THESIS

----

# INFLUENCE OF DAY TEMPERATURES ON CARNATIONS

Submitted by

Joe J. Hanan

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

December, 1958

ACKNOWLEDGEMENT

The author wishes to extend to Professor W. D. Holley his sincere appreciation for his thoughtful understanding and supervision, and the willingness to consider and provide for the needs of this investigation and the "ideas" of the author.

Also, to Dr. Frank B. Salisbury and Dr. Richard L. Foskett for their constructive criticism and suggestions in carrying out the study and the preparation of the text; to Dr. Harold W. Chapman for his many suggestions and comments; the Colorado Flower Growers' Association, Denver, Colorado, which provided the research fellowship grant making this work possible, and to his wife, Julia, who, in the preparation of this manuscript, was NOT a hindrance.

# TABLE OF CONTENTS

TABLE OF CONTENTS.--Continued

# LIST OF TABLES

## LIST OF FIGURES

LIST OF FIGURES.--Continued

Chapter I

# INTRODUCTION

The nature of biological material is such that a change in one environmental factor may produce a corresponding change in optimum values for growth in all other factors. This is also complicated by the difficulty of obtaining and determining precise values for all the environmental influences. It thus becomes difficult to interpolate results for situations outside of the actual conditions used in a particular investigation.

Went (80) states that under exact environmental control it may be possible to approach the conditions and results commonly obtained by physicists and chemists in their investigations. However, such control is not presently obtainable. Therefore, the work done by Monsalise (52) on carnations, for example, at the California Institute of Technology, is not particularly applicable to Colorado conditions (e.g., higher altitude, higher latitude). To apply the information obtained by Monsalise, who used temperatures ranging from 54° to 73° nights and 63° to 86°F. days, would appear of doubtful value since most of these temperatures are rather far removed from those used by commercial growers in Colorado.

In 1946, Parker (55) stated that for practical value, the optimum temperature for growth of any particular plant must be determined under conditions closely approximating those in which it will be grown. He concluded that no artificial illumination had been developed that was the equal of sunlight, although artificial light was necessary for uniform conditions.

When one then compares the light intensity difference between the high altitude of Colorado and that obtained under artificial and natural conditions in the phytotron in California (80) and other parts of the United States (13), the necessity of this investigation is made clear.

## The problem

What are the reactions of a carnation plant to different day temperatures under Colorado conditions?

Problem analysis.--Solution of the problem was facilitated by investigating the effects of different day temperatures on the following factors:

1. Color
2. Dry matter
3. Flower size
4. Green weight

5. Internode length
6. Keeping quality
7. Leaf width
8. Production
9. Stem strength
10. Mean grade

Delimitations.--The problem was limited to a constant night temperature and four different day temperatures including those generally recommended by other investigators as optimum for carnations (37, 42, 53, 56).

No attempt was made to control light or $CO_2$. During the summer, the cooling system operated to reduce the temperatures as long as they were above the cut-off point of the thermostats. Otherwise, in that period, the temperature was allowed to reach equilibrium with the outside air temperature.

## Background

In commercial practice, the last two years have seen the practical application of the first economical method of cooling greenhouses. This is especially true in Colorado where relatively low humidity allows the fan and evaporative pad as described by DeWerth (22) to operate with high efficiency.

The use of this system has allowed a large increase in the accuracy of temperature control over a greater part of the year by introducing the possibilities of constant air flow and doing away with former methods of greenhouse ventilation.

This improved accuracy requires that the grower have more precise information concerning temperatures since he now can use temperature to a greater advantage in controlling the growth of his plants.

# Chapter II

# REVIEW OF LITERATURE

## Introduction

An attempt to cover all the factors influencing the response of a plant to its environment would require more space than is available. This discussion will be confined to those points which may help to elucidate reasons for some of the findings.

## Previous recommendations

Many of the temperature recommendations in use today have been arrived at by the process of trial and error. Some show a rather wide range.

Post (56), in 1950, stated that carnations grow best under high light intensity when the night temperature is not over 50°F. He recommended increasing the day temperature five to ten degrees above the night temperature on cloudy days and ten to fifteen degrees on sunny days.

However, Kiplinger (42) suggested 48° to 50°F. nights, dropping to 46° during the winter. He stated that some growers allow their temperatures on cloudy days to remain at 48° to 50°F.

At a later date, Nelson (53) suggested 48° to 50°F. nights, 55° on cloudy days and 60°F. on bright days.

In 1956, Schmidt (61) found indications that cooling to 60°F. during summer days might reduce yield. In later experiments (62), he found 52°F. night likely to be the best for commercial practice, although he obtained highest quality of cut flowers at 54°F. nights and 60° to 68°F. days.

Holley (37), in discussing some factors which may cause undesirable soft growth, thought it best to prevent the day temperature from going above 65°F. during January and early February.

Night versus day temperatures

Several investigators (3,11, 23, 46, 71, 78, 80), when limiting themselves to responses of a plant such as stem elongation, leaf size, flowering, and so forth, state that night temperature has the greatest influence. Apparently, it is during the night that most plants are engaged to the greatest extent in actual growth, hence, night temperature may exert the most influence.

Went (80) found in the case of the African violet that the optimum night temperature exceeded the optimum day temperature. This may be true for other plants not yet investigated, but for most plants, such as the chili pepper (23), tomato (3, 80), some California annuals (46), and the sugar beet (71), night temperatures are lower than optimum day temperature and appear to play the greatest role.

It should be mentioned that the growth of most plants may also be influenced by controlling light intensity (38, 70).

Effects of temperature on gross morphology

There are many observable responses of a plant to changes in temperature. In some instances, the cause of the reaction may be obscure, since not all environmental factors can be controlled.

Morphological responses to temperatures.--The consensus is that as temperature increases, especially night temperature, the rate of stem elongation also increases (2, 3, 11, 23, 80). At high temperatures the leaves of chili peppers became yellow (23), while at low temperatures in the case of tomato leaves (2) the color was more intense and at the same time the foliage became small and fleshy.

With carnations, Monsalise (52) found that cooler temperatures caused wider leaves with more rigid and heavy stems. Stem lengths also decreased with decreasing temperature, while the flower size increased.

Davidson (17) stated that, with gardenias, low temperatures reduced the length of internodes and the size of the foliage. Schmidt (62), however, found a significant trend towards shorter internodes as night temperatures were increased from 48° to 54°F. for carnations.

Went (80) considers that increasing the temperature usually hastens flowering. In some instances (38), with carnations, the use of fan and evaporative pad cooling systems during the summer may hasten growth by as much as four to six weeks between crops and two weeks from planting to pinching.

Color.--While color in carnations may vary without drastically reducing the grade, extremes definitely limit the usefulness of the cut flower. For the purpose of this study only anthocyanin will be considered since the varieties Red Gayety and White Sim were the only ones studied.

Some investigators (49, 56, 58, 59, 72) report that a lowering of temperature favors anthocyanin accumulation, due perhaps to the increase of available sugars in the cell.

Over what range a lowering of the temperature causes an increase in anthocyanin is not yet clear. In 1925, Onslow (54) reported evidence that anthocyanin was not produced readily when carbon assimilation was most active. She speculated that any decrease in photosynthesis would be favorable to anthocyanin formation. Blank (6), on the other hand, concluded his review with the opinion that the optimum for color formation coincides with the optimum temperature for metabolism.

Bonner and Galston (9) state that high temperature may either increase or decrease anthocyanin production depending upon the species involved, and the range of temperature used.

The statement of Bonner and Galston, together with the decrease of color with a decrease in light intensity as found by Uota (72) are substantiated by the observations of Schmidt (62) who found a gradual increase in color intensity in carnations with an increase in night temperature from $48^{\circ}$ to $54^{\circ}$F., and with an increase in light intensity.

Calyx splitting.--A particular habit of certain carnation varieties which may result in considerable monetary loss to the commercial grower is the tendency for the calyx to split.

According to Wagner (74), the tendency to split is largely controlled by inheritance in some varieties, and some clones of a variety may possess the tendency to split more than others.

Research by Wagner (75) and by Wagner and Holley (76) showed that splitting was caused by unusually high day temperatures in the late winter and early spring. They stated that this was probably initiated by the cool growing conditions during the fall and early winter which served to precondition the flower to splitting by filling the calyx to its maximum with petals. A sudden increase in temperature then split the calyx.

Keeping.--While not a readily noticeable physical characteristic, the ability of any cut flower to remain for a reasonable period of time in a desirable condition is a prime requisite which may be influenced by the environment.

Knappenberger (41) measured the sugar content of carnation cut flowers and concluded that the more sugar a cut carnation possessed at the time of cutting, the longer the keeping life.

That the environment may affect keeping life of the cut flower was brought out by Mastalerz (48) who found that high growing temperatures previous to cutting gave poor quality and short-lived carnations. He also stated that whenever light intensity was reduced keeping life was also decreased.

Effect of other environmental factors

In considering the effects of temperature on plants in the previous sections, very little has been said of other factors which may influence the plant, or of the two physiological processes with which the investigation is most intimately concerned, photosynthesis and respiration.

In 1843, Leibig (47) formulated the hypothesis that a deficiency of certain minerals in the soil could limit plant growth. Blackman (4), in 1905, suggested the law of limiting factors wherein a deficiency of any one of such factors as $CO_2$, light, or temperature could limit photosynthesis and, finally, growth. Presently, Rabinowitch (57) considers Blackman's and Liebig's laws to operate only under idealized conditions, and his opinion is backed by other authors (9, 20, 25, 26, 68). The problem is: Not only may one factor be limiting under certain conditions, but also an entire series of different factors may operate to cause a composite reaction of the plant to its surroundings. This problem can and does lead to confusion.

For convenience, some investigators (25, 26, 57) have divided these different environmental factors into two classes; those generally thought to operate internally, and those which affect the plant from without.

The effect of internal factors.--The natural ability of the plant, and the problem of genetic variability (78), play an important role in determining the maximum response of a plant, even though certain ecological factors may be limiting at a given time.

Rabinowitch (57) states that such internal processes as the ability of the plant to produce certain substrates may limit the maximum rates of important reactions and may also affect the rates of uptake and transportation of critical substances.

Closely related to the natural capacity of a plant is the effect of age, which has been well established by various authors (26, 27, 57, 64). As the plant matures, its ability to carry on various internal processes connected with growth, such as photosynthesis, decreases. The relation of the plant age to temperature is summarized by Went (80) and others (3, 11, 23) by the statement that as the plant matures the optimum temperature for its growth decreases.

Another internal factor has been recently reviewed by Bunning (10). He suggests that natural endogenous rhythms may account for a few of the unpredictable fluctuations found by others (25, 32, 33).

However, Bohning (7) found that some of the variation of photosynthesis in apple leaves was correlated with the fluctuation of $CO_2$ concentration of the air.

Effect of external ecological factors on metabolism.--The primary interests in this section are the effects of temperature, light and $CO_2$ on photosynthesis and respiration. No consideration will be given to other physiological processes, as translocation, which are usually directly influenced by temperature (14, 15, 34, 40, 80) and which may in turn modify the reactions reviewed.

It is well known (24, 25, 26, 57, 68) that photosynthesis is composed of two distinct processes, a photochemical reaction and a chemical reaction. The former utilizes light energy and is little affected by temperature, while the latter exhibits a temperature dependency similar to respiration. Various authors (24, 25, 57, 68) point out the significance of this situation. The effect of temperature on photosynthesis is not manifested until the light intensity is high enough for the chemical reaction to become limiting.

That light would play a more important role than temperature during certain periods of the year is suggested by Miller (50) and Lauritzen et al (45). For example, Lauritzen et al found that most varieties of Erianthus and sugar cane showed an increase in growth with each increase in light intensity. As temperature increased so did the minimum light intensity required for survival. Went (77) states the relationship of temperature to light in a slightly different manner: The higher the light intensity the higher the optimal temperature.

In attempting to obtain better growth of snapdragons, Miller (51) subjected the plants to different temperatures depending upon the amount of light received. He found a positive effect if the night temperature was raised following a sunny day.

Finally, mention should be made of $CO_2$ which is considered by some (4, 5, 8, 9, 26, 57) to be fully as important as light or temperature with respect to photosynthesis. The normal content of $CO_2$ in the air is considered to be approximately 0.03 per cent (12), an amount thought to be limiting to photosynthesis (20, 63, 69).

Singh and Lal (63) state that leaves could tolerate up to ten times the normal $CO_2$ concentration under high light intensity and otherwise normal conditions in the field. Chapman and Loomis (12) also concluded an increase above the 0.03 per cent level could increase the rate of photosynthesis. They found with potatoes that the saturation level of light increased as $CO_2$ was increased, and state that, normally $CO_2$ is limiting to photosynthesis and plant growth. Verdiun and Loomis (73) found little response in plant growth by depleting the $CO_2$ in the air.

In still air, $CO_2$ may definitely become limiting. Decker (19) found the rate of photosynthesis to vary hyperbolically with the rate of air supply and linearly with the mean $CO_2$ concentration, over a limited range. He quotes Deneke (21) as stating that the rate of photosynthesis increases with an increase in air flow. The results of Deneke and Decker may be partially explained by Scarth and Shaw (60) who concluded that low rates of air flow result in reduced $CO_2$ concentration outside and inside the leaf, and this effect of air movement is substantiated by Went (80).

From the literature cited, it might be expected that temperature would have very little influence on plant growth under low light conditions. However, other processes such as respiration usually proceed continually whether or not the plant is photosynthesizing (9, 16, 49, 50).

Assuming other factors as optimum, the rate of respiration usually possesses a $Q_{10}$ of 1 to 3 (9, 16, 49, 50, 60, 78). The rate of respiration increases with increase in temperature until some other factor intervenes. Should there be insufficient products from photosynthesis it is possible for the plant to break down cellular materials in order to continue respiration (8, 9).

The preceeding paragraph points up the conclusions of Post (56), Holley (35) and others (3, 11, 23, 80), that for some plants including carnations, high temperatures during periods of low light intensity may result in very undesirable types of growth. If temperatures are high enough, even at high levels of light intensity, the plant may become so seriously weakened as to prevent full recovery.

