil the smaller the amount of soluble salts generally found.

One method of determining the soluble salt content in soils is by the electrical conductivity of soil extracts. This property is dependent on the number and kinds of ions. Measurements are accomplished by means of the Solu-Bridge Soil Tester, Model RD-15,[3] which is a modified form of the

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[1]Manufactured by the Exact Weight Scale Company, Columbus, Ohio.
[2]Manufactured by the Torsion Balance Company, Clifton, New Jersey.
[3]Manufactured by Industrial Instruments, Inc.

Wheatstone bridge with a 1000-cycle alternating current to avoid polarization. To standardize the current, a vacuum tube oscillator is employed with an amplified current-detector connected to a graduated scale through a cathode-ray tube used for making the readings.

With the use of the Solu-Bridge, the units of conductivity of soil solutions are expressed in mho's, which is a measure of electrical conductance and is defined, according to the Handbook of Chemistry and Physics (20), as the conductance of a body through which one ampere of current flows when the potential difference (between the ends of a conductor) is one volt. The conductance of a body in mho's is the reciprocal of the value of its resistance in ohms. Since this conductivity is so small, the readings are amplified and expressed as mho's x 10^{-5}.

V. METHODS

A. Experimental Methods

1. Preliminary Investigation

MSC No. 16 snapdragon seeds were sown in a bench watered by constant water level on July 7, 1955. The seedlings were above ground by July 10. They were potted into 3-inch pots on July 29 in sterilized soil consisting of three parts loam soil, one part Canadian peat, and one part sharp sand, to which a 4-inch pot of superphosphate had been added per wheelbarrow of soil. The plants were selected for uniformity in size and shape on August 8 and reselected, on the same basis, on August 10.

The experiment was set up to utilize seven levels of nitrogen and potassium, with phosphorus remaining constant. Four pots of each fertilizer level were randomized in each plot, giving 28 pots per plot. Fifty milliliters of nutrient solution (composition outlined in Part III, section D) were applied at weekly intervals. Five replicates of the above plots were maintained.

To establish a starting point, one replicate was harvested on August 15. The mean dry weight of the plants harvested was 0.0785 grams, with a standard deviation of 0.0078 grams. The mean leaf area of the plants was

25.2 square centimeters with a standard deviation of 0.61 square centimeters.

The fertilizer levels used were: 0, .25X, .50X, 1X, 2X, 4X and 8X. The "0" treatment received only distilled water. The "1X" treatment was equivalent to 1.9 Baule units, Table II. All remaining plots, after the first harvest, were fertilized on 15, 22 and 29th of August and September 19th, with subsequent harvests on August 25 and September 12, 19 and 23. Tap water was used in the watering of the pots. Guard rows of plants were set up completely surrounding the plots to prevent undue water loss from occurring from plants in the actual experiment.

The differences in the fresh weight, leaf area and dry weight of these snapdragons, when harvested, indicates the growth rate. The data in Tables III and IV show the ratio of increase of the plants from the zero point of the experiment, or the mean point of the first harvested replicate. Each harvest figure is listed in terms of increase over the preceding harvest figure with a cumulative figure given for the entire harvest period.

The absence of values for fertility level "7" beginning with September 12 resulted from the death of the plants because of too high a nutrient concentration. Fertility level "7" was equivalent to more than 15 Baule units, Table II. Progressive decline of growth rate at successive harvests is demonstrated, Tables III and IV.

TABLE III

Ratio of Increase of Fresh Weight of Snapdragon Plants - Summer Crop

Fertility Levels	Harvest Periods				
	8/15-8/25	8/25-9/12	9/12-9/19	9/19-9/23	8/15-9/23
1 (0)	5.842	1.168	2.025	0.747	10.3
2 (.25X)	6.656	2.445	1.381	1.047	23.6
3 (.50X)	6.355	2.995	1.225	1.228	28.6
4 (1X)	7.474	2.859	1.235	1.158	30.6
5 (2X)	5.889	3.488	1.195	1.245	30.6
6 (4X)	4.490	3.754	1.406	1.031	24.4
7 (8X)	1.010	4.154	-	-	-

TABLE IV

Ratio of Increase of Leaf Area and Dry Weight of Snapdragon Plants - Summer Crop

Fertility Levels	Harvest Periods				
	8/15-8/25	8/25-9/12	9/12-9/19	9/19-9/23	8/15-9/23
Leaf Area					
1	3.9	1.1	1.1	0.7	4.8
2	4.2	1.8	1.0	0.9	6.5
3	3.5	2.1	1.1	1.0	8.0
4	4.9	2.2	1.0	0.9	9.5
5	4.1	2.6	1.1	1.0	11.2
6	3.2	3.2	1.2	0.8	9.8
7	0.4	-	-	-	-
Dry Weight					
1	6.7	2.1	1.6	0.7	15.7
2	6.9	3.8	1.3	1.0	32.1
3	6.5	4.2	1.2	1.2	41.2
4	7.5	4.1	1.1	1.1	43.0
5	6.2	4.7	1.2	1.2	42.4
6	5.3	3.4	1.0	1.0	29.9
7	1.7	4.9	-	-	-

It is apparent that for all practical purposes leaf expansion has ceased about midway through the experiment and remains at a constant figure after September 12. This corresponds roughly with the data in Table III. These plants had not reached the anthesis stage at this time but many of them were approaching bloom. The values for dry weight follow closely the leaf area values, although some increase is recorded after the plant comes into bloom. This can be contrasted with the apparent cessation of leaf expansion at a comparable stage.

Using visual appearances as well as fresh weight, leaf area, and dry weight data, it was determined to discard the following nutrient application levels, .25X, 4X, and 8X, and to use the remaining levels, 0, .50X, 1X, and 2X, in succeeding studies.

2. Plot Design and Physical Set-Up for Principle Investigation

Seeds of the snapdragon MSC No. 16 were sown in flats on January 17, 1956 at 60°F night temperature, in a mixture of equal parts by volume of sterilized sand, soil, and acid peat. When 15 days old, the seedlings were potted into 3-inch clay pots. On February 7, the seedlings were selected for uniformity in height and leaf development, and reselected again, on the same basis, on February 14, at which time they were placed into randomized, replicated split plots at the three temperatures employed in this study. These plants were grown at 55°F from the time of potting until moved into the various temperature chambers; during this time they were watered with tap water. Treatments were started on February 14, 1956.

This, the main experiment, was set up to utilize four levels of nitrogen and potassium, with phosphorus remaining constant. Phosphorus was thoroughly mixed, as 20 percent superphosphate, into the potting soil at the rate of one 4-inch pot per three cubic feet of soil prior to planting. In addition to the four levels of fertility there were three temperatures and three light intensities employed. The greenhouses and physical equipment used are detailed in Part III, Section C. In each temperature chamber (50, 60 and 70°F) the benches were divided into equal thirds. Each one of the thirds was fitted for one of the light intensities listed in Part III, Section C, 4. These light intensities were randomized within the three chambers. Within each light chamber in each temperature chamber four pots of each fertility level employed were randomized in one replicate consisting of 16 pots. There was a total of five replicates within each light chamber in each temperature chamber. These replicates were randomized within the various chambers. There was a total of 80 3-inch pots in each light chamber, 240 in each temperature chamber, for a grand total of 720 plants in the experiment.

The Thermo-Humidigraphs, listed in Part III, section E, were placed in each temperature chamber, under the shade making the one-third light intensity chamber. Night temperatures were regulated according to the readings obtained from these instruments.

3. Nutrient Application

The nutrient solutions used in this study were made up in keeping with the Mitscherlich-Baule theory as outlined in Part III, section D, 1. Stock solution was made up to ten liters with distilled water. The application rates are found in Table V. The first nutrient application was made on February 14, 1956, with subsequent treatments on February 22 and 29, and on March 7 and 10, 1956. Fifty milliliters of nutrient solution, in the appropriate strength, were applied to each pot individually through the use of a calibrated beaker. All fifty milliliters were allowed to percolate into the soil in each pot. The plots were watered with ordinary tap water in the morning hours and the nutrient solution applied in the afternoon.

