THESIS

EFFECT OF SOLAR ENERGY ON THE OPTIMUM DAY TEMPERATURE FOR CARNATION GROWTH

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JIMMY DARRELL MANRING

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BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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TABLE OF CONTENTS

TABLE OF CONTENTS.—Continued

LIST OF TABLES

LIST OF TABLES.--Continued

LIST OF FIGURES

LIST OF FIGURES.—Continued

Chapter I

INTRODUCTION

The environment can be subdivided into two parts--internal and external. The internal environment for gene action is the cell and its physical and chemical make up (94). The external environment consists of the surrounding air, the soil, numerous pests, diseases, viruses, radiation in all its forms and manifestations, the physical effects of neighboring plants, and many other factors.

For many years investigators in the field of plant physiology have recognized the fact that the environment influences plant growth (1, 7, 28, 75, 76). It became apparent that even slight differences in external environment may affect certain morphological factors. However, the same alteration may not produce the same effect under a different environment (92, 94).

Intensive investigations on the effect of temperature on photosynthesis, respiration, and many morphological factors have been conducted. The role of light in such physiological processes as phototropism, photoperiodism, and photosynthesis have been investigated. At the present time investigations on the quality of light, and light energy relationships are being studied for their effect on plant growth.

The problem

Should day temperature be correlated with seasonal variations in light to obtain optimum carnation growth?

Problem analysis.--To facilitate the investigation of the effect of solar energy and day temperature on carnation growth these different factors were measured:

1. Amount of solar energy the plants received
2. Yield
3. Mean grade
4. Flower production
5. Green weight and dry weight comparisons
6. Cut flower keeping life
7. Internode length
8. Stem strength
9. Leaf length
10. Leaf width
11. Flower volume

Delimitations.--This investigation will be limited to the study of light intensity and its effect on White Sim and Red Gayety carnations grown under different temperature combinations. Effects of night temperature will not be investigated. The day temperatures will be limited to a range recommended by previous investigators, especially those carried on in the temperature controlled greenhouses at Colorado State University. The changes in temperature will be arbitrarily set by selecting periods in the fall and spring that have equal amounts of solar energy.

No attempt will be made to measure the carbon dioxide content of the different compartments even though the amount of fresh air circulated through them will vary. Soil fertility and moisture will be kept as constant as possible.

Definition of terms

Slabsided flower--A flower that does not open properly on one side. This is caused by the formation of a small auxiliary whirl of petaloids.

Bullhead flower--A flower having several auxiliary whorls of petaloids.

Mean grade--A quality index obtained by assigning the following values: fancy-5; standard-4; short-3; and design-2.

Solar energy and light--The meanings of these two words are so closely related that they may be used interchangeably.

Background

In Colorado and many other areas of the United States the size and quality of carnations decreases with high summer temperatures, thus reducing their saleability (55, 66). In the past few years the fan and wet evaporative pad cooling system has been used to cool greenhouses and to lessen the number of poor quality flowers. However, this method of cooling has an adverse effect on the quality of the winter and spring crops by producing a large number of breaks during a period of decreasing solar energy (43, 44).

Better quality and greater yield are the goals of the carnation industry. Therefore the factors affecting quality and yield should be thoroughly investigated. Of these factors two of the most important are light and temperature.

According to Bonner (12) and Shirley (76), all physiological processes are directly or indirectly influenced by light and temperature, with light being the more important. However, it is difficult to separate their effects on plant growth.

Recent advancements in temperature control equipment have made it possible to regulate temperature to plus or minus one degree. Slight modification to further increase sensitivity and control has allowed for greater accuracy in studies of temperature on specific crops. As these studies progressed it was found that no one temperature would give optimum growth of carnations the year around. Following two years of day temperature research on carnations, Hanan (36, 38) postulated that day temperature should be correlated with seasonal solar energy.

Chapter II

REVIEW OF LITERATURE

Introduction

Although the concepts of growth analysis were first formulated more than forty years ago there is little information available at the present time on the relationships between growth and development and seasonal changes in light intensity and temperature. The tomato is the only plant on which continuous records for growth under greenhouse conditions have been kept. These records included variations in net assimilation rate and the relative growth rate for plants at a comparable stage of development (34). A number of other workers (35, 91, 95) have linked variations in growth with fluctuations in environment.

Any attempt to cover all facets of light and temperature and their effect on plant growth would be impossible. This review will be limited to light and temperature factors directly related to this study.

Previous temperature recommendations

The recommendation of one specific temperature for all carnation growing areas would be impossible due to the use of different varieties and environmental conditions. Ball (3) recommended a night temperature of 50° F. for carnations, but he felt it was advisable to have a slight fluctuation of day temperature depending upon the amount of light available. For cloudy days he recommended 58° F. and for clear, sunny days 62-65° F.

Kiplinger (51) and Laurie and Kiplinger (55), stated that during the heating season some growers kept their day temperatures at 48^{o} F. to 50^{o} F. the same as their night temperature. If cloudy weather continued for several days during the winter the temperature should be decreased to 46^{o} F.

Post (66), however, felt that under periods of high light intensity carnations grew best with a night temperature not over 50^{o} F. The day temperature recommended for clear days was 10 to 15 degrees above the night temperature, and on cloudy days 5 to 10 degrees above the night temperature. He said that during periods of high light intensity air temperatures were not undesirable until they exceeded 90^{o} F.

According to Schmidt (72) each of the major factors affecting quality had a specific optimum night temperature. He obtained results indicating that cooling the day temperature to 60^{o} F., when light was not a limiting factor, might reduce yield (71). In later experiments he concluded that a night temperature of 52^{o} F. would be the best for commercial practice (72).

Hanan (38, 41), working with four different continuous day temperatures, stated that neither yield nor dry matter production of carnations was affected by temperatures between 60^{o} to 75^{o} F., but that they were in direct relationship to the amount of solar energy received. He found highest cut flower quality on plants grown at 60^{o} F., with quality related to light intensity and age of the plant. His final postulation was that higher quality carnations might be maintained the year around by correlation of day temperature with light intensity (36).

Holley (42) had previously recommended a temperature not to exceed 65° F. as a means of coping with soft growth during periods of low light intensity.

Later Holley and Hanan (47) gave the following recommendations: (a) during periods of high light intensity, March 15 to October 1, a day temperature of 70° F. should be maintained when possible; (b) from October 1 to November 15 the temperature should be dropped to 65° F.; (c) during the period when light is lowest, November 15 to February 1, the day temperature should be set at 60° F.; (d) with increasing light from February 1 to March 15 the temperature should be increased to 65° F.; (e) night temperature from October 1 to March 15 should be 50° or 52° F. The remaining part of the year, outside temperature permitting, the night temperature should be 54° F.

<u>Effects of day and night temperature</u>

<u>Photosynthesis</u>.--Blackman, as noted by Dorland et.al. (26) and Shirley (77), in 1905 found that under certain conditions photosynthesis cannot be accelerated by increasing the light intensity. Photosynthesis continues to increase with light until secondary effects such as the following set in: (a) high temperatures brought about by increased light; (b) the over-accumulation of photosynthate in the leaves resulting in a reduction in photosynthesis; (c) water deficit causing closure of the stomata; or (d) some other internal factor (76, 77, 81).

Bohning (10) states that the length of time the initial rate of photosynthesis can be maintained in apple leaves exposed to continuous illumination will be influenced by the intensity of illumination and previous history of the plant. Other investigators (1, 12) have found that under continuous illumination certain crops have a rapid initial rate of photosynthesis which decreases with time. It has also been found that a flashing light of a given intensity produces more photosynthate than a continuous light at the same intensity (15).

Many investigators (13, 31, 33, 59, 81) have found that photosynthesis is a two-step reaction. The first reaction is a non-photochemical reaction, which may be carried out in either the presence or absence of light. Many refer to this reaction as the "Blackman reaction", or the "dark reaction". Some of these investigators seem certain that there are several "dark reactions" involved in photosynthesis. The second is a photochemical reaction which proceeds only in light. This reaction has been termed the "Hill reaction" or the "chloroplast reaction", a mechanism whereby the light energy absorbed by chlorophyll is converted to chemical energy.

Light, besides being the energy source for assimilation of carbon dioxide in the photosynthetic processes, has many other known functions in plants. It affects the permeability of cell membranes (91), the physical and chemical properties of photoplasm (87), and the development of stems, leaves, and other plant organs (63), along with many of the reproductive processes (27, 64).

Temperature.--Early assumptions were that all photochemical reactions of plants proceed faster at low temperatures. This was brought about by high values of Q_{10} at low temperatures, a common occurrence in biological processes (11, 81). Various authors (28, 29, 67, 82) point out that the photochemical reaction utilizes light energy and is unaffected by temperature, while the enzymatic reactions exhibit varying Q_{10}. The temperature range for the enzymatic reactions is similar to the range for respiration. When the light intensity is high enough to cause the enzymatic reactions to become limiting, the effect of temperature on photosynthesis is evident. However, at low carbon dioxide concentrations diffusion processes may become important (18).

Temperature also influences many other plant responses such as growth, flowering, leaf size, and stem elongation. Many investigators (6, 17, 26, 36, 57, 85, 92) feel that night temperature has the greatest effect on these responses because a majority of the sugars and water are transported to meristematic regions during the night.

In a few cases night temperature in excess of the day temperature gives better plant growth (66, 93), but for the majority of plants already studied such as sugar beet (85), tomato (6, 93), chili pepper (26), apples (73), and some California annuals (57), the optimum night temperature is below the optimum day temperature.

Boodley and Seeley (14) grew the rose varieties Better Times, Golden Rapture, Peter's Briarcliff, and Lily White, under standard and adjusted night temperatures for four seasons. During the first three seasons the night temperature was adjusted to 60° F.

following clear days and 55° F. following cloudy days; the fourth year they increased both temperatures five degrees. The standard night temperature was 60° F. regardless of the previous weather conditions. They found that decreasing the night temperature only decreased plant growth and yield with the keeping quality the same for both treatments. They concluded that it was desirable to maintain a standard night temperature during the fall, winter, and spring regardless of light intensity for the previous day.

Miller (60) carried out a similar experiment on snapdragons, and found an increase in growth and quality when the night temperature was raised following sunny days.

Light investigations

Investigations concerning the influence of light on plants have been directed in two ways: (a) the effect of different intensities of illumination, and (b) the influence of different frequencies or wave lengths.

Light quality.--In this investigation the only concern will be light frequencies within the greenhouse. Kohl (54) has found that new greenhouse glass transmits light of 3250 A° to 20,000 A°, which was the limit of his instrument. He found that 85 to 90 per cent of the visible light was transmitted through glass.

Curtis and Clark (20) found that light used as an energy source for photosynthesis was correlated with the absorption bands for chlorophyll. Effective photosynthesis in the red region was high, agreeing with what was expected, but the high rate of photosynthesis in the green region, and the low rate of photosynthesis in the blue region were not expected. In a few of their experiments where neither carbon dioxide nor temperature was limiting, red light was the most effective in photosynthesis, blue light was somewhat less effective, and green light was still less effective. The low effectiveness of green light is due to the large amount that is reflected by the chlorophyll. Ultraviolet light of wave lengths less than 2900 A° was distinctly injurious. In general, ultraviolet light may be stimulating to plant growth above 2900 A° (2, 96).

Popp (65) found that plants receiving the complete spectrum of light differed only slightly from plants receiving all light except ultraviolet. He stated that ultraviolet is not indispensible, and the blue-violet range of the visible spectrum is necessary for normal growth of chrysanthemum, begonia, fuchsia, beet, cucumber and potato.

Shirley (76) found that production of dry matter for *Geum*, *Galinsoga*, sunflower, and buckwheat under the complete solar spectrum was higher than for any portion of it. No light condition was more advantageous for normal growth of *Zinnia* and *Kalanchoe* than daylight (50). It has been concluded by Crocker (19) and Popp (65) that no light source or combination of colored light has proven superior to the full spectrum for plant growth.

Recent studies of light quality have been on the amount of energy from different light sources and the amount of energy used in photosynthesis, and have little bearing on this investigation.

Light intensity.--There are many factors affecting the light intensity received at the earth's surface, but dust and water vapor are the two major obstructions which decrease the intensity.

Even with these obstructions the earth intercepts 5×10^{20} kilocalories per year. At any location in the United States the sun's energy reaches the earth at a rate of about one cal./cm.^{2}/min. (22).

Thut and Loomis (84) stated that plants grown in varying intensities of light from full sun to darkness show characteristics and well known differences in growth and development. The most common of these characteristics are decrease in the percentage of dry matter, elongation of the internode, and loss of chlorophyll when light becomes very limiting.

Schrader and Marth (73) found that the red color of apples shaded with bags decreased markedly from apples grown in full sun. They did offer the possibility of temperature differences between the bagged fruit and unbagged fruit having some effect on color as well as size.

Shirley (76) gave evidence that during the winter the dry weight produced by plants was directly correlated with solar energy received in the greenhouse. He also stated that during the summer some plants were capable of more efficient use of light at higher intensities. The plants used were dwarf sunflower, peanut, buckwheat, loblolly pine, tomato, tobacco, California redwood, and wandering Jew.

Carnations respond most favorably to light intensities of 1500 foot candles or more (42, 77). Temperature becomes increasingly important in the production of carnations when light intensity decreases (76). Under low intensities of 100 to 200 foot candles, carbohydrate production can easily be exceeded by loss due to respiration. This helps to account for the poor yield and quality of cut flowers obtained by careless growers.

Some investigators (18, 23, 38, 56) have found that for each increase in light intensity there is an increase in yield. This statement seems valid for carnations grown under greenhouse conditions unless carbon dioxide nutrition or some other factor is limiting. At different times throughout the year carbon dioxide or nutrition may be the factor controlling yield.

Shantz (75) found little or no reduction in growth of radishes, lettuce, corn, potatoes, cotton, and mustard when the light was reduced by one-fifth that of full sun light. He used general appearance of the plant, number of nodes, fresh weight, and height as a measurement of growth. He commented that light one-fifteenth that of full sun caused a marked reduction in the rate of growth.

Effects of light and temperature on plant anatomy

Arthur et. al. (1) in summary stated, "Unless all factors are controlled, any attempts to measure a single factor as a causative agent of a particular development of the plants would seem to be mainly speculative." In other words, a plant's responses may be very evident under one set of environmental conditions and be unnoticed under a different environment.

Effect of temperature on plant anatomy.--Monsalise (38) found that decreasing temperatures caused carnations to have increased flower size, wider leaves, and more rigid stems with decreasing stem length. His results agreed closely with those of Hanan (38). Hanan also found increases in color, internode length, percent of dry matter in stems, and fresh weight of fancy and standard grade carnation; along with a decrease in stem length and a progressive delay in flowering with lower temperatures (38, 41). He found that flowering was hastened only slightly and quality reduced markedly by raising the day temperature during the winter to increase production for good market periods. When the day temperature was increased to 70° F. or more it caused a reduction in cut flower weight. There were no measureable differences in yield (36).

Holley (43) has given evidence to show that summer carnation growth can be hastened as much as four to six weeks between crops, and two weeks from planting to pinching by using an evaporative pad and fan cooling system. He also stated that this cooling suppressed the apical dominance (44), promoting early growth of lateral branches. Low temperatures give tomato foliage an increase in color and make the leaves small and fleshy (4). Went (93) found that flowering is usually hastened by an increase in temperature. He has also shown that the leaves of chili peppers become yellow at high temperatures. Many investigators state that higher temperature increases the rate of stem elongation (4, 6, 17, 26, 93).

Effect of light on plant anatomy.--Shirley (77) has shown that as light is decreased, tomato leaves become thinner, and under low intensities the palisade tissue decreases from two to one layer, while the intercellular spaces are increased slightly. The chlorophyll content increases with decreasing light intensities until a critical intensity was reached. This increase was more pronounced when considered on the basis of leaf area.

At low light intensities the production of dry matter for buckwheat and sunflower is almost directly proportional to the intensity received up to about 20 per cent of full sun light (77). The percentage of dry matter in the tops, the ratio of dry matter of the roots to dry matter of shoots, the number of lateral branches and the strength of stem all increase with increasing light intensity. Shirley (77) stated that first flowers were produced in about the same time under all light intensities unless the light was so low it seriously injured growth. There was no appreciable delay in the time of appearance of the first flower when shade was used, but maximum flower development occurred earlier on plants receiving higher light intensities. Insufficient light causes an elongation of lateral branches without originating any new side breaks. Similar symptoms are also associated with a lack of available nitrates (49).

The amount of vitamin C found in plants is directly or indirectly influenced by the amount of light and activity of the chloroplast. Light appeared to be essential also for the synthesis of a substance other than ascorbic acid which is concerned with the expansion of the leaf blade (21, 69).

Effects of light and temperature on color.--Many investigators (5, 9, 52, 66, 68, 86) agree that temperature and light effects anthocyanin concentration, and that lowering the temperature favors anthocyanin production. This effect could be due to the increased concentration of carbohydrates when light is increased and temperature is decreased. Onslow (62) has shown that anthocyanin was produced only during light periods when photosynthesis was actively taking place.

Schmidt (72) found an increase in light intensity along with an increase in temperature from 48° to 54° F. gave increased carnation color. Bonner and Galston (13) in agreement with Uota (86) found a decrease in color with a decrease in solar energy.

The color of carnations may vary without decreasing saleability. Only when the flower is disfigured does color become a serious problem.