## Summary

From the review of literature, the response of the carnation plant to differences in day temperatures may be divided thus; yield and quality.

At low light intensities commonly experienced during a part of the year, temperatures probably do not influence yield. In the summer, under high light intensities, temperature may be expected to play an important role in determining yield. Therefore, by determining and providing optimum temperatures during periods of high light intensity, yield should vary directly with the available solar energy over the entire year.

Quality refers to various morphological characteristics such as color, stem length and rigidity, flower size and cut-flower weight. While there may be differences due to different temperatures, it can be expected that these differences will not be as large as if the same temperature differentials were applied at night. Nevertheless, as day temperatures decrease, flower size should increase, stem length decrease, rigidity increase, keeping increase and fresh weight of the cut flower increase. The influence of temperature on color is doubtful. However, since temperature may largely influence quality, it should be possible to vary quality more or less at will during a relatively large portion of the year by properly manipulating temperatures.

Since light and $CO_2$ are not controlled in this investigation, the opinion of Arthur et al (1) should be kept in mind. They state that, unless all factors are controlled, attempts to measure variations in the development of the plant as the result of a particular environmental treatment would appear questionable.

Therefore, some of the results presented in later chapters may be due to the effects of factors other than temperature.

# Chapter III

## METHODS AND MATERIALS

For convenience, this chapter is divided into sections dealing first with the environment to which the biological material was subjected; second, the four treatments; third, the methods used in obtaining the results; and fourth, statistical methods.

### The greenhouse environment

All experiments described in this thesis were carried out in a greenhouse especially constructed for temperature research (Figures 1 and 2). First described by Schmidt (62), who conducted night temperature investigations, the house is 70 feet long, running east and west, and divided into four compartments which are approximately 15 feet by 17 feet. Each compartment contains two beds, oriented east and west. The north bed is capable of holding 126 plants and the south bed 112 plants at a six-by-eight-inch spacing. The compartments were assigned the letters A, B, C, D, beginning with the west unit.

Throughout the investigation, temperature control underwent constant improvement in accuracy and

Figure 1.--The Colorado State University temperature house.

Figure 2.--Temperature controls in one of the compartments.

reliability. During most of the investigation, the day temperature normally varied $\pm 1\frac{1}{2}^{\circ}$F. (Figure 3). The steam heat and fan and evaporative pad cooling systems allowed temperature differentials in the four compartments to be maintained approximately nine months of the year. For more complete information concerning the operation and accuracy, reference may be made to a series of articles by the author (28, 30, 31).

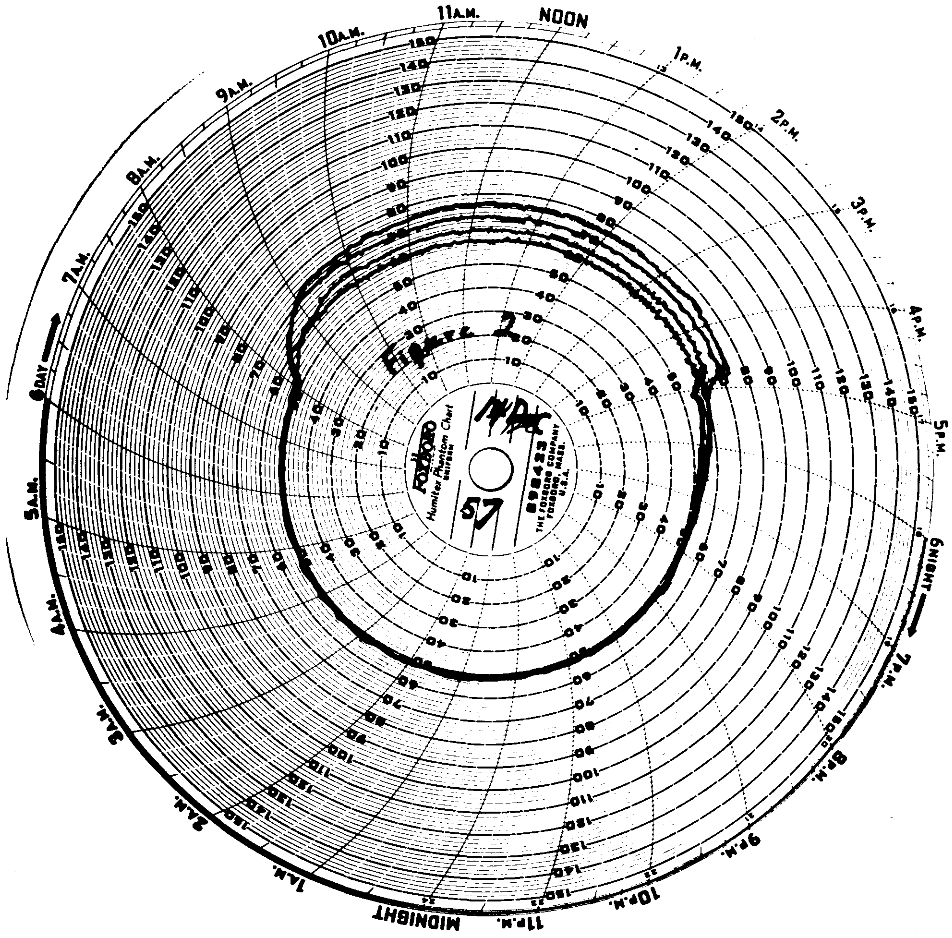


Figure 3.--Twenty-four-hour record of temperature in the Colorado State University temperature house.

Two light intensity measurements were made in the greenhouse to determine possible light differences between units. Due to orientation of the greenhouse, D received more light in the mornings while A received more in the late afternoons. During most of the day (10 a.m. to 3 p.m.) the units could be considered equal.

However, it was quite possible that compartments B and C received slightly less total light energy than A and D. Varying atmospheric conditions could lead to rather large differences in all houses from day to day.

Plants were watered according to Lark tensiometer readings (tensions of 300 to 500 centimeters of water). Fertilizer was injected into the water line at each watering (39). Also, monthly soil tests were made and dry fertilizer added whenever necessary to maintain adequate levels.

All soil was steamed and care was taken to prevent contamination. Regular fumigation and spray schedules were followed with additional applications when necessary. After allowing sufficient time for plants to establish themselves, a sterilized leaf mulch was added to prevent compaction and too rapid drying of the soil.

Carnation plants used in this research came from the Colorado State University foundation stock, preselected for desirable characteristics and uniformity, and cultured for freedom from disease in the manner described by Tammen et al (67).

Beginning with the west compartment on May 21, 1957, the day temperatures were as follows: 65°, 75°, 70° and 60°F. During the heating season (October to

May) night temperatures in all units were 52°F. In the summer, the night temperature was allowed to seek that of the outside air temperature provided it was below the shut-off point of the cooling system. Plants in one of the experiments received different temperature treatments, but this did not involve the day temperature investigation and will be described as encountered.

<u>The experiments</u>

The first experiment dealt with quality and green weight of fancy carnations, the second and third with yield, quality, and green weight of fancy and standard grade cut flowers, and the fourth with dry matter production and stem elongation.

<u>Experiment one</u> consisted of Red Gayety carnations benched June 25, 1956, pinched for steady production, and subjected to night temperatures of 48°, 50°, 52° and 54°F. until May 21, 1957, with day temperatures ranging in each unit from 60° to 68°F. Records for the day-temperature investigation started for quality on May 21, but green-weight data did not begin until two months later. The experiment was concluded October 4, 1957.

<u>Experiment two</u> began with direct benching of Red Gayety rooted cuttings on May 21, 1957, in the

north bed of each compartment. The plants were given a single pinch on June 15, and the experiment was terminated May 30, 1958.

Experiment three concerned the variety White Sim which was placed in a nursery bed on August 21, 1957, pinched September 12 and transplanted to the south bed of each compartment on October 18, 1957. This experiment was concluded on May 30, 1958.

Experiment four was the determination of the increase in dry weight of carnations grown for equal lengths of time over the year and included the varieties Red Gayety, White Sim and Crowley's Pink Sim.

Beginning on August 21, 1957, five crocks containing a total of ten plants were put directly into each of the four temperature treatments. Every three weeks a new series of ten plants was started until four sets of crocks were in each treatment, after which a set was harvested to make room for the next group.

For each four sets, 250 cuttings were propagated and placed in cold storage at 33°F. until needed. At each planting, ten cuttings were taken at random, dried at 180°F. for three days and weighed on a torsion balance. After three weeks of growth, the plants were pinched to four sets of leaves, the pinchings dried and weighed in the same manner as the cuttings. At the end of approximately 84 days the plants were pulled from the crocks, their roots washed, and the plants dried and weighed. The increase in dry weight, plus the dry weight of the portion removed by the pinch minus the average weight of the ten cuttings was considered the increase in dry matter.

Water and fertilization schedules were the same as for the plants in beds, but during the summer months one-fourth teaspoon of a complete fertilizer was applied to each crock three weeks before harvest.

At the time of harvest, the heights of the plants were measured with a yardstick. The two terminal leaves were stretched to their highest point and the height taken from their tips to the top side of a one-by-two-inch block of wood placed on the top edge of the crock. In all instances, the top branch was measured. The distance from the block of wood to the junction of the top branch and the main stem was subtracted from the total height giving the stem elongation from time of pinch to harvest.

On June 11, 1958, records for this treatment were terminated.

Measurements

The following paragraphs describe the various measurements used to evaluate the effect of day temperatures on the first three experiments.

Color of Red Gayety carnations was determined periodically by using a multi-disc colorimeter as described by Sparks (66) and modified for carnation use by Schmidt (61). Dupont Gloss Alkyl Enamel Red, number 347, was applied to eight discs in the percentages indicated below:

| Disc Number | Percentage Red |
|---|---|
| 1 | 100 |
| 2 | 99 |
| 3 | 98 |
| 4 | 97 |
| 5 | 96 |
| 6 | 95 |
| 7 | 94 |
| 8 | 90 |

The flowers were then graded for color by comparing them with the spinning discs under a Westinghouse daylight fluorescent lamp in an otherwise darkened room.

Dry matter, expressed as per cent, was obtained by drying the top five internodes of a flower stem for three days at 180°F. and weighing on a torsion balance.

Flower size is expressed as milliliters of water displaced by an immersed carnation bloom. A large volumetric cylinder was fitted with a glass siphon tube running from the bottom of the cylinder to six inches below the rim on the outside where it was drawn to a fine point. The cylinder was filled and the water allowed to siphon through until equilibrium was reached. Then the flower was inserted until the water line coincided with the junction of the stem and calyx. The resulting siphoned water was caught in a smaller volumetric cylinder and measured.

*Green weight* was obtained by weighing all fancy and standard grade flowers to the nearest gram immediately after cutting.

*Internode length* was measured in centimeters at the fifth internode from the calyx.

*Keeping quality* was tested whenever sufficient cut flowers were available during the spring of 1958. The flowers were placed, immediately after cutting, in one gallon of tap water to which one-fourth teaspoon of disinfectant had been added. The samples were set in a keeping chamber maintained at $70^{\circ}$F. $\pm 1^{\circ}$ and a relative humidity of 50 to 70 per cent. When a flower showed a withering or curling of petals it was removed and one day subtracted from the actual number of days it had remained in the keeping room. The average number of days that the flowers of a sample remained in the room was then computed.

Leaf widths were measured in centimeters, periodically choosing one leaf of the fifth set from the calyx. A one-inch-wide ruler was placed on top of the leaf with one edge against the stem. The width of the leaf was taken where it appeared under the opposite edge of the ruler.

Yield constituted the total number of flowers cut.

Stem strength determinations made use of the Colorado State University Limberometer (29) to measure the number of degrees of arc through which an 18-inch cut flower bent from the horizontal (Figure 4). Immediately after cutting, the flowers were placed in warm water and kept at 33°F. for at least one hour before stem strength determinations were made.

Mean grade was obtained by grading the flowers after cutting according to the Colorado State University system which comprises four grades (36): (1) fancy, any large flower with no defects and possessing a minimum weight of 25 grams and a stem length of 24 inches when measured from the junction of stem and calyx; (2) standard, flowers without defects having a stem length of 20 inches and a minimum weight of 15 grams; (3) short, flowers having a stem length less than 20 inches or a

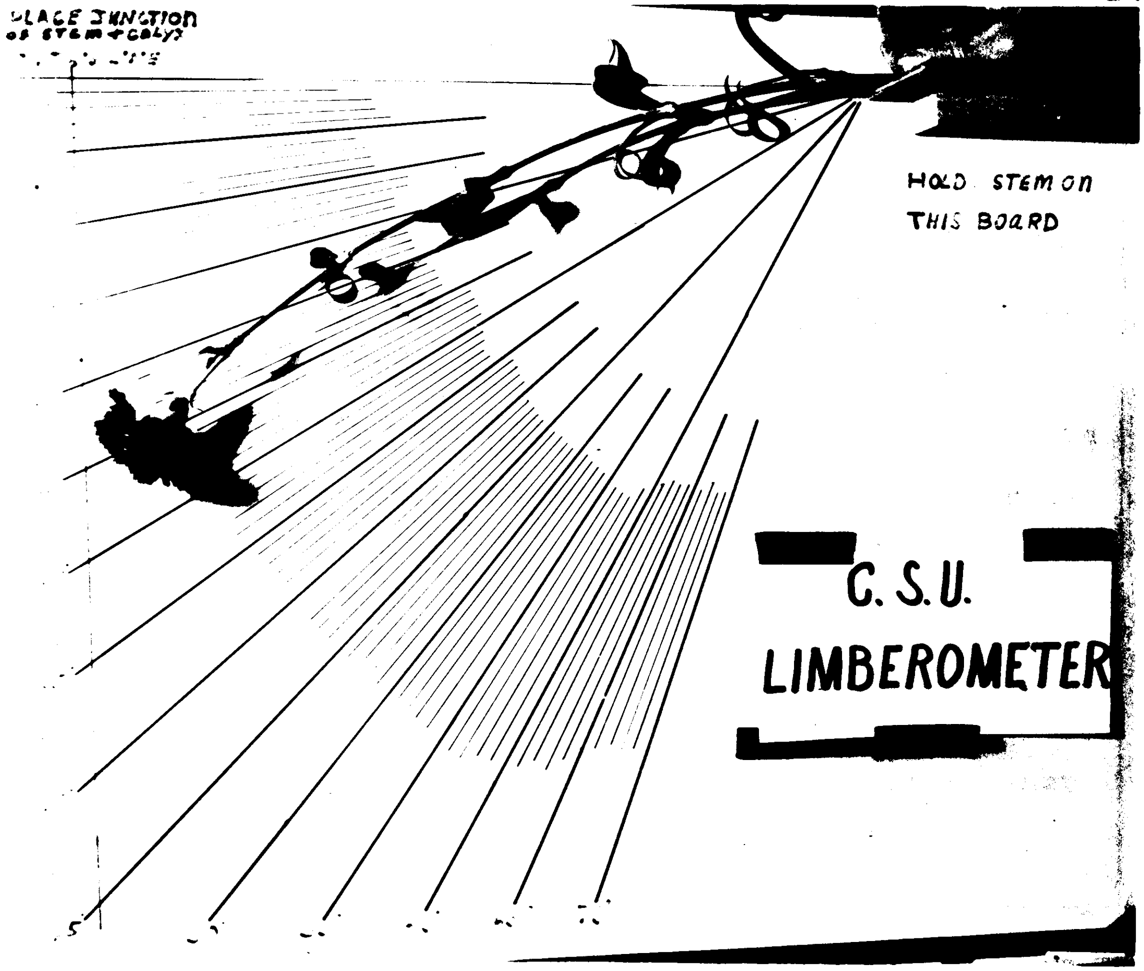


Figure 4.--The limberometer for measuring stem strength of carnations.

weight less than 15 grams; (4) design, all flowers failing to meet the specifications for the above grades. The mean grade was obtained by assigning the values of 5, 4, 3, and 2 to the respective grades beginning with fancy.

