THESIS

EFFECT OF ETHYLENE ON CARNATION GROWTH

Submitted by
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JOHN RICHARD PIERSOL ENTITLED EFFECT OF ETHYLENE ON CARNATION GROWTH BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT

EFFECT OF ETHYLENE ON CARNATION GROWTH

Carnation flowers are susceptible to damage when exposed to rather low ethylene dosages. This research confirmed that ethylene also affects the growth of the carnation plant. Severe growth reduction occurred when plants were treated continuously with 100 ppb, 300 ppb, and 500 ppb C_2H_4. Plants treated with the same concentrations for shorter periods showed less damage. Ethylene treatment at different growth stages produced varying plant responses. Plants treated during rapid growth stages (e.g. "rapid elongation" and "bud initiation") were more susceptible to ethylene than were plants treated at stages of relatively less rapid growth (e.g. after pinching and after planting).

It was suggested that low ethylene levels for prolonged periods could result in serious growth reduction. Ethylene levels in most urban areas are high enough to warrant concern by growers in such areas. Ambient ethylene levels in the Denver Metropolitan area may cause more stem shortening than was previously thought. A grower should consider ambient C_2H_4 levels before locating his range in an urban area.

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INTRODUCTION

Ethylene's effect on plants has been suspected since the early 1900's when illuminating gas leaks caused damage to street trees and greenhouse crops. The first accounts of ethylene damage were sketchy (19, 20, 21, 37, 53, 54). The concern over air pollutants and their effects on vegetation has resulted in further research.

There have been numerous studies on the role of ethylene in fruit ripening (13, 14, 15, 36), and there are many publications on the various plant responses to different ethylene concentrations (4, 11, 16, 19, 20, 21, 23, 27, 29, 33, 37, 38, 41, 42, 43, 45, 46, 52, 53, 54). For example, Rudich, Kedar, and Halevy (46) gave an account of the use of ethylene to produce all female flowers on normally monoecious cucumber plants. Crocker (19) mentioned the use of ethylene to loosen the shucks of English walnuts and pecans. Although studies (7, 41, 52) have dealt with the effects of ethylene on cut carnations, there is little published research on the effect of ethylene on the carnation plant. This information would be invaluable to greenhouse operators in urban areas where ambient ethylene levels are often high enough to cause chronic damage.

It is known that ethylene is a growth regulator acting at low concentrations (1, 2, 4, 13, 29, 37, 45). It may be produced endogenously (1, 2, 3, 13, 17, 18, 24, 36), or as a product of nearly all

combustion processes (2, 4, 25, 40). Its economic seriousness to the greenhouse trade has been appreciated for some time (7, 21, 26, 27, 41, 47, 52, 53, 54).

The purpose of this study was to determine the extent of plant damage when carnations (Dianthus caryophyllus L., cv. 'Red Sim') were subjected to chronic and acute ethylene dosages.

LITERATURE REVIEW

Early Accounts of Ethylene Damage

Hasek, James, and Sciaroni (27) gave an account of ethylene history. In their article, they mentioned that more than 100 years ago, Girardin reported damage to street trees in Germany as a result of leaks in gas mains. They also noted that the important constituent of the gas was not known until Neljubov, in 1901, showed it to be ethylene.

In the early 1900's, Crocker and Knight (21) received reports from carnation growers of heavy plant loss caused by gas leaks. The reported injury seemed worse in the winter when ventilation was decreased, and when the ground was frozen forcing the lateral diffusion of the gas into the greenhouse. In their experiments with illuminating gas on carnations, Crocker and Knight noted injury with all concentrations used. They concluded that ethylene must form about 4% of the illuminating gas to be toxic. When pure ethylene was used, they noted injury to carnations with levels down to 500 ppb.

Also in the early 1900's, Wilcox (53) mentioned a case where illuminating gas leaked into a greenhouse. Carnations that were in bud at the time of the leak showed the following symptoms: 1) the styles projected from the tips of the buds, 2) buds that started to open remained closed, and 3) the calyxes dried and shriveled.

Opened flowers showed premature senescence. Roses being grown in the same greenhouse complex were completely defoliated.

Around 1930, Zimmerman, Hitchcock, and Crocker (54) experimented with the effects of illuminating gas and ethylene on roses. In November, 1930, they reported that leaves on rose plants exposed to 0.01% illuminating gas for 48 hours at room temperature yellowed along the veins, and the leaflets abscised. Rose leaves also showed an epinastic reponse to ethylene. They also found a stimulatory effect on the growth of roses by ethylene in which treated plants produced 2.25 times more buds than control plants.

Some Common Ethylene Sources

Hasek, James, and Sciaroni (27) listed some common sources of ethylene: natural decay of organic matter, burning of organic matter, burning of fossil fuels, some solvents, weed oils, and surfacing oils. The burning of fossil fuels is a major cause of air pollution, and such fuels supply significant amounts of ethylene and other substances that are potentially harmful to plants and animals. The increasing number of automobiles on the roads has added considerably to the problem. Ethylene levels as high as 500 to 1000 ppm have been recorded from automobile exhausts (4, 27, 40). Automobile exhausts are diluted in the atmosphere, but severe concentrations of pollutants can accumulate as a result of many automobiles concentrated in a limited area along with certain weather conditions. Altshuller and

Clemons (6) stated that, on the West Coast of the United States, dilution of automobile exhausts is about 1000 to 2000: 1 in moderate to heavy pollution. Abeles and Heggestad (4) calculated that automobile exhausts in the United States produced 12 million metric tons of ethylene in 1966, while plants produce about 20, 000 metric tons of ethylene per year. In July and August 1972, they recorded C_2H_4 concentrations ranging from 700 ppb in center Washington, D.C., to 39 ppb in outlying areas.

In greenhouses, internal CO_2 generators and unit heators that burn natural gas can produce considerable ethylene if O_2 is deficient. Hanan (25) noted internode shortening on carnations in greenhouse ranges where such a situation occurred. For "complete combustion," he recommended a fresh air supply to each burner to provide at least 10 C.F.H. air per C.F.H. gas.

Ethylene is also produced endogenously by plants. Around 1935, Denny and Miller (23) noted a delay in the sprouting of potato tubers and an abnormal development of sprouts due to ethylene evolved from apples stored in the same containers with potatoes. According to Goeschl, Pratt and Bonner (24), ethylene production from etiolated pea seedlings was confined to the plumule and plumular hook portion of the epicotyl, and enough ethylene was produced to give physiologically active concentrations within plant tissue. By exposing etiolated seedlings to a single dose of red light, ethylene production was decreased, and there was an increase in plumular expansion. Treating

seedlings with far-red light following the red light treatment decreased the effect of the red light to the level achieved by the far-red light alone. In research on light-induced ethylene production in sorghum, Craker, Abeles, and Shropshire (18) discovered maximum ethylene production at the 372 nm wavelength.

Lyons, McGlasson, and Pratt (36) used gas syringes to extract samples from inside canteloupe fruits. During ripening, there was an increase in internal CO_2, a decrease in internal O_2, and a great increase in internal, evolved, ethylene. Burg and Burg (15) discussed the involvement of ethylene in fruit ripening. Because of endogenous ethylene production, ventilation would not remove enough ethylene to delay ripening.

Fungi and bacteria are also producers of ethylene. Burg (13) noted the following fungi as producers: 1) Penicillium digitatum, 2) the fungus causing Alternaria leaf spot of carnations, and 3) Botrytis cinerea of carnations. Pratt and Goeschl (45) noted increased ethylene production in carnations when the flowers were inoculated with spores of Botrytis, although the fungus did not produce C_2H_4 in pure culture. Ray blight (Mycosphaerella liquilicola) fungus infection of chrysanthemum flowers can produce enough ethylene to cause "sleepiness" in carnations placed in a confined atmosphere with the diseased chrysanthemums (27). Ethylene production has been determined for 80 species of fungi (45). Pseudomonas solanacearum, a bacterium which infects bananas, also produces ethylene (45).

Reports indicate that injuring or stressing plants stimulates endogenous ethylene production (3, 17, 45). A simple stress such as growing against an obstruction led to ethylene production by pea seedlings (45). Changing the orientation towards gravity of tomato stem sections and Coleus plants increased their ethylene output and caused leaf abscission in Coleus (45). In work by Abeles and Abeles (3), ethylene production from bean and tobacco leaves increased rapidly following the application of toxic compounds such as $CuSO_4$, Endothal, and ozone. Craker (17) noted that ozone injured bean plants produced more ethylene than uninjured plants.

Effects of Ethylene on Plants

Ethylene is the simplest organic compound which affects plants (45). Burg and Burg (15) gave a list of some of the plant responses to ethylene. Ethylene causes leaves to abscise, chlorophyll to blanch, and flowers to fade. In its presence, plants lose the ability to orient normally with respect to gravity; stems assume a horizontal position as do the secondary roots, and normal growth movements cease. In some cases, ethylene induces rooting of cuttings, causes gutation, and enhances protoplasmic permeability. According to Burg (13), characteristic responses of shoots to ethylene are epinasty, reduced growth rate, and swelling. Ethylene stimulates lateral root formation, breaks the rest period of bulbs and tubers, causes yellowing of some leaves, and can cause an increase or decrease

in respiration rate. Pratt and Goeschl (45) stated that ethylene is 60 to 100 times more active than its nearest competitor, propylene, in terms of concentrations required for ethylene-like effects. Some of the various plant responses to ethylene are given in Table 1.

Various other plant responses to ethylene have been reported. Nitsch and Nitsch (43) induced the short day plant, Plumbago indica L., to flower under 16 hours of light by treating it with an ethylene releasing compound. Depending on the dosage, ethylene can cause cotyledon and leaf abscission in cotton, thicker leaf blades, shortened internodes, and profuse lateral growth (29). Chlorophyll decomposition by ethylene hastens the coloring of citrus fruits and blanches the stalks of celery (20). Burg (13) referred to the use of ethylene to promote early flowering, and thus uniform fruiting of pineapples. Ethylene has been reported to cause increased permeability of mitochondrial membranes, but the concentrations needed for that effect were markedly higher than biologically active concentrations (33). Also, similar swelling responses have occurred using other alkenes that lack the biological activity of ethylene (33).

In general, dicots are more susceptible to ethylene damage than are monocots (1). Sensitive broad leaf plants may exhibit a general chlorosis of older leaves, necrosis, leaf abscission, abscission of flower buds, and/or failure of buds to open. More resistant plants may show only growth retardation and loss of apical dominance (12). On conifers, ethylene commonly causes abscission of needles, retarded

Table 1. Various plant responses to ethylene.

Plant	Concentration (ppb)	Length of Exposure	T°F	Response	Reference
African Marigold	17[a]	2 days	77°	Epinasty	20
Tomato	100[a]	2 days	--	Epinasty	22
Tomato	400[a]	3-4 hrs.	--	1st signs of Epinasty	22
Cut Carnations	30	3 days or 8 days	50° 32°	Threshold level for visual damage to petals	52
Cut Carnations	100-200	16 hrs.	65°	"sleepiness"	41
Cut Carnations Open Flowers	2,000[b]	- hrs.	70°	Keeping life 83% of control	7
Bud - Cut Carnations	2,000[b]	- hrs.	70°	Keeping life 93% of control	7
Rose	330[a]	5 days	Room temp.	Leaf abscission started	54
Rose	1,000[a]	5 days	--	Yellowing along leaf veins	54
Rose	40,000[a]	96 hrs.	70°	Complete defoliation	54
Salvia	100[a]	2 days	--	Epinasty	22
Cotton Seedlings	10,000	60 hrs.	--	Cotyledon & leaf abscission	29

Table 1. (Cont'd.)

Plant	Concentration (ppb)	Length of Exposure	T°F	Response	Reference
Sweet Pea Seedlings	200[a]	3 days	--	Declination from vertical growth	22
Young Buckwheat	50[a]	12 hrs.	--	Epinasty	22
Common Lambsquarter	50[a]	12 hrs.	--	Epinasty	22
Azalea	5,000	10 days	c	Floral death	28
Ligustrum	5,000	10 days	c	Complete defoliation	28
Pinus thumbergi	5,000	10 days	c	Chlorosis of older needles; growth inhibition of younger needles	28
Blackberry	5,000	10 days	c	Death of plant	28
Graminae	10,000	10 days	c	Inhibition of leaf elongation	28

[a] Accurate methods for ethylene analysis were not available to early researchers. Serial dilutions were often used.

[b] "ppb - hours" refers to a dosage: concentration times length of exposure.

[c] Heck and Pires used a day temperature of 84-88°F. and a night temperature of 71-76°F.

elongation of new needles, abscission of young cones, or poor cone development (12). At high ethylene concentrations, grasses may show retardation of growth and heavy tillering (12, 28).

Research by Barden (7) on cut carnations showed four factors that contributed to the extent of ethylene damage: 1) ethylene concentration, 2) length of exposure, 3) exposure temperature, and 4) stage of flower development. Although this work dealt with excised plant parts, basically, these four factors determine the extent of damage to most plants.

