THESIS

CARNATION GROWTH AS INFLUENCED BY TEMPERATURE ADJUSTED WITH LIGHT INTENSITY AND BY CARBON DIOXIDE

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY CHARLES H. KORNS

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

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Chapter I

INTRODUCTION

Accurate control of temperatures has been well established as a means of maintaining high quality carnations (8). Additional benefits may accrue to the grower when temperatures are correlated with seasonal solar energy (14). To investigate the effects of even more accurate correlation of temperatures with incident light, the following experiments were initiated in January 1961.

This work was designed to compare the effects on carnation growth of temperatures correlated seasonally with day temperatures adjusted by incident light minute by minute and night temperatures adjusted by total light received during the preceding light period.

In this investigation the following temperatures were supplied:

1. Seasonally adjusted day and night temperatures as recommended by Manring and Holley (15).

2. Constant night temperatures and day temperatures adjusted minute by minute by incident solar energy.

3. Night temperatures adjusted by total daily solar energy and day temperatures adjusted by incident solar energy.

4. The same temperature adjustments as 3 plus the addition of carbon dioxide during daylight hours when the ventilation fan was off.

Chapter II

REVIEW OF LITERATURE

The review of literature covers briefly: (a) the latest experimental work on carnation temperatures, (b) plant growth under increased carbon dioxide concentrations, (c) the effects of light, temperature, and carbon dioxide on certain physiological processes, and (d) recent research on temperatures correlated with solar energy. A more comprehensive literature review can be found in Manring's (14) and Goldsberry's (6) theses.

All temperatures referred to in the review of literature and throughout this paper are in degrees Fahrenheit.

All elementary physiological processes in the plant except the photochemical ones are temperature dependent (11). The higher the temperature the more rapid the chemical reaction, consequently, the physiological process (4). In general, chemical reactions have a Q_{10} value of 2 to 3 (16).

Photosynthesis is perhaps the most sensitive of all physiological processes to light variations (16). Singh and Lal (19) stated that the net assimilation rate is linearly related to the logarithm of the light intensity. This is not true of the respiration rate which goes on independently of light.

Temperature and light are inextricably related in their influence on plant growth. Laruitzen, et. al. (13) stated that for every temperature within the normal range there is a definite quota of light required for maximal growth. Under high light maximum photosynthesis occurs at a higher temperature than it does at low light levels. Therefore, when light is low, an increase in temperature would be a disadvantage because it would speed up respiration but not photosynthesis (12). It should be possible to regulate the use of photosynthate, and in turn plant growth, by proper adjustment of temperatures with available light intensity.

According to Bonner and Galston (1) photosynthesis consists of at least two different steps, one requiring light and one requiring carbon dioxide. Temperature does not affect the light step but does influence the carbon dioxide step. With low light and adequate carbon dioxide the photochemical reaction is light limited with very little temperature effect. However, with high light and adequate carbon dioxide, temperature influences the photosynthetic rate. Ferry and Ward (5) state that the rate of photosynthesis at any given light level is directly correlated with available carbon dioxide; and a change in either factor brings an immediate response on the photosynthetic rate.

Goldsberry and Holley (7) found that the carbon dioxide level inside a greenhouse is more variable than outside. For instance, in February in a carnation greenhouse the daily mean carbon dioxide level never reached that of the outside air (300 ppm) and fluctuated from below 200 ppm to above 250 ppm. Ventilating the house raised the carbon dioxide level to about equal that of the outside air. According to Curtis and Clark (3), the carbon dioxide content may go as low as 100 ppm on a bright sunny day in a tightly closed greenhouse. Levels of this magnitude are probably the limiting factor for photosynthesis at certain times of the year.

In later work, Goldsberry (6) grew carnations at carbon dioxide concentrations of 200, 350 and 550 ppm. With increased concentrations there was an increase in yield, rate of development, and percentage of dry matter of the cut flower. Higher concentrations resulted in shorter stems and internodes. There was no difference in keeping life, fresh and dry weights of cut flowers, and amounts of sucrose and fructose.

Schmidt (18) grew carnations at night temperatures of 48, 50, 52 and 54. Flower yield, mean grade, and flower color improved slightly with each 2° rise in temperature. There was no difference in keeping life or dry matter of the cut flowers at night temperatures in this range. He did find, however, that the lower temperatures produced longer internodes. He recommended 52 nights and 60 to 68 days.

Hanan (8) found that carnation yield was not affected by day temperatures of 60, 65, 70 and 75. As temperature decreased from 75 to 60, the following occurred: (a) color intensity, flower size, leaf width, stem strength, and internode length increased; (b) percentage of dry matter in cut flower stems and stem length decreased; (c) fresh weight of fancy and standard grade cut flowers increased; (d) flowering was progressively delayed; and (e) keeping life in the 60 temperature range was significantly less than for any of the others.

More recently Manring (14), working with carnations, studied the effects of day temperatures correlated with seasonal changes in light intensity. He used temperatures of: (a) constant 65 days; (b) 65 from March 15 to November 15, and 60 from November 15 to March 15; (c) 70 during the summer, lowered to 65 on October 1, then to 60 on December 25, back to 65 on February 15, and again to 70 on March 15 -- during the second winter temperatures were shifted to 60 on September 30; and (d) heated to 60 and cooled to 70 until March 15 the first year at which time it was cooled to 65. Year around mean grade of flowers was maintained at a higher level by correlating day temperatures with seasonal changes in solar energy. Mean grade was found to follow available light intensity with a 9 to 11 week lag when no temperature adjustment was made. Flowers from correlated temperatures were heavier and did not become hollow centered during periods of low light as did flowers from the uncorrelated temperatures. Stem strength was higher at the cooler temperatures while keeping life, percentage of dry matter in the cut flowers, and yield were not affected by these temperatures.

