THESIS

EFFECTS OF GLASS AND FIBERGLASS ON CARNATION GROWTH

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY ROBERT A. BRIGGS ENTITLED EFFECTS OF GLASS AND FIBERGLASS ON CARNATION GROWTH BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Chapter I

INTRODUCTION

Holley (15) in 1956 obtained evidence to indicate that plastic coverings increased the growth of both carnations and tomatoes during the winter months (December to February). Clear Alsynite showed an increase of 26 per cent over the growth obtained under glass alone. Polyethylene, kodapak and polyflex increased growth over glass by eight to ten per cent. The increase in dry matter was considered growth in this experiment.

No doubt these results were due to modification of light striking the plants. Modification of the light is quite easily accomplished with selected greenhouse coverings. If it is possible to increase growth by modifying the light, this should be a practical method of growing more flowers in the same area.

The problem

To compare carnation growth and quality under glass and fiberglass coverings.

Problem analysis.--The following comparative effects of glass and fiberglass on carnation growth will be measured:

1. Yield as measured by number of flowers produced as solar energy varies throughout the year.

2. Quality of flowers as measured by weight, stem length, flower volume, and cut flower life.

The extent to which glass and fiberglass alter solar energy will be investigated.

Delimitations.--With the exception of screening tests, the investigation will be limited to three greenhouses constructed for this study at Colorado State University. The greenhouses will be covered with Coral Filon fiberglass, Clear Filon fiberglass, and greenhouse glass. The following varieties will be investigated: Red Sim, Pink Mamie, Pikes Peak Frosted, and White Sim.

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

The day and night temperatures will be set as recommended by previous investigators and will be constant in all three houses (13, 22, 31).

Definition of terms

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

Solar energy and light--Visible light and solar energy correlate closely.

Diffused light--Light that is uniformly dispersed.

Direct light--Light that is not obstructed from source to the receiver.

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

Background

Fiberglass panels have been produced for about ten years. Everyday a new use is found for these materials. They offer many advantages for greenhouse construction:

1. The greenhouse architecture can now be changed to get the most advantage of solar energy.

2. The use of fiberglass requires less superstructure.

3. Fiberglass material is hailproof, resulting in a reduced insurance cost.

4. The cost of upkeep is lowered with fiberglass plastic.

5. Ease of installation with fiberglass results in reduced construction costs.

Chapter II

REVIEW OF LITERATURE

Research into the effects of light on plants has been with either the quality or the intensity of light. A phase of light research that has been neglected is the effects of diffused light on plant growth. Since it is not feasible to cover all the articles published, only the articles directly connected with this research will be reviewed.

Light quality

Many researchers (8, 17, 27, 28, 35) state that the plant should have a complete spectrum of light for the best growth. Hoover (17) showed the rate of photosynthesis to be a function of the wave length of light when the incident energy was equal. Ultraviolet light is not indispensable, but the blue-violet light is necessary for normal plant growth (28). This research was strengthened by Meier (23) who, while working with green algae, showed that the algae produced the most chlorophyll when the blue-violet region of the spectrum was included in the light.

Shirley (35) found that the production of dry matter for *Geum*, *Galinsoga*, sunflower, and buckwheat under the complete solar spectrum was higher than that for any portion of it. No light condition was more advantageous for normal growth of *Zinnia* and *Kalanchoe* than daylight (19). It has been concluded by Crocker (8) and Popp (28) that no light or combination of colored light has proven superior to the full spectrum for plant growth.

Red light is the most efficient in photosynthesis (4) even though there is more energy per quanta of blue light. Hoover (17) working with young wheat plants found peak photosynthetic activity around 3650 A° on the violet end of the spectrum and between 7200 A° and 7500 A° on the red end. Sayre (30) found the effectiveness of radiant energy on field crops to increase with wave length to about 6800 A° and then to end abruptly.

Curtis and Clark (9) 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 (4, 17, 30), 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 still less effective. The low effectiveness of green light is due to the large amount that is reflected by the chlorophyll. Ultra-violet light of wave lengths less than 2900 A° was distinctly injurious. In general, ultra-violet light may be stimulating to plant growth above 2900 A° (2, 5, 37).

Meier (24) grew green algae in darkness and in various colors of light. She found over a four fold increase in numbers under natural daylight compared to the control grown in darkness. Growth was threefold in blue light, and twofold in yellow and red. Green light produced fewer cells than the control.

The light frequencies normally found within the greenhouse as found by Kohl (20) are 3250 A° to 20,000 A°, the limit of his instrument. He found that 85 to 90 per cent of the visible light was transmitted through glass.

Johnston (18) showed the phototropic sensitivity of _Avena sativa_ varied when different wave length regions of the visible spectrum were used. The phototropic sensitivity curve rises sharply from 4100 A° to a maximum at 4400 A°, drops to a minimum at about 4575 A°, and again rises to secondary maximum in the region of 4700 to 4800 A°. The fall is rapid from this point to 5000 A° where it tapers off gradually to about 5461 A°.

Van der Veen and Meijer (38) worked with colored light on the flower formation of _Hyoscyamus niger_, a long day plant; _Salvia occidentalis_, a short day plant; Petunia, non-obligate long day; and _Plantago media_, obligate long day plant. They state that the long day effects represent a very complex interplay of numerous reactions. The following is a summary of these reactions:

1. A long day reaction can be obtained by exposing plants to long days of light containing blue or infra-red radiations.

2. Long day effects can also be produced by exposure to short days of light containing blue or infra-red and interrupting the dark-period with light containing red. A short day containing

blue or infra-red therefore renders the plant sensitive to red nightbreak light. A short day of green or red light alone will not always do this.

Light intensity

There are many factors affecting the light intensity received at the earth's surface, the two major obstructions for the decrease of light intensity are dust and water vapor. The earth intercepts 5×10^{20} kilocalories per year even with these obstructions. The sun's energy, at any location in the United States, reaches the earth at about one cal./cm^2/min. (10).

Many investigators (7, 11, 13, 21) have found that for each increase in light intensity there is an increase in yield. Unless other factors such as carbon dioxide and nutrition are limiting, this statement may be valid for carnations grown under greenhouse conditions. Carbon dioxide or nutrition may be the factor controlling yield at different times of the year.

Shantz (34) working with radishes, lettuce, corn, potatoes, cotton, and mustard found little or no reduction in growth when the light was reduced by one-fifth that of full sunlight. His measurement of growth was by general appearance of the plant, height, fresh weight, and number of nodes. Rate of growth was markedly reduced when the plants were grown in light one-fifteenth that of full sunlight.

Bohning and Burnside (3) measured the apparent rate of photosynthesis in relation to light intensity in the leaves of several species of plants. The plants were exposed to similiar conditions of light, temperature, moisture and carbon dioxide. Light saturation and compensation points for the species that were accustomed to full sunlight were 2000 to 2500 foot-candles, and 100 to 150 foot-candles respectively. For shade species the light saturation point was between 400 to 1000 foot-candles, and the compensation point about 50 foot-candles.

Burkholder and Johnston (6) found that light of high intensities has a destructive or inactivating action on plant growth. Shirley (35) reported that the percentage of dry matter, the ratio of dry weight of roots to the dry weight of shoots, the density of growth, the strength of stem, and the leaf thickness all increased with increasing light intensity. The leaf area was greatest and maximum height was attained at light intensities of about 20 per cent of full summer sunlight.

While working with red color of apples, Schrader and Marth (32) found that the color of apples shaded with bags decreased markedly from apples grown in full sun. The possibility of temperature differences between the unbagged and bagged fruit was not mentioned. The temperature could have some effect on color as well as size.

Odom (26) while working with Sim varieties and Miller's Yellow variety of carnations found that food supply in cuttings was affected by the average daily light intensity. Both the dry weight and non-protein soluble solids were reduced after several days of cloudy weather. When the average light intensity was high the dry weight and soluble solids fluctuated within a fairly constant range. The greatest accumulation of food followed the maximum light intensity by one or two hours. The light compensation point for carnations was reached when the average daily light intensity was below approximately 1700 foot-candles.

Many researchers show that light may limit plant growth (2, 13, 14, 26, 27, 35). Among these researchers, Thut and Loomis (37) measured differences between plants in growth and development with wide variations in light intensity. Some of the most common of these effects are decrease in the percentage of dry matter, elongation of the internode, and loss of chlorophyll when light becomes very limiting.

Shirley (35) working with dwarf sunflower, peanut, buckwheat, loblolly pine, tomato, tobacco, California redwood, and wandering Jew gave evidence that the dry weight produced by plants, during the winter, was directly correlated with solar energy received in the greenhouse. But during the summer, he felt that some plants were capable of a more efficient use of light at higher intensities.

Diffused light

Seemann (33) working with lettuce used two different types of glass for greenhouse coverings. He used gartenklarglass, which is an opaque glass that diffused the light, and blankglass, which is about the same as normal greenhouse glass. He found that the diffuse light contains more green and blue light by percentage than direct light. The average glass will absorb 8 to 15 per cent of the total radiation and about 1.6 to 2.5 per cent of the visible spectrum. The surface and impurities in the glass determine the amount of either parallel or diffuse light that is reflected. The beam shadow reduced the amount of usable light in the blankglass by 10 per cent. The gartenklarglass increased the usable light by 5 per cent over the blankglass. This was attributed to the diffusion of the light.

