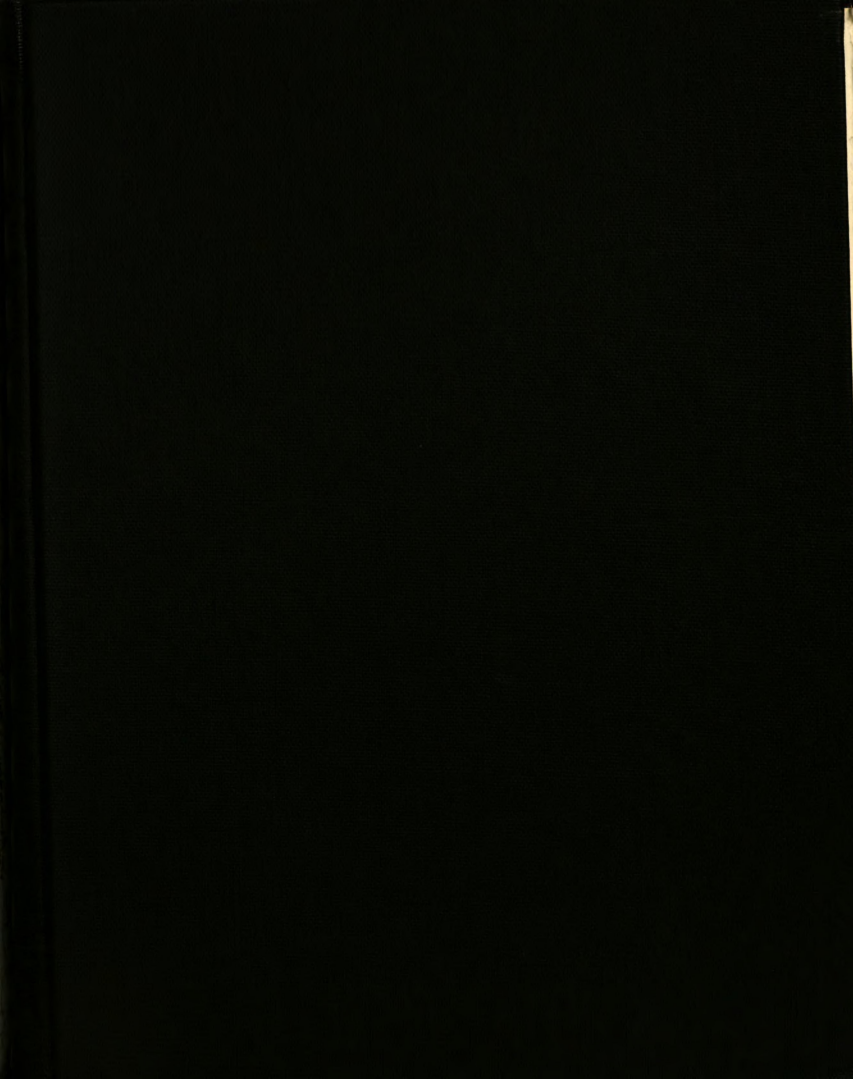
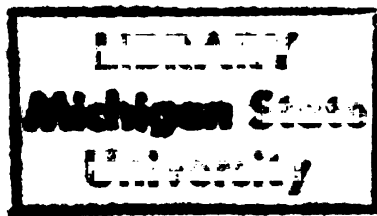






This is to certify that the

dissertation entitled

The Influence of Environmental Factors
on Postproduction Keeping Quality of
Bedding Plants
presented by

Louella J. Nelson

has been accepted towards fulfillment
of the requirements for

M.S. degree in Horticulture

William H. Carlson
Major professor

Date Oct 22, 1984



RETURNING MATERIALS:
Place in book drop to
remove this checkout from
your record. FINES will
be charged if book is
returned after the date
stamped below.

--	--	--

THE INFLUENCE
OF ENVIRONMENTAL FACTORS
ON POSTPRODUCTION KEEPING QUALITY
OF BEDDING PLANTS

By

Louella Jane Nelson

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

1984

ABSTRACT

THE INFLUENCE OF ENVIRONMENTAL FACTORS ON POSTPRODUCTION KEEPING QUALITY OF BEDDING PLANTS

By

Louella Jane Nelson

Research was undertaken to develop guidelines to extend marketability of 7 popular bedding plant species. The retail environment and effects of ethylene exposure were investigated. Plants were produced in both a peat-lite and a soil-based medium. Immediately postharvest, plants were exposed to quantum flux density levels of 7, 36 and $102 \mu\text{mol s}^{-1} \text{m}^{-2}$, air temperatures of 4.5, 13, 21 and 29°C , and three moisture regimes under laboratory conditions simulating the retail environment. Quantitative and qualitative data were accumulated over 36 days. In general, based on fresh weight, plant height and flower and foliage quality, extended marketability required a QFD range of 36 to $102 \mu\text{mol s}^{-1} \text{m}^{-2}$, a temperature range between 13 and 21°C , and high moisture in either medium type. In another experiment, plants were exposed to ethylene at 1 or 10 ppm for 6, 12, 24 or 48 hours. Epinasty and floral abscission occurred after only 6 hours in impatiens, salvia and tomato.

ACKNOWLEDGEMENTS

I wish to thank the members of my committee Drs. William H. Carlson, Royal Heins and Christine Stephens.

Appreciation also goes to Charles Bethke, Norman Blakely, Fred Hall, Meriam Karlsson and Sharon Roback who each had significant input in the development of this thesis.

Special gratitude goes to family members and friends for their patience and support.

Financial support for this study was provided by the Fred C. Gloeckner Foundation, the George J. Ball Seed Co. and the Michigan Peat Co.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vi
LIST OF FIGURES	viii
INTRODUCTION	1
LITERATURE REVIEW	2
Light	2
Photosynthesis of Sun and Shade Plants	2
Light Saturation Characteristics	2
Anatomy	3
Parameters Influencing Photosynthetic Rates	4
Acclimatization and the Postproduction Environment	5
Temperature	10
Temperature Relations of Plants	10
Heat Stress	11
Chilling Injury	11
Acclimatization and Postharvest Keeping Quality	12
Media	15
Container Media	15
Soil Based and Artificial Media	17
Water	21
Plant Anatomy	21
Water Stress	22
Development	22
Photosynthesis	23
Waterlogging	24
Acclimatization and the Postharvest Environment	25
Ethylene	27
Physiology of Ethylene Production	27
Rates of Production	27
Environmental Control	28
Temperature	28
Light	28
Atmospheric Gases	29
Growth and Developmental Effects of Ethylene	30
Epinasty	30
Flowering	31
Leaf Expansion	31
Ethylene and Senescence	32

	Page
Flower Fading	32
Leaf Senescence	32
Abscission	33
Ethylene, Air pollution and the Postharvest Environment	34
Air Pollution	34
The Postharvest Environment	35
Senescence	37
Leaf Senescence	37
Physiological Decline	37
Environmental Regulation	39
Light	39
Temperature	40
Water Relations.....	41
Hormonal Regulation.....	42
Flower Senescence	44
Physiological and Ultrastructural Changes	44
Changes in Pigmentation	45
Flower Abscission	45
SECTION ONE: INFLUENCE OF QUANTUM FLUX DENSITY, TEMPERATURE, MEDIA AND WATER REGIME ON POSTPRODUCTION KEEPING QUALITY OF BEDDING PLANTS	
Materials and Methods.....	47
Alyssum	
Materials and Methods.....	51
Results	51
Discussion	53
Tables and Figures.....	55
Begonia	
Materials and Methods.....	62
Results	62
Discussion	63
Tables and Figures.....	65
Coleus	
Materials and Methods.....	68
Results	68
Discussion	71
Tables and Figures.....	73
Geranium	
Materials and Methods.....	84
Results	84
Discussion.....	86
Tables and Figures.....	88
Impatiens	
Materials and Methods.....	100

	Page
Results	100
Discussion	103
Tables and Figures.....	105
Petunia	
Materials and Methods.....	118
Results	119
Discussion	123
Tables and Figures.....	125
Tomato	
Materials and Methods.....	136
Results	136
Discussion	142
Tables and Figures	143
Conclusion.....	152
SECTION TWO: INFLUENCE OF ETHYLENE ON POSTPRODUCTION KEEPING QUALITY OF BEDDING PLANTS	
Introduction	154
Materials and Methods	154
Results	156
Discussion	156
Conclusion	157
LITERATURE CITED.....	159

LIST OF TABLES

Table	Page
1. Influence of postproduction environmental factors on fresh weight of alyssum 'Snowcloth'.....	55
2. Influence of quantum flux density and temperature on the visual rating of alyssum 'Snowcloth'	61
3. Influence of postproduction environmental factors on fresh weight of begonia 'Scarletta'.....	65
4. Influence of postproduction environmental factors on change in stem height of begonia 'Scarletta'.....	67
5. Influence of postproduction environmental factors on fresh weight of coleus 'Rose Wizard'.....	73
6. Influence of postproduction environmental factors on change in stem height of coleus 'Rose Wizard'.....	79
7. Influence of postproduction environmental factors on fresh weight of geranium 'Sooner Red'.....	88
8. Influence of postproduction environmental factors on leaf weight of geranium 'Sooner Red'.....	90
9. Influence of postproduction environmental factors on leaf area of geranium 'Sooner Red'.....	93
10. Influence of postproduction environmental factors on change in stem height of geranium 'Sooner Red'.....	97
11. Influence of postproduction environmental factors on new growth of geranium 'Sooner Red'.....	99
12. Influence of postproduction environmental factors on fresh weight of impatiens 'Super Elfin Red'.....	105
13. Influence of postproduction environmental factors on change in stem height of impatiens 'Super Elfin Red'.....	110

Table	Page
14. Influence of postproduction environmental factors after 36 days on number of new flowers in impatiens 'Super Elfin Red'.....	115
15. Influence of postproduction environmental factors on fresh weight of petunia 'White Magic'.....	125
16. Influence of postproduction environmental factors on change in stem height of petunia 'White Magic'.....	131
17. Influence of postproduction environmental factors on change in stem height of petunia 'White Magic'.....	133
18. Influence of postproduction environmental factors after 36 days on number of flowers to mature in petunia 'White Magic'.....	136
19. Influence of postproduction environmental factors on fresh weight of tomato 'Better Boy'.....	143
20. Influence of postproduction environmental factors after 36 days on change in stem height of tomato 'Better Boy'..	149
21. Recommendations for optimum 36 day marketability of seven bedding plant species.....	153
22. Symptom development over time after ethylene treatment of nine bedding plant species.....	158

LIST OF FIGURES

Figures	Page
1. Influence of temperature and quantum flux density on fresh weight of alyssum 'Snowcloth'.....	56
2. Influence of time and quantum flux density on fresh weight of alyssum 'Snowcloth'.....	57
3. Influence of time and temperature on fresh weight of alyssum 'Snowcloth'	58
4. Influence of temperature and media on fresh weight of alyssum 'Snowcloth'.....	59
5. Influence of time and water regime on fresh weight of alyssum 'Snowcloth'	60
6. Influence of time and water regime on fresh weight of begonia 'Scarletta'	66
7. Influence of temperature and quantum flux density on fresh weight of coleus 'Rose Wizard'.....	74
8. Influence of time and quantum flux density on fresh weight of coleus 'Rose Wizard'.....	75
9. Influence of time and temperature on fresh weight of coleus 'Rose Wizard'	76
10. Influence of time and water regime on fresh weight of coleus 'Rose Wizard'	77
11. Influence of quantum flux density and media on fresh weight of coleus 'Rose Wizard'	78
12. Influence of quantum flux density and temperature on change in stem height of coleus 'Rose Wizard'	80
13. Influence of quantum flux density and media on change in stem height of coleus 'Rose Wizard'	81
14. Influence of quantum flux density and water regime on change in stem height of coleus 'Rose Wizard'	82

Figures	Page
15. Influence of time and media on change in stem height of coleus 'Rose Wizard'.....	83
16. Influence of time and quantum flux density on fresh weight of geranium 'Sooner Red'	89
17. Influence of time and quantum flux density on leaf weight of geranium 'Sooner Red'.....	91
18. Influence of time and temperature on leaf weight of geranium 'Sooner Red'	92
19. Influence of temperature and quantum flux density on leaf area of geranium 'Sooner Red'	94
20. Influence of time and quantum flux density on leaf area of geranium 'Sooner Red'.....	95
21. Influence of time and temperature on leaf area of geranium 'Sooner Red'	96
22. Influence of temperature and time on change in stem height of geranium 'Sooner Red'	98
23. Influence of time and temperature on fresh weight of impatiens 'Super Elfin Red'	106
24. Influence of temperature and water regime on fresh weight of impatiens 'Super Elfin Red'	107
25. Influence of time and water regime on fresh weight of impatiens 'Super Elfin Red'	108
26. Influence of temperature and media on fresh weight of impatiens 'Super Elfin Red'	109
27. Influence of time and quantum flux density on change in stem height of impatiens 'Super Elfin Red'.....	111
28. Influence of time and temperature on change in stem height of impatiens 'Super Elfin Red'.....	112
29. Influence of quantum flux density and media on change in stem height of impatiens 'Super Elfin Red'	113
30. Influence of time and media on change in stem height of impatiens 'Super Elfin Red'.....	114

Figures	Page
31. Influence of temperature and quantum flux density on number of new flowers after 36 days in impatiens 'Super Elfin Red'.....	116
32. Influence of temperature and media on number of new flowers after 36 days in impatiens 'Super Elfin Red'...	117
33. Influence of temperature and quantum flux density on fresh weight of petunia 'White Magic'.....	126
34. Influence of time and quantum flux density on fresh weight of petunia 'White Magic'.....	127
35. Influence of time and temperature on fresh weight of petunia 'White Magic'.....	128
36. Influence of quantum flux density and media on fresh weight of petunia 'White Magic'.....	129
37. Influence of time and media on fresh weight of petunia 'White Magic'.....	130
38. Influence of time and temperature on change in stem height of petunia 'White Magic'.....	132
39. Influence of temperature and quantum flux density on change in stem height of petunia 'White Magic'.....	134
40. Influence of time and temperature on change in stem height of petunia 'White Magic'.....	135
41. Influence of temperature and quantum flux density after 36 days on number of flowers to mature in petunia 'White Magic'.....	137
42. Influence of quantum flux density and water regime after 36 days on number of flowers to mature in petunia 'White Magic'.....	138
43. Influence of temperature and quantum flux density on fresh weight of tomato 'Better Boy'.....	144
44. Influence of time and quantum flux density on fresh weight of tomato 'Better Boy'	145
45. Influence of time and temperature on fresh weight of tomato 'Better Boy'	146

Figures	Page
46. Influence of temperature and media on fresh weight of tomato 'Better Boy'	147
47. Influence of time and media on fresh weight of tomato 'Better Boy'	148
48. Influence of temperature and quantum flux density on change in stem height of tomato 'Better Boy'	150
49. Influence of temperature and media on change in stem height of tomato 'Better Boy'.....	151

INTRODUCTION

Bedding plants tend to lose quality quite rapidly when moved from the greenhouse to unfavorable conditions existing in the shipping and retail environments and ideally should be marketed within a one to two week period. However, due to annual weather variation, it is not always possible to market within two weeks. Consequently, it is desirable to be able to hold the plants in a salable condition for up to 30 days postharvest.

Extension of marketability involves research into the production, shipping and retail environments. Earlier production studies showed that plants most tolerable of the marketing environment required a soil based medium, infrequent to normal watering, low to medium fertility levels, growth regulators, open cell packs and lowering of night temperature to 10 - 16°C two to three weeks preharvest.

This study investigated the shipping and retail environments. Both ethylene concentrations in the shipping phase and environmental conditions met in the retail situation were simulated in order to determine optimum conditions for 36 day marketability of 7 popular bedding plants species. As a result of this study, guidelines for keeping quality of bedding plants will be provided to the bedding plant industry.

LITERATURE REVIEW

LITERATURE REVIEW

The literature has been reviewed for light, temperature, media, water, ethylene and senescence.

LIGHT

Light, or more correctly, solar or radiant energy varies in intensity, quality and duration. The photosynthetic and photomorphogenic photoprocesses of plants are based on photochemical reactions carried on by specific pigment systems that respond to the various wavelengths of the electromagnetic spectrum (25). The pigments chlorophyll, phytochrome and the carotenoids influence the photosynthetic, photomorphogenic, tropic and high-energy photomorphogenic responses of plants in the PAR range of 400 - 780 nm range throughout their life cycle (66).

PHOTOSYNTHESIS OF SUN AND SHADE PLANTS

According to Boardman (30), plants which occupy shaded habitats are incapable of high photosynthetic rates, but perform efficiently at low light intensities. Plants which grow under high light intensities in their native habitats have a high capacity for photosynthesis at a saturating light intensity, but exhibit lower rates of net photosynthesis (P_n) than shade plants at low light intensities.

Light Saturation Characteristics

Bohning and Burnside (34) examined a representative sample of sun and shade plants and found that CO_2 uptake by the sun species was saturated at $300 \text{ to } 450 \mu\text{mol s}^{-1} \text{ m}^{-2}$ whereas the shade species were saturated at $50 \text{ to } 150 \mu\text{mol s}^{-1} \text{ m}^{-2}$. Light saturated rates of

photosynthesis were much higher in the sun species (16 to 20 mg CO₂ dm⁻² hr⁻¹) than in the shade species (2 to 5 mg CO₂ dm⁻² hr⁻¹) and the light compensation points (LCP) were more in the sun plants (15 to 25 μmol s⁻¹ m⁻²) than the shade plants (7 μmol s⁻¹ m⁻²).

Bjorkman (27) selected sun and shade species of various taxonomic groups of herbaceous species. The shade plants exhibited low dark respiration rates of 0.06 to 0.16 mol CO₂ dm⁻² min⁻¹ compared with 0.4 to 0.8 mol CO₂ dm⁻² min⁻¹ for the sun species. Light saturated rates of CO₂ uptake were in the range of 2.1 to 3.1 mg CO₂ dm⁻² hr⁻¹ for the shade species and 21 to 36 mg CO₂ dm⁻² hr⁻¹ for the sun species. The shade species were photoinhibited at light intensities as low as 320 μmol s⁻¹ m⁻².

Anatomy

Shade plants in their native habitats often have thin leaves with a lower fresh weight per leaf area and a higher content of total chlorophyll expressed on a weight basis than do sun species. However, the chlorophyll content of shade plants per unit leaf area is often lower. Bjorkman (26) and Goodchild et al (77) reported that shade plants have lower ratios of soluble protein to chlorophyll than do sun species.

Shade plant chloroplasts possess large grana stacks which can contain up to 100 thylakoids per granum as observed by Anderson et al (11). Grana are irregularly arranged within a chloroplast and not oriented in one plane as in sun plant chloroplasts. This orientation might be expected to increase their efficiency for the collection of weak diffuse radiation. Park and Sane (132) relate that the greater

degree of grana formation in the shade plant is consistent with its higher proportion of chlorophyll b, since it is believed that grana thylakoids contain a lower chl a/chl b ratio than do stroma lamellae.

Parameters Influencing Photosynthetic Rates

According to Gaastra (72), the capacity of light saturated photosynthesis is expected to be independent of the efficiency of light absorption and the primary photochemistry. It will be influenced by one or more of the dark reactions of photosynthesis: the resistance to CO₂ diffusion at the stomata; the rate of diffusion of CO₂ from the cell wall to the chloroplast; the carboxylation reaction and the rate of photosynthetic electron transport and photophosphorylation. Other factors include the temperature dependence of the photosynthetic rate and the partitioning of photosynthetic products.