Table V gives the cumulative total of the amounts of nitrogen and potash (K_20) applied per pot and also converts this total to Baule units and to pounds per 100 square feet. For comparison, Table VI lists the Baule units and their equivalents in pounds per 100 square feet, as well as grams per 3-inch pot. These values were derived from the Baule unit value expressed as pounds per acre six inches.

TABLE V

Nutrient Application Rates and Conversions

Fertility Levels	Weekly Applications of 50 ml Nutrient Solution/3-inch Pot		
	Ml Stock per Pot	Mg N per Pot	Mg K_2O per Pot
1 (0)	-	-	-
2 (.5X)	3.91	29.8	11.1
3 (1X)	7.81	59.4	22.1
4 (2X)	15.63	118.9	44.2

Fertility Levels	Five Applications of 50 ml Nutrient Solution/3-inch Pot (During Experimental Period)					
	Ml Stock per Pot	Mg N per Pot	Mg K_2O per Pot	Baule Unit per Pot	Lbs/100 Sq. Ft.	
					N	K_2O
1	-	-	-	-	-	-
2	19.55	148.8	55.3	3.2	1.6	0.6
3	39.05	297.2	110.6	6.4	3.2	1.2
4	78.15	594.6	221.0	12.5	6.5	2.2

1 ml stock solution contains - 19.330 mg NH_4NO_3

- 6.068 mg KNO_3

NH_4NO_3 = 35.0 percent N

KNO_3 = 13.9 percent N, 46.6 percent K_2O

TABLE VI

Baule Units Equivalency Table

Baule Units	Nitrogen Lbs/Acre	Nitrogen Lbs/100 Sq. Ft.	Nitrogen Gm/3-inch Pot	Potash Lbs/Acre	Potash Lbs/100 Sq. Ft.	Potash Gm/3-inch Pot
1	225	0.52	0.047	82	0.19	0.017
2	450	1.03	0.095	164	0.38	0.035
3	675	1.55	0.142	246	0.57	0.052
4	900	2.07	0.189	328	0.75	0.069
5	1125	2.58	0.236	410	0.94	0.086
6	1350	3.10	0.283	492	1.13	0.103
7	1575	3.62	0.330	574	1.32	0.120
8	1800	4.13	0.377	656	1.51	0.137
9	2025	4.65	0.424	738	1.69	0.154
10	2250	5.17	0.471	820	1.82	0.171

4. Harvesting Method

Plants were harvested by cutting the stem off even with the surface of the soil in the pot and using the entire upper structure of the plant. Fresh weight was obtained immediately upon cutting of the stem. To prepare for harvesting, the plants were watered in the forenoon and harvested in the afternoon. Since all of the pots held 50 milliliters of liquid, it was assumed that the relative turgidity of the plants was approximately equal when harvested.

B. Analytical Methods

1. Plant Material

a. Fresh Weight

Fresh weight is an important measure of growth in the case of those crops whose value is determined on a fresh weight basis. As a scientific measurement it is subject to much variation and external influence. However, fresh weight was determined on all plants harvested by means of a Shadowgraph, described under Part III, Section E, and recorded to hundredths of grams.

The plants were harvested weekly beginning with the first day of treatment, February 14, 1956. This first harvest established the zero point for future measurements. At weekly intervals thereafter, four replicates, under each light condition and at each temperature, were harvested, with the exception of the last harvest, which went ten days from the preceding harvest. There was a total of five harvests. These periodic samplings enabled the data taken to be utilized in the construction of growth rate curves.

b. Leaf Area

After obtaining the fresh weight the individual plants were placed between wet paper towels to keep them in a turgid condition until the leaf area could be measured. The measurement of leaf area was done by means of the Area-Photometer, described in Part III, Section E. Individual leaves were removed from the stems and the petiole of the leaf severed at the base of the blade. This gave a measurement of only the blade or leaf area in square centimeters. In the early stages of growth all of the leaves of one plant were placed on the glass tray of the Area-Photometer at the same time. However, as the number and size of the leaves of individual plants increased, it was necessary to make several measurements to obtain the total area of all of the leaves of one plant.

For these measurements all leaves on the plant were used with the exception of the small bracts subtending the immature inflorescence in the later stages of growth.

c. Dry Weight

Reducing plant material to a condition where the volatile and liquid substances have been removed, allows the resulting plant weights to be compared directly, without including the varying proportions of the above substances.

After measuring the leaf area, all portions of the plant, with the exdeption of the roots, were placed in individual two-pound Kraft paper bags. These bags were placed in a forced-draft oven at a temperature of 97° Centigrade for 24 hours. Upon removal the contents were weighed with a Torsion balance, weights recorded to tenths of grams, after which they were discarded.

2. Soluble Salt Content of the Soil

To determine the soluble salt content of the soil in each experimental condition, the four replicates of each treatment, at each harvest, were thoroughly mixed and a representative sample chosen for each treatment, for a total of 180 samples. The sample was then diluted at the rate of 50 grams of air-dry soil to 100 ml of distilled water. The resulting mixture was stirred for two minutes, allowed to settle for five minutes, and the supernatant liquid poured off and the conductivity of this liquid measured with a Solu-Bridge, readings being recorded in mho's x 10^{-5}.

C. Statistical Analysis

Although visual observations can readily attest that there are obvious differences in appearances in the plants treated in this experiment, it is another thing to state that these differences are sufficiently significant to warrant new cultural methods. The greater the difference the easier to see that the experiment has succeeded. The smaller the difference the more difficult it is to establish the experimental result.

As most experimental data are obtained in numerical form, they lend themselves readily to analysis by means of statistical methods. With this in mind the results of this experiment were subjected to analysis of variance, as outlined by Snedecor (51). Realizing that the complete growth response of the plants, under the varying cultures and as obtained through this experiment, would be represented in the fifth and final harvest, the data obtained from this harvest were analyzed statistically.

Data from the three temperatures, 50, 60 and 70° F, and for the interactions of light and fertility, light and temperature, fertility and temperature, and light, fertility and temperature, for both dry weight and leaf area were analyzed for the significance of their variations, using the multiple range and F tests of Duncan (11).

VI. RESULTS AND DISCUSSION

A. Effect of Light Intensity on Optimum Fertility Level

The slope of the growth curve is modified by changing environmental conditions. In comparing the effect of varying light intensity on optimum fertility levels, in the growth of snapdragons in this study, it can be seen from Figures 2, 3 and 4 that the slope of the growth curve when plotted as leaf area expansion at the highest level, changes as the light intensity varies. In full light the growth curves for all three temperatures are approximately equal in slope, while a decrease in light causes a steepening of the slope.

The data in Table VII show the overall ratio of increase in yield on a fresh weight, dry weight, and leaf area basis. For example, at a temperature of 70°F, full light intensity, and No. 2 fertility level, these data show that plants in this particular replicate increased their fresh weight 33.7 times over the weight established as the "zero" point when they were 29 days old.

The differences in yield, on a dry weight and leaf area basis, due to the interaction of light intensity and fertility, within a temperature group, were not significant.