Malformation of carnations.--Malformation of certain carnation varieties is to some extent an inherited characteristic (88), which can be accentuated by environmental conditions. The calyx splitting problem has two different concepts. Wagner (89) and Wagner and Holley (90) state that erratic variations in day temperature causes splitting. Other investigators (55, 66, 74) state large fluctuations in night temperature caused splitting. Recent investigations (48) carried on at Colorado State University gave an insight into the complexity of the malformation problem. The production of malformed flowers can be associated with the age and vigor of the plant, temperature relations, time of year, and the variety of carnations. Usually plants produce more malformed flowers during their first year of growth than in the second. Certain temperature relations seem to increase the production of malformed carnations. These relations are not clearly defined, but observations in commercial greenhouses indicate that plants in the path of incoming cold air (from ventilators) produce a high percentage of malformed flowers. The number of malformed flowers and the degree of malformation was correlated with the number of degrees of temperature drop. One observation of a twelve degree drop showed a significant increase of malformed flowers but no splitting of the calyxes was observed. The development of malformed flowers was favored by chilling of the bud three to five weeks before the flower was cut. The production of malformed carnations is greater during certain periods of the year. Malformation was the highest for plants in their first year in September, decreasing in the late November and December, with high week to week fluctuations occurring in January and early February. The second year high malformation occurred in July, September and October. The yield and percentage of malformed flowers was found to be different for each variety and selections within a variety were different in this respect.

Cut flower life.--Mastalerz (58) found that the amount of light and temperature prior to cutting affected the number of days flowers would keep. Fairchild (30) also showed that carnation cut flower life was influenced by a combination of light, temperature, and humidity. He was not able to separate the effects of these factors, but his observations indicated that temperature exerted the greatest influence on cut flower life. Even though light is a very important factor for plant growth he found that extremely high or low intensities did not affect cut flower life. This was not in agreement with Knappenberger's (53) findings that the higher the concentration of sugars present at the time of harvesting the longer the keeping life.

Fairchild (30) found variations in cut flower life gradually rose and fell over periods of several days or weeks. He concluded that these were common and were caused by preharvest environment. Some extremely erratic variations in cut flower life were correlated with erratic weather conditions. He found no difference between the keeping life of flowers cut before or after watering.

Dry matter.--Dry weight of barley plants was correlated positively with mean day temperature and total radiation (35), but negatively with mean night temperature. Eighty per cent of the total variation was due to these three factors. The dry weight of oats correlated with the mean day temperature (95), with light being correlated with day temperature. The percentage of dry matter in carnations increased with increasing solar energy, and decreased with decreasing solar energy (46).

Other factors affecting plant growth

In considering the effects of light and temperature on plants there are many other factors that may influence the results obtained. The amount of carbon dioxide, water, and nutrients present along with the genetic variability (92) and age (17, 32, 67, 79) of the plant affect its behavior under a given light intensity and temperature.

The natural capacity of a plant is closely associated with the age of the plant. As a plant reaches maturity the speed of many internal processes decreases (31, 32, 67, 79). Many of these same processes are affected by temperature. Went (93) stated that the optimum temperature for growth decreases as a plant matures. Age and genetic variability control the production of certain hormones that regulate the rate of many important plant reactions. These hormones may be a controlling factor in translocation, transportation, and rate of uptake of essential substances.

There are many unpredictable fluctuations associated with plants (29). Some of these may be accounted for by natural endogenous rhythms (16).

Many investigators (7, 8, 12, 13, 31, 67) state that photosynthesis is affected by light, carbon dioxide, and temperature. Some investigators (59, 83) state that normal concentration of 0.03 per cent carbon dioxide is not sufficient for maximum photosynthesis. Carbon dioxide probably becomes a limiting factor in still air. Decker (23), working with air flow, found photosynthesis to increase as air movement increased. Scarth and Shaw (70) found slow moving air resulted in a reduction of the carbon dioxide concentration outside and inside the leaf. This was in agreement with Went's work several years later (93).

Chapter III

METHODS AND MATERIALS

This chapter is divided into five sections: (a) the procedures for measuring solar energy,(b) the greenhouse environment that the carnations were grown in, (c) explanation of the five experiments conducted in this investigation, (d) the procedures for measuring and obtaining results for the various morphological factors, and (e) the statistical analysis used to measure the results.

Measurement of light

Daily measurements of solar energy received at the Lake Street greenhouse were taken with an Eppley ten-junction pyrheliometer mounted on a small platform on the roof of the head-house.

During the daylight hours the solar energy from the sun strikes the element of the pyrheliometer producing a minute electromotive force. This electromotive force is then collected by the ten junctions of the pyrheliometer and recorded on a Foxboro twenty-four hour recorder. The full scale for the pyrheliometer is six millivolts, which equals a reading of one hundred on the recorder. The charts from the recorder are subjected to a planimetric analysis with a Foxboro radial planimeter. This converts the charts from millivolts to gram calories of heat energy received/Cm^2 of surface area at that location, during the twenty-four hour period.

Figure 1.--The temperature research greenhouse at Colorado State University.

The greenhouse environment

All investigations on the effect of light and temperature on carnations were carried on in the temperature control research greenhouse (Figure 1). It runs east and west and is approximately 15 feet wide and 70 feet long. The interior is divided into four compartments of equal size. The west most compartment is A with B, C, and D running on to the east. With this orientation of the greenhouse, D received more light in the mornings while A received more light in the afternoons. B and C received the same amount of solar energy in the mornings and afternoons. Theoretically, the compartments would be equal in total solar energy received. Periodic light intensity measurements were conducted when there were no atmospheric obstructions. These measurements indicated that compartments B and C received less solar energy than A and D. Daily variations of atmospheric conditions could cause variations of 25 per cent in the total solar energy received in the various compartments on a given day.

An opaque wall about 2½ feet high surrounds each compartment. On the north wall of each compartment there is a ventilator which is hinged at the eave. This ventilator is four feet wide and runs the full length of the compartment. When the ventilator is fully open it rests against the top of a 34 inch evaporative cooling pad. During the winter, louvers are installed along the bottom of the vent to regulate the flow of incoming air, and to mix this air with the warm air within the compartments.

Each compartment contains two benches approximately 42 inches wide and 12 feet long, and each bench is capable of holding 126 plants at a six by eight inch spacing. These benches are about eight inches above ground level.

A thermostat control shelter is located in the middle of each compartment, about three feet above the ground. The cabinet opens to the north and is louvered to prevent sunlight from striking the instruments. It also allows free passage of air over the thermostats. To increase the air movement over these instruments a small fan is located above and to one side of each control unit. Thermostats within these units control the temperature to plus or minus $1\frac{1}{2}^{\circ}$ F. of the specified temperature for the given compartment. During the summer months a plastic ceiling was used to decrease temperature and the volume of air cooled.

During periods of high temperature and high humidity, the desired temperatures could not be maintained, but with the aid of baffles the five degree temperature differential was maintained between the compartments (37, 39, 40).

A ferto-jet system was employed to water the plants with a dilute solution of fertilizer (45). Additional dry fertilizer was applied when periodic soil tests indicated nutrients might not be adequate. The plants were watered when a Lark tensiometer showed a tension of three to five meters of water. This tension varied with the season of the year. The higher tension was used during the fall and winter, and the lower tension was used during the spring and summer.

The soil was steamed and precautions were taken to prevent recontamination. Carnation plants came from the Colorado State University foundation stock, which was a part of the pathogen-free stock program. After allowing sufficient time for the plants to establish themselves, a sterile leaf mold mulch was added to decrease evaporation of water, to prevent compaction, and to build soil structure.

A spray and fumigation program was used to maintain an insect free crop. During the spring and summer fumigants were

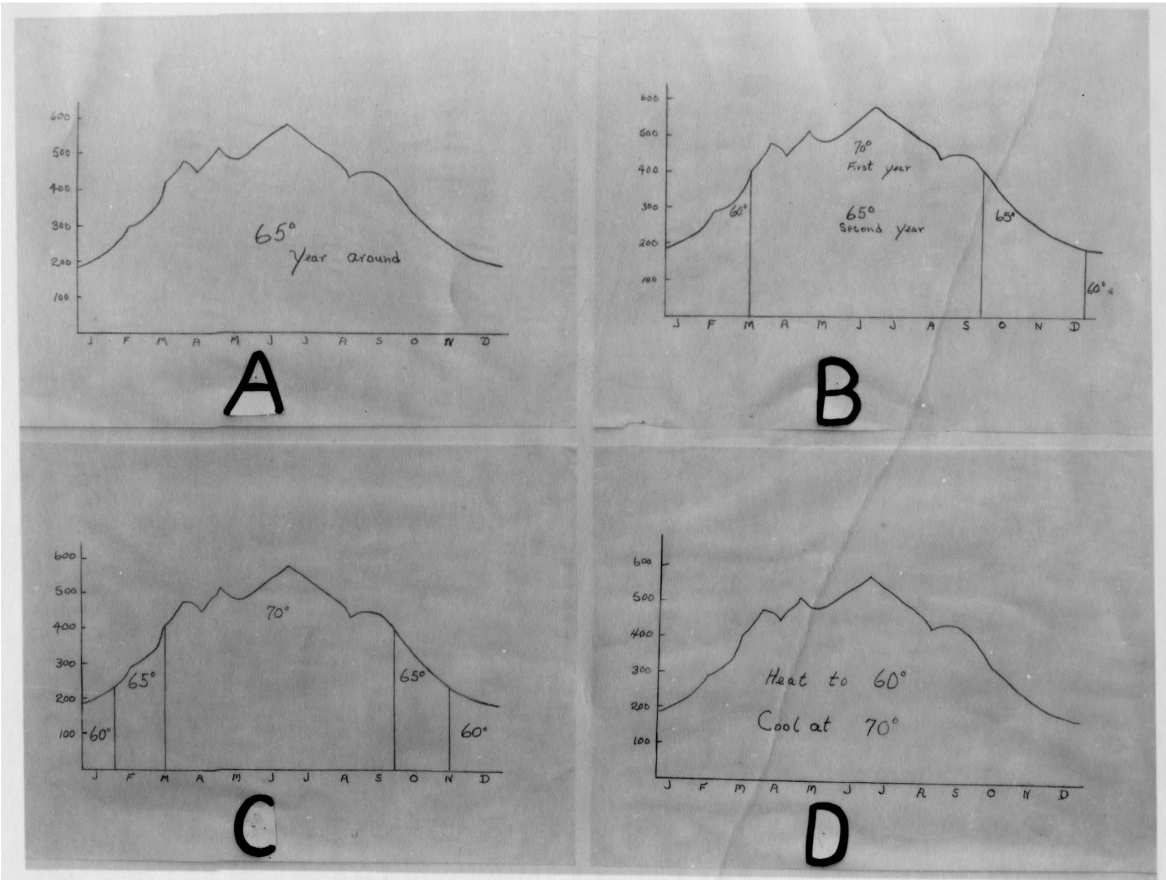


Figure 2.--Four year average solar energy curve, 1944-1948, from the U.S. Weather Bureau, Boulder, Colorado, and correlated dates of temperature change first used in the investigation.

applied every one to two weeks, but during the winter longer periods elapsed between applications.

The night temperature was the same in all compartments. During the heating season (October to May) the night temperature was maintained at 52° F. The remainder of the year the night temperature was the same as the outside temperature provided it was below the day temperature shut-off point for the cooling system.

The temperature range selected for each compartment is indicated in Figure 2, along with the moving mean of solar energy received at Boulder, Colorado, for the years 1944-1948. Further temperature alterations were made after one year's results had been obtained. The 70° F. temperature was decreased to 65° F. on March 13, and in the C compartment the temperature was decreased to 60° F. on September 30, and maintained until the conclusion of the investigation.

The experiments

This investigation was divided into five experiments. The first experiment dealt with the measurement of solar energy. The second, third, and fourth experiments were to determine the effect of different combinations of day temperature on carnation yield, keeping, fresh weight, dry weight, quality, and many other morphological factors. The fifth experiment was to determine the effect of different temperature combinations on the production of dry matter.

Experiment one.--A 15-day moving mean of the solar energy received at Fort Collins, Colorado, was graphed. The amount of solar energy received during different seasons of the year, and the fluctuation for the two years involved in this investigation was also compared.

Experiment two.--Red Gayety carnations were direct benched on June 6, 1958. They received one-and-one-half pinches to give steady production. These plants started blooming on October 4, 1958. Records of the effect of the different day temperature combinations on the various morphological factors were started at that time, with the exception of dry matter accumulation which was started on January 2, 1959. The experiment was concluded September 4, 1959.

<u>Experiment three</u>.--Work was started on September 5, 1959. The same Red Gayety carnation plants were used as in experiment two. This experiment was to determine the effect of the different day temperatures on two-year old plants. Information from the first year's work indicated a modification of temperature was necessary. Compartments <u>A</u> and <u>D</u> continued at the same temperature. Compartment <u>B</u> was decreased 5° F. on November 15, 1959, and brought back to 65° F. on March 15, 1960. Compartment <u>C</u> was lowered ten degrees by decreasing the temperature two degrees a day from September 25-30th, and remained at 60° F. Until the conclusion of the experiment on May 1, 1960.

<u>Experiment four</u>.--White Sim carnation plants, which were planted into peat pots and handled as a nurse bed for six weeks, were planted on May 20, 1959. The same temperatures were used as in experiment three. These plants received the one-and-one-half pinch method to induce branching and give steady production. They began blooming on September 5, 1959, and records were taken until the conclusion of the experiment on May 1, 1960.

<u>Experiment five</u>.--This experiment determined the increase in dry matter of Red Gayety carnations grown for twelve week periods each year. On September 2, 1959, ten gallons of volcanic scoria were fertilized with 6 ozs. of calcium carbonate and 3 ozs. of treble superphosphate and then steamed. Twenty crocks were filled with this mixture and five crocks, containing ten rooted cuttings were placed in each compartment. Every three weeks a new set of ten

plants were started until four sets of crocks were in each compartment. At the end of the twelfth week a set was harvested to make room for the next set.

The Red Gayety cuttings weighed 7 to 9 grams when they were planted in the rooting medium. The cuttings for each set of crocks were then propagated and placed in cold storage at 33° F. until planted.

Three weeks after planting they were pinched to the fifth set of leaves. These pinchings were dried at 176° F. for 48 hours and weighed to the nearest hundreth gram.

The plants were harvested at the end of twelve weeks, and the roots were washed. The plants were dried and weighed in the same manner as the pinchings. The scoria was again fertilized with calcium carbonate and treble superphosphate and steamed for re-use. The scoria was used a maximum of four times.

The crocks were watered with the same nutrient solutions, and at the same time, that the benches were watered. During the summer one-fourth teaspoon of complete dry fertilizer was applied at the end of six weeks growth.

Dry matter was determined by adding the dry weight of pinches and plants and subtracting the dry weight of ten cuttings.

<u>Measurements</u>

The following measurements were used to evaluate the effect of the different day temperature combinations in experiments two, three, and four.

Yield was the total number of flowers cut from a single compartment.

Mean grade was computed from the total flowers cut four times a week and graded in accordance with the Colorado State University grading system. This system is comprised of four grades: (a) fancy, any large flower with no defects and possessing a stem length of 24 inches when measured from the junction of the stem and calyx, and a minimum weight of 25 grams; (b) standard, a flower without defects and having a stem length of 20 inches and a minimum weight of 15 grams; (c) short, a flower without defects and having a stem length less than 20 inches or a weight less than 15 grams; (d) design, all flowers failing to meet the above specifications. (38).

A mean grade was computed by assigning the following values to the above grades; fancy-5, standard-4, short-3, and design-2. The mean grade could then be used to compare the effects of the various treatments.

Records were compiled on the number of flowers downgraded due to the following faults: (a) malformation of the bloom; (b) lack of stem length; (c) insufficient weight; and (d) poor flowers. Any flower downgraded due to malformation of the bloom became a design grade. A flower having a hollow center or a small flower with protruding stamens, but having sufficient weight was downgraded one grade due to a poor flower.

Green weight was obtained by weighing all the fancy and standard grade cut flowers to the nearest gram immediately after they were cut.

Dry weight was measured every three weeks. A sample of five fancy and/or standard flowers were cut to a standard stem length and placed in warm water for an hour or two, after which they were weighed and then dried in the same manner as the plant samples.

Cut flower keeping life was recorded when there were sufficient flowers available to do so. All flowers meeting the requirements of fancy and standard that were downgraded due to lack of stem length were used. They were placed in one gallon of warm tap water, which contained one-fourth of a teaspoon of disinfectant (Steri-Chlor), and held in a keeping chamber maintained at 70° F. (+ or - 1°) and a relative humidity of 55 to 75 per cent. The flowers remained there until they showed a curling of the center petals or began to wither. One day was subtracted from the actual number of days they had been in the keeping chamber and a mean was computed for each sample.

Length of internode was determined by measuring the distance between the second and third set of leaves below the blossom. Schmidt referred to this as "Internode B" (72).

Stem strength was measured after the flowers had been placed in warm water and kept at 33° F. for at least one hour. This was done by measuring the number of degrees in the arc formed by the bending of an 18 inch cut flower from the horizontal (38).

Length of leaf was measured by placing a ruler perpendicular to the stem of the flower. The leaf below internode "B" was pulled away from the stem so that it rested on the ruler and a measurement was taken at the tip of the leaf.

Leaf width was determined at the widest point of the leaf.

Flower volume was expressed as milliliters of water displaced when the carnation bloom was immersed in water to the junction of the calyx and stem.