Records were kept on the number of flowers downgraded due to poor flowers, insufficient weight or short stems. Those downgraded due to the first two causes were required to possess sufficient stem length to satisfy the qualifications for fancy or standard grades. The latter were required to have minimum weights of 15 or 25 grams before being recorded as downgraded due to short stems.

Statistical methods

Flowers were cut early in the morning and graded. After grading, and where possible, flowers that were to be used in the various determinations were selected at random. Due to variations in time of flowering, it was impractical to attempt equal numbers per sample in all cases, and in some instances all the flowers cut were used in a sample.

Where necessary, the analyses of variance and least significant differences were computed according to Snedecor (65). Except where noted, all figures are means and the analyses were made on this basis, the two-way classification generally being used.

# Chapter IV

# RESULTS

The results of the day-temperature investigations follow the same outline as the preceeding chapter. The tables and figures are grouped together by experiment. Line graphs use three-week means in order to smooth out some of the variation. Measurements other than those given are shown separately. Where significance between treatments existed, least significant differences are included. For more information concerning the statistical analysis see the Appendix.

## Experiment one

Table 1 and Figures 5 and 6 give the results obtained on summer-cooled carnations in 1957. In both mean grade and fresh weight, significance occurred between treatments. The yield is not included because of the night temperature treatments to which the plants were subjected during 1956 to 1957. In mean grade (Table 1), the lack of any difference between the 60° and 65°F. cut flowers is due to the limitations of the cooling system described in Chapters I and III, and is shown in Figure 6 by the decline in fresh weights of all treatments with the possible exception of the 75°F. All plants were in continual production.

Table 1.--SUMMARY OF PRODUCTION FOR EXPERIMENT ONE, RED GAYETY, BENCHED JUNE 25, 1956, DAY TEMPERATURES BEGUN MAY 21, 1957.

| | Day temperatures | | | |
|---|---|---|---|---|
| | 60°F. | 65°F. | 70°F. | 75°F. |
| Mean grade (LSD 5 per cent level 0.1) | 4.52 | 4.52 | 4.47 | 4.32 |
| Mean fresh weight of fancy cut flowers in grams (LSD--five per cent level 0.3) | 30.8 | 31.1 | 30.1 | 28.2 |
| Per cent distribution of grades | | | | |
| Fancy | 74.9 | 74.3 | 71.4 | 58.7 |
| Standard | 12.6 | 10.6 | 14.1 | 25.7 |
| Short | 6.1 | 10.6 | 7.4 | 8.2 |
| Design | 6.4 | 4.5 | 7.1 | 7.4 |

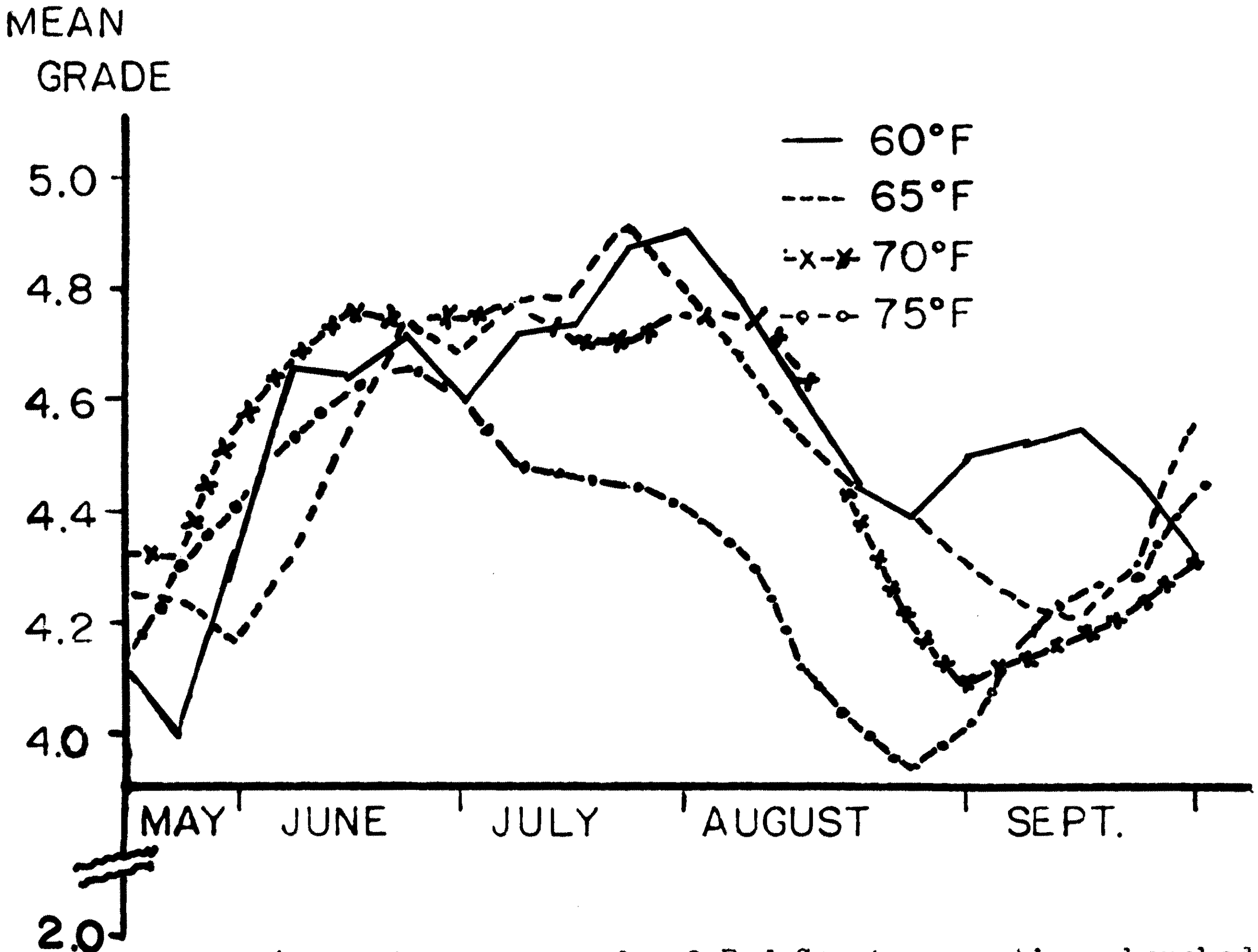


Figure 5.--Weekly mean grade of Red Gayety carnations benched June 25, 1956, with day-temperature differentials begun May 21, 1957.

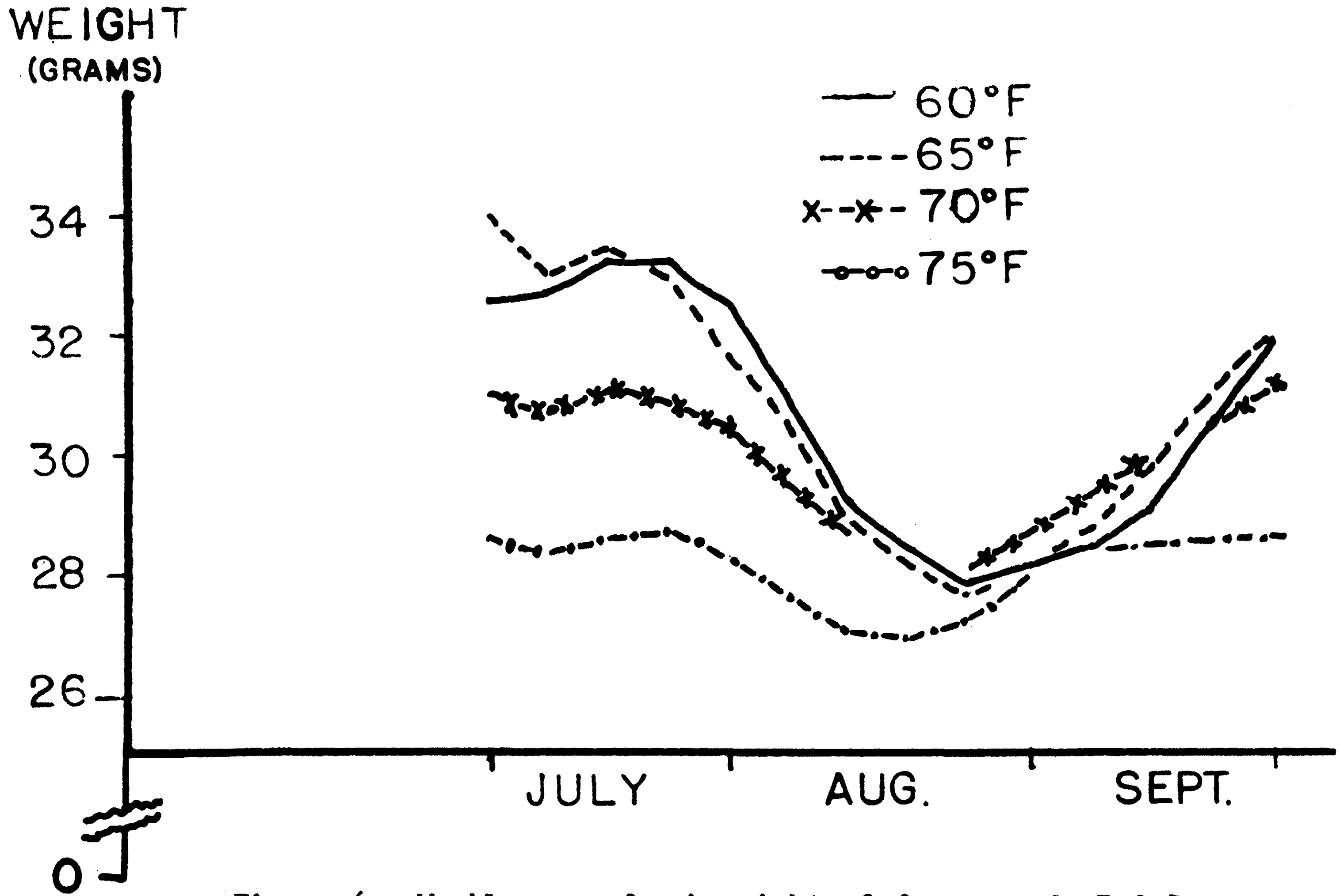


Figure 6.--Weekly mean fresh weight of fancy grade Red Gayety carnations benched June 25, 1956, with day-temperature treatments begun May 21, 1957

Experiment two

The plants in this experiment were grown under summer-cooled conditions, coming into production in August, 1957; when differences between treatments could not be maintained consistently and, then, beginning the last of September through May 31, 1958, carried under the regimen described in Chapter III. The results are summarized in Table 2.

Table 2.--SUMMARY OF PRODUCTION FOR EXPERIMENT TWO, RED GAYETY, BENCHED MAY 21, 1957.

| | Day temperatures | | | |
|---|---|---|---|---|
| | 60°F. | 65°F. | 70°F. | 75°F. |
| Total yield------------------- | 1619 | 1634 | 1696 | 1634 |
| Flowers/sq ft/year---------- | 38.4 | 38.9 | 40.4 | 38.9 |
| Mean grade-------------------- | 4.15 | 4.27 | 4.16 | 3.86 |
| (LSD, 5 per cent level 0.2) | | | | |
| Mean fresh weight of cut flowers | | | | |
| Fancy------------------------- | 30.1 | 28.8 | 27.8 | 27.4 |
| (LSD, 5 per cent level 1.0) | | | | |
| Standard---------------------- | 23.6 | 22.0 | 20.5 | 19.5 |
| (LSD, 5 per cent level 0.9) | | | | |
| Per cent distribution of grades | | | | |
| Fancy------------------------- | 29.6 | 30.2 | 31.1 | 24.5 |
| Standard---------------------- | 59.4 | 60.5 | 52.0 | 43.5 |
| Short------------------------- | 8.7 | 8.0 | 12.8 | 19.8 |
| Design------------------------ | 2.3 | 1.3 | 4.1 | 12.2 |
| Per cent flowers downgraded | | | | |
| Insufficient weight---------- | 2.8 | 12.7 | 20.2 | 18.9 |
| Defective flowers----------- | 0.2 | 3.4 | 21.8 | 32.2 |
| Short stems----------------- | 27.8 | 18.1 | 5.1 | 0.5 |
| Split calyxes--------------- | 2.4 | 1.2 | 0.8 | 1.0 |
| Total downgraded----------- | 33.2 | 35.4 | 47.9 | 52.6 |

The flowers per square foot per year are for the entire year, May 21, 1957, when they were benched, to May 31, 1958, when they were removed. No significance existed between yields.