Miller (17) grew snapdragons at the following temperatures: (a) 50 every night regardless of light conditions; (b) 60 after bright days and 50 after dark or average days; (c) 40 after dark days and 60 after bright or average days; and (d) 60 after bright, 50 after average, and 40 following dark days. Plants that received some 60 nights flowered 2 weeks earlier than those not receiving any 60 nights. Growth at 50 or below was somewhat smaller but not enough to affect grade. Little or no increase in size or quality resulted from giving 40 nights after cloudy days when compared to growing continuously at 50 regardless of light intensity. Night temperature increases after bright days caused earlier flowering but slightly smaller saleable stems. Miller concluded that temperature adjustments of this magnitude were not effective in regulating the carbohydrate supply of the plant.

Similar work was done on roses by Boodley and Seeley (2). They used temperatures of: (a) 55 following cloudy days; (b) 60 regardless of light conditions; and (c) 65 following clear days. Lowering temperatures following cloudy days reduced the yield of Better Times by 28 per cent from November 28 to April 28, and 33 per cent from December 24 to April 28. It did not increase keeping quality of the cut flower. Increasing night temperatures after clear days did not improve flower production over the continuous 60 temperature. They postulated that the effect of one day's environment may be carried over for several days and one adjustment in night temperature may not be enough. The answer may lie in Daubermires' (4) statement that stimulation of protoplasm often does not find expression in form and function until after the condition that set it in motion has passed.

Adjustment of night temperatures according to total light received by plants the previous day has not shown particular promise for roses and snapdragons. Correlation of day temperature with incident light should increase the rate of metabolic processes while allowing more efficient use of solar energy.

Holley and Manring (10) stated that temperature fluctuations are the important determinants for the development of extra whorls of petaloids within the calyx, causing malformed flowers. For instance, they found that rapid drops in bud temperature of 10^{o} or more increased the number of growth centers in the calyx. The degree and number of malformed flowers was the highest on young plants in their most vigorous stage. According to Holley (9) split calyxes may occur when a combination of chilling and heating is working at the same time. Whether carnations will tolerate the temperature fluctuations inherent in an automatic adjustment with incident light is an important part of this investigation.

Chapter III

METHODS AND MATERIALS

This investigation was conducted in the temperature control research greenhouse at Colorado State University. The greenhouse is oriented east and west and is divided into 4 compartments of equal size. The compartments were lettered from A to D and from west to east. Each contained 2 benches. A more detailed description of the house can be found in the following theses (8, 14).

The north bench of each compartment was planted January 7, 1961 with 126 uniformly selected White Sim carnations at a 6 x 8 inch spacing. After the plants became established, they were given a single pinch.

The south bench of each compartment was divided into 4 groups of thirty 6-inch pots. On January 10, 1961 the first group in each compartment was planted with 30 Pink Sim carnation cuttings. Three weeks later the second group was planted and 3 weeks later the third, etc. After 4 weeks of growth the plants were pinched to the fifth pair of leaves. The plants were harvested after 12 weeks of growth and a new group started in its place. Beginning with the September 19 planting, White Sim carnations were used. All cuttings weighed from 6 to 8 g prior to rooting.

Cultural practices

1. The soil was steamed for the north benches as well as for each new planting in the pots.

2. A complete nutrient solution was used for irrigation. Soil testing was done periodically and dry fertilizer added when needed.

3. Steamed leaves were used as a mulch on the north benches after the plants were established.

4. The north benches were watered thoroughly at a tensiometer reading of 300 to 500 millibars. When any of the plants within a group of pots began to wilt, the entire group was watered thoroughly.

5. Superphosphate was added to the pots at the rate of 1/4 tsp per 4 pots every third crop.

6. A recommended spray and fumigation program was used to control insects.

Environment

Day temperatures were controlled in compartments A, B and C by the Ventender System which automatically adjusted temperatures according to the amount of solar energy being received. The solar energy was divided into 3 arbitrary levels -- high, normal, and low -- with each level having a different temperature regimen. The night temperature in A was constant throughout the heating season, whereas, in B and C it was adjusted automatically according to the light level of the previous day -- high, normal or low. Temperatures in D were adjusted manually with seasonal changes in light intensity as recommended by Manring and Holley (15). A 24-hour record of the temperature of each compartment was recorded by a Foxboro multirecord temperature recorder.

Carbon dioxide was automatically injected into C during the daylight hours whenever the ventilating fan was off. Carbon dioxide was supplied at 4 ft^2/hr/1000 ft^2 from a dry ice converter. A record was kept of the number of hours that the carbon dioxide was on. Samples of the carbon dioxide content of each compartment were recorded periodically by a Beckman infra-red gas analyzer.

The automatic temperature controlling mechanism (Figure 1) used for compartments A, B and C consists of the following:

TABLE 1.--TEMPERATURE REGIMEN FOR EXPERIMENT I. (JANUARY 7, 1961 TO JANUARY 24, 1962).[a]

Compart-ment	Light Level	Cool to Day	Cool to Night	Heat to Day	Heat to Night	Vent Closes Day	Vent Closes Night	Vent Opens Day	Vent Opens Night	CO_2 Off Day
	High	63	63	61	52	62	62	65	65	
A	Normal	61	61	59	52	60	60	63	63	
	Low	59	59	57	52	58	58	61	61	
	High	63	63	61	54	62	62	65	65	
B	Normal	61	61	59	52	60	60	63	63	
	Low	59	59	57	50	58	58	61	61	
	High	63	63	61	54	62	62	65	65	63
C	Normal	61	61	59	52	60	60	63	63	61
	Low	59	59	57	50	58	58	61	61	59
D	March 15 to Oct.15	65	65	60	54	64	64	67	67	
	Oct.15 to Mar.15	62	62	60	52	61	61	64	64	

[a] The thermostats used in compartments A, B and C were accurate to ± 0.1° while those in D were accurate to ± 1.5°. From June 10, 1961 to September 10, 1962, all compartments were cooled to 65 and the vents were open continuously.