Statistical methods

Following grading a random sample of five flowers was selected. Whenever there were insufficient flowers to select a random sample, the entire flower cut for that compartment was used. The analysis of variance was computed on all measurements except yield (25, 80). The means were used in the analysis unless otherwise noted.

Chapter IV

RESULTS

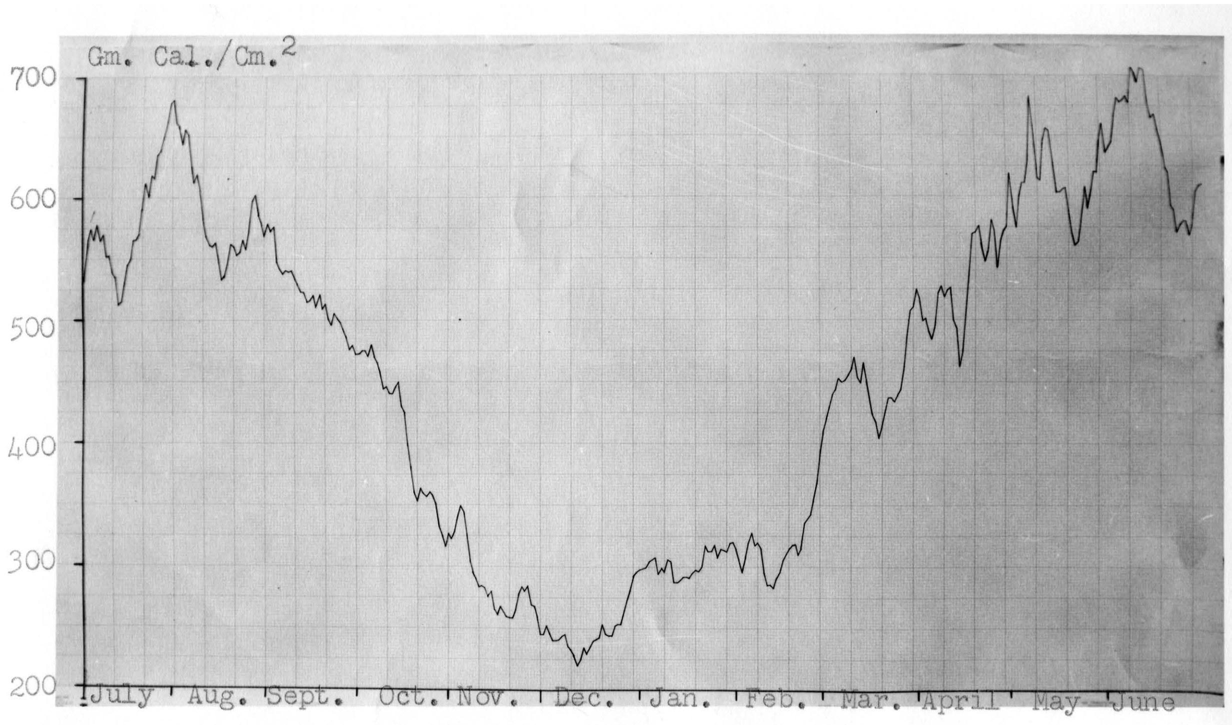


Figure 3.--Solar energy received from July 4, 1958, to July 1, 1959, at the Lake Street Greenhouse, Fort Collins, Colorado

<u>Experiment one</u>

Figures 3 and 4 give the solar energy received at the Lake Street greenhouse during this investigation. The 1958-59 winter season (Figure 3) is typical for the area, but the long extensive dark period for the 1959-60 winter (Figure 4) was the darkest since records have been kept at Colorado State University. This extensive dark period was brought about by an early September snow storm and a long cloudy period following. This dark period affected all of the morphological factors that were correlated with changes in solar energy. These data will be presented later in this section.

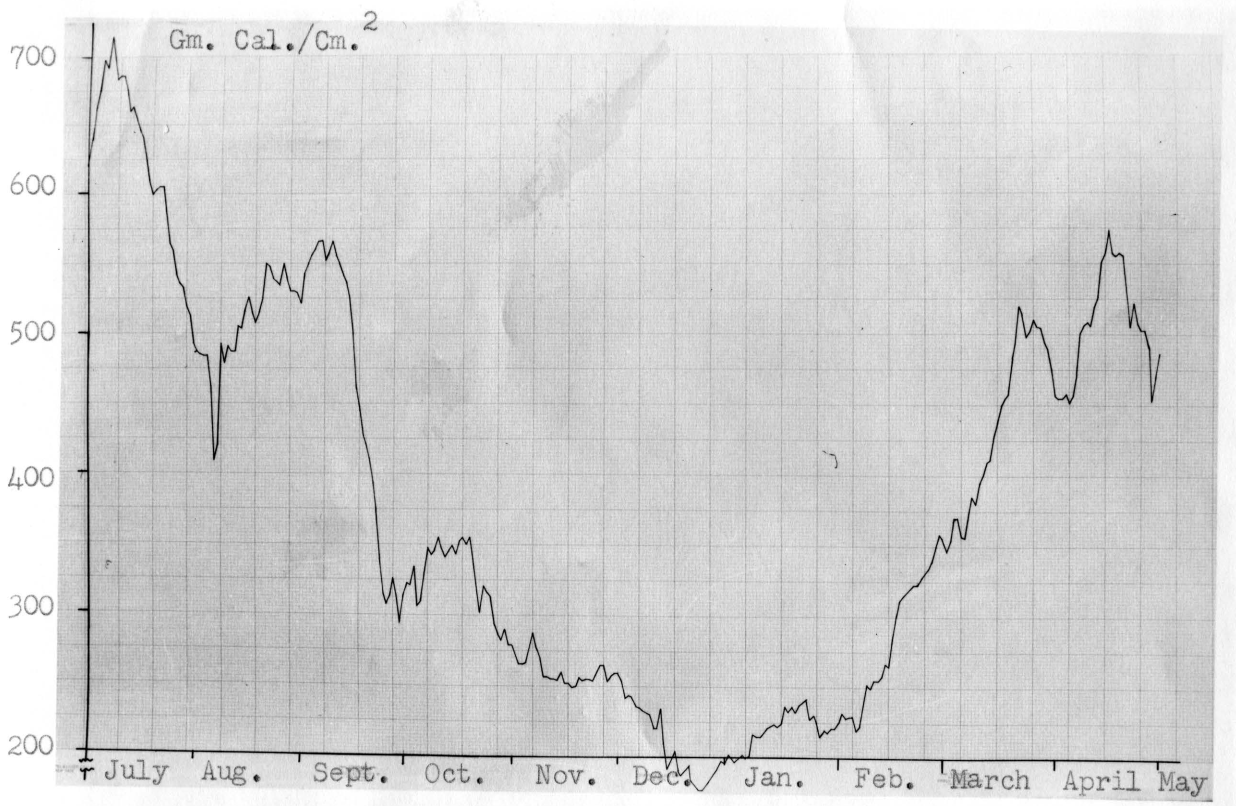


Figure 4.--Solar energy received July 1, 1959, to May 1, 1960, at the Lake Street Greenhouse, Fort Collins, Colorado.

The daily charts (Figure 5) show typically that the summer mornings are clear and the afternoons are overcast or partially cloudy in the Fort Collins area. Cloudy afternoons coupled with low humidity make it possible for the wet pad evaporative cooling system to maintain temperatures low enough to grow high quality carnations the year around. Cloudy afternoons caused a variation in solar energy received by the different compartments. These differences are minor, however, and were estimated at less than five per cent from foot candle readings. They were also greater

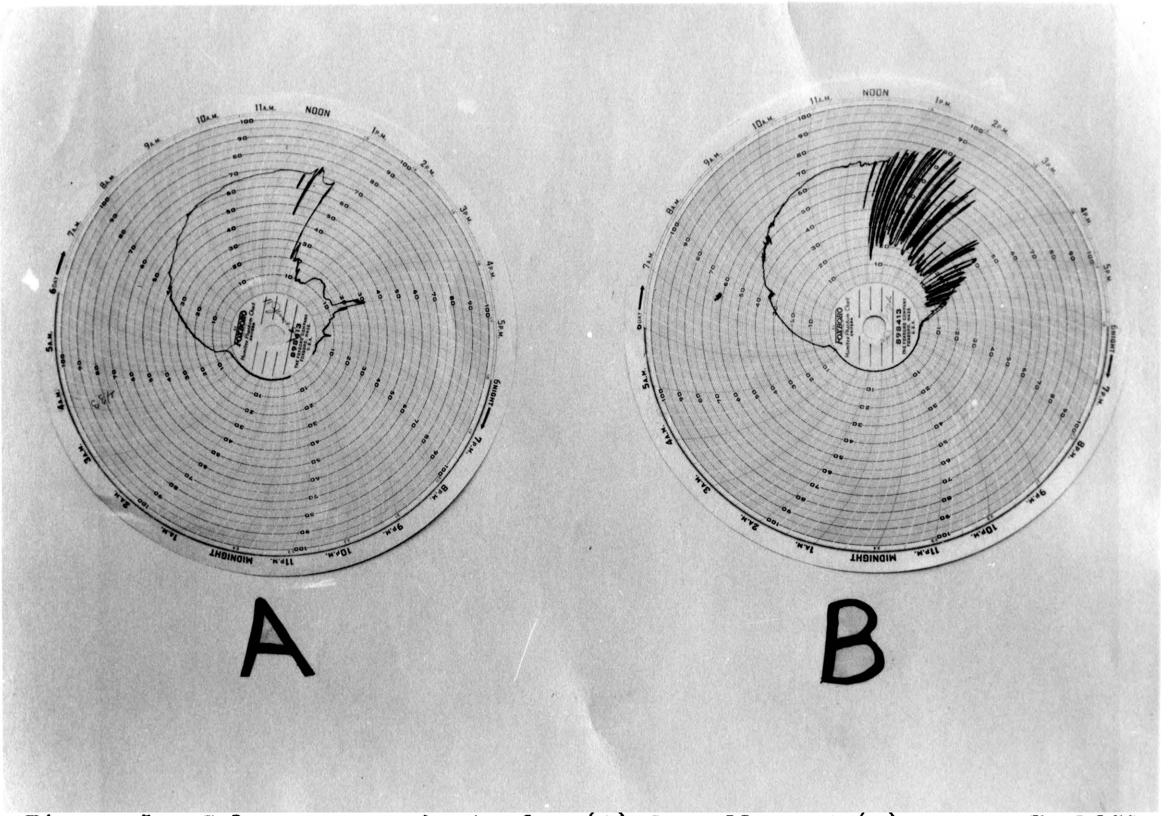


Figure 5.--Solar energy charts for (A) June 11, and (B) August 7, 1959.

during the summer months than during the winter when light is more uniform throughout the day, although of shorter duration.

Solar energy decreases with the change in daylength from season to season (Figure 6): (A) June 5, 1959, the total solar energy received was 801 gm. cal./cm.^{2}, (B) the solar energy received on September 12, 1958, was 576 gm. cal./cm.^{2}, (C) one of the shortest days of the year, December 26, 1958, received a total of 272 gm. cal./cm.^{2}. The changing of seasonal solar energy is one factor frequently over looked by investigators in biological studies when comparing data from different experiments.

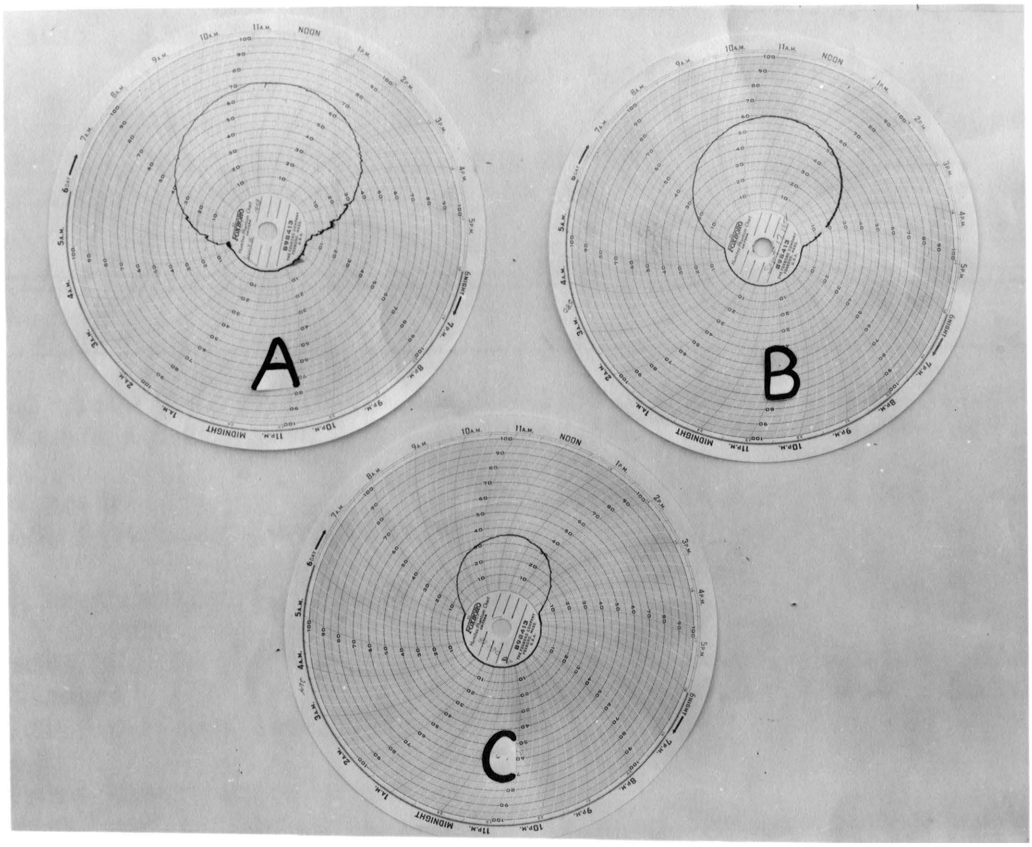
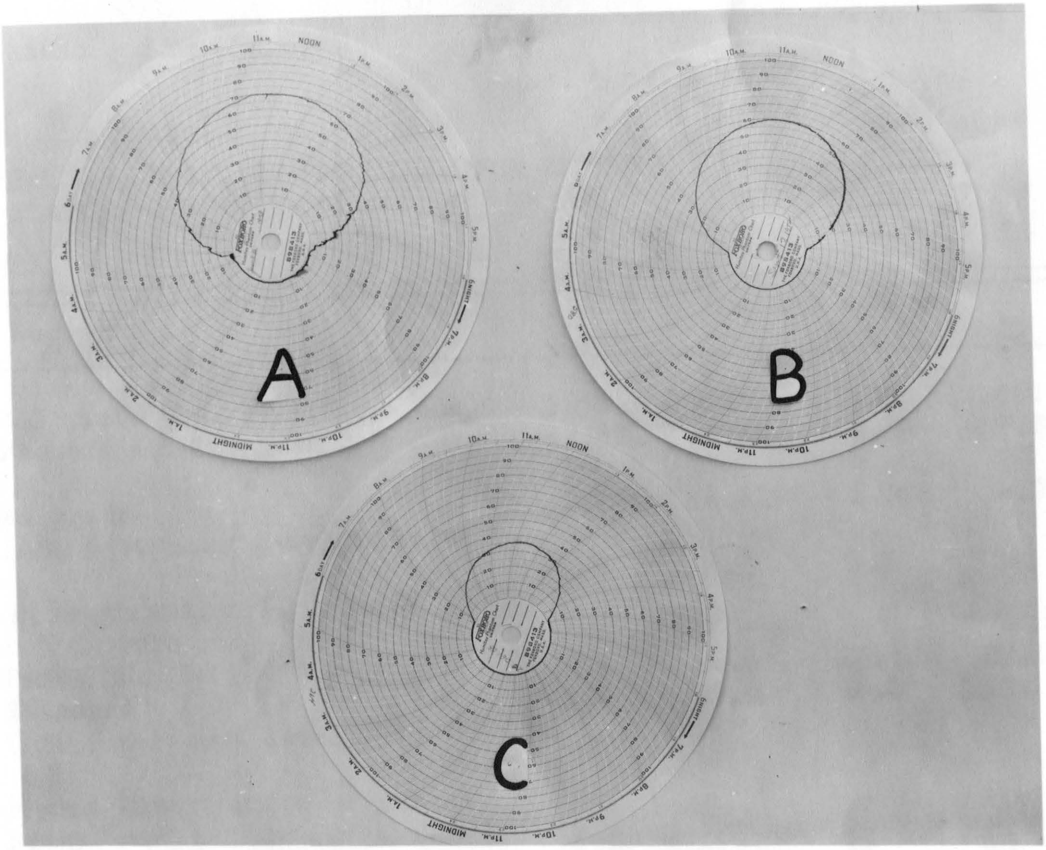


Figure 6.--Solar energy charts for (A) June 5, 1959, (B) September 12, 1958, and (C) December 26, 1958.

Violent fluctuations in solar energy occur from day to day at Fort Collins. For example, on April 22, 745 gm. cal./cm.^{2} was recorded while on April 19, three days earlier, only 91 gm. cal./cm.^{2} was received.

Experiments two, three and four

The analysis of variance for the data is in the Appendix. Least significant differences are included where differences between compartments were found by the analysis of variance.



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Violent fluctuations in solar energy occur from day to day at Fort Collins. For example, on April 22, 745 gm. cal./cm.^{2} was recorded while on April 19, three days earlier, only 91 gm. cal./cm.^{2} was received.