Although not significant here, the effect of light on optimum fertility

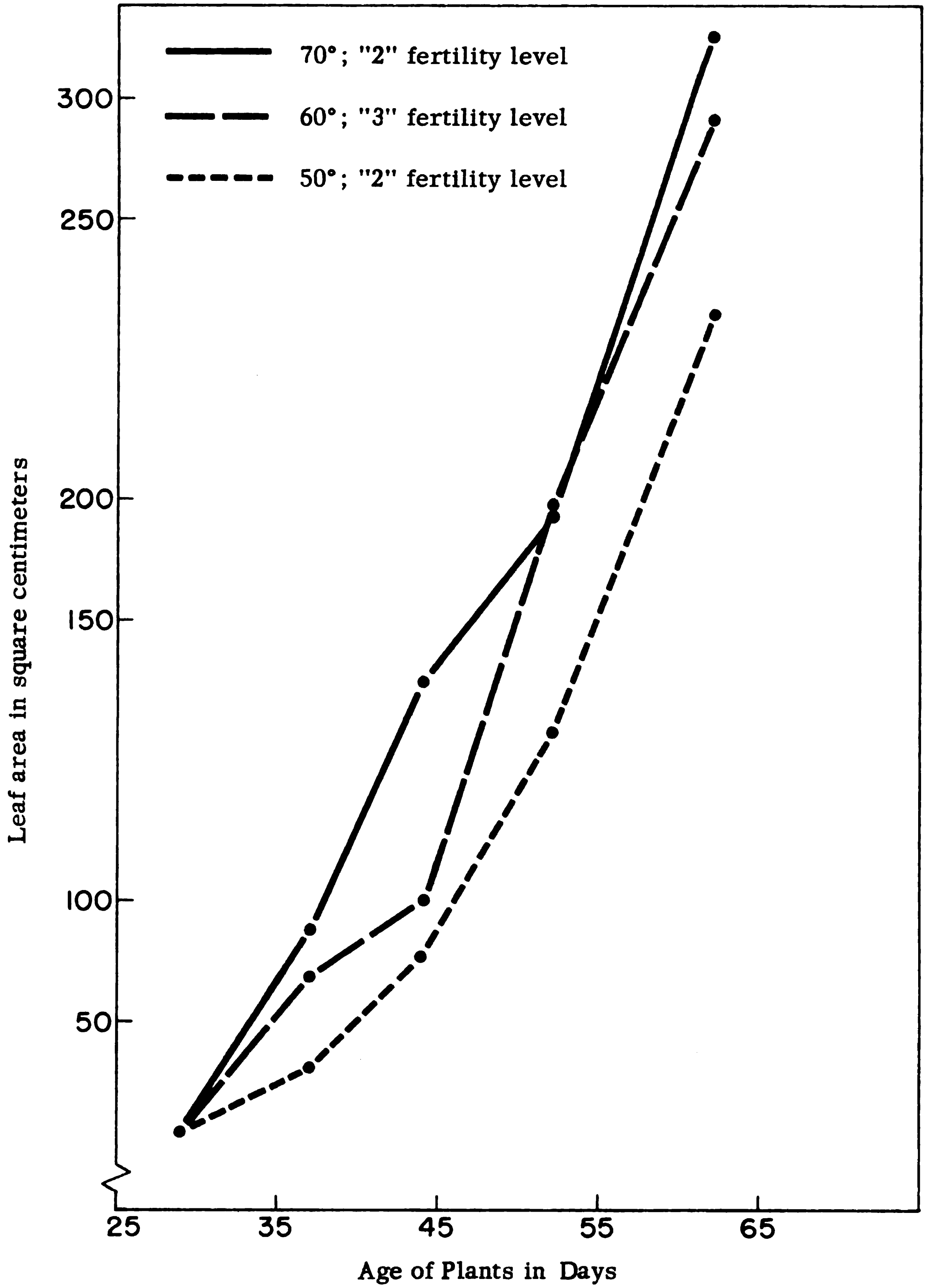

Figure 2. The effect of full light intensity and optimum fertility level on leaf area at 50, 60 and 70° Fahrenheit.

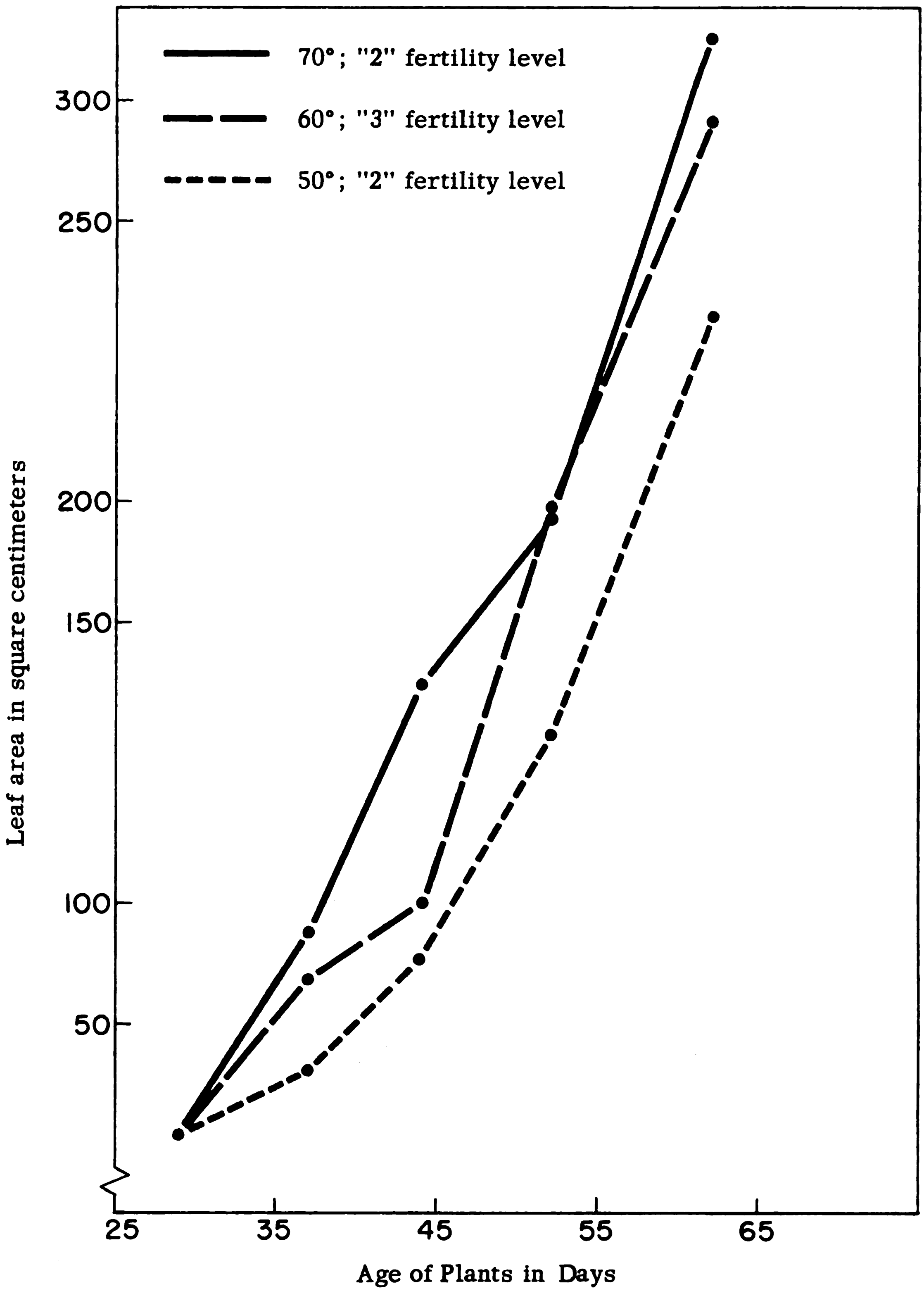

Figure 2. The effect of full light intensity and optimum fertility level on leaf area at 50, 60 and 70° Fahrenheit.

