# INTERACTION OF SOME ENVIRONMENTAL FACTORS AND GROWTH OF *SALVIA SPLENDENS* KER-GAWL

By

CALVIN C. COOPER

A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Horticulture

1954

ACKNOWLEGEMENT

The author wishes to express his gratitude to his major professor, Dr. Donald P. Watson, for suggestions and direction of the research reported in this thesis.

Sincere thanks are also expressed for the constructive suggestions of Doctors Leo W. Mericle, Harold B. Tukey, and Alvin L. Kenworthy.

The assistance of Dr. Erwin J. Benne in the determination of the nutrient analyses is gratefully acknowledged.

# INTERACTION OF SOME ENVIRONMENTAL FACTORS AND GROWTH OF SALVIA SPLENDENS KER-GAWL

By

Calvin C. Cooper

AN ABSTRACT

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

DOCTOR OF PHILOSOPHY

Department of Horticulture

Year 1954

Approved Donald P. Watson

CALVIN C. COOPER ABSTRACT

The interaction of environmental factors upon the growth of Salvia splendens was studied to obtain information concerning the growth of Salvia and the possibilities of its introduction to the florist pot plant industry. For this purpose the growth of ten cultivars was compared. The influence of cold treatment, night temperature, "pinching", photoperiod, root temperature and light intensity was studied. Information was gathered concerning the timing of a crop of Salvia for the Christmas market, and the keeping quality of the plants at room temperature.

For the production of short, dense plants the cultivars of the dwarf type proved most suitable, and for the production of a slightly more vigorous plant the cultivars of the semi-dwarf type were recommended. The cultivar, America, was selected for use in all ohter experiments.

The 40°F constant temperature cold treatment for 1 week appeared to retard growth more when it was supplied at the two- than at the four-node stage of growth. At either stage, the influence of the relatively short period of cold treatment was not extremely large.

The study of night temperature influences indicated that Salvia grew more vigorously and flowered sooner with 60°F than

with 50°F night temperature. This was particularly true while the plants were young. Some additional stem elongation was obtained by moving the plants from 60°F to 50°F night temperature 90 days after seeding. Stem weight was not greatly influenced by night temperature and flower color was not affected.

The removal of the terminal meristem (a "pinch") resulted in plants with short, dense growth. Plants "pinched" twice were larger and took 10 days longer to flower than those "pinched" once. When plants were "pinched" three times the flowers which were produced were approximately 50 per cent smaller in size. It was recommended that plants be grown with one "pinch" except for special purposes where a larger plant would be profitable and then two "pinches" could be supplied.

When seed was planted September 1st, 98 days were required for production of flowering pot plants with one "pinch". A schedule for the production of a Christmas crop was suggested.

Some florets were observed to absciss after the plants had been in the homes 1 to 3 days with many falling after an average of 4 days in the home. Several methods of preventing the floret abscission were attempted, but no effective method was found. It was suggested that further work with growth regulating substances might prove successful.

Flowers were produced under both 8- and 16-hour photoperiods. A photoperiodic inhibition of vegetative growth was observed when the plants were grown with 8-hour photoperiods and the amount of inhibition increased with groups of plants that were supplied with a greater number of short days. A loss of apical dominance was also noted in those plants supplied with 60 or more 8-hour photoperiods. In order to produce a flowering Salvia plant with relatively short laterals of approximately the same length, in the shortest period of time it was recommended that the plants be supplied with 20 long days of 16-hour photoperiods followed by short days consisting of 8-hour photoperiods until the plants were in flower. In this experiment the required time was 98 days from the date of seeding. It was mentioned that these conditions could be approximated for the production of a Christmas crop in Michigan by supplying the plants with the natural photoperiod. Photoperiod had no observed influence on the plants after they were in flower.

Plants consistently produced greater height in all treatments when they were grown in the fall with 70°F and 50°F root temperature with 100 per cent and 63 per cent light intensity, than when they were grown under the same conditions during the winter months. This was thought to be caused by a shorter photoperiod during the growth of the winter crop.

Stem elongation was slightly greater when the plants were grown with reduced, than when they were grown with full light intensity.

A morphological study of the flower bud was made, in which five stages in flower bud development were arbitrarily distinguished.

The plants grown with the 70$^{o}$F root temperature produced approximately twice as much stem elongation as the plants grown with the 50$^{o}$F root temperature, but the plants in all of the treatments flowered over a period of only 7 days.

The largest top-root ratio was obtained from plants grown with reduced light intensity and 70$^{o}$F root temperature.

According to each of the methods of determining plant growth, the 70$^{o}$F root temperature was found to favor the growth of Salvia more than the 50$^{o}$F root temperature. The reduced light intensity favored flowering, stem elongation, and nutrient accumulation more than full light intensity. Full light intensity, however, resulted in greater accumulation of fresh and dry weight.

Fifteen figures and nineteen tables were included.

TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# INTRODUCTION

There is a limited selection of flowering plants available at Christmas. *Salvia splendens* Ker-Gawl (Salvia) has outstanding and appropriate color, grows rapidly, and appears to have possibilities as a popular and profitable pot plant for the Christmas market.

In order to produce flowers for holiday markets, accurate timing of the crop is essential, and depends upon the reaction of the species to light, temperature, and the artificial conditions of the greenhouse. Differences among cultivars in respect to environmental response are also important.

This investigation was designed to study the varieties and conditions most favorable for the commercial greenhouse production of Salvia, its suitability as a pot plant in the home, and to obtain information concerning the influence of some environmental factors on its growth.

# REVIEW OF LITERATURE

## Taxonomy

In Hortus Second, Bailey has described the genus Salvia as belonging to the family Labiatae, which in general has four angle stems, opposite or whorled leaves, irregular two-lipped gamopetalous flowers, two or four stamens, superior four-lobed ovary, two stigmas, and fruit of four one-seeded nutlets. Saunders (1934) stated that while two pairs of the stamens develop, the posterior pair is represented by very small lobe-like enlargements. Although only one pair of functional stamens develop in Salvia (Salvia splendens) and some other species, Saunders (1934, 1940) observed that normally four androecium bundles arise from the central cylinder in exactly the same way as in those species which produce two pairs of functional stamens.

## Photoperiod

In 1891, Bailey reported being able to induce flowering and seed formation in spinach (Spinacia oleracea) and lettuce (Lactuca sativa) with the use of electric lights to lengthen the period of illumination. Garner and Allard (1920) extensively investigated the effect of the relative length of day on flowering. They termed the response of organisms to the relative length of day as photoperiodism, and classified plants into three general groups in regard to their response to photoperiod: (1) species whose flowering is not affected by the duration of the exposure to light, (2) species which flower only when the duration of the exposure to light is shorter than the critical period for flowering, and (3) species which flower only when the duration of the response to light is longer than the critical. In addition to flowering response, Murneek (1948) observed a photoperiodic inhibition of vegetative growth with a short photoperiod in plants that normally flowered when supplied with a short photoperiod. Garner and Allard succeeded in inducing flowering and seeding in Maryland Mammoth tobacco (Nicotiana tobacum) by exposing the plants to a "short" light period. Cosmos (Cosmos bipinnatus) and poinsettia (Euphorbia pulcherrima) were prevented from flowering during the short days of the winter months by illuminating the plants from sunset to midnight. The flowering of plants in response to a short photoperiod was believed by Hamner (1938) to be due to a stimulus which was produced by the leaves of the plant during the dark period. During the succeeding light period this substance was believed to be broken down. Hamner used this to explain why short photoperiod plants flowered much more quickly when supplied with a photoperiod decidedly less than the critical than when supplied with one slightly less than the critical.

The work of Gilbert (1926) indicated that response to photoperiod might be influenced by temperature and humidity. Gilbert (1926) observed in soybeans (Soya Max) and cotton (Gossypium sp.) that there was a definite retardation of flowering with lower temperature and higher humidity. Cosmos flowered earlier with lower temperature and higher humidity. Salvia and buckwheat (Fagopyrum esculentum) produced no change in photoperiod response as a result of variations in temperature and humidity.

Roberts and Struckmeyer (1938) found that Salvia flowered under a short photoperiod of 9 hours and grew vegetatively under a long photoperiod of 16 hours. Arthur, Guthrie and Newell (1930) obtained an abundance of flowers when Salvia plants were exposed to a photoperiod of 15 hours or less. Hamner (1938) obtained flowers from plants of Salvia under a photoperiod of 14 hours, but concluded that the "number of flowers produced at this photoperiod was greatly influenced by the supply of nitrogen".

## Light Intensity

A smaller reduction in light intensity was obtained under a cloth netting by Gray (1934) on cloudy than on clear days. Angstrom (1919) distinguished between radiation from the sky and radiation from the sun and concluded that the cloth net shading material cut out very little of the radiation from the sky. This radiation from the sky was relatively great. With a high sun and a clear sky it was about 20 per cent of the solar radiation, and its percentage increased rapidly with increase in cloudiness.

Influence on Plant Growth: As early as 1836 Dauberry concluded that light intensity had a greater influence on plant processes than did the heat emitted by the light rays.

He stated, "Both the exhalation and the absorption of moisture by plants, so far as they depend upon the influence of light, are affected in the greatest degree by the most luminous rays".

Loomis (1933) pointed out that since the light rays are known to have a large influence upon photosynthesis, growth substance formation and activity, and pigmentation in growing plants, the light rays can also be expected to influence morphogenesis and histogensis. Furthermore, Huxley (1932) stated that it appeared highly probable that light exerts its influence in the development of plants in many ways which are not clearly understood.

Burkholder (1936) produced a rather thorough review of "The role of light in the life of plants". In this review it was quite generally agreed that there is an optimum light intensity for the growth of each species. In the case of many plants this optimum was found to be considerably less than full sunlight on a clear day. Davis and Hoagland (1928) found tissue formation to be more "efficient" when the illumination was distributed at a moderate intensity over a longer period of time than under the opposite conditions of high light intensity and short duration. The optimum light intensity for a given species was observed by Combs (1910) and Hearn (1922) to change with the age of the plant. As the plants grew older, they became less sensitive to light and the light intensity which was optimum for the production of dry matter increased with the increasing age of the plants.

Post (1931) and Laurie (1932) suggested that variations in plant growth under reduced light intensity might be partially due to slower transpiration, higher humidity, higher soil moisture, and higher temperature under the shade structure.

In "The role of light in the life of plants" by Burkholder (1936) it was pointed out that the effect of light intensity upon growth could be observed in characteristic responses of the plant. Stem elongation, fresh and dry weight of stems and roots, flowering and fruiting, moisture and nutrient accumulation, and foliage structure were all affected by the intensity of the light under which the plants were grown.

The presence of daylight tended to inhibit stem elongation of plants (Went, 1941). Went found that the intensity of the sunlight was of greater importance in inhibiting stem elongation in pea (Pisum *sativum* var. Little Marvel) than was the duration of the illumination. The intensity of the sunlight was found by Porter (1936) to be inversely related to the elongation of the stems of tomato (*Lycopersicum esculentum*) plants grown under full intensity, half intensity and quarter intensity of sunlight in the greenhouse. Popp (1926) observed that the greatest stem elongation of soybeans grown under light intensities ranging from 26 to 4,285 foot candles occurred under an illumination of 560 foot candles and the least amount of elongation took place under an illumination of 26 foot candles. In general, it appeared that below a certain minimum intensity of light the inverse relation between light intensity and stem elongation disappeared and stem elongation was inhibited by a severely low light intensity.

Arthur and Stewart (1931) found that the fresh and dry weights of stems and roots of plants grown under reduced radiation depended largely on the magnitude of the total radiation. When sunflower (*Helianthus* sp.), salvia, buckwheat, dahlia (*Dahlia* sp.), and tobacco plants were grown under 100, 78, 58 and 35 per cent total radiation during June and July, all of these plants except Salvia produced greater fresh and dry weight of tissue when the plants were shaded with cheesecloth than when the plants were grown in the open sunlight. When these same species were grown under the same conditions during August and September, the plants grown in the open sunlight produced the maximum amount of dry weight.

Temperature has been shown to be very important in determining the optimum light intensity for dry weight accumulation. Bolas (1934) found that at a higher temperature a higher light intensity proved optimum for dry weight accumulation. He plotted the rate of dry weight accumulation for tomatoes during a 7-hour period at 60, 75 and 85°F over a range of intensity from 100 to 1,000 foot candles. At 60°F maximum dry weight accumulation occurred at approximately 200 foot candles, while at 75°F it occurred at approximately 750 foot candles and at 85°F, 1,000 foot candles.

Much variability in growth response to light intensity has been reported. The fresh weight of potato (Solanum tuberosum), radish (Raphanus sativus), some parts of which were underground parts, cotton and lettuce, has been found by Shantz (1913) to increase with decreasing light intensity from 50 to 15 per cent of full sunlight in Louisiana. None of these plants was able to grow beyond the seedling stage when the sunlight was reduced to 6 per cent of full sunlight. No dry weight determinations were made by Shantz.

Shirley (1929) found that the amount of dry matter produced by plants of sunflower (Helianthus annuus), geum (Geum sp.) and buckwheat was almost directly proportional to the light intensity up to the highest intensities available under two 1500-watt incandescent lamps with 12 hours illumination daily. During the winter months the dry weight production was almost directly proportional to light intensity up to the highest intensities available in the greenhouse. During the summer, these plants exhibited a tendency toward a slower rate of dry weight production at the higher intensities of illumination. Shirley further observed that the intensity of the sunlight of mid-summer could be reduced 50 per cent without greatly affecting the growth of the plants. A further reduction to 20 per cent of full light intensity caused a decrease in dry weight accumulation. This could be correlated with the decrease in light intensity. These two observations were, in general, confirmed by Clements and Long (1934) using sunflower and clarkia (Clarkia elegans) with treatment of "full", 32, 16, and 8 per cent sunlight as furnished by lath houses. No constant recordings were made of the intensity. Lubimenko (1908), working with plants of pine (Pinus sp.), ash (Fraxinus sp.), and linden (Filia sp.) obtained results which seem to be similar to those of Shirley (1929). Lubimenko made no measurements of light intensity and it is therefore difficult to make a comparison of data. Chandler (1953) obtained increases in fresh weight production by rose (Rosa hybrida) plants under full sunlight as compared to plants grown under radiation reduced by the use of layers of cheesecloth. Records of the light intensity under each treatment were made with a Leeds and

Northrup Speedomax Type G recorder.

Garner and Allard (1920) obtained a definite decrease in the number of flowers and fruits produced on soybean plants under reduced light intensity. Similar reductions in flower bud and fruit formation were observed by Kraybill (1923) when peach (Prunus persica) and apple (Malus pumila) trees were grown under reduced prevailing daylight for a period of three years. Porter (1936) obtained two-thirds production of tomato fruit when the light intensity was reduced 50 per cent below normal, and one-half production when the light intensity was cut 75 per cent. Time of flowering and fruiting of tomato and a large number of other plants were found to be delayed considerably under low light intensity (Zillich, 1926; Shirley, 1929).

Moderate variations in soil moisture were found by Shirley (1929) to cause insignificant changes in the dry weight produced by plants of tomato, tobacco, geum, sunflower and other plants, providing the moisture content was not low enough to approach the wilting coefficient, or high enough to approach saturation. Variations in light intensity caused significant differences in the moisture content of plant tissue. According to work of Clements and Martin (1934) and Kramer (1940) with sunflower, and Bailey and Jones (1941) with blueberry bushes (Vaccinium sp.), water absorption by roots showed a close relationship to soil temperature. Water absorption increased with a rise in temperature to a maximum above which further increase in temperature resulted in water absorption at a slower rate and in a smaller quantity. Either extremely low or high soil temperatures caused wilting when transpiration was sufficiently high.

Porter (1936) working with tomatoes, and Chandler (1953) working with roses, found that plants produced a greater expanse of leaf surface at lower light intensities, but the leaves were thinner and may have had less total mass. The epidermal cells were larger, stomates more numerous, and the mesophyll and midvein were larger. The greater expanse of leaf surface under reduced light intensity was found by Penfound (1931) to allow greater exposure and tended in some degree to compensate for the smaller quantity of total light received per unit of leaf surface exposed.

Porter (1936) believed that the partially shaded leaves of tomato used their limited supply of light more efficiently than the unshaded leaves used their normal supply of light. He even reported a large variation in the ability of different plants of the same species to utilize the available light.

<u>Influence on Abscission Layer</u>: Myers (1940) observed that the petioles of Coleus (<u>Coleus blumei</u>) tended to absciss more rapidly when the plants were placed in the dark than when the plants were placed in the light. This abscission was found to be delayed if the

plants were treated with 0.5 to 1.0 per cent of heteroauxin in lanolin. LaRue (1936) was able to delay the abscission of petioles from which the leaf blades had been removed by treating the tips of the petioles with 0.5 per cent heteroauxin in lanolin.