Holmgren et al (90) found the minimal stomatal resistance for CO₂ at ambient CO₂ concentration to be 0.72 sec cm⁻¹ for Helianthus annuus, a sun species to 21 sec cm⁻¹ for Circaea lutetiana, a species which grows in shaded woodlands. Mesophyll resistance was much lower in Helianthus (2.5 sec cm⁻¹) than in Lamium galeobdolan, a shade plant (14.3 sec cm⁻¹). Photosynthesis by leaves of C. lutetiana showed a nonlinear dependence on CO₂ concentration, whereas a linear dependence was observed for the sun species.

Boardman (30) states that the RuDP carboxylase activity of sun and shade plants paralleled their rates of CO₂ uptake, suggesting that the reduced amount of the enzyme in shade plants is at least partly responsible for their low light saturated photosynthetic rates.

Several investigators (31 to 33 & 109) have shown that the

capacity for photosynthetic electron transport is considerably higher in sun plant than shade plant chloroplasts. For example, the light saturated methylamine uncoupled rate of reduction of DCIP in the Hill reaction was only 98 meq mg chl⁻¹ hr⁻¹ for Cordyline chloroplasts compared with 1350 meq mg chl⁻¹ hr⁻¹ for the sun species A. patula grown at high light intensity. The corresponding coupled rates were 45 and 500 meq mg chl⁻¹ hr⁻¹.

ACCLIMATIZATION AND THE POSTPRODUCTION ENVIRONMENT

Conover and Poole (50) define acclimatization as the climatic adaptation of an organism (plant) from the optimum conditions of greenhouse production to the limiting conditions of an interior environment. In this discussion we shall expand the definition to include adaptation of the plant from the greenhouse to the retail environment.

Although foliage plants have always been important in commercial floriculture, the public's interest in environment and plants ignited a boom in foliage plant production and sales reached almost \$272 million in wholesale value in 1977 (11). Production in Florida under high outdoor light and the need for adjusting plants to their new situations in the home or interiorscape have led to research on plant acclimatization not only for light, but also for water and nutrients (52).

Leaves can adapt to different light intensities even after leaf expansion has ceased. Hatch et al (86) in 1969 demonstrated that the photosynthetic rate of fully expanded maize and Amaranthus leaves changed over a 6 day period on transfer of plants from low to high

intensity or vice versa to become comparable with the rate of control plants grown continuously under the same light intensity. Changes in the levels of PEP carboxylase and pyruvate, P_i dikinase accounted for the altered photosynthetic rates.

However, the photolability of extreme shade plants to growth at high light intensity is explainable by their lower levels of RuDP carboxylase and their consequent inability to utilize higher quantum fluxes. This would cause the photochemical traps of the photosystems to be closed for a higher proportion of time, thus increasing the probability of photo inactivation (30).

Adaptation to growth at low light appears to be a question of the economical use of available light energy as stated by Bjorkman et al (28). The shade plant invests a greater proportion of its synthetic capacity in the synthesis and maintenance of the light harvesting machinery than do sun plants.

While there has been an abundance of research with regard to the light acclimatization of foliage plants, only recently have there been studies using flowering plants. In 1981, Conover and Poole (51) initiated an experiment to determine whether African violets would acclimatize to lower light levels with time. They discovered that flowering ceased when plants were transferred from a greenhouse $175 \mu\text{mol s}^{-1} \text{m}^{-2}$ to interior light levels of 7, 13 or $27 \mu\text{mol s}^{-1} \text{m}^{-2}$. Plants placed under $27 \mu\text{mol s}^{-1} \text{m}^{-2}$ acclimatized and flowered after 3 months, whereas plants under $13 \mu\text{mol s}^{-1} \text{m}^{-2}$ flowered after 6 months and minimal flowering occurred at $7 \mu\text{mol s}^{-1} \text{m}^{-2}$ after 9 months. Flowering was highly correlated with production of new leaves under

interior light intensities.

Nell et al (129) investigated the effect of light reduction and LCP on growth characteristics of potted chrysanthemums. LCP was decreased 28.1% at 25% shade and 65% under 63% shade as compared to plants grown in full sun. Increased shade level decreased plant growth characteristics measured while increased light intensity produced earlier flowering. The low LCP for the chrysanthemums under increasing shade did not improve quality as it has for Ficus benjamina. Those produced under 63% shade were not of high salable quality and keeping quality was projected to decrease.

Staby and Kofranek (161) studied how production techniques affected the harvest and postharvest qualities of a poinsettia cultivar. Plants maintained under relatively high light and warm conditions had smaller bracts and were shorter. Also there was an 8-fold increase in the number of botrytis infected bracts at harvest compared to those produced at a 2°C lower temperature with 50% light reduction. Plants grown under high light and warm temperature were generally inferior as measured by increased foliar abscission, chlorosis, premature death of the cyathia and increased numbers of bract abnormalities.

Two popular bedding plants, impatiens and geranium are often grown under similar light levels in the greenhouse even though impatiens is a shade tolerant species while geranium is sun tolerant, according to Armitage and Vines (13). Physiological functions of the two species and their adaptation to environmental change may affect

their growth when placed in the garden under different light levels. They investigated whether net photosynthesis (P_n), diffusive resistance and chlorophyll content of the two species would adapt to changes in light regimes. Diffusive resistance decreased and chlorophyll content increased in *impatiens* leaves subjected to 14 days of low quantum flux density (QFD) compared with high QFD while there was no difference in the two parameters with geranium regardless of QFD. Light saturation of P_n occurred at higher light levels in *impatiens* treated with low QFD compared with those treated with high QFD while light saturation in geraniums was the same under either treatment. Stomatal density in *impatiens* was greater and stomatal area was smaller than in geranium. They concluded that physiological processes of *impatiens* appear to be more sensitive to QFD changes than those of geranium and that production of sun and shade tolerant species under similar greenhouse conditions is not a sound horticultural practice.

Most bedding plants are sold in the spring of the year when air temperatures can fluctuate from 10 to 35°C with QFD ranging from full sun to heavy shade in the retail area. Since most bedding plants are marketed in containers with very small media volume, the elevated temperature and light regimes can induce severe plant stress. In view of this situation, Armitage and Kowalski (15) in 1983 devised a study to determine optimum conditions of light and temperature for enhanced postproduction life of commercially produced petunia plants.

Plants were placed in postproduction conditions simulating the retail environment of low ($300 \mu\text{mol s}^{-1} \text{m}^{-2}$) medium ($600 \mu\text{mol s}^{-1}$

m^{-2}) or high ($900 \mu\text{mol s}^{-1} \text{m}^{-2}$) QFD at temperatures of 10, 20 or 30°C after first flower opening. Change in dry weight and number of senesced flowers were determined. Plants held at 20 and 30°C had the greatest dry weight accumulation and flower number but poorest visual rating at 10 days when kept under high QFD compared with those kept under medium or low QFD. When plants were held at 10°C , QFD was of little importance to postproduction quality. Although temperature appeared to provide the major environmental input in keeping quality, it was influenced by QFD. The reduced rate of growth through day 10 in plants maintained under the low QFD and 10°C regime could possibly be attributed to decreased photosynthesis or other photoresponses inhibited at low light and temperatures. Since the main objective in the postproduction bedding plant area is maintenance and not growth, a slow growth rate is beneficial if visual ratings do not decline.

TEMPERATURE

Temperature has a significant role in the postharvest life of horticultural crops. Temperature response is largely determined by the stage of plant growth.

Temperature regulates the rate of plant growth by its influence on the metabolic processes of photosynthesis, respiration and transpiration. It also controls developmental events such as seed germination, the breaking of bud dormancy and flower initiation.

TEMPERATURE RELATIONS OF PLANTS

Due to the extreme variability of soil and air temperatures, most investigations of plant response to temperature have been carried out under controlled conditions with root and shoot at the same constant temperature, or, more rarely, with soil and air at different but still constant temperatures (53) (143).

According to Fitter and Hay (66), the individual processes contributing to plant growth do not all respond to temperature in the same manner. For example, gross photosynthesis in many temperate species ceases at temperatures just below 0°C (minimum) and well above 40°C (maximum), with optimum rates in the 20-35°C range. In contrast, respiration tends to be slow below 20°C but due to the thermal disruption of metabolism at higher temperatures, it accelerates rapidly up to the compensation temperature where the rate of respiration equals the rate of gross photosynthesis, and there can be no net assimilation. Consequently, the response of net Pn to temperature is broadly similar to that of overall growth.

Boodley (35) stated that temperature mainly affects leaf transpiration. As leaf temperature rises, the rate of transpiration increases and continues to increase with temperature provided the plant can absorb water from the soil and the water can be transported to the leaves.

HEAT STRESS

Berry and Bjorkman (23) reported that elevated temperatures inhibit photosynthesis by disrupting the functional integrity of the photosynthetic apparatus at the chloroplast level. When isolated chloroplasts were heated, there was inactivation of PSII activity as well as noncyclic photophosphorylation. Heat stress is also known to inactivate the enzymes of photosynthetic carbon metabolism.

Bauer and Sensor (21) showed in Hedera helix leaves that heat inactivated photosynthetic electron transport and induced alterations in chloroplast ultrastructure. This effect was reversible as long as the heat did not cause extensive impairment of the cell's partitioning membranes or leaf necrosis. Hedera helix leaves lost about 50% of their photosynthetic electron transport activity when exposed for 30 minutes to 44°C but recovered in 7 days when placed at 20°C. Exposure to 48°C led to 75% activity loss with a 2 month recovery time.

High temperature is directly implicated in plant deterioration in transit. Halevy and Kofranek (78) demonstrated flower bud and leaf abscission in potted roses subject to heat stress during simulated shipping conditions.

CHILLING INJURY

The primary response of plants to chilling injury, as first

suggested by Lyons and Raison (112) is a physical phase transition of membranes from a flexible liquid-crystalline to a solid-gel structure. Paull (134) reported an increased leakage of cell electrolytes in tomato as a result of this membrane change. This membrane change may or may not lead to secondary responses or irreversible changes depending on the temperature, length of exposure and susceptibility of the plant species to that particular temperature, according to Wang (177). Secondary responses include stimulation of ethylene production, an increase in respiration rate, interference in energy production, an increase in cellular permeability, reduction in photosynthesis and an alteration of cellular structure.

Taylor and Rowley (168) observed a time-dependent destruction of the photosynthetic apparatus with the extent of damage increasing with light intensity and length of exposure at chilling temperature. Garber (74) demonstrated that chilling under light could cause rapid loss of proton uptake. Margulies (114) and Smillie and Nott (156) found that the ability of chilled tissues to use water as donor for PSII was lost or greatly reduced.

The manifestations of chilling injury include discoloration and internal tissue breakdown, growth inhibition, an accelerated rate of senescence and a shortened postharvest life (177).

ACCLIMATIZATION POSTHARVEST KEEPING QUALITY

A considerable amount of research has been directed toward adjustment of light levels, fertilization and irrigation practices in acclimatization of foliage plants grown in the southern U.S. and marketed in the north for interiorscapes. Temperature studies in this

regard are minimal. However, recently, Poole and Conover (139) demonstrated that certain foliage plants adapted better to interior conditions by lowering the temperature toward the end of the production phase. Night temperature reduction proved to be the most beneficial. More recently, in a simulated shipping study and subsequent interior keeping quality of Ficus benjamina, Collins and Blessington (49) dark-stored plants for 4, 8 or 12 days at 3, 7, 21, 35, or 39°C and then held them indoors for 30 days. Plants were not damaged when stored at 21 or 35°C or when stored for 4 days at any temperature treatment. Leaf loss and foliar damage were more severe and dry weight, chlorophyll content and plant grade were reduced as exposure time increased from 4 to 12 days. Plants exposed to 21 or 35°C had less leaf loss and no foliar damage plus greater dry weight, chlorophyll content and plant grade than those exposed to 3, 7 or 9°C. Chlorophyll content was least in plants exposed to 39°C.

Only very recently has any research been directed toward acclimatization of bedding plants in making the adjustment from the greenhouse environment to transit and retail conditions. In seed propagated geraniums, flower shattering occurs during transit and marketing but can be delayed by low temperature. Armitage et al (14) showed less petal abscission at 1.7 and 4.4°C than at 10 and 21°C. Nelson et al (130) report optimum keeping quality for marigolds and impatiens when grown at 10 and 16°C night temperature respectively three weeks preharvest rather than at 21°C when placed at simulated retail temperatures of 10, 21 and 32°C. In a simulated postproduction environment experiment with Petunia hybrida, Armitage and Kowalski

(15) showed that after 15 days, all plants in the postproduction environment declined in visual quality when held at 20 or 30°C but remained satisfactory at 10°C.

MEDIA

The growing medium serves several functions in relation to plant growth. It provides plant anchorage and support, supplies water and essential nutrients and allows gas exchange between the air and root system.

CONTAINER MEDIA

Spomer (158) states that since most floriculture crops are produced in containers including house plants and an increasing number of landscape plants, floriculturalists must be aware that container soils differ from ground bed soils.

According to Bunt (40), the use of containers alters the normal physical relationship between root and substrate in the following ways: the small container volume leads to a high root concentration with demands for a high rate of oxygen supply and carbon dioxide removal; the large amount of water necessary to maintain the rapid growth rates during greenhouse production must be available from the very restricted soil volume; the shallow depth of the container with its low tension head leads to improper drainage with waterlogging risk, especially under winter conditions; the high frequency of watering makes the substrate liable to leaching.

Spomer (159) reported that because container soils have a relatively small volume and are shallow, there is a tendency to store insufficient water and minerals to sustain plant growth for only a short time. At the same time, these soils can be "too wet" for the plant to utilize even the inadequate available water supply due to the shallow depth. He added that the dilemma of a "too dry" and "too wet"

container soil can be solved by using soil amendments or soilless media.

Hanan et al (79) reported that field soils can seldom be used directly in container planting because they have bulk densities ranging from 1.0 to 1.4 gms cc⁻¹, with attending porosities and infiltration characteristics.

Greenhouse soils generally have bulk densities ranging from 0.1 to 0.8 gms cc⁻¹ with total porosities often exceeding 90% and infiltration rates in excess of 60 inches/hr. Zimmerman and Kardos (193) observed that soils will virtually exclude root growth that have bulk densities in excess of 1.8 gm cc⁻¹.

In discussing water retention of transplanted container soils, Spomer and Nelms (160) reveal that when a container soil is transplanted into a ground bed, the soil type and volume remain the same until the plants' roots grow out into the field soil. However, the drainage water from the soil increases several fold so that the transplanted soil retains less water after irrigation or rainfall than it would if in the container. Compounding the effects of the reduced water retention is the decrease in irrigation frequency or the complete lack of irrigation in many field locations. The net effects are water stress and reduction of growth and survival of the transplants. To avoid such stress, it is necessary to provide more frequent irrigation, shade or other protection from excessive drying and a soil mix that contains enough small water-retention pores to reduce the water drainage out of the transplanted soil ball. This is important with bedding plants grown in very shallow packs or flats.

SOIL BASED AND ARTIFICIAL MEDIA

Highly modified growing media have generally replaced unamended field soil in commercial floriculture crop production. According to Mastalerz (117), an effective growing medium should possess the following characteristics: it should be porous and well drained, yet meet water requirements of plants between waterings; it should be relatively low in soluble salts but possess adequate exchange capacity; be uniform from batch to batch; remain free of harmful soil pests organisms and weed seeds; and offer biological and chemical stability following pasteurization. Boodley (35) stated that in an ideal growing medium, the solid phase, consisting of all organic and inorganic materials should comprise 50% of the total volume while the liquid and gas phases should occupy 25% each.

The choice of amendments available to modify soil-based media is wide. According to Hanan et al (79), an amendment should decrease bulk density, increase total porosity and increase water and air content. Whatever is added to the basic soil should equal at least one-third to one-half of the final volume if significant changes are to be made. Any mixtures which have infiltration rates less than 20-30 inches/hr, air-filled porosities less than 10% at maximum moisture capacity, or bulk densities exceeding 1.0 gms cc^{-1} are likely to create problems when in shallow, restricted, freely draining layers such as benches or pots.

According to Bunt (41), the principle advantage of a soil-based medium versus an artificial medium is the ease of plant nutrition

especially with respect to nitrogen and phosphorus. Also, minor element deficiencies are uncommon. However, the phytotoxicity with steam sterilization and the difficulty with continuity of supply and quality control remain problematic.

White (180) stated that the proportions of the three basic components (field soil, organic matter and coarse aggregate) in a soil mixture should be adjusted by each grower to compensate for differences in soil type, size or grade of organic matter and coarse aggregate, cropping cycle, growing container, depth of container, condition of greenhouse, environmental factors, type of growth desired and irrigation and fertilization practices.

Seeley (149) stated that soilless (artificial) mixes have become widely used in the last 20 years in the horticulture industry. The success with the U.C. mixes (peat moss and sand combinations) led to the development of the peat-lite mixes (sphagnum peat and vermiculite or perlite combinations) which are used extensively for potted and bedding plants because of light weight, ease of transplanting, adaptability to automation and the scarcity of good topsoil. Other advantages cited by Boodley (35) include: materials of known properties, uniformity from batch to batch and season to season, availability, control of nutrient content, no sterilization requirement and drainage and aeration properties designed for good root growth.

Warncke and Krauskopf (179) reported that while soilless growth media possess good moisture-holding and aeration properties, they exhibit limited nutrient-holding capacities and as a result, fertility

management in the greenhouse is more important than ever before. In an experiment conducted by Mastalerz (117), the growth of potted chrysanthemums was best in a soilless medium when fertilizers were applied at each irrigation. However, when fertilizer was applied weekly, plants grew best in a soil based medium.

Currently, there are many artificial products commercially available to the consumer. Brown and Emino (39) recently studied the response of container grown plants to six different consumer artificial growing media. In an effort to relate bulk density, moisture-holding capacity, pH, initial nutrient level and aeration or soluble salt characteristics to growth response, they observed that the growth response in species representing 5 plant families was highly variable among the 6 media tested.

It has been observed by Ecke (62) that highly porous growing mixtures yield best top growth and root development of poinsettia. Larson et al (104) found soil to be an essential mixture component for highest quality poinsettias on water mats. However, with hose or tube watering, highest quality plants were produced in mixtures containing 3 parts pine bark to 1 part sand. Poole and Fretz (138) recommend 25 to 30% aggregated fly ash as a substitute for sand and/or perlite in soilless mixtures for poinsettias and other pot plants. However, none of the above plant responses were related to physical growing media characteristics. Pertuit and Mazur (136) in the development of growth media for poinsettias in 1981, planted rooted cuttings of 'Annette Hegg Lady' into growing media of equal volumes clay loam and sand or ash with 30 or 60% by volume pine bark, sphagnum peat moss, perlite or

rubber (from ground automobile tires). Media physical measurements revealed better drainage with 60% perlite during maximum vegetative growth resulting in plants of highest quality: greater aerial fresh weight, increased height, larger inflorescence diameter and higher grade.