TABLE 2.--TEMPERATURE REGIMEN FOR EXPERIMENT II. (JANUARY 24, 1962 TO MAY 10, 1962).

Compart-ment	Light Level	Cool to Day	Cool to Night	Heat to Day	Heat to Night	Vent Closes Day	Vent Closes Night	Vent Opens Day	Vent Opens Night	CO_2 Off Day
	High	69	69	65	53	67	67	71	71	
A	Normal	65	65	61	53	63	63	67	67	
	Low	61	61	57	53	59	59	63	63	
	High	69	69	65	56	67	67	71	71	
B	Normal	65	65	61	53	63	63	67	67	
	Low	61	61	57	50	59	59	63	63	
	High	69	69	65	56	67	67	71	71	69
C	Normal	65	65	61	53	63	63	67	67	65
	Low	61	61	57	50	59	59	63	63	61
D	Mar.15 to Oct.15	65	65	60	54	64	64	67	67	
	Oct.15 to Mar.15	62	62	60	52	61	61	64	64	

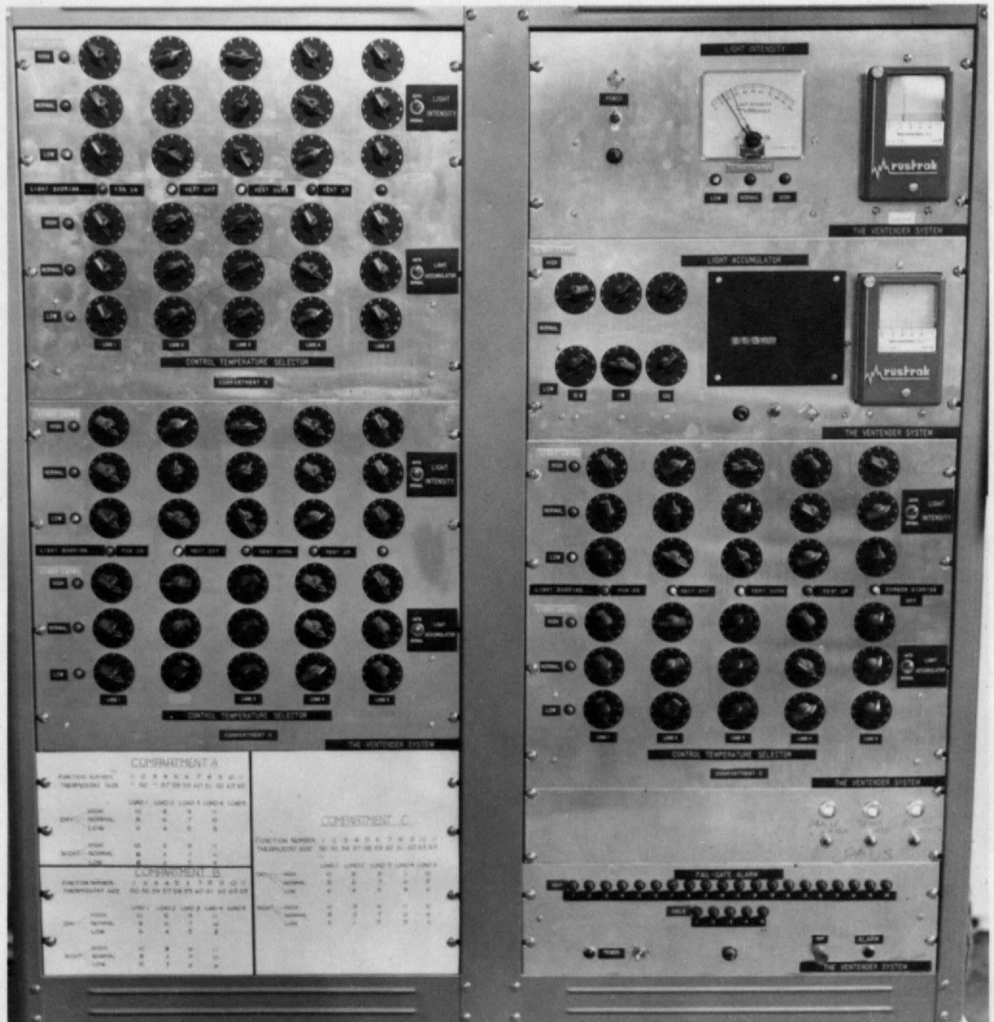


Figure 1.--Automatic temperature controlling system used for compartments A, B and C.

1. Light intensity adjuster (day control). A phototube (Figure 2) feeds a signal to the adjuster which visually indicates the light intensity on a galvanometer. The meter has 2 pick-off points which are arbitrarily set on 10 and 20 (approximately 3,000 and 6,000 ft-c). When the intensity is in contact with the low pick-off point, temperatures are controlled on the low level. If between the 2 points, normal level temperatures are controlled; and if in contact with the upper, high level temperatures are controlled.

2. Light accumulation adjuster (night control). A solar battery (Figure 2) feeds a signal to the light integrator where light intensity and time are integrated to give a light accumulation measurement. The accumulated amount is indicated on a face mounted counter. If the accumulated value for the daylight period is between the artibrarily set points of 13,100 and 18,100 (approximately 290 and 400 gm cal/cm^2), normal night temperatures are controlled. When below 13,100, low temperatures are controlled and if above, 18,100 high temperatures. On November 29, the units were changed to 8,100 and 15,200 (approximately 200 and 350 gm cal/cm^2).

3. The control temperature selector has selector switches with 11 possible temperature selections for each function in each band of intensity and accumula-

tion. The 11 temperature selections correspond to the 11 thermostats located in the aspirator boxes in each compartment (Figure 3). A time clock automatically switches from day to night control. Day temperatures are controlled from approximately sunrise to sunset.