## Temperature

It is thought that each plant species has an optimum air temperature for growth (Burkholder, 1936). For practical purposes Post (1949) has listed optimum night air temperature for the growth of common greenhouse crops. For salvia, Post agreed with Roberts and Struckmeyer (1938) that the optimum night temperature for growing Salvia was between 55 and 60°F.

Holley (1942) stated that the importance of air temperature became increasingly significant as the light intensity decreased. He found that with carnations (Dianthus caryophyllus) growing under a light intensity of 100 to 200 foot candles, the production of carbohydrates was so low that the amount of material respired easily exceeded that manufactured.

Temperature in the surface layer of soil was effectively reduced by as much as 14°F by Dravid(1940) with the use of mulches of french chalk, with heavy waterings equal to one-quarter inch of rain, and with coverings of vegetation. A comprehensive review of the importance of soil temperature to plant growth was published by Richards, Hagen, and McCalla (1952). Doring (1935), Rouschal (1935) and Kramer (1942) concluded that the importance of soil temperature to growth varied with the plant species. In general, they found that growth of tropical plants could be more closely related to soil temperatures than could the growth of plants native to temperate climates.

The optimum soil temperature for forage crops, as measured by dry weight production, was found by Jones and Tisdale (1921), Darrow (1939), Stuckey (1942), Brown (1943), and Earley and Cartter (1945) to vary with variety, but there was a tendency for top growth of each crop to be reduced by both excessively high and excessively low temperatures. Similar results were obtained with cotton by Camp (1927). Yield of flowers was observed to be reduced by either excessively high or low temperatures supplied to beans (*Phaseolus vulgaris*) by Burkholder (1920), and to roses by Pfahl *et. al.* (1949), and Kohl *et. al.* (1949). The work of Jones and Tisdale (1921) has been interpreted by Earley and Cartter (1945) as showing a relation between light intensity, root temperature, and root development in soybeans (*Glycine Max*). It was observed that root growth increased with increase in temperature from 35 to 75$^{o}$F, but only to an extent limited by the light intensity.

Roberts (1953) observed a direct correlation between growth of aerial parts of the strawberry (*Fragaria* sp.) and increase in root temperature, but this positive correlation did not exist between root growth and root temperature. Consequently, he concluded top-root ratio increased as root temperature increased. A progressive decrease in the amount of rose roots was reported by Shanks and Laurie (1949) when the root temperature was increased from 56°F to 72°F and the air temperature was maintained at 60°F during the night. Cannon (1917) was able to increase shoot growth under unfavorably low atmospheric temperature by maintaining root temperatures favorable for good growth. The maturity date of stock (*Mathiola incana*), calendula (*Calendula* sp.), and snapdragon (*Antirrhinum majus*) was observed by Allen (1934) to be affected very little by variations in soil temperature.

## Nutrient Absorption

From work completed in 1933, Nightingale concluded that Salvia was very sensitive to the level of nitrates in the nutrient solution. Groups of Salvia plants were grown for 8 weeks under a 7-hour and a 17-hour photoperiod. At the end of this period the plants were transferred to a 14-hour photoperiod. Half of each group was supplied with a nutrient solution lacking nitrogen in contrast to the other half with a nitrate nutrient solution. When the short photoperiod plants were given the nutrient solution minus nitrate, "they shed their blossoms profusely and continued to grow for three and a half weeks when the experiment was discontinued".

Hagen (1952) has reported that he found it difficult to separate the effects of low temperature on the absorption process from those on translocation and assimilation. After reviewing the subject of nutrient absorption, he concluded that there was not sufficient evidence available to prove that a reduced rate of nutrient absorption was responsible for the slow growth of plants at low root temperature. Nevertheless, Hoagland (1923) and Ashby and Oxley (1935) had previously concluded that nutrient absorption by roots was influenced by light intensity, concentration of the nutrient solution, and temperature.

Hoagland and Davis (1923) observed the rate of uptake of bromine and chlorine by Nitella cells to be more rapid by illuminated cells than by cells which were kept in the dark. The quality and quantity of light was not designated, but the concentration of bromine and chlorine in the cells was proportional to the number of hours of daily illumination. They explained that "The absorption of ions by plants from dilute solutions involves energy exchanges with light as the ultimate source of the energy".

Gracanin (1932) reported no difference in the absorption of phosphorus by plants of barley (Hordeum vulgare) when shoots were illuminated or kept in the dark. Kraybill (1923) observed the leaf tissue of apple and peach trees grown in the "shade" to be considerably higher in moisture and total nitrogen than the leaf tissue of trees grown in the sun. Similar results were obtained by Blackman and Templeman (1940) with grasses and clover (Trifolium repens) comparing radiation of 37 to 44 per cent with full sunlight.

The manganese content of leaves of soybean (Glycine max), snapbean (Phaseolus vulgaris), and tobacco was observed by McCool (1935) to decrease with decrease in light intensity. Plants were grown in soil under full, 58 and 35 per cent solar radiation, the reduced radiation being provided by cheesecloth and unbleached muslin.

A larger amount of total nitrogen, potash, and phosphorus was accumulated in coffee (Coffea arabica) plants grown under full sunlight than was accumulated in plants grown under definite reductions of full solar radiation (Arrillaga and Gomez, 1942; Tanada, 1946). In the work of Arrillaga and Gomez (1942), the reduced radiation of two-thirds, one-half, one-third full sunlight was furnished by lath houses with the laths spaced to give the desired radiation. Solar radiation records were supplied by Micromax recorders and Pyrheliometers.

Seedlings of ash were grown by Steinbauer (1932) under low light intensities of 31, 48, 70, and 130 foot candles of incandescent light with controlled temperature and humidity. The concentration of the nutrients was varied from 0.1 to 1.0 atmosphere to test the effect of nutrient supply upon the length of the period of survival at subnormal light intensities. Steinbauer observed that a greater response to an increase in nutrients was found at the higher light intensities but the minimum light requirement could not be lowered by increasing the amount of available nutrients.

Wanner (1948a, b) suggested that salt absorption from higher concentrations was less dependent upon temperature than salt absorption from lower concentrations because less energy was required to complete the absorption of the salt. This theory was supported by results obtained by Roberts (1953) with strawberry. He found that the concentration of potassium, phosphorus, and boron in both leaves and roots of plants grown at 45, 55, 65, and 75°F root temperature could be closely correlated with the concentration of salts in the nutrient solution. It was found further that root temperature was an insignificant factor in the concentration of ash in the aerial portions of the plants. The concentration of ash in the roots increased with temperature above 55°F. At 45 and 75°F root temperature the ash content of the roots was insignificantly different. Roberts, also, theorized that this could have been due to the reduction in growth at the 45°F root temperature.

# PROCEDURE

## Tests of Cultivars

In order to compare the habit of growth of different cultivars, six plants of each of ten cultivars of Salvia splendens were grown in 6-inch pots in the greenhouse with a 60° Fahrenheit night temperature (F N T) during the months of March, April and May, 1953. The cultivars used were: St. Johns Fire, Vaughn's Masterpiece, Splendens America, America for Zuruch, Clara Bedman, Splendens Scarlet Sage, Splendens Brightness, Rose Flame (furnished by Vaughn's Seed Company, Chicago, Illinois), Bonfire, and Blaze of Fire (Ball Seed Company, West Chicago, Illinois). An 8-hour photoperiod was provided by covering the plants with a black sateen cloth from 16:30 to 08:30 hours Eastern Standard Time. Three plants of each cultivar were pinched (cultural term used to describe the removal of terminal growth) distal to the third node and three plants were allowed to grow without pinching.

Each cultivar was compared on the basis of flower color, plant height, plant shape with and without pinching, date of flowering (four whorls of expanded sepals), and number of flower shoots per plant.

Interaction of Cold Treatment and Growth

To determine the effect of a cold treatment on young plants, plants of the cultivar, America were planted in 4-inch pots, grown in the greenhouse at 50 and 60° F N T without pinching, and supplied with the following six treatments, using five plants per treatment:

(a) Plants grown at 50° F N T in the greenhouse

1. Continual 50° F N T
2. Constant 40° F T (Fahrenheit temperature) for 7 days as soon as plants had reached a two-node seedling stage
3. Constant 40° F T for 7 days as soon as plants had reached a four-node seedling stage

(b) Plants grown at 60°F N T in the greenhouse

1. Continual 60° F N T
2. Constant 40° F T for 7 days as soon as plants had reached a two-node seedling stage
3. Constant 40°F T for 7 days as soon as plants had reached a four-node seedling stage

The 7-day cold temperature treatments consisted of placing the plants in a 40°F constant temperature chamber where they were illuminated with 200 foot candles of florescent light for 12 hours a day. After the cold temperature treatment, the plants were returned to the greenhouse to 50 and 60° F N T respectively, and allowed to grow to maturity. Rate of shoot elongation, date of flowering and fresh weight of the aerial portion of the plants were recorded.

### Interaction of Night Temperature and Growth

It was desired to study the growth response of Salvia grown at 50 and 60° F N T without pinching. Seeds of cultivar America were sown February 1, 1952. One hundred and sixty plants were grown in 4-inch pots at 50 and 60° F N T. The seedlings were planted in 4-inch pots 37 days after seeding. Ninety days after seeding 40 plants from each treatment were moved to the opposite temperature to complete their growth.

The rate of shoot elongation and date of flowering at the different temperatures was recorded. Observations were made on foliage and flower bud appearance.

### Form of Plant

In growing a greenhouse crop it is helpful to know how many times the shoots of a plant should be "pinched" to produce desirable plants most rapidly. Seeds of cultivar America were sown on October 14, 1952, and allowed to germinate at 60° F N T. Twenty-one days after seeding the seedlings were transplanted.

Thirty-five days after seeding the plants were placed in 6-inch pots, and supplied with the following four treatments, using 15 plants per treatment:

1. Plants not "pinched"
2. Plants "pinched" once distal to the third node, 49 days after seeding
3. Plants "pinched" twice, once distal to the third node of terminal shoot, and once distal to the third node of primary lateral shoots, 83 days after seeding
4. Plants "pinched" three times, once distal to the third node of terminal shoots, once distal to the third node of primary lateral shoots, and once distal to the third node of secondary lateral shoots 106 days after seeding.

The date of flowering as well as the form of the plant produced under each treatment was recorded.

## Timing of a Commercial Crop

Seeds of cultivar America were planted on August 15, September 1, and September 15, 1953. The seedlings were transplanted in flats 20 days after seeding. Forty days after seeding, the plants were potted in 6-inch pots, and the terminal growth distal to the third node was removed. Each group was grown in the greenhouse at $60^{o}$ F N T with 15 plants in the August 15, and September 15 plantings, and 50 plants in the September 1 planting. Fifty plants from the group sown on September 1 were grown by the Molesta Floral Company, Grand Rapids, Michigan, and 50 plants were grown by the Wayside Greenhouses, Ithaca, Michigan. All of the plants were potted in 6-inch pots, and pinched once at the third node of the terminal shoot. Data were collected on the rate of bud development and date of flowering.

## Keeping Quality

To collect information on consumer opinion of keeping quality, thirty plants of the cultivar America were placed in homes in the area of East Lansing, Michigan, in the custody of residents for 15 days. Questionnaires (Table 1) were supplied to obtain opinions of the consumer. It was explained to the residents that floret drop referred to the abscission of the individual lateral florets.

Preliminary tests, using four plants per treatment, were made to study the effect of three treatments on keeping quality.

1. $60^{\circ}$ F N T supplied 21 days before flowering with chemical treatment of 12.5 ppm of para-chlorophenoxyacetic acid applied by the dip method
2. $50^{\circ}$ F N T supplied 21 days before flowering, no chemical treatment
3. $60^{\circ}$ F N T supplied 21 days before flowering, no chemical treatment

TABLE 1

QUESTIONNAIRE FOR OBTAINING PUBLIC OPINION OF SALVIA PLANTS

It would be appreciated if you will accept this salvia plant and care for it as is your usual practice.

Please record the following information and return form to Calvin C. Cooper, Department of Horticulture.

PLEASE CHECK:

1. How often are you watering the plant?

_________Every day _________ 3 times a week ______once a week

2. What source of heat do you have in your home?

_________Forced air _________ Steam ______Hot Water

3. What type of fuel do you use?

_________ Coal _________ Oil ______ Gas

4. What was the approximate room temperature?

_________ 85° _________ 75° _________ 65° _________ 55°

5. Was the plant

________In east window ________In south window _____In west window

________In north window ________Near a window _____Far from window

6. Date three leaves had fallen ________________________

Date six leaves had fallen ________________________

Date many leaves had fallen ________________________

7. Date three florets had fallen ________________; Date six florets had fallen ______________;Date many florets had fallen _______________

TABLE 1 (Continued)

8. Date of discard of plant ______________________________

9. Would you be inclined to buy one of these plants from a florist at 2/3 the price of a poinsettia? ________yes ________perhaps _____no

10. General opinion of plant as pot plant for the home:

    ________ Good ________ Fair ________ Poor

    Any comments on reverse of page

At the date of flowering two plants from each of the three treatments remained in the greenhouse with $60^{\circ}$ F N T and two plants were moved to a room temperature of $70^{\circ}$ F for observation.

Interaction of Photoperiod and Growth

Salvia has been reported to produce flowers only when it was grown under "short days". To further study this response, 20 plants of the cultivar America, from seed planted September 15, 1953 were grown in 6-inch pots.

Light periods of 16 and 8 hours were applied in 24-hour cycles, the remaining hours of each 24 consisting of darkness. The following combinations of photoperiod were used with four plants in each treatment:

1. 16-hour light period for 110 days followed by 8-hour light period for 0 days
2. 16-hour light period for 65 days followed by 8-hour light period for 45 days
3. 16-hour light period for 50 days, followed by 8-hour light period for 60 days
4. 16-hour light period for 35 days, followed by 8-hour light period for 75 days
5. 8-hour light period for 110 days followed by 8-hour light period for 0 days

All of the plants were pinched 35 days after seeding, and only four laterals were allowed to develop per plant.

At the end of 110 days two plants from each treatment were placed in a 16-hour photoperiod and two in an 8-hour photoperiod for 10 days. The 16-hour photoperiod was supplied by extending the normal daily period of light with 100 foot candles of incandescent light from 04:00 to 20:00 hours. The 8-hour photoperiod was supplied by reducing the normal daily period of light by moving the plants into a dark chamber between 16:30 and 08:30 hours. The date of flowering was recorded. Observations were made on the appearance of the plants and flowers grown under each photoperiodic treatment.

## Interaction of Root Temperature and Light Intensity With Growth

Four controlled temperature tanks consisting of large insulated vats of water were constructed with heating and refrigeration coils. Thermostats controlled the temperature of the root medium within a three-degree range (Figure 6). Earthenware crocks were suspended in the water. These crocks contained quartz sand and 0.5 Hoagland's complete nutrient solution (Hoagland and Arnon, 1950) in which the plants were placed. Each week the sand in which the plants were growing was drained, leached with one liter of distilled water, and drained again. The drains were then closed and one liter of nutrient solution was added and allowed to remain in the crocks. If necessary, an additional one-half liter of nutrient solution was added during the period between leachings. This was more often necessary at the 70°F root temperature than at the 50°F root temperature.

Seeds of cultivar America were sown in soil on September 23 and allowed to germinate at 60° F N T. The seedlings were allowed to grow in soil for a period of 35 days when they had produced approximately three to four nodes of vegetative growth. At that time they were removed from the soil, and after the roots were thoroughly and carefully washed, the plants were placed in the sand in the constant temperature tanks to grow to maturity. The following treatments were arranged with 24 plants per treatment:

1. 50°F root temperature, 63 per cent sunlight
2. 50°F root temperature, 100 per cent sunlight
3. 70°F root temperature, 63 per cent sunlight
4. 70°F root temperature, 100 per cent sunlight

The air was 60° F N T in each treatment. The light intensity was reduced on the two treatments with the use of cheesecloth covering (Figure 6). The plants were grown at the normal photoperiod (approximately 10.5 to 12.5 hours of daylight) occurring at East Lansing, Michigan, during October, November, and December. Date of flowering, height of plants, fresh and dry weight of stems, fresh and dry weight of roots were recorded. Observations were made on foliage and flower size and color.

The nutrient content of stem and root tissue was determined as a percentage on oven dry weight basis. Total $NO_3$ was determined by the modified Kjeldahl method, $P_2O_5$ by precipitation as ammonium phospho molybdate and volumetric evaluation, and $K_2O$ by the flame photometer.