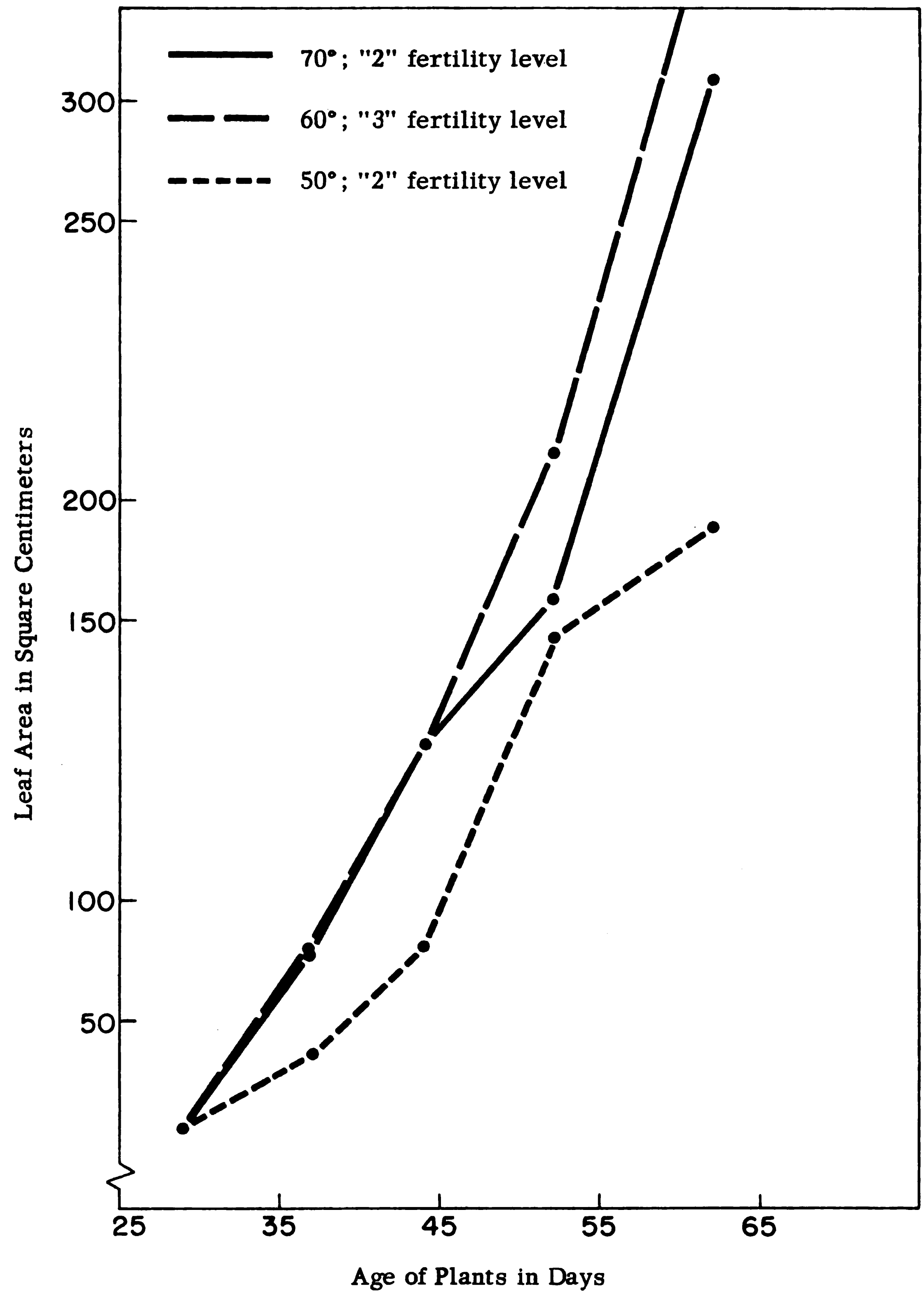

Figure 3. The effect of two-thirds light intensity and optimum fertility level on leaf area at 50, 60 and 70° Fahrenheit.

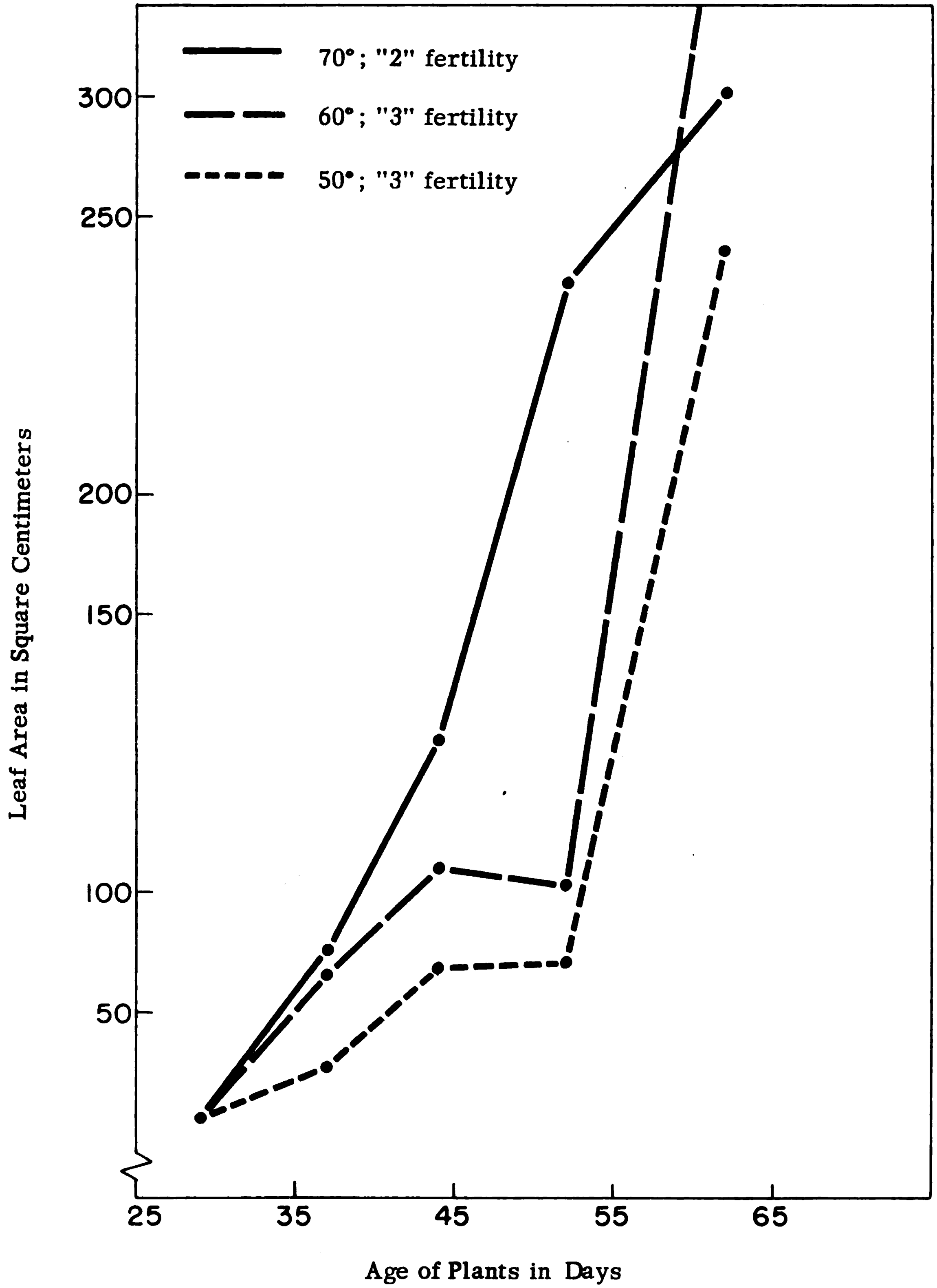

Figure 4. The effect of one-third light intensity and optimum fertility level on leaf area at 50, 60 and 70° Fahrenheit.