The lettuce, when grown under gartenklarglass, increased about 4.5 per cent in the number of heads harvested and about 7.0 per cent in weight over the lettuce grown in blankglass. Seemann attributed this increase in growth by gartenklarglass to the fact that there was less variation in the light within the greenhouse.

Nordmeijer (25) investigated the effects of klarglass and blankglass on the growth and development of cucumber, head lettuce, black radish, and paprika. The houses that were built from these materials were 12 by 81 feet, and were built in the north - south direction. No control of temperature was possible, but a daily record of both temperature and humidity was made. The average temperature and humidity under the klarglass was 4° C. and 5 per cent higher, respectively, than those under the blankglass. The klarglass produced 13 per cent more cucumbers than the plants grown under the blankglass. This increased yield brought about a 9 per cent increase in weight of the crop.

Chapter III

METHODS AND MATERIALS

This investigation is divided into (a) preliminary screening tests, (b) the greenhouse environments provided, (c) carnation growth measurements, (d) measurements of solar energy in the houses, and (e) statistical methods.

The screening tests

Structures with approximate dimensions of 4 by 8 feet, 3 feet high at the eaves and 50 inches at the ridge, were constructed of wood. The following materials were used to cover them: (1) greenhouse glass, (2) mylar W2 (5 mil thickness), (3) Eskaylite polyvinyl (8 mil), (4) velon screen (14 mesh) and (5 to 11) Filon 180 corrugated fiberglass paneling in the colors of clear white, frost white, coral, jade, amber, yellow and a special light purple. The sides of all houses were of velon screen to permit natural ventilation.

For ease of construction, all corrugated fiberglass paneling on the roof was arranged with the corrugations running lengthwise of the house. The structures were washed free of dust at least once each week and were spaced so there was no shading of one house by another.

On June 3, 1959, 50 carnation plants were transplanted to each house. These plants had been grown from April 7 in peat pots under a glass house, and were quite uniform. Throughout the experiment all plants were irrigated and fertilized with a nutrient solution (33). They were watered at tensions of 0.3 to 0.5 bars. Fumigants were applied weekly to avoid damaging infestations of insects.

All plants were pulled, their roots washed free of soil and their fresh weights obtained August 24. The plants were then dried in a 70° C. forced draft oven to constant weight, and individual plant weights were obtained.

Greenhouse environment

All investigations on the effects of glass and fiberglass on carnations were carried on in the three light study research greenhouses (Figure 1). The houses run east and west and are approximately 15 feet wide and 18 feet long with the eave 7 feet and the ridge 10 feet high. The framework was constructed of wood with an opaque wall about 2-1/2 feet high surrounding each house. The houses were covered with clear Filon fiberglass, coral Filon fiberglass, and greenhouse glass and were so spaced that they did not shade each other. Theoretically, the houses were equal in total solar energy received.

On the west wall were constructed two ventilators, 2-1/2 by 4-1/2 feet which were hinged at the truss. These ventilators were manually operated and can be removed during the summer months. Four evaporative cooling pads, 34 by 54 inches were located directly in front of the ventilators. The water for the pads was turned on

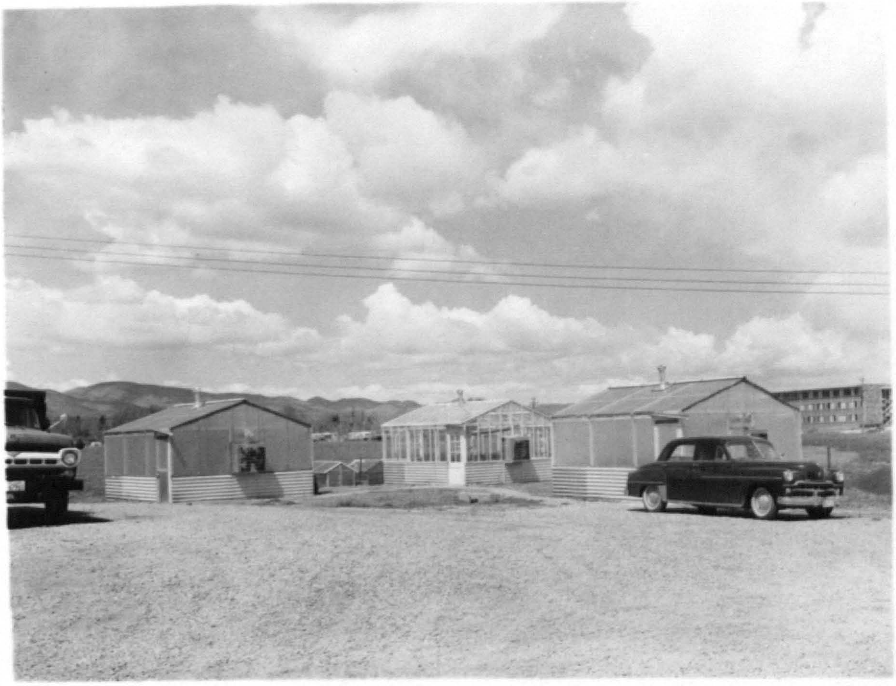

Figure 1.--The three light research greenhouses at Colorado State University.

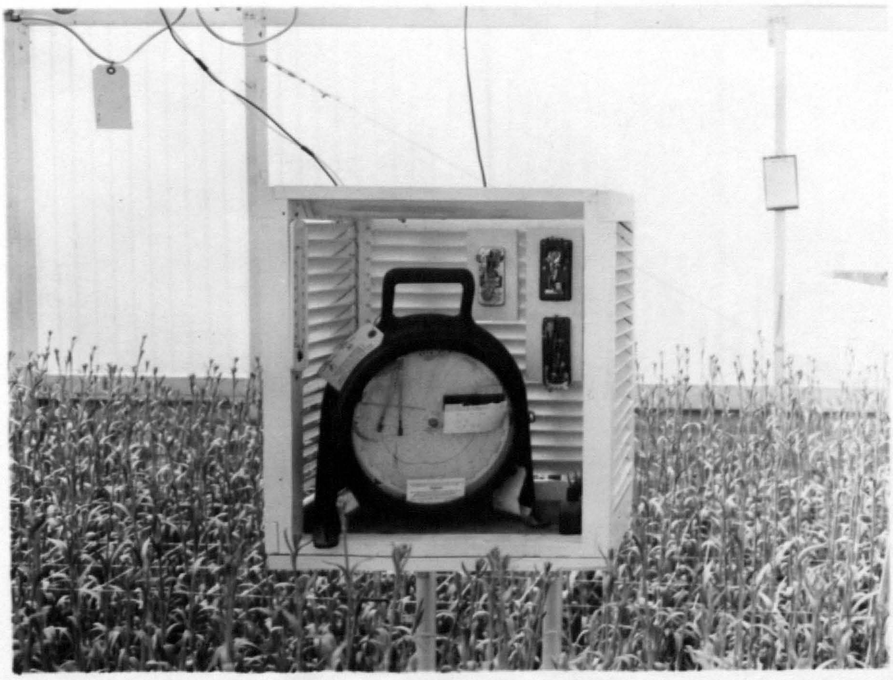

Figure 2.--The thermostat control shelter located in each of the three light research greenhouses.

by an outside thermostat set at 56° F. Excess heat over 65° F. was removed by 30-inch Acme exhaust fans with louvers which would open and close with air movement.

Heat was supplied by Janitrol 85,000 BTU input gas heaters. These heaters were humg from the ridge, in the center of the house, 7 feet above the ground, facing north, with the fans running continuously during the heating season.

A thermostat control shelter was located in the middle of each house, about 3 feet above the ground (Figure 2). The cabinet opens to the north and is louvered to prevent sunlight from striking the instruments and to allow free passage of air over the thermostats. Thermostats within these units control the temperature to within ± 1-1/2° F. of the specified temperature for the house. Night temperature during the heating season (October to May) was maintained at 52° F. The remainder of the year the night temperature was regulated by the outside temperature provided it was below 65° F. During the heating season the day temperature was maintained at 60° F. The fan thermostat was set at 65° F. A Foxboro 24-hour hygrothermograph was used in each house continuously.

Each house contains two benches 4 by 13 feet, with each bench capable of holding 160 plants at a six by eight inch spacing. The tops of these benches were 12 inches above ground level. The plants were irrigated and fertilized with a dilute nutrient solution and additional dry fertilizers were applied when periodic soil tests indicated a need. The plants were watered at moisture tensions of 0.3 to 0.5 bars, the higher tension used during the fall and winter. The soil was steamed and precautions were taken to prevent recontamination. Carnation plants came from the Colorado State University foundation stock, which is a part of the pathogen-free stock program. After allowing sufficient time for the plants to establish themselves, a steamed leaf 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 applied every one to two weeks, but during the winter applications were made as needed.

Yield and quality of flowers

Four varieties of carnations were directly benched on January 3, 1960. These varieties, Red Sim, Pink Mamie, Pikes Peak Frosted, and White Sim, first bloomed on May 15, 1960, after a single pinch. The measurements were taken from this date until the conclusion of this experiment on April 1, 1961.

The following measurements were used to evaluate the effect of the fiberglass and glass on carnation growth:

Yield included the total number of flowers cut.

Mean grade was computed from all flowers cut and graded by 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 cālyx, 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 of less than 20 inches or a weight less than 15 grams, and (d) design, all flowers failing to meet the above specifications.

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 houses.