The previous root temperature experiment was repeated by sowing seeds on December 1, 1952, and moving the plants to the same tanks 40 days after seeding. The plants were grown as before, and at the normal photoperiod (approximately 10 to 12 hours of light) occurring in East Lansing, Michigan, during January, February, and March. At 72-hour (3-day) intervals the terminal bud was removed from one plant in each treatment and killed and fixed in FAA. The buds were dehydrated and cleared with the ethyl alcohol, chloroform series and embedded in paraffin. Longitudinal sections were cut 10 microns in thickness, stained with Conant's quadruple stain and mounted permanently in Canada balsam. Rate of bud development, date of flowering, height of plants, fresh and dry weight of stems, and fresh and dry weight of roots were recorded. Observations were made on foliage and flower size and color.

A continuous recording of the light intensity in the different treatments was made with a Leeds and Northrup Speedomax type G recorder. The nutrient content of stem and of root tissue ($NO_3$, $P_2O_5$ and $K_20$) were determined as before.

## RESULTS

### Tests of Cultivars

The plants of all of the cultivars used in this comparison were planted in seed flats 19 days after seeding. The terminal growth was removed distal to the third node 36 days after seeding when the plants were placed in 6-inch pots.

At the time of flowering the "pinched" plants were shorter and more dense in their growth habit than the "non-pinched" plants of the same cultivar. An average of 2.3 more flowers and 4.6 fewer lateral flower buds were produced on "pinched" plants than on plants that were not "pinched". In general, at the 5 per cent level there were no significant differences in the number of lateral flower buds and flowers produced among the cultivars. The only case of significance was where plants of cultivar Rose Flame produced no lateral flower buds on the non-pinched plants. This was significantly less at the 1 per cent level.

Based on plants that were pinched once, the cultivars of Salvia grown appeared to be of three general types of growth:

1. Dwarf: Cultivars St. John's Fire and Vaughn's Masterpiece were included in this type. The plants averaged 17.0 to 17.5 centimeters in height, which was significantly shorter at the 1 per cent level than plants of the semi-dwarf and tall types. They developed a short, dense type of growth (Figure 1) and produced flowers of brilliant red color.

2. Semi-dwarf: Cultivars Splendens America, America for Zuruck, Bonfire, Blaze of Fire, and Rose Flame were of this type. The plants averaged 21.2 to 27.0 centimeters in height which was significantly taller than the dwarf and significantly shorter than the tall group at the 1 per cent level. The cultivars produced a moderately short, dense type of growth (Figure 2), and brilliant red flowers with the exception of cultivar Rose Flame. This cultivar produced light pink flowers.

3. Tall: Cultivars Clara Bedman, Splendens Scarlet Sage, and Splendens Brightness were of this type. The plants averaged 35.0 to 47.0 centimeters in height which was significantly taller than the other two types at the 1 per cent level. They developed a tall, open, type of growth (Figure 3), but did produce flowers of brilliant red color.

Figure 1. Salvia plant of the dwarf type exhibiting the short, dense growth typical of this group.


Figure 1

Figure 2. Salvia plant of the semi-dwarf type exhibiting the moderately short, dense growth typical of this group.


Figure 2

Figure 3. Salvia plant of the tall type exhibiting the tall, open growth typical of this group.


Figure 3

## TABLE 2

Effect of Pinching Cultivars on Growth of Salvia

| | St. John's Fire | Vaughn's Master-piece | Splendens America | America for Zuruck | Bonfire | Blaze of Fire | Clara Bedman | Splendens Scarlet Sage | Splendens Bright-ness | Rose-flame |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of Days Required to Reach Bud State Five and Flowering** | | | | | | | | | | |
| Bud stage five* | | | | | | | | | | |
| Pinched plants | 64 | 64 | 64 | 64 | 64 | 64 | 66 | 66 | 65 | 66 |
| Non-pinched plants | 49 | 56 | 59 | 59 | 59 | 59 | 59 | 64 | 64 | 66 |
| Flowering | | | | | | | | | | |
| Pinched plants | 73 | 74 | 73 | 74 | 73 | 74 | 76 | 78 | 76 | 76 |
| Non-pinched plants | 59 | 64 | 73 | 69 | 69 | 69 | 69 | 78 | 73 | 76 |
| **Height of Plants in Centimeters** | | | | | | | | | | |
| Pinched plants | 17.0 | 17.5 | 21.2 | 23.0 | 27.0 | 25.0 | 35.3 | 47.0 | 38.0 | 23.5 |
| L.S.D. 5% 2.0; L.S.D. 1% 2.8 | | | | | | | | | | |
| Non-pinched plants | 14.5 | 18.7 | 29.3 | 22.5 | 25.5 | 27.2 | 33.7 | 48.0 | 42.3 | 26.5 |
| L.S.D. 5% 3.5; L.S.D. 1% 4.7 | | | | | | | | | | |
| **Number of Flower Buds and Flowers Per Plant** | | | | | | | | | | |
| Flower buds | | | | | | | | | | |
| Pinched plants | 3.0 | 3.7 | 3.7 | 2.0 | 2.3 | 1.7 | 0.7 | 4.0 | 3.7 | 1.0 |
| L.S.D. 5% 2.0; L.S.D. 1% 2.7 | | | | | | | | | | |
| Non-pinched plants | 7.7 | 8.3 | 8.0 | 9.0 | 7.7 | 7.0 | 9.0 | 7.7 | 7.7 | 0.0 |
| L.S.D. 5% 2.3; L.S.D. 1% 3.2 | | | | | | | | | | |
| Flowers | | | | | | | | | | |
| Pinched plants | 3.7 | 3.7 | 3.7 | 3.0 | 5.3 | 2.7 | 3.3 | 3.0 | 2.7 | 2.0 |
| L.S.D. 5% 1.1; L.S.D. 1% 1.6 | | | | | | | | | | |
| Non-pinched plants | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| L.S.D. 5% 1.7; L.S.D. 1% 2.3 | | | | | | | | | | |

*Flower bud 1.5 cm long

TABLE 3

Interaction of Cold Treatment and Growth

| | 50°F N T | | | 60°F N T | | |
|---|---|---|---|---|---|---|
| | Continual 50°F N T | 40°F Temp. at 2 Node | 40°F Temp. at 4 Node | Continual 60°F N T | 40°F Temp. at 2 Node | 40°F Temp. at 4 Node |
| | Time for Flowering (Days) | | | | | |
| | 124.4 | 126.4 | 123.8 | 103.4 | 107.4 | 105.4 |
| L.S.D.5% 3.9 | | | | | | |
| L.S.D.1% 5.3 | | | | | | |
| | Stem Elongation (Centimeters) | | | | | |
| | 26.30 | 26.70 | 25.60 | 35.90 | 35.10 | 35.30 |
| L.S.D.5% 10.34 | | | | | | |
| L.S.D. 1% 13,99 | | | | | | |
| | Total Stem Weight (Grams) | | | | | |
| | 44.60 | 55.20 | 41.80 | 44.72 | 39.36 | 52.30 |
| L.S.D. 5% 11.46 | | | | | | |
| L.S.D. 1% 15.51 | | | | | | |
| | Stem Weight per Unit Stem Length (Gm/Cm) | | | | | |
| | 1.746 | 2.134 | 1.638 | 1.254 | 1.122 | 1.430 |
| L.S.D. 5% 0.328 | | | | | | |
| L.S.D. 1% 0.443 | | | | | | |

TABLE 4

Effect of Night Temperature on Height of Plants

| Days | Treatments | | | |
|---|---|---|---|---|
| | 50°F N T | 50° to 60° F N T | 60° to 50°F N T | 60°F N T |
| | Average Height in Centimeters | | | |
| 30 | 1.41 | 1.43 | 2.70 | 2.69 |
| 60 | 4.65 | 4.28 | 18.28 | 17.85 |
| 90 | 20.53 | 21.33 | - - - | - - - |
| 115* | 26.28 | 29.72 | 38.38 | 35.94 |

L.S.D.** 5% 1.20

L.S.D. 1% 1.59

*Average number days. Measurements made at date of flowering.

**Between treatments.

The number of days required for flower production varied with the cultivar. Approximately 7 days less was required for flowering of the dwarf cultivars than was required for most of the semi-dwarf and tall cultivars.

## Interaction of Cold Treatment and Growth

Total stem weight and stem elongation were not significantly influenced by cold treatment (40°F constant temperature for 7 days) regardless of whether the plants were provided with a 50° or 60° F N T.

The number of days required for flowering when plants were supplied with a 50°F N T was not significantly influenced by cold treatments. The plants, when supplied with a 60° F N T and a cold treatment at the 2-node stage, required a significantly greater number (four) of days for flowering to occur, than was required for those supplied with 60°F N T and no cold treatment. When treated at the four-node stage the increase (two days) over the plants given no cold treatment was not significant.

Stem weight per unit of stem elongation in plants growing at 50°F N T was increased (0.388 grams) significantly by the cold treatment supplied at the two-node stage, but not when the cold treatment was supplied at the four-node stage. With plants grown at the 60°F N T the stem weight per unit of stem elongation was not significantly influenced by the cold treatment supplied at the two- or the four-node stage (Table 3).

Interaction of Night Temperature and Growth

Salvia plants grown at the 50° F N T became chlorotic and grew slowly for 60 days. Necrosis did not develop and the plants gradually regained their green color within 30 more days, and grew to maturity. The growth increment as influenced by night temperature (Table 4) shows quite clearly the retardation of growth at 50°F N T during the first 60 days, and the increase in growth rate after this period. Moving plants to the opposite temperature 90 days after seeding gave increases in final stem elongation which in both groups were significantly greater when compared to the elongation of the plants that continued to grow at the original temperature. Both groups of plants which were grown at 60°F N T during the first 90 days of the experiment produced approximately 9 centimeters more elongation than the groups grown at 50°F N T. These differences were highly significant.

The flowers produced in all treatments were essentially equal in color and quality. Flowering at 50° F N T required 17.3 more days on the average than did flowering at 60°F N T. Plants grown at 50°F N T during the first 90 days and at 60°F N T during

TABLE 5

Effect of Night Temperature on Rate and Amount of Growth

| L. S. D. | Treatments | | | |
|---|---|---|---|---|
| | $50^{o}$F N T | $50^{o}$ to $60^{o}$F N T | $60^{o}$ to $50^{o}$F N T | $60^{o}$F N T |
| | Time from Seed to Flower (Days) | | | |
| | 124.3 | 122.0 | 107.0 | 107.0 |
| 5% 2.03 | | | | |
| 1% 2.69 | | | | |
| | Total Average Stem Weight at Flowering (Grams) | | | |
| | 46.20 | 44.45 | 48.18 | 44.00 |
| 5% 4.06 | | | | |
| 1% 5.37 | | | | |
| | Average Stem Weight per Centimeter of Stem Length (Grams) | | | |
| | 1.76 | 1.50 | 1.26 | 1.22 |
| 5% 0.20 | | | | |
| 1% 0.26 | | | | |

TABLE 6

Average Number of Days Required for Flowering with Respective Number of "Pinches"

| | Treatment | | | |
|---|---|---|---|---|
| | No "Pinch" | One "Pinch" | Two "Pinches" | Three "Pinches" |
| Days | 102 | 126 | 136 | 146 |

Figure 4. Salvia plant grown without "pinching".

Figure 5. Salvia plant growh with two "pinches"; one applied distal to the third node of the terminal shoot, and one distal to the third node of the primary lateral shoots.

Figure 4

Figure 5

the remainder of the experiment flowered on an average of 2.3 days earlier than plants grown the entire time at 50°F N T. Moving plants from a 60°F N T to a 50°F N T 90 days after seeding did not significantly affect the number of days required for flowering (Table 5).

There were no significant differences between the treatments in total stem weight per plant. There seemed to be a trend toward greater stem weight per centimeter of stem length in plants grown at the 50°F N T (Table 5). The differences, however, were not significant.

## Form of Plant

The "non-pinched" treatment produced no lateral branching of the plant at the time of flowering, and consequently produced plants with undesirable form similar to that in Figure 4. If the plants were allowed to continue to grow in the greenhouse for approximately 30 days lateral branches with large flowers developed, Figure 4. Pinching the plants once, twice, or three times produced plants with form similar to that shown in Figure 2. One "pinch" produced plants with sufficient branching to give desirable form and required the least time for flowering of any treatment, since 10 days was added to the time required for flowering with each additional "pinch" (Table 6). Plants which were "pinched" twice produced larger plants with large flowers (Figure 5). Three "pinches" produced plants of about the same overall size as did two "pinches". The flowers, although more numerous were only half as large as those produced by plants with one or two pinches.

## Timing of a Commercial Crop

Crop one, for which the seed was sown August 15, 1953, reached the flowering stage over a range of 4 days with the average date of flowering being November 13, 1953 (90 days). Although the seed for the second crop was sown only 16 days later, the plants in this group flowered approximately 21 days after the first crop. The dates at which these plants reached the flowering stage ranged over 12 days, with the average date of flowering being December 7, 1953 (98 days). The flowering dates for crop three, for which the seed was sown September 15, 1953, ranged over a period of 4 days with the average date of flowering being December 23, 1953 (99 days). The number of days required for crop one to flower was significantly less at the 1 per cent level than the number of days required for crop two and three to flower. The number of days required for crops two and three to flower were not significantly different (Table 7).

From Table 7 it can be observed that at 60°F N T a period of from 16 to 19 days was required for flower development to proceed

TABLE 7

Average Number of Days from Seeding Required for Flower Bud Development

| | Stage Five* | Flowering |
|---|---|---|
| Crop one | 74 | 90 |
| Crop two | 79 | 98 |
| Crop three | 80 | 99 |

L. S. D. 5% 4.4
L. S. D. 1% 5.9

*Stage five is that stage in flower bud development when the overall length of the bud is 1.5 cm and the flower parts are all differentiated.

TABLE 8

Rate of Flower and Leaf Abscission from Plants Exposed to Room Temperature in Private Homes

| Abscission Of Parts Per Plant | Time in Number of Days | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1-3 | 4-6 | 7-9 | 10-12 | 13-15 | 15+ | Average |
| 3 florets | 26 | 3 | 1 | 0 | 0 | 0 | 2.5 |
| 6 florets | 17 | 10 | 2 | 1 | 0 | 0 | 3.7 |
| Many florets | 4 | 6 | 9 | 5 | 3 | 3 | 8.5 |
| 3 leaves | 5 | 5 | 11 | 5 | 0 | 4 | 8.1 |
| 6 leaves | 1 | 4 | 4 | 8 | 4 | 9 | 11.4 |
| Many leaves | 0 | 0 | 3 | 2 | 9 | 16 | 14.3 |

from stage five to flowering.

The fifty plants grown by the Molesta Floral Company reached the flowering stage over an extended period of 3 weeks and were much smaller at the time of flowering than those grown by the investigator at the college. Somewhat larger plants were obtained by the Wayside Floral Company and the flowering stage was reached at dates which more nearly corresponded with results of the investigator.

## Keeping Quality

Eighteen of the thirty plants in the custody of residents exhibited evidence of floret abscission during the first day (Table 8). Two and one-half days elapsed on the average, however, before three florets had abscissed from the plants. Six florets abscissed 3.7 days and many abscissed 8.5 days after the plants were moved to room temperature in the homes. This indicated that plants remained in optimum condition in a home for an average period of 4 to 8 days.

The foliage appeared to be much more durable under home conditions (Table 8). An average of 8.1 days passed before three leaves abscissed, 11.4 days before six, and 14.3 days before many leaves abscissed. At the end of the 15-day period, the foliage of

16 plants remained in good condition. The other 14 plants had been neglected, because the residents were not interested in the plants after the flowers ceased to be attractive.

The variability in frequency of watering, heating method, temperature, and location of the plant in the home, appeared to have no consistent effect on the length of plant life in the home.

In the preliminary tests no floret abscission occurred on any plants that were allowed to remain in the greenhouse with $60^{o}$F N T regardless of whether they were previously treated with a dip of 12.5 ppm para-chlorophenoxyacetic acid with $60^{o}$F N T, no chemical treatment with $50^{o}$F N T, or no chemical treatment with $60^{o}$F N T. Flower abscission occurred from the plants in all three treatments 2 days after they were moved to a room temperature of $70^{o}$F for observation. The rate of abscission was slightly reduced by the $50^{o}$F N T. At the end of 5 days an average of 33.5 florets had abscissed from plants treated with 12.5 ppm of para-chlorophenoxyacetic acid with $60^{o}$F N T, and plants exposed to no chemical treatment with $60^{o}$F N T, while only an average of 12 florets had abscissed from plants supplied with no chemical treatment and $50^{o}$F N T for 21 days before moving to the room temperature.

Foliage expansion was retarded and flowering delayed 7 days on plants treated with para-chlorophenoxyacetic acid and $60^{o}$F N T in the greenhouse. Slight chlorosis developed in the foliage within a week after moving the plants to the 50°F N T. This chlorosis disappeared before the plants were in flower, and time of flowering was not altered by the lower temperature at this stage in development.