Worrall (1985) recently compared composted hardwood and peat based media for the production of foliage and flowering plants. He found that the growth rates of Adiantum raddianum, Asplenium nidus, Coleus blumei, Diffenbachia picta, Nephrolepis elata, Peperomia scandens, Philodendron sellonium X speciosum, Pilea cadleri, Saintpaulia and Schefflera actinophylla in media containing 50 to 80% composted hardwood sawdust were equivalent to, or significantly better than growth media containing an equal percentage of sphagnum peat and receiving the same level of liquid or slow-release fertilizer. Substitution of sphagnum peat with composted sawdust reduced the leaf area and dry weight of Impatiens wallerana without a significant effect on either the number of flowers or their surface area. The growth of Pilea and Saintpaulia was best where the media contained equal percentages of sawdust and peat than where either was used alone.

WATER

Water is an indispensable factor in plant life. It constitutes 80-90% of the fresh weight of most herbaceous plant parts. Adequate water and turgor pressure are essential for cell enlargement, for the regulation of gas exchange between leaves and the atmosphere, and for photosynthesis and other major physiological processes within the plant.

PLANT ANATOMY

Reports on the influence of different soil moisture contents on plant growth are numerous compared to investigations on the anatomical structure of plants exposed to different soil moisture regimes. However, Stocker (163) found that the root/shoot weight ratio was greater in dry soils than in wet soils and that the height of plants increased as soil moisture increased. With Trifolium incarnatum, the total dry weight and leaf weight increased by raising the soil moisture from 40 to 60%.

Penfound (135) reported with sunflower plants that the average leaf area of those grown in wet soil was more than 12 times that of plants grown in dry soil. He also discovered that stems of plants grown in soil with high moisture content had more and larger xylem vessels, and larger cells and thicker-walled fibers than those grown in soil with low moisture content. On leaves he found a greater width of all regions in the mesophyll and mid-vein so that leaves were thicker with high rather than low soil moisture.

Amer and Williams (9) reported that leaves of geranium plants

growing in dry soil had smaller epidermal cells and more cells per unit area than those grown in wet soil, but observed very little difference in number of cells on a per leaf basis.

Metwally et al (120), in a study involving the effect of three soil moisture regimes on the growth and anatomy of Pelargonium hortorum found that the diameter of petioles and stems and leaf thickness increased as soil moisture increased. The number of xylem elements per unit area increased substantially in stems and petioles of plants subjected to a high moisture regime, while phloem tissue was greater in plants grown in medium moisture. More vascular bundles were differentiated in leaves per unit as soil moisture decreased.

Manning et al (113), in reviewing the effect of moisture stress on leaf anatomy of peas noted that intercellular air spaces and substomatal cavities of plants grown at 20 to 40% of field capacity were much reduced and had less xylem area and fewer xylem elements in the primary vascular bundle than plants in the other treatments. Stomatal density increased with increasing soil moisture stress.

WATER STRESS

Development

Kaufmann (96), in a recent review on the development of water stress in plants cites 4 factors in the shoot environment -- CO₂, visible radiation (400-700nm), temperature and humidity -- to have important effects on the development of plant water deficits. He stated that physically, temperature and humidity affect the water vapor or humidity gradient from leaf to air while radiation has no physical effect on the humidity gradient except that introduced by

temperature changes. Physiologically, all 4 factors may influence leaf water loss through their effects on stomatal behavior. CO₂ concentration changes relatively little in the field, but, under greenhouse conditions, depletion or enrichment of CO₂ can alter leaf conductance.

According to Taylor and Klepper (169), root characteristics such as distribution, stage of development and radial hydraulic conductivity can influence the ability of root systems to absorb water. Kaufmann (96) stated that soil water potential, temperature and aeration can also determine the capacity of root absorption of water and that reduced soil water availability causes reduced leaf water potential leading to water stress.

Photosynthesis

Slavik (154) stated that water deficits drastically reduce photosynthesis as a result of stomatal closure and disruption of metabolic activities due to cytoplasmic and cell membrane dehydration. Kriedemann and Smart (100) reported a linear relationship between decreasing photosynthesis and leaf water potential below -5 bars. Reduced photosynthesis, which influences carbohydrate supply can check growth. Kozłowski (97) found that the growth of Pinus strobus and Pinus taeda declined at soil water potentials of approximately -1 bar and lower.

Armitage et al (17) studied the relationship of Pn to soil water potential, leaf diffusive resistance, leaf water potential and relative water content with Pelargonium X hortorum Bailey cv 'Sprinter Scarlet' grown under greenhouse pot culture conditions. They reported

that P_n passed through 4 stages according to the effects of water stress on the plants. As water stress increased, P_n went from a steady-state maximum rate to slow decline, to rapid decline to total cessation. During rapid P_n decline, soil water potential rapidly decreased from -4 bars to -14 bars and leaf diffusive resistance increased from $4s\ cm^{-1}$ to $80s\ cm^{-1}$. Leaf water potential was -7 bars and relative leaf water content was 81-87%. They observed that leaf water potential appeared to be the best indicator of imminent P_n decline. They also found that after rewatering moisture stressed plants, 3 days were required to return P_n to a steady-state maximum which was only 90% of initial steady-state P_n .

Bedding plants are usually grown in containers which provide little soil volume for water retention. Therefore, the potential for fluctuation in moisture level is great. Repeated drying cycles could permanently impair growth capacity.

WATERLOGGING

According to Bradford and Yang (37), the overriding effect of soil flooding is the limitation of oxygen diffusion to the root zone. The symptoms of flooding injury which include reduced stem growth, leaf chlorosis and epinasty, adventitious root formation and leaf wilting are ethylene induced responses to root anaerobiasis.

Although most of the current literature on physiological responses to waterlogging is restricted to ethylene physiology, Bradford and Yang (37) have shown that after flooding the tomato for 24-48 hours, ABA and IAA levels were increased and GA and CK levels were reduced in the xylem suggesting broad hormonal involvement.

Waterlogging is often considered to be a subset of water stress. Kramer (98) stated that it is true that waterlogging can cause wilting especially if stress is rapidly imposed and transpirational demand is high. However, Kramer (99) concluded in a later report that while wilting is often observed after flooding, epinasty hypocotyl swelling and adventitious rooting are all growth processes requiring turgor and are inconsistent with wilting or low leaf water potential.

Bartlett (20) suggested that for plants to survive waterlogging they need to possess some of the following characteristics: low O_2 requirements in the root system; direct diffusion of atmospheric O_2 from the shoots to the roots; utilization of O_2 derived from nitrate reduction; specific tolerance to toxin formed under flooding conditions; and anaerobic respiration ability.

ACCLIMATIZATION AND THE POSTHARVEST ENVIRONMENT

Watering is generally reduced in foliage plants for acclimatization and growers commonly reduce water to harden-off at the end of a crop cycle.

Armitage and Kowalski (16) studied the effect of production irrigation frequency on the postproduction quality of Petunia hybrida Vilm. using three production moisture regimes of -4 to -10 bars (dry), -0.8 to -3 bars (normal), and > -0.6 bars (wet). They evaluated performance under cool (10°C DT & NT), moderate (20°C DT & NT) and hot (30°C DT & 20°C NT) postproduction temperatures. They found that irrigation frequency was not significant when plants were placed in the cool postharvest environment. In moderate or hot postproduction conditions, plants treated with high water frequency declined in

quality most rapidly. Low moisture plants had slower flower development and senescence, greater dry weight and better visual quality than plants with other moisture treatments. Plants tend to decline rather quickly when moved from the greenhouse environment and should be marketed within the first five days. If plants are placed in a cool postharvest area, irrigation frequency during production is of little consequence to keeping quality if plants are marketed within 5-10 days. However, in areas of the country where warm temperatures increase rapidly in the spring, plants grown under frequent irrigation will decline faster than those plants which have been allowed to dry out.

In another study of the influence of drought stress and light intensity during production on Ficus benjamina L., Johnson et al (93) found that water stress reduced dry matter accumulation in those plants grown in the sun. Accumulation of carbohydrates and reduction of chlorophyll was associated with water stress in sun plants, but there were no stress related changes of carbohydrate or chlorophyll levels in plants grown under 47% shade. Electron micrographs of chloroplasts in water stressed plants showed starch deposits and disruption of thylakoid structures in sun plants with less disruption in shade grown plants. Lowest light compensation points occurred in shade plants with no influence due to water stress, but moisture stress caused high light compensation points in sun grown plants.

ETHYLENE

Ethylene is a plant hormone which regulates many aspects of plant growth, development and senescence whether it is of endogenous origin or is applied exogenously. Within the normal life cycle of a plant, ethylene production is induced during certain growth stages such as seed germination, fruit ripening and senescence of leaf and floral parts. Ethylene production is also promoted following stress from chemicals, temperature extremes, irradiation, drought, waterlogging, insect damage and disease or mechanical wounding (1) (187).

PHYSIOLOGY OF ETHYLENE PRODUCTION

Rates of Production

Nearly all plant tissues appear to be capable of producing ethylene although the production rate is normally low. According to Abeles (1), rates of ethylene production during the development of higher plants varies from organ to organ and time of development. He showed with the etiolated pea seedling that meristematic and nodal tissue produced higher rates of ethylene than tissue from internodal regions. Blanpied (29), observed that ethylene rates were highest in dormant buds, slowly decreased with leaf and floral expansion and increased again during the senescence and abscission of floral and leaf tissue.

Ethylene production increases during fruit development. Abeles (1) demonstrated with tomato that while immature 17 and 25 day old fruit were capable of responding to ethylene in terms of increased coloration and respiration, were not sufficiently mature to produce

the amount of ethylene associated with fruit maturation and ripening.

Plants subjected to stress can increase ethylene production from 2 to more than 50 times the basal level, depending on the stress imposed and the sensitivity of the plant tissue (173). Abeles and Abeles (3) have shown that application of toxic compounds such as CuSO_4 or ozone to bean and tobacco leaves caused a rapid increase in ethylene production. Hanson and Kende (82) observed a remarkable increase in ethylene production with cutting or bruising of rib segments from the morning glory flower.

Environmental Control

Temperature

Ethylene production rates are very susceptible to environmental factors. Either low or high temperatures can depress the production rate. Burg (42) stated that 30°C is the optimum. As the temperature increases above 30°C , the rate of production falls until it ceases at 40°C . Burg and Thimann (45) discovered with apple that high temperature inhibition of ethylene production at 40°C was reversible with about 50% of the inhibition disappearing after 5 hours at room temperature.

Wang (178) reported a disease called "premature ripening" of Bartlett pears which caused a \$5 million loss in Washington, Oregon and California. Fruit drop correlated with low temperatures 4 to 5 weeks prior to normal harvest time. These cool temperatures correlate with an early increase in ethylene production which ages the fruit prematurely.

Light

Abeles (1) stated that ethylene production can be regulated by light, and depending on the tissue involved, can increase or decrease the production rate. Kang et al (95) found that the epicotyl hook formation of etiolated pea seedlings is a morphological response to the ethylene produced by the seedling apex. Red light, which is known to convert the seedling from a hook to a straight stem form causes a sharp depression in the amount of ethylene formed. Goeschl et al (75) reported that this light control is a phytochrome mediated system, since the depression of ethylene production caused by red light is reversed by far-red light.

An increase in the rate of ethylene production following illumination has been observed by Abeles and Lonski (5) in lettuce seeds, and was shown not to be due to a red, far-red system, eliminating phytochrome as the mediating pigment. The effect of light on cranberries was found to be two-fold. Chadwick and Burg (47) showed that not only did it promote ethylene production, but was also required for ethylene-induced anthocyanin formation.

Atmospheric Gases

The requirement for oxygen in ethylene responses has been known since the early experiments of Denny in 1924. The Burgs established that depressed oxygen levels inhibit ethylene action. According to Mastalerz (117), plants do not respond to ethylene when carbon dioxide levels are high. He further added that ethylene acts by stimulating enzyme synthesis and by influencing transport of materials through membranes. Carbon dioxide apparently acts as a competitive inhibitor of the enzyme reactions activated by ethylene. Marousky and Harbaugh

(115) found that carbon dioxide concentrations of 5% inhibited the action of ethylene on Philodendron. They implicated stomatal closure high CO₂ concentrations, which decreased absorption of exogenous ethylene.

GROWTH AND DEVELOPMENTAL EFFECTS OF ETHYLENE

Epinasty

In many plants, ethylene causes a downward bending of the leaves called epinasty which is thought to result from an accumulation of auxin in the upper side of the petiole. Lyon (110) postulated that this accumulation of auxin resulted from a disruption of lateral auxin transport in the petiole mediated by ethylene. The response is specific for ethylene or its analogs, is sensitive to low concentration and occurs rapidly making it a useful bioassay for ethylene production.

Not all plants give an epinastic response to ethylene. Crocker et al (57) tested 202 species and varieties of plants and found that 72 gave a marked response, 17 showed a slight effect, and 113 gave no response. He also demonstrated a species and variety variation as only 13 of 31 sweet pepper varieties displayed ethylene induced epinasty.

The ability of leaf petioles to respond to ethylene depends on their physiological age, with young leaves showing the highest sensitivity. The response time to ethylene has been measured by a number of investigators and is in the order of 1-3 hours. Funke et al (71) showed curvature of tomato petioles one hour after ethylene treatment, with bending continuing for a 10 hour period. He found that tomato petioles will recover to some extent after treatment.

Flowering

According to Abeles (1), the effects of ethylene on flowering fall into the three categories of promotion, inhibition and sex reversal. Promotion of flowering is associated primarily with bromeliads and sex reversal with cucurbits, while inhibition of floral initiation has been described in a number of families.

Induction of flowering in pineapple requires a 6 hour treatment. Cooper and Reece (54) found that a 4 hour exposure of 1000 ppm ethylene failed to induce flowering of pineapple, while a 6 hour treatment was fully effective. The quantity of ethylene required was a function of duration of incubation. A 6 hour incubation with 100 ppm or 10 ppm resulted in 33% and 0% flowering respectively while both concentrations caused 100% flowering after a 12 hour incubation.

The rate of floral initiation of iris, as reported by Stuart et al (164) was shown to be increased by ethylene. On the other hand Zhdanova (191) reported that 300 ppm ethylene blocked flowering of Perilla and cocklebur plants under short day conditions.

According to Minina (122), when cucumbers were treated with ethylene in the three to four leaf stage with two 12 hour treatments, female flowers were produced as well as larger fruit set.

Leaf Expansion

Inhibition of leaf expansion by ethylene is a specialized example of growth inhibition. Hitchcock et al (89) found that illuminating gas retarded or altered the development of leaves of lily, tulip and hyacinth. In addition to preventing leaf expansion, ethylene caused curling, looping, double bending and irregular inward rolling. In

studying expansion of sunflower, Funke et al (71) reported that in addition to preventing normal expansion of leaf cells, ethylene altered the ratio of epidermal cells to stomates. On the upper surface the ratio increased while on the bottom it decreased. According to Burg et al (43), prevention of leaf expansion is caused by an inhibition of cell division.

ETHYLENE AND SENESCENCE

Flower Fading

The first report of floral senescence was made by Crocker and Knight (56) in 1908 and was initiated by reports of damage to carnations by illuminating gas. They reported that ethylene prevented the opening of young blossoms, caused open flowers to close, and discolored and wilted the petals.

"Dry sepal" or orchid senescence is characterized by progressive drying and bleaching of the sepals beginning at the tips and extending toward the bases. Davidson (58) reported that ethylene produced this response at .04 - 0.1 ppm for 8 hours. Burg and Dijkman (44) observed an increase in ethylene production from orchid flowers when they were pollinated or treated with IAA. Fading usually became obvious after the rise in ethylene.

Leaf Senescence

It is well known that ethylene production increases as leaves age and may be responsible for triggering senescence. Leaf senescence involves the loss of RNA, protein and chlorophyll. The effect of ethylene on these degradative processes has been measured by Abeles et al (4) and the data showed minimal effect on RNA degradation but a

significant effect on the reduction of protein levels in bean explants. Sacher and Salminen (147) found that ethylene decreased the rate of RNA and protein synthesis in bean pods but had no effect on Rhoeo discolor leaf sections. Delay in the degradative processes occurred when leaves were treated with IAA. This suggests that ethylene may regulate some master reaction, for example, control of auxin levels, which in turn regulates or maintains juvenility of plant tissue.

Leaf yellowing is usually associated with abscission although Zimmerman et al (192) report acceleration of abscission at high ethylene levels without concomitant yellowing. Abeles et al (4) stated that while abscission appears to be separate from the yellowing process, factors that retard or block ethylene action such as IAA or CO₂ also prevent or delay yellowing. They suggest that destruction of chlorophyll parallels but is separate from other processes that occur during senescence.

Abscission

Ethylene, auxin and ABA have all been shown to share a role in leaf, flower and fruit abscission. Galston et al (73) reported that in addition to hastening senescence of the abscission zone cells, ethylene causes the dissolution of the cell walls by promoting synthesis and release of cellulase, a wall degrading enzyme.

The ability of auxins to delay or prevent abscission has been associated with their juvenility or anti-senescent activity. Young leaves have a greater supply of auxin than older leaves. As leaves age and the auxin level is depleted, sensitivity to ethylene is increased.

Valdovinos et al (174) have shown that ethylene reduced auxin levels in coleus and peas by decreasing the activity of the enzyme system which converted tryptophan to auxin. Beyer and Morgan (24) found that levels of ethylene required to promote abscission of intact cotton plants also reduced the capacity of the auxin transport system to function.

Craker and Abeles (55) found little or no effect of ABA on senescence or aging of leaf tissue but, rather that ABA increased the rate of cellulase synthesis.

ETHYLENE, AIR POLLUTION AND THE POSTHARVEST ENVIRONMENT

Air Pollution

In identifying ethylene as a major component of air pollution, Abeles (2) includes plants, soil, natural gas and burning vegetation as natural sources, and industry, combustion of coal and oil and automobiles contributing as man made sources.

Most of the damage to plants by ethylene in the U.S. has been in greenhouses situated near roads or major urban areas. James (92) reported that in the 1962 crop of orchids in the Bay Area consisting of one million blooms, 10% were unsalable due to ethylene damage at a loss of \$100,000. Benedict et al (22) estimated that the total ornamental loss from air pollutants in the U.S. in 1969 was \$47.1 million.

Operators of greenhouses are especially vulnerable to loss by ethylene since their crops are produced in a confined air space. Tija et al (172) reported that chrysanthemum growers suffered losses when exhaust gases of oil heaters or open flame burners were used for

heating during cold weather. Chrysanthemums failed to enter the reproductive stage even though the photoperiod favored flowering. Hasek et al (85) pointed out that proper adjustment and venting of heaters was needed to prevent damage to greenhouse crops.

To control atmospheric ethylene, 90% of which is produced by automobiles, catalytic filters have been installed. Brominated charcoal, potassium permanganate and ozone filters have been used to reduce ethylene levels in greenhouses and fruit storage areas.

The Postharvest Environment

Acceleration of aging by ethylene is the major cause of economic damage to floral and foliage crops in the postharvest environment. Symptoms of ethylene-induced deterioration such as chlorosis, abscission and subsequent poor growth are abundant under transit and marketing conditions.

In a temperature, light, ethylene simulated shipping conditions experiment with geranium seedlings, Marousky and Harbaugh (116) showed that while seedlings exposed to ethylene in darkness at 23°C showed the most severe damage, little or no injury occurred at 4.5°C. As temperature decreased with any ethylene concentration tested, incidence of injury decreased. They concluded that while ethylene and darkness during shipping contribute to plant damage, the effect can be reduced if a low, but non-chilling temperature is maintained.