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

Production of dry matter by young plants

Two rooted cuttings per pot of the variety Red Gayety were planted in 18 6-inch pots of old greenhouse soil on June 6, 1960. Six pots were placed in each house and watered on demand with nutrient solution for nine weeks. All soil used was steamed and calcium carbonate and treblesuperphosphate were added to the soil to supply adequate calcium and phosphorous. At three-week intervals after June 6, a similiar lot of 18 pots were started.

To gain increased uniformity of cuttings, they were weighed before rooting. Only those cuttings were used that weighed 7 to 9 grams before December, and 6 to 8 grams thereafter.

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. This weight was later added to the final dry weight of the plants. After nine weeks of growth each lot of plants was pulled, the roots washed free of soil, and fresh and oven dried weights obtained.

Cut flower keeping life was measured when there were sufficient flowers available. Only fancy and standard grade flowers were used. They were placed in one gallon of warm tap water, which contained 100 ppm chlorine from calcium hypochlorite, and held in a keeping chamber controlled at a temperature of 70° F. ± 1° and a relative humidity of 55 to 75 per cent. The cut flower life was measured as the number of days each flower remained turgid minus one day. The mean life per sample was computed.

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.

Flower color on the varieties Pink Mamie and Pikes Peak Frosted was rated by visual inspection. An arbitrary rating scale of (1) good color, (2) slightly faded color, and (3) faded color, was used.

Measurement of solar energy in the houses

Measurements of solar energy in the greenhouses were made by: (a) pyrheliometers, (b) silicon solar cells, (c) selenium photovoltaic cells, (d) heat accumulated by the houses. In addition light transmission measurements were made using a Beckman spectrophotometer.

Periodic measurements of the emf produced by Epply pyrheliometers were made with a 6 millivolt potentiometer. The Epply 10-junction pyrheliometers were placed in the same location in the clear fiberglass and glass houses.

Silicon solar cells were placed in the same location in all three houses and the emf produced by these cells was recorded on a Rustrak recorder from September 13, 1960 to January 10, 1961. The silicon solar cell shows a spectral response within the visible and infra-red range (38).

The ultra-violet and visible spectral range was measured by selenium photovoltaic cells in the same location in all three houses and recorded from January 12, 1961, to March 10, 1961. Both the silicon and selenium cells were purchased from International Rectifier Company.

The operating time of the cooling fan in each house is a good indication of the absorbed solar heat. With the fans set at equal RPM and amperage, electric clocks were used to measure the length of time of the operation.

A Beckman, Model B, spectrophotometer was used to measure the per cent transmission of light of 3250 to 10,000 A°, at every 50 A°.

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 house was used. The *t* test was computed for the screening tests, the yield, and the mean grade (12, 36).

Chapter IV

RESULTS

Due to gas injury caused by the heating system, the results of the coral, and the results after November 5, 1960, in the clear and glass houses are not included in yield and grade results.

Screening of materials

The effects of glass, mylar, eskay-lite (a polyvinyl film), velon screen, and seven colors of corrugated fiberglass paneling were compared on growth of young carnation plants from June 3, to August 24, 1959. Eskay-lite, and clear, coral, amber, jade and frost colors of fiberglass produced significantly more dry matter than glass (Table 1 and Table A, Appendix). Mylar and glass gave approximately equal yield, while velon screen and yellow and lavendar fiberglass were detrimental to the growth of young carnation plants. Clear and coral fiberglass were selected for later comparisons with glass, since they are more permanent building materials.

Yield and grade of flowers

The yield and grade of flowers harvested from the clear and glass houses are included in Table 2. The clear fiberglass

Table 1.--EFFECTS OF COVERING MATERIALS ON GROWTH OF YOUNG CARNATION PLANTS FROM JUNE TO AUGUST, 1959.

Material	Average fresh weight (gm)	Average dry weight (gm)	Dry weight index
Clear fiberglass	172.0	32.21	118
Coral fiberglass	168.2	31.21	115
Eskay-lite	166.5	31.21	115
Amber fiberglass	160.7	29.98	110
Jade fiberglass	154.9	28.88	110
Frost fiberglass	157.1	29.69	109
Mylar	148.0	28.40	104
Glass	138.6	27.24	100
Velon screen	136.9	24.58	90
Yellow fiberglass	129.8	23.58	87
Lavendar fiberglass	118.9	22.17	81

Table 2.--SUMMARY OF PRODUCTION AND GRADE OF CARNATIONS GROWN UNDER CLEAR FIBERGLASS AND GLASS FROM JANUARY 3, TO NOVEMBER 5, 1960.

	Houses	
	Clear	Glass
Total yield (no. of flowers cut)	4423	3961
Flowers/sq.ft./year	42.53	38.09
Mean grade	4.267	4.079
Mean fresh weight (gm) of cut flowers		
Fancy	28.8	28.1
Standard	20.9	21.5
Per cent distribution of grades		
Fancy	44	34
Standard	45	49
Short	4	8
Design	7	9
Per cent flowers downgraded		
Insufficient weight	28	18
Short stems	19	37
Malformed flowers	9	11
Total downgraded	56	66

house produced 12 per cent more flowers and 10 per cent more flowers in the fancy grade. The clear house also produced less flowers in the short and design grades, giving a significant improvement in mean grade of all flowers cut (Table A, Appendix). The mean fresh weights of fancy and standard grades of flowers were approximately the same in both houses.

All flowers not grading fancy were considered as downgraded. Insufficient weight was the primary reason for downgrading flowers from the clear fiberglass house while short stems was the serious limitation to grade on flowers from the glass house.

Weekly yields from the two houses (Figure 3) show the first crop one week earlier from the glass house, however, first and second crops were completed earlier in the clear house.

Figure 4 shows a three-week moving mean for the mean grade of flowers cut from the two houses. The mean grade for the clear house was higher every month except August. The Appendix has three-week moving means, summaries of production for all varieties, and summary of total production from January 3, 1960, to April 1, 1961, in Figures A, B, C, D; Tables B, C, D, E and F respectively.

Production of dry matter by young plants

Rooted cuttings were planted in pots on the south side of the clear and glass houses every three weeks and grown for nine weeks before being harvested and dried. From June 6, 1960, to

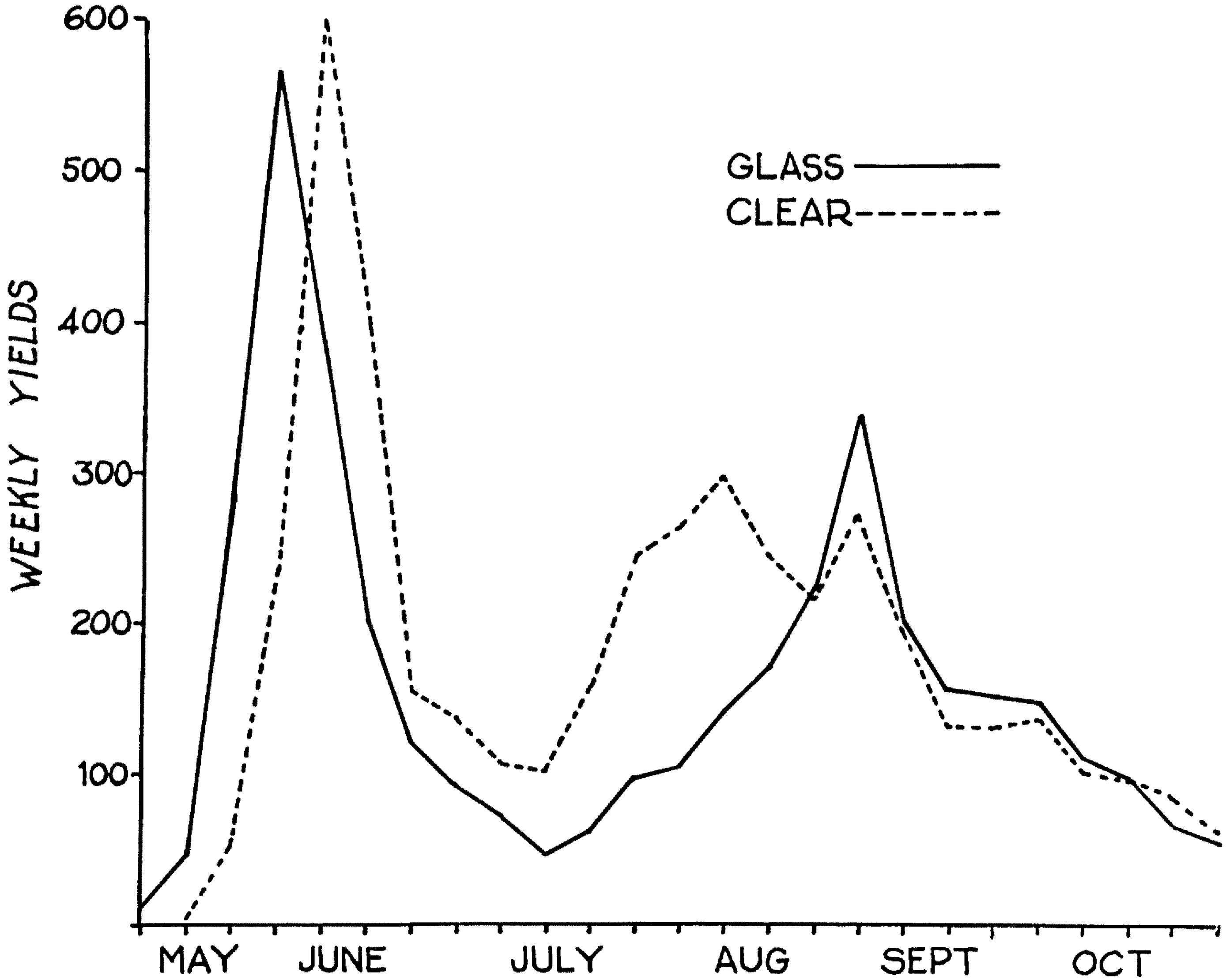

Figure 3.—The weekly yield of carnations in number of flowers from clear fiberglass and glass houses from January 3, to November 5, 1960.