Physiology of Ethylene

Although ethylene moves through the plant by simple diffusion rather than by directed transport, it is usually considered a plant hormone. According to Craker, Abeles, and Shropshire (18), ethylene appears to be produced in plant tissue only through enzyme controlled pathways. Both endogenous ethylene produced by leaves and stress ethylene, induced by toxic compounds, come from methionine (3).

Auxin transport is thought to effect abscission, growth, and epinasty. Thus, if ethylene has an effect on auxin transport, it follows that ethylene would indirectly affect these same growth phenomena (2). Evidence indicates that ethylene does inhibit auxin transport (2, 9, 10, 11, 16, 39, 44, 45). Burg and Burg (16) discovered that pea seedlings grown in ethylene for 6 to 7 days transported indole-acetic acid at a normal velocity, but the apparent capacity of the

transport system was reduced by about 90%. Beyer and Morgan (9) confirmed their finding, although in some of their experiments they found evidence of a slight reduction in auxin velocity.

Beyer and Morgan (11) discussed ethylene's role in leaf abscission on cotton plants, and concluded that senescence, an increase in ethylene production, and a decrease in auxin transport were all closely related and were an integral part of a series of events that occur during leaf abscission. Their opinion was that as the leaf senesceses, ethylene production increases, reducing the auxin supply to the cells of the separation layer by an effect of ethylene on auxin transport, and perhaps, a destruction of the synthesis process. Ultimately, the separation-layer cells pass the threshold from insensitivity to sensitivity to ethylene, and the initiation of RNA and protein synthesis occurs. This leads to the formation of cell wall degrading enzymes, and perhaps to their release from the cytoplasm to the cell wall (11). From their work, Jackson and Osborne (32) concluded that large quantities of ethylene are produced shortly before leaf fall in tissues adjacent to the zone of separation. They too credited ethylene with initiating biochemical sequences responsible for separation. They felt that the timing of abscission was caused by an increase in sensitivity of the tissue to ethylene and not by an increase in ethylene production. In leaf epinasty, Lyon (35) discovered ethylene altered lateral auxin transport in petioles. This caused auxin accumulation in the upper part of the petioles and the resultant growth differential.

Suppression of Ethylene Effects

Nichols (41) discovered that the system producing ethylene in plants is aerobic, and that carnation flowers stored in a slow stream of nitrogen produced no measurable amounts of ethylene. Five percent CO_2 was sufficient to counteract a dose of 200 ppb ethylene for 2 days; the CO_2 suppressed the morphological response of the flower to ethylene. Nichols concluded that CO_2 accumulation and not O_2 depletion suppressed ethylene production. According to Uota (51), 7% to 20% CO_2 for 24 hours reversed the effects 125 ppb or 250 ppb ethylene; 10% and 20% CO_2 reversed the effects of 250 ppb C_2H_4, 20% CO_2 reversed the effects of 500 ppb C_2H_4, and 30% or 40% CO_2 reversed the effects of 1000 ppb C_2H_4.

Working with apples, Burg and Burg (15) stated that CO_2 competes with ethylene for the site in the plant tissue that ethylene must occupy in order to exert its influence. They attributed this to ethylene being a close structural analogue to allene, a compound which mimics the effects of ethylene:

$CH_2 = C = CH_2$ allene

$O = C = O$ carbon dioxide

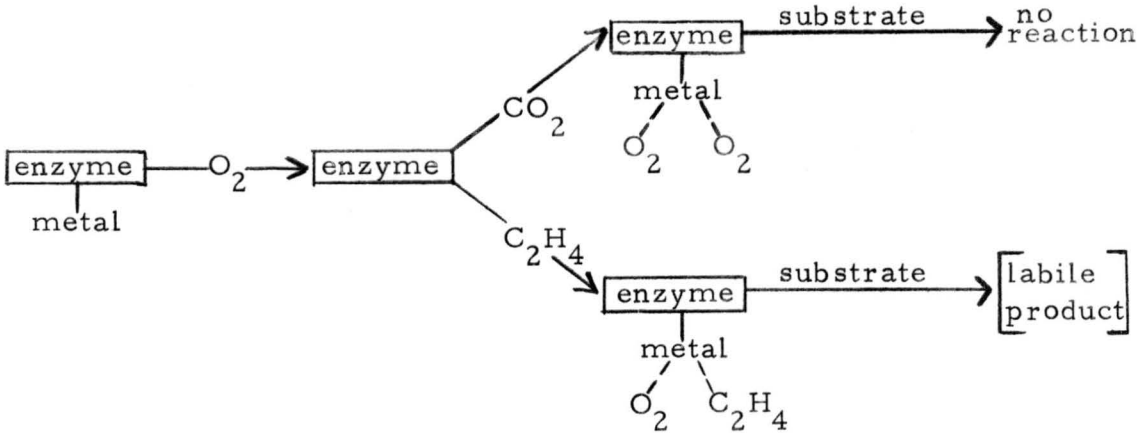
The competitiveness of CO_2 with ethylene is influenced by the law of mass action and by ethylene's one million-fold greater affinity for the receptor site in the plant. No amount of CO_2 will stop ethylene action if enough ethylene is present. When CO_2 is added to fruits, it does not make the fruits immune to ethylene, but rather it raises the

threshold value for ethylene stimulation. Lowered O_2 concentrations hinder ethylene reactions, because ethylene apparently can not attach itself to the receptor site in the plant unless O_2 has already been attached to that same site (15). Burg and Burg (15) also stated that ethylene produces no lasting effect in vegetative tissue unless it is continuously present. The effect is irreversible in fruits because exogenous ethylene increases endogenous production. Ethylene oxide was thought to suppress ethylene action, but Burg and Burg (15) found that small concentrations of ethylene oxide actually hinder or completely inhibit the growth of certain plants.

Burg and Burg (15) gave five empirical rules governing the biological activity of compounds:

1. All biologically active compounds are unsaturated.
2. Smaller molecules tend to be more active than larger ones.
3. The more the bond order resembles that of ethylene's, the greater its activity.
4. The unsaturated linkage must be adjacent to a terminal carbon atom.
5. The terminal carbon next to the unsaturated position must not bear a positive charge.

Burg and Burg (15) drew a schematic diagram for the activation of the receptor site by ethylene:



Ethylene Detection

Early ethylene analysis was difficult and often inaccurate. Paper chromatography was an early method for qualitative ethylene analysis (2). Early methods for quantitative ethylene analysis included: 1) microbromination, 2) gravimetric analysis, 3) $KMnO_4$ oxidation, 4) bromocoulometric analysis, 5) dilution techniques, and 6) ethylene traps (2). Gas chromatography enabled simpler, more accurate ethylene analysis. Crude gas chromatographic analysis was attempted as early as 1943 (2). Around 1959, researchers could measure 10 - 100 ppm ethylene with gas chromatographs equipped with thermal conductivity detectors (2). The advent of flame ionization detectors enabled researchers to measure ethylene levels as low as 1 ppb (2, 8, 24). Plants sensitive to ethylene can be used as indicator plants. African marigolds, tomatoes, and pea seedlings are often suggested for this use (14, 19, 45).

Summary

It is evident that ethylene was noticed as a phytotoxic pollutant as long as 100 years ago. Much interest in the problem has been generated since that time, and a variety of experiments have been done on numerous different plants. With increased knowledge of the effects of ethylene on plants and with the use of better techniques and apparatus, a better concept of how ethylene affects the growth of plants has been developed.

The symptoms and signs of ethylene damage seem to be fairly well defined. Early researchers could not agree on ethylene's effect on auxin transport, but now it is well accepted that ethylene inhibits auxin transport. Ethylene is normally considered an essential plant hormone (2, 11, 13, 15, 16, 30, 45).

In relation to the effect that ethylene has on carnations, much work has been done using cut carnations, such as research done by Nichols (41), Barden (7), Uota (51), Smith and Parker (47), Lieberman, Asen, and Mapson (34), and Crocker and Knight (21). There have been some references to the effect that ethylene has on flowers still attached to the plant (13, 35, 42, 53). The literature dealing with the whole carnation plant usually refers to ethylene's effect on buds or opened flowers, and no references are made to ethylene's effect on the vegetative parts of the plant. Also, most researchers refer to acute ethylene damage in which ethylene dosages are used that result in visual plant damage. Little mention is made of chronic damage which might occur

at low dosages but which is difficult to detect visually. Chronic damage may be of increasing importance to growers in urban areas where air pollutants are posing a possible threat to their crops. More research is needed on how low concentrations of pollutants affect plants over prolonged periods.

MATERIALS AND METHODS

General

Carnations (Dianthus caryophyllus L., cv. 'Red Sim') grown 2 plants per 8" pot in gravel were used for all experiments conducted at the Colorado State University Lake Street Research Greenhouses. The plants were subjected to approximately 100, 300, and 500 ppb ethylene for various periods at different growth stages. The plants were placed in chambers for C_2H_4 treatment, after which they were grown under normal greenhouse conditions (31). The plants were watered automatically 3 times a day during low light periods and 4 times a day during high light periods. The following nutrient solution was incorporated into the water supply through a 100:1 Smith injector:

Nutrient Concentrate Per 25 Gallon Barrel

Fertilizer	Amount
KNO_3	12.5 lbs.
$MgSO_4$	6 lbs.
NH_4NO_3	2.5 lbs.
85% Food Grade H_3PO_4	200 ml.
$Na_2B_4O_7 \cdot 10H_2O$	53 grams
$ZnSO_4$	7.1 grams
$Ca(NO_3)_2$	12.5 lbs. (separate 25 gallon barrel)

A summary of the experiments conducted is shown in Table 2.

Table 2. Experiments conducted on Red Sim carnation plants between April 4 and December 29, 1973.

Experiment Number	Dates	Exposure Period	Plant Stages	No. of pots/ Stage/Chamber
1	4/4/73 to flowering	Planting to flowering	Just planted	7
2	8/30/73 to 9/13/73	2 weeks	a. rapid elongation[1]	2
			b. bud initiation[2]	2
			c. just pinched[3]	2
3	9/25/73 to 10/9/73	2 weeks	a. rapid elongation	2
			b. bud initiation	2
			c. just pinched	2
4	10/11/73 to 10/18/73	1 week	a. showing bud color	2
			b. just pinched	2
			c. just planted	2
5	11/9/73 to 11/12/73	3 days	a. rapid elongation	3
			b. bud initiation	3
6	a. 11/13 - 11/15 b. 11/26 - 11/28 c. 12/ 9 - 12/11 d. 12/19 - 12/21 e. 12/27 - 12/29	Five 2-day treatments	2 to 4 fully expanded leaf pairs	3

[1] 7 - 10 fully expanded leaf pairs
[2] 4 - 7 fully expanded leaf pairs
[3] single pinch leaving 4 - 5 leaf pairs

Ethylene Chambers

Four chambers, 96" long, 15" wide, and 66" high, covered with clear vinyl plastic, were constructed in a 16' x 18' greenhouse covered with rigid PVC panels. Three stages of heating, 2 stages of air conditioning, and 2 mist nozzles controlled the environment in the chambers. Two fans maintained a constant positive pressure in all chambers. Air was not recirculated, but passed through the system one time. A diagram of the chamber arrangement is shown in Fig. 1. Thermostatic controls were placed in an aspirated box in chamber 2 (Fig. 1). Day temperatures ranged from 62-65°F, and night temperatures from 52-55°F. Ethylene was injected into the air stream at the inlet to each treatment chamber (Fig. 1). A plexiglass diffusion plate, with the same dimensions as the chambers, consisting of 1/8" diameter holes on approximately 1/4" centers, was placed in each chamber 4.5" from the air inlet (Fig. 1). This enhanced gas mixing. The exhaust end of each chamber was covered with vinyl punched with enough holes to maintain a positive pressure. Ethylene was not filtered from the control chamber, so ambient C_2H_4 levels of 5 - 35 ppb were constantly present. The other chambers contained 100, 300, and 500 ppb total C_2H_4 ($\pm$ 10%).