TABLE VII

The Effect of Light Intensity and Fertility Level on the Overall Ratio of Increase in Yield on Fresh Weight, Dry Weight, and Leaf Area in 33 Days

Temperature	Fertility Level	Light Intensity								
		Full Light			Two-thirds Light			One-third Light		
		Fr. Wt.	Dry Wt.	Leaf/Area	Fr. Wt.	Dry Wt.	Leaf/Area	Fr. Wt.	Dry Wt.	Leaf/Area
70° F.	1	26.7	43.7	17.5	24.8	36.6	16.1	25.5	29.1	18.3
	2	33.7	51.8	24.2	36.1	48.0	24.4	29.0	44.2	23.6
	3	24.1	33.4	18.3	29.9	40.2	23.2	19.1	24.8	16.2
	4	27.6	40.4	21.6	25.0	32.6	20.8	20.8	25.7	18.1
60° F.	1	21.2	29.6	13.2	22.5	30.2	15.6	23.4	28.5	15.7
	2	26.1	35.9	18.8	32.1	41.5	23.4	38.8	45.3	20.4
	3	35.3	42.0	22.4	34.6	46.8	25.8	35.5	40.6	27.2
	4	22.3	27.9	17.4	19.4	29.8	21.5	24.6	30.6	10.2
50° F.	1	14.2	19.3	8.4	17.4	21.9	10.8	17.7	19.4	13.5
	2	25.2	31.5	17.5	20.9	24.7	14.7	26.0	29.3	17.2
	3	20.5	23.1	14.1	22.6	26.6	14.4	27.5	30.2	19.1
	4	17.4	20.7	11.3	15.7	18.9	11.6	14.3	15.5	10.5

shows some trends or directions. On the basis of ratio of increase of fresh weight, a decrease in light intensity, at all fertility levels, brought about a decrease in the ratio of fresh weight increase at 70°, while at 60° and 50° the fresh weight ratio remained relatively the same or increased. A reduction in growth can be noticed at 50° with the number 4, or highest, level of fertility. With decreasing light intensity and increasing fertility levels the height of the plant was less and stems were larger in diameter, until the optimum fertility level was reached.

There is an increase in dry weight ratio due to decreasing light and increasing fertility levels, except at the highest level where there was a marked reduction in growth.

Leaf expansion was different, in that with decreasing light there was an indication that the ratio of increase was greater, especially in the lower temperatures. This would indicate that when light becomes limiting, one of the benefits of soil fertility may be found in an increase in foliar area.

B. Effect of Temperature on Optimum Fertility Level

The influence of temperature on the effect of level of fertility can be seen in Figures 5, 6 and 7, which show the ratio of increase in dry weight during the period of this study. At a temperature of 70° F, fertility level "2" produced the greatest increase regardless of light intensity, while at 60° F, the plants made more growth at the higher level of "3". When the light intensity was cut to one-third, the plants did not respond to nutrients in level "3" as well as to those in level "2". This indicates that at 60° F a greater growth rate can be expected with a higher fertility level than level optimal for a temperature of 70° F, as shown in Figures 5 and 6.

Reducing the temperature to 50° F will delay snapdragon ontogeny when compared to 60 or 70° F. Data in Figure 7 show a decided advantage in growth rate at level "2" in full light, which did not hold for the other two light intensities. As light was decreased, the higher fertility rate (3) produced a higher ratio of growth. Plants in the 50° F group were much shorter than those in either the 60 or 70° F group, and the ratio of increase in both fresh weight and leaf area data paralleled this.

Data from Table VII indicate that the growth curves for leaf area and fresh weight follows the slope of the dry weight curve. The rate of stem elongation increases with temperature as did dry weight, indicating that even though growth rate was accelerated, soil fertility was not primarily responsible for the increases in fresh and dry weight.

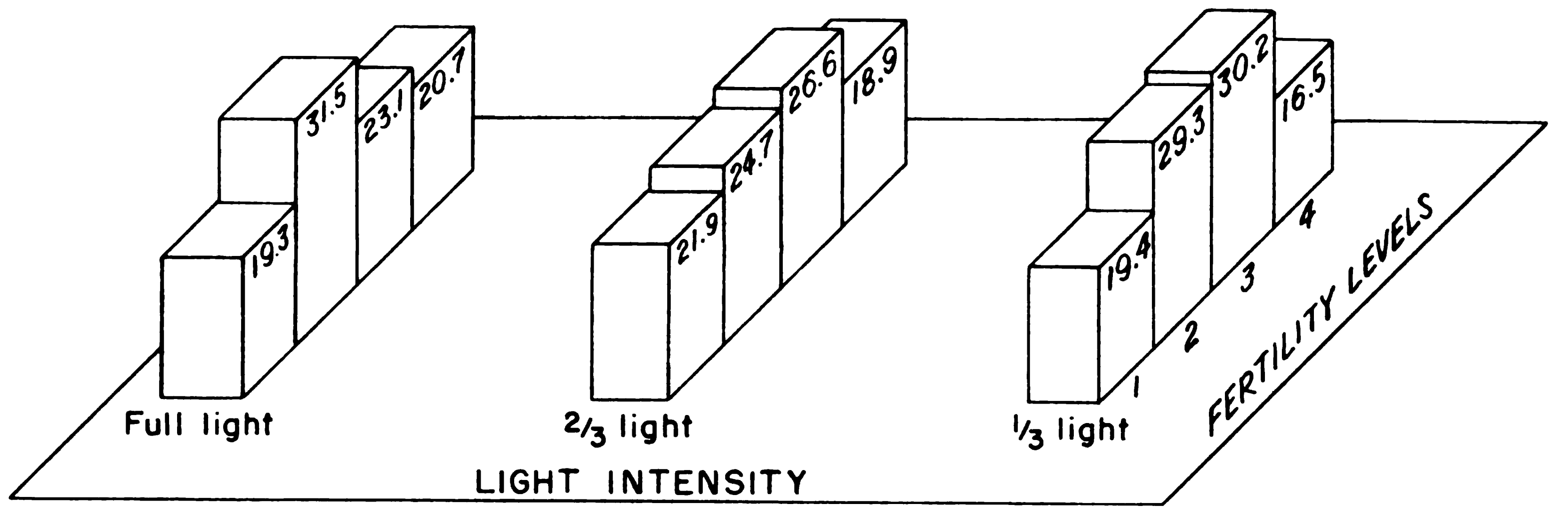

Figure 7. The effect of light and fertility interactions on the ratio of increase in yield on a dry weight basis at 50°F in 33 days.

C. Interaction of Light and Temperature on Optimum Fertility Level

The interaction of temperature on the level of fertility varies with each light intensity. At 70° F, and with all light intensities employed, fertility level "2" produced the highest yields in fresh and dry weights and leaf area. Figure 8 shows graphically dry weight yield in grams on the basis of interaction of fertility, light and temperature. As temperature decreased to 60° F, fertility level "3" produced the highest yields in both full light and two-thirds light, but did not do so with the lowest light intensity, where level "2" produced the greatest weight, both dry and fresh. At this light intensity and temperature, the greatest expansion in leaf area was produced by a level of "3".

Decreasing the temperature to 50° F and decreasing the light intensity, allowed a higher level of fertility to produce the greater yield, not only in dry weight, but in fresh weight and leaf area, also.

With the exception of the value of the low light intensity at 60° F, as the temperature and light intensity decrease, the optimum fertility level tends to increase, indicating that increased fertility might substitute partially for a lack of light.

Using an integrated statistical analysis of variance, values for the least significant difference of yields, and for those differences between yields, on a dry weight basis, attributable to varying temperature and fertility rates, were analyzed with the procedure advocated by Duncan (11). Varying degrees of significance were present.