## Interaction of Photoperiod and Growth

Total stem elongation was reduced on plants provided with an 8-hour photoperiod compared to plants receiving a 16-hour photoperiod. This difference was present after the plants had been growing for 50 days, and was in general maintained as growth progressed. The reduction in total stem elongation at the end of 110 days of growth was significant at at least the 5 per cent level when the plants were exposed to 60 or more short days, Table 9. More than 60 short days tended to cause less total stem elongation (Figure 7), however, these differences were not significant among the plants supplied with 60, 75 and 110 short days, Table 9.

The average amount of linear growth was likewise less when the plants were supplied with an 8-hour photoperiod, Figure 7. After 110 days of growth, the plants supplied with 60, 75 and 110 short days were significantly and consecutively shorter at the 1 per cent level than those supplied with 110 long days consisting of a 16-hour photoperiod (Table 10). These differences were evident after 50 days

TABLE 9

Interaction of Photoperiod and Time on Total Stem Elongation Per Plant

| Days From Seeding | L.S.D. | Short Days 0 | 45 | 60 | 75 | 110 |
|---|---|---|---|---|---|---|
| | | Cm. | Cm. | Cm. | Cm. | Cm. |
| 50 | 5% 2.00<br>1% 2.77 | 6.60 | 4.85 | 3.55 | 2.95 | 2.30 |
| 70 | 5% 14.68<br>1% 20.33 | 38.87 | 34.00 | 21.50 | 19.50 | 16.75 |
| 90 | 5% 31.12<br>1% 43.10 | 90.00 | 62.63 | 55.63 | 50.25 | 116.50 |
| 110 | 5% 33.02<br>1% 45.73 | 134.38 | 91.38 | 90.75 | 72.88 | 83.13 |

TABLE 10

Interaction of Photoperiod and Time on Plant Height

| Days From Seeding | L.S.D. | Short Days 0 | 45 | 60 | 75 | 110 |
|---|---|---|---|---|---|---|
| | | Cm. | Cm. | Cm. | Cm. | Cm. |
| 50 | 5% .70<br>1% .97 | 2.03 | 1.48 | 1.04 | 0.85 | 0.70 |
| 70 | 5% 4.09<br>1% 5.66 | 12.50 | 10.94 | 5.94 | 5.25 | 4.38 |
| 90 | 5% 7.07<br>1% 9.79 | 28.50 | 21.13 | 15.19 | 13.13 | 12.25 |
| 110 | 5% 9.10<br>1% 12.60 | 41.00 | 31.31 | 26.00 | 20.88 | 22.13 |

Figure 6. Greenhouse equipment showing the earthenware crocks suspended in four constant temperature tanks, and the reduced light intensity provided to two groups with the use of cheesecloth.

Figure 7. Salvia plants 95 days after seeding demonstrating the influence of photoperiod on vegetative growth. The numbers below the plants indicate the number of short days the plants had received at the time the photograph was taken. From left to right, the plants are typical of groups which received 95 long days (LD) followed by 0 short days (SD), 65 LD followed by 30 SD, 50 LD followed by 45 SD, 35 LD followed by 60 SD, and 0 LD followed by 95 SD.

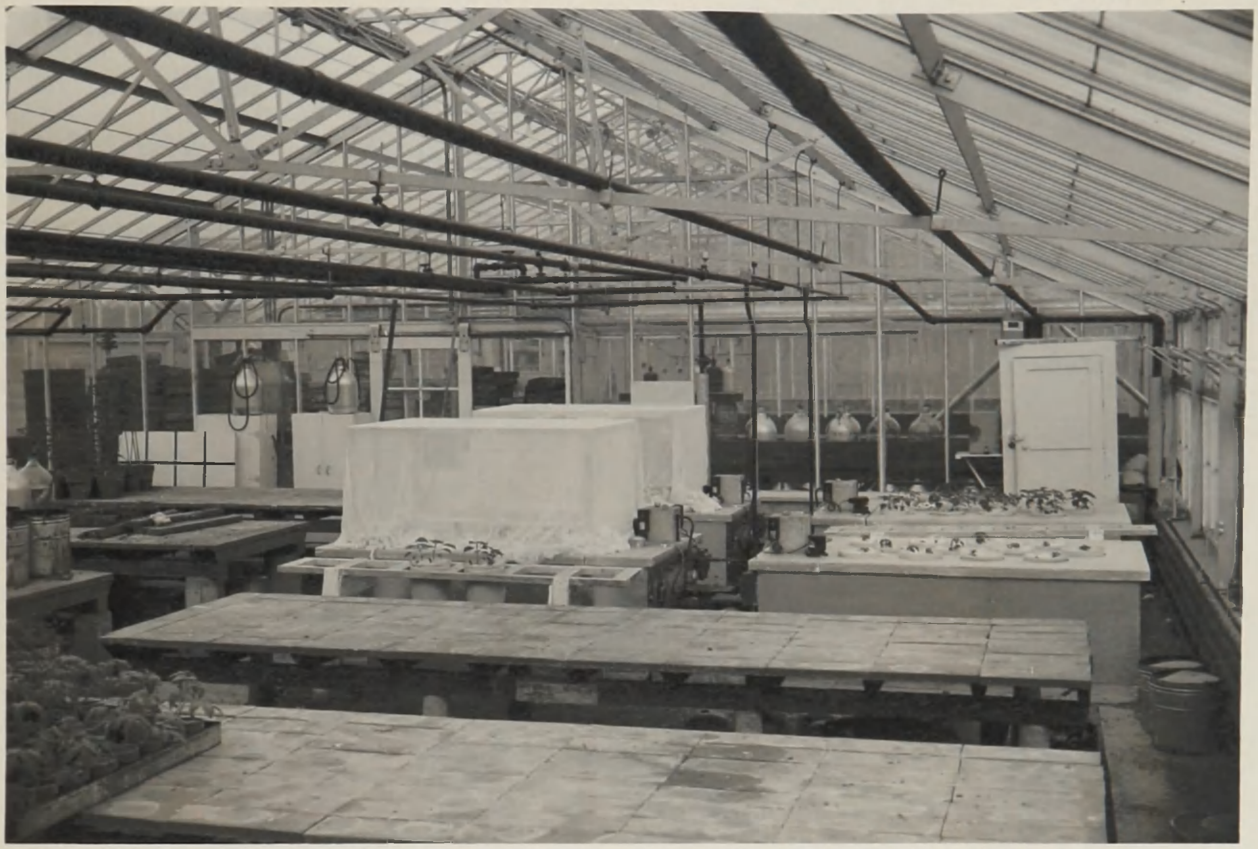

Figure 6


Figure 7

and throughout the remainder of the experiment. Those plants supplied with 45 short days exhibited reduction in height, but this reduction was not significant until 90 days after seeding.

In addition to having a definite affect on stem elongation, photoperiod appeared to affect apical dominance. When the plants were supplied with 60, 75, and 110 short days, the four laterals all produced approximately equal elongation. When no short days, or only 45 short days were supplied, the two laterals emerging from the more distal node of the main stem attained much greater elongation than the two laterals emerging from the more proximal node (Figure 7).

All treatments produced flowering plants, although the time required for flowering in the different treatments ranged over a period of 10 days. Those supplied with no short days required the longest period of time to flower (108 days). Those supplied with 45 and 110 short days were intermediate in number of days required for flowering (105 days). Plants supplied with 60 short days required slightly less time (102 days), and a significantly shorter time (5 per cent level) for flower production than those plants supplied with no long days. Those receiving 75 short days produced flowers in the shortest period of time and in a period significantly shorter at the 5 per cent level than 0, 45, and 110 short day treatments, Table 11.

TABLE 11

Interaction of Photoperiod and Time on Number of Days Required for Flowering

| | L.S.D. | Short Days | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 45 | 60 | 75 | 110 |
| Bud Stage V | 5% 5.51<br>1% 7.60 | 93 | 88 | 84 | 81 | 91 |
| Flowering | 5% 5.10<br>1% 7.02 | 108 | 105 | 102 | 98 | 105 |

Photoperiod appeared to have no affect on the plants or their flowers 110 days after seeding when two plants from each treatment were supplied with ten short days consisting of 8-hour photoperiods, and two plants were supplied with ten long days consisting of 16-hour photoperiods.

Interaction of Root Temperature and Light Intensity with Growth

General: After 14 days of exposure to 50°F root temperature, plants exhibited a chlorosis of the lower leaves, stunted growth, dark green foliage and anthocyanin development in the petioles and stems. In contrast, the plants provided with 70°F root temperature were growing vigorously, showing bright green foliage and no anthocyanin development in the petioles and stems.

Twenty-one days later, and throughout the remainder of their

Figure 8. Cameralucida drawing of a Salvia flower bud demonstrating the five arbitrary stages in development.

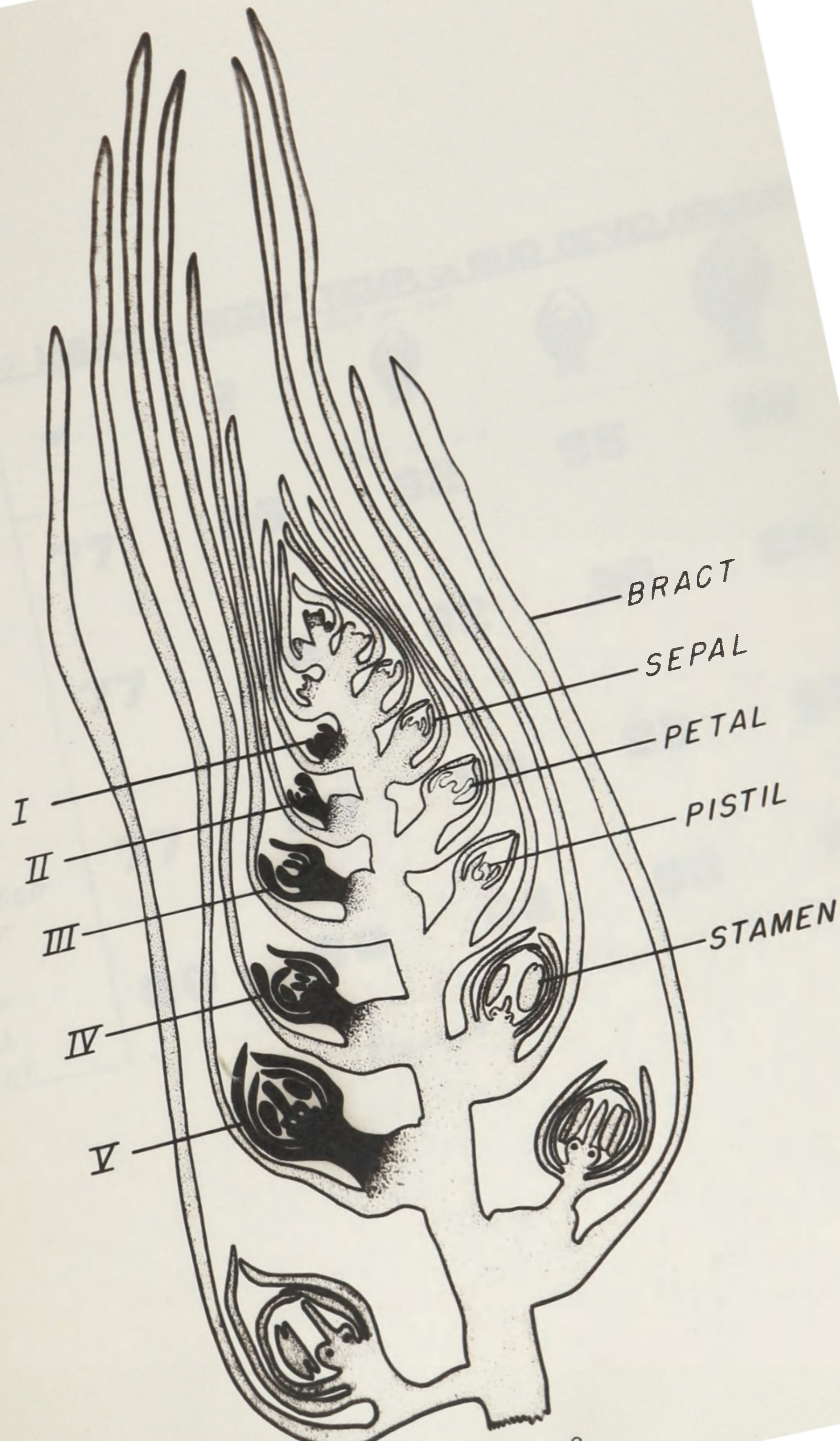


Figure 8

## INFLUENCE OF LIGHT & ROOT TEMP. ON BUD DEVELOPMENT

| TREATMENT | TIME IN DAYS | | | | |
|---|---|---|---|---|---|
| 50°F REDUCED LIGHT | 77 | 86 | 92 | 95 | 98 |
| 50°F FULL LIGHT | 77 | 86 | 92 | 95 | 98 |
| 70°F REDUCED LIGHT | 77 | 80 | 83 | 86 | 92 |
| 70°F FULL LIGHT | 80 | 83 | 86 | 92 | 95 |

Figure 9

growth the plants at the $50^{\circ}F$ root temperature exhibited less evidence of chlorosis, and grew more rapidly than before. The plants exposed to $70^{\circ}F$ root temperature grew the most rapidly, produced thicker stems, larger leaves, and greater stem elongation (Figures 10 and 11).

Flower Bud Development: Five arbitrary stages in the development of the florets were distinguished: 1. Sepal primordia present; 2, petal primordia present; 3. first indication of reproductive primordia; 4. developing androecium; 5. gynoecium present and androecium in advanced stages of development (Figure 8). The number of days required for the development of the respective stages in each of the four treatments is recorded in Figure 9.

Root temperature and light intensity had little influence on the time of floret initiation. Florets developed more slowly at the $50^{\circ}F$ than at the $70^{\circ}F$ root temperature. However, while their development was less rapid during the earlier stages when exposed to a $50^{\circ}F$ root temperature, it was less rapid during the later stages when the plants were provided with a $70^{\circ}F$ root temperature (Figure 9).

The period of time required for flowering at $50^{\circ}F$ root temperature was not consistently longer than the period of time required at $70^{\circ}F$. Plants flowered in the shortest period of time when provided with $70^{\circ}F$ root temperature and the reduced (63 per cent) light intensity, and required the longest period of time when supplied with $70^{\circ}F$

TABLE 12

Interaction of Root Temperature and Light Intensity on Number of Days Required for Flowering in the Fall Crop

| | L.S.D. | 50°F Reduced Light Intensity | 50°F Full Light Intensity | 70°F Reduced Light Intensity | 70°F Full Light Intensity |
|---|---|---|---|---|---|
| Days required for flowering | | 85.57 | 81.36 | 77.29 | 86.79 |
| | 5% 29.09 | | | | |
| | 1% 38.82 | | | | |

TABLE 13

Approximate Length of Photoperiod Occurring During Growth of Fall and Winter Crops*

| | Days of Crop Growth: 1 to 35 Days | 35 to 70 Days | 70 to 105 Days |
|---|---|---|---|
| Fall crop | 13 hrs 30 min to 11 hrs 30 min | 11 hrs 30 min to 10 hrs 20 min | 10 hrs 20 min to 10 hrs 10 min |
| Winter crop | 10 hrs 20 min to 10 hrs 10 min | 10 hrs 10 min to 11 hrs 0 min | 11 hrs 0 min to 12 hrs 10 min |

*From Post, 1949, p. 71.