Ethylene Injection

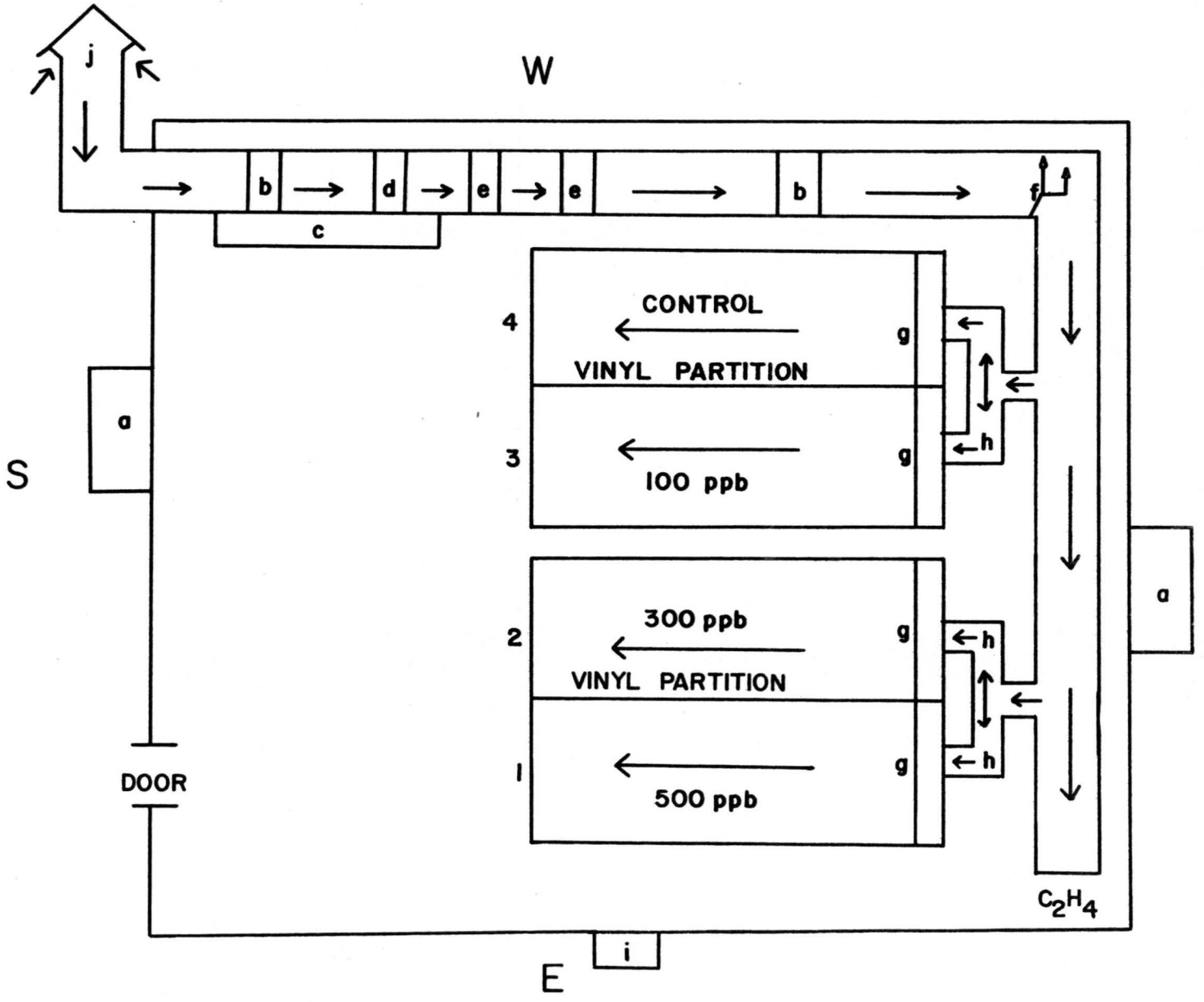
A 225 cu. ft. gas cylinder was evacuated to approximately 0.50 mm Hg. Pure C_2H_4 flowing at approximately 26.5 C.F.H. for

Figure 1. Diagram of ethylene chambers located at the Lake Street Research Greenhouses, Fort Collins, Colorado.

a. air conditioning compressors
b. fans
c. control panel
d. three stage heating unit
e. cooling units
f. two mist nozzles
g. diffusion plates
h. point of ethylene injection
i. house exhaust fan
j. air intake

1. chamber no. 1: 500 ppb ethylene
2. chamber no. 2: 300 ppb ethylene
3. chamber no. 3: 100 ppb ethylene
4. chamber no. 4: control chamber

C_2H_4: marks position of 225 cu. ft. ethylene mix tank


W
S
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CONTROL
g
VINYL PARTITION
3
100 ppb
g
h
a
2
300 ppb
g
h
VINYL PARTITION
1
500 ppb
g
h
a
DOOR
C_2H_4
i

10 minutes through a N_2 flowmeter was injected into the tank, and the mixture pressurized to about 1000 PSI with a tank of compressed air. Replication of the C_2H_4 mix tanks was sufficient. For injection to each chamber, the gas mixture was regulated to 5 - 7 inches water column pressure through 3 stages and passed through glass capillary tubes for each chamber. The gas flow through the low pressure regulator was usually changed slightly with each new mix tank to offset slight differences in cylinder C_2H_4 concentrations. The lengths of the glass capillary tubes were varied to provide the required ethylene concentrations when mixed with the chamber air supply. The final C_2H_4 concentration present in each chamber was periodically checked with a gas chromatograph.

Analytical Procedure

Periodically during each treatment, 50 ml samples were drawn from the exhaust holes in each chamber. Samples were taken from both the top and the bottom of the chamber to test ethylene homogeneity in the chambers. Ethylene concentrations differed as much as 14% from top to bottom. Samples were also taken from the control chamber and outside the greenhouse. Gas samples were analyzed in a Hewlett-Packard (model 5750b) gas chromatograph equipped with flame ionization detectors. The analysis followed procedures outlined by Stephens and Burleson (49, 50). Briefly, air samples were first concentrated by injection into a 1/8" O.D. stainless steel sample loop

packed with 10% dimethyl sulfolane on 42/60 mesh C-22 firebrick and submerged in liquid oxygen. The sample was volatized at 0°C and simultaneously injected into a column (1.52 mm long, inside diameter 2.38 mm) packed with 100/120 mesh poropak N. The carrier gas was nitrogen flowing at 80 ml/min. The flame ionization detectors were fed with O_2 flowing at 300 ml/min and H_2 at 60 ml/min. The column temperature was maintained isothermally at 60°C. Detector temperature was 210°C (7).

Peak heights were used to determine the amount of ethylene in each sample. The analyzer was calibrated by measuring samples of known ethylene concentrations. Identical air samples run through the chromatograph could be expected to be $\pm$ 5%. Calibration charts were made showing known ethylene concentrations at various peak heights.

Data Collection

Pictures and visual observations were taken throughout each experiment. After treatment, the plants were grown under greenhouse conditions until there was at least one fully opened flower per pot. The plants were cut off at the soil line and the following data collected: 1) height (cm., from top of pot to middle of terminal buds or flowers), 2) leaf length (average of three leaves per plant, 4th leaf pair from the terminal), 3) leaf width at widest point of leaf, 4) stem length (average of 3 stems, from origin to middle of bud or flower), 5) number of nodes (average of 3 stems), 6) internode length (stem length/number of nodes),

7) number of lateral shoots (average of 3 stems), 8) fresh weight, 9) dry weight, and 10) date of harvest. One-way and two-way analysis of variance as outlined by Snedecor and Cochran (48) was used.

RESULTS AND DISCUSSION

The ethylene treatments can be separated into three phases: 1) a continuous ethylene treatment from time of planting to flowering, 2) short ethylene treatments (from three days to two weeks) at different growth stages, and 3) a periodic ethylene treatment (five 2-day treatments over a seven week period).

Continuous Ethylene Treatment

Severe damage was evident with the continuous ethylene treatment (Fig. 2). The C_2H_4 treated plants developed buds and flowered sooner than the controls. Flowers that opened on the plants during treatment lasted only a couple of days before senescence. Stem and internode length decreased significantly with increased C_2H_4 concentrations (Fig. 3, 4). There was a similar relationship for leaf length, fresh weight and dry weight (Fig. 5, 6). The C_2H_4 treated plants showed an increase in the number of laterals per stem (Fig. 7).

Short Treatments

Two Weeks. -- With the two week C_2H_4 exposure, "rapid elongation," "bud initiation," and "just pinched" growth stages were used. The "rapid elongation" and "bud initiation" stages were more sensitive to ethylene than was the "just pinched" stage. The 300 ppb concentration seriously shortened stem length, whereas 500 ppb C_2H_4

Figure 2. Effect of continuous ethylene treatment (from time of planting, April 4, 1973, to flowering) on carnation growth. Picture taken on June 22, 1973.


CONTROL
100 PPb
300PPb
500PPb

Figure 3. Effect of continuous (plot A) and periodic (plot B) ethylene treatments on carnation stem length. Continuous treatment from time of planting to flowering; periodic treatment (five 2-day treatments over a 7 week period) with carnations showing 2 to 4 fully expanded leaf pairs at the start of treatment. The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

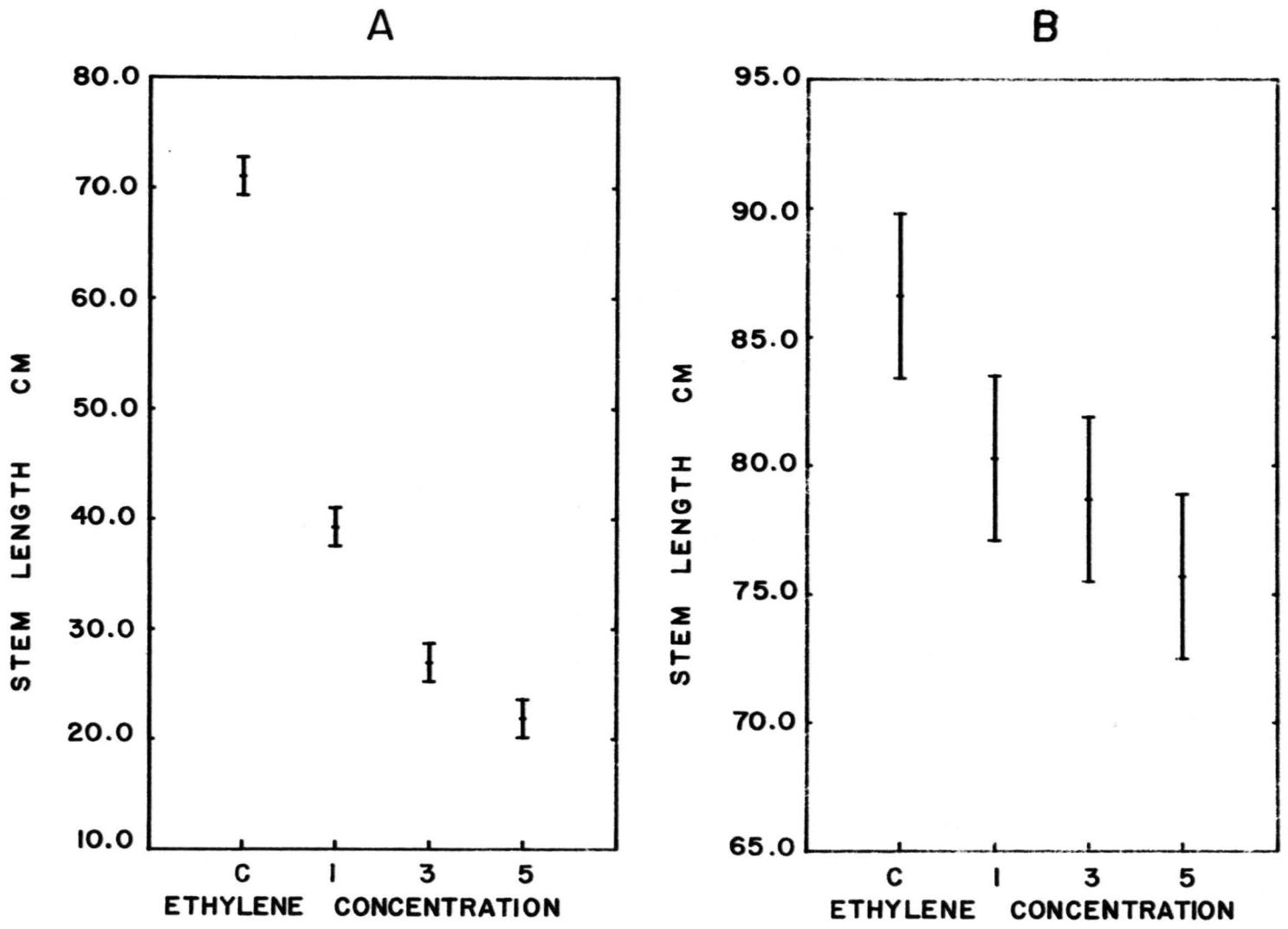

A
B
STEM LENGTH CM
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
C
1
3
5
ETHYLENE CONCENTRATION

Figure 4. Effect of continuous (plot A) and periodic (plot B) ethylene treatments on carnation internode length. Continuous treatment from time of planting to flowering; periodic treatment (five 2-day treatments over a 7 week period) with carnations showing 2 to 4 fully expanded leaf pairs at the start of treatment. The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