Differences do occur with mean grade and fresh weights. The percentage of flowers downgraded due to undesirable characteristics is high enough to make a significant contribution to the low mean grade. Particular attention should be paid to the increase in defective flowers (hollow centers, small, poor color), insufficient weight and the decrease in short stems as the day temperatures became higher. Records on the per cent downgraded were not kept for the entire period, since downgrading did not become noticeable until late November, 1957, (Figure 7). The means do not show the rather large variation which existed, and observation of Figures 7 and 8 will illustrate that in some instances the relationship of treatments to each other apparently was reversed.

The single pinch used in Experiments 2 and 3 caused the plants to assume alternating heavy and light production periods, the peak and low cutting periods gradually becoming less extreme as the plants continued to flower. A close study of production records indicated that fresh weight of cut flowers (Figure 8) increased as

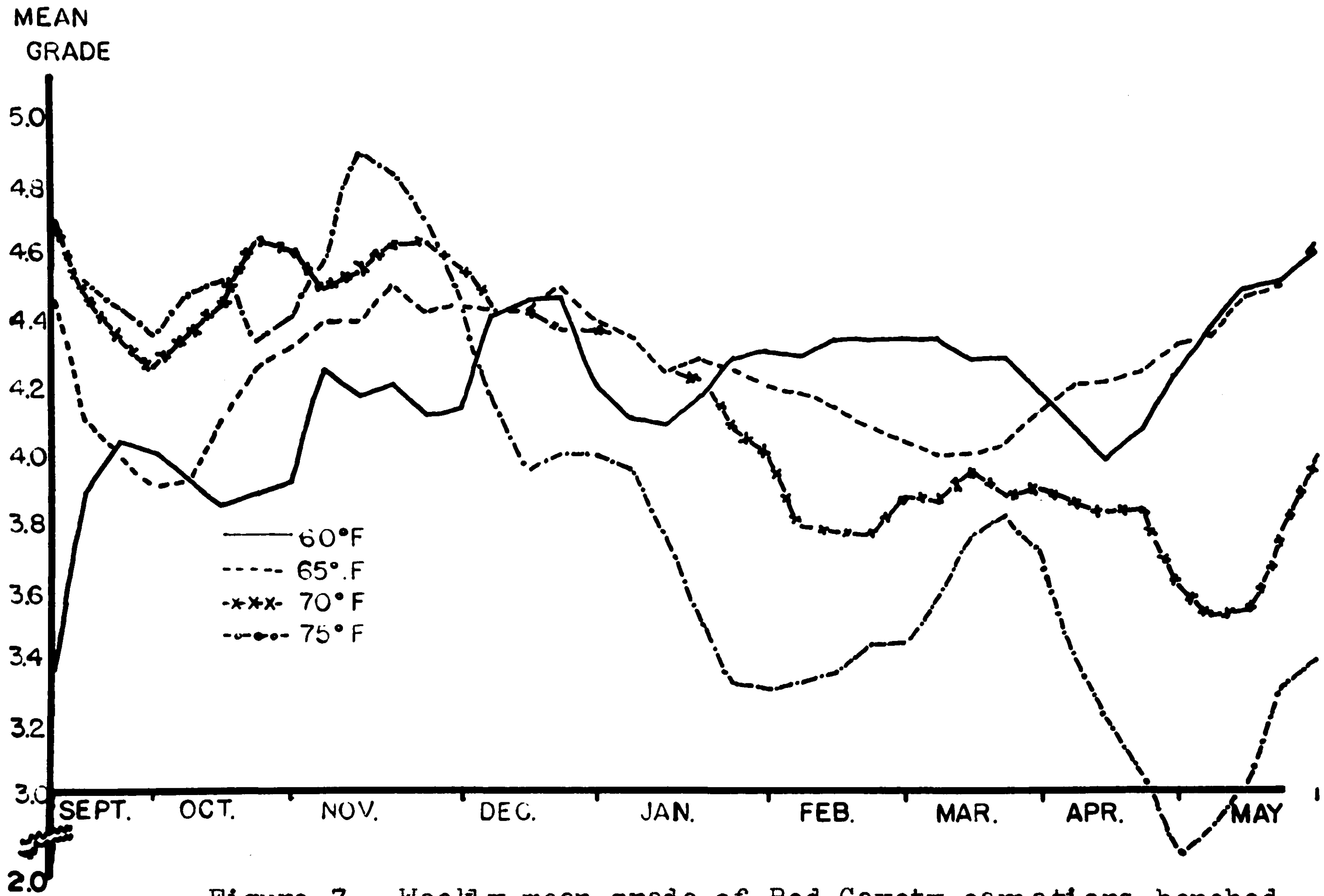


Figure 7.--Weekly mean grade of Red Gayety carnations benched May 21, 1957

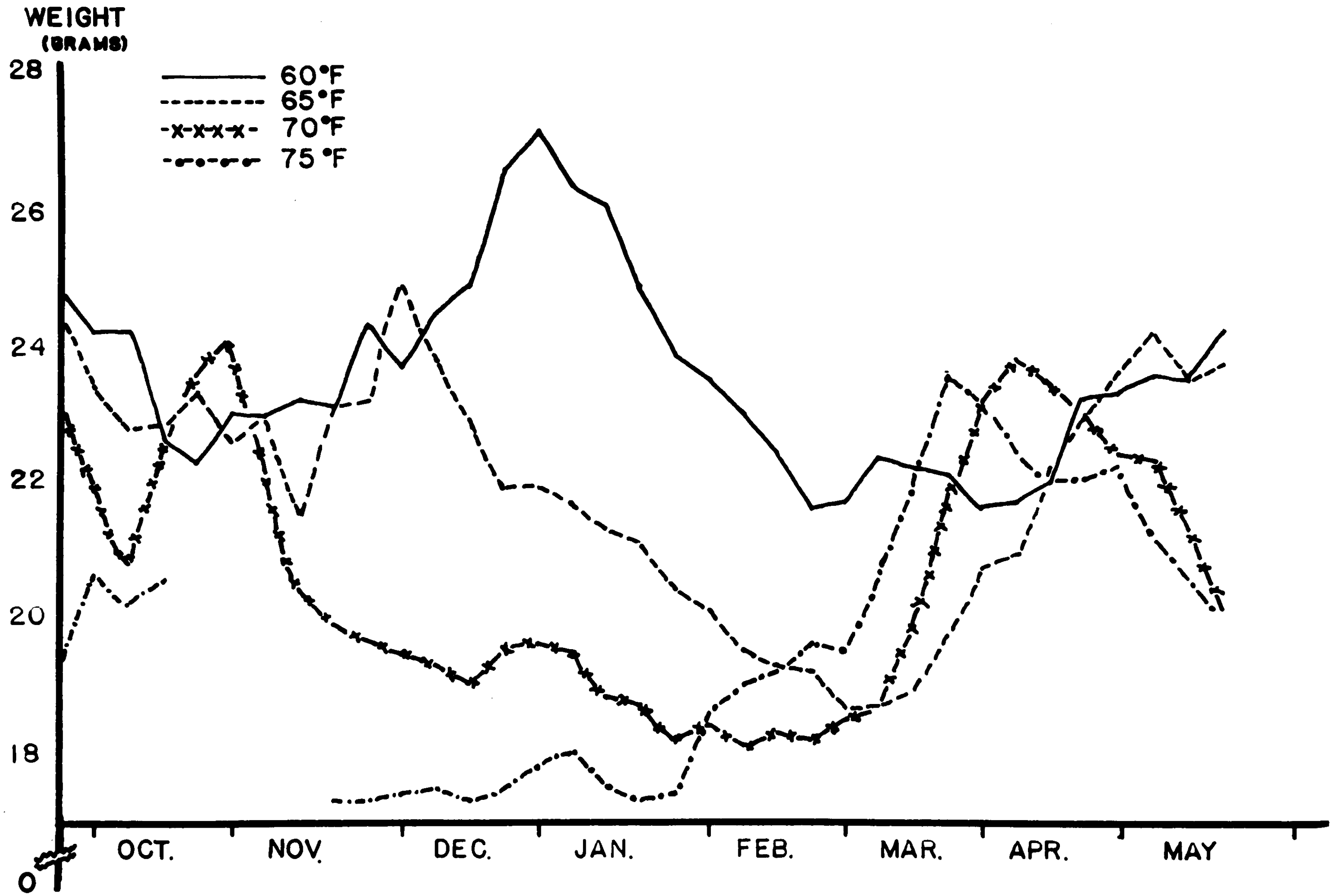


Figure 8.--Weekly mean fresh weight of standard-grade Red Gayety carnations benched May 21, 1957

the crop came into production. Throughout the period of heavy cut the fresh weight gradually declined with minimum occurring at the "tail-out" of the crop. It increased again as the plants returned to heavy production during February through April.

Experiment three

The plants considered here were all equally exposed to the same summer-cooled conditions during their early stages of growth and did not come into peak production until the first part of February, 1958 (Figure 9). It was possible to subject these plants to more exact temperature differentials than those in Experiment two. In Table 3, it can be seen that no significance occurred between treatments as far as yield was concerned. Yet, the peak of production for the 60°F. treatment was almost two months later than the 75°F. peak, (Figure 9). The results for other measurements are more definite than those shown in Tables 1 and 2. Variations which existed during the period of the experiment are shown in Figures 10 and 11. The 65°F. treatment maintained a consistently higher mean grade throughout the period while the 60° treatment maintained consistently higher fresh weight. Close study of Figures 9 and 10