TABLE 14

Interaction of Root Temperature and Light Intensity on Plant Height in Centimeters

| | L.S.D. | 50°F Reduced Light Intensity | 50°F Full Light Intensity | 70°F Reduced Light Intensity | 70°F Full Light Intensity |
|---|---|---|---|---|---|
| | | Fall Crop | | | |
| 83 days* | | 13.39 | 12.61 | 28.69 | 38.11 |
| | 5% 10.16 | | | | |
| | 1% 13.56 | | | | |
| 105 days** | | 29.23 | 29.20 | 50.46 | 58.64 |
| | 5% 11.04 | | | | |
| | 1% 14.76 | | | | |
| | | Winter Crop | | | |
| 105 days** | | 9.38 | 9.15 | 29.11 | 27.54 |
| | 5% 6.85 | | | | |
| | 1% 9.14 | | | | |

*Average day of flowering

**Day of harvest

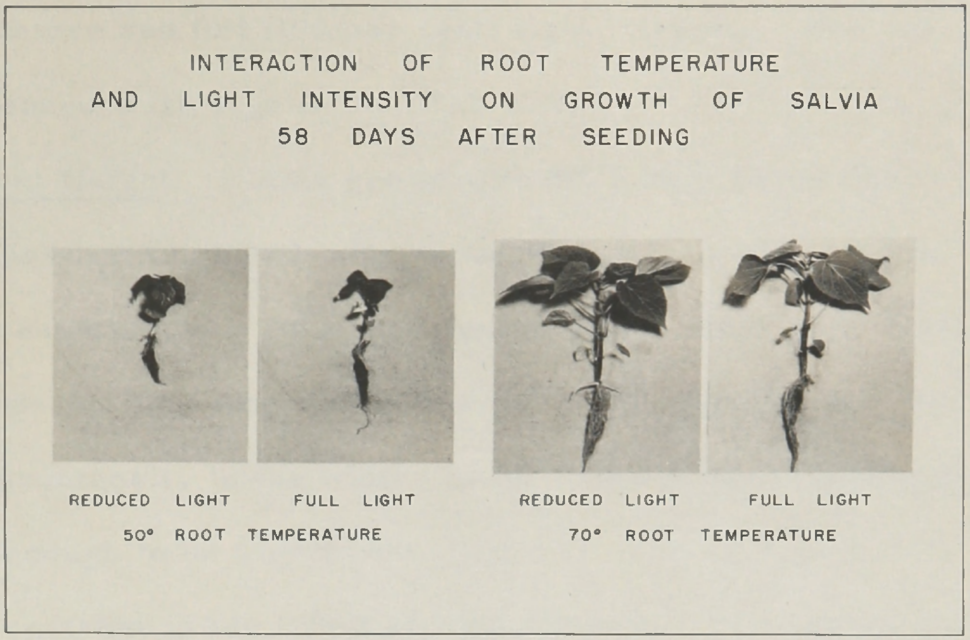


Figure 10

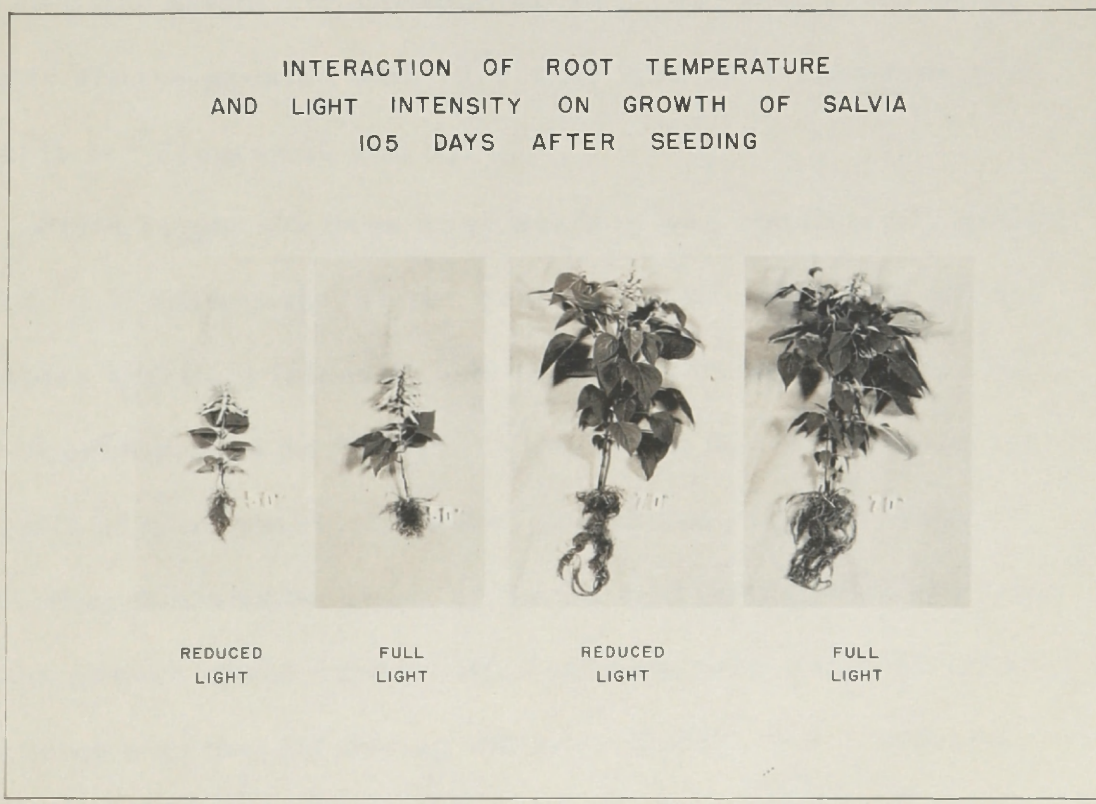


Figure 11

root temperature and full (100 per cent) light intensity. None of these differences were significant (Table 12).

Plant Height: Plants grown with 50°F root temperature produced more linear growth with reduced light intensity. When plants were supplied with 70°F root temperature, their height was less with reduced light intensity in the fall crop, and greater with reduced light intensity in the winter crop. None of these differences were large enough to be significant.

In contrast to the effect of light intensity, root temperature influenced plant height significantly at the 1 per cent level. Plant height was always greater with 70°F than with 50°F root temperature (Table 14, Figures 10 and 11).

Plant height 105 days after seeding was consistently greater in the fall crop than in the winter crop under all conditions of root temperature and light intensity. In the section concerning the influence of photoperiod on growth, it was found that duration of specified lengths of photoperiod did affect vegetative growth. Thus, it was seen that this was an affect of the natural photoperiod occuring during the growth of the crops. Approximate values for the naturally occuring photoperiod during the growth of the two crops are given in Table 13.

<u>Fresh Weight</u>: Fresh weight of both stems and roots was greater with full light than with reduced light intensity regardless of the root temperature. The amount of increase in the fresh weight was, however, greater when the plants were grown with 70°F than with 50°F root temperature. In the fall crop, plants which were supplied with the 50°F root temperature exhibited insignificant differences in fresh weight as a result of different light intensities. Plants grown with 70°F root temperature also exhibited insignificant differences in stem weight due to light intensity, however the roots of these plants had a fresh weight which was 21.4 grams more than the fresh weight of roots of plants supplied with a reduced light intensity. This difference was significant at the 1 per cent level.

The same general trends appeared in the winter crop. No tests of significance were made on weights of the winter crop, since the plants from the individual treatments were weighed as a group. The differences in fresh weight production due to light intensity were greater than in the fall crop with the exception of root weight of plants grown with 70°F root temperature. Here the increase with full light intensity was not as great as in the fall crop.

The differences in fresh weight of stems and roots of plants grown with 70°F root temperature and 50°F root temperature were significant at the 1 per cent level in the fall crop. The fresh weight of stems averaged 7.2 times heavier and fresh weight of roots averaged 4.8 times heavier with 70°F than with 50°F root temperature. These differences in fresh weight production as a result of temperature differences were greater in the winter crop where fresh weight of stems averaged 11.4 times heavier and fresh weight of roots averaged 8.6 times heavier with the 70°F root temperature (Table 15).

Dry Weight: Irrespective of root temperature, dry weight of stems and roots in the fall crop was also greater with full than with reduced light intensity. The differences in dry weight because of light intensity were not significant at the 5 per cent level with the plants grown at a 50°F root temperature. When the plants were grown with a 70°F root temperature, an average of 2.7 grams more dry weight of stems, and 2.6 grams more dry weight of roots was produced with the full light intensity. These differences were significant (Table 16).

The same general trends existed in the winter crop. The increases in dry weight with full light intensity in the winter crop were larger, except for the dry weight of roots produced by plants supplied with a 70°F root temperature. Here the increase with full light intensity was not as great as in the fall crop.

Root temperature did not influence the dry weight of stems and roots as much as fresh weight. Dry weight production of plants grown with a 70°F root temperature was consistently greater than

TABLE 15

Interaction of Root Temperature and Light Intensity on Fresh Weight of Stems and Roots in Grams

| | 50°F | | 70°F | |
|---|---|---|---|---|
| | Reduced Light Intensity | Full Light Inten-sity | Reduced Light Intensity | Full Light Inten-sity |
| | | Fall Crop | | |
| Stem weight | 7.58 | 9.08 | 53.29 | 68.02 |
| L.S.D. 5% 17.20 | | | | |
| 1% 22.99 | | | | |
| Root weight | 4.33 | 6.49 | 16.63 | 37.99 |
| L.S.D. 5% 8.69 | | | | |
| 1% 11.62 | | | | |
| | | Winter Crop | | |
| Stem weight | 2.00 | 3.57 | 25.30 | 36.44 |
| Root weight | 1.03 | 3.15 | 11.70 | 18.66 |

TABLE 16

Interaction of Root Temperature and Light Intensity on Dry Weight of Stems and Roots in Grams

| | 50°F | | 70°F | |
|---|---|---|---|---|
| | Reduced Light Intensity | Full Light Inten-sity | Reduced Light Intensity | Full Light Inten-sity |
| | | Fall Crop | | |
| Stem weight | 1.02 | 1.36 | 6.09 | 8.83 |
| L.S.D. 5% 2.30 | | | | |
| 1% 3.08 | | | | |
| Root weight | 0.30 | 0.34 | 1.08 | 3.68 |
| L.S.D. 5% 1.63 | | | | |
| 1% 2.18 | | | | |
| | | Winter Crop | | |
| Stem weight | 0.29 | 0.83 | 3.10 | 5.50 |
| Root weight | 0.04 | 0.19 | 0.90 | 2.45 |

that of plants grown with a 50°F root temperature. The increases in dry weight of stems and roots of plants grown with a 70°F root temperature were significant at the 1 per cent level with the exception of the dry weight of roots produced by plants supplied with a reduced light intensity. Here there was no significance. The dry weight of the stems averaged 6.2 times heavier and the dry weight of the roots averaged 2.3 times heavier with the 70°F than with the 50°F root temperature. The increases in dry weight as a result of differences in temperature were greater in the winter crop with an average of 8.7 times as much stem weight, and an average of 17.7 times as much root weight produced with the 70°F root temperature (Table 16).

Top-root Ratio: Both temperature and light intensity appeared to affect the top-root ratio considerably. With the calculations made on a fresh weight basis, a larger ratio was consistently obtained at the reduced light intensity and the 70°F root temperature (Table 17).

TABLE 17

Interaction of Root Temperature and Light Intensity on Top-Root Ratio

| | 50°F | | 70°F | |
|---|---|---|---|---|
| | Reduced Light Intensity | Full Light Intensity | Reduced Light Intensity | Full Light Intensity |
| | Fresh Weight Basis | | | |
| Fall crop | 1.75 | 1.40 | 3.20 | 1.79 |
| Winter crop | 1.94 | 1.13 | 2.16 | 1.95 |

TABLE 18

Interaction of Root Temperature and Light Intensity on Nutrient Element Composition of Roots and Tops (Per Cent Dry Weight)

| | 50°F | | 70°F | |
|---|---|---|---|---|
| | Reduced Light Intensity | Full Light Intensity | Reduced Light Intensity | Full Light Intensity |
| | | Fall Crop | | |
| Roots | | | | |
| % N | 1.63 | 1.66 | 1.01 | 1.43 |
| % P | 0.175* | 0.180* | 0.146 | 0.172 |
| % K | 1.91 | 1.09 | 0.911 | 1.45 |
| Tops | | | | |
| % N | 3.18 | 3.19 | 3.90 | 4.02 |
| % P | 0.370 | 0.338 | 0.496 | 0.454 |
| % K | 3.26 | 2.73 | 3.36 | 3.95 |
| | | Winter Crop | | |
| Roots | | | | |
| % N | 2.47 | 2.96 | 1.40 | 1.61 |
| % P | --** | --** | 0.184 | 0.210 |
| % K | 3.39 | 3.33 | 1.88 | 2.59 |
| Tops | | | | |
| % N | 2.56 | 2.79 | 3.26 | 3.98 |
| % P | 0.268 | 0.256 | 0.456 | 0.478 |
| % K | 3.17 | 4.13 | 2.90 | 4.51 |

*Results from single determinations because of insufficient sample. All other values are averages of duplicate determinations.