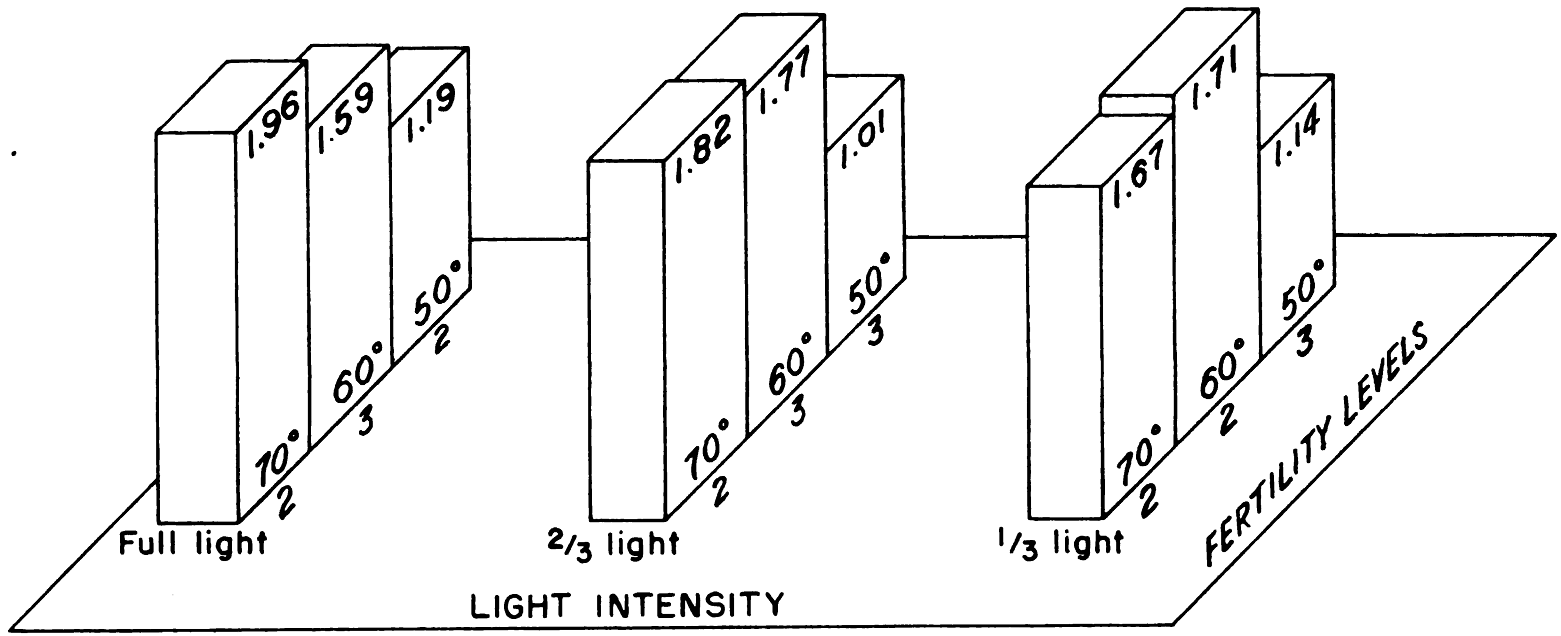

Figure 8. The interaction of light, fertility level, and temperature on the basis of dry weight yield in grams; each yield unit shown is the largest value for the temperature-light treatment, in 62 days.

TABLE VIII

Significance of the Differences in Averages of Fertility Level Values, for Dry Weight Yields

Fertility Levels	Averages	Significance
1	1.09	
2	1.48	Significantly larger at the 1% level than all other values
3	1.26	Significantly larger at the 1% level than level "4" and larger at the 5% level than level "1"
4	1.02	

On the basis of values in Table VIII, it can be seen that the differences in yield between fertility levels are all significant with the exception of the differences between fertility level "1" and "4". Level "1" received only distilled water and "4" had nutrients in excess. Dry weight increases brought about by application of fertility level "2" were significantly greater at the 1 percent level than values received from levels "1", "3" and "4", while "3" was significantly larger at the 1 percent level than "4", but only greater at the 5 percent level than "1".

In the same manner, values were derived for differences brought about through variation in temperature. They are shown in Table IX.

TABLE IX

Significance of the Differences in Averages of Temperature Values, for Dry Weight Yields

Temperature	Averages	Significance
70°F	1.417	
60°F	1.327	Significantly larger at the 1% level than 50°
50°F	0.885	

No significance was found for the differences in yield brought about through the effect of variation in temperature between 70 and 60°F. However, differences between 70 and 50°F were highly significant. No significance was found for the changes in yield values brought about by light intensity, the interactions between light and temperature, light and fertility, and light, temperature and fertility.

Beside dry weight values, the other measurement of value here is that of leaf area in square centimeters. Data collected has been subjected to statistical analysis, the results of which are seen in Tables X and XI.

All differences in leaf area yields due to variation in fertility level are highly significant with the exception of the differences between fertility level "2" and "3" which are not significant. Table XI shows the significance of leaf area yield difference due to variation in temperature.

TABLE X

Significance of the Differences in Averages of Fertility Level Values for Leaf Area Yields

Fertility Levels	Averages	Significance
1	180.5	
2	267.6	
3	255.8	Significantly larger at the 1% level than levels "1" and "4"
4	214.7	Significantly larger at the 1% level than level "1"

TABLE XI

Significance of the Differences in Averages of Temperature Values for Leaf Area Yields

Temperature	Averages	Significance
70° F	340.5	Significantly larger at the 1% level than all other values
60° F	260.3	Significantly larger at the 1% level than 50° F
50° F	173.6	

All yield differences due to variation in temperature are highly significant. No significance was found for the changes in yield values brought about by light intensity, the interaction between light and temperature, light and fertility, and light, temperature and fertility.

No toxic levels of soluble salts were found in any of the soils tested with the Solu-Bridge as outlined in Part IV, Section B, 2. The highest level of salts was found in those soils treated with fertility level "4". Using a reading of "70" as the lower limit of injury to snapdragons, the highest reading recorded was "36", which was not high enough to cause injury. It was, therefore, concluded that most of the fertilizer had been absorbed by the plants, even though they may not have been able to efficiently utilize all of it, as in the case of fertility level "4".

D. General Discussion of Results

In subjecting the snapdragon plants in this study to varying combinations of light, temperature and fertility, the slope of the growth curve can readily be seen. Using as measurement data, increase in dry weight in grams, and expansion in leaf area in square centimeters, trends can be established for the interactions of light and fertility, temperature and fertility, and light, temperature and fertility.

The first investigation into the highest level of fertility, under full light intensity and high temperature, revealed that the highest level of nitrogen and potassium fertility, that could safely be applied in the Baulic ratio of 5-1-2, was equivalent to approximately four (4) Baule units. This would equal about two (2) pounds of nitrogen per 100 square feet. This was considerably more nitrogen than was recommended for optimum growth of snapdragons by Post (41), and Laurie and Kiplinger (22). However, this level fell far short of the theoretical Mitscherlich-Baule level of ten (10) units, which would be equal to about five (5) pounds of nitrogen and two (2) pounds of K_2O per 100 square feet (Table VI). The application of about 15 Baule units brought almost instant necrosis, while eight Baule units reduced growth so markedly that it obviously was not optimal. Phosphorus level was not a factor in that it was kept constant.

The greatest amount of growth made during this summer period was made in the early stages, and those plants making the greatest increase in growth finished with the largest overall ratio of increase. This would lend support to the theory of Gregory (16) that over 90 percent of the nitrogen has been accumulated when the dry weight has reached 25 percent of its final value, and it is upon this erserve that later growth and development depend. After this early spurt, leaf expansion, and fresh and dry weight increase remain at a constant rate (Tables III and IV). Upon the basis of this full intensity summer study, it can be said that -

(1) Optimum nitrogen and potassium level is in excess of that now commercially recommended per single application for a summer period comparable to the conditions of this study;

(2) Optimum nitrogen and potassium level on the basis of applied fertility rates in this study is less than the theoretically optimal Mitscherlich-Baule ratio of ten units; and

(3) The greatest ratio of increase in dry weight, fresh weight, and leaf area, was in the earlier stages of growth, and thereafter growth was at a smaller, constant rate.

In the second investigation four fertility levels, three light intensities, and three temperatures were used to determine effects on the growth curve.

With a decrease in light intensity, the slope of the growth curve steepened, with a noticeable lag in the early stages in leaf area expansion and a corresponding decrease in dry weight increase. The interaction between light intensity and fertility level did not prove significant, indicating that the optimum fertility level would depend more upon the temperature than upon light. This was shown by the fact that differences in dry weight yield between temperatures of 70 and 50, and 60 and 50°F were highly significant, but with no significance found in yield differences between 70 and 60°F. Leaf area differences, due to temperature, were all highly significant.