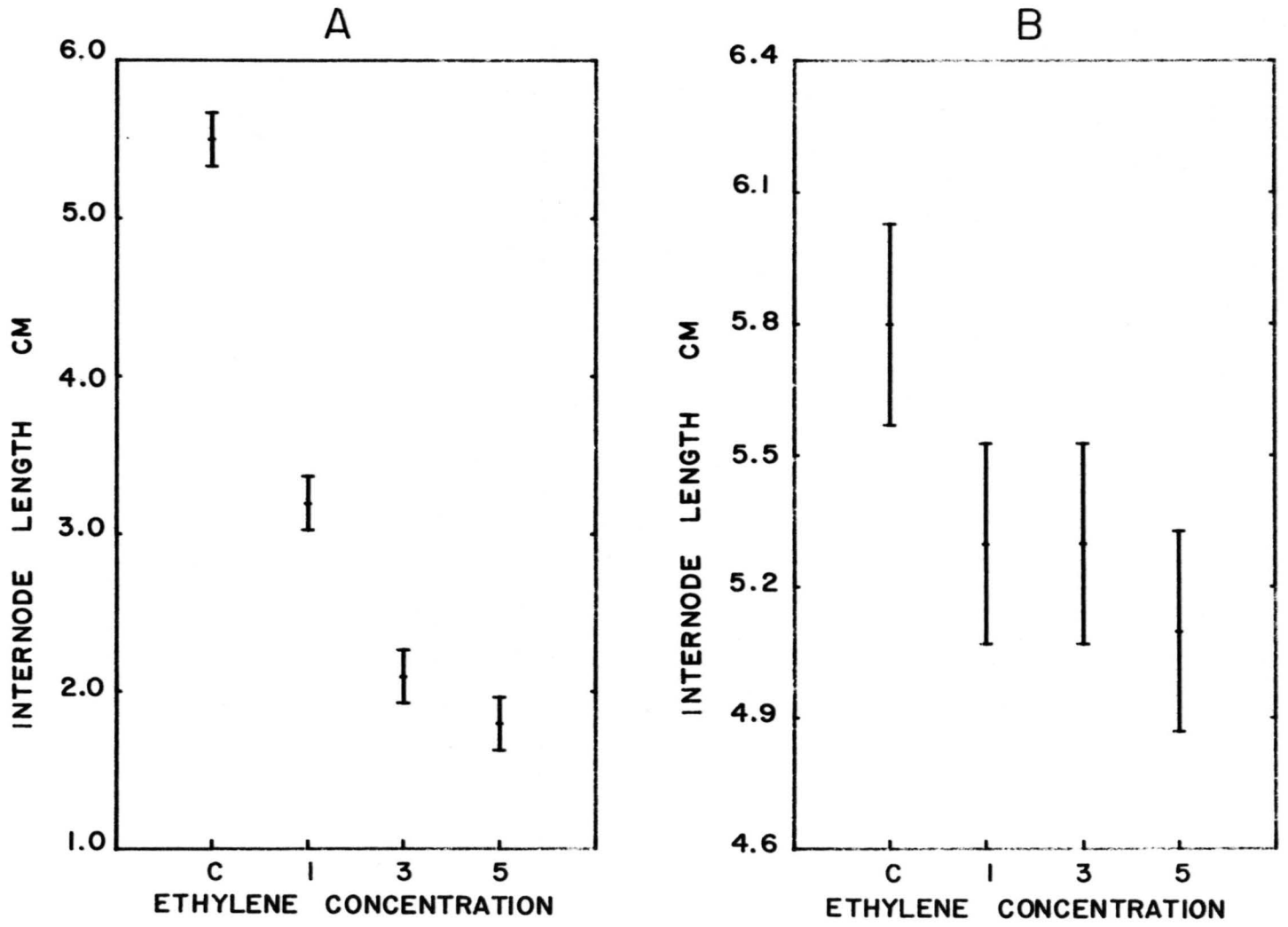

A
6.0
5.0
4.0
3.0
2.0
1.0
INTERNODE LENGTH CM
C
1
3
5
ETHYLENE CONCENTRATION
B
6.4
6.1
5.8
5.5
5.2
4.9
4.6
INTERNODE LENGTH CM
C
1
3
5
ETHYLENE CONCENTRATION

Figure 5. Effect of continuous (plot A) and periodic (plot B) ethylene treatments on carnation leaf length. Continuous treatment from time of planting to flowering; periodic treatment (five 2-day treatments over a 7 week period) with carnations showing 2 to 4 fully expanded leaf pairs at the start of treatment. The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

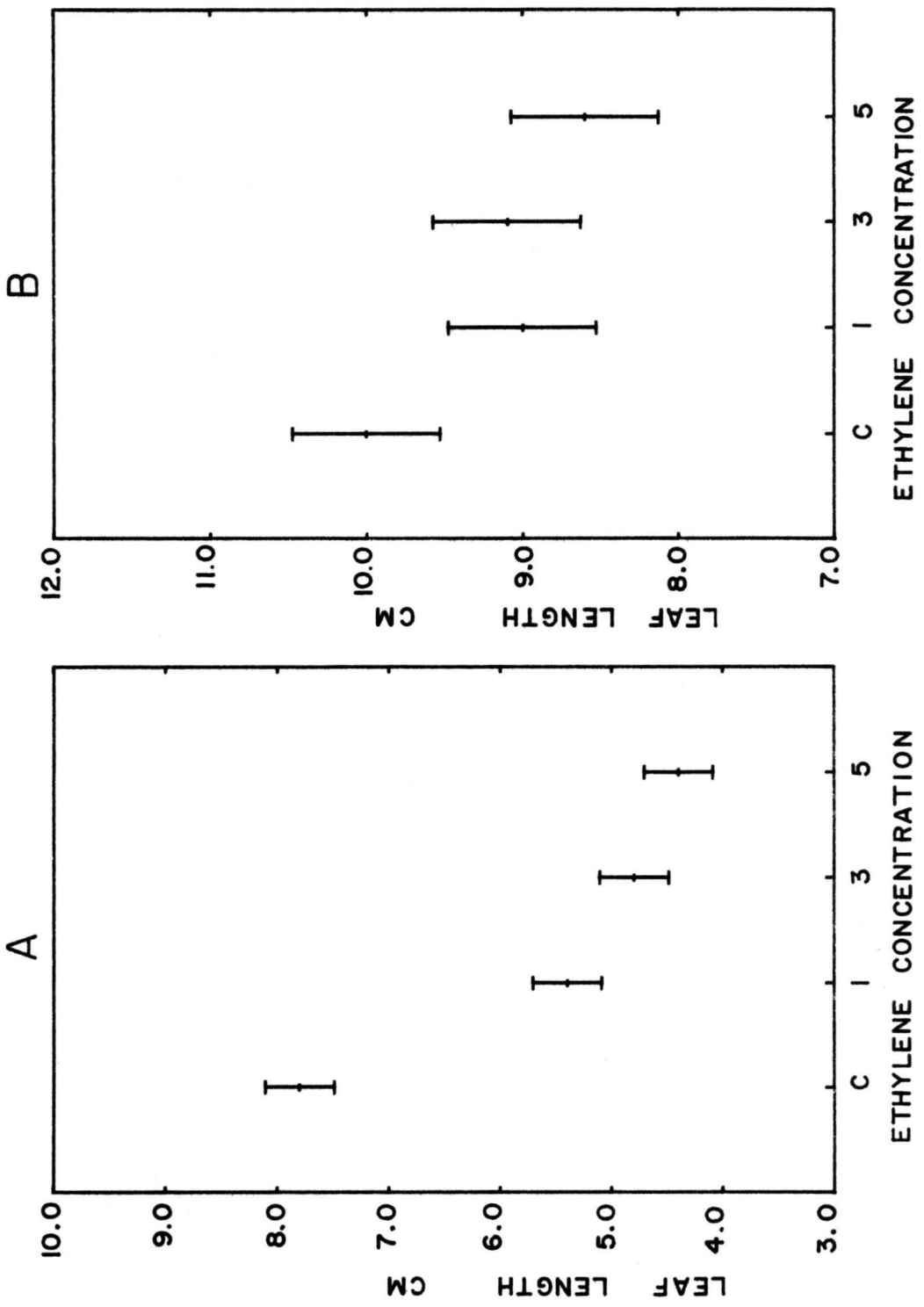

A
B
LEAF LENGTH CM
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
12.0
11.0
10.0
9.0
8.0
7.0
C
1
3
5
ETHYLENE CONCENTRATION

Figure 6. Effect of continuous ethylene treatment (from time of planting to flowering) on carnation fresh weight (plot A) and dry weight (plot B). The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

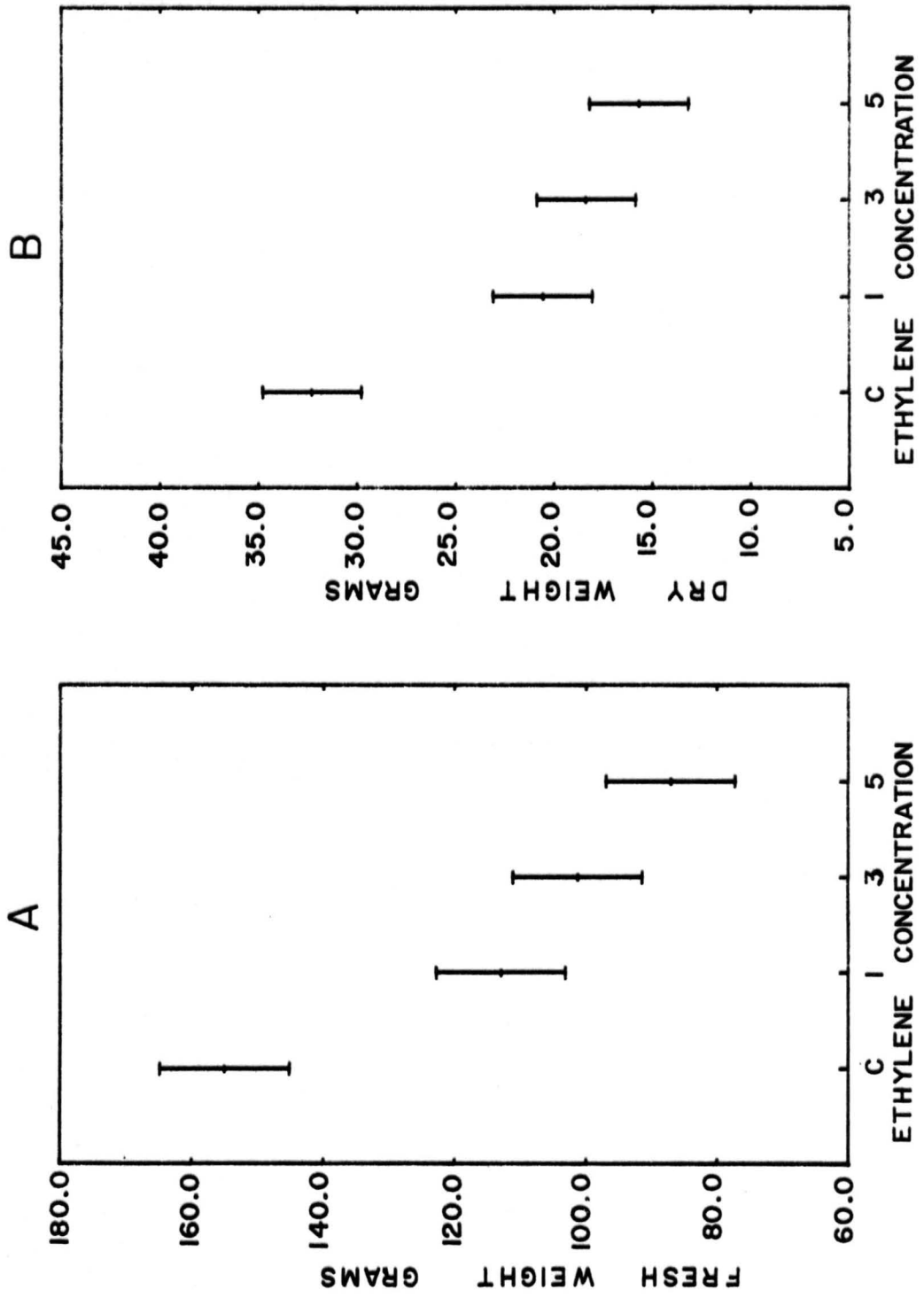
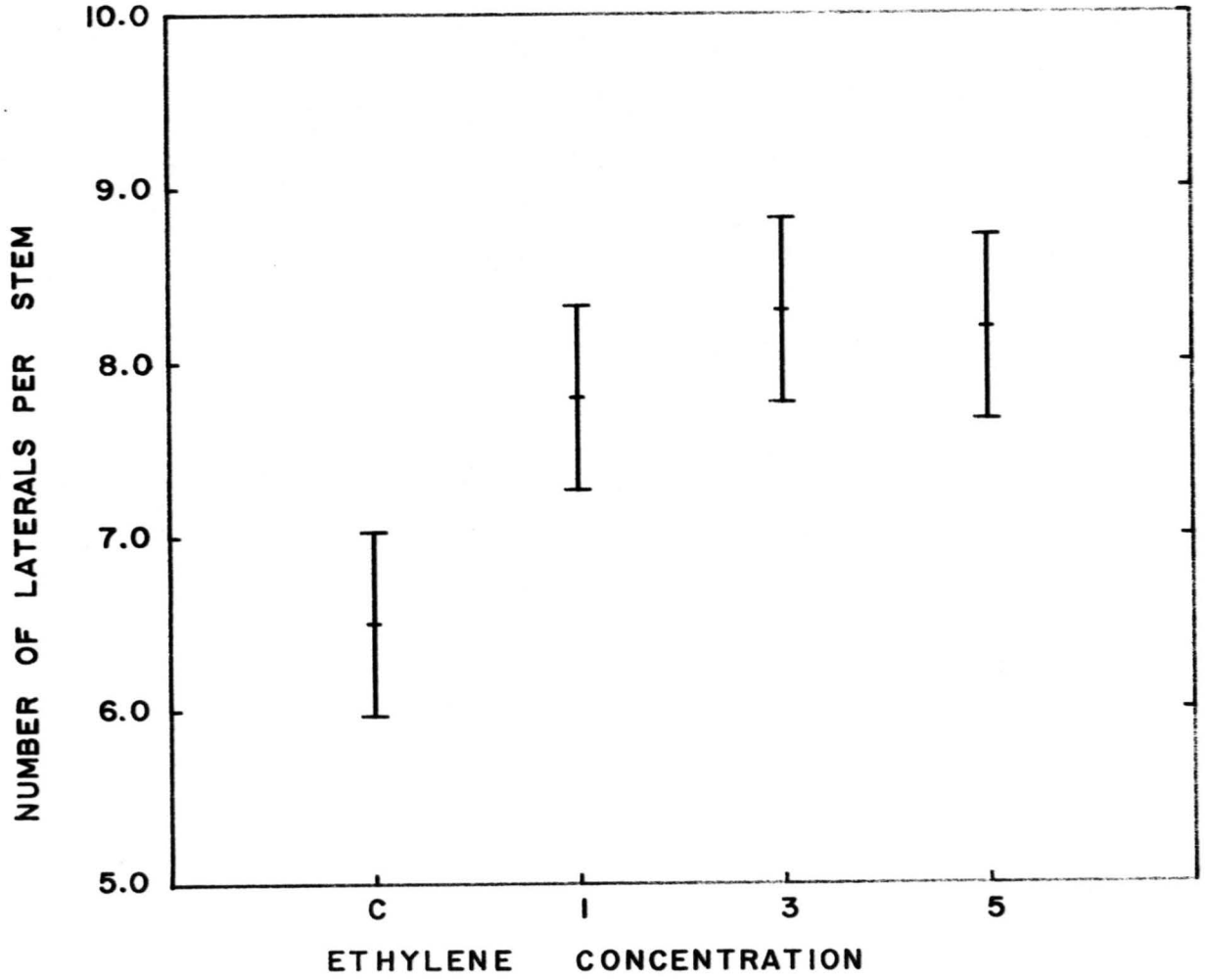