Experiments two, three and four

The analysis of variance for the data is in the Appendix. Least significant differences are included where differences between compartments were found by the analysis of variance.

Tables 1, 2, 3, and Figures 7, 8, and 9 give the results of yield and mean grade.

Table 1.--SUMMARY OF PRODUCTION FOR EXPERIMENT TWO, RED GAYETY, PLANTED JUNE 6, 1958.

	Compartments			
	A	B	C	D
Total yield (No. of flowers cut)	2550	2476	2604	2660
Flowers/sq. ft./year	48.57	47.14	49.59	49.80
Mean grade	4.231	4.419	4.298	4.010
(LSD 5 per cent level 0.2)				
Mean fresh weight (gm.) of cut flowers				
Fancy	28.4	28.6	28.6	27.1
Standard	20.0	19.8	20.0	19.1
(LSD 5 per cent level .97)				
Per cent distribution of grades				
Fancy	46	55	51	34
Standard	39	36	36	43
Short	8	5	6	13
Design	7	4	7	10
Per cent flowers downgraded				
Insufficient weight	27	22	21	34
Defective flowers	11	9	12	14
Short stems	12	11	11	11
Malformed flowers	4	3	5	7
Total downgraded	54	45	49	66

Table 2.--SUMMARY OF PRODUCTION FOR EXPERIMENT THREE, RED GAYETY, DURING THE SECOND YEAR.

	Compartments A	B	C	D
Total yield (No. of flowers cut)	1215	1241	1239	1359
Flowers/sq. ft./year	49.2	50.4	50.4	55.2
Mean grade	4.15	4.35	4.39	4.21
(LSD 5 per cent level 0.17)				
Mean fresh weight (gm.) of cut flowers				
Fancy	28.4	28.6	29.7	29.1
(LSD 5 per cent level 0.3)				
Standard	19.6	19.9	20.8	19.6
(LSD 5 per cent level 0.7)				
Per cent distribution of grades				
Fancy	40	51	53	43
Standard	43	39	37	42
Short	10	6	5	9
Design	7	4	5	6
Per cent flowers downgraded				
Insufficient weight	20	20	21	15
Defective flowers	35	23	20	36
Short stems	4	4	4	5
Malformed flowers	1	1	2	1
Total downgraded	60	48	46	57

Table 3.--SUMMARY OF PRODUCTION FOR EXPERIMENT FOUR, WHITE SIM PLANTED MAY 30, 1959.

	Compartments			
	A	B	C	D
Total yield (No. of flowers cut)	1663	1555	1527	1774
Flowers/sq. ft./year	39.5	37.0	36.3	42.2
Mean grade	3.697	3.947	4.003	3.742
(LSD 5 per cent level 0.3)				
Mean fresh weight (gm.) of cut flowers				
Fancy	27.3	27.5	27.8	26.7
(LSD 5 per cent level .67)				
Standard	19.3	19.5	19.0	19.1
(LSD 5 per cent level .3)				
Per cent distribution of grades				
Fancy	18	29	28	13
Standard	51	50	53	59
Short	16	10	12	18
Design	15	11	7	10
Per cent flowers downgraded				
Insufficient weight	20	19	23	29
Defective flowers	23	15	15	17
Short stems	31	30	30	37
Malformed flowers	7	7	4	4
Total downgraded	82	71	72	87

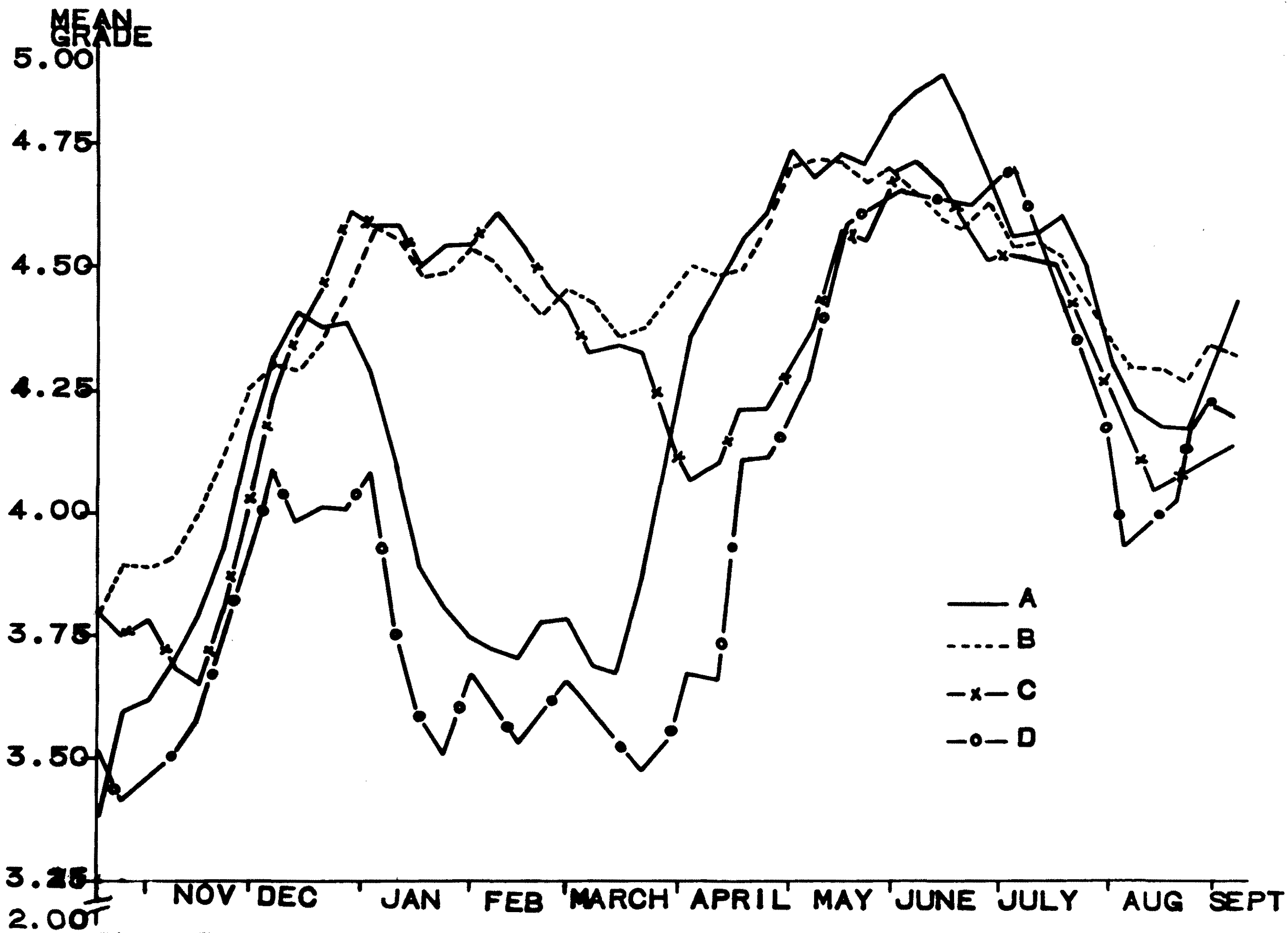

Figure 7.--Three week moving mean of mean grade of Red Gayety carnations benched June 6, 1958, in the compartments for temperature investigation, experiment two.

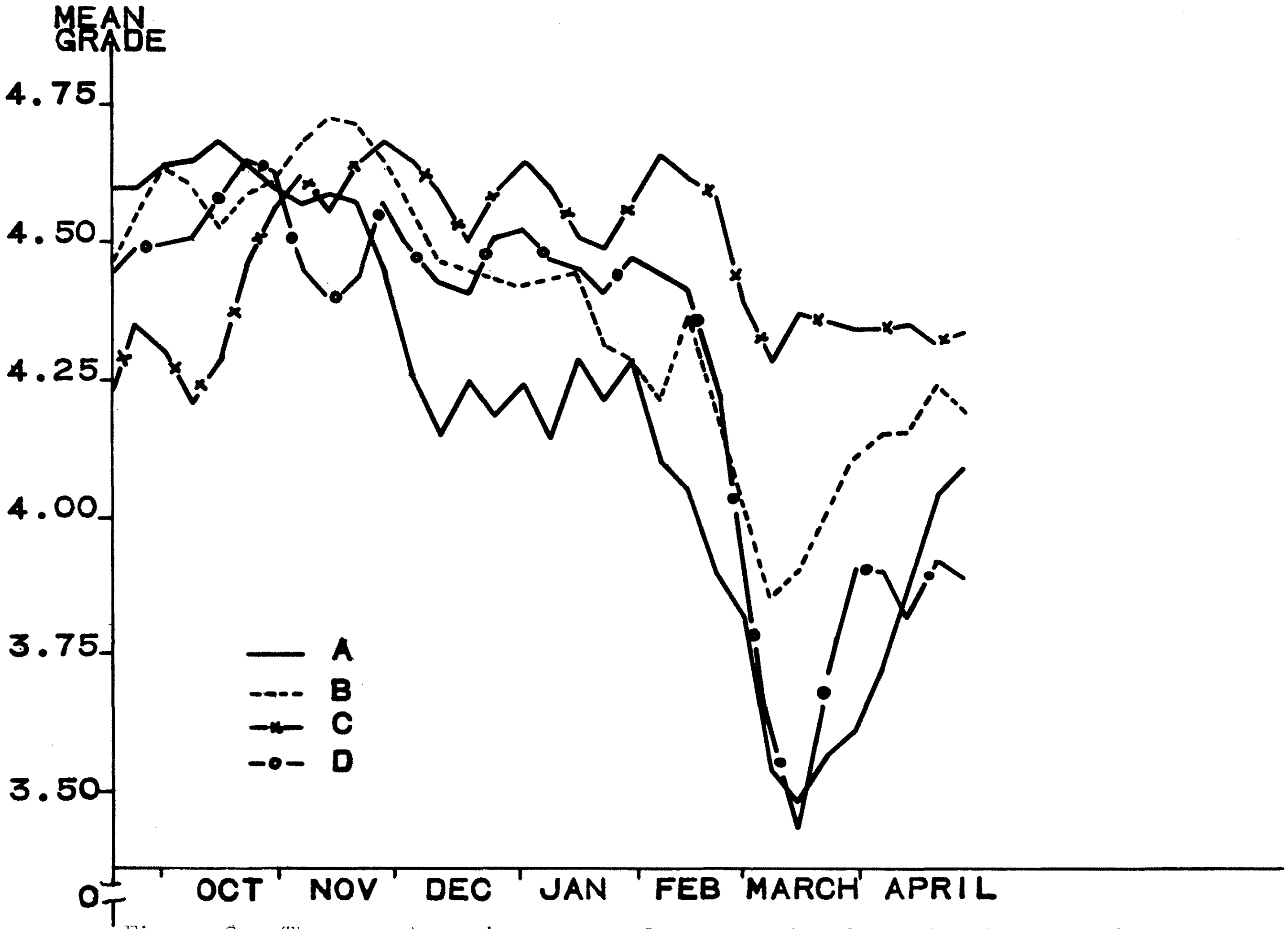

Figure 8.--Three week moving means of mean grade of Red Gayety carnations in their second year of production, experiment three.

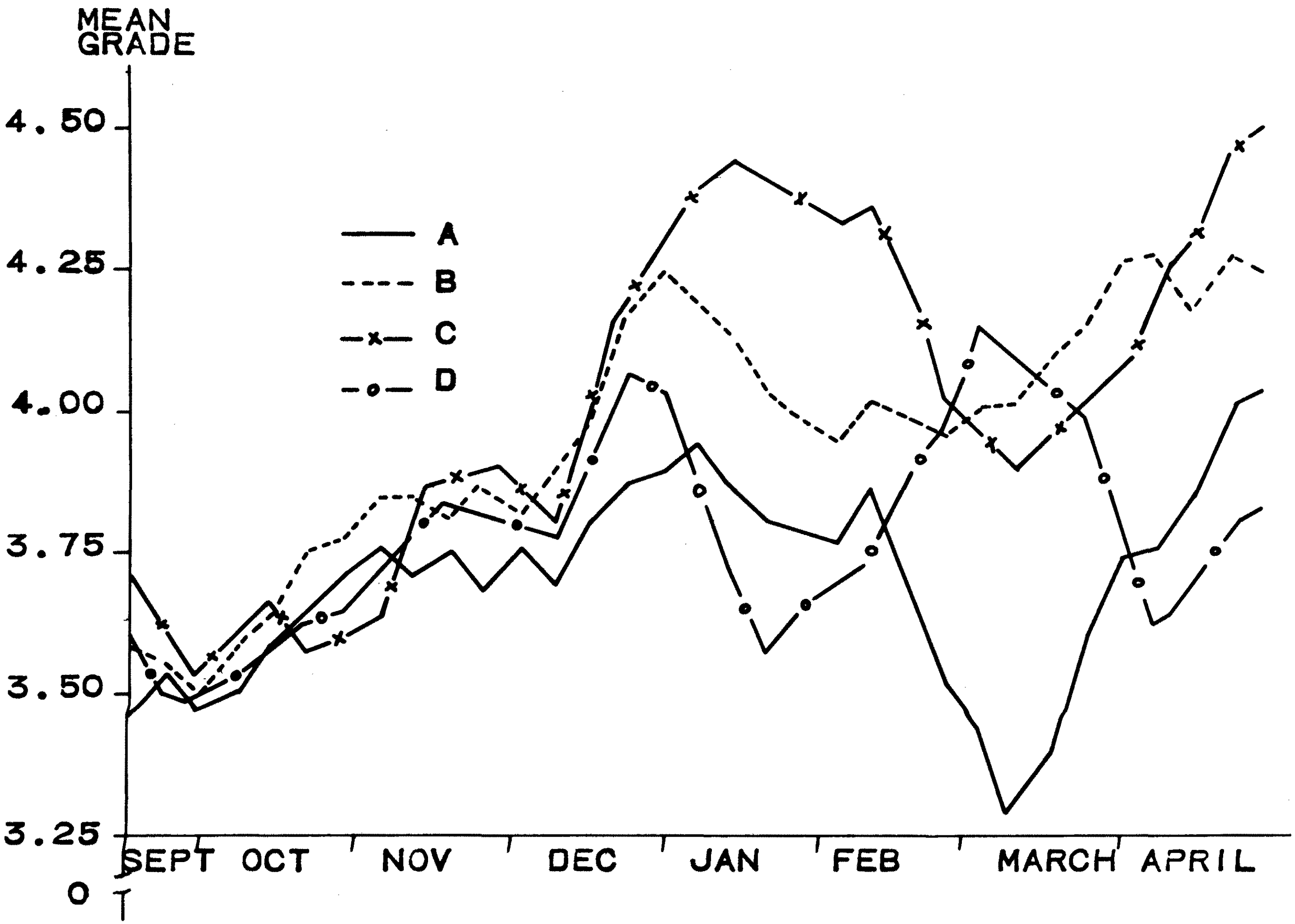

Figure 9.--Three week moving means of mean grade of White Sim carnations benched May 30, 1959, for temperature investigations, experiment four.

Yield.--All compartments, except C for experiment four, and D for experiment two, maintained an identical yield. The yield differences for compartment C in experiment four could be attributed to two factors. First, the young non-flowering plants were grown at a 5° F. higher temperature than the other compartments, which decreased the number of lateral branches. Second, the 10° F. decrease in day temperature on September 30, slowed the growth of the flowering plant, causing a decrease in yield. Compartment D in experiment two showed an increase in yield. This is considered to be due to the fact that D had the highest day temperature during sunny periods of the winter.

Mean grade.—There was a highly significant difference in all experiments between the various compartments and the time of year the flowers were cut. In compartment C where yield was decreased the mean grade was higher, and in compartment D yield was increased at the expense of mean grade. In the case of D the mean grade was so low that this temperature range was not continued the second year. The increase in mean grade in compartment C of experiment two could be attributed to increasing day temperatures too early in the spring. When day temperature is correlated with solar energy, mean grade is improved.

Production

The total yield for each of the three experiments was essentially the same, but the time of production, and the size of separate crops were different as indicated in Figures 10, 11, and 12.