During a similar experiment with Philodendron scandens subsp. oxycardium, Marousky and Harbaugh (115) revealed that plants exposed to 5 µl ethylene/liter air at 16°C had negligible leaf abscission or injury compared to the same concentration of ethylene at 23.5° where

plants were severely injured. Control plants subjected to air for 3 days at 27°C in darkness had no visible signs of injury. They suggested that physiological damage in this plant species was not directly due to high temperatures during shipment but, rather to the greater activity of ethylene at elevated temperatures.

Milbrath and Hartman (121) demonstrated that ethylene stimulated abscission in English holly. By controlling storage temperature and using fresh air and NAA, they prevented defoliation of packaged holly.

A major problem during transit and marketing of seed geraniums is severe petal shattering. Armitage et al (14) reported that after 12 hours exposure to 1 and 10 ppm ethylene, petal shattering occurred.

In commercial practice, plants can arrive at their destination with no visible symptoms of deterioration and yet develop chlorosis or abscission of leaf and floral parts within a few days. The above citations suggest that ethylene exposure can predispose a plant to deterioration.

Ethylene can be reduced in the postharvest environment by inhibiting its synthesis and preventing its action, by keeping it below biologically active threshold levels with absorbants, and finally through utilization of hypobaric storage conditions.

SENESCENCE

Senescence can be defined as the deteriorative processes occurring in living organisms which lead to death, and can be caused by pathogens, environmental stresses or inherent physiological changes in the organism. It can affect the whole organism or some of the organs, tissues or cells (105). (125) (183).

In the life cycle of an angiosperm, there are associated manifestations of senescence with each succeeding stage. Many of these expressions of senescence are attributes of the normal developmental processes that constitute the life cycle of the plant (184). For monocarpic species, including most herbaceous annuals, longevity is linked to flowering or fruiting at which time there is a uniform death of the entire population (106).

LEAF SENESCENCE

Physiological Decline

The obvious character of leaf senescence is yellowing from chlorophyll disappearance accompanied by a decline in photosynthetic rate. Richardson (144) found with Acer and Quercus leaves that the saturating level of light intensity which rose from $100 \mu \text{mol s}^{-1} \text{m}^2$ in young leaves to about $300 \mu \text{mol s}^{-1} \text{m}^2$ in the fully expanded leaf, fell back to $108 \mu \text{mol s}^{-1} \text{m}^2$ with increasing age. Photosynthetic rate usually decreases before appreciable loss of chlorophyll. For example, Hernandez and Schaedle (88) noted in attached leaves of poplar that CO_2 assimilation and phosphorylation were at their maximal rates when the leaves were about 10 days old, whereas the chlorophyll content continued to increase until about the age of 50 days.

Proteolysis during leaf senescence has been realized from some of the earliest studies. Vickery et al (175), in 1937, followed the senescence of detached tobacco leaves and discovered that protein breakdown soon began and continued for at least 7 days. Yemm (189) (190) made comparable observations on detached barley leaves and noted that the respiratory quotient fell after the first day to about 0.75, which suggested that the amino acids liberated by proteolysis were now the main respiratory substrate. According to Thimann (170), among the proteins undergoing hydrolysis are included not only RuBPCase but RNAase, which interrelates the process with nucleic acid metabolism.

There are marked changes in the nucleic acids of senescing leaves. There is a decline in both RNA and DNA with the decrease in DNA being typically smaller. Wollgiehn (182) showed with tobacco leaves that after 3 days, RNA decreased by 16% and DNA by 3%. Dyer and Osborne (61) with Xanthium leaves, found that after 4 days RNA decreased by 55% and DNA by 39%.

Among the changes in ultrastructure includes the disappearance of starch in the chloroplasts causing the bulk of carbohydrate to appear as reducing sugars. Chloroplasts swell up along with the endoplasmic reticulum which, according to Thimann (170) denotes energy loss. In cucumber cotyledons, as shown by Butler (46), free ribosomes disappear followed by the polysomes. Shaw and Manocha (151) found distortion of the mitochondrial cristae, followed by disappearance or shrinkage in senescing wheat leaves. Eventually the tonoplast and plasmalemma disappear. The weakening and dissolution of membranes induce cell permeability changes and solute leakage. Sacher (146) showed visible

leakage of anthocyanin from the vacuole with leaf discs from Mesembryanthemum and Rhoeo. Recently, Poovaiah and Leopold (141) showed suppression of each of the measured functions of leaf senescence (chlorophyll content, protein decrease, apparent free space increase and hydraulic permeability increase) with calcium ions. They interpreted this effect to be a consequence of the calcium function of maintaining cellular membranes.

In general, the net photosynthetic rate increases as leaves grow and begins a gradual decline at maximum leaf expansion. This was confirmed by Smillie (155) with pea leaves. Sestak and Catsky (150) found that the decline in photosynthesis was more pronounced in the younger leaves rather than the older basal leaves of Nicotiana.

Respiration generally declines but rather late in the senescence process, and at first there is a sharp increase suggestive of the climacteric respiratory rise in ripening fruit. Hardwick et al (84) in attached Perilla leaves, found the respiratory rate almost constant until the 56th day with a subsequent rise to double its value just before abscission. In tomato leaf segments, McGlasson et al (119) found the rise to be preceded by a steep fall for the first 6 days.

Environmental Regulation

Light

Light is strongly implicated in delaying the typical senescence syndrome. Frank and Kenney (69) found that Zea mays L. seedlings exposed to darkness lose chlorophyll, protein and RNA more rapidly than lighted plants. Goldthwaite and Laetsch (76) observed in bean leaf discs a faster loss of protein and chlorophyll in the dark than

those remaining in light up to 36 days old, with the rate of loss increasing as the plants aged.

In studying the effects of daylength on senescence, Misra and Biswal(123) found that leaves of Hibiscus rosa-sinensis which senesce in the dark in 20 days, survive up to 35 days in 8 hr photoperiods and to 45 days in 16 hr photoperiods. In a study of autumnal senescence with Malus leaves, Spencer and Titus (157) observed a decline in protein and sugars when the daylength reached 14 hrs. At 12 hrs, chlorophyll, nucleic acid, fresh weight, rate of protein synthesis and dehydrogenase activity declined.

In the bedding plant industry, plants can be exposed for up to five days in the shipping environment without light with deleterious consequences. In a simulated shipping study by Dean (59) with geranium seedlings, an increase in duration of darkness from 24 to 96 hrs increased leaf mortality and the number of days to flower after potting while decreasing the ability of plants to recover after planting.

Temperature

According to several investigators (7) (108) (111), exposure to temperatures in either the low or high range can initiate yellowing, presumably as a consequence of structural or metabolic damage. Yarwood (188) demonstrated an acceleration of geranium leaf senescence at chilling temperatures. Low temperatures can also interact with other environmental variables such as light intensity and encourage a senescence like response (167). Kumpf et al (102) demonstrated that alysium, petunia, salvia and marigold have successfully been stored at

5°C for 4-6 weeks with 18 hrs of light per day. Kaltaler (94) found with geraniums grown from cuttings, that plants maintained at 4-6°C in darkness during shipment senesced slower, possibly due to a general lower metabolic rate at low temperature. In a recent simulated shipping study by Poole and Conover (140) with foliage species, Schefflera and Ficus shipped best at 10°C for up to 21 days without significant loss of keeping quality.

Heat stress applied selectively to maize root systems causes developmental abnormalities and premature shoot senescence thought to be due to interference with calcium translocation (142) (176). Exposure of leaves of Nicotiana and Pennisetum to a temperature of 50°C for only a few minutes resulted in acceleration of yellowing and protein degradation (64) (103). Thomas and Stoddart (171) suggested that heat stress may not trigger the entire senescence syndrome, but may have deleterious effects on individual metabolic pathways such as chlorophyll turnover, which may produce compositional changes normally characteristic of aging.

Water Relations

Acceleration of leaf aging in plants subjected to varying degrees of drought has been described for Helianthus and Nicotiana by Mothes (127) with emphasis on accelerated proteolysis and respiration rate. Brady et al (38) found that water stress reduces incorporation of amino acids into RuBPC relative to other proteins, and depresses leaf nitrate reductase activity by reducing nitrate flux.

In sugar beets, Morton and Watson (126) found leaf senescence to be affected by alternating high and low water regimes and not by

continuous water regimes. There was a hastening of senescence when high water regime plants were subjected to a dry regime, but plants transferred from a low to a high water situation had less leaf death.

Petrie et al (137) reported a decrease in protein when tobacco leaves were subjected to drought. If plants were watered, the protein assimilation rate returned to a rate similar to plants maintained continuously on a high water regime.

Hormonal Regulation

In general, the cytokinins, auxins and gibberellins are known to defer leaf senescence while ethylene and abscisic acid are stimulators.

In a classic experiment, Mothes and Engelbrecht (128) showed that if a small area of a basal tobacco leaf was treated with kinetin, only that area remained green, with the rest of the leaf yellowing normally. When a ^{14}C -amino acid was applied to another area, its radioactivity became concentrated in the kinetin treated area.

The first reports that hormones might participate in the control of leaf senescence were those of Sacher (145) (146) who found α -naphthalene-acetic acid to retard senescence of leaf discs and bean pods. Shortly after, Osborne and Hallaway (131) reported that 2,4-D butyl ester, a synthetic auxin used largely as a herbicide retarded the proteolysis of detached leaves of Prunus serrulata. Auxins, however, have not generally been found to be very potent in retarding leaf senescence. A complication is that auxin, at levels only slightly above the physiological, stimulates ethylene production, a promoter of senescence.

In leaves of Taraxacum, kinetin has little effect on senescence, but GA acts powerfully (68). As Tropaeolum leaves senesce, their GA content steadily decreases as observed by Chin and Beevers (48). Aharoni et al (8) reported a similar decrease in lettuce leaves under water stress.

Eder and Huber (63) showed abscisic acid to clearly inhibit protein synthesis in Pennisetum leaves. It has been shown to increase rapidly in water stressed leaves by Wright and Hiron (186) which corresponds to the often observed tendency of water stressed leaves to turn yellow. Mittelheuser and vanSteveninck (124) have shown ABA to accelerate membrane breakdown, including the chloroplast envelope, plasmalemma and tonoplast in wheat leaves.

Krone (101) reported symptoms of epinasty, yellowing and premature abscission of leaves in several species exposed to natural gas composed of 6.1% ethylene. Heck and Pires (87) fumigated 89 species from 39 different families with 2.5 and 10 μ l/liter of ethylene for 10 days. Symptoms were inhibition of leaf expansion, stunting, increased abscission, epinasty chlorosis and necrosis. Dean (59), in a simulated shipping study with geranium seedlings, reported leaf yellowing to be affected by ethylene concentration as well as duration of exposure while the plants were in darkness. At 0.1 μ l/liter, yellowing was significant in about 12 hours while at 10 μ l/liter, 72% of the leaves were yellow. Increasing the duration of exposure enhanced leaf yellowing at all ethylene concentrations. She also demonstrated that shipping at cooler temperatures (2-10°C) slowed ethylene synthesis and thus senescence.

FLOWER SENESENCE

Relatively little has been published on the physiology of flower and petal senescence according to Mayak and Halevy (118) compared to other plant organs such as leaves. Since chloroplast senescence does not necessarily follow the same path as that of the rest of the cell, petal tissue can serve as an excellent model for the study of senescence processes not related to or influenced by the presence of chloroplasts. For example, chloroplast degradation can be reversed up to a certain stage whereas petal senescence is an irreversible process. This suits Sacher's 1973 definition of senescence as the last phase in life in which "a series of normally irreversible events is initiated that leads to cellular breakdown and death."

Physiological and Ultrastructural Changes

The two major metabolic events occurring in senescing petals are an increase in respiration and hydrolysis of cell components (118). The enzymic changes are associated mainly with these two processes. In Ipomoea, a sharp increase was reported in RNase, DNase and hydrolases of cell wall polysaccharides by Wiemken (181). During petal aging, there is also a sharp drop in starch, cell wall polysaccharides, proteins and nucleic acids.

Senescence associated phenomena were accelerated in Tradescantia and morning glory flowers by low pH, an effect similar to ethylene observed by Horie (91). An increase in apparent free space and membrane permeability has been reported in aging rose petals by Parups and Chan (133). A sharp increase in microviscosity of the plasmalemma was observed during aging by Borochoy et al (36) in protoplasts

isolated from intact flowers as well as cut flowers or isolated petals and corresponded to an increase in the molar ratio of free sterol to phospholipid.

Changes in Pigmentation

Color fading and discoloration is a common phenomenon in many flowers during aging. The carotenoids and anthocyanins are the two major pigments contributing to flower color. The most important factor determining color change in senescing petals is a pH change of the vacuole according to Stuart et al (165). However, Asen (18) stated that only in a very few cases is the color caused by a very low (< 3.0) or a very high (> 7.0) pH affecting the anthocyanins per se. In most flowers, the decisive factor determining color intensity and its bluing is the copigmentation with other flavonoids and related compounds. The degree of copigmentation is influenced to a great extent by even slight pH changes. According to Asen et al (19), this may explain the infinite variations in the color of flowers that exist in the pH range of 4 to 6 which is most prevalent in petals where anthocyanins per se are virtually colorless. The bluing of red flowers with aging usually parallels an increase in pH while a blue to red color change shows a pH decrease. In some flowers, according to Singleton (153), aging of petals is characterized by browning and blackening of the petals caused by oxidation of flavones, leucoanthocyanins and other phenols and tannin accumulation.

Flower Abscission

The final stage of flower senescence is accompanied by abscission of whole inflorescences, flowers or parts of flowers. A comprehensive

work was published in 1911 by Fitting on the physiology of petal shedding. Addicott in 1977 published the next major work. Mayak and Halevy (118) indicate that the process of leaf abscission may not be identical to petal abscission. According to Hanisch et al (81) and Simons (152), an abscission layer is formed as with leaves when whole flowers or flower buds are shed. However, Esau (65) showed that cell division usually does not precede petal shedding, no clear abscission layer is present and petal shedding is caused by softening of the middle lamella.

Fitting (1911) had observed that external factors such as shaking, wounding, high temperatures and some gases induced very rapid petal abscission in sensitive species which is a much quicker response than known for leaves. CO_2 which is known to antagonize ethylene and retard leaf abscission promotes petal abscission according to Fitting (67). In many species, pollination promotes abscission of flower parts usually associated with an ethylene rise. Abscission of flower buds and petals has been promoted by ABA as with leaves as shown by Hanisch and Bruinsma (80) and Addicott (6).

SECTION I

INFLUENCE OF QUANTUM FLUX DENSITY, TEMPERATURE
MEDIA AND WATER REGIME ON POSTPRODUCTION KEEPING
QUALITY OF BEDDING PLANTS

MATERIALS AND METHODS

PRODUCTION

Seeds of the following bedding plant species were sown in March and germinated at 24°C under intermittent mist:

COMMON NAME	SCIENTIFIC NAME	CULTIVAR
Alyssum	<u>Lobularia maritima</u>	'Snowcloth'
Begonia	<u>Begonia X semperflorens</u>	'Scarletta'
Coleus	<u>Coleus X hybridus</u>	'Rose Wizard'
Geranium	<u>Pelargonium X</u> <u>hortorum</u>	'Sooner Red'
Impatiens	<u>Impatiens wallerana</u>	'Super Elfin'
Petunia	<u>Petunia X hybrida</u>	'White Magic'
Tomato	<u>Lycopersicon</u> <u>lycopersicum</u>	'Better Boy'

Four hundred and thirty two seedlings of each species were selected for uniformity and transplanted into both a peat-lite and a soil based medium. The peat-lite medium (VSP, Michigan Peat Co., Sandusky, MI) was composed of 60% sphagnum peat, 20% vermiculite and 20% perlite with a nutritive charge consisting of nitrogen, potassium and phosphorus plus trace elements. Dolomitic limestone was added to adjust pH to 5.5. The soil-based medium (1:1:1) consisted of one part each of soil, sphagnum peat and perlite and was adjusted to pH 5.5 with dolomitic limestone. Plastic cell packs (13 X 13 cm) were used containing four units and eight of these packs were placed in a standard bedding plant tray (28 X 53 cm).

Plants were placed in a greenhouse environment and grown under a

natural photoperiod at 21°C DT and 17°C NT 3°. Nutrition was maintained using a 20 - 20 - 20 soluble fertilizer to provide 200 ppm nitrogen. Plants were leached with tap water every fourth watering.

Growth regulators were used to control stem elongation. Begonia, coleus, impatiens, petunia and tomato were sprayed with a foliar application of B-9 (2500 ppm). Begonia, coleus, impatiens and tomato were sprayed two weeks after transplant while petunias were sprayed when plants were 3 cm. Geraniums were sprayed with Cycocel (1500 ppm) at 35 and 42 days after sowing date.

The following production schedule was used for each plant species:

PLANT SPECIES	DAYS IN GERMINATION ENVIRONMENT	WEEKS FROM SEEDING TO TRANSPLANT	WEEKS FROM TRANSPLANT TO BLOOM OR SALE
Alyssum	3	4	3
Begonia	14	8	7
Coleus	7	3	5
Geranium	5	2	13
Impatiens	7	4	4
Petunia	5	4	5
Tomato	5	3	3

Two to three weeks before the keeping quality experiment was started, night temperature was lowered to 13° C.

POSTHARVEST

Experimental Design

Four temperatures and three quantum flux density (QFD) levels were arranged in a split-plot design with the QFD levels randomized within each temperature. Split at right angles within each of the twelve temperature, QFD treatment combinations were three water

regimes and two media types and there were four sampling dates over time for data analysis.

Within the seventy two treatment combinations there were three replications and four observations per replication for a total of eight hundred sixty four plants per species. The experiment was analyzed as a completely randomized design with factorial partitioning using the Genstat statistical package.

Treatments

Eight hundred sixty four plants of each of the 7 species were subjected to the following postproduction treatments: when plants reached 50% anthesis (or in the case of tomato when the plants were deemed salable), four hundred thirty two plants from each growth medium were equally divided into 4 temperature groups (4.5, 13, 21 and 29°C). Each temperature chamber had 3 QFD levels (7 (low), 36 (medium) and 102 (high) $\mu\text{mol s}^{-1} \text{m}^{-2}$). Each QFD level was further subdivided into low, medium and high moisture levels. Under low moisture, media was allowed to dry completely and plants were wilted before re-irrigation. Surface of media was allowed to dry out between waterings for medium moisture but plants were not allowed to wilt. Under high moisture, media was kept constantly moist. QFD was supplied by 800 watt (H0) cool white fluorescent tubes for a 14 hour photoperiod. QFD readings were measured and adjusted periodically with a Li-Cor LI-185B meter and LI-1905B quantum sensor at the plant canopy and data were collected for a 36 day period.

General Data

Fresh Weight (FW)

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations for all species.

Change in Stem Height

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

Visual Assessment

At 12 day intervals, a numerical rating was assigned to flower quality for alyssum and new growth for geranium. Begonia, coleus, impatiens, petunia and tomato were given a visual assessment at 12 day intervals describing flower and foliage quality as an overall indication of postharvest keeping quality.

ALYSSUM

MATERIALS AND METHODS

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Visual Rating

A visual rating (Table 2) from 1 to 5 (1= dead, 2= alive with no flowers, 3= sparse flowering, 4= flowering, marketable, 5= floriferous, excellent marketability) was determined at 12 day intervals as an indication of overall keeping quality. On day 0, most plants were in stage 4.