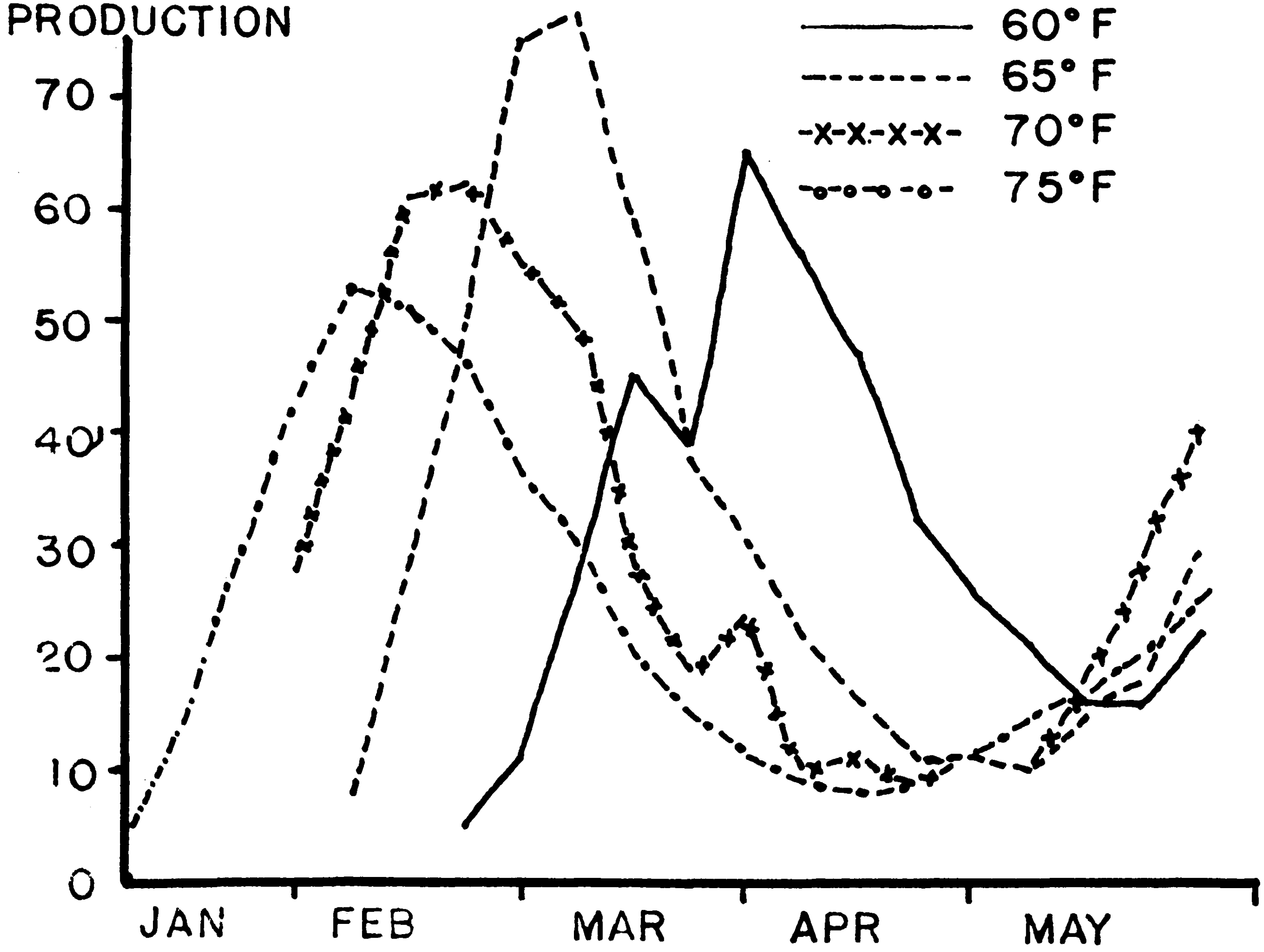


Figure 9.--Weekly yield of White Sim carnations benched October 18, 1957

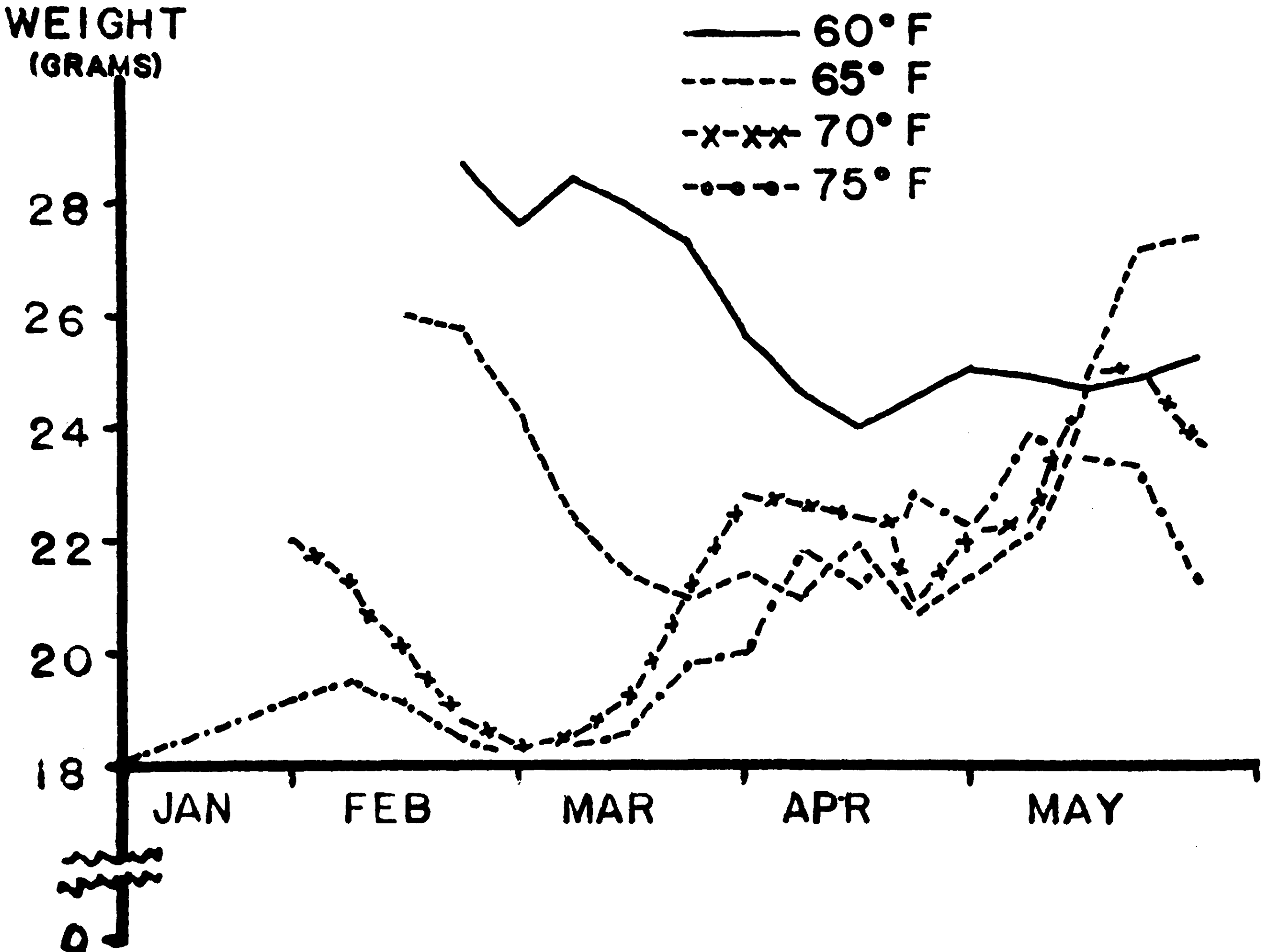


Figure 10.--Weekly mean fresh weight of standard-grade White Sim carnations benched October 18, 1957

will again show a similar relationship between weight and production as pointed out in the results of Experiment two.

Table 3.--SUMMARY OF PRODUCTION FOR EXPERIMENT THREE, WHITE SIM BENCHED OCTOBER 18, 1957.

| | Day temperatures | | | |
|---|---|---|---|---|
| | 60°F. | 65°F. | 70°F. | 75°F. |
| Total yield | 478 | 528 | 551 | 486 |
| Mean grade | 4.15 | 4.57 | 4.25 | 3.85 |
| (LSD 5 per cent level 0.2) | | | | |
| Mean fresh weight of cut flowers | | | | |
| Fancy | 32.0 | 31.8 | 31.0 | 29.8 |
| Standard | 26.1 | 23.5 | 21.5 | 20.8 |
| (LSD 5 per cent level 1.9) | | | | |
| Per cent distribution of grades | | | | |
| Fancy | 21.3 | 64.4 | 39.9 | 21.8 |
| Standard | 68.6 | 33.1 | 49.5 | 53.4 |
| Short | 8.8 | 1.0 | 9.6 | 19.4 |
| Design | 1.3 | 1.5 | 1.0 | 5.4 |
| Per cent flowers downgraded | | | | |
| Insufficient weight | 0.6 | 5.3 | 19.8 | 23.6 |
| Defective flowers | 1.3 | 1.3 | 15.6 | 24.0 |
| Short stems | 52.9 | 11.9 | 5.6 | 1.0 |
| Split calyxes | 0.6 | 1.1 | .... | 1.0 |
| Total downgraded | 55.4 | 19.1 | 41.0 | 49.6 |

Experiment four

The cultural data for Experiment four is given in Table 4 and the per cent increase in dry matter in Table 5. Day temperatures did not cause significant differences in dry matter. Computing the results in

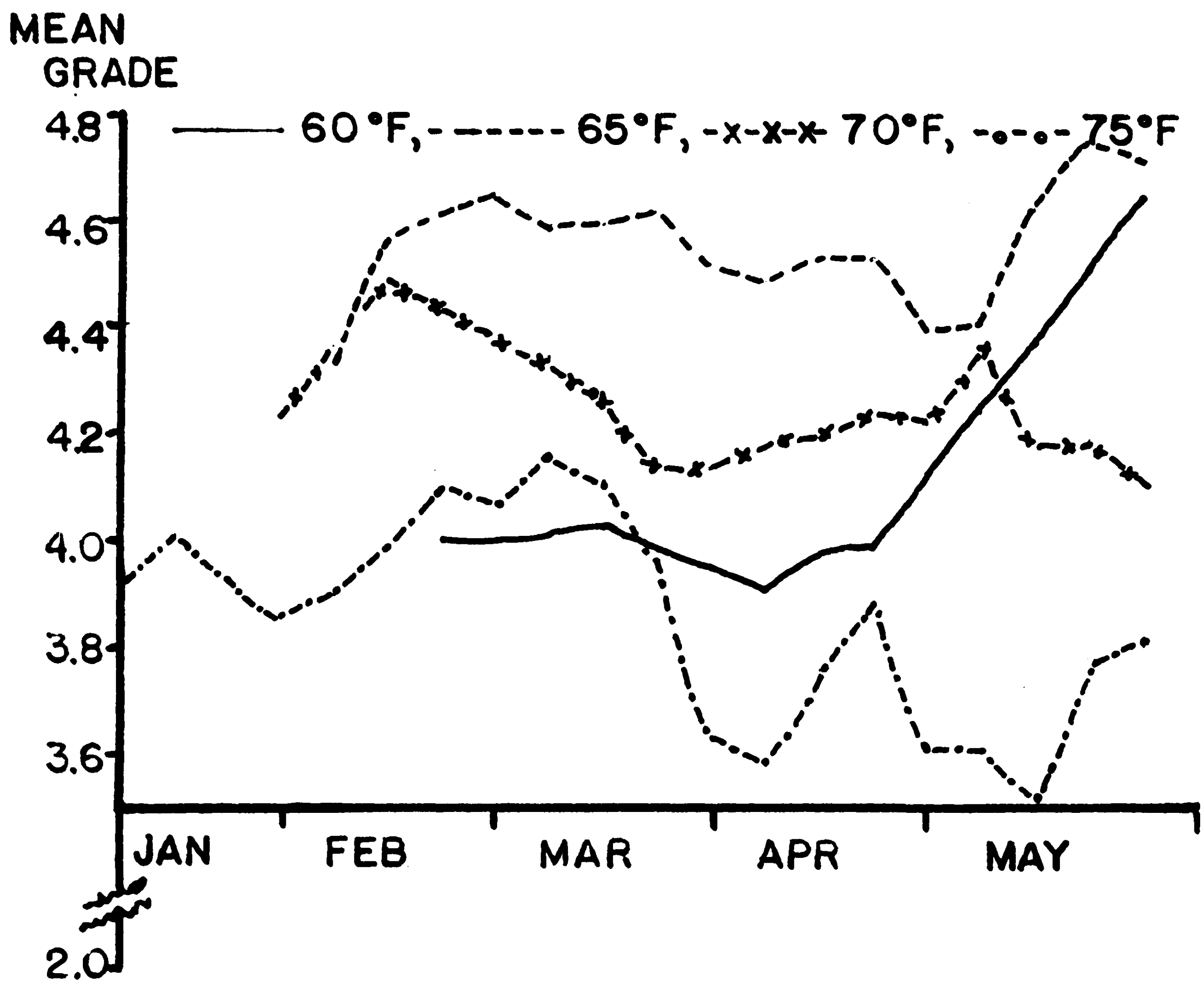


Figure 11.--Weekly mean grade of White Sim carnations benched October 18, 1957

percentage of original weight removed some of the variation in the data. The cuttings differed highly in dry weight (Table E, Appendix), when propagated and only slightly less so when removed from cold storage. The stem elongation of these plants (Table 6 and Figure 12) shows significance between treatments.

<u>Other measurements</u>

The results obtained on the effects of day temperatures on various phenotypic characteristics of carnation plants play a large role in determining the quality of the cut flowers but are considered separately in order to facilitate presentation of the data. Keeping life is also included which, while not playing a part in determination of grade, is important commercially and must be taken into consideration by the grower.

<u>Color</u> is shown in Table 7 and Figure 13. No significance was found between treatments, but from general observation, as the winter progressed, the flowers in the highest temperature were first to become poor in color, followed successively by the other treatments.

Table 4.--CULTURAL DATA FOR EXPERIMENT FOUR.

| Crop | Bench | Pinch | Harvest |
|---|---|---|---|
| A | August 21, 1957 | September 11 | November 12 |
| B | September 21 | October 2 | December 4 |
| C | October 2 | October 23 | December 24 |
| D | October 23 | November 13 | January 12, 1958 |
| A-1 | November 13 | December 4 | February 6, 1958 |
| B-1 | December 4 | December 24 | February 26 |
| C-1 | December 24 | January 13 | March 18 |
| D-1 | January 13 | February 5 | April 8 |
| A-2 | February 6 | February 26 | May 1 |
| B-2 | February 26 | March 22 | May 20 |
| C-2 | March 19 | April 8 | June 11 |

Table 5.--SUMMARY OF DRY WEIGHT INCREASE IN PERCENTAGE OF ORIGINAL WEIGHT OF YOUNG CARNATION PLANTS IN EXPERIMENT FOUR.

| Crop | No. plants per sample | Day temperatures | | | |
|---|---|---|---|---|---|
| | | 60°F. | 65°F. | 70°F. | 75°F. |
| A | 10 | 84.6 | 83.7 | 86.7 | 83.0 |
| B | 10 | 73.1 | 74.6 | 79.0 | 77.8 |
| C | 10 | 62.7 | 68.0 | 73.2 | 72.0 |
| D | 10 | 73.2 | 69.6 | 76.6 | 72.4 |
| A-1 | 10 | 68.1 | 73.8 | 66.9 | 71.3 |
| B-1 | 10 | 68.8 | 66.8 | 65.0 | 66.0 |
| C-1 | 10 | 72.0 | 78.1 | 75.4 | 78.9 |
| D-1 | 10 | 77.4 | 84.3 | 82.0 | 77.5 |
| A-2 | 10 | 86.8 | 87.5 | 84.8 | 83.2 |
| B-2 | 10 | 73.5 | 81.8 | 74.0 | 71.0 |
| C-2 | 10 | 89.8 | 88.3 | 87.9 | 86.8 |
| Mean | | 75.5 | 77.9 | 77.4 | 76.4 |

Table 6.--EFFECT OF DAY TEMPERATURE ON TOTAL STEM ELONGATION (IN INCHES) OF CARNATIONS.

| Crop* | No. plants per sample | Day temperatures 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|
| C** | 10 | 7.1 | 8.2 | 9.2 | 9.6 |
| D | 10 | 9.7 | 9.6 | 12.3 | 12.0 |
| A-1 | 10 | 7.0 | 9.5 | 9.5 | 11.2 |
| B-1 | 10 | 8.4 | 10.0 | 11.2 | 11.1 |
| D-1 | 10 | 12.9 | 8.6 | 14.7 | 16.3 |
| A-2 | 10 | 10.9 | 13.6 | 14.9 | 14.2 |
| B-2 | 10 | 8.4 | 8.8 | 11.3 | 9.3 |
| Mean (LSD 5 per cent level 1.4) | | 9.1 | 9.8 | 11.9 | 12.0 |

* See Table 4 for the period of growth from pinch to harvest.
** Measurement includes only the period from November 1 to December 21, 1957

Table 7.--EFFECT OF DAY TEMPERATURES ON COLOR OF RED GAYETY CARNATIONS.

| Date | Ave. No. flowers per sample | Day Temperature 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|
| June 20, 1957 | 13 | 2.7 | 2.3 | 1.7 | 3.9 |
| July 19 | 16 | 3.1 | 2.3 | 1.9 | 2.7 |
| August 26 | 12 | 2.9 | 1.7 | 3.2 | 2.3 |
| December 27 | 16 | 3.7 | 5.8 | 6.3 | 6.8 |
| January 10, 1958 | 12 | 2.4 | 4.7 | 4.7 | 6.3 |
| Mean | | 3.0 | 3.4 | 3.6 | 4.4 |


Figure 12.--Effect of day temperatures on height of young carnations. Picture taken on December 4, 1957

<u>Flower volume</u> (Table 8 and Figure 13) contains only two measurements but was significant between treatments.

Figure 13.--Effect of day temperatures on bloom size and color of Red Gayety carnations benched May 21, 1957. Picture taken January 1, 1958. (See Tables 7 and 8).