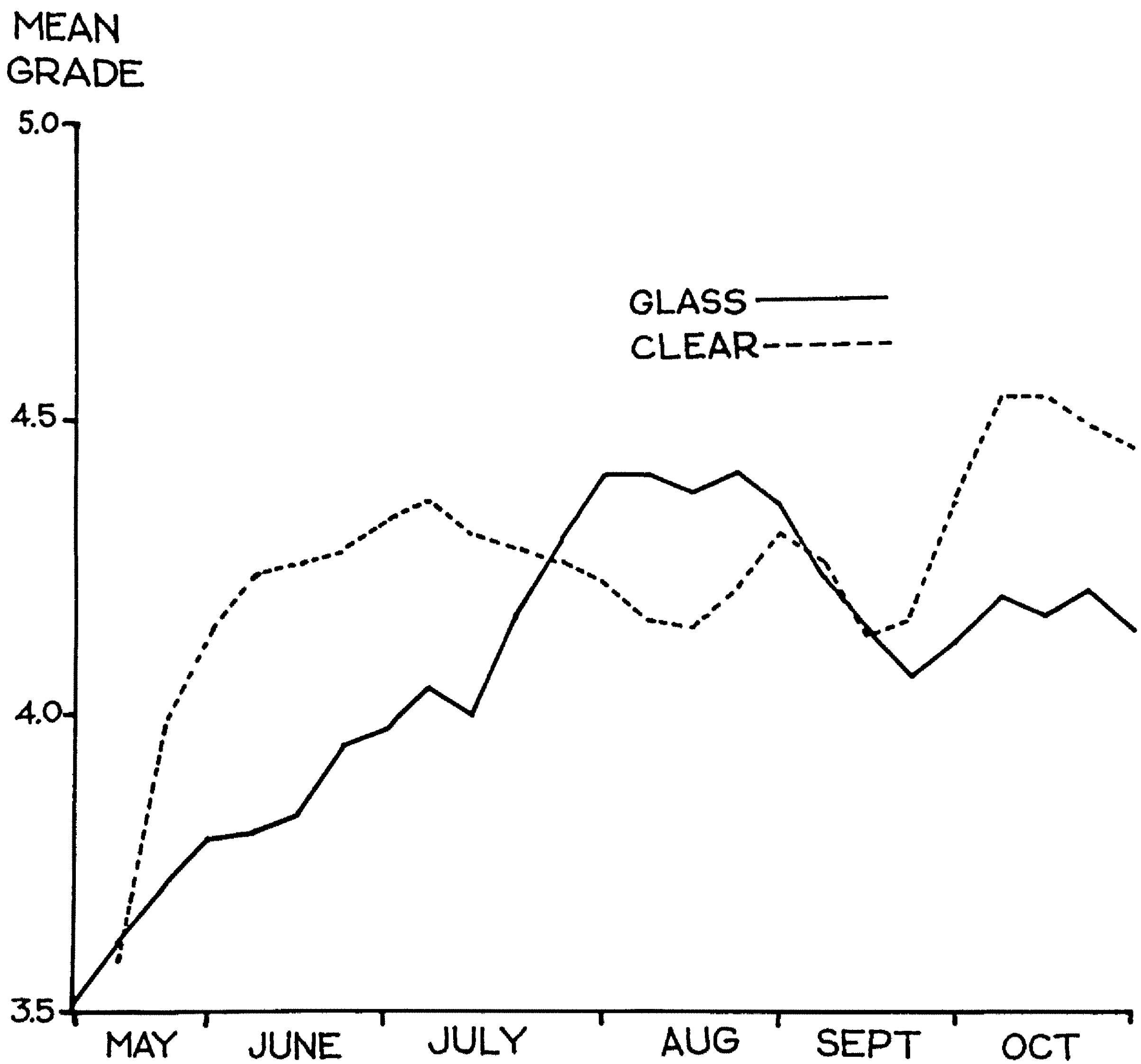

Figure 4.—The mean grade of carnations from clear fiberglass and glass houses from January 3, to November 5, 1960.

March 28, 1961, plants grown in the glass house produced an average of 10 per cent more dry matter (Figure 5). Dry matter production in the clear house exceeded that in the glass house for only one of the 12 lots of plants.

Cut flower keeping life

Samples of flowers were placed in a controlled keeping room on 14 dates and their useful life measured. Table 3 shows a difference in cut flower life with sampling dates, but no difference due to glass or fiberglass coverings.

Table 3.—MEAN CUT FLOWER LIFE OF CARNATIONS GROWN UNDER CLEAR AND CORAL FIBERGLASS AND GLASS.

Date of sample	No. of flowers per sample	Cut flower life in days		
		Clear	Glass	Coral
August 15, 1960	20	7.0	7.9	7.1
August 17, 1960	20	6.1	6.0	6.0
August 19, 1960	20	7.3	7.5	7.0
August 22, 1960	20	7.4	7.4	7.2
August 24, 1960	20	6.8	7.1	6.9
August 26, 1960	20	6.9	6.9	6.9
August 31, 1960	20	8.3	8.1	8.0
September 21, 1960	20	8.8	8.5	8.0
October 10, 1960	12	7.9	7.6	7.8
November 16, 1960	12	6.4	6.8	6.5
January 4, 1961	12	6.3	6.2	6.0
February 24, 1961	8	5.9	6.3	6.4
March 4, 1961	20	7.3	7.0	7.4
March 29, 1961	20	7.6	7.1	7.3
Mean		7.14	7.17	7.04

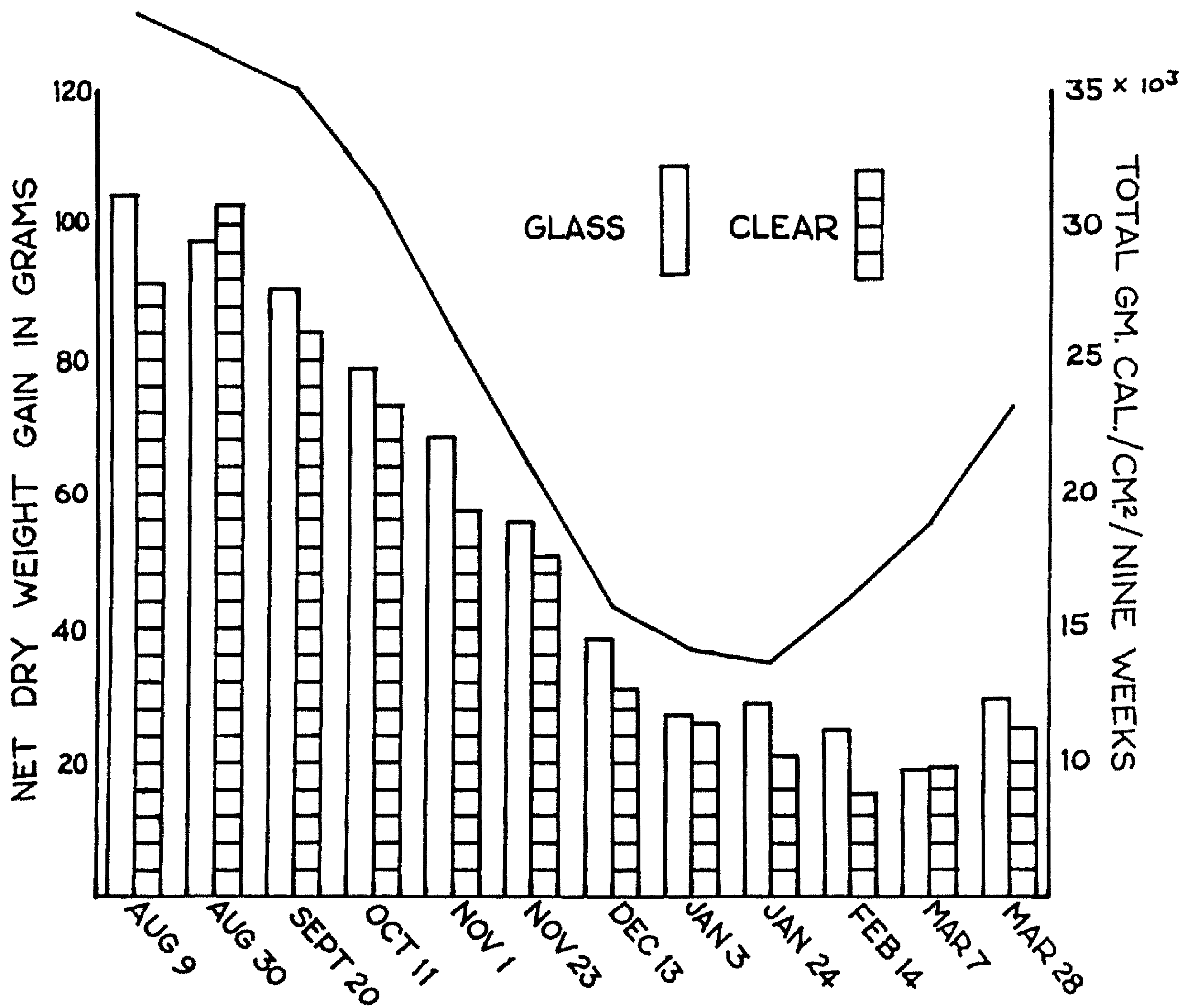

Figure 5.--The production of dry matter in nine-week periods for young carnation plants compared to the total gram calories/cm^2 of energy received.