**Insufficient sample to make determinations.

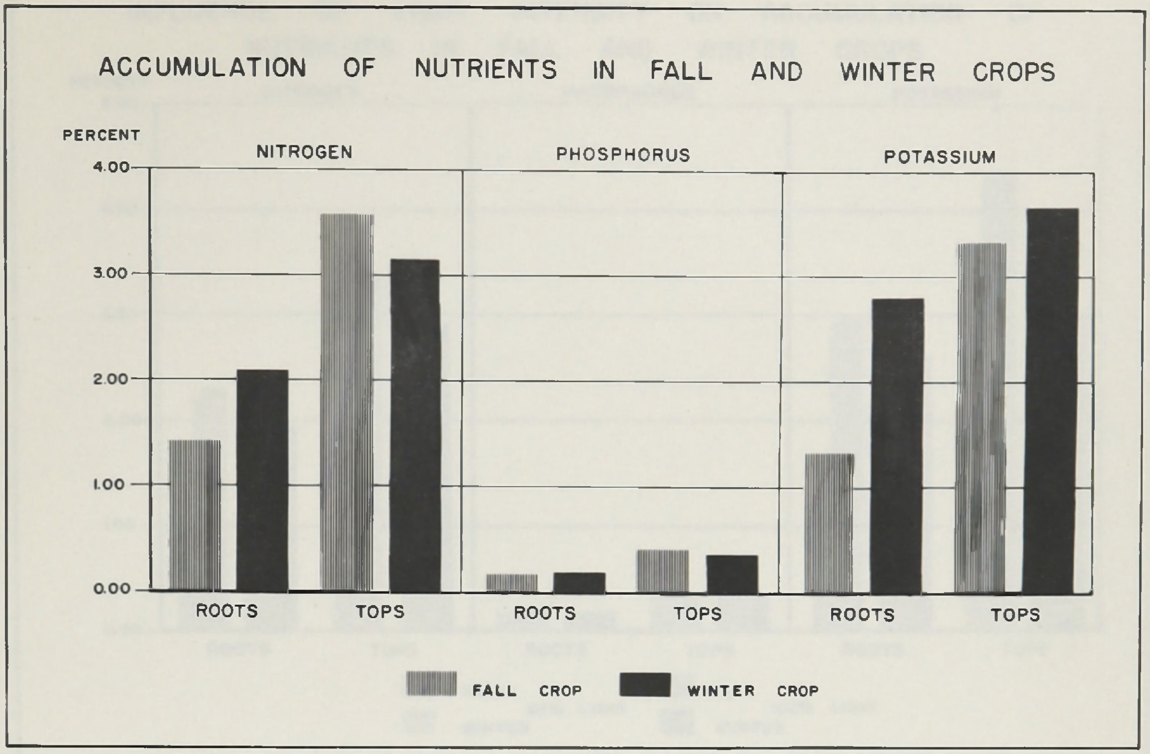


Figure 12

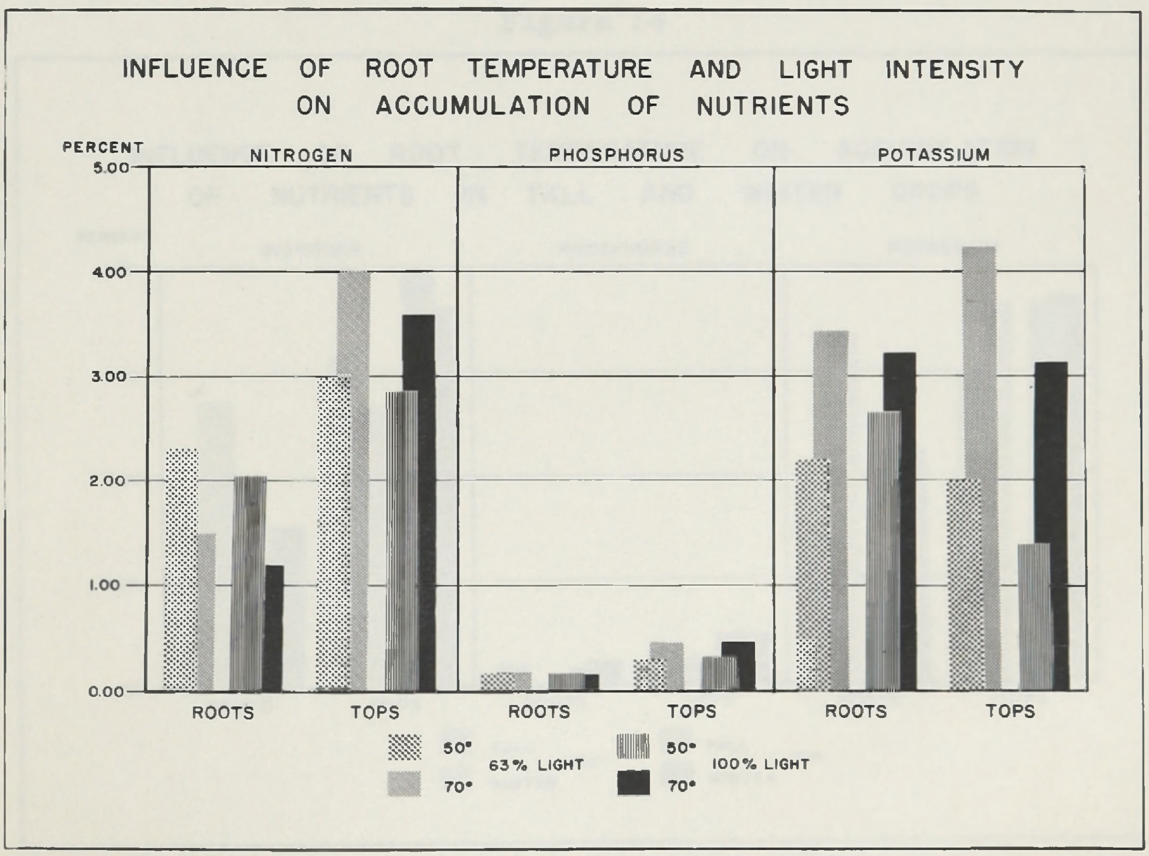


Figure 13

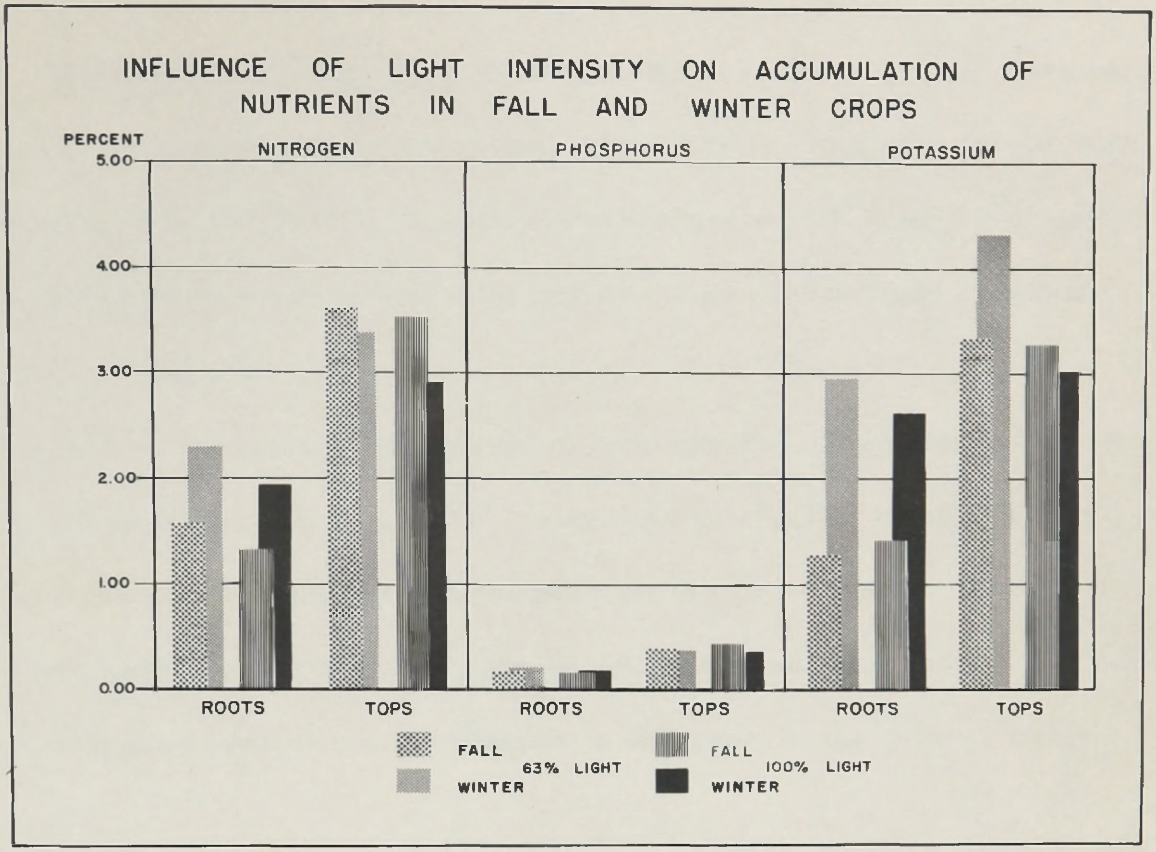


Figure 14

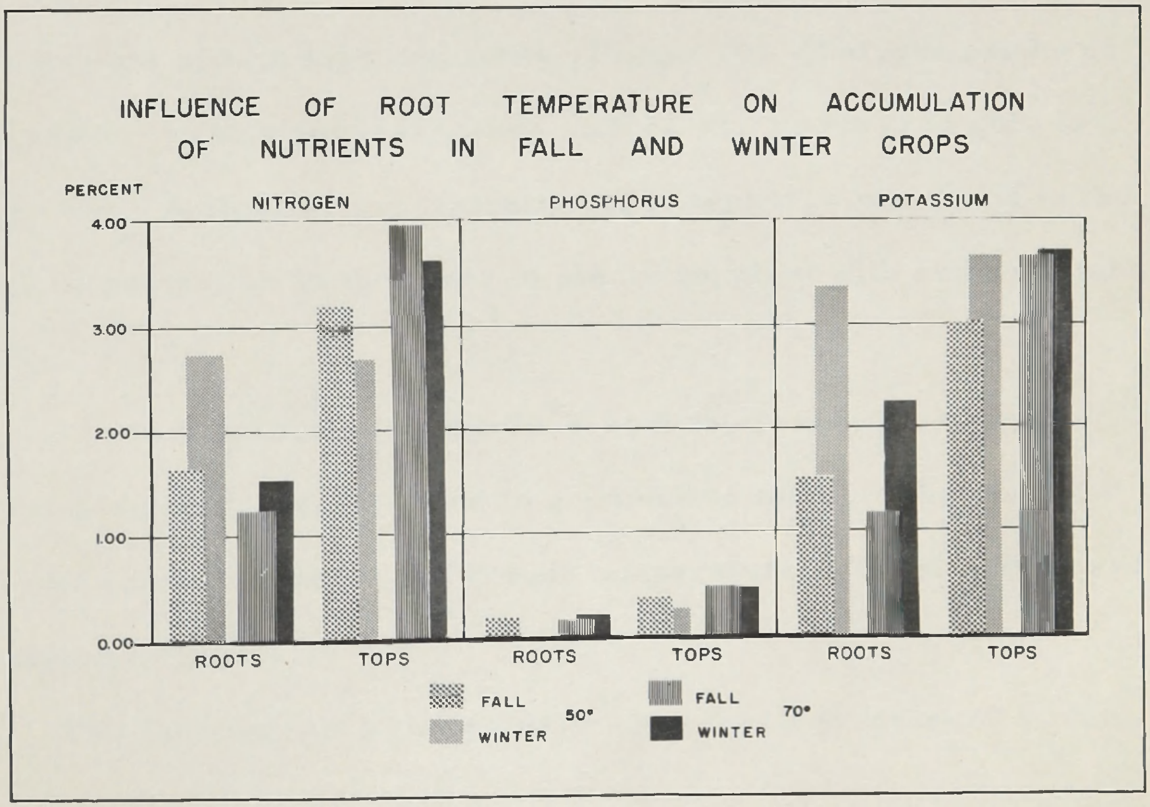


Figure 15

Nutrient Accumulation, Fall and Winter Crops: The data for the average accumulation of nitrogen, phosphorus, and potassium with an atmosphere at 60°F N T, a root temperature of 50°F or 70°F and a reduced (63 per cent) or full (100 per cent) available light intensity are given in Table 18.

The accumulation of nitrogen, phosphorus, and potassium in the roots was higher in the winter crop than in the fall crop. Their accumulation in the tops, however, was not as consistent. More potassium accumulated in the tops, while nitrogen and phosphorus did not reach as high a level of concentration in the tops in the winter crop (Figure 12).

Reduced light intensity favored a higher accumulation of all three nutrients in both tops and roots, Figure 14. Analyses produced two exceptions to this general trend, both of which appeared only in the fall crop. A smaller concentration of phosphorus was found in the tops and of potassium in the roots of plants supplied with reduced light intensity.

It was evident that at the 70°F root temperature nitrogen, phosphorus and potassium tended to accumulate more in the tops and less in the roots than at the 50°F root temperature. These trends are represented in Figure 15.

The influence of light intensity upon nutrient accumulation followed the same trends when the data for the two crops were combined to show the average accumulation of nutrients with each combination of temperature and light intensity, Figure 13. One exception, was a higher concentration of potassium in the roots of plants grown with full light intensity and with a 50$^{o}$F root temperature. When the root temperature was 70$^{o}$F, there was a higher concentration of potassium in the roots of plants grown with reduced light intensity.

The plants growing with a reduced light intensity accumulated an average of 0.05 per cent more nitrogen, 0.021 per cent more phosphorus, and 0.45 per cent more potassium in the roots; and accumulated an average of 0.21 per cent more nitrogen, 0.012 per cent less phosphorus, and 0.48 per cent more potassium in the tops when grown with 70$^{o}$F than when grown with 50$^{o}$F root temperature.

## SYNOPSIS OF RESULTS

The ten cultivars that were tested for general growth characters were able to be classified into three general groups: 1. Dwarf, 2. Semi-dwarf, and 3. Tall. Only the dwarf and the semi-dwarf types produced attractive, short plants with dense growth after being "pinched" once. The number of days required for flowering varied with cultivar, but was not consistently longer or shorter in any one of the groups.

A cold treatment of 40°F constant temperature did not significantly influence total stem weight and stem length of plants growing at 50° or 60°F N T. Stem weight per unit of stem length was significantly influenced by the cold treatment only when the plants were growing with a 50°F N T and when the cold treatment was supplied at the two-node stage of growth. The number of days required for flowering was significantly increased by a cold treatment only when the plants were growing with a 60°F N T and when treated at the two-node stage of growth. These plants required four more days for flowering than did those plants growing with 60°F N T and not supplied with a cold treatment.

Vegetative growth was definitely retarded with a 50°F N T. This was particularly apparent during the first 60 days of plant growth when chlorosis was evident. As the plants became older their rate of growth increased and at the date of flowering the plants growing with the 50°F N T produced an average of nine centimeters less stem elongation than plants growing with 60°F N T.

Those plants that were moved to the opposite night temperature 90 days after seeding attained an average of 2.5 to 3.4 centimeters greater stem elongation than those remaining at the original temperatures.

Night temperature did not greatly influence total stem weight or stem weight per unit length. The flowers were of equally good color and quality in all treatments, but the number of days required for their production was significantly increased with the 50°F N T.

Plants grown with one "pinch" produced more desirable form similar to that shown in Figure 2. More than one "pinch" served to increase the size of the plant and the time required for production, but did not greatly improve the form. Flower size was considerably smaller on plants receiving three "pinches".

Ninety days were required to produce flowering plants from seed sown August 15th. When seed was sown September 1st and 15th, 98 and 99 days were required respectively. Flowering plants for the Christmas market were produced from seed sown September 1st.

One-half of the plants moved to homes exhibited evidence of floret abscission during the first day, and many florets abscissed an average of 8.5 days after the plants were moved to the homes. The foliage was more durable under home conditions. An average of 8 days passed before three leaves abscissed, and the foliage of over half of the plants was in good condition at the end of the 15-day period. The frequency of watering, heating method, temperature, and location of the plant in the home had no consistent effect on the life of the plant in the home. No floret abscission occurred in the greenhouse from plants treated with para-chlorophenoxyacetic acid and grown at either 50°F N T or 60°F N T. The rate of floret abscission after the plants were moved to room temperature was not greatly influenced by the chemical treatment, but was reduced by the 50°F N T.

Total stem elongation and plant height was less on plants provided with an 8-hour photoperiod, than on plants provided with a 16-hour photoperiod. The reduction in stem elongation and plant height increased directly with an increase in the number of days with 8-hour photoperiods, Figure 7. Apical dominance was affected when the plants were supplied with 45 or less short photoperiods. Flowering plants were produced in all treatments with the largest number of days being required for flower production by plants provided with no short photoperiods, and the smallest number being required by plants provided with 75 short photoperiods. Photoperiod had no apparent influence on the plants after they were in flower.

The plants with the $50^{\circ}F$ root temperature grew much more slowly, produced more deep green foliage, and developed more anthocyanin in their petioles and stems than did the plants grown at the $70^{\circ}F$ root temperature. In spite of the large difference in the vegetative growth, flowers were initiated in all treatments at approximately the same time. The development of florets was observed and five stages in development were arbitrarly distinguished. Florets on plants growing with a $50^{\circ}F$ root temperature were observed to develop more slowly than those on plants growing with a $70^{\circ}F$ root temperature, but neither root temperature nor light intensity had any significant influence on rate of floret development, or number of days required for flowering. Although the difference was not significant, the longest period of time for flowering was required for plants growing with full light intensity, and the shortest period of time was required with reduced light intensity with $70^{\circ}F$ root temperature.

Plants growing with either $50^{\circ}F$ or $70^{\circ}F$ root temperature attained in general greater stem elongation under reduced light intensity. Those plants growing with $70^{\circ}F$ root temperature produced at least twice as much stem elongation as plants growing with the $50^{\circ}F$ root temperature, with the increases being greater with full light intensity, Figures 10 and 11.

Fresh and dry weight of both stems and roots was greater with full light intensity than with reduced light intensity regardless of root temperature. The largest value for top-root ratios was obtained from plants grown with reduced light intensity and 70$^{\circ}$F root temperature, Table 16.

In general, a higher accumulation of nitrogen, phosphorus and potassium was found in the winter than in the fall crop (Figure 12).

Nutrients tended to accumulate more in the tops and less in the roots with a 70$^{\circ}$F than with a 50$^{\circ}$F root temperature (Figure 15). A reduced light intensity favored a higher accumulation of all three nutrients in both tops and roots. Two exceptions to this general rule were a smaller concentration of phosphorus in tops and of potassium in roots when grown with reduced light intensity (Figure 14).

# DISCUSSION

## Tests of Cultivars

Comparison of the cultivars grown indicated that, if a dwarf plant (17.0 cm high) was desired, St. John's Fire or Vaughn's Masterpiece would be suitable. If a larger plant (24.0 cm high) was desired, Splendens America, America for Zuruck, Bonfire, or Blaze of Fire would produce a suitable plant with brilliant red flowers and dense growth. Rose Flame produced a dense growth, but was considered to be undesirable because of the light pink flower color. Cultivars of the tall type, Clara Bedman, Splendens Scarlet Sage, and Splendens Brightness did not appear to be suitable for pot plant culture because of their extreme height (35.0 to 47.0 cm) and spreading growth.

The number of days required for flowering varied slightly (Table 2) with the dwarf cultivars flowering approximately 7 days earlier than the semi-dwarf cultivars.

## Interaction of Cold Treatment and Growth

The cold treatment of 40$^{o}$F constant temperature, when it was supplied at the four-node stage, for 7 days had no significant influence upon the growth measurements. When the cold treatment was supplied at the two-node stage, it had no highly significant influences, but the plants grown at 60°F night temperature (F N T) required more days for flowering, and the plants grown at 50°F N T produced more stem weight per unit of stem length when the cold treatment was supplied at the two-node stage (Table 3).

It appeared from these data that growth of Salvia was more greatly retarded when the plants were supplied with a cool temperature at the two-node stage than when the cool temperature was supplied at the four-node stage of growth. At either stage, however, the influence of a relatively short period of cool temperature was not large.

### Interaction of Night Temperature and Growth

The opinion that Salvia growth was more greatly retarded by cool temperature at the earlier stages of growth was supported by the results obtained from studying the influence of 50° and 60°F N T on growth. During the first 60 days, those plants growing at 60°F N T produced approximately four times as much stem elongation as plants growing at 50°F N T. After 115 days of growth those plants at 60°F N T possessed only 1.3 times as much stem elongation as plants grown at 50°F N T (Table 4). The number of days required for flowering was increased by the lower night temperature, if it was supplied during earlier stages of growth, but this was not true if it was supplied after

90 days from the date of seeding (Table 5).

Holley (1942) stated that the importance of air temperature became increasingly significant as the light intensity decreased. Since the plants were supplied with a gradually increasing intensity of light such as occurs in Michigan from February to May, the retarded growth while the plants were young may not have been caused entirely by the $50^{\circ}$F N T.

Reversing the temperature 90 days after seeding gave statistically significant increases in final stem elongation when compared to plants which continued to grow at the original temperatures. It is believed that the increase in stem elongation of plants growing at the $50^{\circ}$F N T and moved to $60^{\circ}$F N T 90 days after seeding was the result of a more optimum night temperature for linear growth. Similarly, the plants formerly grown at the $60^{\circ}$F N T were probably high in nitrogen and when moved to a $50^{\circ}$F N T an increase in stem elongation resulted. Fifty and $60^{\circ}$F night temperature did not influence stem weight, flower color or quality.