Measurements

Flowers cut from the north benches were graded according to the Colorado State University system (14). Records were compiled on the total number of flowers cut (yield), fresh weight of fancy and standard grade flowers, and number of flowers downgraded. Mean grade was calculated according to Manring (14).

The percentage of dry matter in the cut flower and flower head weight (head removed at the junction of calyx and stem) of fancy and standard grade flowers was measured at approximately 2-week intervals. Turgid samples were used for fresh weight measurements. Samples were dried at 180° for 72 hours.

Cut flower life was measured by placing samples of the flowers in 1 gal of tap water containing 1/4 tsp of steri-chlor. The samples were placed in a 33° (± 1°) refrigerator for 24 hours and then in a 70° (± 1°) keeping chamber. When the petals began to curl and lose turgor, the flower was removed. Keeping life was the number of days from cutting to removal minus two.

Figure 2.--Light sensing elements -- phototube (left) and solar battery (right).

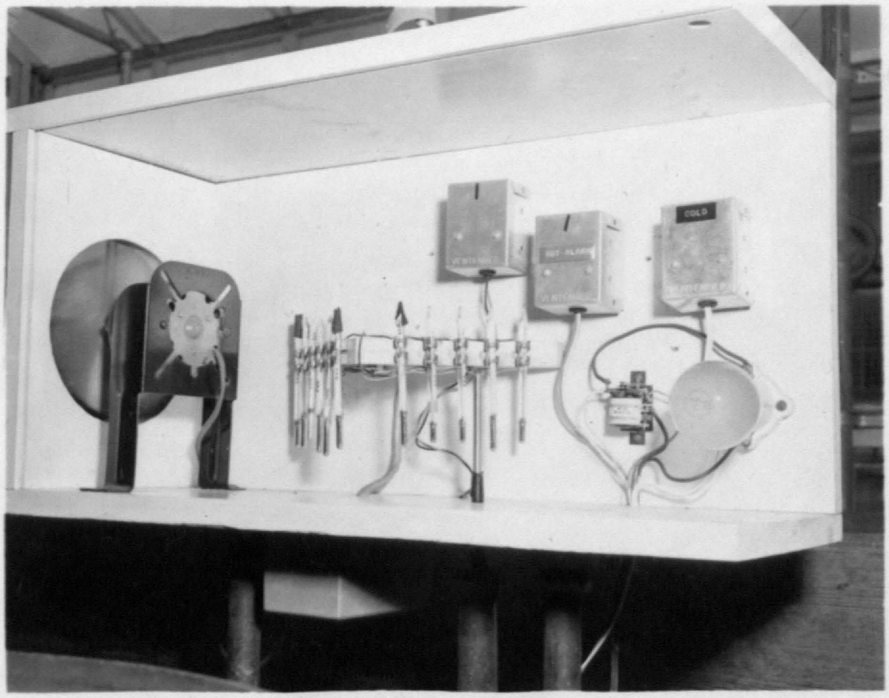


Figure 3.--Aspirator box in one of the automated compartments showing the 11 thermostats.

The potted plants were harvested after 12 weeks of growth and the roots removed. The plants were oven-dried at 180^{o} for 72 hours. Increase in dry matter equaled the dry weight at harvest plus the dry weight of the pinch minus the dry weight of the rooted cutting.

Chapter IV

RESULTS

<u>Experiment I</u>

Temperatures in the automated compartments (A, B and C) were controlled with a 2 degree differential between the 3 light levels (Table 1). Compartment A had automatically adjusted days and constant nights; B had automatically adjusted days and nights; and C had the same temperature control as B with carbon dioxide added. Seasonal temperature adjustments were made in D.

Results of the treatment effects in this experiment are based on measurements made from the beginning of the experiment to July 2, and from September 10 to January 27, 1962. Table A in the appendix shows the results to February 11 and includes those measurements taken during the summer.

The mean grade (Table 3) of flowers produced under automatically adjusted days (A) was significantly higher than those produced under seasonally adjusted days and nights (D). The data on per cent grade distribution and reasons for downgrading, in the same table, indicate that the higher mean grade resulted from a greater number of fancy flowers and fewer designs. The malformation rate was lowest under automatically adjusted days.

TABLE 3.--SUMMARY OF PRODUCTION ON WHITE SIM CARNATIONS BENCHED JANUARY 7, 1961. EXPERIMENT I.

	Compartment			
	A	B	C	D
Number of flowers cut	938	792	914	1012
Mean grade (LSD 5 per cent level 0.11)[a]	4.69	4.61	4.59	4.58
Mean fresh weight of cut flowers				
Fancy (C*-B, D*-A and C*-A)[b]	30.3	30.7	31.5	31.0
Standard (D*-A, C*-B, A*-B, C*-A and D*-B)[b]	21.4	20.3	22.4	22.1
Per cent distribution of grade				
Fancy	80	78	73	74
Standard	14	13	16	17
Short	2	2	2	2
Design	4	7	9	7
Per cent flowers downgraded				
Insufficient weight	4.9	6.7	4.2	4.8
Insufficient stem length	6.3	5.1	10.1	10.2
Inferior flowers and weak stems	4.9	4.3	4.5	4.1
Split calyxes	0.7	1.1	1.7	1.4
Bullheads	0.8	1.7	2.8	1.8
Slabs	1.3	2.5	2.7	2.5
Hollow centers	1.1	0.6	1.0	1.2

[a] Based on 4-week means.

[b] Indicates significance at the 5 per cent level (t analysis).

Seasonally adjusted day and night temperatures (D) produced heavier fancy and standard grade flowers (Table 3) when compared to those produced with automatically adjusted day and constant night temperatures (A). The fresh weights of flowers from adjusted day and night temperatures were increased by injecting carbon dioxide in the atmosphere (C). The highest fresh weights occurred under automatically adjusted temperatures and lowest light, i.e. November through January.