RESULTS

Fresh Weight (FW)

Main Effects

FW increased with increasing QFD level and decreased with increasing temperature above 13°C. FW was highest in the peat-lite medium and increased with increasing moisture level (Table 1).

Interactions

At temperatures above 13°C (Figure 1) FW showed a marked decrease regardless of QFD level.

Over time (Figure 2), plants at both the low and medium QFD levels declined in FW from day 0 through day 24 and then began to gain, while those at the high QFD level lost FW from day 0 to day 12 and then gained through day 36. Over time (Figure 3), plants lost

FW through day 12 regardless of temperature. However, after day 12, plants held at 4.5 and 13°C gained FW for the remainder of the postharvest period, while those at 21 and 29°C declined up through day 24 followed by a gain to day 36.

Above 13°C (Figure 4), there was FW loss in both growth media. FW decreased under all moisture regimes (Figure 5) from day 0 to day 12. Subsequently, plants under low moisture gained to day 24 and declined again to the 12 day level, while those under medium and high moisture lost FW through day 24 and then gained to day 36.

Visual Rating

4.5°C

Most plants, over all treatments, maintained a 4 flower index (Table 2) even at the low QFD level after 12 days. Anthocyanin was evident on the stems at the medium and high QFD levels with stem elongation in low QFD level plants. After 36 days, the flower index was 4.5 under the medium and high QFD levels and had declined to 3 under low QFD.

13°C

After 12 days, plants under the medium QFD level maintained a floral index of 4 and improved to 5 at the high QFD level while low QFD level plants had declined to stage 2.5. After 24 days anthocyanin was prominent on stems at the high QFD level with only trace amounts visible at the medium QFD level. At the low QFD level, anthocyanin was absent, foliage was pale green and stems were elongated.

After 36 days, plants at the high QFD level were given the best keeping quality rating over all other QFD and temperature combinations

with a floral index of 5. Medium and low QFD level plants had declined to stage 3 and 2 respectively.

21°C

After 12 days, the floral index had declined at all QFD levels. After 36 days plants were not marketable at all QFD levels. Flower stage had declined to stage 3, 2 and 1 respectively for high, medium and low QFD level plants.

29°C

At this temperature, plants were also not marketable under all QFD levels after 12 days. After 36 days the floral index was 1.5 at the medium and high QFD levels and 1 at the low QFD level.

DISCUSSION

Based on fresh weight and the visual rating, the results indicate that temperature seems to be a stronger controlling factor of keeping quality in the postproduction life of this species than QFD level within the ranges tested. Postharvest life was longer at the cooler temperatures (4.5 & 13°C) regardless of QFD level. At all temperatures greatest deterioration in keeping quality occurred at the low QFD level ($7 \mu\text{mol s}^{-1} \text{m}^{-2}$).

In the retail postproduction environment, maintenance not necessarily growth is the objective. However, a slow growth rate (increase in fresh weight) is beneficial if visual ratings do not decline. Fresh weight loss is undesirable and indicates loss of keeping quality. In this study, at all QFD levels and temperatures tested, plants lost fresh weight for 12 days after leaving the production area. There was a continued loss of fresh weight at the low

and medium QFD levels and the two higher temperatures to day 24. From day 24 to day 36, plants gained fresh weight at all QFD levels and temperatures. The acclimatization period appears to be longer at lower QFD levels and higher temperatures for this plant species. However, regardless of QFD and temperature treatment, fresh weight was less after 36 days than at day 0.

Plants grown in the peat-lite medium had a larger fresh weight when entering the postproduction treatments due to a production influence. However the trend for fresh weight loss was approximately 25% for both media after 36 days. Under low moisture, fresh weight loss was 40% while medium and high moisture plants lost 20% after 36 days.

Anthocyanin appeared on the plant stems at the lower temperatures (4.5 & 13°C) and the medium and high QFD levels. Anthocyanin synthesis is light mediated (70) (83) and induced by low temperature. Tan (166) found 100% more anthocyanin in apple skins at 6°C than at alternating 6 and 18°C temperatures. Without light, no anthocyanin was synthesized. In a study by Armitage (12), anthocyanin on marigold foliage changed the hue of the plant, possibly affecting marketability.

In considering visual rating in conjunction with fresh weight, best 36 day postharvest marketability for alyssum requires the following conditions: a QFD level in the $100 \mu\text{mol s}^{-1} \text{m}^{-2}$ range, a temperature range of 4.5 to 13°C and medium to high moisture conditions in either the artificial or soil based medium.

Table 1. Influence of postproduction environmental factors on fresh weight (g) of alyssum 'Snow cloth'.

Environmental Factor	Level	Days Postproduction				Mean ^x
		0	12	24	36	
QFD ^y ($\mu\text{mol s}^{-1} \text{m}^{-2}$)	7	7.83	4.73	4.69	4.81	5.39 a
	36	8.24	5.79	5.75	6.27	6.51 b
	102	8.21	5.88	6.29	7.23	7.03 c
Temperature (°C)	4.5	8.54	7.26	7.40	7.81	7.75 c
	13	8.53	6.83	7.48	8.23	7.77 c
	21	7.87	5.42	5.01	5.67	5.99 b
	29	8.09	2.36	1.75	2.72	3.73 a
Media	VSP	8.87	5.89	6.00	6.64	6.85 a
	1:1:1	7.64	5.04	4.82	5.57	5.77 b
Water Regime	Low	8.21	5.02	5.27	5.03	5.88 a
	Med	7.99	5.28	5.23	6.46	6.24 a
	High	8.57	6.10	5.74	6.82	6.81 b

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density)

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	
Linear	**
Quadratic	NS
Time	
Linear	**
Quadratic	**

Interactions

QFD X Temperature	*
QFD X Media	NS
QFD X Time	*
QFD X Water	NS
Temperature X Media	**
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	*

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

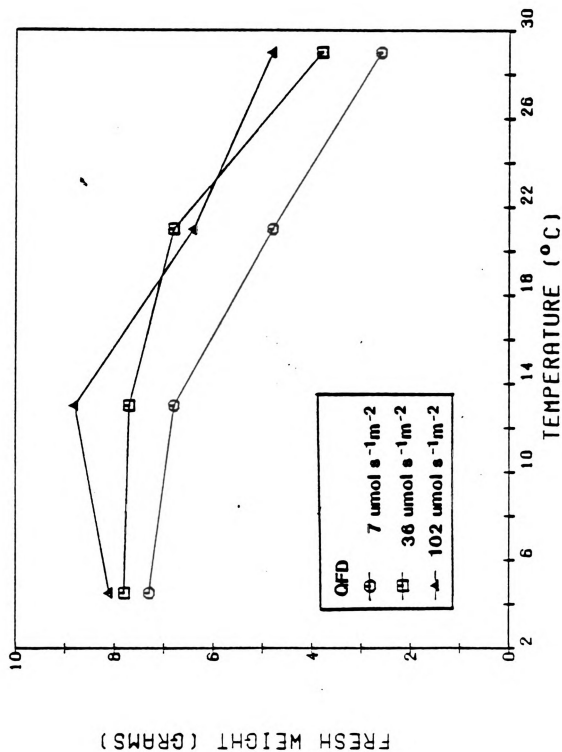


Figure 1. Influence of temperature and quantum flux density on fresh weight of *Alyssum 'Snowcloth'*.

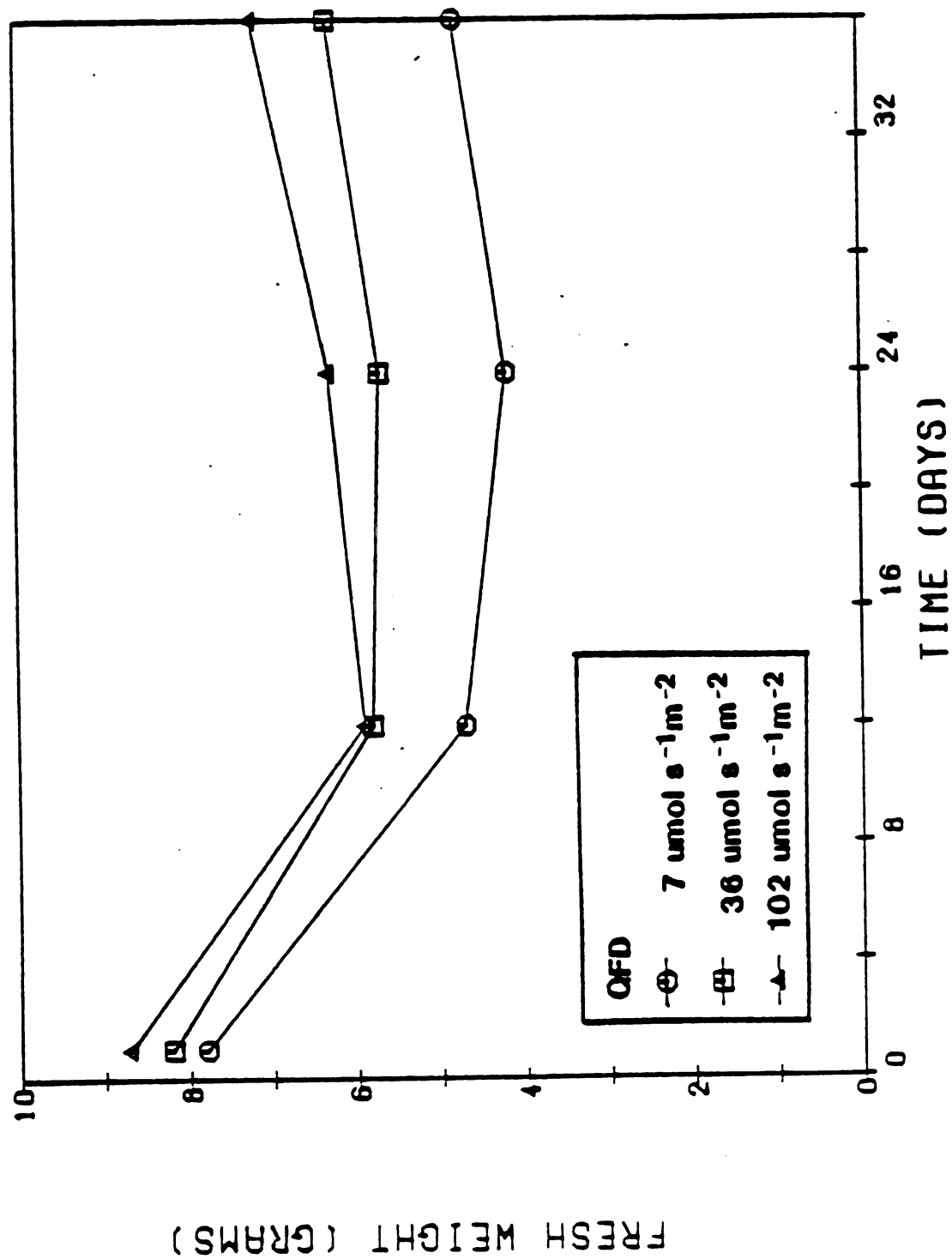


Figure 2. Influence of time and quantum flux density on fresh weight of alyssum 'Snowcloth'.

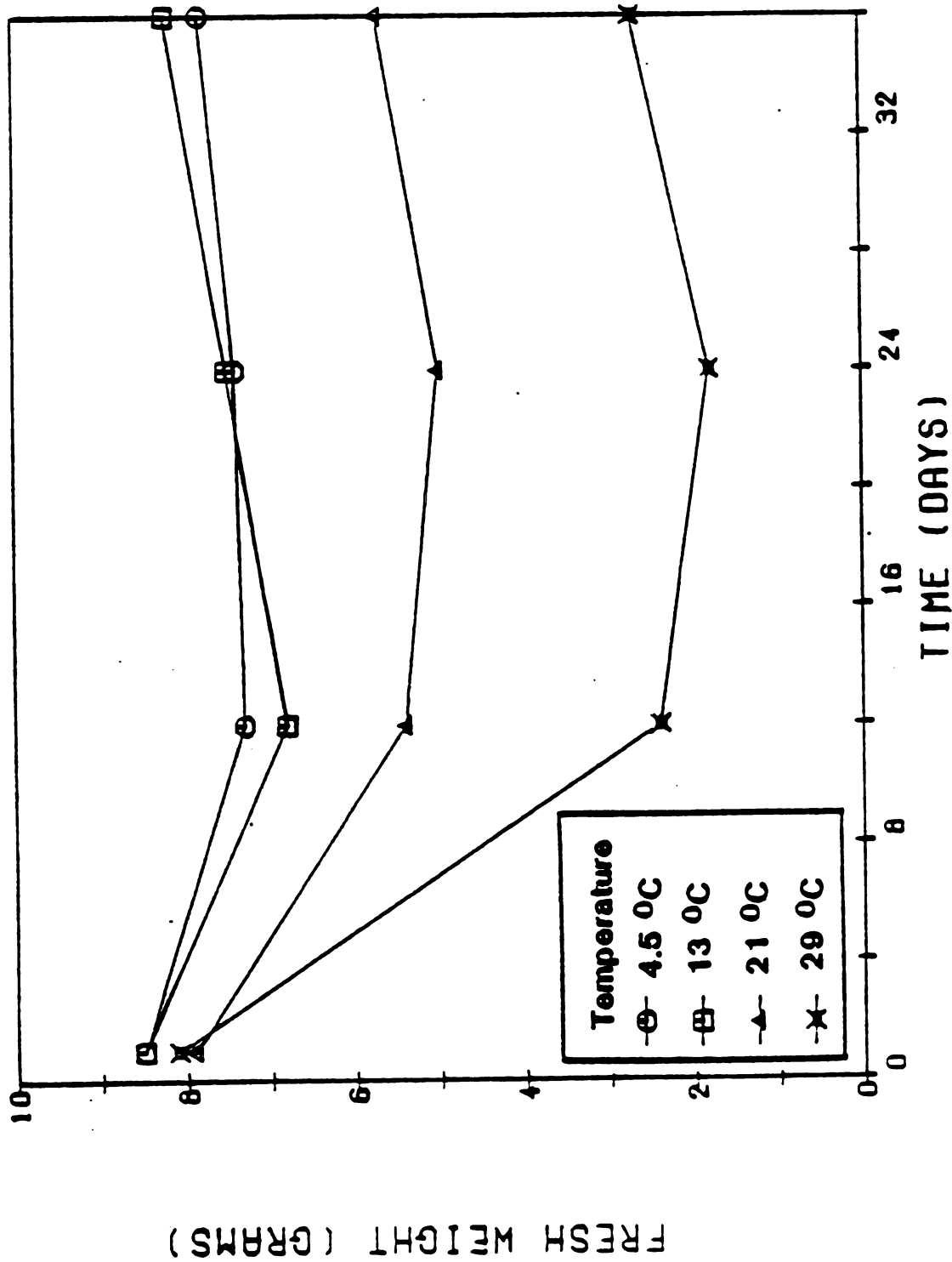


Figure 3. Influence of time and temperature on fresh weight of alyssum 'Snowcloth'.

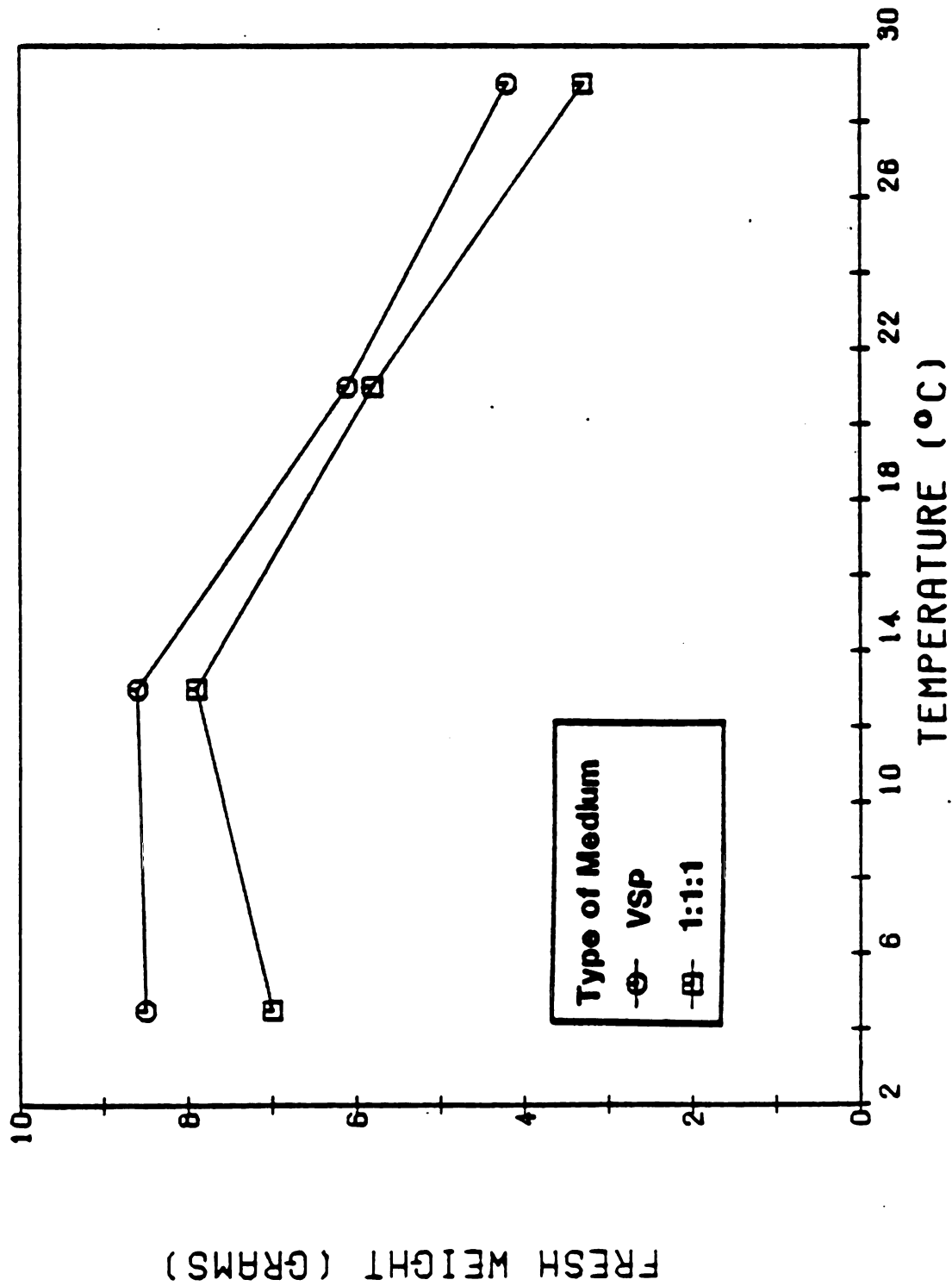


Figure 4. Influence of temperature and media on fresh weight of alyssum 'Snowcloth'.