As the light intensity decreases, there is a tendency for leaf area ratio of increase to become greater, especially with decreasing temperature. This could indicate a partial substitution of soil fertility for light intensity in the lower temperature range.

Leaf area expansion increases in the early stages faster at the higher temperature of 70°F than at 50°F under all light intensities, but there is an almost equal increase at the two-thirds light intensity between 70 and 60°F. Decreasing the light intensity to one-third brought about a leveling off, or plateau, in leaf area expansion at both 60 and 50°F, followed by a very steep slope to the growth curve. This plateau was not noticeable at higher light intensities or at 70°F within this light level.

There was no significant interaction between temperature and fertility. However, differences in dry weight yields brought about by variation in fertility level, were highly significant, with the exception of the differences between fertility levels of "1" and "4", which were not significant. Differences between levels of "1" and "3" were significant at the 5 percent level. Using leaf area data, all differences due to fertility rates were highly significant, except that no significance was attached to yield differences between levels "2" and "3". Here again, the interaction of light and fertility, temperature and fertility, and light, temperature and fertility, produced no significant yield differences. This would indicate that fertility will make great differences in yields within a temperature and that the temperature will largely govern the maximum yield obtainable.

The fertility level that produced the greatest yield on both a dry weight and leaf area basis was either level "2" or "3"; levels "1" and "4" did not produce optimal growth. In most cases the higher level depressed growth. On a dry weight comparison, the yield differences produced by these two levels were highly significant, but there was not a significant difference in leaf area. This can be correlated with the growth curve which shows that the ratio of increase in leaf area levels off and remains relatively constant while there is an increase in the late stages of growth in dry weight. This comes about through stem elongation and flowering which will produce additional weight, but not necessarily leaf area.

On conversion to pounds per 100 square feet and Baule units, fertility level "2" contained 1.6 pounds of nitrogen and 0.6 pounds of K_2O per 100 square feet and was equal to 3.2 Baule units; fertility level "3" contained 3.2 pounds of nitrogen and 1.2 pounds of K_2O per 100 square feet and was equal to 6.4 Baule units. It was thought that possibly a greater number of Baule units than 6.4 and less than the 12.5 units in level "4", would give better growth. Each application of "4" put 2.5 Baule units on per pot. Therefore, one application was equal to 2.5 units, two applications to 5.0 units, three applications to 7.5 units, and four applications to 10.0 units, the theoretical optimum. At none of these points in the growth curve did ratio of increase measure up to levels "2" or "3". Level "4", equivalent to 12.5 units, was not optimal, nor were 10.0 or 7.5 Baule units. Under the conditions of this study, the steepest slope to the growth curve varied between either 3.2 or 6.4 Baule units, depending upon the temperature. In growing this crop for dry weight production, a fertility level of 3.2 units would give maximum yield at a temperature of 70° F, while at 50 and 60° F an application 6.4 units would produce the greatest yield. This would not be true for leaf area yield, where the lower rate would bring the greater economic return, since there are no significant differences in yields between the two.

Under the conditions of this experiment, there were no significant interactions between light intensity and fertility rate, nor between temperature and fertility. Regardless of light intensity, one fertility rate was usually optimal for a temperature group. With decreased temperature, dry weight and leaf area yields declined except at one-third light intensity, Table VII. Simultaneously, fertility optima shift upward from the "2" to the "3" levels. This unexpected trend indicates possible substitution of fertility for light which may well be a function of greater leaf area at higher fertility levels. Additionally, as shown by Russell (45), higher levels of potassium increased photoperiodic efficiency at low light levels.

There is an indication that decreasing light intensity may be compensated for by an increase in leaf area, with a tendency toward increasing dry weight, provided an adequate fertility level is maintained. Selection of a greenhouse snapdragon adapted to low light intensity conditions would be economically practical in that low temperature and low light intensity are conditions that are found in Michigan in the winter. Also, a snapdragon adapted to high temperatures and high light intensity would find a use in the summer period. Adjusting the fertility level to match growth potential is easily done. A comparison of dry weight yields at the various temperatures, light intensities, and fertility rates are presented in Figure 8.

VII. SUMMARY

During the months of January through March, 1956, snapdragon plants were grown at three light intensities, three temperatures (50, 60 and 70° Fahrenheit), and four fertility levels, in all possible combinations, in a randomized split-plot design. The phosphate level was constant throughout, while nitrogen and potash were varied, using ammonium and potassium nitrate. Nitrogen and potash were combined in ratios determined by the Mitscherlich-Baule theory of optimum plant growth. Ten Baule units are equal to 5.17 pounds of nitrogen and 1.82 pounds of potash per 100 square feet.

Under optimum growing conditions, as approached in commercial culture, optimum fertility levels, in this study, did not approach ten Baule units of either nitrogen or potash. Optimum yields, on both a dry weight and leaf area basis, although varying with temperature and light intensity, were obtained with fertility levels not in excess of 6.4 Baule units, which contained 3.2 pounds of nitrogen and 1.2 pounds of potash per 100 square feet.

Hybrid snapdragons, designated MSC No. 16, were grown in 3-inch clay pots, to which liquid nutrient solutions were added at weekly intervals for five applications. Weekly harvests, obtaining fresh weight, dry weight, and leaf area data, enabled the slope of the growth curves to be determined.

Through manipulation of temperature levels, light intensity, and the four fertility levels, the influence, or interactions of environmental factors on optimum fertility level were determined. All measurement data was subjected to analysis of variance and tested for significance. The light intensities used were full light, two-thirds light, and one-third light. Fertility levels were based on levels determined in a preliminary investigation to bracket the observed optimum fertility level. Fertility level "4" was obtained by application of 12.5 Baule units of both nitrogen and potash, "3" by 6.4 Baule units, "2" by 3.2 Baule units, and "1" had no added nutrients, being only distilled water. One-fifth of the total nutrient supply was applied weekly giving the total supply after five applications.

No significant yield differences were produced by the interactions between light and fertility, temperature and fertility, and light, temperature and fertility. Yield differences due to variation in fertility levels were significant, with the exception of the differences between levels "2" and "3" which were not significant. Significance at the one percent level was also found with dry weight yield differences due to temperature, except that differences between 70 and 60° F were not significant. Differences due to fertility were all highly significant, except there was no significance between levels "1" and "4", and between "1" and "3" the differences were significant at the five percent level.

The greatest ratio of increase in yield, both dry weight and leaf area, occurred early in the ontogeny of the plant, later becoming constant, and increasing again in dry weight as plants attained flowering status. No significance was found in yield differences brought about by variation in light intensity. There is an indication that decreasing light intensity may be compensated for by an increase in leaf area, with a tendency toward increasing dry weight, provided an adequate fertility level is maintained. Optimum fertility level, under the conditions of this study, was found to be greater than commercial fertilizer recommendations.

VIII. BIBLIOGRAPHY

1. Anderson, P. J., T. R. Swanback and O. E. Street. Conn. Agr. Exp. Sta. Bul. 422: 6, 1939.

2. Ballard, L. A. T., and A. H. K. Petrie. Austr. Jour. Exp. Biol. Med. Sci. 14: 135-163, 1936.

3. Balmukand, B. Jour. Agr. Sci., 18: 602, 1928.

4. Baule, B. Landwirtschaftlich Jahrbuch, 51: 363, 1918; 54: 493, 1920.

5. Blackman, G. E., and A. J. Rutter. Ann. Bot., N. S., 12: 1, 1948.

6. ____________, and G. L. Wilson. Ann. Bot. (London), 18: 71-94, 1954.

7. Boersch, K. Handbuch der Pflanzenernahrung und Dungerlehre. Berlin: J. Springer, 180, 1931.

8. Bondorff, K. A. Kgl. Vet. Landbolhojsk. Aarsskr., 293, 1924.

9. ____________. Nord. FordbrForsk., 5: 136, 1923.