A
180.0
160.0
140.0
120.0
100.0
80.0
60.0
FRESH WEIGHT GRAMS
C 1 3 5
ETHYLENE CONCENTRATION
B
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
DRY WEIGHT GRAMS
C 1 3 5
ETHYLENE CONCENTRATION

Figure 7. Effect of continuous ethylene treatment (from planting to flowering) on the total number of both vegetative and reproductive laterals per carnation stem. The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene


10.0
9.0
8.0
7.0
6.0
5.0
NUMBER OF LATERALS PER STEM
C
1
3
5
ETHYLENE CONCENTRATION

was needed to exert a similar effect on the "just pinched" stage (Fig. 8).

One Week. -- Plants showing bud color, after pinching, and after planting were treated with C_2H_4 for one week. The only noticeable effect on the bud color stage was pistil protrusion. A concentration of 500 ppb adversely affected the stem length of the plants treated after pinching and planting (Fig. 9).

Three Days. -- Plants at "rapid elongation" and "bud initiation" were treated with ethylene for three days. Only at 500 ppb were there marked differences (Fig. 10).

Periodic Ethylene Treatment

Plants with two to four fully expanded leaf pairs were given five 2-day C_2H_4 treatments over a seven week period to simulate air pollution episodes in the Denver Metropolitan area. Statistically significant (at the 5% level) stem shortening occurred with C_2H_4 levels of 300 ppb and greater (Fig. 3). Although the difference between the control and 100 ppb treatment was not statistically different, it is worth noting (Fig. 3).

Ethylene Dosage

This work followed investigations by Barden (7), who used a dosage term (ppb-hours) to show ethylene effects on cut flowers. In the case of longer experiments, ppb-days was more convenient. Ethylene's effect on plant growth depends on the ethylene concentration

Figure 8. Effect of two week ethylene treatment (9/25/73 - 10/9/73) on carnation stem length with ethylene applied at: 1) "rapid elongation," 2) "bud initiation," and 3) "pinched." The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

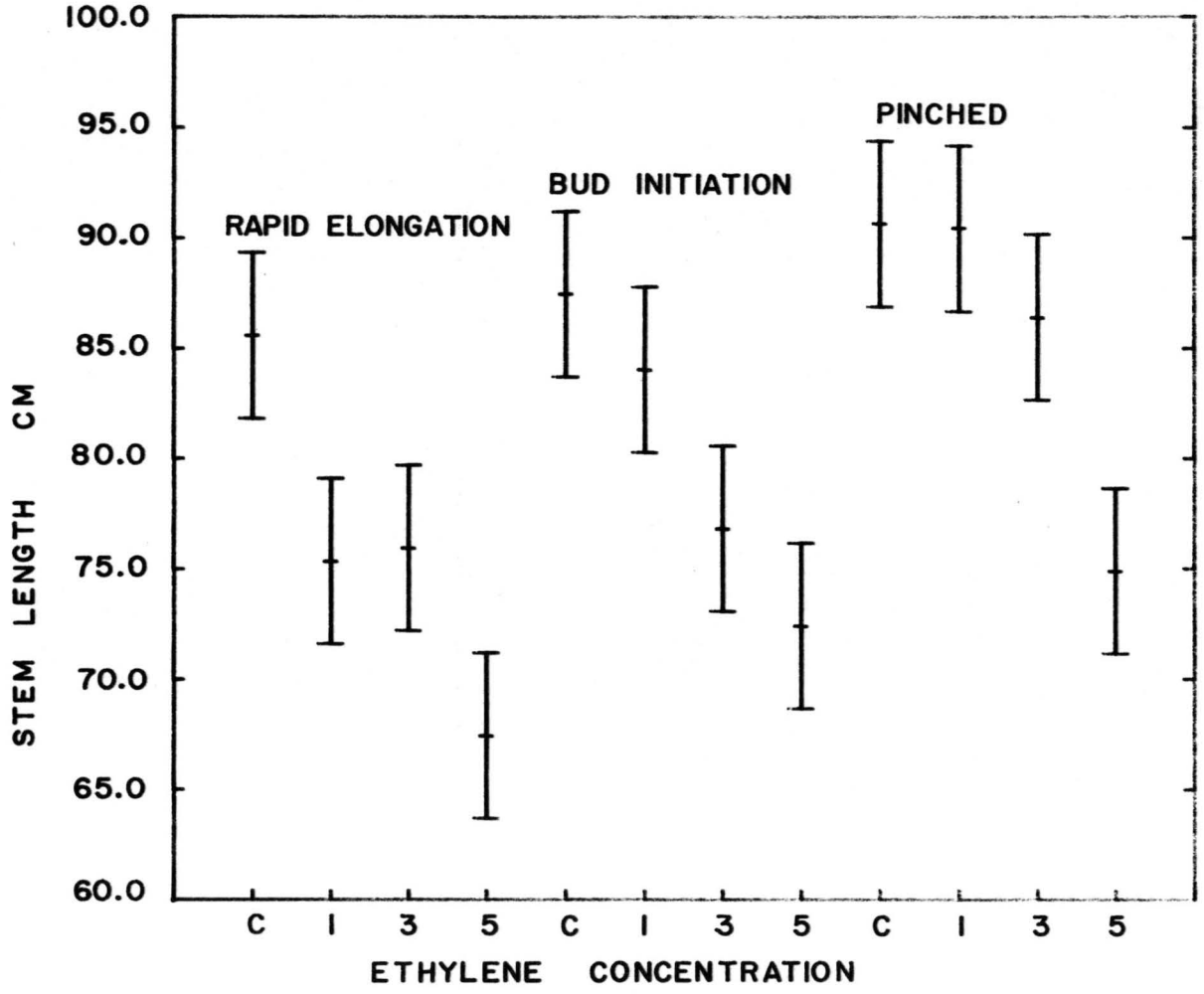

100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
STEM LENGTH CM
RAPID ELONGATION
BUD INITIATION
PINCHED
C I 3 5 C I 3 5 C I 3 5
ETHYLENE CONCENTRATION

Figure 9. Effect of one week ethylene treatment (10/11/73 - 10/18/73) on carnation stem length with ethylene applied at: 1) "showing bud color," 2) "pinched," and 3) "planted." The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