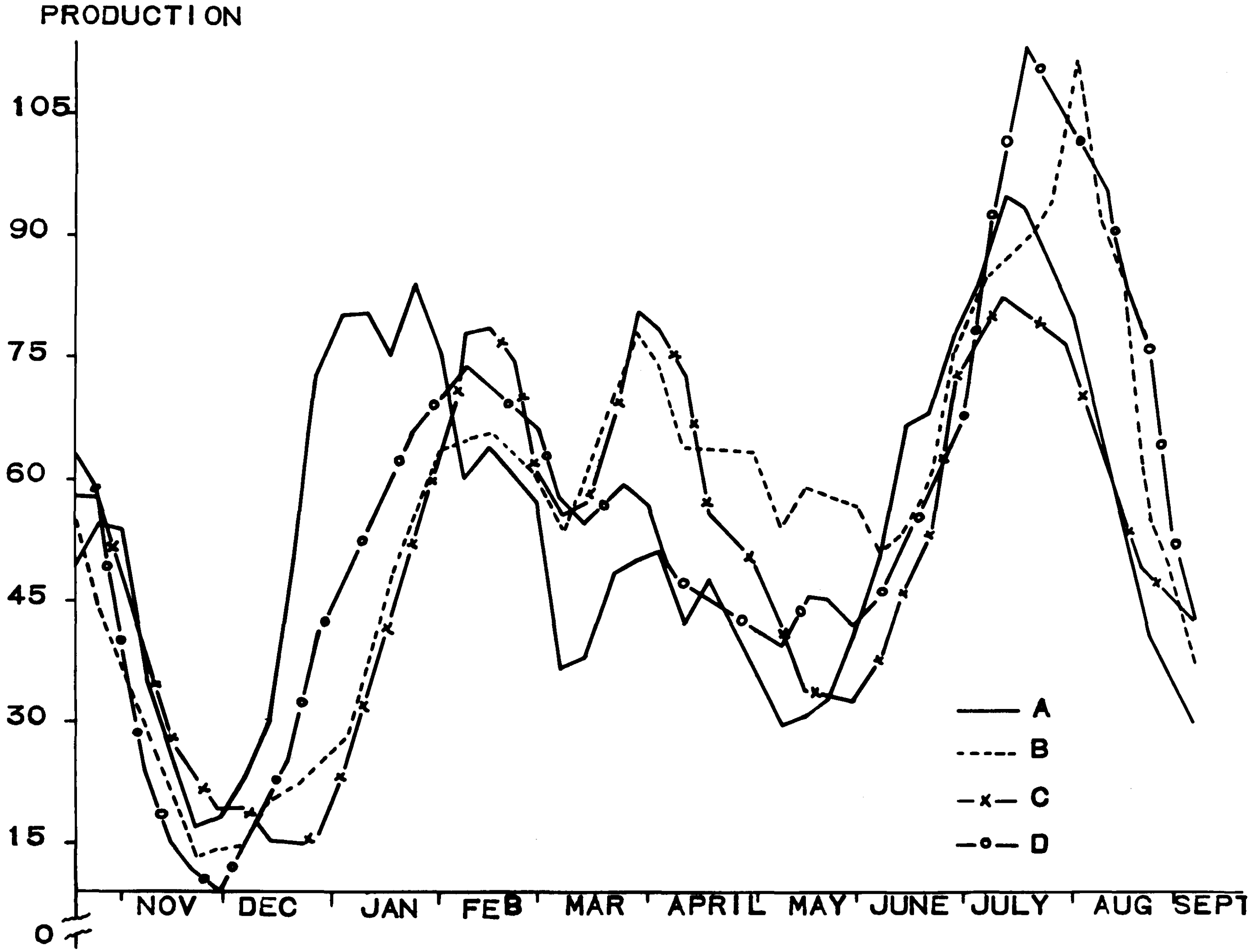

Figure 10.--Three week moving mean of weekly production for Red Gayety carnations benched June 6, 1958, experiment two.

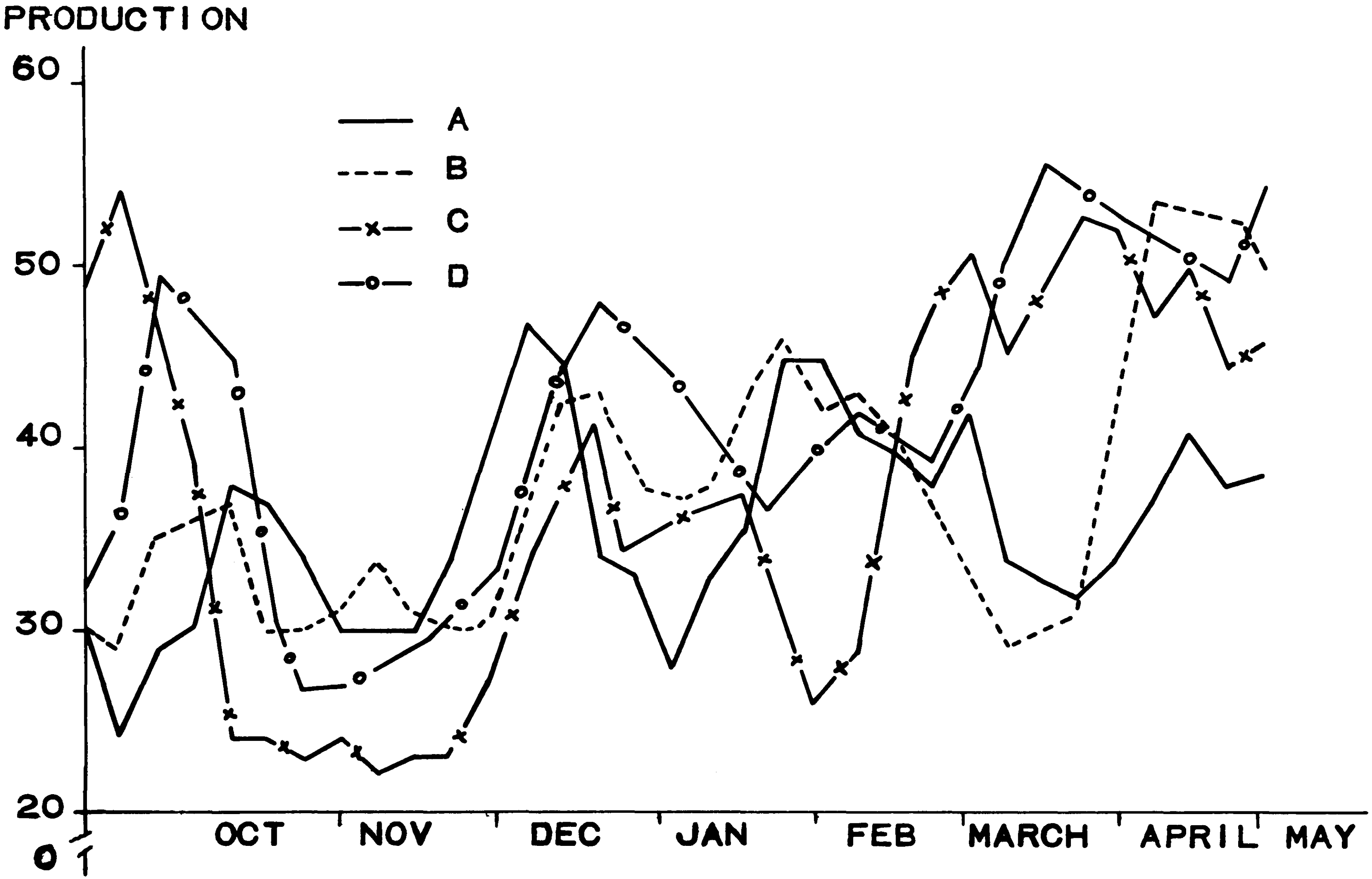

Figure 11.--Three week moving mean of weekly production for Red Gayety carnations in their second year of production, experiment three.

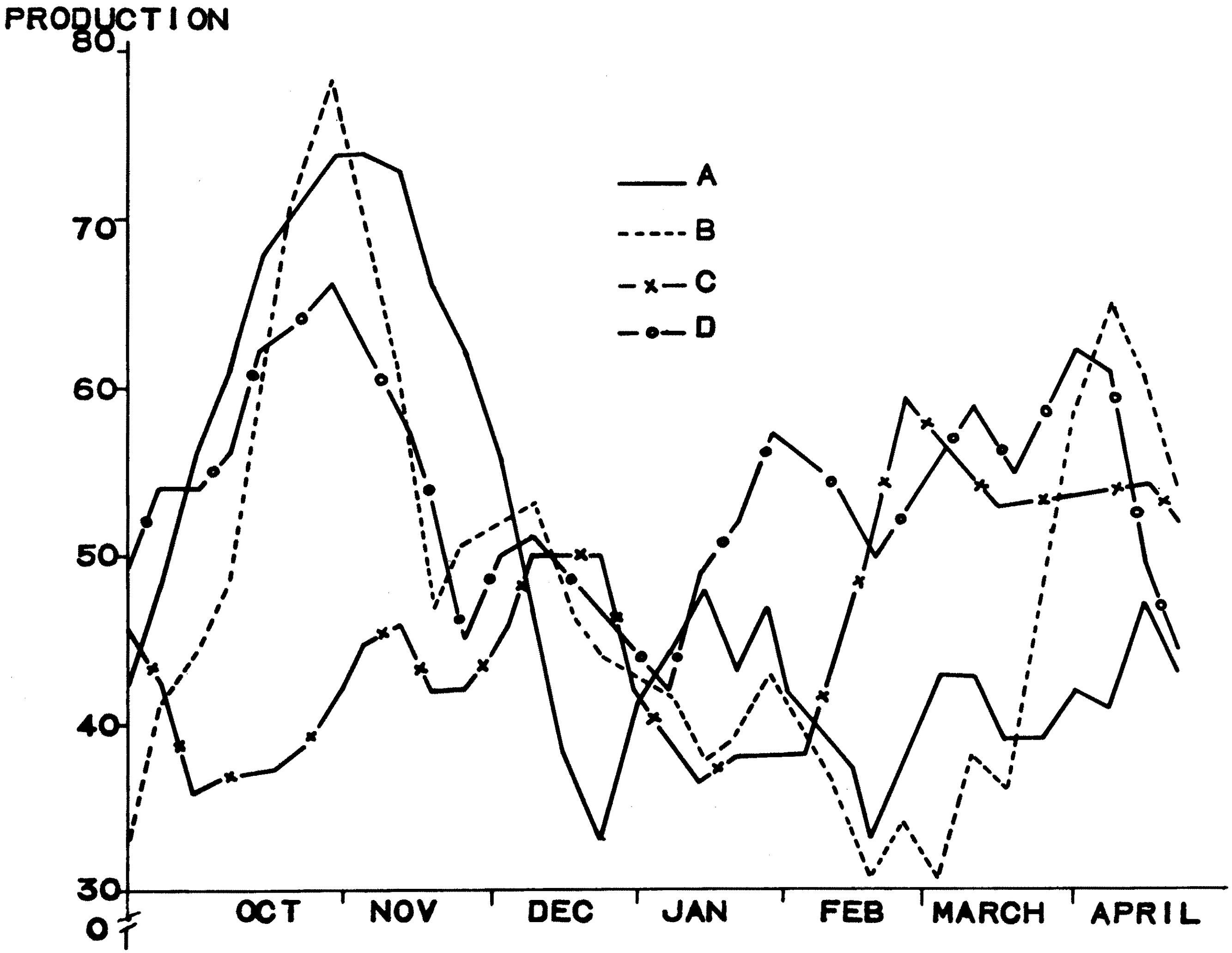

Figure 12.--Three week moving mean of weekly production for White Sim carnations benched May 30, 1959, experiment four.

The very low production for experiment two during the last two weeks of December was due to the second pinch being made too low. However, this did cause high production during January and February. The production for the uncorrelated compartments followed solar energy with high production in the fall and spring. In the correlated compartments, the production was more uniform throughout the year.

Fresh weight, dry weight, and percentage of dry matter of standard length cut flowers is given in Tables 4, 5, and 6. The percentage of dry matter is an indication of stem brittleness, and the amount of organic materials produced.

During the summer higher temperatures were present in all the compartments. This caused the results for all the compartments to be essentially the same in experiment two. The highest accumulation of dry matter was in October and November when light was still high and outside temperatures began to decrease. The lowest accumulation of dry matter occurred in March. This was attributed to low light intensities during the vegetative growing period of these flowers.

Leaf length and width is an important factor in the synthesis of carbohydrates, but has little influence on saleability of carnations. Tables 7, 8, and 9 give the effect of the various treatments on leaf length and width. The temperatures that were correlated with solar energy increased leaf width, while leaf length was affected in experiment two due to the shorter leaves found in the D compartment.

Table 4.--SUMMARY OF FRESH AND DRY WEIGHT (IN GRAMS) AND PER CENT DRY MATTER OF CUT FLOWERS, EXPERIMENT TWO, RED GAYETY, PLANTED JUNE 6, 1958. [a]

Date	Compartments											
	A			B			C			D		
	Fresh Weight	Dry Weight	% Dry Matter	Fresh Weight	Dry Weight	% Dry Matter	Fresh Weight	Dry Weight	% Dry Matter	Fresh Weight	Dry Weight	% Dry Matter
1959												
January 28	168.5	26.93	15.98	260.3	44.27	17.00	264.3	42.80	16.19	178.1	28.66	16.09
February 18	97.3	19.26	19.79	113.7	22.77	20.02	128.6	23.79	18.49	91.1	18.24	20.02
March 11	117.0	24.23	20.70	140.6	27.77	19.75	120.4	20.21	19.27	93.8	20.31	21.65
April 1	118.0	24.22	20.50	141.9	27.43	19.30	114.5	22.51	19.26	105.6	22.08	20.90
April 22	144.6	31.06	20.60	152.9	31.06	20.30	112.0	22.28	19.80	116.4	24.78	21.20
May 13	152.3	31.83	20.89	118.1	23.17	19.61	142.6	28.26	19.81	123.2	26.44	21.46
June 4	163.3	33.69	20.00	152.6	29.04	19.03	167.5	35.11	20.90	154.7	30.09	19.50
June 25	140.0	28.95	20.70	127.9	26.88	21.00	151.1	31.23	20.70	130.2	25.59	19.60
July 16	140.6	30.53	21.71	133.8	27.54	20.58	147.9	30.77	20.80	128.3	27.21	21.20
August 6	130.7	27.39	20.95	128.8	27.17	21.09	141.4	29.19	20.60	131.2	26.79	20.41
August 26	138.4	29.55	21.35	139.9	28.60	20.40	141.8	28.61	20.10	128.4	26.71	20.80
Mean (LSD for mean of per cent fresh weight at 5 per cent level 7.9).	126.4	25.64	20.23	134.2	26.30	19.82	136.0	26.23	19.66	115.1	23.07	20.25

[a] Each sample contains 5 flowers.

Table 5.--SUMMARY OF FRESH AND DRY WEIGHT (IN GRAMS) AND PER CENT DRY MATTER OF CUT FLOWERS, EXPERIMENT THREE, RED GAYETY DURING THE SECOND YEAR OF PRODUCTION. /a

Date	A Fresh Weight	A Dry Weight	A % Dry Matter	B Fresh Weight	B Dry Weight	B % Dry Matter	C Fresh Weight	C Dry Weight	C % Dry Matter	D Fresh Weight	D Dry Weight	D % Dry Matter
1959												
Sept. 16	146.2	31.49	21.53	151.5	32.17	21.23	156.0	32.03	20.53	167.3	37.24	22.25
Oct. 7	160.1	35.26	22.02	149.4	33.13	22.17	138.3	28.12	20.33	163.5	33.94	20.75
Oct. 28	141.2	32.91	23.30	140.3	29.83	21.26	130.7	28.94	21.12	154.5	35.57	23.02
Nov. 18	163.6	33.31	20.36	155.1	29.86	19.25	154.8	33.07	21.37	159.7	33.12	20.73
Dec. 9	119.0	21.05	17.68	122.3	17.86	14.60	133.4	23.59	17.62	129.0	23.17	17.96
1960												
Jan. 27	123.1	22.41	18.20	97.1	18.36	18.90	127.4	22.86	17.94	102.6	20.34	19.91
March 2	86.6	19.37	22.36	113.1	24.94	19.92	116.3	23.91	20.55	83.3	17.72	21.28
March 23	102.6	21.20	20.60	107.5	20.49	19.00	121.8	22.54	18.50	100.9	19.36	19.20
April 13	101.2	20.84	20.59	101.7	20.03	19.69	114.9	21.30	18.53	90.2	17.04	18.89
Mean	127.1	26.43	20.73	126.4	25.18	19.55	132.6	26.20	19.61	127.9	26.38	20.43

/a Each sample contained 5 flowers.

Table 6.--SUMMARY OF FRESH AND DRY WEIGHT (IN GRAMS) AND PER CENT DRY MATTER OF CUT FLOWERS, EXPERIMENT FOUR, WHITE SIM BENCHED MAY 30, 1959. [a]

	Compartments											
	A			B			C			D		
Date	Fresh Weight	Dry Weight	% Dry Matter	Fresh Weight	Dry Weight	% Dry Matter	Fresh Weight	Dry Weight	% Dry Matter	Fresh Weight	Dry Weight	% Dry Matter
1959												
Sept. 16	126.2	21.34	16.90	124.7	22.72	18.21	102.1	18.68	18.29	115.6	20.05	17.34
Oct. 7	110.7	19.36	17.49	110.0	19.36	17.30	98.7	18.32	18.56	99.3	17.38	17.50
Oct. 28	112.3	21.21	18.88	103.0	18.41	17.88	98.5	19.28	19.52	109.0	20.07	18.41
Nov. 18	106.7	19.14	17.93	122.3	20.24	16.54	109.2	19.27	17.66	112.8	19.52	17.30
Dec. 9	109.5	13.95	12.73	105.4	11.69	11.09	128.4	16.08	12.52	102.7	13.71	13.34
1960												
Jan. 27	107.4	19.36	16.49	109.2	19.01	17.40	101.8	19.16	18.82	96.1	17.64	18.36
March 2	106.8	22.89	21.42	93.0	19.34	20.79	87.7	18.02	20.55	86.9	18.31	20.86
March 23	114.0	23.05	20.21	107.9	23.04	21.30	111.5	20.80	18.56	91.9	17.29	18.80
April 13	110.4	21.13	19.14	116.5	21.30	18.28	107.7	19.77	18.35	97.6	19.27	19.74
Mean	111.6	20.16	17.91	110.2	19.45	17.64	105.1	18.82	18.10	101.3	18.13	17.96
(LSD 5 per cent level 3.7 For fresh weight)												
(LSD 5 per cent level 1.6 for dry weight)												

[a] Each sample contained 5 flowers.