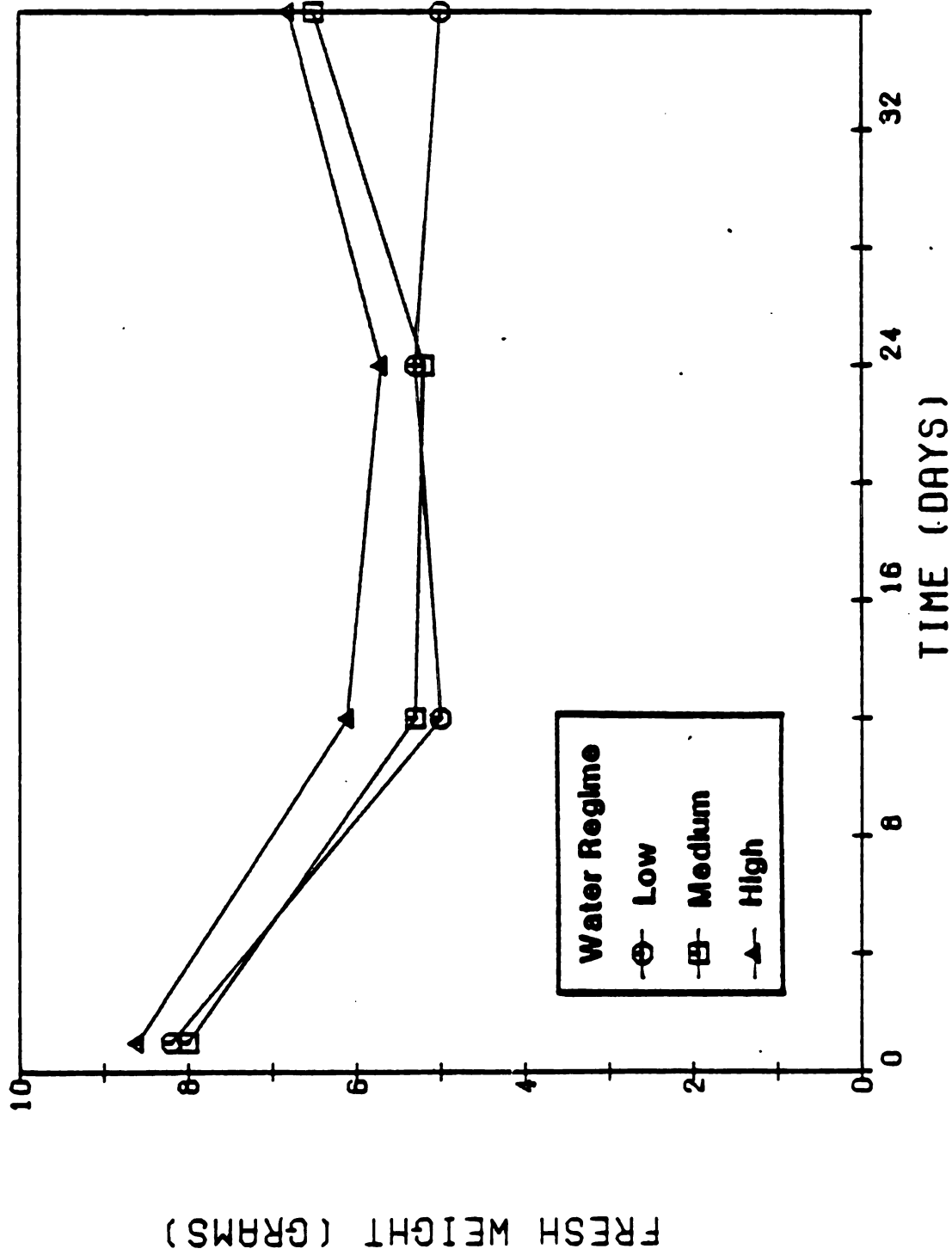


Figure 5. Influence of time and water regime on fresh weight of alyssum 'Snowcloth'.

Table 2. Influence of quantum flux density and temperature on the visual rating of alyssum 'Snowcloth'.

Temperature (°C)	QFD ($\mu\text{mol s}^{-1} \text{ m}^{-2}$) x									
	7			36			102			
	7	36	102	7	36	102	7	36	102	
	Day 12			Day 24			Day 36			
4.5	4	4	4	3	4.5	4.5	3	4.5	4.5	
13	2.5	4	5	2	3	5	2	3	5	
21	2	3	3	1	2	3	1	2	3	
29	1	1.5	1.5	1	1.5	1.5	1	1.5	1.5	

x QFD (Quantum Flux Density)

Rating: 1= Dead 2= Alive with no flowers 3= Sparse flowering

4= Flowering, marketable 5= Floriferous, excellent marketability

BEGONIA

MATERIALS AND METHODS

This plant species was studied at 21 and 29°C.

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Change in Stem Height

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

Visual Assessment

Plants were given a visual assessment at 12 day intervals describing flower and foliage quality as an overall indication of postharvest keeping quality.

RESULTS

Fresh Weight (FW)

Main Effects

FW increased with increasing QFD level and decreased with increasing temperature. FW was highest in the peat-lite medium under

Interactions

Over time (Figure 6), plants under low moisture lost FW to day 24 and gained to day 36. Under medium moisture, plants gained FW to day 12, lost to day 24 and gained to day 36 while high moisture plants

were stable to day 12 and gained today 36.

Change in Stem Height

Main Effects

Stem height increased with increasing QFD level and plants were taller at 21°C in the soil based medium under medium to high moisture (Table 4).

Visual Assessment

21°C

After 12 days, there were many flowers on plants held under the medium and high QFD levels while those at the low QFD level had dull green foliage with flowers fading from red to pink. This trend continued after 24 days at both the medium and high QFD levels with anthocyanin traces appearing on the upper leaves and loss of flower color under low moisture. At the low QFD level, flowers had further faded to a very pale pink and stems were elongated. After 36 days, flowers remained abundant with superior foliage quality at the high QFD level. As QFD level decreased, flower number declined and stem elongation increased.

29°C

After 12 days, floral number was greatest at the high QFD level and declined as QFD level decreased. After 36 days, there were fewer flowers even at the high QFD level along with flower fading at both the medium and high QFD levels.

DISCUSSION

After 36 days, based on fresh weight, this study suggests inferior marketability at the $7 \mu\text{mol s}^{-1} \text{m}^{-2}$ QFD level (20% fresh

weight loss) and at 29°C.

Stem elongation is an undesirable characteristic. While fresh weight loss was the greatest at the low QFD level and at 29°C over time, stem height gain was least.

The visual assessment revealed a decline in flower number at all QFD levels at 29°C and at the medium and low QFD levels at 21°C after 36 days.

The following conditions are optimum for 36 day marketability of begonia at the two temperatures tested: a QFD range from 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$, temperature of 21°C with high moisture in either the peat-lite or soil-based medium.

Table 3. Influence of postproduction environmental factors on fresh weight (g) of begonia 'Scarletta'.

Environmental Factor	Level	Days Postproduction				Mean ^x
		0	12	24	36	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	40.55	36.20	30.03	33.84	35.15 a
	36	39.16	37.16	37.03	40.32	38.41 a
	102	43.46	40.93	40.41	46.79	42.90 b
Temperature (°C)	21	41.86	39.64	40.11	44.46	41.52 a
	29	40.25	36.55	31.53	36.17	36.13 b
Media	VSP	43.87	39.47	37.49	43.76	41.15 a
	111	38.24	36.72	34.15	36.87	36.50 b
Water Regime	Low	44.78	34.74	34.18	41.92	38.91 AB
	Med	39.06	40.38	32.02	36.04	36.88 A
	High	39.32	39.17	41.26	42.98	40.68 B

^x Mean separation within environmental factors by HSD test, 5% (capitals) or 1% level.

^y QFD (Quantum Flux Density)

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Media	**
Water Regime	*
Time	
Linear	NS
Quadratic	*

Interactions

QFD X Temperature	NS
QFD X Media	NS
QFD X Time	NS
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	NS
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	**

Nonsignificant (NS) or significant at 5% (*) or 1%(**) level.

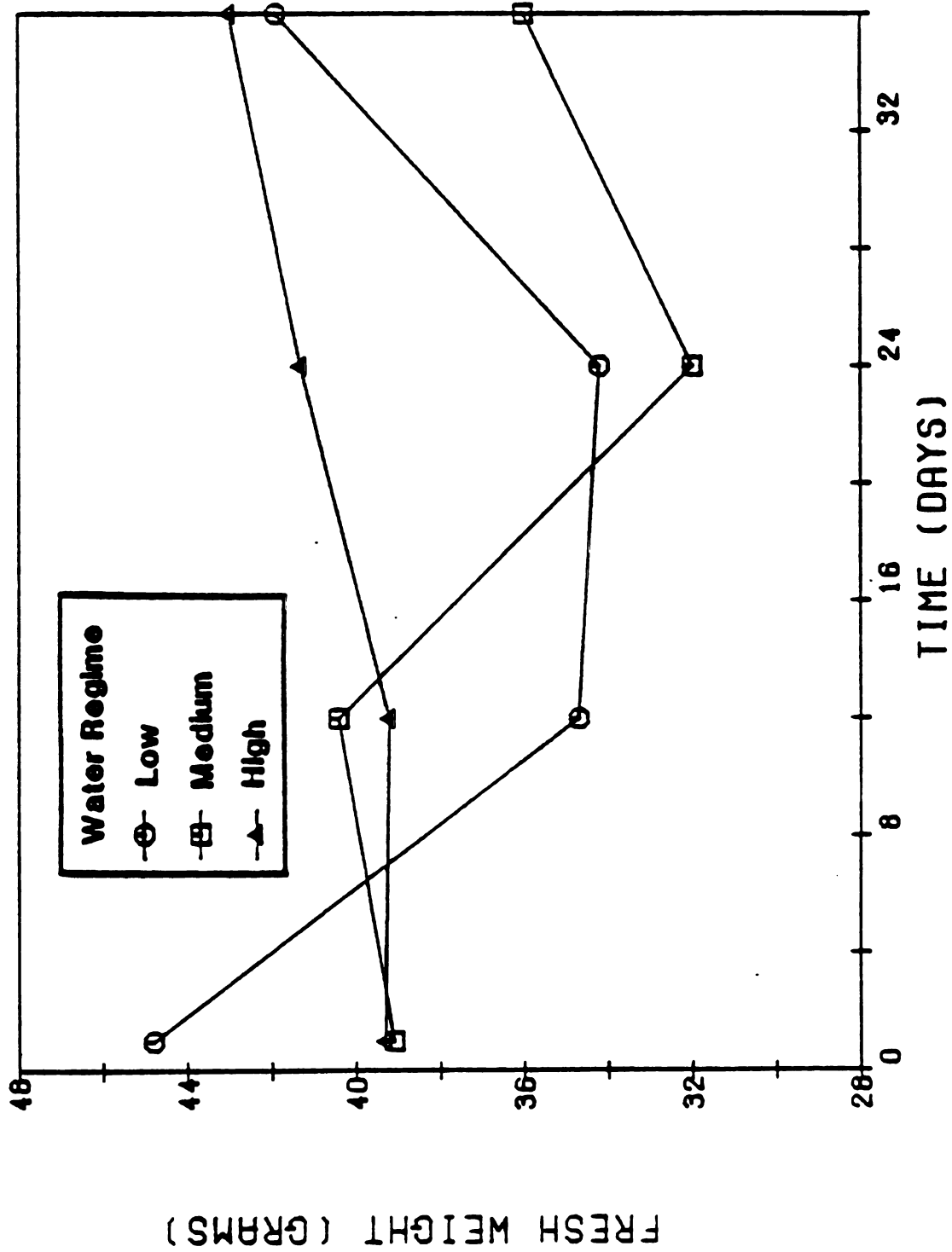


Figure 6. Influence of time and water regime on fresh weight of begonia 'Scarletta'.

Table 4. Influence of postproduction environmental factors on change in stem height (cm) of begonia 'Scarletta'.

Environmental Factor	Level	Days Postproduction ^x		Mean ^y
		12	36	
QFD ^z ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	1.9	3.1	2.5 a
	36	2.2	3.7	2.9 a
	102	2.7	4.4	3.5 b
Temperature ($^{\circ}\text{C}$)	21	2.8	4.3	3.5 b
	29	1.7	3.2	2.4 a
Media	VSP	1.9	3.6	2.7 a
	1:1:1	2.6	3.8	3.2 b
Water Regime	Low	1.9	2.9	2.4 a
	Med	2.5	3.9	3.2 b
	High	2.4	4.4	3.4 b

^x Calculation of stem height at postproduction intervals as change from day 0.

^y Mean separation within environmental factors by HSD test, 1% level.

^z QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Media	**
Water Regime	**
Time	
Linear	**

Interactions

QFD X Temperature	NS
QFD X Media	NS
QFD X Time	NS
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	NS
Temperature X Water	NS
Media X Time	*
Media X Water	NS
Water X Time	*

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

COLEUS

MATERIALS AND METHODS

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Change in Stem Height

Data were recorded for this parameter at 21 and 29°C. Chilling injury prevented accurate measurement at 4.5 and 13°C.

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

Visual Assessment

Plants were given a visual assessment at 12 day intervals describing flower and foliage quality as an overall indication of postharvest keeping quality.

RESULTS

Fresh Weight (FW)

Main Effects

FW increased with increasing QFD level and with increasing temperature up to 21°C and then declined to 29°C. FW was highest in the peat-lite medium while water regime was not significant (Table 5).

Interactions

FW increased in value as temperature increased up to 21°C

regardless of QFD level and then declined to 29°C (Figure 7).

Over time (Figure 8), plants lost FW to day 24 at all QFD levels. After 24 days, low and medium QFD level plants remained stable to day 36, while those under the high QFD level showed FW gain. After 12 days (Figure 9), there was a 65% FW loss for plants held at 4.5°C. FW continued to decline dramatically to day 36. Plants at 13°C lost FW to day 24 and then gained to day 36. At 21°C, plants lost FW to day 12, remained stable to day 24 and then gained FW higher than their pretreatment level by day 36. At 29°C, plants lost FW after 12 days to day 36. Over time (Figure 10), FW declined under all moisture regimes to day 24. After 24 days, plants held under low moisture remained stable while those at medium and high moisture gained FW to day 36.

The trend was similar (Figure 11) for plants in both media with the highest FW at the high QFD level.

Change in Stem Height

Main Effects

Stem height increased with increasing QFD level and increasing temperature while medium type and water regime were not significant as main effects (Table 6).

Interactions

Plants held at 21°C (Figure 12) gained stem height from the low to the medium QFD level and then stabilized to the high QFD level. At 29°C, stem height was similar for plants at the low and medium QFD levels with a subsequent gain to the high QFD level.

The trend (Figure 13) was similar for stem height gain for plants in both media from the low to the medium QFD level. From the

medium to the high QFD level, plants in the peat-lite medium remained stable while there was stem height gain for plants in the soil-based medium. In general (Figure 14), stem height increased with increasing QFD levels under all moisture regimes. There was stem height gain (Figure 15) for plants in both media for 24 days. Subsequently, plants in the peat-lite medium remained stable while those in the soil-based medium increased stem height to day 36.

Visual Assessment

4.5°C

After only two days at all QFD levels, plants exhibited chilling injury with wilted brown foliage and water soaked spots. Many meristems were dead. Plants were not marketable after 2 days.

13°C

After 12 days, there was intense color development of the foliage at the medium and high QFD levels. Stems were elongated at the low and medium QFD levels with necrosis at the low QFD level. After 24 days, plants demonstrated chilling injury at all QFD levels with the number of dead plants increasing to day 36.

21°C

At the high QFD level, plants developed a uniform foliage color pattern after 12 days. After 36 days, flowers were present and plants at this temperature and QFD level were considered to be the most marketable over all other temperature, QFD treatment combinations. Stem elongation was evident at the medium QFD level after 24 days with less foliage color development. There was marked stem elongation after 12 days at the low QFD level with negligible color development

of the foliage. The number of necrotic plants increased over time.

29°C

At the high QFD level, the central portion of the foliage developed color over time while the periphery remained green. After 36 days, flowers were present and plants were considered to have superior marketability as with high QFD level plants at 21°C.

At the medium QFD level, there was negligible foliage color development from day 0 with lower leaf defoliation and stem elongation after 12 days. New leaves were small in both media after 24 days.

Negligible color development and significant stem elongation characterized low QFD level plants with an increase in necrotic plants over time.

DISCUSSION

Postharvest results revealed that at 4.5°C, based on fresh weight and visual assessment, that marketability would not extend beyond two days in the QFD range tested due to chilling injury damage.

A highly significant trend was observed with the loss of fresh weight to day 24 at all QFD levels. Only plants given the high QFD treatment were able to acclimatize by day 36. This would indicate only marginal keeping quality at the low and medium QFD levels for 36 days postharvest. Generally, this same trend of fresh weight loss to day 24 occurred at all temperatures tested. Only plants held at 21°C clearly acclimatized by day 36 showing this to be the optimum temperature with regard to fresh weight for keeping quality.

Flowering occurred at the high QFD level at both 21 and 29°C after 36 days. While marketability does not depend on flowering for

this plant species, favorable conditions were established for flower production.

Coleus requires the following conditions for optimum 36 day marketability: QFD level in the $100 \mu\text{mol s}^{-1} \text{m}^{-2}$ range, a temperature of 21 to 29°C under high moisture in either the peat-lite or soil-based medium.

Table 5. Influence of postproduction environmental factors on fresh weight (g) of coleus 'Rose Wizard'.

Environmental Factor	Level	Days Postproduction				Mean ^x
		0	12	24	36	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	7.12	4.86	2.96	2.78	4.43 a
	36	7.11	4.89	4.08	4.19	5.07 a
	102	7.66	6.04	5.22	6.91	6.46 b
Temperature ($^{\circ}\text{C}$)	4.5	8.05	2.99	1.29	0.39	3.18 a
	13	6.81	5.68	3.75	4.28	5.13 b
	21	7.88	5.76	5.52	8.99	7.04 c
	29	6.44	6.64	5.78	4.85	5.93 b
Media	VSP	8.57	6.30	5.15	5.66	6.42 a
	1:1:1	6.03	4.23	3.02	3.60	4.22 b
Water Regime	Low	8.04	4.90	4.02	4.01	5.24 a
	Med	6.99	5.47	3.75	4.72	5.24 a
	High	6.85	5.43	4.48	5.14	5.48 a
^x Mean separation within environmental factors by HSD test, 1% level.						
^y QFD (Quantum Flux Density).						