Although the data in Table 3 show considerable differences, statistical analysis did not indicate significance. The lower yield under automatically adjusted day and night temperatures (B) is somewhat substantiated by the slower rate of bud development (Table 4). Increasing the carbon dioxide level significantly increased the rate of bud development.

TABLE 4.--MEAN NUMBER OF DAYS FROM ONE-QUARTER INCH BUD DIAMETER TO HARVEST DATE. EXPERIMENT I.

Compart-ment	Date buds one-quarter inch in diameter[a]							Mean (LSD 5 per cent level 1.6)
	9/13	10/11	11/8	11/15	11/22	11/29	12/6	
A	51.3	51.2	52.4	52.6	56.2	54.8	53.4	53.1
B	51.5	51.2	56.4	55.0	60.8	57.8	57.0	55.7
C	49.3	48.8	54.8	53.8	57.8	55.8	55.8	53.7
D	46.5	49.8	53.0	54.0	56.6	57.4	58.0	53.6

[a] Five buds measured per sample.

When young carnation plants were grown for 12 weeks in the several temperature combinations, automatically adjusted day and night temperatures (B) produced the least dry matter increment (Table 5). This dry matter accumulation was increased in significant steps by: (1) automatic adjustment of day and constant night temperature, (2) seasonal adjustment of both night and day temperature, and (3) automatic adjustment of day and night temperature with the addition of carbon dioxide.

The higher mean increase under seasonally adjusted days and nights resulted from the growth made after March 15 and before October 15 when plants were growing at higher temperatures. Differences between growth periods were highly significant. The mean per cent of dry matter in young plants was not significantly affected by these treatments. This was also true for the per cent of dry matter in the cut flower and flower head (Table 6), however, fresh weight of the flower head was greater at the higher carbon dioxide level.

In Table 6, the number of internodes per fancy length stem (counted to the nearest one-quarter) and the stem strength appeared to be closely related -- the more internodes the greater was the stem strength.

TABLE 5.--MEAN INCREASE IN DRY WEIGHT AND PER CENT OF DRY MATTER IN YOUNG SIM CARNATION PLANTS[a] GROWN FOR 12 WEEKS IN 6-INCH POTS. EXPERIMENT I.

Growth Period	Dry weight increase as per cent of original weight				Per cent of dry matter			
	A	B	C	D	A	B	C	D
1/10 to 4/4/61	795	718	829	767	14.78	14.54	14.53	14.65
1/31 to 4/25	861	834	966	850	14.07	14.15	14.10	14.43
2/21 to 5/16	1117	1066	1119	1091	13.94	14.32	14.39	14.95
3/14 to 6/6	1129	1192	1230	1368	14.71	13.67	14.22	14.59
8/29 to 11/21	612	612	699	697	13.84	13.79	14.13	13.91
9/19 to 12/12	484	460	495	484	14.34	13.79	14.21	14.28
10/10 to 1/2/62	332	312	340	314	14.85	14.76	14.98	15.38
10/31 to 1/23	335	323	402	393	14.40	14.04	14.40	14.67
11/21 to 2/12	394	402	446	369	13.77	13.13	13.22	13.99
Mean	673	657	725	704	14.30	14.02	14.24	14.54
(LSD 5 per cent level)		13				N. S.		

[a] Pink Sim was used during the first part of the experiment and White Sim after the August 19 planting.

TABLE 6.--MEAN VALUES OF VARIOUS MEASUREMENTS MADE ON WHITE SIM CARNATIONS FROM SEPTEMBER 1, 1961 TO FEBRUARY 1, 1962. EXPERIMENT I.

Measurements	Number of Samples	LSD 5%	Compartment A	B	C	D
Percent of dry matter						
Flower and stem	9	N.S.	18.2	18.0	18.1	18.4
Flower head	9	0.7	18.6	18.5	17.9	19.2
Fresh weight of flower head (g)	9	0.4	9.8	9.6	10.2	9.5
Internodes per fancy length stem	8	0.4	7.9	8.1	8.7	8.1
Stem strength[a]	5	2.5	6.1	4.8	2.9	4.2
Keeping life (days)	6	N.S.	8.2	8.4	8.3	8.4

[a] Degrees divergent from horizontal.

Periodic measurements showed that keeping life of the cut flowers was not influenced by these treatments (Table 6). Variations did occur between sampling dates.

Experiment II

Temperature differentials in the automatically controlled compartments were increased to 4 degrees between light levels for day control and 3 degrees for night control (Table 2). Experiment II includes measurements made from February 11 to May 10, 1962. The short duration of the experiment limited the value of statistical analysis

TABLE 7.--SUMMARY OF PRODUCTION OF WHITE SIM CARNATIONS FROM FEBRUARY 11, 1962 TO MAY 5, 1962. EXPERIMENT II.

	Compartment			
	A	B	C	D
Number of flowers cut	656	592	607	692
Mean Grade	4.72	4.60	4.57	4.67
Mean fresh weight of cut flowers				
Fancy (A*-B, C*-B, D*-A, D*-C and D*-B)[a]	28.9	28.1	28.9	29.9
Standard (N.S.)	18.4	18.6	18.3	18.8
Per cent distribution of grades				
Fancy	77	66	68	77
Standard	20	31	26	18
Short	1	1	2	1
Design	2	2	4	4

[a] Indicates significance at the 5 per cent level (t analysis).

There appeared to be a trend toward a higher mean grade when plants were subjected to automatically adjusted days and constant nights as is shown in Table 7. The lower mean grade under automatically adjusted days and nights resulted from a decrease in the number of fancy flowers produced.

Statistical analysis of the fresh weight of fancy grade flowers (Table 7) indicated differences similar to those in experiment I. Treatments did not affect the weight of standard grade flowers, or the per cent of dry matter in the cut flowers or flower heads (Table 10).