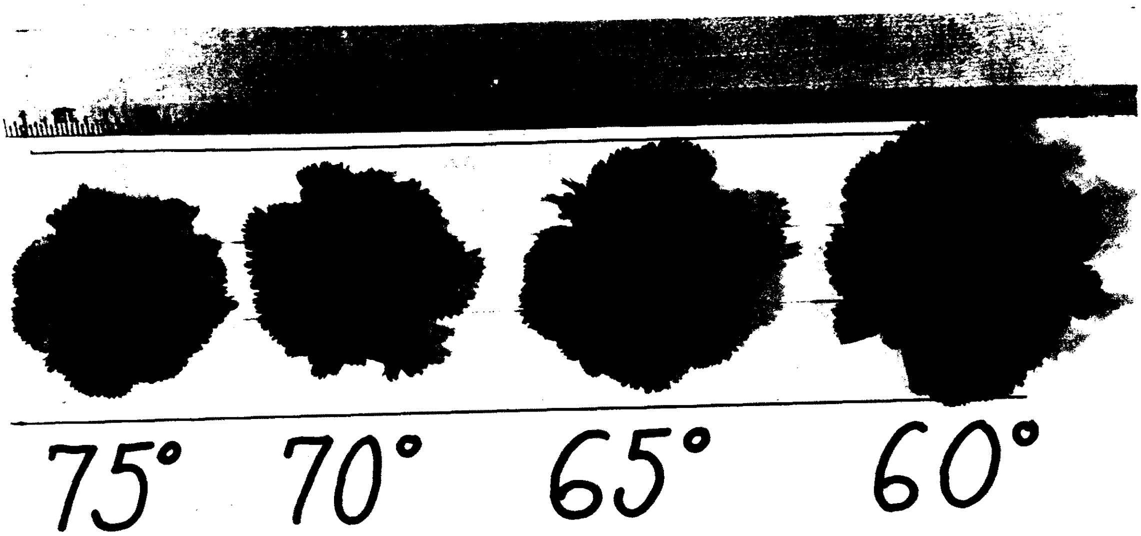


Table 8.--EFFECT OF DAY TEMPERATURES ON FLOWER VOLUME IN MILLILITERS.

| Date | Ave. No. flowers per sample | Day temperatures 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|
| January 6, 1958 | 18 | | | | |
| January 14 | 21 | 21.1 | 20.3 | 15.7 | 14.2 |
| | | 20.6 | 17.2 | 15.4 | 13.3 |
| Mean | | | | | |
| (LSD 5 per cent level 2.9) | | 20.9 | 18.8 | 15.6 | 13.8 |

**Fresh, dry and per cent dry matter** presented in Table 9 give an indication of the brittleness of the flower stem as influenced by day temperatures.

Table 9.--EFFECT OF DAY TEMPERATURES ON FRESH AND DRY WEIGHT (IN GRAMS) AND PER CENT DRY MATTER OF CARNATION CUT FLOWERS.

| Date | Ave. No. flowers per sample | Day temperatures 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|
| Fresh weight | | | | | |
| February 17, 1958 | 10 | 10.4 | 8.3 | 7.3 | 6.9 |
| April 19 | 8 | 7.8 | 8.8 | 8.8 | 9.1 |
| March 27 | 8 | 8.4 | 8.0 | 9.5 | 8.5 |
| May 22 | 8 | 12.5 | 11.0 | 8.2 | 6.6 |
| Mean | | 9.8 | 9.0 | 8.5 | 7.8 |
| Dry Weight | | | | | |
| February 17 | 10 | 1.88 | 1.58 | 1.39 | 1.38 |
| April 19 | 8 | 1.48 | 1.65 | 1.71 | 1.83 |
| March 27 | 8 | 1.61 | 1.42 | 1.87 | 1.68 |
| May 22 | 8 | 2.40 | 2.05 | 1.61 | 1.32 |
| Mean | | 1.84 | 1.68 | 1.65 | 1.55 |
| Per cent dry matter | | | | | |
| February 17 | 10 | 18.1 | 19.0 | 19.0 | 20.0 |
| April 19 | 8 | 19.0 | 18.8 | 19.4 | 20.1 |
| March 27 | 8 | 19.2 | 17.8 | 19.7 | 19.8 |
| May 22 | 8 | 19.2 | 18.6 | 19.6 | 20.0 |
| Mean (LSD 5 per cent level 0.7) | | 18.9 | 18.6 | 19.4 | 20.0 |

Leaf width (Table 10) shows a significant increase toward the lower day temperature, although individual means on a given date indicated an apparent reversal in some instances.

Table 10.--EFFECT OF DAY TEMPERATURES ON CARNATION LEAF WIDTHS IN CENTIMETERS.

| Date | Variety | Ave. No. leaves per sample | Day temperatures 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|---|
| February 17, 1958 | White Sim | 10 | 1.12 | 1.04 | 1.04 | 0.96 |
| February 28 | " | 5 | 1.41 | 1.28 | 1.10 | 0.89 |
| March 10 | " | 8 | 1.41 | 1.14 | 1.04 | 0.87 |
| March 13 | " | 6 | 1.39 | 1.10 | 1.05 | 0.98 |
| March 27 | Red Gayety | 8 | 0.99 | 0.90 | 1.10 | 1.13 |
| April 10 | " | 7 | 0.99 | 0.96 | 1.14 | 0.98 |
| May 15 | " | 10 | 1.09 | 1.23 | 1.18 | 1.07 |
| May 22 | " | 8 | 1.31 | 1.13 | 1.14 | 0.99 |
| Mean (LSD 5 per cent level 0.4) | | | 1.21 | 1.10 | 1.10 | 0.98 |

Stem strength, while usually increasing with decreased day temperatures (Table 11), was reversed for March 27 and April 10. Study of the production (Figure 9) for the different treatments indicated that this reversal occurred at different stages of cutting for the various treatments; during the "tail-out" for the 60° and 65°F. plants in one cycle of production, while the 70° and 75°F. plants were either coming into production or at their peaks.

Table 11.--EFFECT OF DAY TEMPERATURES ON STEM STRENGTH OF CARNATION FLOWERS.

| Date | Ave. No. flowers per sample | Day temperatures 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|
| December 27, 1957 | 17 | 5.7* | 9.1 | 13.8 | 17.5 |
| January 6, 1958 | 15 | 10.0 | 11.5 | 14.6 | 22.8 |
| January 7 | 12 | 6.6 | 10.0 | 13.2 | 16.3 |
| January 13 | 18 | 8.7 | 10.6 | 13.8 | 17.9 |
| February 17 | 5 | 7.5 | 15.9 | 20.1 | 20.2 |
| February 28 | 10 | 6.4 | 15.0 | 13.0 | 17.4 |
| March 10 | 8 | 1.1 | 17.8 | 16.9 | 16.5 |
| March 13 | 6 | 6.3 | 25.5 | 14.8 | 14.8 |
| March 27 | 8 | 17.0 | 25.5 | 11.9 | 13.0 |
| April 10 | 7 | 14.4 | 11.4 | 6.2 | 8.4 |
| May 15 | 10 | 6.0 | 3.6 | 7.9 | 11.6 |
| May 22 | 8 | 5.0 | 9.1 | 4.6 | 8.0 |
| Mean (LSD 5 per cent level 3.8) | | 7.9 | 13.8 | 12.6 | 15.4 |

*Degrees divergent from horizontal

Table 12.--EFFECT OF DAY TEMPERATURES ON CARNATION INTERNODE LENGTH IN CENTIMETERS.

| Date | Ave. No. flowers per sample | Day temperatures 60°F. | 65°F. | 70°F. | 75°F. |
|---|---|---|---|---|---|
| February 17, 1958 | 10 | 9.7 | 9.6 | 9.7 | 9.3 |
| February 28 | 5 | 9.1 | 10.1 | 10.2 | 9.8 |
| March 10 | 8 | 11.2 | 11.8 | 10.9 | 9.8 |
| March 13 | 6 | 11.4 | 10.6 | 10.9 | 8.4 |
| March 27 | 8 | 10.8 | 11.1 | 11.3 | 10.0 |
| April 10 | 7 | 10.8 | 10.7 | 10.5 | 10.2 |
| May 15 | 10 | 12.7 | 11.4 | 10.7 | 11.3 |
| May 22 | 8 | 12.9 | 12.2 | 11.1 | 10.7 |
| Mean (LSD 5 per cent level 0.5) | | 11.1 | 10.9 | 10.7 | 9.9 |

<u>Internode length</u> (Table 12) indicates rather surprising results. A significant difference occurred between treatments, with the longest internodes produced at 60°F. However, Table 6 shows that the height of the plants was greater in the 75°F. treatment. This apparent anomaly occurred because the 75° plants possessed more internodes than those grown at lower temperatures.

<u>Keeping quality</u>, the last item to be considered (Table 13) revealed rather surprising results in that the cut flower life of the 60°F. plants was significantly shorter than any of the other three groups used in this investigation. The number of flowers for each sample ranged from 6 to 20, depending upon the supply.

The more complete breakdown of statistical analysis (Appendix) brought out that differences occurred between dates in many of the measurements given in this section; for example, color, internode length, keeping life and, especially, time of peak production.

Table 13.--EFFECT OF DAY TEMPERATURES ON CUT FLOWER LIFE OF CARNATIONS.

| Date | Day temperatures | | | |
| --- | --- | --- | --- | --- |
| | 60°F. | 65°F. | 70°F. | 75°F. |
| January 29, 1958 | 6.8* | 7.0 | 7.9 | 6.8 |
| February 5 | 7.1 | 7.5 | 7.4 | 7.5 |
| February 10 | 8.0 | 7.8 | 8.4 | 8.0 |
| February 19 | 6.6 | 7.3 | 7.5 | 6.8 |
| February 21 | 7.0 | 7.3 | 7.5 | 7.4 |
| March 5 | 5.8 | 7.8 | 7.0 | 7.0 |
| March 7 | 6.7 | 7.7 | 7.5 | 7.7 |
| March 21 | 7.7 | 7.9 | 8.3 | 7.9 |
| March 23 | 8.3 | 8.7 | 8.5 | 8.5 |
| March 28 | 7.1 | 7.1 | 7.6 | 7.2 |
| April 7 | 6.6 | 7.3 | 7.5 | 7.6 |
| April 11 | 7.2 | 7.1 | 7.6 | 8.0 |
| April 16 | 7.4 | 7.2 | 7.6 | 7.5 |
| May 2 | 7.3 | 8.4 | 7.8 | 8.0 |
| May 19 | 7.8 | 7.8 | 7.2 | 7.7 |
| May 28 | 7.3 | 7.6 | 7.9 | 7.5 |
| Mean (LSD 5 per cent level 0.2) | 7.2 | 7.6 | 7.7 | 7.6 |

*Days

# Chapter V

# DISCUSSION

From the summary in Chapter II, and a close study of the results, it becomes apparent that the two items which should be most seriously considered are yield of the plant and quality of the carnation flowers. One without the other is useless, particularly to the commercial grower who might wish to apply the results obtained in this research.

## Yield

Within the range of 60° to 75°F., day temperatures did not affect yield of the carnation plant, although there was a slight increase in production, in two instances, in the 70°F. treatment. Nor did day temperatures affect the increase in dry matter of carnation plants over an 84-day period.

The inability of temperature to decrease or increase yield in this range might be expected from the conclusion reached by various authors in regard to photosynthesis (24, 25, 26, 57, 68). Some investigators (12, 18, 45), however, have found an increase in yield for each increase in light intensity. Thus, the significant differences found at different times (Experiment four, Table D, Appendix) lead to the hypothesis that, during this investigation, light was the major factor influencing yield.

A general relationship between dry matter increase and light intensity is shown in Figure 14. The light records are those of the U. S. Weather Bureau, Boulder, Colorado, and are average for the years 1944 to 1948. Total energy received is indicated on the abscissa. The variations in dry matter increase are probably due to fluctuations of light during the experiment which would not be found in a four-year average. Light records for the time of this experiment are not available.

In Figure 9, the time of peak production of White Sim indicates that it may be possible to lower day temperatures to 65°F. during periods of low light intensity without drastically delaying time of flowering. A decrease to 60°F. during such periods would further improve quality but would seriously delay production.

Quality

The easiest and most often used indication of quality of the cut flower is mean grade. This criterion commonly uses two objective measurements; length of stem, and weight of the entire cut flower. As has been