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	NS
Time	
Linear	**
Quadratic	**

Interactions

QFD X Temperature	**
QFD X Media	*
QFD X Time	**
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	*

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

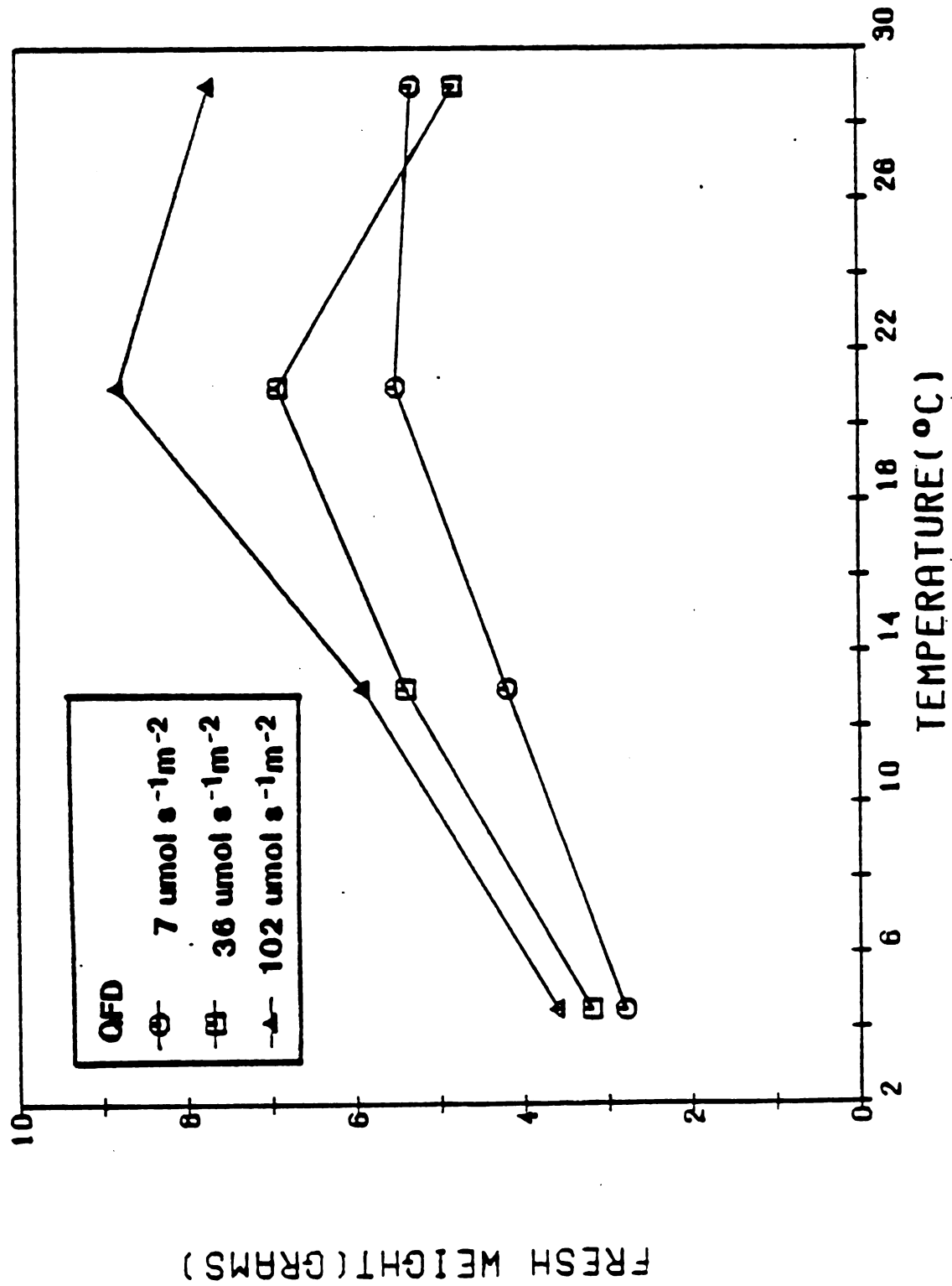


Figure 7. Influence of temperature and quantum flux density on fresh weight of coleus 'Rose Wizard'.

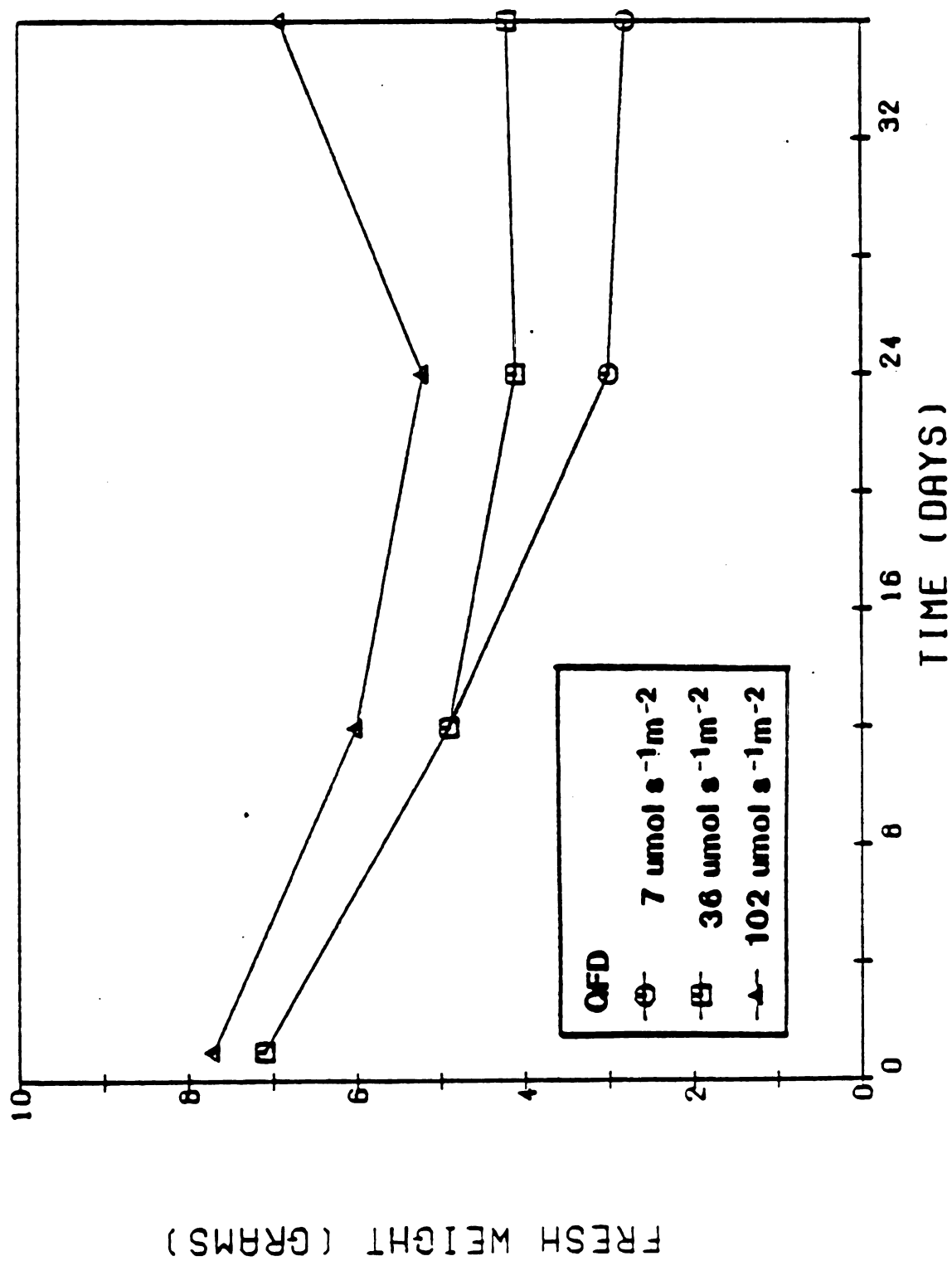


Figure 8. Influence of time and quantum flux density on fresh weight of coleus 'Rose Wizard'.

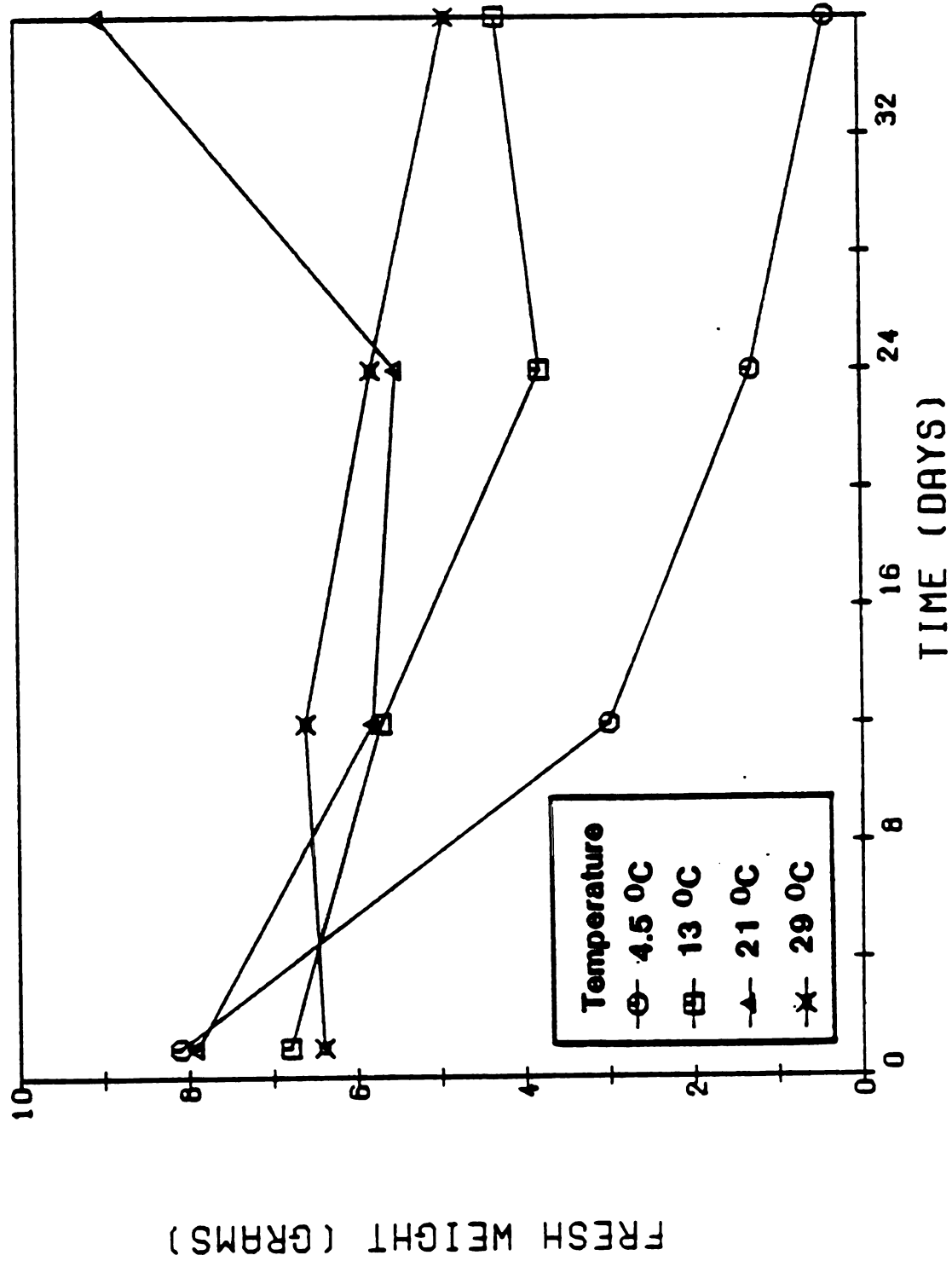


Figure 9. Influence of time and temperature on fresh weight of coleus 'Rose Wizard'.

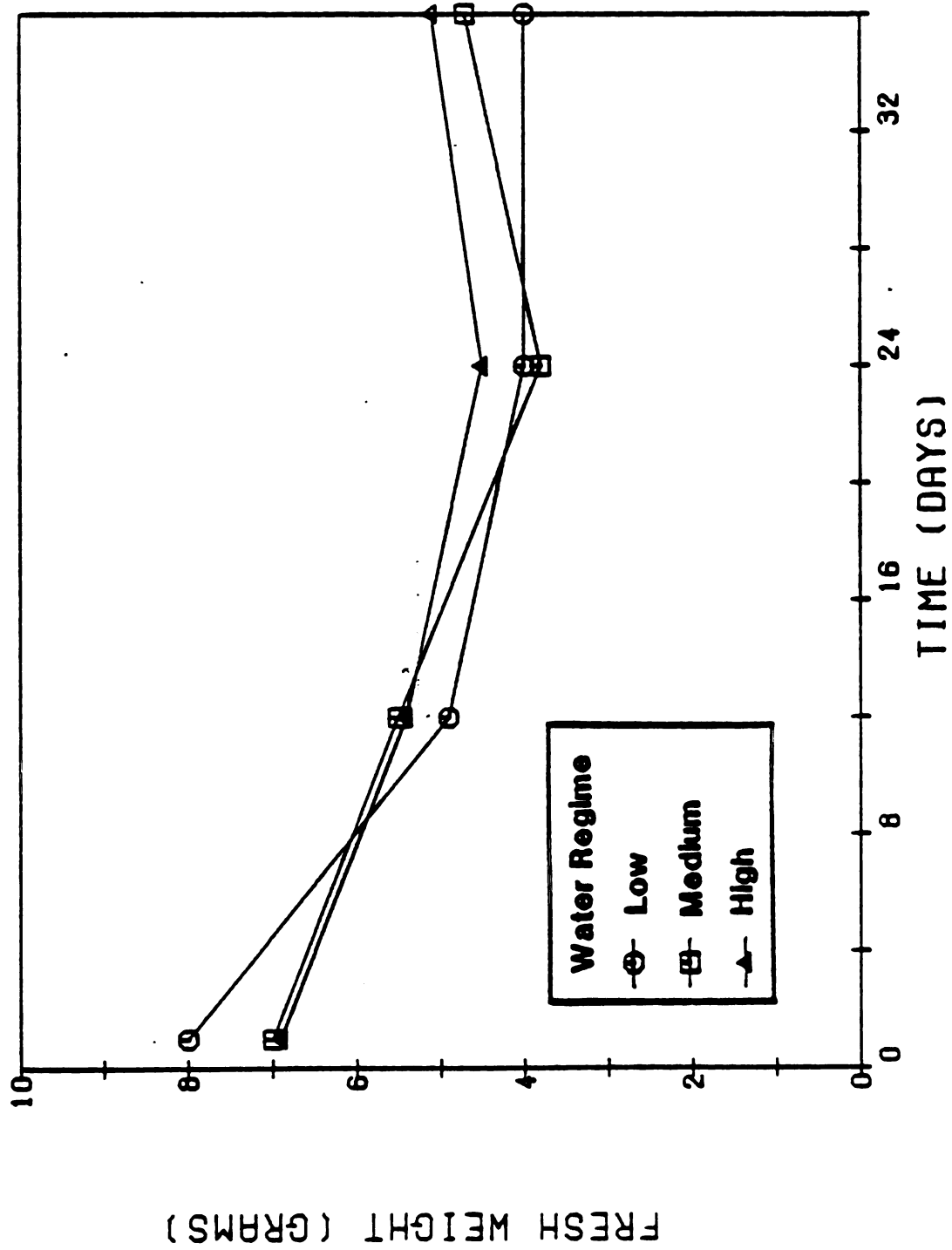


Figure 10. Influence of time and water regime on fresh weight of coleus 'Rose Wizard'.

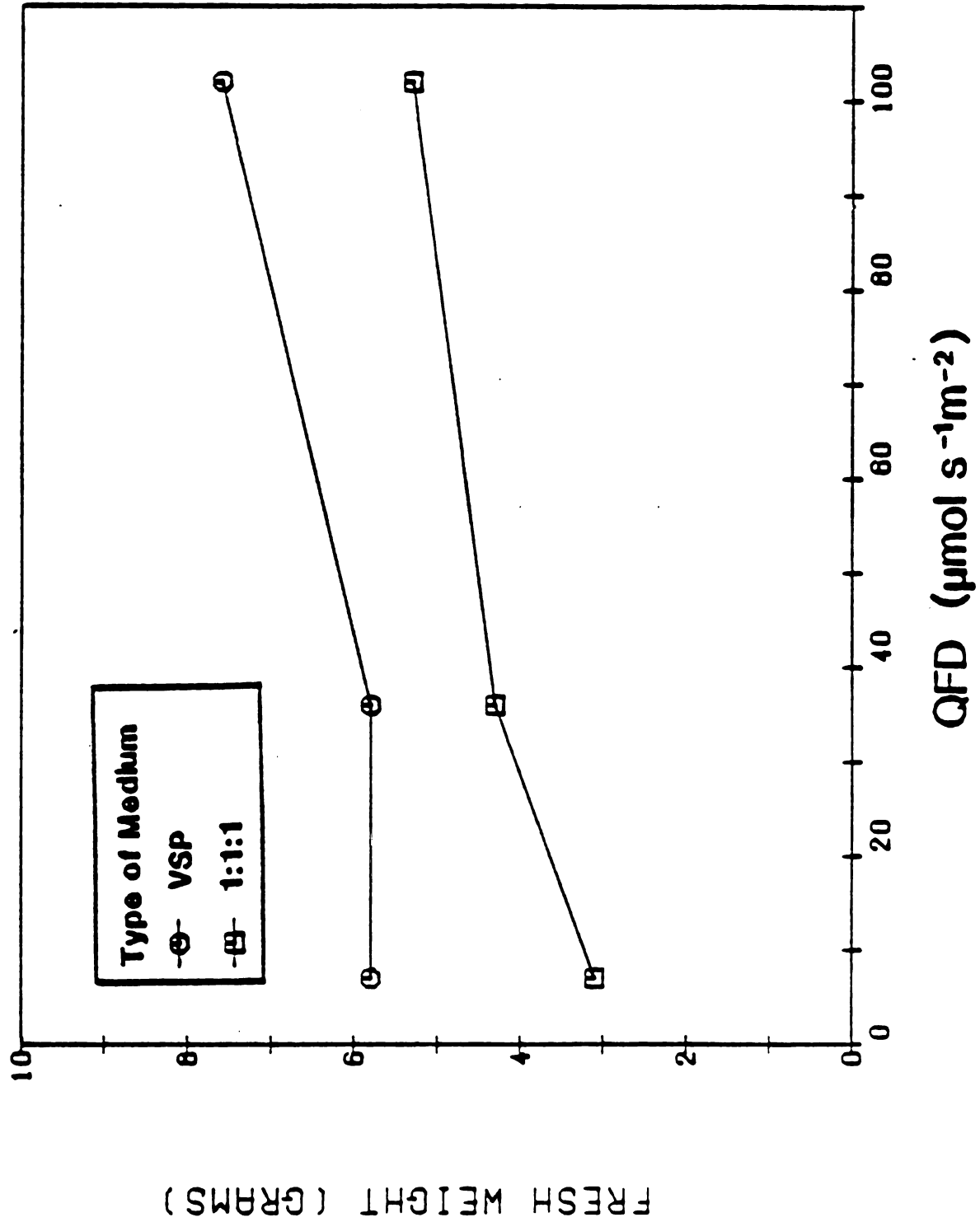


Figure 11. Influence of quantum flux density and media on fresh weight of coleus 'Rose Wizard'.

Table 6. Influence of postproduction environmental factors on change in stem height (cm) of coleus 'Rose Wizard'.

Environmental Factor	Level	Days Postproduction ^x			Mean ^y
		12	24	36	
QFD ^z ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	1.8	2.1	2.5	2.1 a
	36	1.7	2.6	2.6	2.3 a
	102	2.0	2.9	3.3	2.7 b
Temperature (°C)	21	1.7	2.2	2.8	2.2 a
	29	1.9	2.8	2.8	2.5 b
Media	VSP	1.7	2.7	2.7	2.4 a
	1:1:1	1.9	2.3	2.9	2.4 a
Water Regime	Low	1.8	2.5	2.7	2.3 a
	Med	1.9	2.5	2.8	2.4 a
	High	1.7	2.4	2.9	2.3 a

^x Calculation of stem height at postproduction intervals as change from day 0.

^y Mean separation within environmental factors by HSD test, 1% level.