In general, the results of this experiment indicated that the $60^{\circ}$F N T favored the growth of Salvia, and that some additional stem elongation could be obtained by moving the plants to a $50^{\circ}$F N T 90 days after seeding. This is in agreement with information furnished by Roberts and Struckmeyer (1938) and Post (1949) where the optimum night temperature for growth of Salvia was given as $55^{\circ}$ to $60^{\circ}$F N T.

## Form of Plant

The removal of the apical growth distal to the third node (a "pinch") resulted in the formation of branches and subsequent improvement in the appearance of plants when compared to those which were not "pinched". When more than one "pinch" was applied an additional 10 days of growing time per "pinch" was necessary to produce flowering plants. Unless the larger plants that would be obtained from additional "pinches" were especially desired, it was not felt that more than one "pinch" resulted in plants that were sufficiently more attractive to warrant the additional time required for their production. A reduction in flower size was particularly apparent on plants that were pinched three times. Thus, in order to obtain a combination of the largest plant with large flowers, the plants should not be pinched more than twice.

## Timing of a Commercial Crop

The proper time for sowing seed in a greenhouse to obtain flowering plants for Christmas 1953 proved to be the first week in

September. This allowed approximately 98 days to produce flowering plants. On the basis of information obtained in this and preliminary experiments, the following schedule was devised for the production of a Christmas crop of Salvia in Michigan with natural photoperiod.

1. Sow seed September 1 to 7 and germinate at 60 to 70°F N T.
2. Space seedlings 1 1/2 x 1 1/2 inches in flats September 20 to 27. Grow at 60°F N T.
3. Pot the plants in 5 to 6 inch pots October 10 to 17, and remove the terminal growth distal to the third node. Grow the plants at 60°F N T.
4. Flowering plants may be expected by December 7 to 14.
5. The plants should be watered freely. Fertilize weekly at a rate equivalent to 1 to 1 1/2 ounces of 12-31-14 fertilizer per 50 plants.

The period during which the plants in each crop reached the stage of flowering ranged from 4 to 12 days. Preliminary work has indicated that greater uniformity in stage of growth of the plants could be obtained by the use of a desirable cultivar which was vegetatively propagated.

## Keeping Quality

Abscission of florets began from 1 to 3 days after the plants were moved to the homes. The leaves remained on the plants under the conditions of the home. On the basis of data obtained from these plants, it was concluded that time and rate of floret abscission were not influenced by the frequency of watering, the heating method, or the temperature of the room. In spite of the durability of the leaves, the average attractive period of the plants was only 4 to 8 days as a result of floret abscission.

The para-chlorophenoxyacetic acid was not effective in reducing floret abscission at the concentration used when it was applied 21 days before flowering. A 50°F N T for 21 days before flowering did appear to have some relation to a reduction in floret abscission after the plants were moved to room temperature. The influence of the 50°F N T in retarding floret abscission was not sufficient to make Salvia an extremely desirable plant to be used as a pot plant in the home.

Theories are suggested concerning floret abscission of Salvia. The work of LaRue (1936) in successfully delaying the abscission of Coleus petioles with growth hormones after the leaf blades had been removed served to indicate that the use of growth regulators in delaying the abscission of leaves was possible. The results obtained for Salvia by no means eliminated the possibility that floret abscission might be retarded by the timely application of an optimum quantity of some growth substance. It was concluded that floret abscission was not influenced by the room temperatures which were supplied.

No floret abscission occurred from plants that remained in the greenhouse. Myers (1940) observed that the abscission of petioles of Coleus plants placed in the dark was more rapid than the abscission from the plants placed in the light. It was possible that relative humidity and/or light intensities might have been a factor in the rapid rate of abscission at room temperature. The effectiveness of the $50^{\circ}$F N T in reducing the rate of floret abscission after the plants were moved to room temperature could have been due to an increase in the percentage of carbohydrates in the plant. This could have resulted in greater resistance to lower relative humidity.

The availability of nutrients may have been involved in the rate of floret abscission as was found by Nightingale (1933). He concluded that Salvia was very sensitive to the level of nitrates in the nutrient solution, and when the plants were supplied with a short photoperiod and a nutrient solution minus nitrate he stated that: "they shed their blossoms profusely".

Interaction of Photoperiod and Growth

Salvia plants attained progressively less height and less total stem elongation as they were supplied with an increasing number of short days during the 110 days of growth (Figure 7, Tables 9 and 10). This was in agreement with results of Murneek (1948) who observed a "photoperiodic inhibition" of vegetative growth of plants that flowered when supplied with a short photoperiod. Since short dense growth was desirable in the production of attractive pot plants, this response of Salvia to short photoperiods was very important.

The appearance of apical dominance in plants supplied with 65 or more long days may have been related to the more rapid stem elongation that occurred when the plants were supplied with long days consisting of 16-hour photoperiods. The plants supplied with 65 or more long days were grown under 16-hour photoperiods for 30 or more days after the terminal portion of the main stem was removed. This could have influenced the laterals on these plants to develop more rapidly than the laterals on the plants that were supplied with short days of 8-hour photoperiods after the terminal portion of the main stem was removed. Consequently, there could have been a more rapid rate of accumulation of growth regulating substance in the stems of the plants grown with a 16-hour photoperiod. This could have tended to inhibit the elongation of the laterals emerging from the lower portions of the main stem; a theory that is at least partially supported by Murneek (1948) who stated that growth in height could be photoperiodically inhibited during the initiation of floral primordia, the period of full bloom, and the period of fruit and seed formation. The results of this experiment seemed to indicate that under certain photoperiods a growth inhibiting substance was produced by the plant and translocated to the lower portions of the stems even before floral initiation took place.

Flowers were produced in all treatments independent of the photoperiods supplied. This did not agree with the results obtained by Roberts and Struckmeyer (1938) where Salvia plants were reported to have grown vegetatively with photoperiods of 16 hours or longer. A shorter period of time (98 days) was definitely required for flower production when the plants were supplied with 20 long days followed by short days for the remainder of their growth. If the plants were supplied with all short days, or the number of long days designated in the other treatments, a longer period of time was required for flowering (Table 11). The plants supplied with 20 long days followed by short days produced more rapid growth initially than those plants supplied with all short days. Thus, when the plants were moved to the environment of the short day, the leaves became sufficiently mature to synthesize the flower initiating substance at an earlier date. Those supplied with a greater number of long days may not have been able to accumulate sufficient material to cause initiation of flowers until a greater number of days had elapsed. This reasoning is supported by Hamner (1938) when he concluded that plants which gave a short photoperiodic type of response accumulated the flower initiating substance during the dark period. During the light period this accumulated material was believed to be broken down. Thus, once the leaves were mature enough to be sensitive to the photoperiod, the flower initiating substance could be accumulated more rapidly with a light period decidedly less than the critical.

In order to produce flowers on a plant with relatively short but uniform laterals in the shortest period of time, one should supply the plant with 20 days of a 16-hour photoperiod followed by short days of 8-hour photoperiods until the plant is in flower. Fortunately these conditions can be closely approximated in Michigan for the production of a Christmas crop of Salvia by using the photoperiods that exist naturally in the Fall of the year.

## Interaction of Root Temperature and Light Intensity with Growth

A constant reduction of light intensity was not obtained by the use of cheesecloth in this experiment (Table 19). According to Angstrom (1919) the reason a constant reduction was not obtained was that the cheesecloth cut out only a portion of the radiation which came from the sky, and was most effective in reducing the radiation which came from the sun. The percentage of the total radiation which was from the sky increased with increased cloudiness and thus the percentage of reduction of radiation that could be obtained with the use of the cheesecloth was decreased with increased cloudiness.

Determination of date of flowering, of plant height, of fresh weight, of dry weight, and of nutrient accumulation might be used as an index of quantity of growth. The conclusions which were arrived at in regard to the influence of root temperature and light intensity upon the growth of Salvia depended upon which of these criteria were selected.

Using the date of flowering as an index, it was found that neither root temperature nor light intensity had any significant influence at the 5 per cent level (Table 12). Similar results were obtained by Allen (1934) with Mathiola, Calendula, and Antirrhinum. In both the Fall and Winter crops however, the plants grown with the 70°F

TABLE 19

Total Weekly and Average Daily Radiations of Light During Growth of Winter Crop

| Date | Full Light | | Reduced Light | | Per Cent of Full Light Intensity |
|---|---|---|---|---|---|
| | Per Wk. in Ft. Cd. Hrs | Ave/Day Ft. Cd. Hrs. | Per Wk. in Ft. Cd. Hrs | Ave/Day Ft. Cd. Hrs. | |
| Jan. 11-17 | 51,700 | 7,386 | 43,900 | 6,271 | 84.9 |
| Jan. 18-24 | 52,800 | 7,543 | 38,500 | 5,500 | 72.9 |
| Jan. 25-31 | 74,200 | 10,600 | 53,300 | 7,614 | 71.8 |
| Feb. 1-7 | 75,200 | 10,743 | 39,900 | 5,700 | 53.1 |
| Feb. 8-14 | 95,600 | 13,657 | 54,000 | 7,714 | 56.5 |
| Feb. 15-21 | 153,700 | 21,957 | 99,100 | 14,157 | 64.5 |
| Feb. 22-28 | 178,600 | 25,514 | 127,600 | 18,229 | 71.4 |
| Mar. 1-7 | 159,800 | 22,829 | 71,600 | 10,229 | 44.8 |
| Mar. 8-14 | 140,900 | 20,129 | 66,300 | 9,471 | 47.1 |
| | Average per cent of full light intensity | | | | 63.0 |

root temperature and 63 per cent light intensity produced flowers about 4 days before the plants in any of the other treatments. According to Hamner (1938) plants which flowered when supplied with a photoperiod shorter than the critical, produced the flower initiating substance during the dark period. During the light period a portion of this substance was believed to be destroyed or broken down, with the amount destroyed or broken down depending upon the length of the light period. In this experiment it seemed very probable that the flower initiating substance was not broken down as rapidly by plants supplied with a reduced light intensity, and therefore a quantity of material sufficient to stimulate flower initiation was able to be accumulated sooner with reduced light intensity. It was also possible that the leaves of the plants grown in reduced light intensity were able to function more efficiently in the production of the flower initiating substance. Porter (1936) was of the opinion that the leaves of tomato plants grown in partial shade were able to use their limited supply of light more efficiently. He even observed a large variation in the ability of different plants of the same species to utilize the available light.

This difference in flowering date as influenced by light intensity, did not appear when the plants were grown with 50°F root temperature. Possibly this was because the low root temperature was the limiting factor.

Using the height of the plants as an index of growth, light intensity did not have significant influence on growth (Table 13). There appeared to be a slight trend toward a greater stem elongation with reduced light intensity. Light intensity did not appear to have as great an influence on stem elongation as seemed to be indicated by observations of Went (1941) and Porter (1936). Went (1941) concluded that intensity of the sunlight was an important factor in inhibiting stem elongation. Porter (1936) observed that light intensity was inversely related to stem elongation.

Stem elongation with 70°F root temperature was roughly two to three times greater than with 50°F root temperature (Table 13). This was in general agreement with results obtained by Roberts (1953) who used the same equipment to study the influence of four root temperatures from 56° to 72°F on the growth of strawberry. Roberts observed a direct correlation between the growth of aerial parts of the strawberry and an increase in root temperature.

The plant height produced in the Fall crop was consistently greater than the plant height produced in corresponding treatments of the Winter crop. A photoperiodic inhibition of vegetative growth was observed and since the naturally occuring photoperiod was not modified, it is most probable that the variation in the photoperiod between the Fall and the Winter crops was the factor involved in the consistent differences in stem elongation. By reference to Table 14, it may be observed that during the growth of the Fall crop the length of the photoperiod was decreasing from 13 hours and 30 minutes to 10 hours and 10 minutes; and during the growth of the winter crop the length of the photoperiod was increasing from 10 hours and 20 minutes to 12 hours and 10 minutes.

Considering fresh weight as an index of growth, there was a definite and consistent trend in both crops toward an increase in growth of both roots and stems with the higher root temperature and light intensity. The differences in fresh weight of roots and stems as a result of different light intensities, were in most instances not statistically significant at the 5 per cent level. There was, however, a consistent trend toward an increase in weight with full light intensity (Table 15). This production of greater fresh weight with full light intensity was in agreement with results obtained by Arthur and Stewart (1931). They found that the fresh and dry weight of stems and roots of Salvia increased as sunlight was increased from 35 to 58 to 78 to 100 per cent radiation in June and July. Their results indicated that Salvia was able to utilize full radiation in June and July more efficiently than other plants used in the tests.

The increases in fresh weight of stems and roots as a result of an increase in root temperature in the present investigation were consistent and highly significant (Table 15). This indicated that the growth of Salvia as measured by accumulation of fresh weight was greatly inhibited by a low root temperature of 50°F.

As with fresh weight, there was a definite and consistent trend toward a greater dry weight accumulation in both stems and roots with the higher root temperature and light intensity (Table 16). This was in agreement with the results obtained by Arthur and Stewart (1931). The trend toward an increase in dry weight of stems and roots with full light intensity existed independent of root temperature. The amount of increase was significant with 70°F root temperature, but not with 50°F root temperature.

Root temperature did not influence the dry weight of stems and roots as much as fresh weight, however the increases in dry weight production with 70°F root temperature were significant except for roots produced with reduced light intensity. This was reasonable since Bolas (1934) found that with a higher temperature a higher light intensity was optimum for dry weight accumulation.

The top-root ratio calculated on a fresh weight basis was larger in all instances with 70° than with 50°F root temperature, and was larger with reduced than with full light intensity. Seventy degrees root temperature with reduced light intensity produced the largest top-root ratio, thus it could be concluded that 70$^{\circ}$F root temperature and 63 per cent total light intensity were more favorable to top than to root growth (Table 17). Roberts (1953) obtained similar results with the strawberry.

Reduced light intensity favored a general higher accumulation of nutrients in stems and roots. This explained the general higher accumulation of nutrients in the Winter than in the Fall crop (Figure 12), since somewhat higher light intensities were received during the Fall than during the Winter months.

With the exception of the accumulation of phosphorus in the tops and of potassium in the roots, it was found that there was a higher accumulation of nitrogen, phosphorus, and potassium in plants supplied with reduced light intensity (Figure 14). There is much disagreement in the literature in relation to the influence of light intensity upon the accumulation of nutrients in plants. One factor which was involved in this confusion was the absence of accurate records of light intensities in most data. In many reports no records were offered, and it was even more difficult to compare the results obtained. In spite of this, it appeared that the influence of light intensity upon nutrient accumulation varied with species, as has been discussed previously (pages 14 to 17).

At the 70°F root temperature, nitrogen, phosphorus and potassium tended to accumulate more in the tops and less in the roots than at the 50°F root temperature (Figure 15). Hagen (1952) contrary to previous theories of Hoagland (1923), and Ashby and Oxley (1935) felt that there was not sufficient evidence available to prove that a reduced rate of nutrient absorption was responsible for slow growth of plants at low root temperature. He felt that either or both a reduced rate of translocation or assimulation could also easily be involved. The results of this experiment seemed to support Hagen's ideas. It seemed probable that the higher accumulation of nutrients in the tops and lower accumulation in the roots with a 70°F root temperature could easily have been associated with a more rapid rate of translocation at the higher root temperature.

According to each of the methods of determining plant growth that have been discussed, the 70°F root temperature was found to favor the growth of Salvia. For the production of earlier flowering, abundant top growth, and higher nutrient accumulation, a reduced light intensity was found to, in general, give better results; while for greater fresh and dry weight accumulation, the full light intensity produced better results.

# SUMMARY

The interaction of environmental factors upon the growth of *Salvia splendens* was studied to obtain information concerning the growth of Salvia and the possibilities of its introduction to the florist pot plant industry. For this purpose the growth of 10 cultivars was compared. The influence of cold treatment, night temperature, "pinching", photoperiod, root temperature, and light intensity was studied. Information was gathered concerning the timing of a crop of Salvia for the Christmas market, and the keeping quality of the plants at room temperature.

For the production of short, dense plants the cultivars of the dwarf type proved most suitable, and for the production of a slightly more vigorous plant, the cultivars of the semi-dwarf type were recommended. The cultivar, America, was selected for use in all other experiments.

The 40°F constant temperature cold treatment for one week appeared to retard growth more when it was supplied at the two- than at the four-node stage of growth. At either stage, the influence of the relatively short period of cold treatment was not extremely large.

The study of night temperature influences indicated that

Salvia grew more vigorously and flowered sooner with 60°F than with 50°F night temperature. This was particularly true while the plants were young. Some additional stem elongation was obtained by moving the plants from 60° to 50°F night temperature 90 days after seeding. Stem weight was not greatly influenced by night temperature and flower color was not affected.