Cut flower volume

The cut flower volume as measured by milliliters of water displaced (Table 4) indicates only about 2 per cent difference in size of flowers in favor of the clear fiberglass house.

Table 4.—MEAN VOLUME OF CARNATION FLOWERS GROWN UNDER CLEAR AND CORAL FIBERGLASS AND GLASS.

Date of sample	No. of flowers per sample	Volume in milliliters water displaced		
		Clear	Glass	Coral
August 31, 1960	20	18.0	17.4	18.0
September 21, 1960	20	18.3	18.3	18.0
Mean		18.15	17.85	18.00

Flower color

Flower color was rated for the varieties Pink Mamie and Pikes Peak Frosted on random samples of flowers on 17 dates. The fiberglass houses caused a distinct improvement in flower color (Table 5). Pink Mamie from the coral house was the best color, whereas Pikes Peak Frosted was best in the clear house. Colors were appreciably better under all coverings during the winter months.

Table 5.—AVERAGE FLOWER COLOR OF CARNATION VARIETIES PINK MAMIE AND PIKES PEAK FROSTED GROWN UNDER CLEAR AND CORAL FIBERGLASS AND GLASS.

Date of sample	No. of flowers per sample	Mean color rating /a					
		Pink Mamie			P. P. Fr.		
		Clear	Glass	Coral	Clear	Glass	Coral
June 20, 1960	12	1.8	2.1	---	1.3	1.7	---
July 13, 1960	6	2.3	2.2	2.3	1.2	1.5	1.5
August 2, 1960	4	2.5	2.5	2.0	1.3	1.8	1.8
August 10, 1960	5	2.8	3.0	2.8	1.0	1.0	1.3
August 15, 1960	5	2.6	2.4	1.4	1.2	1.2	1.2
August 19, 1960	5	1.4	2.0	1.2	1.0	1.2	1.2
August 22, 1960	5	2.2	2.6	1.6	1.4	1.6	1.2
August 24, 1960	5	2.0	2.0	1.2	1.2	1.4	1.0
August 26, 1960	5	1.6	1.8	1.4	1.0	1.2	1.4
August 31, 1960	5	2.2	2.0	1.6	1.2	1.4	1.2
September 21, 1960	5	2.0	2.2	1.8	1.5	2.4	1.6
October 10, 1960	3	1.3	1.3	1.0	1.0	1.3	1.0
November 16, 1960	3	1.0	1.0	1.0	1.0	1.0	1.0
January 4, 1961	3	1.7	2.0	1.3	1.7	1.7	1.3
February 24, 1961	2	1.0	1.0	1.0	1.0	1.0	1.0
March 4, 1961	5	1.2	1.6	1.6	1.2	1.0	1.2
March 29, 1961	5	1.2	1.4	1.0	1.4	1.6	1.0
Mean		1.81	1.95	1.51	1.21	1.41	1.24

/a Rating scale: 1 = good color; 2 = slightly faded color; 3 = faded color.

Solar energy measurements

Epply pyrheliometers were used to measure the solar energy in the clear fiberglass and glass house. The solar energy transmitted through the clear fiberglass was about 12 per cent less than that through glass.(Figure 6).

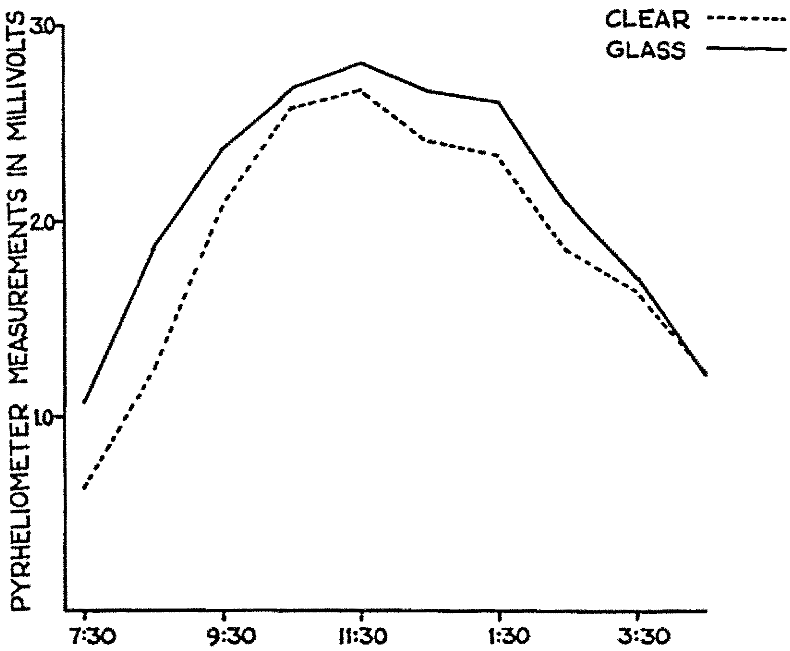

Figure 6.—Mean solar energy under glass and clear fiberglass as measured by an Epply pyrheliometer from August 21 to September 25, 1960.

Silicon cells were used to measure the visible and infra-red regions of the spectrum from September 13, 1960, to January 10, 1961. Coral fiberglass transmitted 83 per cent and clear fiberglass transmitted 96 per cent the amount of solar energy transmitted by glass (Figure 7). On cloudy days the amount of solar energy transmitted was lowest in the coral house, but about the same in the clear and glass houses. On the bright, sunny days the amount of solar energy transmitted varied with the houses.

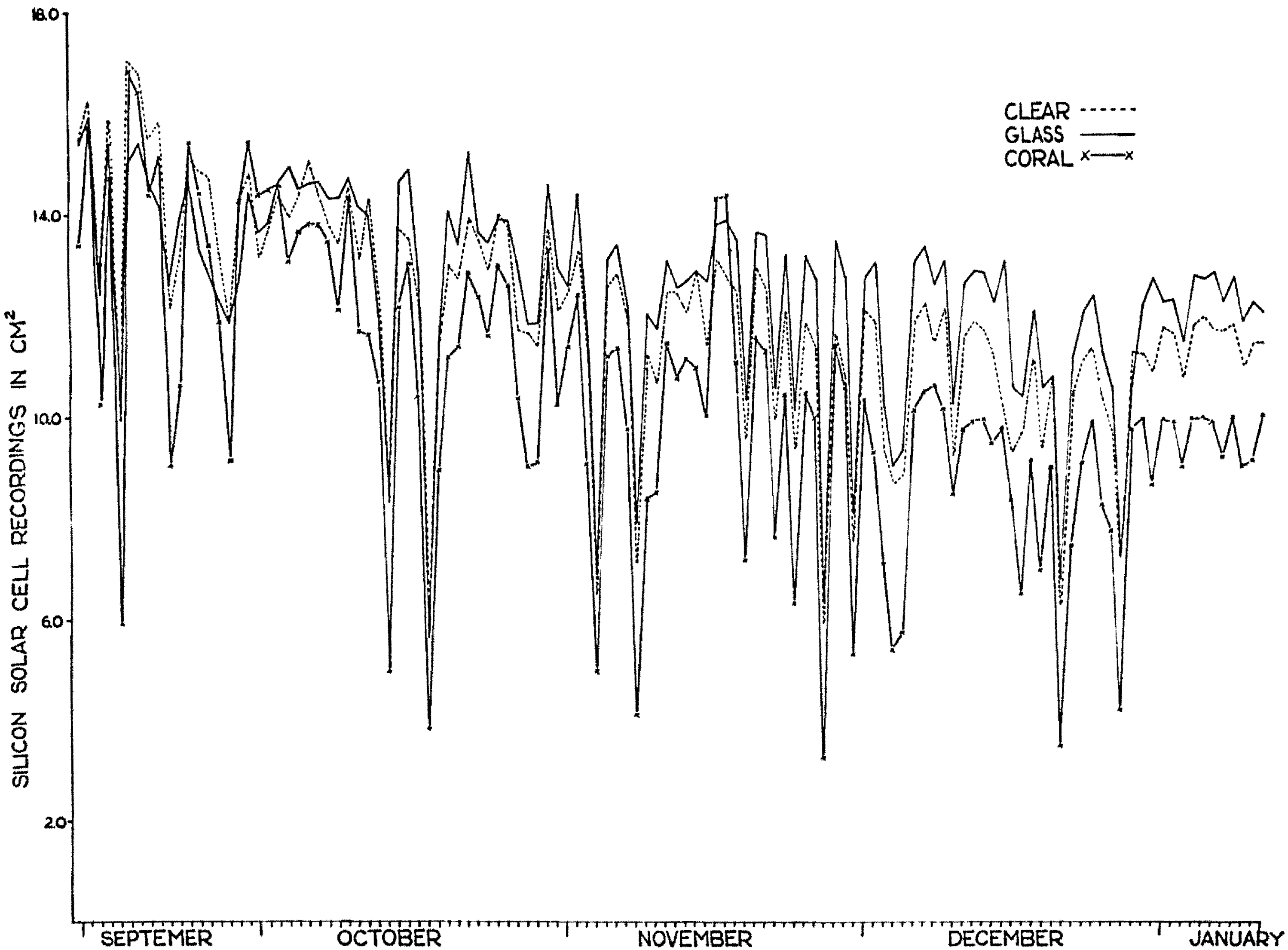

Figure 7.--Silicon cell measurements of solar energy under glass and two colors of fiberglass from September 13, 1960 to January 10, 1961.