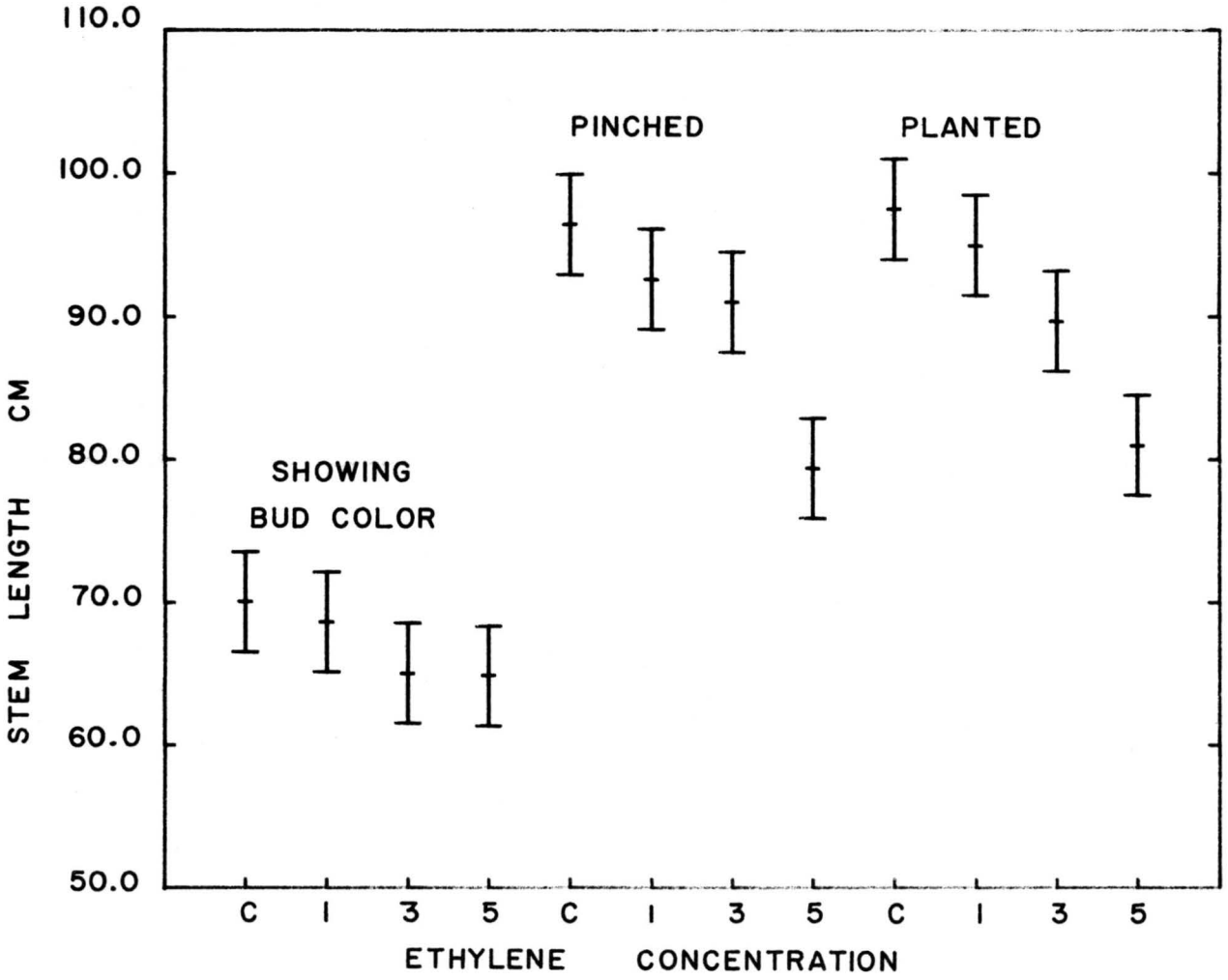
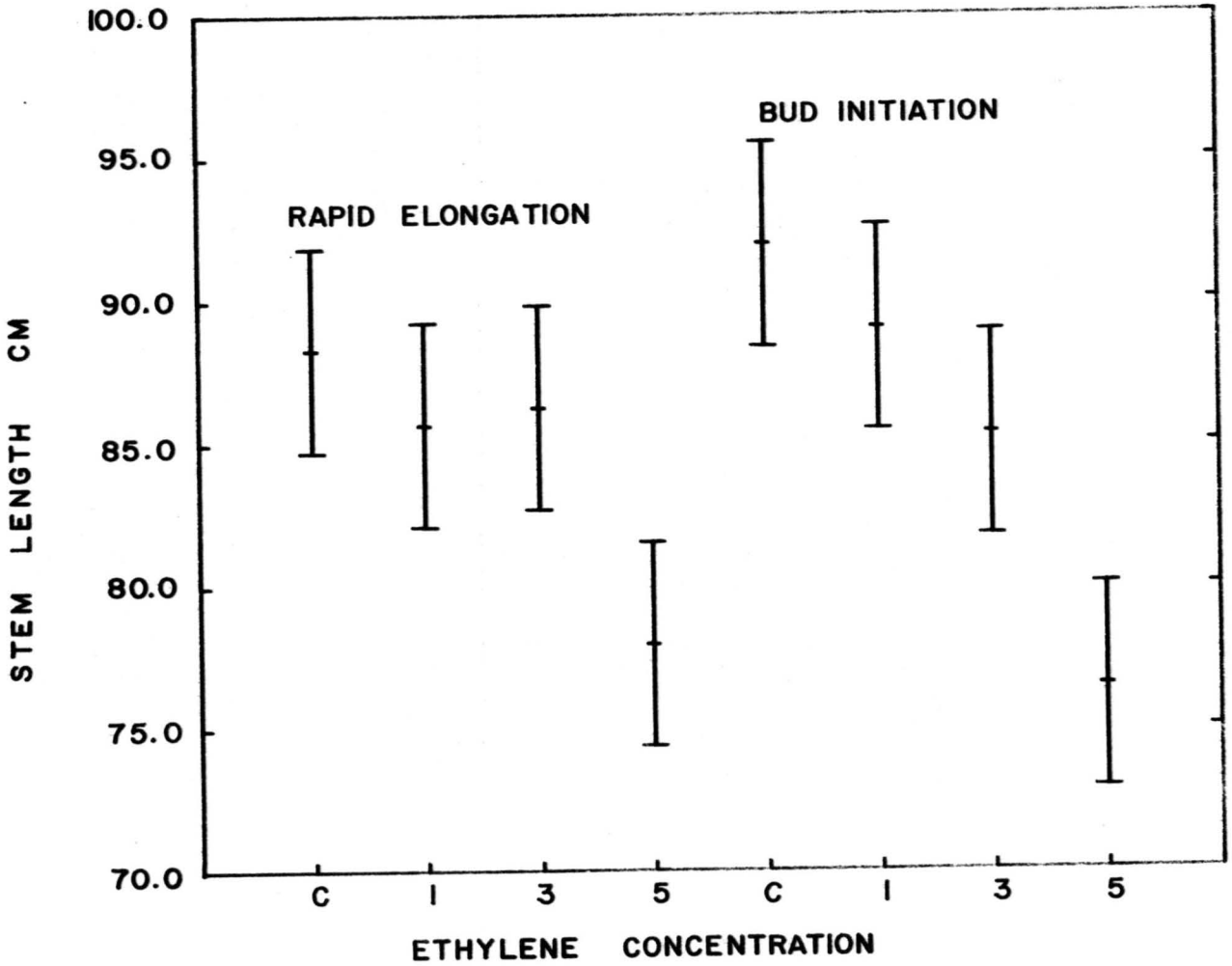

110.0
100.0
90.0
80.0
70.0
60.0
50.0
STEM LENGTH CM
PINCHED
PLANTED
SHOWING
BUD COLOR
C 1 3 5 C 1 3 5 C 1 3 5
ETHYLENE CONCENTRATION

Figure 10. Effect of three day ethylene treatment (11/9/73 - 11/12/73) on carnation stem length with ethylene applied at: 1) "rapid elongation" and 2) "bud initiation." The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene


100.0
95.0
90.0
85.0
80.0
75.0
70.0
STEM LENGTH CM
RAPID ELONGATION
BUD INITIATION
C
1
3
5
C
1
3
5
ETHYLENE CONCENTRATION

and the length of exposure. Thus, theoretically, 300 ppb for one day (300 ppb-days) would produce the same plant responses as 100 ppb for three days (300 ppb-days).

Effect on Stem Growth

Much mention is made concerning ethylene's ability to retard stem elongation (2, 4). The continuous C_2H_4 treatment showed the most drastic stem shortening. Various moderations of stem shortening also occurred with the shorter C_2H_4 exposure depending on the stage of plant growth during treatment and the C_2H_4 dosage. Internode length was also measured, with the continuous C_2H_4 treatment showing dramatic shortening (Fig. 4). A decrease in internode length coincided with stem growth retardation. Ethylene must be constantly present to exert a continuous effect on vegetative tissue; normal plant growth resumed after removal from the C_2H_4 source. Some ethylene effect was noticed for a few days after C_2H_4 treatment because of damage to meristematic tissue.

Effect on Lateral Branching

Increased bud development following C_2H_4 treatment has been noticed for some plant species (2). Only the continuous C_2H_4 treatment caused a statistically significant increase in the total number of laterals per stem (Fig. 7). The shorter C_2H_4 treatments caused an increased "shrubbiness" which was especially noticeable at 300 ppb and 500 ppb. The "shrubby" appearance could be due to a concentration

of laterals within a certain area on the stem. The continuously treated plants did not have a "shrubby" appearance because continuous C_2H_4 prohibited elongation of the laterals. The shorter C_2H_4 treatments initiated lateral growth that elongated normally.

Effect on Leaf Growth

Ethylene is known to inhibit leaf expansion (2, 4), so ethylene's effect on carnation leaf length and width was noted. The continuous, periodic, and two week C_2H_4 exposures produced notable leaf shortening (Fig. 5, 11). The two week C_2H_4 exposure produced a statistically significant decrease in leaf width on the bud initiation stage at 300 ppb and 500 ppb (Fig. 12). Since this phenomenon occurred with the two week exposure and not with the continuous treatment, the possibility of plant growth differences and error in measurement must be considered.

Effect on Fresh and Dry Weights

Due to severe growth retardation, the continuous C_2H_4 treatment produced a marked reduction in both fresh and dry weights (Fig. 6). The shorter C_2H_4 exposures had little effect on plant weights.

Plant Stage Sensitivity

The following carnation growth stages were used during the experimental period: 1) "planted," 2) "pinched," 3) "bud initiation," 4) "rapid elongation," and 5) "showing bud color." The "rapid

Figure 11. Effect of two week ethylene treatment (9/25/73 - 10/9/73) on carnation leaf length with ethylene applied at: 1) "rapid elongation," 2) "bud initiation," and 3) "pinched." The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene

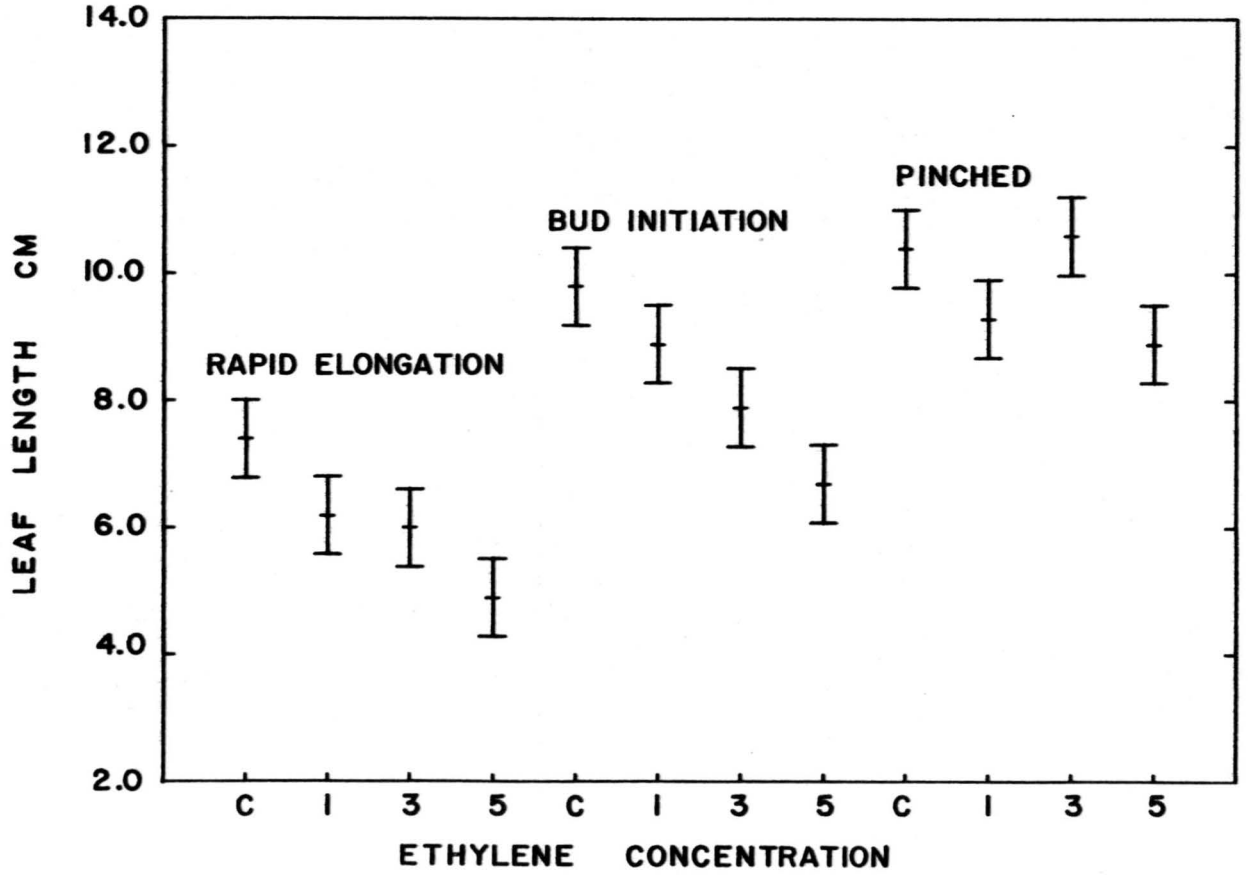
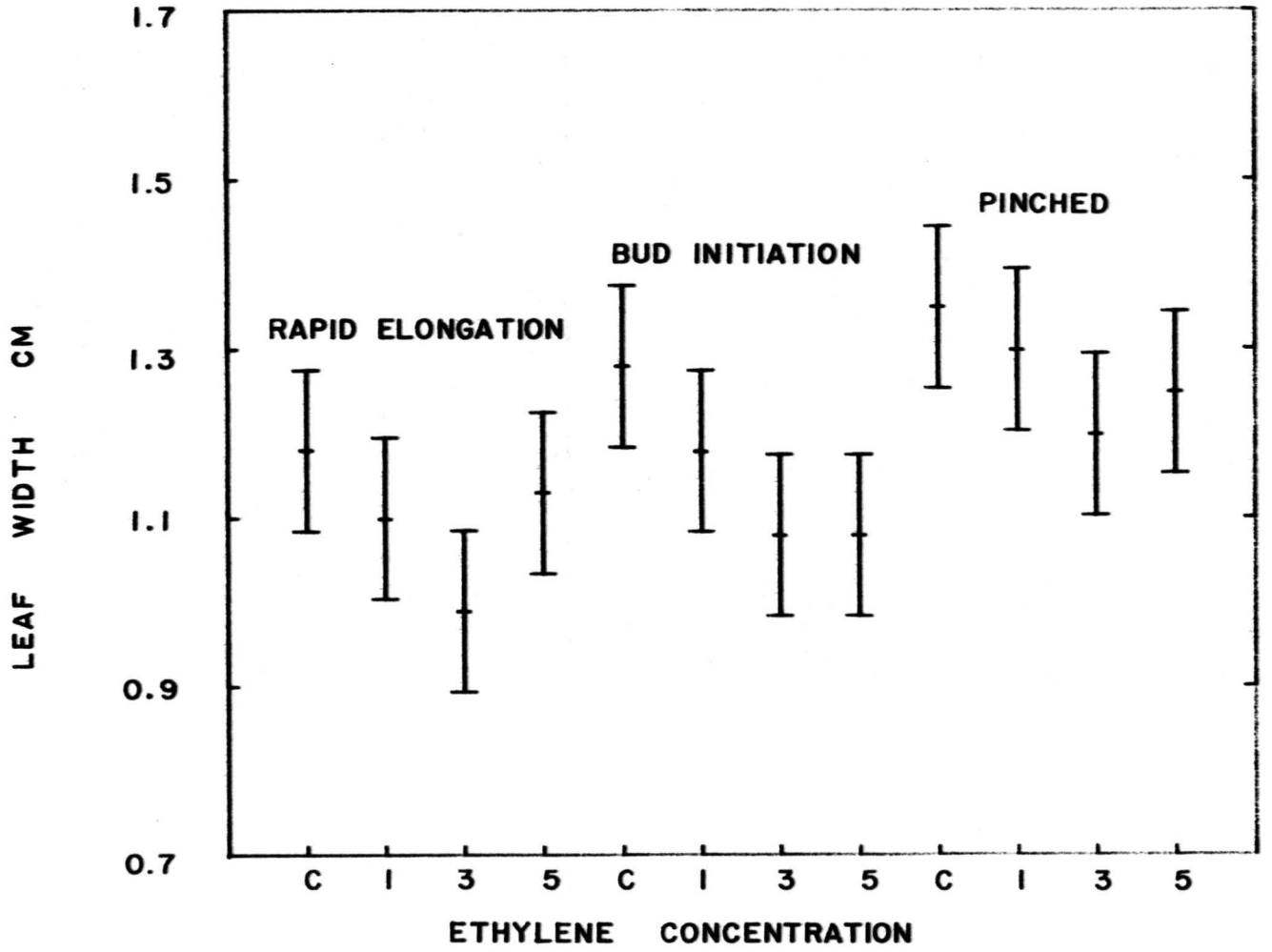