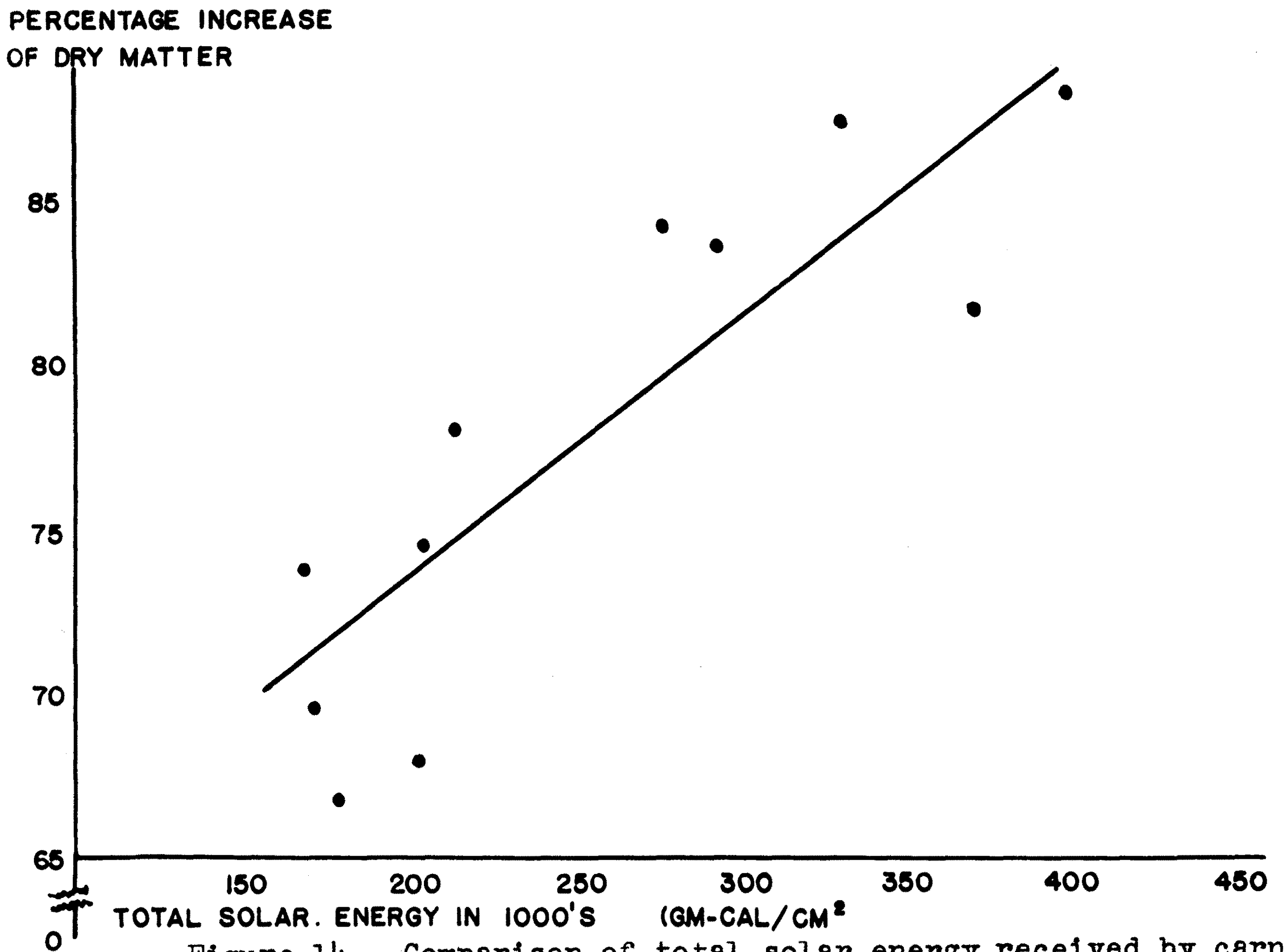


Figure 14.--Comparison of total solar energy received by carnation plants grown for 12 weeks at 65°F. with increase in weight expressed as per cent. (Straight line drawn freehand) See text for more information (Light records from Boulder, Colorado, 1944-1948)

mentioned before, mean grade is not a total measurement of quality, per se, since other phenotypic factors must be considered. The values of these factors (color, stem strength, flower size, leaf width, etc.) are more subjective than weight or length and, hence, not likely to influence mean grade unless easily recognized as detrimental. The role these factors play is subject to a wide variation, indeterminate and dependent upon the experience of the grader. Quality, therefore, is somewhat abstract, encompassing the sum total of cut-flower characteristics which are pleasing to the aesthetic sense. For the purpose of this section, mean grade will be used, with a very general discussion of the other factors which may also be influential.

In the first three experiments, total mean grade was significantly higher in the 65°F. treatment, but the use of those figures might be misleading. There also appears to be a close relationship with light, age of plant and the time during heavy production that the flower was cut. In Figure 15, the highest weekly mean grade in all treatments for Experiments two and three has been plotted against the solar radiation curve from Boulder, Colorado, (1944 to 1948 average). The graph suggests that mean grade might be held consistently high by changing the day temperature, while from Figures 7

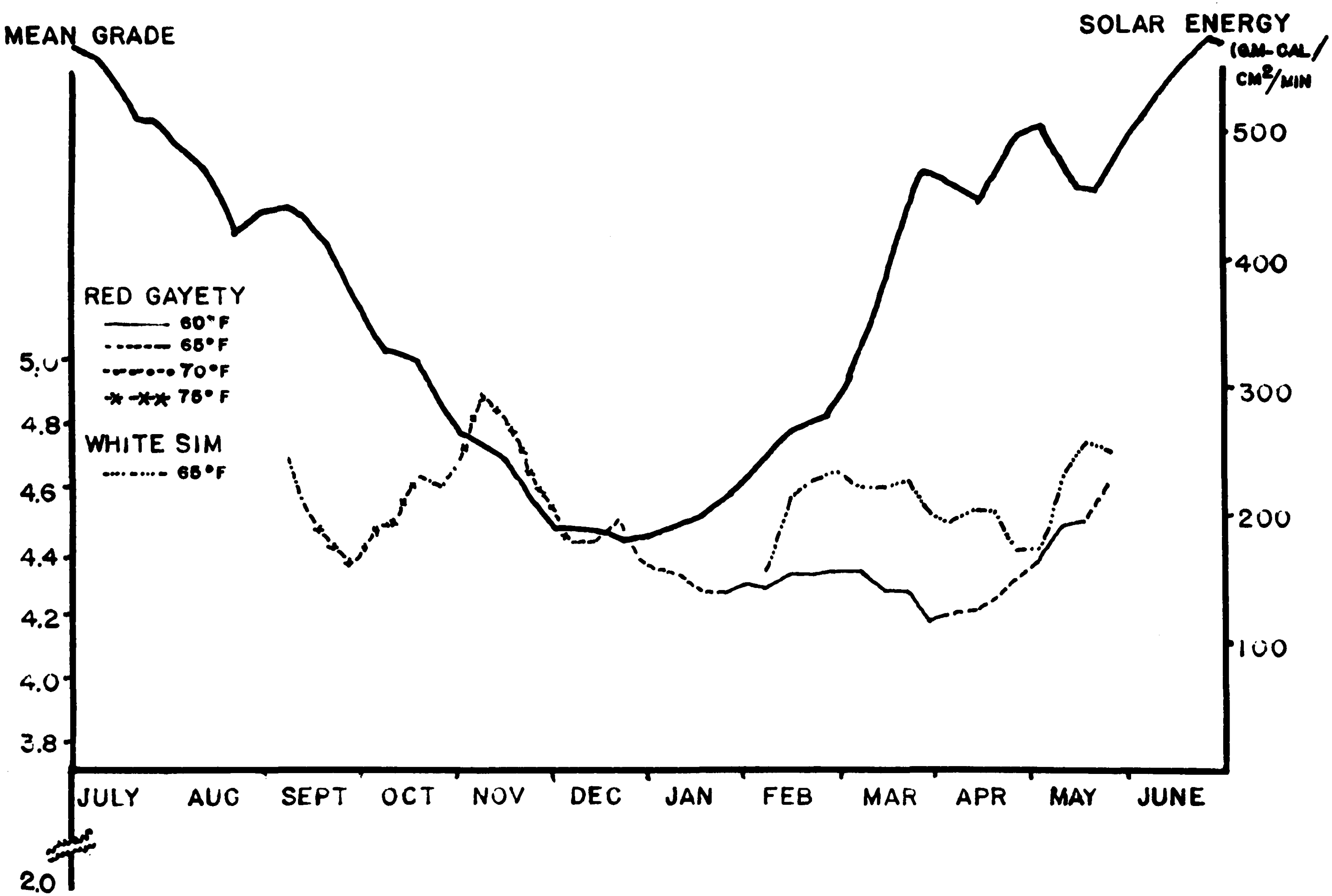


Figure 15.--Comparison of a four-year average light intensity curve, 1944-1948, from the U.S. Weather Bureau, Boulder, Colorado, with mean grade of carnations grown during 1957-1958 at Fort Collins, Colorado. (See text on page 65 )

and 11 the use of steady day temperatures the year around resulted, at times, in extremely low grades.

The effect of age may be deduced from Table 1 and Figure 15. In the first experiment, the Red Gayety plants were beginning their second year of production and the highest mean grade was found in the 60° and 65°F. treatments. In experiment two, the plants which came into production in September, 1957, exhibited the highest grade in the 70° and 75°F. treatments. With increasing age and decreasing light intensity, high grades were produced at 60°F. and under increasing solar energy at 65°F. In Experiment three, the White Sim came into their first peak of production early in 1958, with the highest grade in the 65°F. treatment while at the same time the older Red Gayety of Experiment two maintained highest grade in the 60°F. treatment.

The decrease in fresh weight of the cut flowers from the time heavy production began to the end of peak production was emphasized in Chapter IV. In most instances, this cycle was repeated as the plants returned to heavy cropping.

Apparently, those flowers cut during the initial stages of heavy production received the most light, while those cut during the "tail-out" of peak production were shaded by their predecessors. The influence of cutting time on mean grade is shown clearly in Figure 8 by the 75°F. treatment during October. Returning to peak production, the cut flowers possessed very high weight which caused the grade to increase above what might be considered normal. Later in the season, under low light intensity, poor flowers prevented the next increase in weight at the beginning of heavy production from affecting the grade in a similar manner to that of October-November (Figure 7).

To maintain high quality, several items must be taken into consideration, and this usually results in a compromise. The decision must be made as to whether it is better to delay production (Figure 9) in order to produce stronger stems, bigger flowers and maintain better color (Tables 7, 8 and 11); or, perhaps, to sacrifice those factors in order to bring the crop into production earlier, with longer stems (Table 6) and better keeping life (Table 13).

Disregarding cutting time of the flower, quality might be held reasonably high by temperature manipulation. The conclusion of Went (80) that as the plant grows older and light intensity decreases the optimum temperature for growth decreases, appears true when applied to the carnation plant.

Internode length and keeping

Of the measurements made in this study, and discussed in a general manner under Quality, two gave results which were not expected.

Stems of flowers grown at high temperatures had enough additional nodes to be the longest despite short internodes. The importance of internode length is relatively minor so long as the cut flower possesses sufficient stem length. Obviously, the length of the internode may be misleading when used as a criterion of stem length.

Another item of commercial importance is keeping life of cut flowers grown at 60°F. It was found that these flowers kept significantly less time (0.4 day) than blooms from any of the other three treatments. It may be that 60°F. during the day either prevented maximum photosynthesis (57, 80) or interfered with the translocation of food to the flower (14, 15, 34, 80). The flowers, therefore, may have contained less sugar at the time of cutting than the blooms from other treatments.

In addition to the above two possibilities, the 60°F. day temperatures might have sufficiently lengthened the time until opening of the flower, thereby causing the flowers to be older at cutting time than those in other treatments.

Suggestions for further study

The inadequate light records and lack of records for $CO_2$ levels suggest several areas which could be investigated further in relation to the effects of environment on the carnation plant.

While this study and most others have shown that yield increases as light intensity increases, it is important to find the light intensity at which no further increase is obtained. If saturation is found to occur during high light periods, it might then be possible to increase the yield of carnations by extending the period of saturation with artificial methods.

That light influences yield of carnations in the greenhouse under all conditions may be erroneous. A study of $CO_2$ effects, and methods of increasing $CO_2$ content of the air in greenhouses might lead to ways of increasing yield and quality, and would require re-evaluation of current temperature research related to carnations.

If it is true, as this study has suggested, that quality might be held consistently high by changing the temperatures, there remains the problem of determining when temperatures should be lowered or raised. Also, it is necessary to find out how much a temperature should be raised to take advantage of the increased solar energy available on a clear day. It might be found with carnations, to be more advantageous to regulate temperatures according to seasonal light energy.

# Chapter VI

## SUMMARY

Carnation plants were grown under controlled temperatures, the day temperatures being 60°, 65°, 70° and 75°F. and night temperatures in all treatments 52°F. Temperature differentials were maintained approximately nine months of the year. No control of $CO_2$ was attempted. The results were compared with light records of the U.S. Weather Bureau, Boulder, Colorado, 1944 to 1948.

Neither yield or dry weight production of carnation plants were affected by temperature under the conditions of this investigation. They were directly related to the amount of solar energy received. Quality was related to day temperature and to light intensity, age of the plant and the time at which the flower was cut. When all factors of quality are considered, the 65°F. treatment was nearest optimum.

In considering morphological changes of the carnation cut flower, as the day temperature was reduced from 75°F. to 60°F., the following responses were observed:

1. Color intensity increased (decreasing light intensity also caused a decrease in color).

2. Flower size increased.

3. Leaf width increased.

4. Stem strength increased.

5. Internode length increased.

6. Per cent dry weight of stems decreased.

7. Stem length decreased.

8. Fresh weight of fancy and standard grade cut flowers increased.

9. Flowering was progressively delayed.

The mean keeping life of carnation cut flowers in the 60°F. treatment was found to be significantly less than any of the other three day treatments.

Finally, it is postulated that high quality of carnations might be maintained the year around by proper manipulation of day temperatures, the optimum temperature dropping with plant age and decreasing light intensity.

# A P P E N D I X

The following tables show the analysis of variance applied to the results of this investigation. The asterisk (*) indicates significance.