The amount of solar energy transmitted in the ultra-violet and visible spectrum was measured by selenium cells. These measurements were recorded from January 12 to March 10, 1961, and they are shown in Figure 8. The darkest period (January 12 to February 1, 1961) showed the three houses corresponding very closely. But as the daylength increased the clear and glass houses transmitted more solar energy than the coral house. The coral and clear fiberglass transmitted 58 and 96 per cent, respectively, of the amount of solar energy as glass.

A Beckman Model B spectrophotometer, with a 6-volt tungsten lamp as the light source, was used to measure per cent transmission of light for coral and clear fiberglass and glass. The glass transmits about 84 per cent of this light, while the clear transmits only 36 per cent and coral only 30 per cent (Figure 9).

To measure the solar heat over and above that required to maintain a 65° F. day temperature, a clock was attached to the cooling circuit in each house. The excess solar heat removed from the glass house was 65 per cent greater than that from the coral, and 26 per cent more than that removed from the clear house (Table 6).

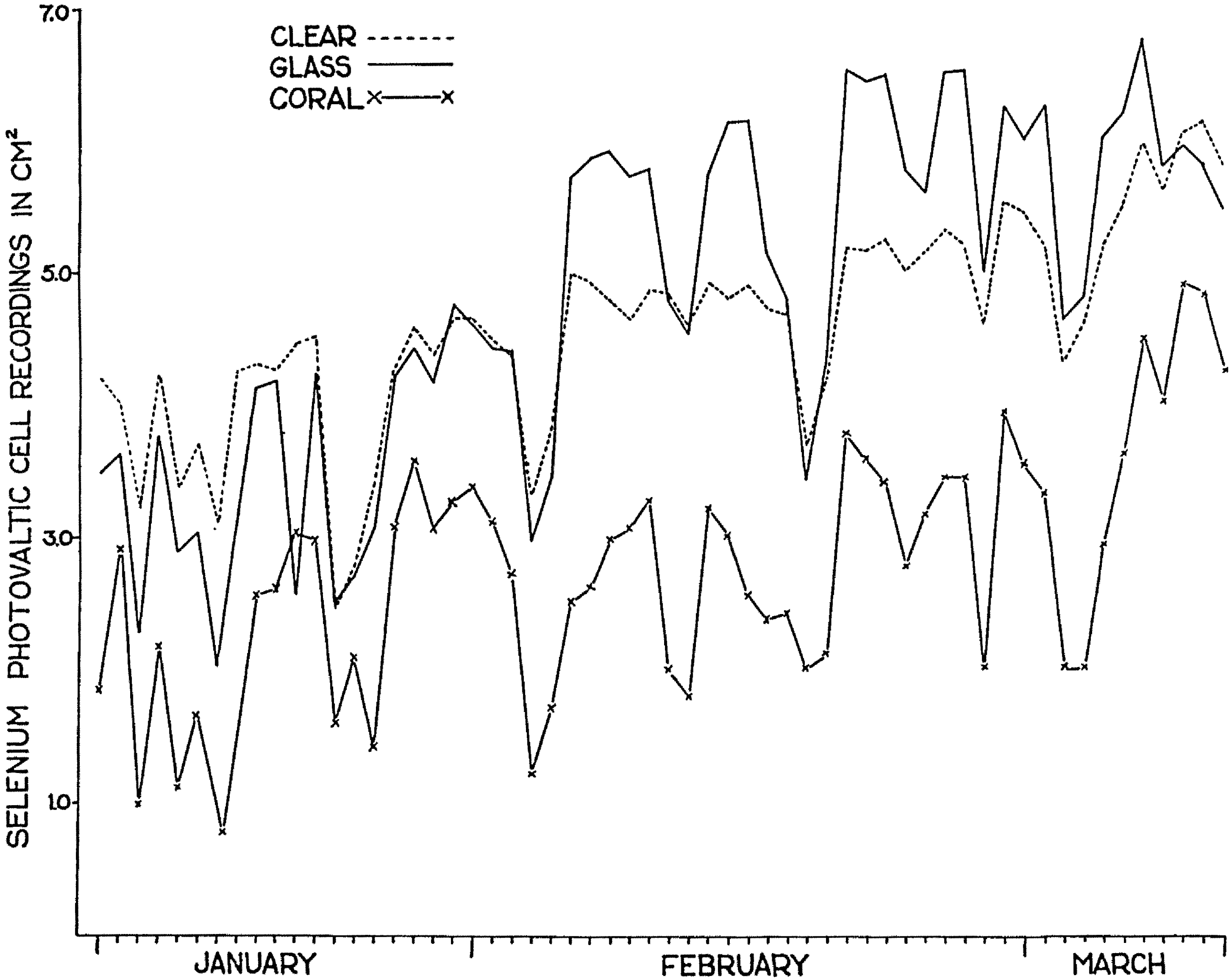

Figure 8.--Selenium cell measurements of solar energy under glass and two colors of fiberglass from January 12 to March 10, 1961.

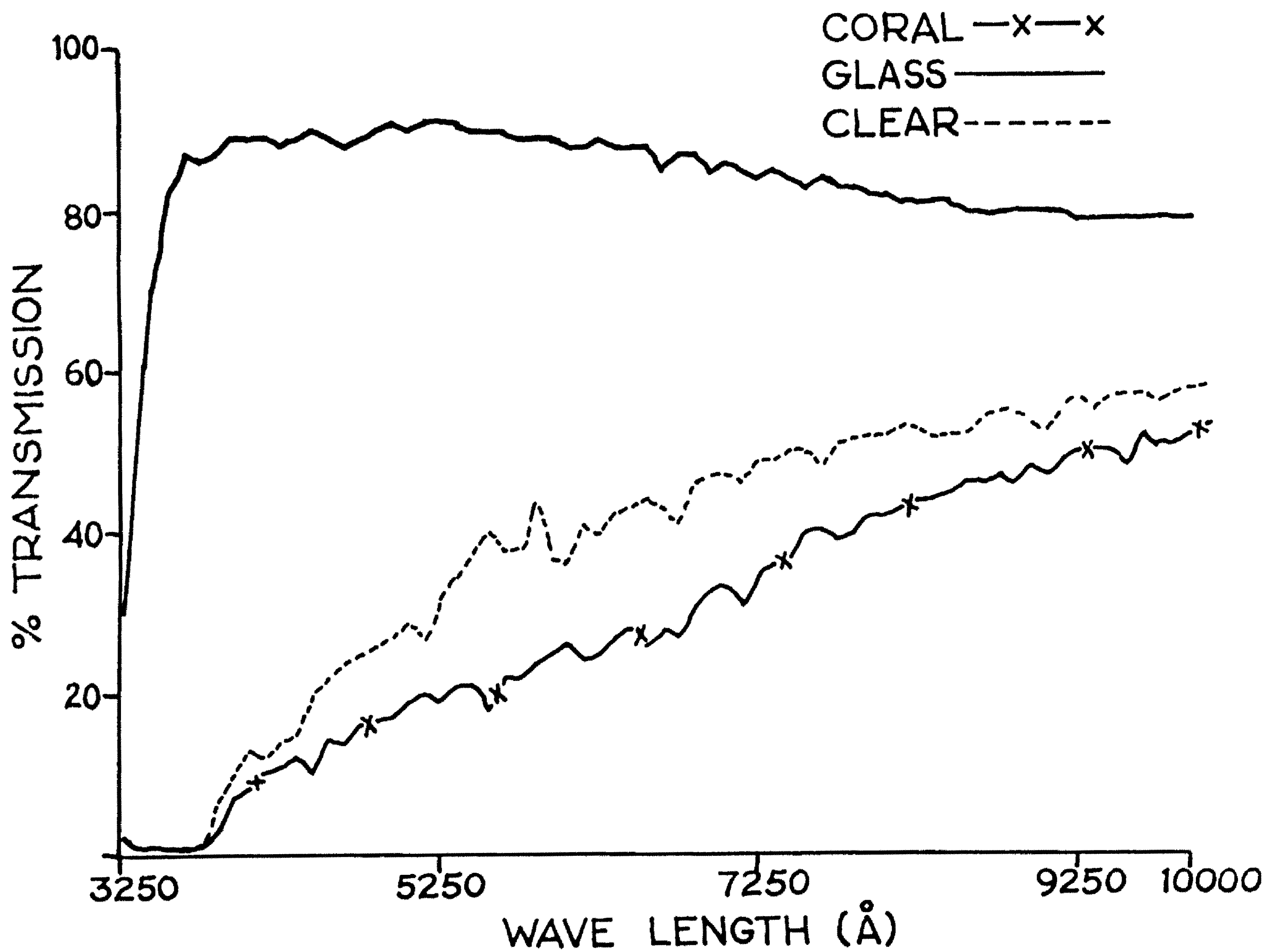

Figure 9.--Beckman spectrophotometer measurements of the per cent transmission of light for glass and two colors of fiberglass.