Table 7.--EFFECT OF TREATMENTS ON LEAF LENGTH AND WIDTH (In Cm.), EXPERIMENT TWO, RED GAYETY PLANTED JUNE 6, 1958.[a]

Date	Compartments							
	A		B		C		D	
	Leaf Length	Leaf Width	Leaf Length	Leaf Width	Leaf Length	Leaf Width	Leaf Length	Leaf Width
1958								
November 22	8.5	1.4	9.9	1.2	9.6	1.3	8.4	1.2
December 22	7.3	1.1	7.4	1.0	6.0	0.9	5.3	0.9
1959								
January 13	7.6	1.0	8.1	1.1	8.7	1.2	8.3	1.0
January 29	8.0	0.9	8.1	1.1	8.3	1.2	8.8	1.0
February 17	7.3	0.9	8.0	1.0	3.2	1.0	8.0	0.9
March 5	8.9	0.9	8.6	1.0	9.0	1.0	7.5	0.9
March 19	10.4	1.1	9.0	1.1	8.3	1.0	8.8	0.9
April 6	8.0	0.9	8.5	1.0	8.4	1.0	8.6	0.9
May 14	8.1	1.0	8.5	1.0	8.1	1.0	8.8	0.9
June 17	8.7	1.1	9.0	1.1	8.0	1.0	9.1	1.1
July 20	7.9	1.1	7.2	1.1	7.5	1.1	7.7	1.0
August 28	10.5	1.0	9.5	1.1	9.9	1.1	8.5	1.0
Mean	8.4	1.0	8.5	1.1	8.3	1.1	8.1	1.0
(LSD 5 per cent level 0.05)								

[a] Each sample contains 5 leaves.

Table 8.—EFFECT OF TREATMENTS ON LEAF LENGTH AND WIDTH (In Cm.), EXPERIMENT THREE, RED GAYETY DURING THE SECOND YEAR OF PRODUCTION.[a]

Date	Compartments A Leaf Length	A Leaf Width	B Leaf Length	B Leaf Width	C Leaf Length	C Leaf Width	D Leaf Length	D Leaf Width
1959								
September 23	9.9	1.1	9.4	1.1	10.0	1.0	8.4	1.0
October 23	7.5	1.0	7.5	1.1	6.7	1.2	7.5	1.1
November 11	7.8	1.1	8.6	1.2	9.0	1.2	8.7	1.3
December 19	7.7	1.0	8.9	1.0	8.6	1.1	8.8	1.1
1960								
January 15	7.9	1.1	8.7	1.1	7.6	1.1	8.5	1.2
February 19	7.1	0.9	8.2	1.0	9.0	1.1	8.5	1.0
March 18	8.0	0.9	7.7	1.0	8.1	1.0	6.8	0.9
April 22	8.3	0.9	7.4	1.0	8.1	1.0	7.8	0.8
Mean	8.0	1.0	8.3	1.0	8.4	1.1	8.1	1.1
(LSD 5 per cent level 0.02)								

Table 9.—EFFECT OF TREATMENTS ON LEAF LENGTH AND WIDTH (In. Cm.), EXPERIMENT FOUR, WHITE SIM BENCHED MAY 30, 1959.[a]

Date	Compartments A Leaf Length	A Leaf Width	B Leaf Length	B Leaf Width	C Leaf Length	C Leaf Width	D Leaf Length	D Leaf Width
1959								
October 23	7.2	1.1	6.4	1.1	6.2	1.0	5.7	1.0
November 11	8.2	1.2	8.0	1.2	7.6	1.2	7.6	1.0
December 19	8.7	1.1	7.6	1.1	7.5	1.0	7.3	1.0
1960								
January 15	9.6	1.0	8.0	0.9	7.1	1.0	7.0	1.0
February 19	7.8	0.9	7.7	0.8	9.3	1.2	8.6	0.9
March 18	7.0	0.9	6.9	0.9	8.2	0.9	8.1	0.8
April 22	8.3	0.9	7.4	1.0	8.1	1.0	7.8	0.8
Mean	8.1	1.0	7.4	1.0	7.7	1.1	7.4	1.0
(LSD 5 per cent level .01)								

[a] Each sample contains 5 leaves.

Table 10.—EFFECT OF TREATMENTS ON INTERNODE LENGTH (IN CMS.) AND STEM STRENGTH, EXPERIMENT TWO, RED GAYETY PLANTED JUNE 6, 1958.

Date	Compartments A	B	C	D
Internode length [a]				
November 22, 1958	10.3	9.6	7.8	8.0
December 22	10.2	8.9	6.9	7.5
January 13, 1959	9.0	8.6	8.3	9.8
January 27	8.3	10.0	8.9	10.9
February 17	10.6	11.5	10.8	12.6
March 5	11.5	12.0	11.2	12.8
March 19	11.8	10.8	11.4	12.6
April 6	11.6	11.3	11.6	12.5
May 14	11.4	10.2	11.3	12.8
June	10.5	11.2	11.0	12.6
July	9.1	8.9	9.2	8.9
August	9.2	9.9	9.8	9.3
Mean	10.3	10.2	9.9	10.8
(LSD 5 per cent level .10)				
Stem strength [b]				
January 13, 1959	21.4	18.2	20.8	25.8
January 27	30.2	14.0	21.8	32.6
February 17	30.2	21.6	20.2	25.4
March 5	29.8	21.2	21.8	22.0
March 19	16.4	18.4	21.4	24.8
April 6	15.4	17.0	22.0	15.4
May 14	11.6	12.5	14.2	16.4
June	9.2	11.8	14.4	6.6
July	7.0	9.8	19.0	13.6
August	9.0	7.6	7.8	14.8
Mean	18.0	15.2	18.3	19.7
(LSD 5 per cent level .06)				

[a] Mean length of internode "B" of five flowers.

[b] Mean stem strength of five flowers in degrees of bending with Colorado State University limberometer.

Table 11.—EFFECT OF TREATMENTS ON INTERNODE LENGTH (IN CMS.) AND STEM STRENGTH, EXPERIMENT THREE, RED GAYETY DURING THE SECOND YEAR OF PRODUCTION.

Date	Compartments A	B	C	D
Internode length [a]				
September 23, 1959	9.2	10.0	10.0	9.3
October 23, 1959	8.4	8.7	7.2	8.6
November 11, 1959	8.2	9.3	9.3	9.9
December 19, 1959	8.2	9.0	8.7	9.8
January 15, 1960	8.4	9.3	8.3	9.5
February 19, 1960	9.3	9.5	10.0	11.3
March 18, 1960	9.9	10.3	10.0	12.1
April 22, 1960	10.2	9.7	9.2	12.0
Mean	8.9	9.4	9.1	10.3
(LSD 5 per cent level .11)				
Stem strength [b]				
September 23, 1959	8.4	7.4	7.0	12.8
October 23, 1959	5.6	8.6	9.6	7.4
November 11, 1959	7.4	9.2	8.0	7.2
December 19, 1959	9.0	10.6	9.0	8.2
January 15, 1960	14.4	13.0	6.0	8.1
February 19, 1960	8.4	12.4	11.6	16.6
March 18, 1960	9.4	8.6	8.8	15.2
April 22, 1960	7.6	8.6	9.6	13.2
Mean	8.8	9.8	8.7	11.1

[a] Mean length of internode "B" of five flowers.

[b] Mean stem strength of five flowers in degrees of bending with Colorado State University limberometer.

Table 12.--EFFECT OF TREATMENTS ON INTERNODE LENGTH (IN CMS.) AND STEM STRENGTH, EXPERIMENT FOUR, WHITE SIM BENCHED MAY 30, 1959.

Date	Compartments A	B	C	D
Internode length[a]				
October 23, 1959	8.6	8.1	9.1	8.1
November 11, 1959	10.5	10.7	9.9	9.6
December 19, 1959	10.2	10.6	10.0	9.4
January 15, 1960	10.6	10.1	9.7	9.4
February 19, 1960	10.2	11.7	11.6	11.7
March 18, 1960	9.6	11.2	11.8	10.5
April 22, 1960	10.2	9.7	9.2	12.0
Mean	9.9	10.3	10.2	9.9
Stem strength [b]				
October 23, 1959	14.4	14.4	15.8	14.8
November 11, 1959	14.0	16.4	13.0	16.2
December 19, 1959	17.4	16.0	14.6	9.8
January 15, 1960	20.2	16.6	15.0	8.1
February 19, 1960	12.0	9.6	8.2	14.8
March 18, 1960	7.6	7.6	4.8	9.0
April 22, 1960	7.6	8.6	9.6	13.2
Mean	13.3	12.7	11.6	12.4

[a] Mean length of internode "B" of five flowers.

[b] Mean stem strength of five flowers in degrees of bending with Colorado State University limberometer.

Keeping quality for the three experiments is given in Tables 13, 14, and 15. The keeping life of cut flowers was essentially the same under all treatments with a significant difference occurring between the different sampling dates. As plants age the keeping life of cut flowers increases. The decrease in keeping life after June in experiment two was probably due to high summer temperature in all compartments. Fairchild also found a decrease in keeping life during periods of high temperatures (30).

Table 13.--CUT FLOWER LIFE (IN DAYS) FOR EXPERIMENT TWO, RED GAYETY CARNATIONS DURING THE FIRST YEAR OF PRODUCTION, OCTOBER 11, 1958, TO SEPTEMBER 12, 1959.

Date	No. of flowers per sample	Compartments A	B	C	D
November 1, 1958	9	6.6	6.8	6.8	6.3
November 8, 1958	8	7.1	6.8	7.2	6.8
November 22, 1958	5	6.0	6.8	6.4	6.8
January 2, 1959	9	5.8	6.3	5.8	6.3
January 8, 1959	5	7.6	6.8	6.8	8.2
January 17, 1959	7	6.3	6.3	6.7	7.3
January 24, 1959	10	6.8	6.2	6.6	6.2
January 30, 1959	10	7.2	6.7	6.8	7.2
February 6, 1959	5	6.8	7.8	6.2	6.8
February 21, 1959	5	6.4	5.8	6.0	6.2
February 28, 1959	5	6.8	6.4	6.4	6.6
March 6, 1959	5	6.4	6.0	6.6	6.8
March 13, 1959	5	6.8	6.6	6.4	7.2
March 30, 1959	5	6.2	5.8	6.0	6.6
April 6, 1959	5	6.2	5.6	5.6	6.4
April 15, 1959	5	7.2	7.0	7.2	7.4
April 21, 1959	5	6.6	6.0	6.6	6.2
June 12, 1959	5	8.8	8.4	8.0	8.6
June 29, 1959	5	6.8	7.0	6.6	7.4
July 20, 1959	5	7.0	7.4	6.8	7.2
August 1, 1959	5	7.0	6.8	6.4	7.4
August 14, 1959	5	6.6	6.9	6.8	7.0
Mean		6.77	6.65	6.53	6.94

Table 14.--CUT FLOWER LIFE (IN DAYS) FOR EXPERIMENT THREE, RED GAYETY CARNATIONS DURING THE SECOND YEAR OF PRODUCTION. /a

Date	Compartments A	B	C	D
September 24	7.6	7.6	6.4	7.6
October 8	8.6	8.6	9.6	9.6
November 11	9.8	9.6	10.0	9.2
January 15	7.2	8.0	7.2	7.4
February 19	7.6	8.2	8.0	8.0
April 27	9.6	8.0	6.6	7.0
Mean	8.40	8.33	7.96	8.10

Table 15.--CUT FLOWER LIFE (IN DAYS) FOR EXPERIMENT FOUR, WHITE SIM BENCHED MAY 30, 1959. /a

Date	Compartments A	B	C	D
October 8, 1959	7.6	6.8	6.4	7.8
November 11, 1959	5.2	6.0	5.6	5.2
January 15, 1960	6.4	8.4	7.6	7.8
February 19, 1960	7.8	7.6	6.8	7.6
April 27, 1960	10.0	7.4	7.4	9.1
Mean	7.40	7.24	6.96	7.50

/a Five flowers per sample.

Flower volume

Figures 13, 14, and 15 give the flower volume for the three treatments. This factor coincided very closely with mean grade, due to the fact that the correlated compartments had greater flower volume during the dark period of the year. Flowers from one-year old plants were affected by the different temperature ranges, while flowers from older plants were not affected.

Experiment five

The various temperature combinations did not significantly affect the production of fresh or dry material by the carnation plants (Figures 16 and 17). The percentage of dry matter was closely correlated with the solar energy received as shown in Figures 13 and 14.

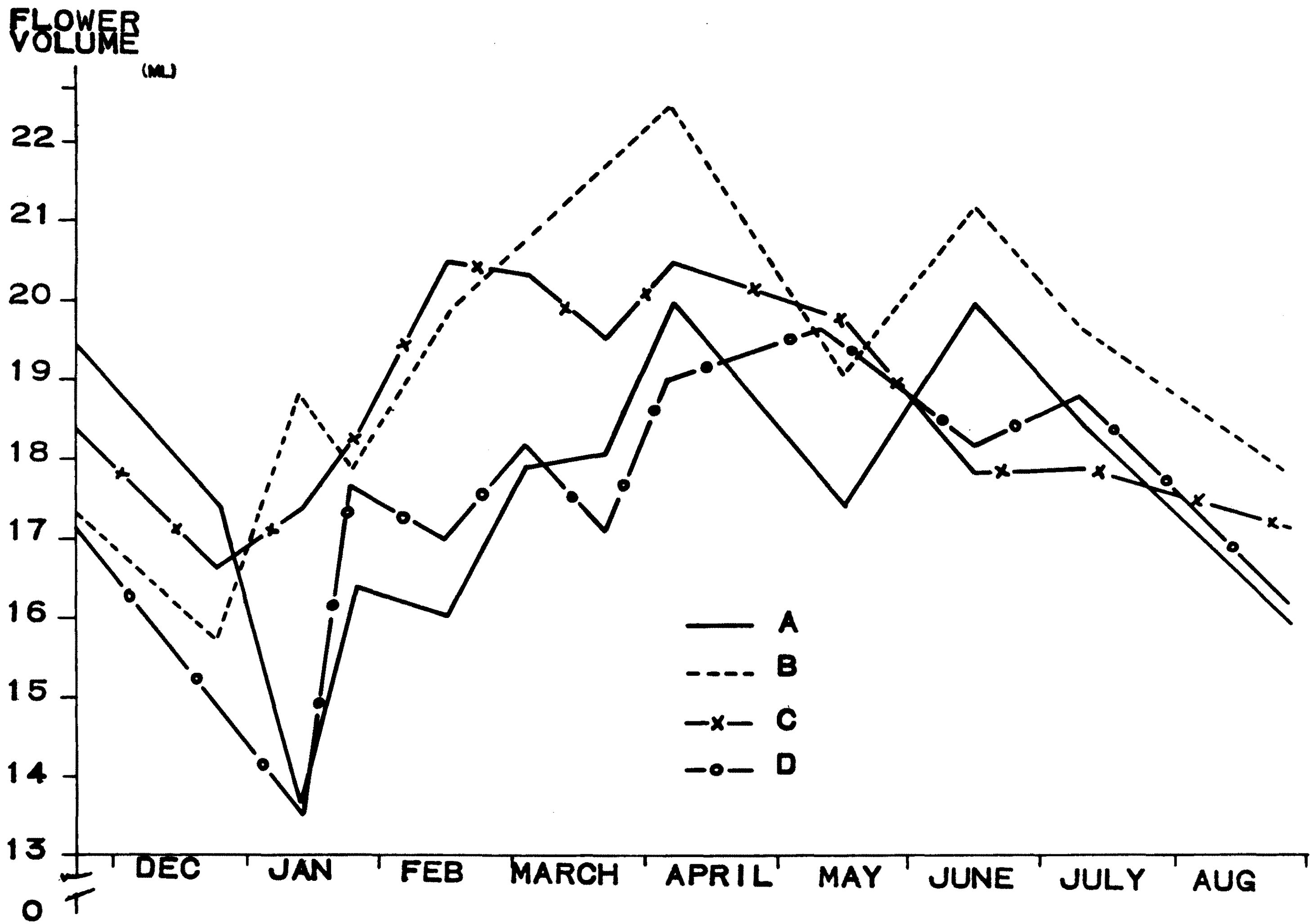

Figure 13.--Periodic means of flower volume for Red Gayety carnations benched June 6, 1958, experiment two.