The rate of bud development (Table 8) was slower under seasonally adjusted days and nights until the temperature was raised March 15. After this date the rate equaled that of the automatically adjusted days and constant nights.

TABLE 8.--MEAN NUMBER OF DAYS FROM ONE-QUARTER INCH BUD DIAMETER TO HARVEST DATE. EXPERIMENT II.

Treatment	Date buds one-quarter inch in diameter[a]								Mean (LSD 5%level 1.7)
	1/24	1/31	2/7	2/15	2/21	2/28	3/24	3/28	
A	44.2	45.0	45.2	43.2	43.6	41.0	42.0	40.8	43.1
B	46.0	44.4	43.8	43.8	43.2	41.4	40.8	39.8	42.9
C	43.4	44.4	43.4	42.4	40.2	42.0	38.2	37.4	41.4
D	54.0	51.2	48.4	49.4	46.4	43.8	41.2	41.4	47.0

[a] Five buds measured per sample.

The differences in growth of young plants during the three periods of Experiment II (Table 9) were not large enough to be significant. Growth increased with increased automation at these higher temperatures. The per cent dry matter in the plants after 12 weeks of growth showed no distinct trends.

TABLE 9.--MEAN INCREASE IN DRY WEIGHT AND PER CENT OF DRY MATTER IN YOUNG WHITE SIM CARNATION PLANTS GROWN FOR 12 WEEKS IN 6-INCH POTS. EXPERIMENT II.

Growth Period	Dry weight increase in per cent of original wt.				Per cent of dry matter			
	Compartment				Compartment			
	A	B	C	D	A	B	C	D
1/2 to 3/27	615	665	742	610	14.06	13.41	13.79	13.76
1/23 to 4/17	805	811	797	670	14.84	14.41	14.45	14.81
2/13 to 5/8	1040	1093	1098	1064	15.70	14.75	15.70	14.87
Mean	820	856	879	781	14.87	14.19	14.65	14.45

TABLE 10.--MEAN VALUES OF VARIOUS MEASUREMENTS MADE ON WHITE SIM CARNATIONS FROM FEBRAURY 11, 1962 TO MAY 5, 1962. EXPERIMENT II.

Measurements	Number of Samples	LSD 5%	Compartment			
			A	B	C	D
Per cent of dry matter						
Flower and stem	6	N.S.	18.0	17.9	18.5	18.2
Flower Head	6	N.S.	18.6	18.5	18.5	18.7
Fresh wt. of flower head (g)	6	N.S.	9.1	9.0	9.1	9.3
Keeping life (days)	3	N.S.	8.6	9.2	9.3	9.5
Stem strength[a]	2	N.S.	3.2	4.0	2.2	3.3

[a] Degrees divergent from horizontal.

The means of various measurements other than those mentioned in the preceding paragraphs are summarized in Table 10. Although differences did occur, they were not large enough to show statistical significance.

Carbon dioxide

The per cent of time that ventilation was off and carbon dioxide was injected into compartment C is shown in Table 11. Peak injection occurred in November and gradually decreased until March. Changing to the higher temperature regimen on January 24 increased the per cent of time that carbon dioxide could be added.

TABLE 11.--PER CENT OF TIME THAT CARBON DIOXIDE WAS INJECTED INTO COMPARTMENT C BY MONTHS FROM AUGUST 1, 1961 TO APRIL 31, 1962.

	Month									Total for the period
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	
Per cent total possible time[a]	8	52	46	72	68	66	62	50	30	50

[a] Possible time:
August and September -- 7 a.m. to 5 p.m. daily.
October 1 to November 7 -- 7:30 a.m. to 4:30 p.m.
November 7 to May 1 -- 8 a.m. to 4 p.m.

A sample of the mean daily carbon dioxide levels in each compartment (Table 12) shows that variations in levels did occur. If the ventilating fan operated in B while carbon dioxide was being injected into C, leakage occurred between the two compartments and raised the level in B to above that of A or D. This was especially true on days when the fan in C operated less than 50 per cent of the time.

TABLE 12.--SAMPLES OF THE MEAN DAILY CARBON DIOXIDE LEVELS IN THE 4 COMPARTMENTS.

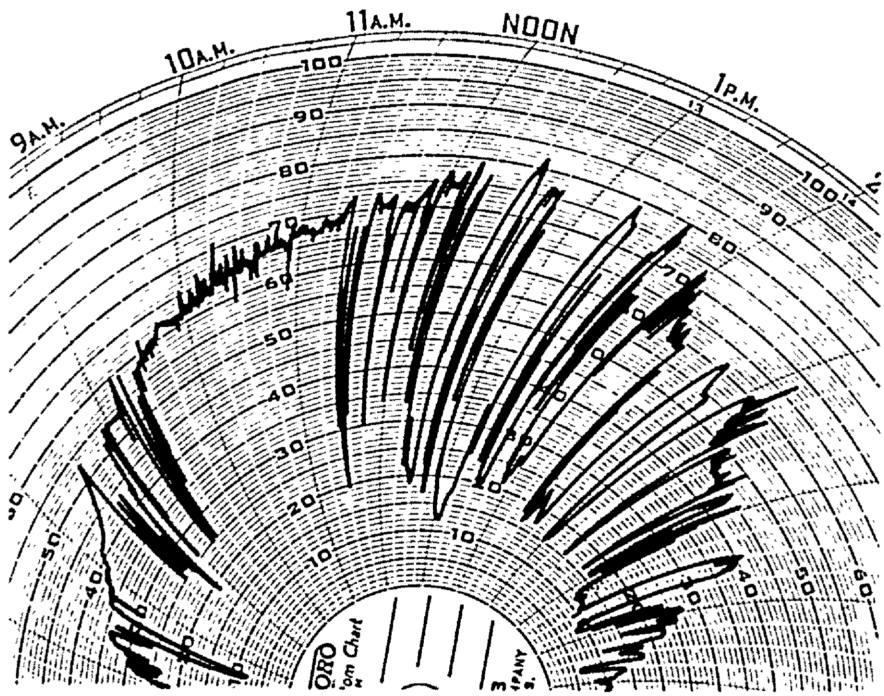
Per cent fan ventilation time in compartment C	Carbon dioxide levels (ppm) Compartments			
	A	B	C	D
More than 50 per cent	330	345	370	320
Less than 50 per cent	288	350	420	290

Chapter V

DISCUSSION

Automatic night temperature adjustments in the range of this investigation did not significantly effect the growth of carnations. The lack of such effects allows simplification of the automatic controlling mechanism by eliminating the need for night temperature adjustments.