14.0
12.0
10.0
8.0
6.0
4.0
2.0
LEAF LENGTH CM
RAPID ELONGATION
BUD INITIATION
PINCHED
C
I
3
5
C
I
3
5
C
I
3
5
ETHYLENE CONCENTRATION

Figure 12. Effect of two week ethylene treatment (8/30/73 - 9/13/73) on carnation leaf width with ethylene applied at: 1) "rapid elongation," 2) "bud initiation," and 3) "pinched." The plot represents Tukey's "honestly significant difference" (hsd) procedure. Means with an hsd half confidence width are plotted. If half width bands do not overlap, the treatment means are significantly different at the 5% level.

C = control
1 = 100 ppb ethylene
3 = 300 ppb ethylene
5 = 500 ppb ethylene


1.7
1.5
1.3
1.1
0.9
0.7
LEAF WIDTH CM
RAPID ELONGATION
BUD INITIATION
PINCHED
C I 3 5 C I 3 5 C I 3 5
ETHYLENE CONCENTRATION

elongation" and "bud initiation" stages seemed to be the most sensitive to ethylene. These stages represented periods of relatively rapid plant growth, so increased ethylene effects were expected. With the "bud color" stage, vegetative growth and bud development had advanced to the point where growth inhibition was not noticeable. The "just pinched" and "just planted" stages are not periods of rapid stem elongation, and plants treated during these early stages were less sensitive to ethylene. Ethylene did appear to have a residual effect on these early stages if the dosage was high enough (Fig. 9). It is suggested that ethylene inhibits stem elongation by redirecting growth in a lateral rather than a longitudinal direction (2, 13). This suggests that during periods of rapid growth, ethylene causes more lateral growth to occur resulting in decreased stem length. As a general observation, the C_2H_4 treated plants seemed harder to the touch and thicker and woodier at the stem bases.

Ambient Ethylene Concentrations

There is strong evidence that an ethylene-filtered control would have revealed more dramatic differences between treatments (2, 4). Abeles and Heggestad (4) discovered reduced vegetative growth at 25 ppb C_2H_4 in all their experiments. Their ambient air treatment (1-60 ppb) produced distinct reduction in cucumber leaf expansion after 21 days when compared with a Purafil[1] filtered control. Red Kidney

[1] $KMnO_4$ absorbed on alumina pellets; a product of Borg-Warner Corp., U.S.A.

beans showed a similar reduction in leaf expansion and stem elongation after 21 days. Figures 13 and 14 seem to support the need for a filtered control. Figure 14 is a result of a collection of data. Logarithmic plots were made of the following data: 1) periodic treatment (R^2 = 0.961), 2) "bud initiation" for three days and two weeks (R^2 = 0.853), 3) "rapid elongation" for three days and two weeks (R^2 = 0.454), and 4) "pinched" for one week and two weeks (R^2 = 0.697). "T" tests showed no significant difference between the four plots. The average slope and intercept of these four plots was used to plot, Log y = a + b (log x), on a linear scale. The continuous treatment (Fig. 13) was plotted separately due to a significant difference in slope from the other four plots. In each case, 25 ppb C_2H_4 was used as the average ambient ethylene level in Fort Collins, and this was computed on a dosage basis. Thus, 75 ppb-days is the lowest data point on Fig. 14 and 3050 ppb-days on Fig. 13. Information beyond these points is hypothetical.

It does appear that low C_2H_4 dosages produce a more marked reduction in stem length in relation to higher dosages. At higher dosages, a point of maximal stem reduction seemed to have been reached. Figure 13 points out an approximate 30 cm. stem reduction between the control (3000 ppb-days) and the 100 ppb treatment (11000 ppb-days). This coincides with Fig. 3. Figure 14 shows about a 15 cm. stem reduction between 75 ppb-days and 1000 ppb-days. Since this figure represents a combination of various plant growth stages

Figure 13. Relationship between carnation stem length and continuous ethylene treatment (from time of planting to flowering) on a dosage basis (ppb-days). An ethylene dosage was computed for the control on the basis of an average 25 ppb ambient ethylene level in Fort Collins. Linear plot of Log y = a + b(log x).

$$R^2 = 0.997$$

Treatment	Dosage (ppb-days)
control (25 ppb for 122 days)	3, 050
100 ppb for 110 days	11, 000
300 ppb for 106 days	31, 800
500 ppb for 104 days	52, 000

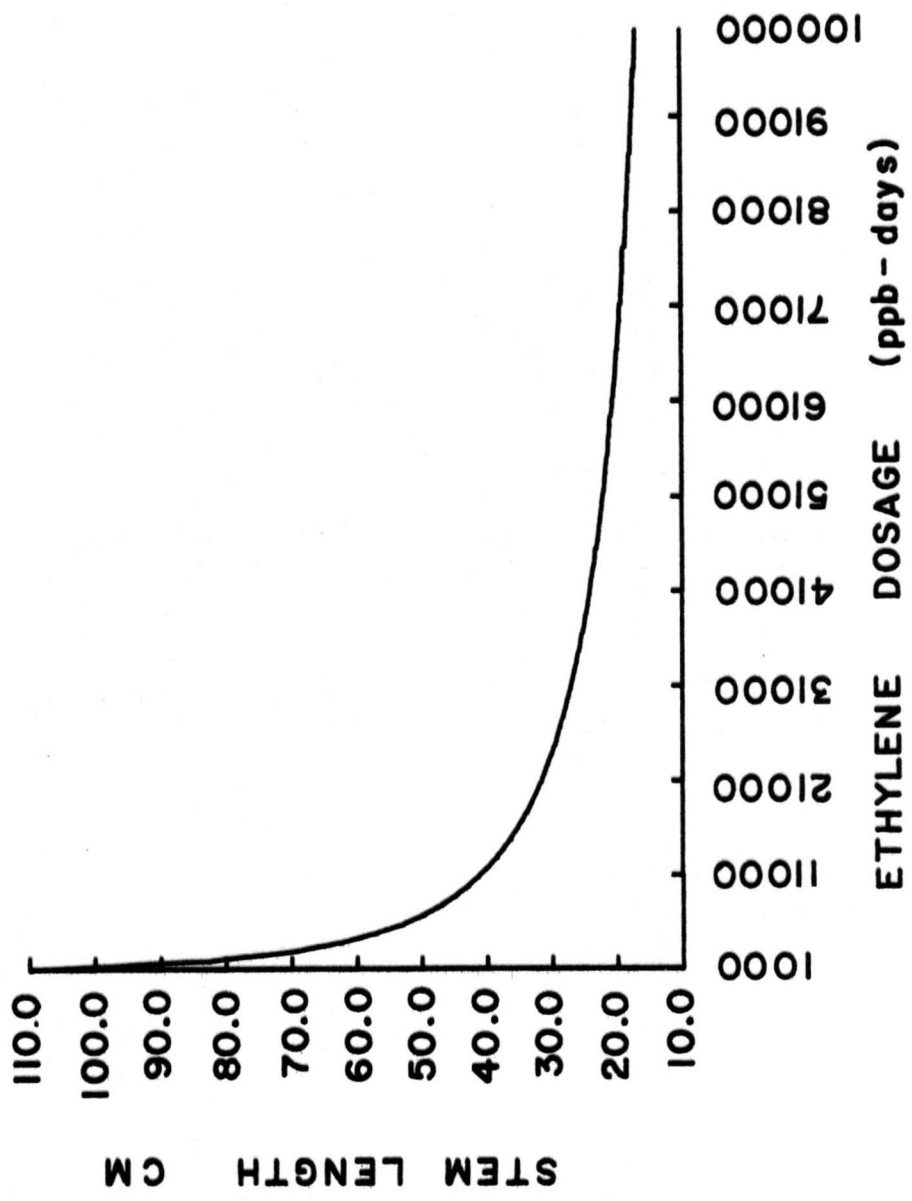
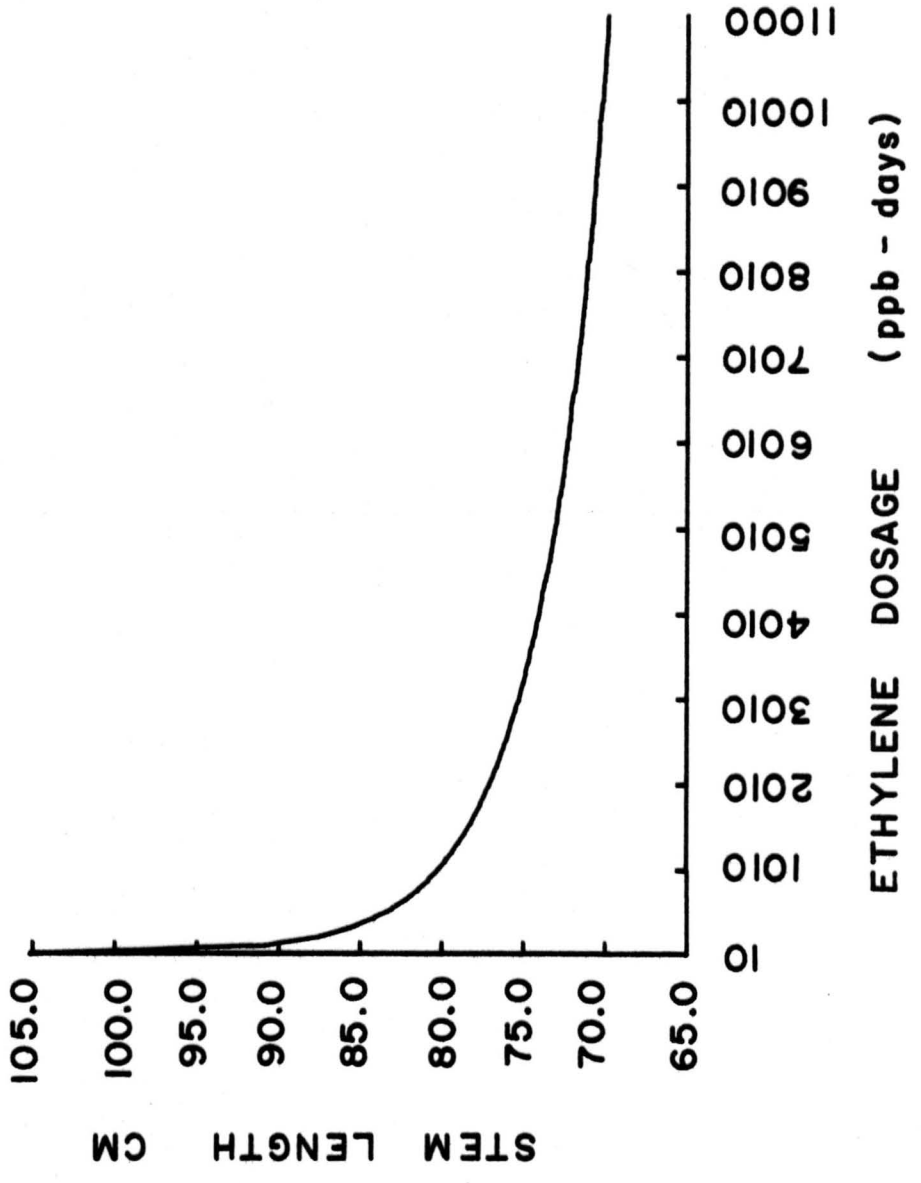

STEM LENGTH CM
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
1000
11000
21000
31000
41000
51000
61000
71000
81000
91000
101000
ETHYLENE DOSAGE (ppb-days)

Figure 14. Relationship between carnation stem length and ethylene dosage (ppb-days). An average slope and intercept was computed from the following logarithmic plots: 1) periodic treatment ($R^2 = 0.961$), 2) "rapid elongation" for three days and two weeks ($R^2 = 0.454$), 3) "bud initiation" for three days and two weeks ($R^2 = 0.853$), and 4) "pinched" for one week and two weeks ($R^2 = 0.697$). An ethylene dosage was computed for the control on the basis of an average 25 ppb ambient ethylene level in Fort Collins. The lowest data point is 75 ppb-days; the highest, 7,000 ppb-days. Linear plot of Log y = a + b(log x).