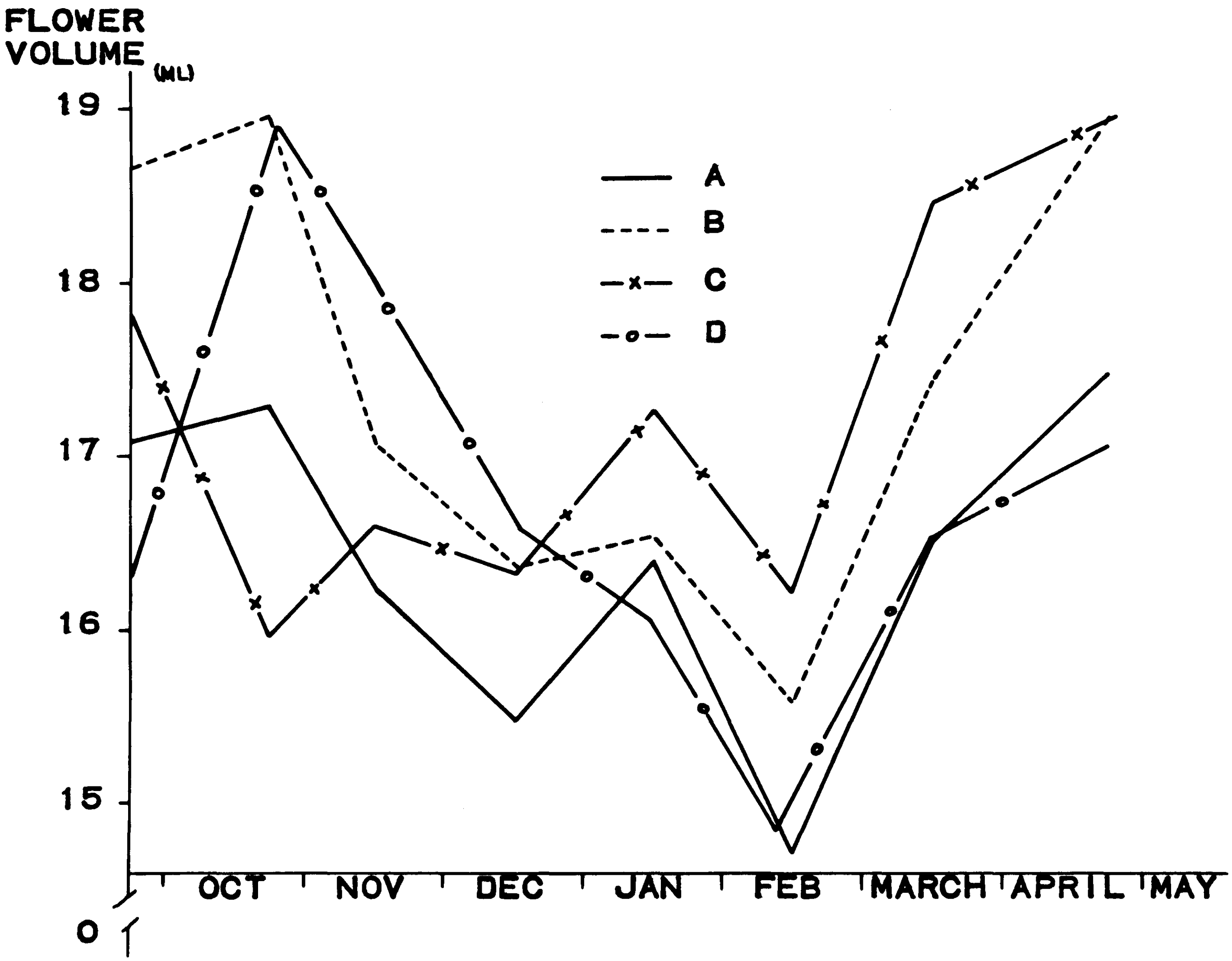

Figure 14.--Periodic means of flower volume for Red Gayety carnations in their second year of production, experiment three.

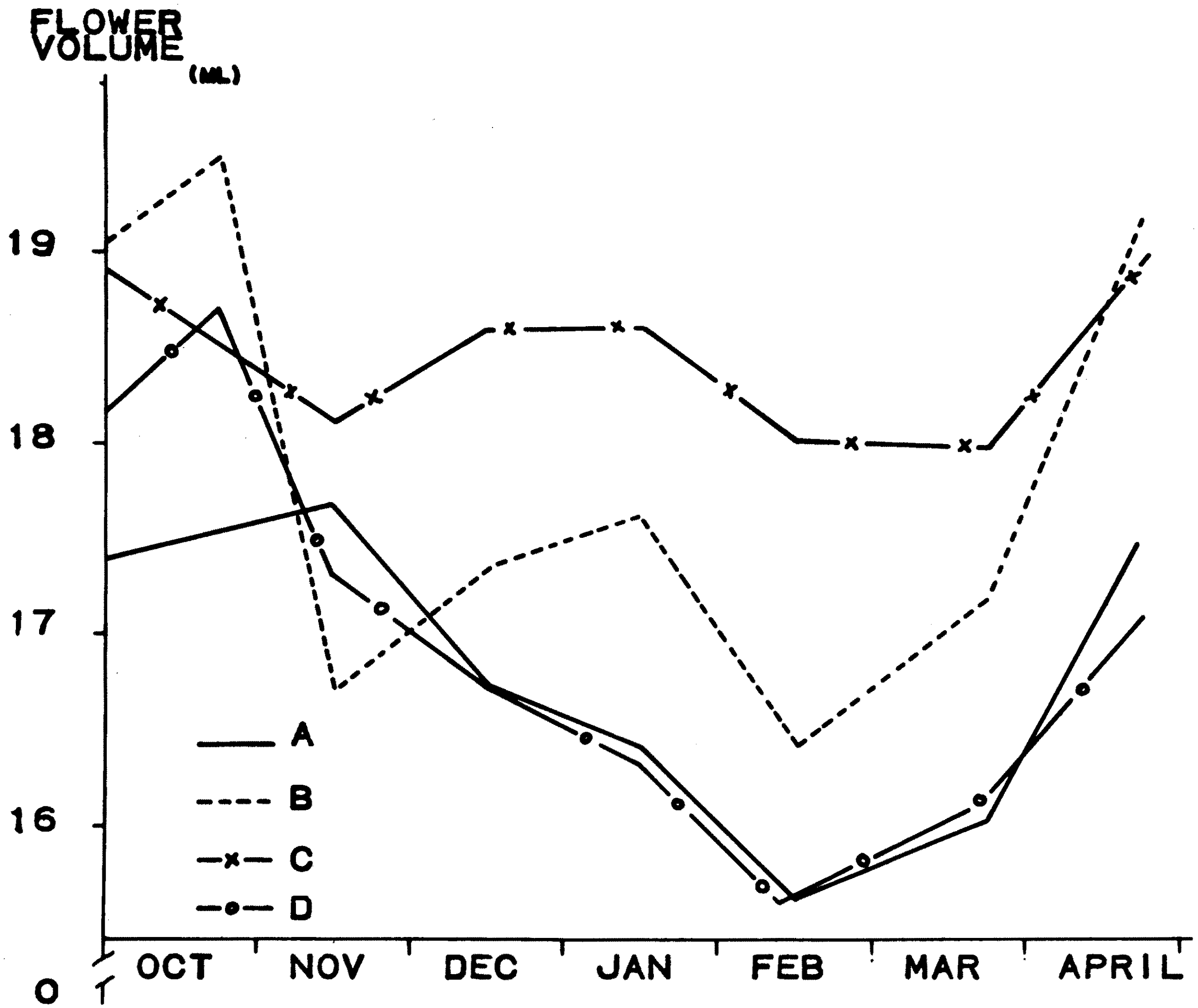

Figure 15.--Periodic means of flower volume for White Sim carnations benched May 30, 1959, experiment four.

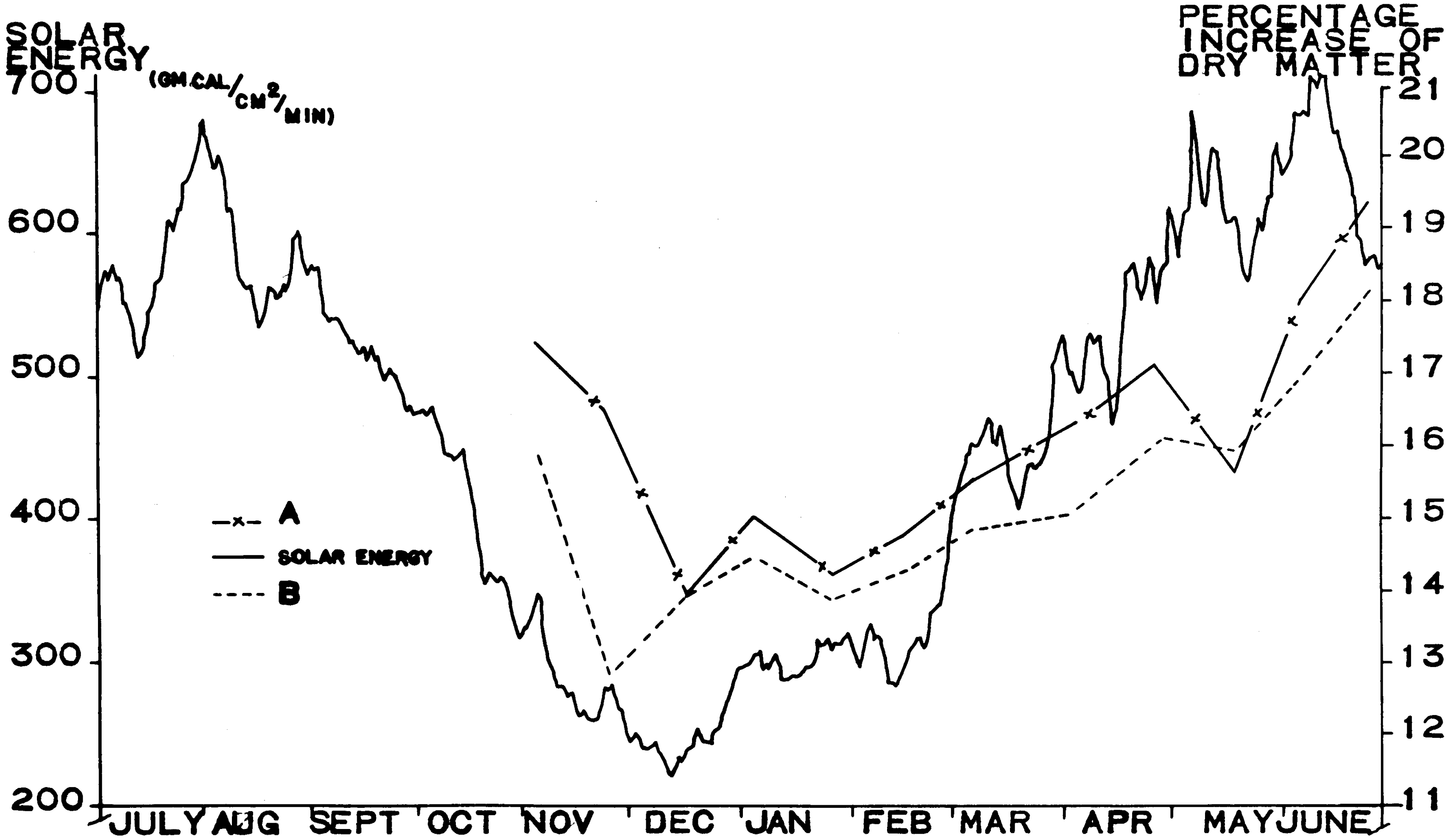

Figure 16.--The comparison of solar energy received at Fort Collins, Colorado, with the percentage of dry matter produced in twelve weeks by young Red Gayety carnation plants, from October, 1958, to July, 1959.

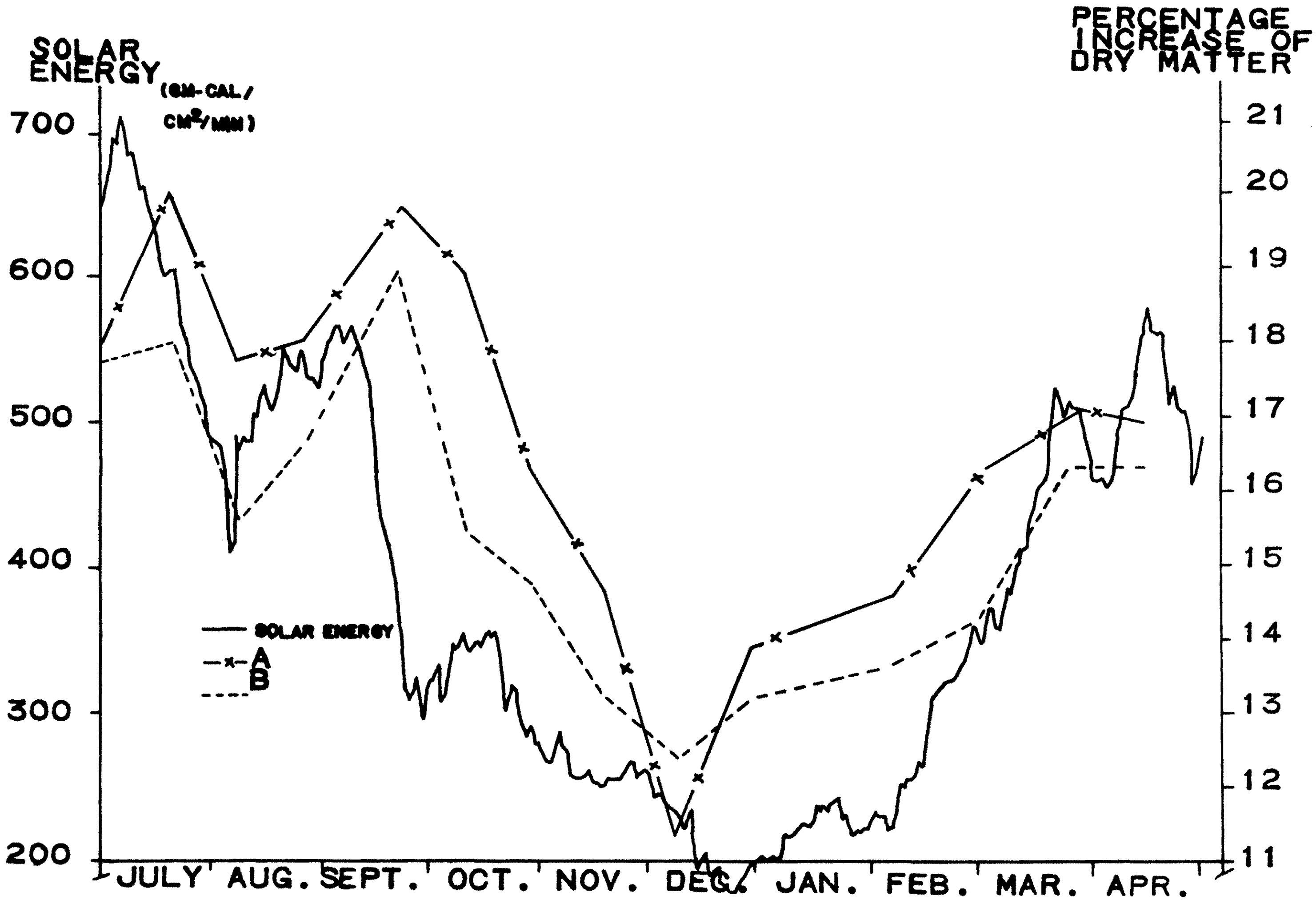

Figure 17.--The comparison of solar energy received at Fort Collins, Colorado, with the percentage of dry matter produced in twelve weeks by young Red Gayety carnation plants from July, 1959, to May, 1960.

Chapter V

DISCUSSION

The two factors of interest to the commercial carnation grower are quality of the cut flower and yield. Therefore, the need for a close study of the results with these two factors becomes apparent. The results for the other morphological factors will be discussed only when they may be used by a commercial grower, or when they apply to the carnation industry.

Yield

The yield of cut flowers was affected by the different treatments. Carnations in compartment C in experiment four (Table 3) had a lower yield than the other three compartments. Compartment D in experiment two (Table 1) had a slight increase in yield due to the higher day temperature maintained on sunny winter days. Hanan (38) observed this effect when growing carnations within a day temperature range of 60-75° F. He stated that these differences did not affect total yield. This was in agreement with various investigators (28, 29, 31, 82) who found that the rate of photosynthesis remained constant at a temperature range of 60-75° F., and would therefore not affect yield.

Light was the major factor influencing carnation yield in this investigation. This was indicated by the significant difference found in experiment five (Table J, Appendix) for the weekly sampling for production of dry matter from standard grade cut flowers, and the close correlation between solar energy and percentage of dry matter of young plants grown for twelve weeks under the various treatments. This is again shown by Figures 16 and 17, which indicate that production follows the solar energy curve.

When day temperature was raised to 60° F. and the sun was allowed to increase temperature an additional 5° F. the production follows the solar energy received (Figure 12). For compartment C of experiment four, the day temperature was held low during the flowering period and production followed the solar energy received, during the two darkest months of the year. The high production at the beginning of these experiments should be disregarded as it is typical for a new crop. Other investigators (18, 23, 56) have found an increase in yield with an increase in solar energy as long as the plants had not reached their solar saturation point.

Since the timing of production is an important factor in the sale of carnations, the effect of changing day temperature on the time flowers are produced is evident. If day temperatures are decreased when flower buds are showing color it will delay the blooming time three to five days. Figure 12 shows that the production of compartments B and C in experiment two were essentially the same until January, 1959. Therefore, the changing of temperature before Christmas in compartment B did not affect the production for Christmas sales. However, by decreasing the day temperature in September to 60° F., the production of one-year old plants was reduced for this period (Figure 13).

Quality

Mean grade is the easiest and most often used method of indicating the effect of environment on plant performance. Mean grade is used interchangeably with quality, but it is not a total measurement of quality. Mean grade considers only the weight, stem length, and flower form; while quality considers such factors as color, flower size, stem strength, foliage, and keeping life. The only time these factors are considered in mean grade is if they are obvious when the flowers are graded. Then the value given them is indeterminate and dependent upon the grader.