Carnations grown at automatically adjusted day and constant night temperatures had a higher mean grade than those grown at seasonally adjusted days and nights. The higher mean grade resulted from a reduction in the number of malformed flowers produced. This can be attributed to a more accurate control of temperatures in the automated compartments. Even the 10 degree temperature fluctuation between high and low light in experiment II (Figure 4) failed to increase the malformation rate over that obtained in experiment I. This shows that carnations can tolerate temperature fluctuations of this magnitude as long as they follow available light intensity. Fluctuations without proper



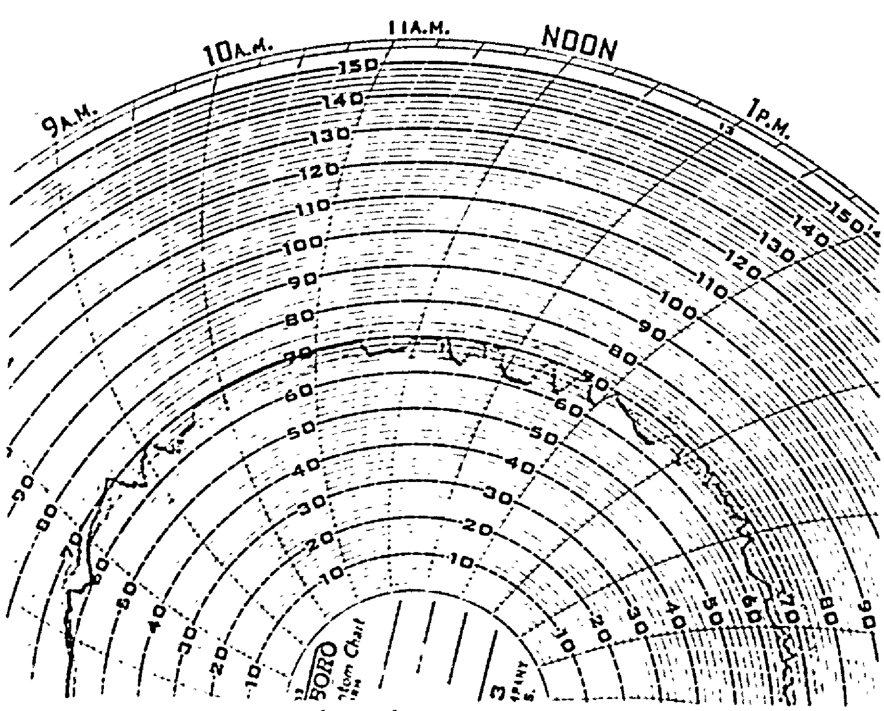


Figure 4.--Light (top) and temperature (bottom) records demonstrating the fluctuations in temperature at various light levels in experiment II. The dark line (bottom) indicates the temperature level in the 3 automated compartments.