Table 6.—TIME OF COOLING FAN OPERATION TO MAINTAIN 65° F. FOR THREE STRUCTURES.

Date	Time in Minutes		
	Clear	Glass	Coral
April 16, 1961	23	29	21
April 17, 1961	193	195	172
April 18, 1961	197	286	143
April 19, 1961	336	396	201
April 20, 1961	174	136	111
April 21, 1961	233	230	167
April 22, 1961	183	225	139
April 23, 1961	148	188	91
April 24, 1961	0	5	0
April 25, 1961	112	181	104
April 26, 1961	84	103	82
April 27, 1961	147	217	135
April 28, 1961	140	156	124
April 29, 1961	172	248	173
April 30, 1961	115	251	86
May 1, 1961	28	51	12
Mean	143	181	110

Chapter V

DISCUSSION

Maximum yield and quality of carnation flowers are most important for the commercial greenhouse. Normally if yield is increased the mean grade and quality will decrease.

Yield

The carnations in the clear fiberglass house produced 12 per cent more flowers than the carnations in the glass house (Table 2). The glass house was in production a week sooner, but the winter of 1959-1960 was one of the darkest winters ever recorded (20). The clear fiberglass house then came into production and the first and second crops were harvested before the glass house completed its second crop. This indicates that glass is more efficient than fiberglass when light is limited. Fiberglass materials reduce the amount of solar energy (Figures 6, 7, and 8) and the amount of solar heat (Table 6). This solar energy is diffused into the houses so that the plants can utilize the energy more efficiently.

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. The value given them is indeterminate and dependent upon the grader.

The mean grade of flowers from the clear fiberglass house was significantly better every month except August (Figure 5), which was the same month that the second crop was in peak production. The flower color was better in the fiberglass houses (Table 5), but the flower volume and the keeping life of the carnation flowers were the same in all three houses (Tables 3 and 4). Glass transmitted more solar energy and heat, therefore causing a higher microenvironment temperature around the buds and leaves. When air was moved through the house these buds would cool rapidly, and if this decrease in temperature was enough, it would cause the flower to be malformed. The bright, cold days during the fall, winter and spring months caused most of the carnation flower malformations. Table F, Appendix, shows the number of malformed flowers to be 18 and 10 per cent of all flowers downgraded in the glass and clear houses, respectively. During the period from November 5, 1960, to April 1, 1961, the glass house produced twice as many malformed flowers as the clear house.

Direct light versus diffuse light

This investigation indicates differences in carnation growth under fiberglass and glass. This difference may be due to the light after it has passed through the greenhouse covering. Direct light is the light which comes through the glass and casts a shadow, while diffuse light is uniformly dispersed light and does not cast a direct shadow after it has passed through the fiberglass. The upper surface of leaves at right angles to the direct light may become light saturated while other leaves are shaded and well below the saturation point. In diffuse light with no shadows all leaves may be functioning at a higher rate.

Discussion of other measurements

The screening of the different materials showed that several colors were better than glass (Table 1). These materials probably could be used for growing plants other than carnations. This also indicates that the discoloration of clear fiberglass with age may still give better growth than glass.

The production of dry matter in the clear and glass houses showed a 10 per cent increase in growth in the glass house (Figure 3). The predominant environment factor for the production of dry matter in young carnation plants is temperature (13). The glass house transmitted more solar heat causing the young plants to be warmer.

Suggestions for further study

1. Investigate the possibility that fiberglass may raise the optimum temperature for yield and quality of carnations.

2. Study the use of fiberglass coverings in closed systems where carbon dioxide, temperature, and humidity are controlled.

3. Investigate the use of various colors of fiberglass on other crops such as roses, chrysanthemums and snapdragons.

Chapter VI

SUMMARY

The effects on carnation growth of glass, mylar, eskaylite, velon screen and 7 colors of corrugated fiberglass paneling were compared from June 3, to August 24, 1959. Clear and coral fiberglass increased growth over glass by 18 and 15 per cent, respectively.

Clear and coral fiberglass were compared to glass as greenhouse coverings for carnations from January 3, 1960, to April 1, 1961. Clear fiberglass increased yield by 12 per cent while significantly improving mean grade of flowers.

Flower color was increased by either coral or clear fiberglass.

Cut flower life and flower volume were not affected by these coverings.

The production of dry matter by young plants during the first nine weeks was greater under glass and this is attributed to higher plant temperature.

Solar energy transmission measurements yielded the following information:

1. Clear fiberglass transmitted 12 per cent less solar energy than glass when measured by an Epply pyrheliometer.

2. Clear fiberglass reduced energy transmission in the visible and infra-red to 96 per cent and coral fiberglass to 83 per cent of that coming through glass.

3. The energy transmission in the ultra-violet and visible regions by clear fiberglass was 96 per cent and by coral 58 per cent of glass.

4. Light transmission from a 6-volt tungsten lamp was 84 per cent for glass, 36 per cent for clear, and 30 per cent for coral.

5. Excess solar heat in the glass house above that required to maintain a 65° F. day temperature was 65 per cent greater than that in the coral house and 26 per cent greater than that in the clear house.

A P P E N D I X

Table A.--TABLE OF t TESTS.

	Calculated t
1. Screening tests	
Clear vs. Glass	4.45**
Coral vs. Glass	3.36**
Eskay-lite vs. Glass	3.36**
Amber vs. Glass	2.45*
Jade vs. Glass	2.45*
Frost vs. Glass	2.22*
Mylar vs. Glass	0.92
Screen vs. Glass	-2.55*
Yellow vs. Glass	-3.45**
Lavendar vs. Glass	-5.02**
2. Total Yield	
Clear vs. Glass	8.43**
3. Total Mean Grade	
Clear vs. Glass	3.06**

* Indicates significance at the 5 per cent level.

** Indicates significance at the 1 per cent level.

Table B.—RED SIM FLOWER PRODUCTION FROM JANUARY 3, TO NOVEMBER 5, 1960, IN THE CLEAR AND GLASS HOUSES.

	Houses	
	Clear	Glass
Total yield (no. of flowers cut)	1193	1016
Flowers/sq. ft./year	45.88	39.08
Mean grade	4.234	4.042
Mean fresh weight (gm.) of cut flowers		
Fancy	28.3	28.0
Standard	19.0	20.5
Per cent distribution of grades		
Fancy	41	33
Standard	49	51
Short	3	3
Design	7	13
Per cent flowers downgraded		
Insufficient weight	42	26
Short stems	9	26
Malformed flowers	8	15
Total downgraded	59	67

Table C.--PINK MAMIE FLOWER PRODUCTION FROM JANUARY 3, TO NOVEMBER 5, 1960, IN THE CLEAR AND GLASS HOUSES.

	Houses	
	Clear	Glass
Total yield (no. of flowers cut)	1132	1020
Flowers/sq. ft./year	43.54	39.23
Mean grade	4,220	3.971
Mean fresh weight (gm.) of cut flowers		
Fancy	29.0	27.5
Standard	19.9	20.7
Per cent distribution of grades		
Fancy	46	27
Standard	42	56
Short	1	5
Design	11	12
Per cent flowers downgraded		
Insufficient weight	26	20
Short stems	16	39
Malformed flowers	12	14
Total downgraded	54	73

Table D.—PIKES PEAK FROSTED FLOWER PRODUCTION FROM JANUARY 3, TO NOVEMBER 5, 1960, IN THE CLEAR AND GLASS HOUSES.

	Houses	
	Clear	Glass
Total yield (no. of flowers cut)	961	859
Flowers/sq. ft./year	36.96	33.04
Mean grade	4.372	4.275
Mean fresh weight (gm.) of cut flowers		
Fancy	28.7	28.7
Standard	22.2	22.9
Per cent distribution of grades		
Fancy	47	44
Standard	45	42
Short	5	11
Design	3	3
Per cent flowers downgraded		
Insufficient weight	25	11
Short stems	24	40
Malformed flowers	4	5
Total downgraded	53	56

Table E.—WHITE SIM FLOWER PRODUCTION FROM JANUARY 3 TO NOVEMBER 5, 1960, IN THE CLEAR AND GLASS HOUSES.

	Houses	
	Clear	Glass
Total yield (no. of flowers cut)	1137	1066
Flowers/sq. ft./year	43.73	41.00
Mean grade	4.269	4.060
Mean fresh weight (gm.) of cut flowers		
Fancy	29.2	28.0
Standard	23.0	22.6
Per cent distribution of grades		
Fancy	45	33
Standard	44	47
Short	3	13
Design	8	7
Per cent flowers downgraded		
Insufficient weight	15	15
Short stems	29	42
Malformed flowers	11	10
Total downgraded	55	67

Table F.--SUMMARY OF TOTAL FLOWER PRODUCTION FOR CLEAR AND GLASS HOUSES FROM JANUARY 3, 1960, to APRIL 1, 1961.