The mean grades of carnations grown in compartments A and B of experiments two and three were compared with solar energy in Figures 18 and 19. There was a close relationship between the mean grade and solar energy received when a constant day temperature was maintained. The mean grade was found to follow the solar energy curve with a nine to eleven week lag when no temperature adjustment was made. Figures 10, 11, and 12 show that by decreasing day temperature as solar energy decreases, it is possible to maintain a higher mean grade during periods of low solar energy without affecting yield. Temperatures used in this investigation were not completely correlated with solar energy during December of 1959, and January, 1960. A decline in mean grade for compartment B during February and March, 1960, indicates that an additional temperature decrease in November, 1959, might have been desirable. This decline in mean grade may be partly attributed to the darker than average

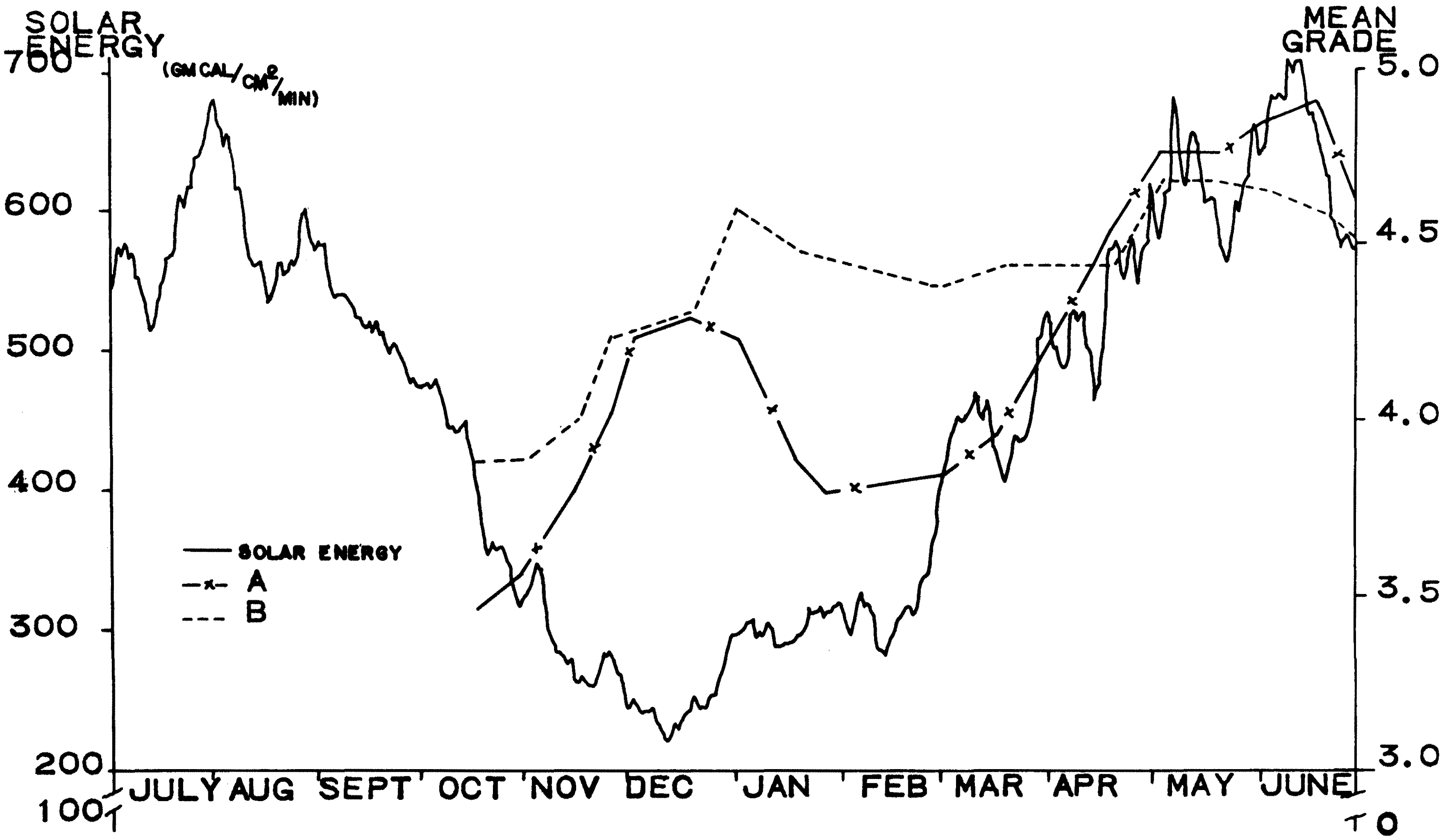

Figure 18.--The comparison of solar energy received at Fort Collins, Colorado, with mean grade for compartment A (uncorrelated) and compartment B (correlated) for Red Gayety carnation plants from October, 1958, to July, 1959.

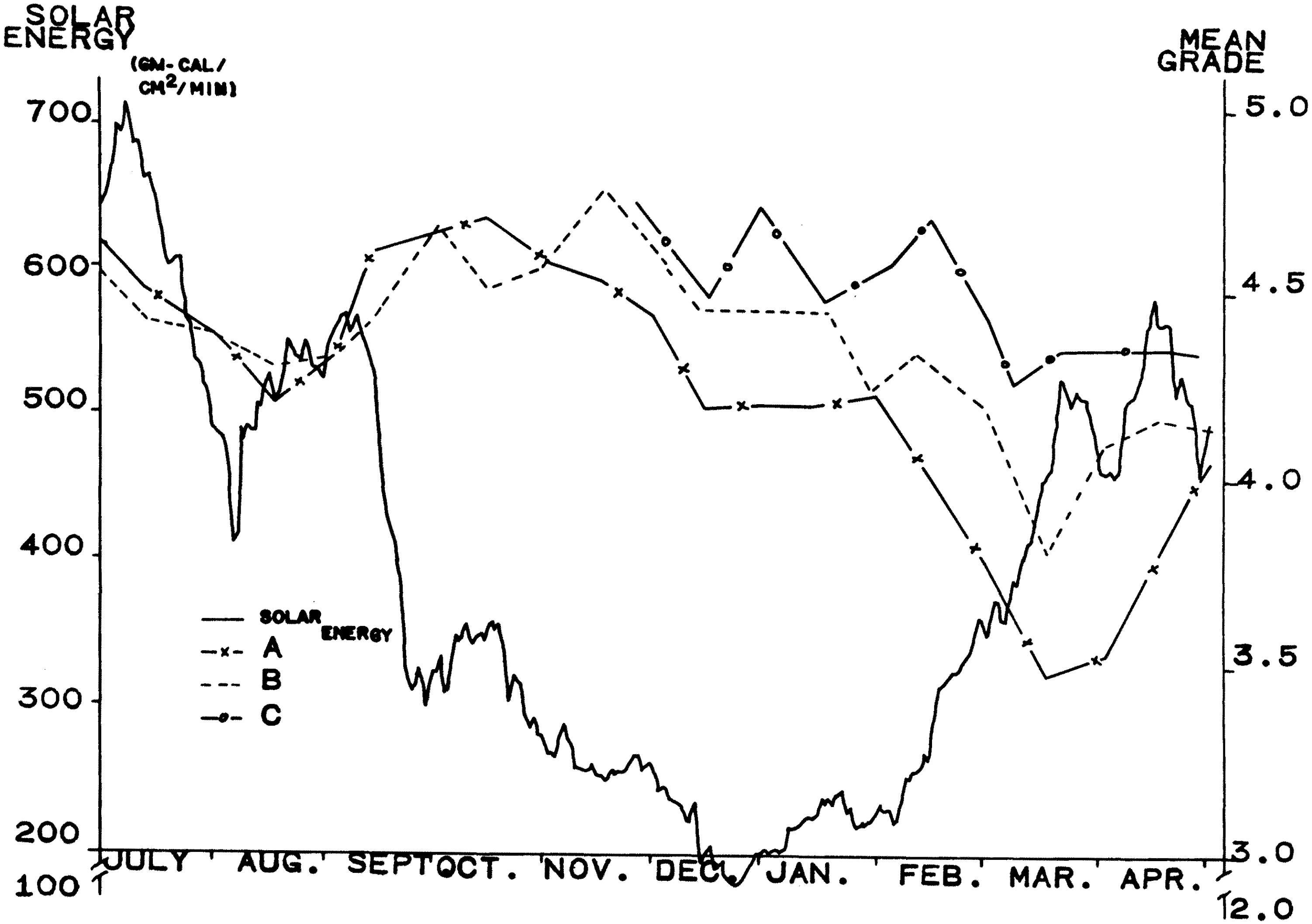

Figure 19.--The comparison of solar energy received at Fort Collins, Colorado, with mean grade for compartment A (uncorrelated) and compartment B (correlated) for Red Gayety carnation plants from July, 1959, to May, 1960.

winter season. The plants were two years old and some investigators (32, 67, 79) state that the age of the plant affects its behavior under a given light intensity and temperature.

Malformed flowers and stem length were not affected by correlating seasonal solar energy and day temperature. The main defect of the uncorrelated treatment was lack of weight. The lack of weight may be caused by the lower rates of photosynthesis during the dark period of the year, while the constant day temperature keeps respiration at the same rate. The respiration thus reduced the supply of carbohydrates causing a lack of weight in the uncorrelated compartments.

The flower defects were different under the two conditions. The flowers from the correlated compartments were flat with protruding stamens; while flowers from the uncorrelated compartments lacked petals making the centers hollow.

The small increases in quality that do not coincide with the solar energy curve represent the beginning of a new crop. As production begins to increase rapidly, the mean grade also increases. Two weeks before maximum production is reached the mean grade peaks. This is apparently due to the flowers cut during the initial stages of a heavy crop receiving more light when they started as lateral branches. Those flowers cut during the "tail out" of a crop start when there is heavy vegetative growth decreasing the solar energy they receive.

Discussion of other measurements

The highest stem strength could be associated with the coolest day temperature. Earlier work had indicated that stems of carnations grown at higher temperatures had the shorter internodes (38). In this investigation the plants grown at the higher temperatures had the longer internodes. The reason for this discrepancy remains unexplained.

The keeping life of carnation cut flowers is important to the carnation industry. It was found that temperatures used in this investigation did not affect keeping life, but keeping life was lengthened as the plant aged. The decrease of keeping life in experiment two after June was probably due to high summer temperature. This phenomenon had been observed by Fairchild (30).

Suggestions for further study

While this investigation increased quality by correlating day temperature with solar energy from season to season, a further study of the effect of correlating day temperature and light each day may be warranted. If it is necessary to correlate day temperature with solar energy for the production of high quality carnations, then a study of night temperatures correlated with seasonal or daily light intensities may be in order. During the darkest period of the year, the quality of flowers from two-year old plants decreased and a further investigation of day temperature on two and three-year old plants might alleviate this problem.

Different colored shading compounds and different materials to reduce high summer temperatures may be of importance to the carnation industry.

A study of carbon dioxide content in the atmosphere within greenhouses may lead to higher quality and yield, and require further research on day and night temperature. An investigation of carbon dioxide concentration in the greenhouse with various amounts of fan operation also seems appropriate.

Chapter VI

SUMMARY

Four compartments were used in a temperature research greenhouse. Compartment A was maintained constantly at 65° F.; compartment B was maintained at 65° F., being lowered to 60° F. from November 15 to March 15 (correlated); compartment C was maintained at 70° F. during the summer, being lowered to 65° F. on October 1, then to 60° F. on December 25, back to 65° F. on February 15 and again to 70° F. on March 15--during the second winter temperatures were shifted to 60° F. on September 30 (correlated); D was heated to 60° F. and cooled to 70° F. until March 13 of the first year at which time it was cooled to 65° F.

Carnations grown in these compartments were harvested and graded four times weekly.

The year around mean grade was maintained at a higher level by correlating day temperature with seasonal solar energy. The mean grade was found to follow solar energy with a nine to eleven week lag when no temperature adjustment was made. The flowers from the correlated compartments were heavier and did not become hollow centered during periods of low solar energy as did the flowers from the uncorrelated compartments. High quality was associated with young plants and the initial stage of a crop. Stem strength was higher at the cooler temperatures, while keeping life, dry matter production and yield were not affected by temperatures used in this investigation. The temperatures in compartment B gave the highest quality carnation cut flowers in this investigation.

A P P E N D I X

The following tables give the analysis of variance for the results of solar energy on the optimum day temperature for carnation growth. A single asterisk (*) indicates significance at the five per cent level, while double astericks (**) indicate the significance is one per cent.

Table A.—ANALYSIS OF VARIANCE FOR FRESH WEIGHT OF FANCY AND STANDARD GRADE CARNATIONS.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Fancy Grade		
Temperature	3	25.33
Weeks	43	19.77*
Error	132	11.21
Standard grade		
Temperature	3	9.00**
Weeks	46	11.10**
Error	138	1.72
Red Gayety (Experiment Three)		
Fancy grade		
Temperature	3	201.66**
Weeks	33	0.57
Error	99	3.94
Standard grade		
Temperature	3	24.33**
Weeks	33	7.57**
Error	99	0.79
White Sim (Experiment Four)		
Fancy grade		
Temperature	3	7.00**
Weeks	26	1.35*
Error	78	0.62
Standard grade		
Temperature	3	14.00**
Weeks	32	5.50**
Error	96	0.46

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

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	1.426**
Weeks	46	0.339**
Error	138	0.047
Red Gayety (Experiment Three)		
Temperature	3	0.683**
Weeks	31	0.245**
Error	93	0.014
White Sim (Experiment Four)		
Temperature	3	0.73**
Weeks	32	0.12**
Error	96	0.03

Table C.--ANALYSIS OF VARIANCE OF KEEPING LIFE OF CARNATION CUT FLOWERS.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	0.06
Weeks	21	5.86**
Error	63	0.04
Red Gayety (Experiment Three)		
Temperature	3	4.33
Weeks	5	102.80**
Error	15	6.20
White Sim (Experiment Four)		
Temperature	3	8.00
Weeks	4	123.00**
Error	12	16.90

Table D.--ANALYSIS OF VARIANCE FOR FRESH AND DRY WEIGHT AND PER CENT DRY MATTER OF CARNATION CUT FLOWERS.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Fresh weight		
Temperature	3	1,215.00*
Weeks	10	3,421.00**
Error	30	331.00
Dry weight		
Temperature	3	217.00
Weeks	10	8.90
Error	30	133.60
Per cent dry matter		
Temperature	3	5.33*
Weeks	10	8.00*
Error	30	0.03
Red Gayety (Experiment Three)		
Fresh weight		
Temperature	3	88.00
Weeks	8	2,280.00**
Error	24	215.80
Dry weight		
Temperature	3	9.33
Weeks	8	152.70**
Error	24	6.25
Per cent dry matter		
Temperature	3	2.66
Weeks	8	9.12**
Error	24	1.45
White Sim (Experiment Four)		
Fresh weight		
Temperature	3	308.00**
Weeks	8	194.50**
Error	24	52.50
Dry weight		
Temperature	3	13.66**
Weeks	8	20.87**
Error	24	1.08
Per cent dry matter		
Temperature	3	7.00
Weeks	8	12.62*
Error	24	3.79

Table E.--ANALYSIS OF VARIANCE OF INTERNODE LENGTH OF CARNATION CUT FLOWERS.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	2.16*
Weeks	11	7.36**
Error	33	0.65
Red Gayety (Experiment Three)		
Temperature	3	23.00**
Weeks	7	23.57**
Error	21	4.38
White Sim (Experiment Four)		
Temperature	3	0.33
Weeks	6	2.50*
Error	18	0.97

Table F.--ANALYSIS OF VARIANCE OF LEAF LENGTH OF CARNATION CUT FLOWERS.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	7.67*
Weeks	11	5.09*
Error	33	1.96
Red Gayety (Experiment Three)		
Temperature	3	0.33
Weeks	7	1.42**
Error	21	0.38
White Sim (Experiment Four)		
Temperature	3	7.33
Weeks	6	15.33
Error	18	7.38

Table G.--ANALYSIS OF VARIANCE OF LEAF WIDTH OF CARNATION CUT FLOWERS.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	2.00
Weeks	11	3.45**
Error	33	1.03
Red Gayety (Experiment Three)		
Temperature	3	2.33**
Weeks	7	3.71**
Error	21	0.47
White Sim (Experiment Four)		
Temperature	3	3.00**
Weeks	6	4.33**
Error	18	0.22

Table H.--ANALYSIS OF VARIANCE OF CARNATION FLOWER VOLUME.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	10.30**
Weeks	11	7.36**
Error	33	1.39
Red Gayety (Experiment Three)		
Temperature	3	3.00
Weeks	7	45.00
Error	21	20.57
White Sim (Experiment Four)		
Temperature	3	10.00**
Weeks	6	3.33**
Error	18	0.50

Table I.--ANALYSIS OF VARIANCE OF CARNATION STEM STRENGTH.

Sources of variance	df	MS
Red Gayety (Experiment Two)		
Temperature	3	216.33**
Weeks	9	189.88**
Error	27	0.22
Red Gayety (Experiment Three)		
Temperature	3	8.66
Weeks	7	8.14
Error	21	6.61
White Sim (Experiment Four)		
Temperature	3	3.67
Weeks	6	39.00**
Error	18	8.88

Table J.--ANALYSIS OF VARIANCE OF FRESH AND DRY WEIGHT AND PER CENT DRY MATTER OF RED GAYETY ROOTED CUTTINGS GROWN FOR 12 WEEKS IN THE DIFFERENT COMPARTMENTS.

Sources of variance	df	MS
Fresh weight		
Temperature	3	18,186
Weeks	22	72,559**
Error	66	18,102
Dry weight		
Temperature	3	137.00
Weeks	22	2,431.27**
Error	66	72.20
Per cent dry matter		
Temperature	3	1.33
Weeks	22	3.72**
Error	66	0.91

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