STEM LENGTH CM
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
ETHYLENE DOSAGE (ppb - days)
10
1010
2010
3010
4010
5010
6010
7010
8010
9010
10010
11000

and treatment durations, it can not be compared directly to any other figure. Stem reduction as indicated in Figs. 13 and 14 at low dosages is very revealing and warrants much concern. If a filtered control were used, the difference between the control plants and the C_2H_4 treated plants would have been greater.

Work by Hanan (26) revealed C_2H_4 levels from three stations, within a two square mile area of Denver, to range from 5 to 160 ppb. The average C_2H_4 level for his test period was about 45 ppb. He put his results on a ppb-hour dosage basis and figured a minimum C_2H_4 level for any six hour period to be 30 ppb-hours and a maximum level, 506 ppb-hours. A continuous ethylene level of 45 ppb could result in serious reduction in plant growth (Fig. 13). More research needs to be done using filtered controls to establish the extent of carnation growth reduction from ambient ethylene levels.

Commercial Applications

Chronic ethylene damage would be difficult to discover by observation in the greenhouse unless control plants in an ethylene-free environment were used for growth comparison. Abeles and Heggestad (4) suggested that C_2H_4 levels as low as 10 ppb may affect many plants. Ethylene levels in urban areas are considerably above 10 ppb (2, 4, 26), so constant, chronic plant damage is likely. It is up to the grower to decide how much stem length reduction, for example, is enough to be considered serious (Fig. 13, 14). Acute damage may occassionally

occur in greenhouses from improperly vented unit heaters (25). Shortened internodes is the most noticeable symptom of acute ethylene dosages. However, if carnations are in flower, C_2H_4 levels high enough to exert a noticeable effect on vegetative tissue will cause "sleepiness" in open flowers (7, 21, 53). It is the "unnoticed" chronic damage that may be the serious threat.

It is possible that ethylene, in the form of ethylene-releasing compounds such as Ethrel, could be used to initiate earlier flowering of carnations. Earlier flowering of C_2H_4 treated plants was noted during the experimental period. Much research could be done to determine how much Ethrel need be applied at what growth stage to cause earlier flowering without adverse effects. It would seem possible to apply Ethrel during bud development without affecting stem length. Ethrel can be translocated throughout the plant (2), and work with Ethrel on grapes has revealed Ethrel movement in the phloem in a source-to-sink relationship (2).

Suggested Research

The following research is suggested:

1. Test the effects of ethylene on carnation growth using a filtered control.

2. Establish, for the Denver Metropolitan area, the extent of plant damage that may occur from ambient ethylene levels.

3. Study the synergistic effects of air pollutants on carnation growth.

4. Explore the practicality of using Ethrel to hasten the flowering of carnations.

5. Compare the keeping quality of flowers cut from ethylene treated plants with flowers cut from plants grown in filtered air.

SUMMARY AND CONCLUSIONS

Carnation plants at various growth stages were treated with 100 ppb, 300 ppb, and 500 ppb ethylene for differing time periods. A continuous ethylene treatment from time of planting to flowering produced readily visible ethylene damage. Shorter ethylene exposures produced less severe damage. Plants treated during periods of rapid growth (e.g. "rapid elongation" and "bud initiation") appeared to be more sensitive to ethylene than plants treated during early growth stages (e.g. "planted" and "pinched"). A concentration of 500 ppb ethylene for three days significantly reduced the stem length of carnations treated during "rapid elongation" and "bud initiation"; 300 ppb ethylene for two weeks produced the same effect. An ethylene concentration of 500 ppb for two weeks was needed to significantly reduce the stem length of plants treated after pinching.

A dosage term (ppb-days), following work by Barden (7), was used to correlate ethylene concentration and treatment duration with the extent of plant damage. Ethylene's effect on carnation 1) stem length, 2) leaf length, 3) leaf width, 4) internode length, 5) fresh weight, 6) dry weight, and 7) laterals per stem was noted. Plant damage occurred even at low dosages although the extent of damage was often statistically insignificant compared to the control.

The need for using a filtered control was established. Relatively speaking, plant growth is affected more rapidly by low ethylene dosages than by higher dosages. It is suspected that the control plants sustained some growth damage by receiving ambient ethylene levels (about 25 ppb in Fort Collins). A clearer distinction between the control and treated plants would have been obtained if the control had been filtered.

Low ethylene dosages producing chronic plant damage may be a serious threat to greenhouse operations. Chronic damage is difficult to detect visually unless the treated plants can be compared to plants grown in an ethylene-free environment. It appears that most urban areas have ambient ethylene levels high enough to cause some plant damage. It is up to the grower to decide how much damage is serious. Presently, there are no practical methods for filtering ethylene on a large scale. The owner of an established greenhouse range in an urban area can do nothing about ambient ethylene concentrations. However, ethylene levels in urban areas should be considered before a grower chooses a site for a new range.

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APPENDICES

Table 1. Data averages from continuous and periodic ethylene treatments. Continuous treatment from time of planting, April 4, 1973, to flowering. Periodic treatment (five 2-day treatments over a seven week period) with carnations showing two to four fully expanded leaf pairs at the start of treatment. Data collected when at least one flower was open per pot.

Treatment	Height (cm)	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)	No. of Nodes	Internode Length (cm)	No. of Laterals per Stem	Fresh Weight (g)	Dry Weight (g)
					Continuous				
control	82.6	71.1	7.8	1.1	13.0	5.5	6.5	155.1	32.3
100 ppb	47.9	39.3	5.4	1.1	12.5	3.2	7.8	113.1	20.6
300 ppb	34.8	27.0	4.8	1.0	12.7	2.1	8.3	101.4	18.4
500 ppb	29.1	21.9	4.4	1.0	12.1	1.8	8.2	87.2	15.7
					Periodic				
control	90.2	86.6	10.0	1.3	14.9	5.8	9.4	273.8	40.4
100 ppb	84.5	80.3	9.0	1.2	15.1	5.3	9.0	242.7	35.9
300 ppb	81.0	78.7	9.1	1.3	14.9	5.3	9.6	243.4	37.8
500 ppb	76.8	75.7	8.6	1.4	14.9	5.1	10.0	259.8	46.8

Table 2: Data averages from two week ethylene treatment (8/30/73 - 9/13/73). Data collected when at least one flower was open per pot. Ethylene applied when plants were at: 1) "rapid elongation," 2) "bud initiation," 3) "pinched."

Treatment	Growth Stage	Height (cm)	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)	No. of Nodes	Internode Length (cm)	No. of Laterals per Stem	Fresh Weight (g)	Dry Weight (g)
control	1	72.0	65.8	7.1	1.2	13.3	4.8	8.1	177.6	30.1
	2	88.8	83.6	8.4	1.3	14.6	5.7	10.0	290.4	50.3
	3	92.0	87.6	9.5	1.4	14.6	6.0	8.8	294.8	54.2
100 ppb	1	67.3	62.1	5.6	1.1	14.6	4.3	7.9	171.1	26.6
	2	87.8	76.9	6.1	1.2	14.4	5.3	10.2	328.3	47.6
	3	91.0	87.3	9.4	1.3	14.8	5.9	10.0	315.4	55.2
300 ppb	1	68.5	61.7	5.3	1.0	14.7	4.2	8.8	203.0	35.0
	2	83.0	76.9	5.0	1.1	14.2	5.4	9.3	260.0	40.9
	3	87.3	80.9	8.2	1.2	13.8	5.9	9.1	250.2	44.7
500 ppb	1	59.3	50.6	6.4	1.1	14.3	3.6	8.7	172.7	29.2
	2	78.8	73.5	5.3	1.1	14.4	5.1	10.5	309.9	49.7
	3	80.0	74.2	8.8	1.3	14.0	5.3	9.8	313.5	53.3

Table 3. Data averages from two week ethylene treatment (9/25/73 - 10/9/73). Data collected when at least one flower was open per pot. Ethylene applied when plants were at: 1) "rapid elongation," 2) "bud initiation," 3) "pinched."

Treatment	Growth Stage	Height (cm)	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)	No. of Nodes	Internode Length (cm)	No. of Laterals per Stem	Fresh Weight (g)	Dry Weight (g)
control	1	92.8	85.6	7.4	1.3	14.9	5.7	10.0	270.5	40.5
	2	89.5	87.5	9.8	1.4	14.7	6.0	9.1	266.5	46.8
	3	94.8	90.7	10.4	1.4	15.3	6.0	9.9	328.3	47.8
100 ppb	1	86.3	75.4	6.2	1.2	14.5	5.2	10.3	295.3	42.3
	2	86.0	84.1	8.9	1.3	14.1	6.0	9.0	284.3	40.6
	3	94.3	90.5	9.3	1.3	14.3	6.4	10.3	299.2	42.6
300 ppb	1	83.8	76.0	6.0	1.1	14.5	5.2	10.2	287.3	40.4
	2	81.5	76.9	7.9	1.2	13.8	5.6	10.0	300.2	42.6
	3	90.8	86.5	10.6	1.4	14.5	6.0	10.3	306.4	49.4
500 ppb	1	76.3	67.5	4.9	1.0	15.0	4.5	10.4	332.7	53.7
	2	75.8	72.5	6.7	1.2	14.2	5.1	10.1	323.9	51.6
	3	80.3	75.0	8.9	1.4	14.8	5.1	11.1	366.6	65.7

Table 4. Data averages from one week ethylene treatment (10/11/73 - 10/18/73). Data collected when at least one flower was open per pot. Ethylene applied when plants were at: 1) "showing bud color," 2) "pinched," 3) "planted."

Treatment	Growth Stage	Height (cm)	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)	No. of Nodes	Internode Length (cm)	No. of Laterals per Stem	Fresh Weight (g)	Dry Weight (g)
control	1	74.0	70.1	-	-	14.7	4.8	8.5	225.3	36.5
	2	97.3	96.5	10.4	1.5	15.6	6.2	10.8	305.9	45.3
	3	98.5	97.6	10.8	1.4	16.0	6.1	9.7	316.2	48.1
100 ppb	1	75.5	68.7	-	-	14.2	4.9	8.7	190.6	33.1
	2	93.0	92.7	11.2	1.5	15.8	5.9	10.1	276.1	41.5
	3	96.5	95.1	10.6	1.4	15.1	6.3	10.3	353.5	56.8
300 ppb	1	71.5	65.1	-	-	13.9	4.7	8.1	167.5	31.3
	2	94.3	91.1	10.7	1.5	14.8	6.2	10.0	267.7	42.2
	3	92.3	89.8	10.6	1.4	14.5	6.2	9.5	308.5	50.1
500 ppb	1	73.8	64.9	-	-	13.8	4.8	6.2	179.5	30.5
	2	82.3	79.5	9.9	1.4	16.3	5.0	11.5	363.9	66.9
	3	83.8	81.1	9.7	1.5	15.5	5.2	10.9	340.6	61.5

Table 5. Data averages from three day ethylene treatment (11/9/73 - 11/12/73). Data collected when at least one flower was open per pot. Ethylene applied when plants were at: 1) "rapid elongation," 2) "bud initiation."

Treatment	Growth Stage	Height (cm)	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)	No. of Nodes	Internode Length (cm)	No. of Laterals per Stem	Fresh Weight (g)	Dry Weight (g)
control	1	91.5	88.3	9.8	1.4	14.8	6.0	9.8	295.2	42.1
	2	95.3	92.1	10.5	1.5	15.3	6.0	10.2	332.4	53.5
100 ppb	1	91.5	85.7	9.4	1.4	14.7	5.8	10.9	352.1	47.0
	2	93.0	89.1	10.3	1.5	14.8	6.0	9.4	329.6	52.0
300 ppb	1	88.3	86.3	9.9	1.5	15.2	5.8	10.9	352.6	50.9
	2	88.7	85.4	10.1	1.4	14.8	5.7	11.0	330.5	50.5
500 ppb	1	82.7	78.1	9.4	1.4	14.8	5.3	11.4	416.7	69.4
	2	80.2	76.5	10.3	1.5	14.7	5.2	11.7	367.2	64.9