Table A.--ANALYSIS OF VARIANCE FOR YIELD OF CARNATIONS.

| Sources of variance | df | MS |
|---|---|---|
| Red Gayety (Benched May 21, 1957) | | |
| Temperature | 3 | 28.59 |
| Time | 40 | 2956.91* |
| Error | 120 | 347.53 |
| White Sim (Benched October 18, 1957) | | |
| Temperature | 3 | 48.22 |
| Time | 21 | 439.73 |
| Error | 63 | 513.37 |

Table B.--ANALYSIS OF VARIANCE OF MEAN GRADE OF CARNATION CUT FLOWERS.

| Sources of variance | df | MS |
|---|---|---|
| Red Gayety (Benched June 25, 1956) | | |
| Temperature | 3 | 0.19* |
| Time | 21 | 0.19* |
| Error | 62 | 0.04 |
| Red Gayety (Benched May 21, 1957) | | |
| Temperature | 3 | 1.21* |
| Time | 39 | 0.21 |
| Error | 117 | 0.18 |
| White Sim (Benched October 18, 1957) | | |
| Temperature | 3 | 1.42* |
| Time | 15 | 0.097 |
| Error | 45 | 0.061 |

Table C.--ANALYSIS OF VARIANCE FOR FRESH WEIGHT OF FANCY AND STANDARD GRADE CARNATIONS.

| Sources of variance | df | MS |
|---|---|---|
| Red Gayety (Benched June 25, 1956) | | |
| Fancy grade | | |
| Temperature | 3 | 27.33* |
| Time | 15 | 10.55* |
| Error | 45 | 0.12 |
| Red Gayety (Benched May 21, 1957) | | |
| Fancy grade | | |
| Temperature | 3 | 46.59* |
| Time | 30 | 2.98 |
| Error | 90 | 4.19 |
| Standard grade | | |
| Temperature | 3 | 113.28* |
| Time | 34 | 7.28 |
| Error | 102 | 3.43 |
| White Sim (Benched October 18, 1957) | | |
| Fancy grade | | |
| Temperature | 3 | 13.75 |
| Time | 12 | 13.98 |
| Error | 36 | 8.69 |
| Standard grade | | |
| Temperature | 3 | 91.10* |
| Time | 15 | 6.23 |
| Error | 45 | 7.20 |

Table D.--ANALYSIS OF VARIANCE OF PER CENT INCREASE IN DRY MATTER OF YOUNG CARNATIONS GROWN FOR 84 DAYS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 12.86 |
| Time | 10 | 202.96* |
| Error | 30 | 8.90 |

Table E.--ANALYSIS OF VARIANCE OF CARNATION CUTTINGS PROPAGATED AT THREE DIFFERENT TIMES DURING THE YEAR OF 1957 TO 1958 AND REMOVED AT REGULAR INTERVALS FROM COLD STORAGE.

| Source of variance | df | MS |
|---|---|---|
| Propagations | 2 | 4.05* |
| Time | 11 | 0.82* |
| Error | 106 | 0.01 |

Table F.--ANALYSIS OF VARIANCE OF COLOR OF RED GAYETY CARNATIONS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 1.83 |
| Time | 4 | 8.33* |
| Error | 12 | 1.04 |

Table G.--ANALYSIS OF VARIANCE OF DRY MATTER OF CARNATION STEMS.

| Source of variance | df | MS |
|---|---|---|
| Green weight | | |
| Temperature | 3 | 0.06 |
| Time | 3 | 0.06 |
| Error | 9 | 0.09 |
| Dry weight | | |
| Temperature | 3 | 2.89 |
| Time | 3 | 1.33 |
| Error | 9 | 2.47 |
| Per cent dry matter | | |
| Temperature | 3 | 1.57* |
| Time | 3 | 0.10 |
| Error | 9 | 0.19 |

Table H.--ANALYSIS OF VARIANCE OF FLOWER VOLUME OF RED GAYETY CARNATIONS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 20.23* |
| Time | 1 | 2.88 |
| Error | 3 | 0.83 |

Table I.--ANALYSIS OF VARIANCE OF INTERNODE LENGTH OF CARNATIONS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 2.06* |
| Time | 7 | 2.92* |
| Error | 21 | 0.19 |

Table J.--ANALYSIS OF VARIANCE OF KEEPING LIFE OF CARNATIONS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 0.87* |
| Time | 15 | 0.68* |
| Error | 45 | 0.10 |

Table K.--ANALYSIS OF VARIANCE OF LEAF WIDTH OF CARNATIONS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 0.070* |
| Time | 7 | 0.014 |
| Error | 21 | 0.015 |

Table L.--ANALYSIS OF VARIANCE OF STEM STRENGTH OF CARNATIONS.

| Source of variance | df | MS |
|---|---|---|
| Temperature | 3 | 123.91* |
| Time | 11 | 39.28 |
| Error | 33 | 20.45 |

# B I B L I O G R A P H Y

# BIBLIOGRAPHY


1. Arthur, J. M., J. D. Guthrie and J. M. Newell. 1930. Some effects of artificial climates on the growth and chemical composition of plants. Cont. Boyce-Thompson Inst. 2:445-511.

2. Bandurski, R. S., F. M. Scott, M. Pflug and F. W. Went. 1953. The effect of temperature on the color and anatomy of tomato leaves. Amer. Jour. Bot. 40:41-46.

3. Bendix, S. and F. W. Went. 1956. Some effects of temperature and photoperiod on the growth of tomato seedlings. Bot. Gaz. 117:326-335.

4. Blackman, F. F. 1905. Optima and limiting factors. Ann. Bot. (London). 19:281-295.

5. Blackman, G. E. and G. L. Wilson. 1951 Physiological and ecological studies in the analysis of plant environment. VI: The constancy for different species of a logarithimic relationship between net assimilation rate and light intensity and its ecological significance. Ann. Bot. (London). 15:63-94.

6. Blank, F. 1947. The anthocyanin pigments of plants. Bot. Rev. 13:241-317.

7. Bohning, R. H. 1949. The time course of photosynthesis in apple leaves exposed to continuous illumination. Plant Physiol. 24:222-240.

8. Bonner, J. 1950. Plant Biochemistry. Academic Press, New York. 537 p.

9. Bonner, J. and A. W. Galston. 1952. Principles of Plant Physiology. Freeman and Company, San Francisco. 499 p.

10. Bunning, E. 1956. Endogenous rhythms in plants. Ann. Rev. Plant Physiol. 7:71-90.

BIBLIOGRAPHY.--Continued

11. Camus, G. C. and F. W. Went. 1952. The thermoperiodicity of three varieties of Nicotiana tobacum. Amer. Jour. Bot. 39:521-528.

12. Chapman, H. W. and W. E. Loomis. 1953. Photosynthesis in the potato under field conditions. Plant Physiol. 28:703-716.

13. Crabb, G. A. 1950. Solar radiation investigations in Michigan. Tech. Bul. 222. Michigan State College, East Lansing.

14. Curtis, O. F. 1929. Studies on solute translocation in plants. Amer. Jour. Bot. 16:154-168.

15. ______________ and S. D. Herty. 1936. The effect of temperature on translocation from leaves. Amer. Jour. Bot. 23:528-532.

16. ______________ and D. G. Clark. 1950. An Introduction to Plant Physiology. McGraw-Hill, New York. 752 p.

17. Davidson, O. W. 1941. Effects of temperature on growth and flower production of gardenias. Amer. Soc. Hort. Sci. Proc. 39:387-390.

18. Decker, J. P. 1944. Effect of temperature on photosynthesis and respiration in red and loblolly pines. Plant Physiol. 19:679-688.

19. ______________ 1947. The effect of air supply on apparent photosynthesis. Plant Physiol. 22:561-571.

20. Demelon, P. 1956. Croisance des Vegetaux Cultives. Dunod, Paris. 576 p.

21. Deneke, H. 1931. Uber den einfluss bewegter luft auf die kohlensaure assimilation. Jahr. Wiss. Bot. 74:1-32.

22. DeWerth, A. F. 1955. A practical method of cooling greenhouses. Texas Florists' Bul. 91.

BIBLIOGRAPHY.--Continued


23. Dorland, R. E. and F. W. Went. 1947. Plant growth under controlled conditions. VIII: Growth and fruiting of the chili pepper. Amer. Jour. Bot. 34:393-401.

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

25. ________________ 1937. Photosynthesis. Ann. Rev. Biochem. 6:535-556.

26. Franck. J. and W. E. Loomis. 1949. Photosynthesis in Plants. Iowa State College Press, Ames. 500 p.

27. Freeland, R. O. 1952. Effect of age of leaves upon the rate of photosynthesis in some conifers. Plant Physiol. 27:685-690.

28. Hanan, J. 1958. Air movement and temperature control. Colo. Flower Growers' Assoc. Bul. 98.

29. ________________ 1958. An objective measurement of stem strength. Colo. Flower Growers' Assoc. Bul. 100.

30. ________________ 1958. Ventilator control. Colo. Flower Growers' Assoc. Bul. 102.

31. ________________ 1958. Air movement and temperature control II. Colo. Flower Growers' Assoc. Bul. 103.

32. Heinicke, A. J. and M. B. Hoffman. 1933. The rate of photosynthesis of apple leaves under natural conditions. Part I. Cornell University Agr. Exp. Sta. Bul. 577:1-32.

33. ________________ and N. F. Childers. 1937. The daily rate of photosynthesis during the growing season of 1935 of a young apple tree of bearing age. Cornell University Agr. Exp. Sta. Bul. 201:1-52.

BIBLIOGRAPHY.--Continued

34. Hewitt, S. P. and O. F. Curtis. 1948. The effect of temperatures on loss of dry matter and carbohydrates from leaves by respiration and translocation. Amer. Jour. Bot. 35:746-755.

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

36. ______________ 1953. Carnations are tolerant to a wide range of soil moistures. Colo. Flower Growers' Assoc. Bul. 46.

37. ______________ 1957. Some factors which influence soft growth. Colo. Flower Growers' Assoc. Bul. 86.

38. ______________ 1957. Some effects of greenhouse cooling on carnation timing. Colo. Flower Growers' Assoc. Bul. 89.

39. ______________ 1958. Feeding greenhouse plants. Colo. Flower Growers' Assoc. Bul. 97.

40. Hull, H. M. 1952. Carbohydrate translocation in tomato and sugar beet with particular reference to temperature effect. Amer. Jour. Bot. 39:661-669.

41. Knappenberger, R. L. 1955. The effect of sugar content on cut flower keeping life of carnations. Master's Thesis. Colorado A. and M. College, Fort Collins. 49 p.

42. Kiplinger, D. C. 1951. Tips to carnation growers. Amer. Carn. Soc. Proc. p. 71.

43. Kramer, P. J. and J. P. Decker. 1944. Relation between light intensity and rate of photosynthesis of loblolly pine and certain hardwoods. Plant Physiol. 19:350-358.

44. Langham, D. G. 1941. The effect of light on the growth habit of plants. Amer. Jour. Bot. 28:951-956.

45. Lauritzen, J. I., E. W. Brandes and J. Matz. 1946. Influence of light and temperature on sugar cane and _Erianthus_. Jour. Agr. Res. 72:1-18.

BIBLIOGRAPHY.--Continued

46. Lewis, H. and F. W. Went. 1945. Plant growth under controlled conditions. IV: Response of California annuals to photoperiod and temperature. Amer. Jour. Bot. 32:1-12.

47. Liebig, J. c. 1843. Liebig's complete works on chemistry. Peterson, Philadelphia. P.1-135.

48. Mastalerz, J. W. 1952. Nitrate levels, light intensity, growing temperature and keeping qualities of flowers held at 31°F. New York State Flower Growers' Bul. 88.

49. Meyer, B. S. and D. B. Anderson. 1952. Plant Physiology. Nostrand Co., New York. 696 p.

50. Miller, E. C. 1938. Plant Physiology. McGraw-Hill, New York. 1201 p.

51. Miller, R. O. 1958. Fifty degrees for snapdragons. New York State Flower Growers' Bul. 145.

52. Monsalise, S. Personal communication with F. W. Went, January 10, 1958.

53. Nelson, K. S. 1953. Concise carnation culture. Ohio Florists' Assoc. Bul. 281.

54. Onslow, M. W. 1925. The Anthocyanin Pigments of Plants. 2nd Ed. University Press, Cambridge, England. 314 p.

55. Parker, M. W. 1946. Environmental factors and their control in plant experiments. Soil Sci. 62:109-119.

56. Post, K. 1950. Florist Crop Production and Marketing. Orange-Judd Pub. Co., New York. 891 p.

57. Rabinowitch, E. I. 1945-1956. Photosynthesis and Related Processes. Interscience Pub., New York. 3 Vols., 2088 p.

58. Ratsek, J. C. 1941. Some factors causing fading in color of rose blooms. Amer. Soc. Hort. Sci. Proc. 39:419-422.

BIBLIOGRAPHY.--Continued

59. ______________ 1944. The effect of temperature on bloom color of roses. Amer. Soc. Hort. Sci. Proc. 44:549-551.

60. Scarth, G. W. and M. Shaw. 1951. Stomatal movement and photosynthesis in Pelargonium. I: Effects of light and $CO_2$. Plant Physiol. 26:207-225.

61. Schmidt, R. G. 1956. Carnations can be cooled too much. Colo. Flower Growers' Assoc. Bul. 83.

62. ________________ 1957. Some effects of night temperatures on carnations. Master's Thesis. Colorado State University, Fort Collins, Colo. 47 p.

63. Singh, B. N. and K. N. Lal. 1935. Limitation of Blackman's Law of limiting factors and Harder's concept of relative minimums as applied to photosynthesis. Plant Physiol. 10:245-268.

64. ______________________ 1935. Investigation of the effect of age on assimilation of leaves. Ann. Bot. (London). 49:291-307.

65. Snedecor, G. W. 1955. Statistical Methods Applied to Experiments in Agriculture and Biology. Iowa State College Press, Ames. 485 p.

66. Sparks, W. C. 1944. The effect of certain minor elements on the skin color of potatoes as measured by the multiple disc colorimeter. Amer. Soc. Hort. Sci. Proc. 44:369-378.

67. Tammen, J., R. R. Baker and W. D. Holley. 1956. Control of carnation diseases through the cultured cutting technique. Plant Dis. Reptr. Supp. 238:72-76.

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

69. ______________ and G. R. Hill. 1937. The continuous measurement of photosynthesis, respiration and transpiration of alfalfa and wheat growing under field conditions. Plant Physiol. 12:285-307.

BIBLIOGRAPHY.--Continued


70. Thut, H. F. and W. E. Loomis. 1944. Relation of light to growth of plants. Plant Physiol. 19: 117-129.

71. Ulrich, A. 1952. The influence of temperature and light factors on the growth and development of sugar beets in controlled climatic environments. Agr. Jour. 44:66-73.

72. Uota, M. 1952. Temperature studies on the development of anthocyanin in McIntosh apples. Amer. Soc. Hort. Sci. Proc. 59:231-237.

73. Verdiun, J. and W. E. Loomis. 1944. Absorption of $CO_2$ by maize. Plant Physiol. 19:278-293.

74. Wagner, D. 1953. Calyx splitting of carnations is inherited. Colo. Flower Growers' Assoc. Bul. 49.

75. ________________ 1953. Some effects of temperatures on carnation calyx splitting. Master's Thesis. Colorado A. and M. College, Fort Collins, Colo. 56 p.

76. ________________ and W. D. Holley. 1953. Unusually high day temperatures cause carnation calyxes to split. Colo. Flower Growers' Assoc. Bul. 43.

77. Went, F. W. 1947. Man-made temperatures help plant growth. Refrig. Engineer. 54:495.

78. ________________ 1953. The effect of temperature on plant growth. Ann. Rev. Plant Physiol. 4:347-362.

79. ________________ 1956. The role of the environment in plant growth. Amer. Sci. 44:378-398.

80. ________________ 1957. The Experimental Control of Plant Growth. Chronica Botanica, Waltham, Mass. 343 p.