10. Crabb, G. A. Jr. Solar Radiation Investigations in Michigan. Mich. Agr. Exp. Sta. Tech. Bul. 222, 1950.

11. Duncan, D. B. Multiple Range and Multiple F Tests. Biometrics II: 1-42, 1955.

12. Eaton, S. V. Bot. Gaz., 114: 165-180, 1952.

13. Flint, H. L., and S. Asen. The effects of various nutrient intensities on growth and development of snapdragons (*Antirrhinum majus L.*). Proc. Amer. Soc. Hort. Sci. 62: 481-486, 1953.

14. Goodall, D. W., and F. G. Gregory. Imperial Bureau of Horticulture and Plantation Crops, Technical Communication, 17: 1, 1947.

15. Gregory, F. G. Ann. Rev. Biochem., 6: 557, 1937.

16. Gregory, F. G. Report of the 13th Intern. Horticultural Congr., 96-105: Royal Hort. Soc., London, England, 573 pp., 1953.

17. Haney, W. J. Private communication dated June 18, 1956. Department of Horticulture, Michigan State University, East Lansing, Michigan.

18. Hewitt, E. J. Sand and Water Culture Methods Used in the Study of Plant Nutrition. Reading, England: Bradley and Sons, Ltd., 93-98, 1952.

19. Hoagland, D. R., and D. I. Arnon. Some problems of plant nutrition. Sci. Monthly, 47: 201-209, 1949.

20. Hodgman, C. D. Editor, Handbook of Chemistry and Physics. 36th edition. Cleveland: Chemical Rubber Publishing Company, 1954-1955.

21. Kreusler, U., A. Prehn and R. Hornberger. Beobactungen uber das Wachstum der Maispflanze. Landwirtschaftlich Jahrbuch, 7: 536-564, 1878; 8: 617-622, 1879.

22. Laurie, A., and D. C. Kiplinger. Commercial Flower Forcing. Philadelphia: The Blakiston Company, 166-167, 1944.

23. Lees, H., and J. H. Quastel. Biochemistry of Nitrification in Soil (I-III). Biochem. Jour., 40: 803-828, 1946.

24. Loehwing, W. F. Mineral Nutrition in Relation to the Ontogeny of Plants. Mineral Nutrition of Plants, E. Truog, ed., Madison: University of Wisconsin Press, 343-358, 1953.

25. Lundegardh, H. Klima und Boden, 2nd edition, Jena: Gustav Fischer, 1930.

26. Maksimov, N. A. Plant Physiology. Harvey, R. B. and A. E. Murneek, eds., I. U. Krassovsky, trans., 2nd English ed., New York: McGraw-Hill Book Company, 1938.

27. Markle, F. G. and E. C. Dunkle. The conductivity of soil extracts in relation to germination and growth of certain plants. Soil Sci. Soc. Amer. Proc., 8: 185-188, 1943.

28. Martin, W. P., T. F. Buehrer and A. B. Carter. Ariz. Agr. Exp. Sta. Tech. Bul. 96, 1942.

29. ________________________________. Soil Sci. Soc. Amer. Proc. 7: 223, 1943.

30. Mason, T. G. and E. Phillis. Ann. Bot., 48:.315-333, 1934.

31. Meyer, B. S. and D. B. Anderson. Plant Physiology. New York: D. Van Nostrand Company, Inc., 589-591, 1947.

32. Miller, E. C. Plant Physiology. New York: McGraw-Hill Book Company, 642-653, 1938.

33. Mitscherlich, E. A. Bodenlehre fur Land-und-Forstwirte. Berlin, 1913.

34. ________________. Handbuch der Bodenlehre, 9: 497-541. Edited by E. Blanck.

35. ________________. Landwirtschaftlich Jahrbuch, 58: 601-617. 1923.

36. Mulder, E. G. Plant and Soil, 5: 246-306, 1954.

37. Nightingale, G. T. The Nitrogen Nutrition of Green Plants, II. Bot. Rev., 14: 185-221, 1948.

38. O'Rourke, E. N. Jr. and S. N. Marshall. Proc. Amer. Soc. Hort. Sci. 61: 56-62, 1953.

39. Pirson, A. Functional Aspects in Mineral Nutrition of Green Plants. Ann. Rev. Plant Physiol., 6: 71-114, 1955.

40. ________, C. Tichy and G. Wilhelmi. Planta, 40: 199-253, 1952.

41. Post, K. Florist Crop Production and Marketing. New York: Orange Judd Publishing Company, Inc., 139, 328-329, 1949.

42. _______ and R. S. Bell. Effect of excess fertilizers on roses, snapdragons and chrysanthemums. Proc. Amer. Soc. Hort. Sci., 34: 644, 1936.

43. Rathje, W. Pflanzenernahr. Dung. u Bodenk., 57: 151-163, 1952.

44. Robbins, W. R. Growing plants in sand cultures for experimental work. Soil Sci., 62: 3-22, 1946.

45. Russell, E. J. Rothamsted Ann. Report, pp. 22-23, 1927-1928.

46. ___________. Soil Conditions and Plant Growth, 8th edition, New York: Longmans, Green and Company, 57, 61, 1954.

47. ___________, and H. B. Hutchinson. Jour. Agr. Sci., 3: 111, 1909; 5: 152, 1913.

48. Schloesing, T. and A. Muntz. C. R., 84: 301, 1877; 85: 1018, 1877; 86: 982, 1878.

49. Schwabe, W. W. Ann. Bot. (London), 17: 225-262, 1953.

50. Seelhorst, C. von. Landwirtschaftlich Jahrbuch, 46: 52, 1898.

51. Snedecor, G. W. Statistical Methods, 4th edition, Ames, Iowa: Iowa State College Press, 485 pp., 1953.

52. Sommer, A. L. Jour. Agr. Res., 52: 133-148, 1936.

53. Spurway, C. H. Soil Fertility Diagnosis and Control for Field, Garden and Greenhouse Soils. Ann Arbor, Michigan: Edwards Brothers, Inc., 176 pp., 1949.

54. ___________. Soil Testing; A Practical System of Soil Fertility Diagnosis. Mich. Agr. Exp. Sta. Tech. Bul. 132, 1949.

55. Thomas, M. D. Effect of ecological factors on photosynthesis. Ann. Rev. Plant Physiol., 6: 135-156, 1955.

56. Wadleigh, E. H. and L. A. Richards. Soil Moisture and the Mineral Nutrition of Plants. Mineral Nutrition of Plants, E. Truog, ed., Madison: University of Wisconsin Press, 411-450, 1953.

57. Wagner, H. Z. Pflanzenernahr. Dung. u Bodenk. (A), 25: 48-102, 1932.

58. Waksman, S. A. Sergei Nikolaevitch Winogradsky. Soil Sci., 62: 197-226, 1946.

59. Wareing, P. F. Photoperiodism in woody plants. Ann. Rev. Plant Physiol., 7: 191-214, 1956.

60. Wassink, E. C. and J. A. J. Stolwijk. Effects of light quality on plant growth. Ann. Rev. Plant Physiol., 7: 373-400, 1956.

61. White, H. C. Ga. Agr. Exp. Sta. Bul. 108, 1914; 114, 1915.

62. Willcox, O. W. ABC of Agrobiology. New York: Norton and Company, Inc., 323 pp., 1937.

63. Williams, R. F. Aust. Jour. Exptl. Biol. Med. Sci., 14: 165-185, 1936.

64. ______________. Redistribution of mineral elements during development. Ann. Rev. Plant Physiol., 6: 25-42, 1955.

65. Winogradsky, S. N. Ann. Inst. Pasteur, 4: 213, 257, 760, 1890.

66. ________________, and W. Omeliansky. Arch. Science Biology (St. Petersburg), 7: No. 3, 1899.

67. ____________________________________. Zbl. Bakt. II, 5: 329, 429. 1899.

68. Withrow, R. B. Light as a Modifying Influence on the Mineral Nutrition of Plants. Mineral Nutrition of Plants, E. Truog, ed., Madison: University of Wisconsin Press, 389-410, 1953.