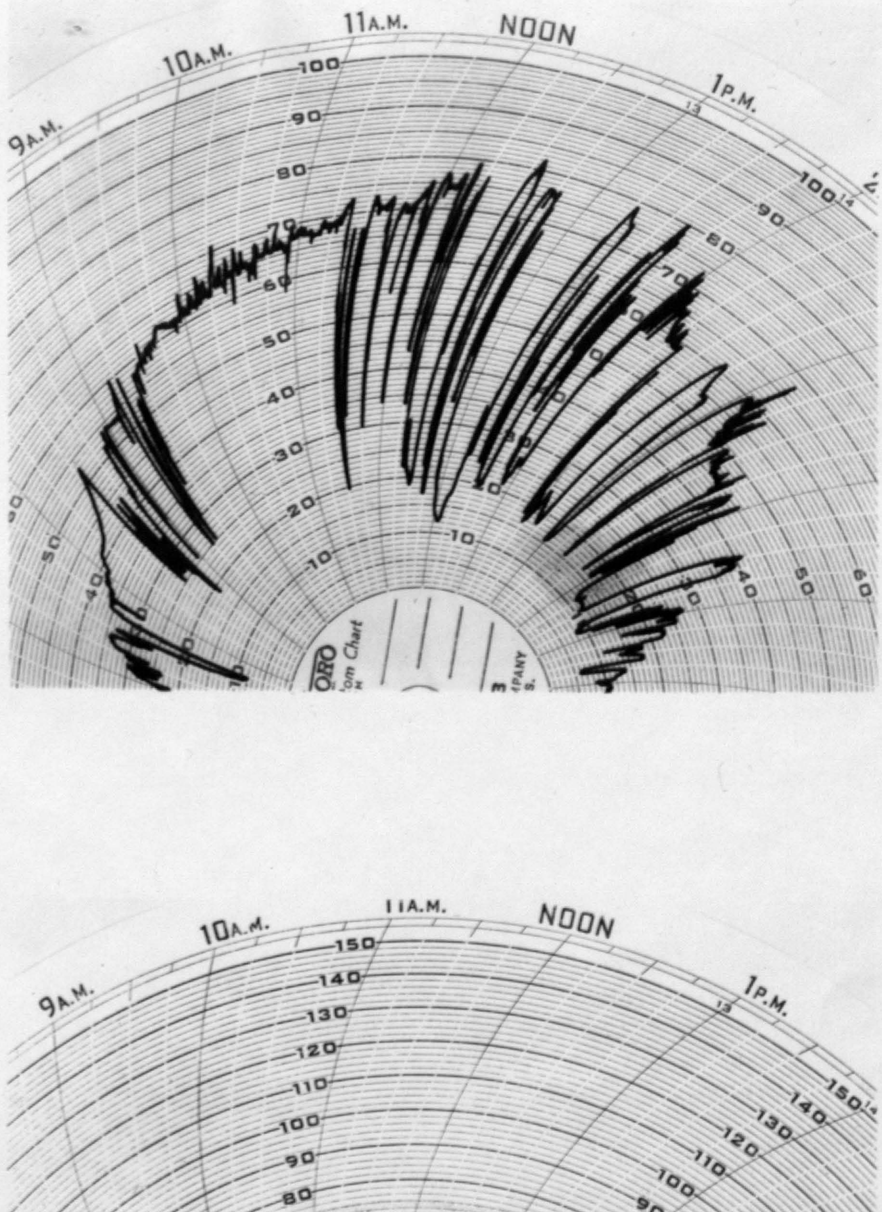


Figure 4.--Light (top) and temperature (bottom) records demonstrating the fluctuations in temperature at various light levels in experiment II. The dark line (bottom) indicates the temperature level in the 3 automated compartments.

light variations due to failure of the automatic system to operate properly, however, resulted in an increase in malformed flowers in the carbon dioxide compartment.

The significant differences obtained in the growth of young plants under the various treatments indicate that at least two factors other than light intensity influence the dry matter increase, namely carbon dioxide and temperature. Raising the carbon dioxide level of the atmosphere increased the growth by 12 per cent in the first two spring plantings and the last two fall plantings of experiment I. The faster growth rate under seasonally adjusted days and nights after March 15 and before October 15 resulted in a higher mean temperature and increased the growth by 12 per cent over that of the automatically adjusted day and constant night temperatures. This is substantiated by the slow growth obtained under automatically adjusted nights from the January, September and October plantings. During these growth periods the light was seldom at the high level hence these plantings were grown mostly at low or normal temperatures. The growth rate of young plants during low light periods can be more closely correlated with available light intensity by growing at a higher carbon dioxide level and higher temperature. The rate of flower bud development followed the growth of young plants.

Results obtained in this investigation on the growth of carnations indicate that it is possible to take advantage of high light by running a higher temperature and increasing the per cent of time that carbon dioxide can be added.

Suggestions for further study

The following should be investigated:

1. A continuation and expansion of experiment II using the same and possibly higher adjusted day temperatures, with and without carbon dioxide.

2. Varietal responses to higher automated temperatures.

3. Effects of automated temperatures on mother stock plants and subsequent growth of the cuttings.

Chapter VI

SUMMARY

The effects on carnation growth of seasonally adjusted day and night temperatures were compared to those automatically adjusted with incident light. Carbon dioxide was injected in one automated house.

Automatically adjusting the night temperature to 50, 52, or 54 following low, normal or high light did not increase growth. A short term experiment using 50, 53 and 56 also gave negative results.

Correlating day temperature with light improved mean grade by reducing the per cent of malformed flowers. There was a trend toward faster growth of young plants and faster bud development during the winter when day temperature was automated. Although these effects were accomplished by temperatures of 59, 61 and 63 for low, normal and high light, a wider temperature range was indicated.

The injection of carbon dioxide during daylight hours when the ventilating fan was off:

1. Increased growth of young plants 12 per cent,
2. Hastened development of flower buds,

3. Increased cut flower and flower head weight, and

4. Decreased the mean length of internodes.

Per cent of dry matter, cut flower life, leaf width, leaf length, and stem strength were not affected by these temperatures.

A P P E N D I X

APPENDIX

TABLE A.--SUMMARY OF PRODUCTION ON WHITE SIM CARNATION FROM JANUARY 7, 1961 TO FEBRUARY 11, 1962.

	Compartment			
	A	B	C	D
Number of flowers cut	1767	1589	1641	1727
Flowers/ft^2	42	38	39	41
Mean grade	4.54	4.52	4.48	4.52
Mean fresh weight of cut flowers				
Fancy	29.5	29.6	30.5	30.0
Standard	19.1	18.9	20.3	20.4
Per cent distribution of grade				
Fancy	65	65	64	66
Standard	27	26	26	24
Short	4	4	4	4
Design	4	5	6	6

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Abstract of Thesis

CARNATION GROWTH AS INFLUENCED BY TEMPERATURE ADJUSTED WITH LIGHT INTENSITY AND BY CARBON DIOXIDE

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Fort Collins, Colorado

May, 1962

This work was designed to compare the effects on carnation growth of temperatures correlated seasonally with day temperatures adjusted by incident light minute by minute and night temperatures adjusted by total light received during the preceding light period.

In this investigation the following temperatures were supplied:

1. Seasonally adjusted day and night temperatures as recommended by Manring and Holley.

2. Constant night temperatures and day temperatures adjusted minute by minute by incident solar energy.

3. Night temperatures adjusted by total daily solar energy and day temperatures adjusted by incident solar energy.

4. The same temperature adjustments as 3 plus the addition of carbon dioxide during daylight hours when the ventilation fan was off.

Automatically adjusting the night temperature to 50, 52 or 54 following low, normal or high light did not increase growth. A short-term experiment using 50, 53 and 56 also gave negative results.

Correlating day temperature with light improved mean grade by reducing the per cent of malformed flowers. There was a trend toward faster growth of young plants and faster bud development during the winter when day temperature was automated. Although these effects were accomplished by temperatures of 59, 61 and 63 for low, normal and high light, a wider temperature range was indicated.

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