The removal of the terminal meristem (a "pinch") resulted in plants with short, dense growth. Plants "pinched" twice were larger, and took 10 days longer to flower than those "pinched" once. When plants were "pinched" three times the flowers which were produced were approximately 50 per cent smaller in size. It was recommended that plants be grown with one "pinch" except for special purposes where a larger plant would be profitable and then two "pinches" could be supplied.

When seed was planted September 1st, 98 days were required for production of flowering pot plants with one "pinch". A schedule for the production of a Christmas crop was suggested.

Some florets were observed to absciss after the plants had been in the homes from 1 to 3 days with many falling after an average of 4 days in the home. Several methods of preventing the floret abscission were attempted, but no effective method was found. It was suggested that further work with growth regulating substances might prove successful.

Flowers were produced under both 8- and 16-hour photoperiods. A photoperiodic inhibition of vegetative growth was observed when the plants were grown with 8-hour photoperiods, and the amount of inhibition increased with groups of plants that were supplied with a greater number of short days. A loss of apical dominance was also noted in those plants supplied with 60 or more 8-hour photoperiods. In order to produce a flowering Salvia plant with relatively short laterals of approximately the same length, in the shortest period of time it was recommended that the plants be supplied with 20 long days of 16-hour photoperiods followed by short days consisting of 8-hour photoperiods until the plants were in flower. In this experiment the required time was 98 days from the date of seeding. It was mentioned that these conditions could be approximated for the production of a Christmas crop in Michigan by supplying the plants with the natural photoperiod. Photoperiod had no observed influence on the plants after they were in flower.

Plants consistently produced greater height in all treatments when they were grown in the Fall with 70°F and 50°F root temperature with 100 per cent and 63 per cent light intensity, than when they were grown under the same conditions during the Winter months. This was thought to be caused by a shorter photoperiod during the growth of the Winter crop.

Stem elongation was slightly greater when the plants were grown with reduced, than when they were grown with full light intensity.

A morphological study of the flower bud was made, in which five stages in flower bud development were arbitrarily distinguished.

The plants grown with the 70°F root temperature produced approximately twice as much stem elongation as the plants grown with the 50°F root temperature, but the plants in all of the treatments flowered over a period of only 7 days.

The largest top-root ratio was obtained from plants grown with reduced light intensity and 70°F root temperature.

According to each of the methods of determining plant growth, the 70°F root temperature was found to favor the growth of Salvia more than the 50°F root temperature. The reduced light intensity favored flowering, stem elongation, and nutrient accumulation more than full light intensity. Full light intensity, however, resulted in greater accumulation of fresh and dry weight.

Fifteen figures and nineteen tables were included.

# BIBLIOGRAPHY

Adams, J. Some further experiments on the relation of light to growth. Amer. Jour. Bot. 12: 398-412. 1925.

Allen, R. C. The effect of soil temperature on the growth and flowering of certain greenhouse crops. Proc. Amer. Soc. Hort. Sci. 32: 635-637. 1934.

Angstrom, Anders. Some problems relating to the scattered radiation from the sky. Monthly Weather Review (Wash.) 47: 797-798. 1919.

Arrillaga, J. G., and Gomez, L. A. Effect of solar radiation intensity on the vegetative growth and yield of coffee. Puerto Rico Univ. Jour. Agr. 26: 73-90. 1942.

Arthur, J. M., Guthrie, J. D., and Newell, J. M. Some effects of artificial climates on the growth and chemical composition of plants. Amer. Jour. Bot. 17: 416-482. 1930.

Arthur, J. M., and Stewart, W. D. Plant growth under shading cloth. Amer. Jour. Bot. 18: 897. 1931.

Ashby, E., and Oxley, T. A. The interaction of factors in the growth of Lemna. VI. An analysis of the influence of light intensity and temperature on the assimilation rate and the rate of frond multiplication. Ann. Bot. 49: 309-336. 1935.

Bailey, J. S., and Jones, L. H. The effect of soil temperature on the growth of cultivated blueberry bushes. Proc. Amer. Soc. Hort. Sci. 38: 462-464. 1941.

Bailey, L. H. Some preliminary studies of the influence of the electric arc light upon greenhouse plants. New York (Cornell) Agr. Exp. Sta. Bul. 30: 83-122. 1891.

Bates, C. G. The relative light requirements of some coniferous seedlings. Jour. For. 23: 869-879. 1925.

Batson, F. S. Studies of the effect of cheesecloth enclosures on the flower production, underground development, and the rate of transpiration of flower crops. Proc. Amer. Soc. Hort. Sci. 30: 580-582. 1933.

Blackman, G. E., and Templeman, W. G. The interaction of light intensity and nitrogen supply in the growth and metabolism of grasses and clover (Trifolium repens) IV. The relation of light intensity and N supply to the protein metabolism of the leaves of grasses. Ann. Bot. 4: 533-587. 1940.

Bolas, B. D. The influence of light and temperature on the assimilation rate of seedling tomato plants var. E.S.I. Amon. Rep. Exp. Sta. Nursery and Market Gard. Industrial Soc. Chestnut. 19: 84-87. 1934.

Brown, E. M. Seasonal variations in the growth and chemical composition of Kentucky Bluegrass. Mo. Agr. Exp. Sta. Res. Bul. 360. 1943.

Broyer, T. C., and Hoagland, D. R. Metabolic activities of roots and their bearing on the relationship of upward movement of salts and water in plants. Amer. Jour. Bot. 30: 261-273. 1943.

Burkholder, W. H. The effect of two soil temperatures on the yield and water relations of healthy and diseased bean plants. Ecology 1: 113-123. 1920.

Burkholder, Paul R. The role of light in the life of plants I-II. Bot. Rev. 2: 1-52, 97-172. 1936.

Camp, A. F., and Walker, M. N. Soil temperature studies with cotton II. The relation of soil temperature to the germination and growth of cotton. Fla. Agr. Exp. Sta. Tech. Bul. 189:17-32. 1927.

Cannon, W. A. Soil temperature and plant growth. Plant World 20: 361-363. 1917.

Chandler, E. L. Contributions of sunlight to greenhouse roses. Thesis, Michigan State College. 1953.

Clements, F. E., and Long, F. L. Factors in elongation and expansion under reduced light intensity. Plant Physiol. 9: 767-781. 1934.

Clements, F. E., and Martin, E. V. Effect of soil temperature on transpiration in Helianthus annus. Plant Physiol. 9: 619-630. 1934.

Combes, R. Determination des intensites lumineuses optima. Ann. Sci. Nat. Bot. IX. 11:75. 1910.

Darrow, R. A. Effect of soil temperature, pH, and nitrogen nutrition on development of Poa pratensis. Bot. Gaz. 101: 109-127. 1939.

Dauberry, C. On the action of lights on plants. Roy. Soc. London, Phil. Trans. 1836: 149-176. 1836.

Davis, A. R., and Hoagland, D. R. Further experiments on the growth of plants in a controlled environment. I. The relation of light intensity and exposure time to yield. II. The interrelationship of temperature and light. Amer. Jour. Bot. 15: 624. 1928.

Dravid, R. K. Studies on soil temperature in relation to other factors controlling the disposal of solar radiation. Indian Jour. Agr. Sci. (Calcutta) 10: 352-387. 1940.

Döring, B. Die temperatur abhängigkeit der wasseraufnahme und ihre okologische bedeutung. Z. Botan. 28: 305-383 (see Hagen 1952). 1935.

Earley, E. B., and Carter, J. L. Effect of the temperature of the root environment on growth of soybean plants. Jour. Amer. Soc. Agron. 37: 727-735. 1945.

Eisenmenger, W. S. The distribution of nitrogen in tobacco when the supplies of nitrogen and of light are varied during the growing period. Jour. Agr. Res. 46: 255-265. 1933.

Ellis, C., and Swaney, M. W. Soilless growth of plants. Revised by T. Eastwood. Ed. 2. N. Y. Reinhold Pub. Co. 1947.

Emerson, R. Photosynthesis as a function of light intensity and of temperature with different concentration of chlorophyll. Jour. Gen. Physiol. 12: 623-639. 1929.

Garner, W. W., and Allard, H. A. Effect of relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agr. Res. 18: 553-607. 1920.

Garner, W. W., and Allard, H. A. Further studies in photoperiodism, the response of the plant to relative length of day and night. Jour. Agr. Res. 23: 871-921. 1923.

Garner, W. W. Recent work on photoperiodism. Bot. Rev. 3: 259-275. 1937.

Gilbert, B. E. Interrelation of relative daylength and temperature. Bot. Gaz. 81: 1-25. 1926.

Gracanin, M. The effect of light on the resorption of salts by plants (Rep Czech Bot Sci) Preslia 11: 35-39. 1932.

Gray, G. F. Relation of light intensity to fruit setting in the sour cherry. Mich. Agr. Exp. Sta. Tech. Bul. 136. 1934.

Gregory, F. G. The control of flowering in plants. Symposia, Soc. Exp. Biol. 2: 75-103. 1948.

Gregory, F. G. The control of flowering by daylength and temperature. Jour. Roy. Hort. Soc. 78, #9: 313-323. 1953.

Hagen, R. M. Temperature and growth processes in soil physical conditions and plant growth. Agron. Vol. II. Pub. by Amer. Soc. Agron. edited by B. T. Shaw, Academic Press Inc. 1952.

Hamner, K. C. Correlative effects of environmental factors on photoperiodism. Bot. Gaz. 99: 615-629. 1938.

Hearn, G. D. Relation of sunlight to plant development. Monthly Weather Review (Wash). 50: 423-424. 1922.

Hoagland, D. R. Lectures on the inorganic nutrition of plants. Waltham Mass. Chronica Botanica Co. 1944.

Hoagland, D. R., and Arnon, D. I. Water culture method for growing plants ~~in~~ without soil. Calif. Agr. Exp. Sta. Circ. 347, pg. 1-32. 1950.

Hoagland, D. R., and Davis, A. R. Further experiments on the absorption of ions by plants, including observations on the effect of light. Jour. Gen. Physiol. 6: 47-62. 1923.

Hoagland, D. R., and Broyer, T. C. General nature of the process of salt accumulation by roots with description of experimental methods. Plant Physiol. 11: 471-507. 1936.

Holley, W. D. The effect of light intensity on the photosynthetic efficiency of carnation varieties. Proc. Amer. Soc. Hort. Sci. 40: 569-572. 1942.

Huxley, J. S. Problems of relative growth. The Dial Press, N. Y. 1932.

Jones, F. R., and Tisdale, W. B. Effect of soil temperature upon the development of nodules on the roots of certain legumes. Jour. Agr. Res. 22: 17-32. 1921.

Kohl, H. C., Foster, G. M., and Weinard, F.F. The effect of several soil temperatures on flower production in roses. Proc. Amer. Soc. Hort. Sci. 54: 491-494. 1949.

Kramer, P. J. Root resistance as a cause of decreased water absorption by plants at low soil temperatures. Plant Physiol. 15: 63-79. 1940.

Kramer, P. J. Species differences with respect to water absorption at low soil temperatures. Amer. Jour. Bot. 29: 828-832. 1942.

Kraybill, H. R. Effects of shading and ringing upon the chemical composition of apple and peach trees. N. H. Agr. Exp. Sta. Tech. Bul. 23. 1923.

LaRue, C. D. The effect of auxin on abscission of petioles. Proc. Nat. Acad. Sci. 22: 255-259. 1936.

Laurie, Alex Studies of the growth of annuals and pompom chrysanthemums under cloth enclosures. Proc. Amer. Soc. Hort. Sci. 29: 550-554. 1932.

Lazarev, P. P., and Formazova, L. N. Ueber den Einfluss der Beleuchtung auf einige Prozasse in Pflanzen. Dokl. Akad. Nauk. USSR (Compt. Rend. Acad. Sci. URSS) 2: 414-418, 419-421. 1935.

Loomis, W. E. Growth differentiation balance vs. carbohydrate-nitrogen ratio. Proc. Amer. Soc. Hort. Sci. 29: 240-245. 1933.

Lubimenko, W. Production de la substance seche et de la chlorophylle chez les vegetaux superieurs aux differentes lumineuses. Ann. Sci. Nat. Bot. IX 7:321-415. 1908.

Lundegardh, H. Environment and plant development. Translated by E. Ashby, 1931. 330 pgs. E. Arnold & Co., London 1881.

Meyers, M. R. Effect of growth substance on the abscission layer in leaves of Coleus. Bot. Gaz. 102: 323-338. 1940.

Miller, E. C. Plant physiology, pgs 1-1201. McGraw-Hill Book Co., 1938.

McCool, M. M. Effect of light intensity upon the Mn content of plants. Contrib. Boyce-Thompson Inst. 7: 427-437. 1935.

Murneek, A. E., and Whyte, R. O. Vernalization and Photoperiodism, a Symposium, pgs. 83-90. Chronica Botanica Co., Waltham, Mass. 1948.

Nightingale, G. T. Light in relation to growth and chemical composition of some horticultural plants. Proc. Amer. Soc. Hort. Sci. 19: 18-29. 1922.

Penfound, W. T. Plant anatomy as conditioned by light intensity and soil moisture. Amer. Jour. Bot. 18: 558-572. 1931.

Penfound, W. T. The anatomy of the castor bean as conditioned by light intensity and soil moisture. Amer. Jour. Bot. 19: 538-546. 1932.

Pfahl, Peter B., Orr, H. P., and Laurie, A. The effect of warm water applications to greenhouse roses. Proc. Amer. Soc. Hort. Sci. 53:489-491. 1949.

Popp, H. W. Effect of light intensity on growth of soybeans and its relation to the auto-catalyst theory of growth. Bot. Gaz. 82:306-319. 1926.

Porter, A. M. Effect of light intensity on photosynthetic efficiency of tomatoes. Plant Physiol. 12: 225-252. 1936.

Post, Kenneth. Summer annuals. Proc. Amer. Soc. Hort. Sci. 28: 393-397. 1931.

Post, Kenneth. Florist Crop Production and Marketing, pgs. 80-83. Orange-Judd Publishing Co., New York. 1949.

Proebsting, E. L. Jr. Leaf analysis and growth of Montmorency cherry trees (Prunus cerasus L.) as influenced by solar radiation and intensity of nutrition. Thesis, Michigan State College. 1951.

Reid, M. E. Growth of seedlings in light and in darkness in relation to available nitrogen and carbon. Bot. Gaz. 87: 81-118. 1929.

Richards, S. J., Hagen, R. M., and McCalla, T. M. Soil temperature and plant growth. Agronomy II. Amer. Soc. Agron. Academic Press Inc. 1952.

Roberts, A. N. Growth and composition of the strawberry plant in relation to root temperature. Thesis, Michigan State College. 1953.

Roberts, R. H., and Struckmeyer, B. Esther. The effects of temperature and other environmental factors upon the photoperiodic responses of some of the higher plants. Jour. Agr. Res. 56: 633-677. 1938.

Rouschal, E. Untersuchungen über die temperaturabhangigkeit der wasseraufnahme ganzer pflanzen. Sitzher. Akad. Wiss. Wien. Math. Naturw. Klasse. 144: 313-348 (see Hagen 1952) 1935.

Saunders, Edith R. Comments on the floral anatomy and its morphological interpretation. New Phytologist 33: 127-170. 1934.

Saunders, Edith R. Further observations on the morphology and anatomy of the flower of Salvia. Ann. Bot. 4: 629-633. 1940.

Shanks, J. B., and Laurie, A. Rose root studies, some effects of soil temperature. Proc. Amer. Soc. Hort. Sci. 54: 495-499. 1949.

Shantz, H. L. Effects of artificial shading on plant growth in Louisiana. U. S. Dept. Agr., Bur. Plant Ind. Bul. 279. 1913.

Shirley, H. L. The influence of light intensity and light quality upon the growth of plants. Amer. Jour. Bot. 16: 354-390. 1929.

Steinbauer, G. P. Growth of tree seedlings in relation to light intensity and concentration of nutrient solution. Plant Physiol. 7: 742-745. 1932.

Stuckey, I. H. Influence of soil temperature on the development of colonial bentgrass. Plant Physiol. 17: 116-122. 1942.

Tanada, A. Utilization of nitrates by the coffee plant under different sunlight intensities. Jour. Agr. Res. 72: 245-258. 1946.

Wanner, H. Untersuchungen uber die temperaturabhangigkeit der salzaufhanme durch pflanzenwurzeln. II. Die temperaturkoeffizienten von kationen- und anionenaufnahme in abhangigkeit von der salzkonzentration. Ber. Schweiz. Bot. Gaz. 58: 383-390. 1948.

Went, F. W. Effects of light on stem and leaf growth. Amer. Jour. Bot. 28: 83-95. 1941.

Zillich, R. Uber den Lichtgenuss einiger Unkrauter und Kulturpflanzen. Fortsch Landwirtschaft. 1: 461-470. 1926.