	Houses	
	Clear	Glass
Total yield (no. of flowers cut)	6077	5997
Flowers/sq. ft./year	58.43	57.66
Mean grade	4.262	3.899
Mean fresh weight (gm.) of cut flowers		
Fancy	29.79	28.47
Standard	22.06	22.67
Per cent distribution of grades		
Fancy	48	31
Standard	40	43
Short	4	11
Design	8	15
Per cent flowers downgraded		
Insufficient weight	21	13
Short stems	21	38
Malformed flowers	10	18
Total downgraded	52	69

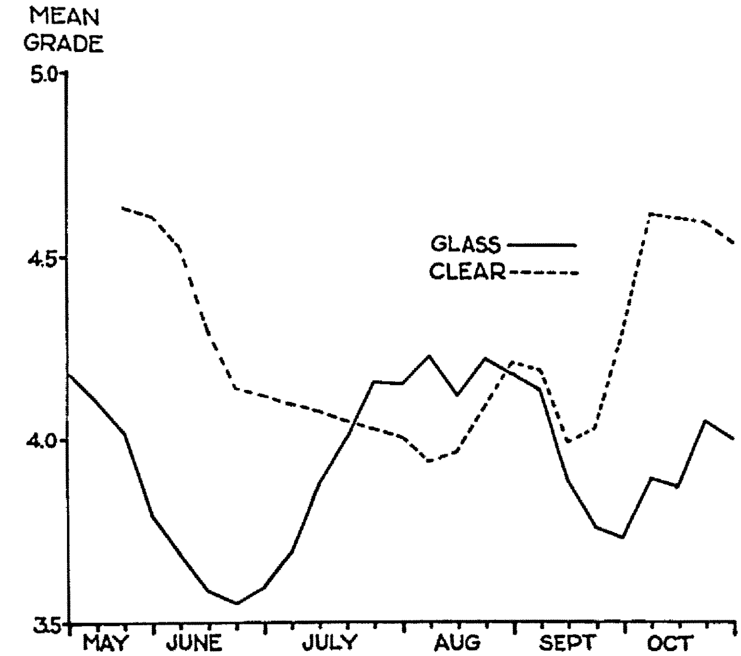

Figure A.—Mean grade for Red Sim carnations in the clear and glass houses.

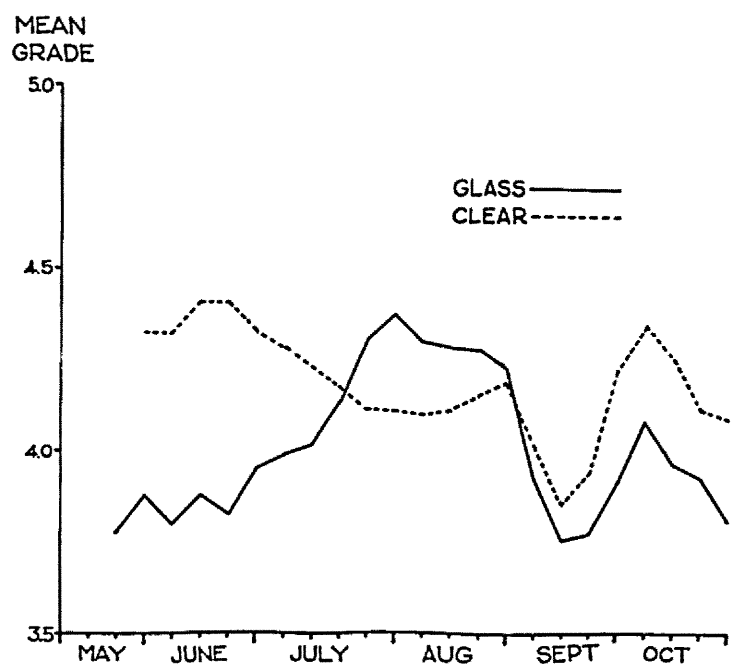

Figure B.—Mean grade for Pink Mamie carnations in the clear and glass houses.

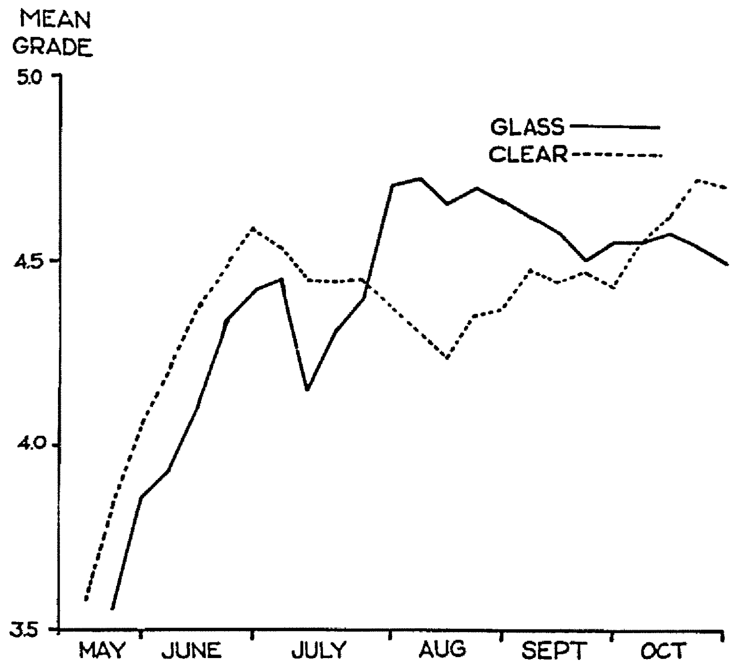

Figure C.--Mean grade for Pikes Peak Frosted carnations in the clear and glass houses.

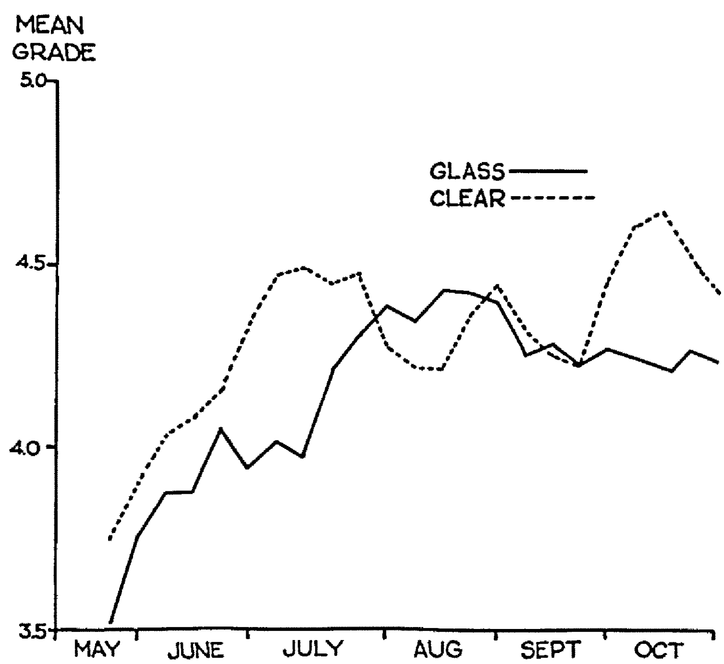

Figure D.--Mean grade for White Sim carnations in the clear and glass houses.

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ABSTRACT OF THESIS

EFFECT OF GLASS AND FIBERGLASS ON CARNATION GROWTH

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

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ABSTRACT

Glass has been used for a greenhouse covering for as long as greenhouses have been built. The growers in these greenhouses have been uneasy about using new materials. When fiberglass plastic was introduced on the market a few years ago, the general conception was that this material reduced the amount of light that the plants would receive, therefore limiting plant growth. But in the last two or three years the interest in this plastic has become more ardent. Research on fiberglass was at a minimum, therefore a project was started to compare fiberglass to glass.

The effects on carnation growth of glass, mylar, eskay-lite, velon screen, and 7 colors of Filon 180 corrugated fiberglass paneling in the colors of clear white, frost white, coral, jade, amber, yellow, and a special light purple were measured by young plants grown from June to August, 1959. The clear and coral fiberglass increased growth over glass by 18 and 15 per cent, respectively.

Three houses were constructed from wood with clear and coral fiberglass coverings, and greenhouse glass. The approximate dimensions were 18 by 15 feet, each house was a complete system with forced air heaters, and air conditioning. They were maintained at the same temperature: 52° F at night, heat to 60° F in day and cool at 65° F.

The four varieties of carnations used in this experiment were Red Sim, Pink Mamie, Pikes Peak Frosted and White Sim. They were planted on January 3, 1960, and grown for this experiment until April 1, 1961. Due to gas injury caused by the heating system the results of yield and quality for the coral house and after November 5, 1960, for the clear and glass houses were not included.

The flowers were harvested from these houses four times a week. They were graded with the fresh weight of the fancy and standard flowers recorded. Periodic random samples were taken to measure cut flower keeping life, flower volume, and flower color.

The clear fiberglass increased yield by 12 per cent while significantly improving mean grade. Cut flower keeping life and volume of the cut flowers were the same in all three structures, but flower color was improved by the fiberglass materials.

The production of dry matter by young carnation plants over a nine week period was measured. The glass house produced more dry matter which was attributed to higher plant temperature.

The solar energy and heat was measured in several ways. The following is some information from these measurements:

1. Clear fiberglass transmitted 12 per cent less solar energy than glass when measured by an Epply pyrheliometer.

2. Clear fiberglass reduced energy transmission in the visible and infra-red regions of the spectrum to 96 per cent and coral fiberglass to 83 per cent of that coming through glass.

3. The energy transmission in the ultra-violet and visible regions of the spectrum by clear fiberglass was 96 per cent and by coral 58 per cent of glass.

4. Light transmission from a 6-volt tungsten lamp was 84 per cent for glass, 36 per cent for clear, and 30 per cent for coral.

5. Excess solar heat in the glass house above that required to maintain a 65° F day temperature was 65 per cent greater than that in the coral house and 26 per cent greater than that in the clear house.