^z QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Media	NS
Water Regime	NS
Time	
Linear	**
Quadratic	NS

Interactions

QFD X Temperature	**
QFD X Media	*
QFD X Time	NS
QFD X Water	*
Temperature X Media	NS
Temperature X Time	NS
Temperature X Water	NS
Media X Time	*
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

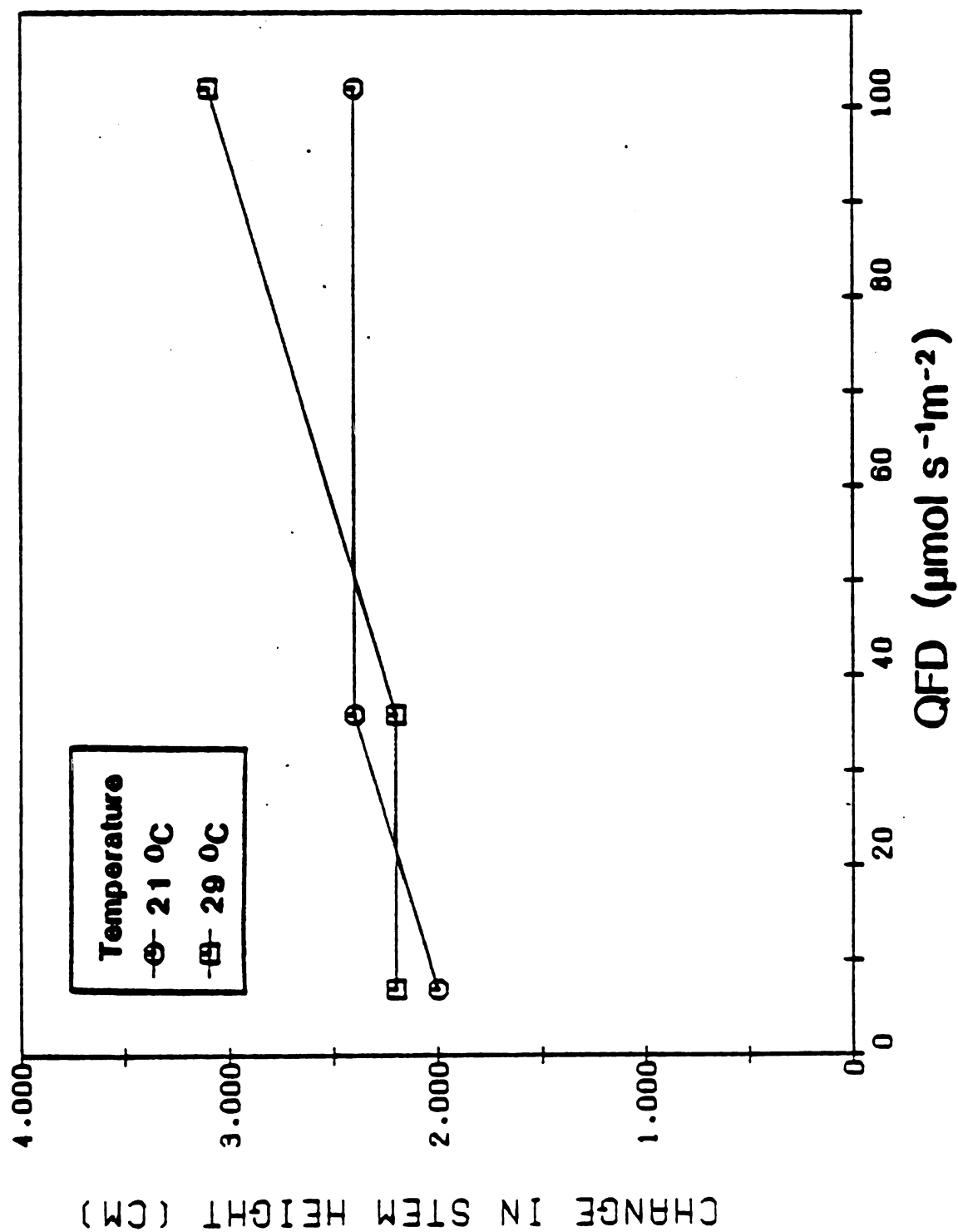


Figure 12. Influence of quantum flux density and temperature on change in stem height of coleus 'Rose Wizard'.

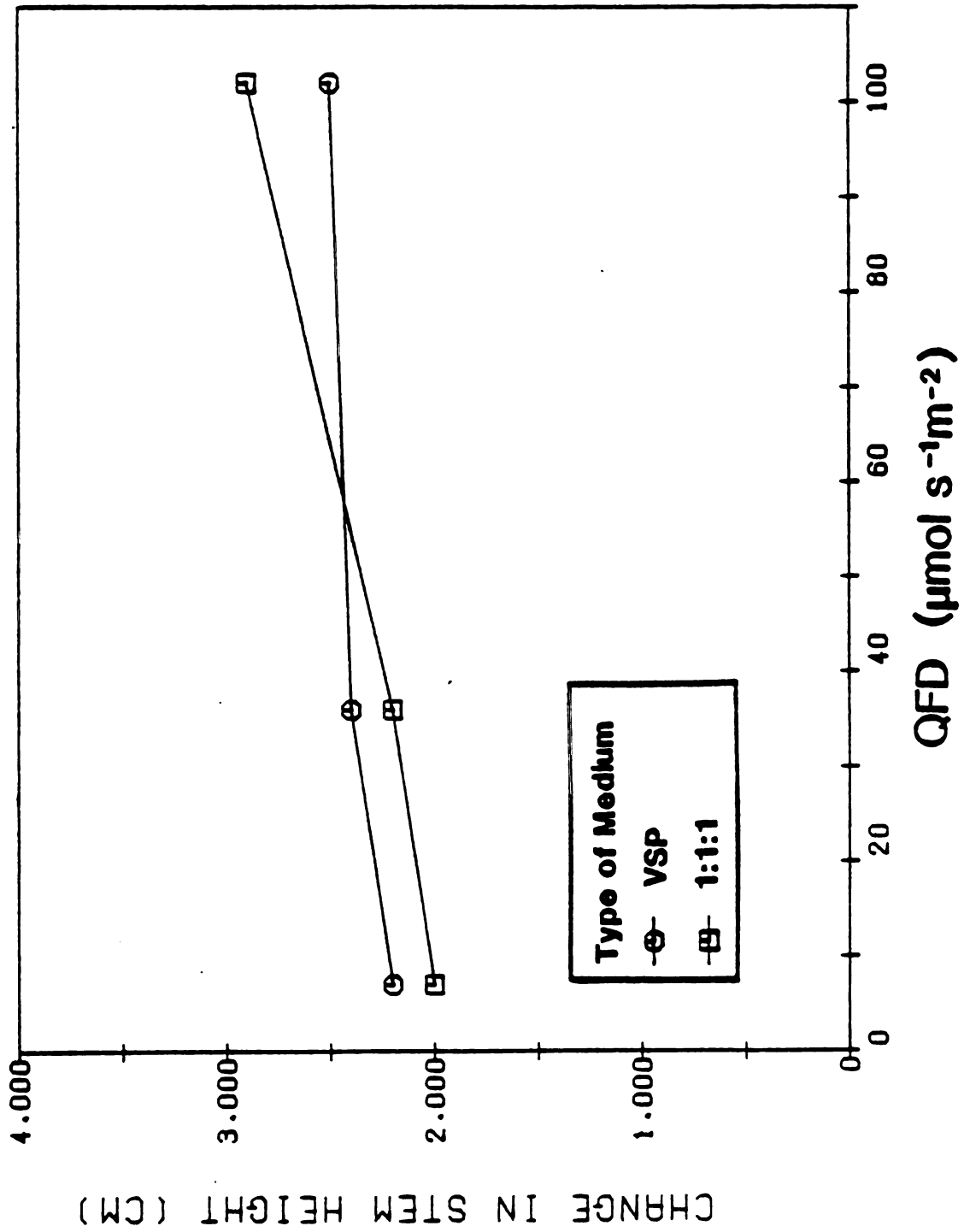


Figure 13. Influence of quantum flux density and media on change in stem height of coleus 'Rose Wizard'.

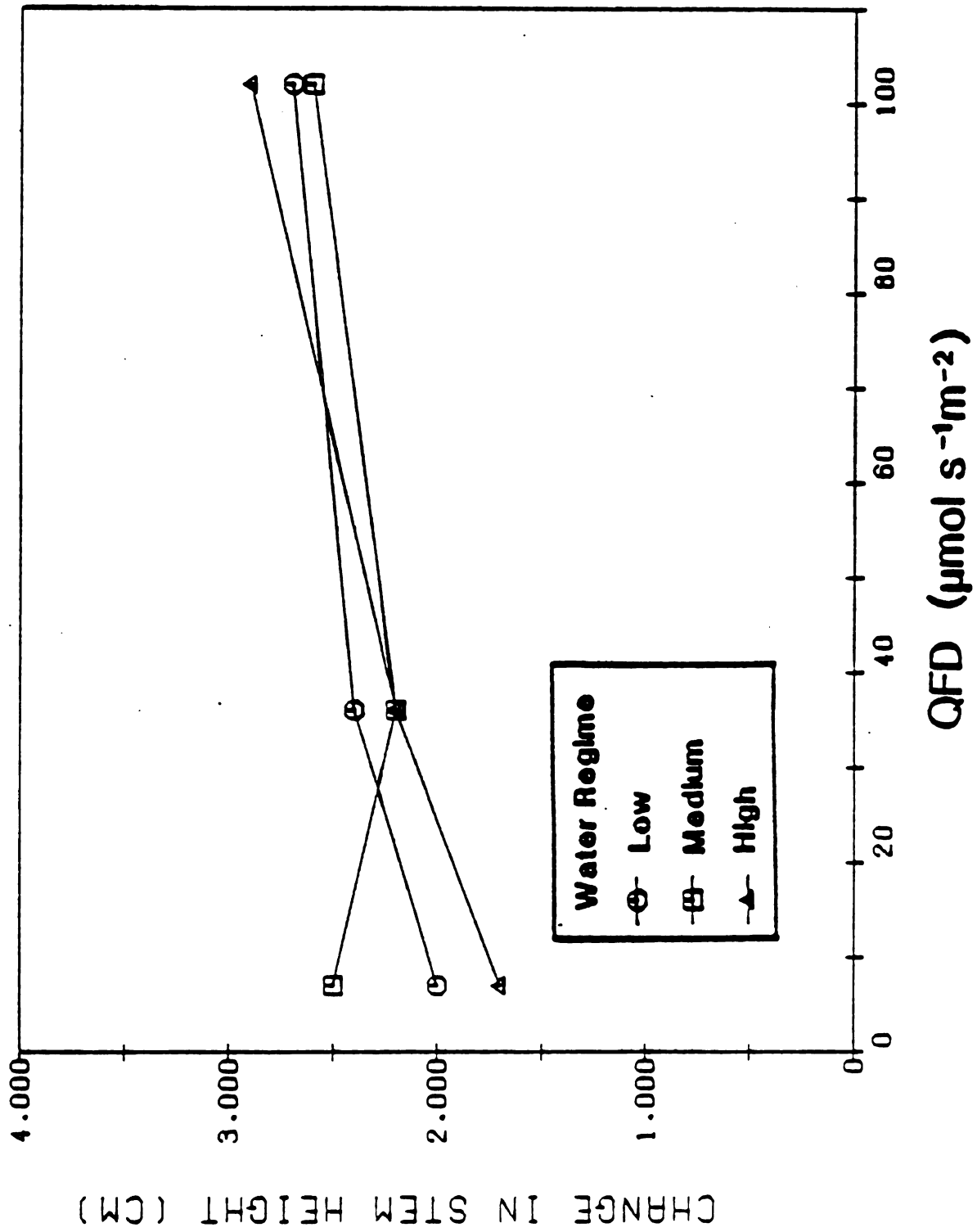


Figure 14. Influence of quantum flux density and water regime on change in stem height of coleys 'Rose Wizard'.

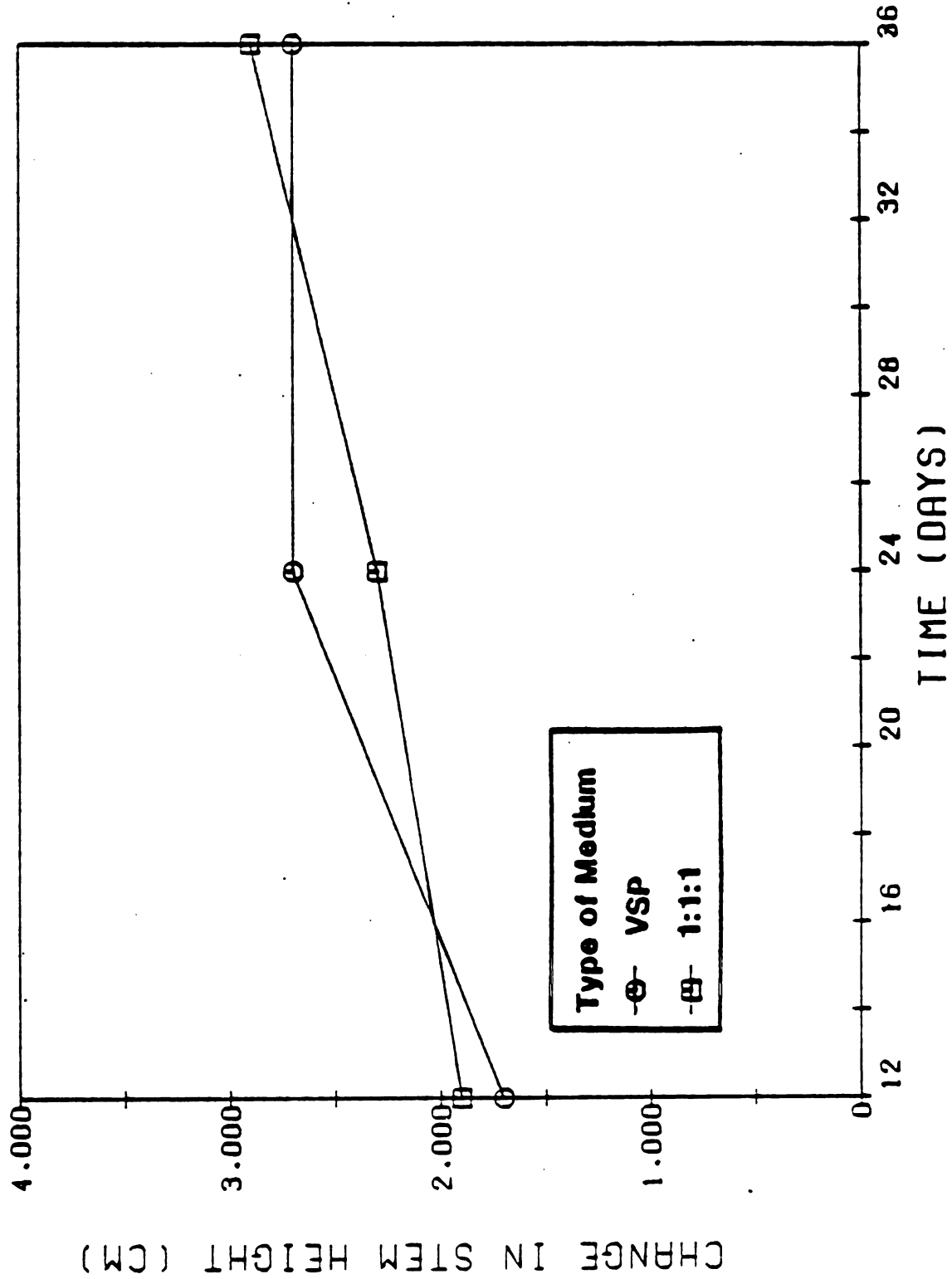


Figure 15. Influence of time and media on change in stem height of coleus 'Rose Wizard'.

GERANIUM

MATERIALS AND METHODS

Postproduction keeping quality of geranium was studied for 24 days.

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Leaf Weight

At 12 day intervals, after fresh weight determination, leaves were separated at the petiole and weighed.

Leaf Area

At 12 day intervals, after fresh weight determination, total leaf area was measured on all expanded leaves on a Li-Cor area meter (Model LI-3000).

Change in Stem Height

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

New Growth

New growth was rated (Table 12) at 12 day intervals from 1 to 5 (1= rapid and strong, 2= moderate and strong, 3= moderate but weak, 4= very weak, 5= no growth).

RESULTS

Fresh Weight (FW)

Main Effects

Highest FW was shared at the medium and high QFD levels at both 4.5 and 13°C and then declined as temperature increased. Medium type and water regime were not significant (Table 7).

Interactions

While low QFD level plants (Figure 16) lost FW to day 24, medium QFD level plants lost FW to day 12 and then gained to day 24. High QFD level plants gained FW to day 12 and remained stable today 24.

Leaf Weight (LW)

Main Effects

Highest LW was shared at the medium and high QFD levels at both 4.5 and 13°C. LW was approximately the same at 21 and 29°C while medium type and water regime were not significant (Table 8).

Interactions

An identical trend (Figure 17) emerged as for FW at the low and medium QFD levels. However, at the high QFD level, there was essentially no LW loss or gain from day 0 after 36 days. Over time (Figure 18), plants held at 4.5 and 29°C lost LW to day 12 and then gained to day 24. There was no LW loss from day 0 in plants held at 13°C while plants at 21°C continued to lose LW from day 0 to day 24.

Leaf Area (LA)

Main Effects

Greatest LA was shared at the medium and high QFD levels at 13°C while medium type and water regime were not significant (Table 9).

Interactions

LA (Figure 19) was greatest at the low QFD level at 4.5°C but at

both the medium and high QFD levels at 13°C. The trend for the effect of QFD level over time on LA (Figure 20) was the same as for LW. Over time (Figure 21), there was a decrease in LA regardless of temperature to day 12. After 24 days, LA had increased substantially for plants held at 13°C, while there was a continued decrease in plants at all other temperatures.

Change in Stem Height

Main Effects

Stem height increased the most under the high QFD level and at 21°C. Differences in media and water regime were not significant (Table 10).

Interactions

Plants were shortest at 4.5°C (Figure 22) while those at 13, 21, and 29°C were nearly equivalent in value after 12 days. After 24 days, plants held at 21°C demonstrated the greatest increase in stem height.

New Growth

Main Effects

Growth was strongest at the high QFD level and at 13°C while medium type and water regime were not significant (Table 11).

DISCUSSION

Both QFD level and temperature are important in the postharvest life of this plant species while minimal influence is exerted by type of medium and watering regime.

The parameters of fresh weight, leaf weight and leaf area each shared their highest values at both the medium and high QFD levels. Stem height was greatest at the high QFD level. Fresh weight and leaf

weight values were highest at 4.5 and 13°C while leaf area was greatest at 13°C. Stem height peaked at 13°C while new growth was best reflected at the high QFD level and at 13°C.

The most favorable conditions for 24 day postharvest marketability for geranium would be a 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$ QFD range and a temperature range of 4.5 to 13°C while there were no definable differences with medium type and water regime. These conditions would probably remain optimal for 36 day marketability.

Table 7. Influence of postproduction environmental factors on fresh weight (g) of geranium 'Sooner Red'.

Environmental Factor	Level	Days Postproduction			Mean ^x
		0	12	24	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	13.88	11.25	9.56	11.70 a
	36	13.76	11.93	12.41	12.70 ab
	102	12.12	13.42	13.20	12.91 b
Temperature (°C)	4.5	14.24	12.73	12.92	13.30 b
	13	12.95	12.84	13.37	13.05 b
	21	12.91	12.51	10.81	12.08 ab
	29	12.91	10.72	10.31	11.31 a
Media	VSP	12.90	12.11	11.83	12.28 a
	1:1:1	13.60	12.29	11.88	12.59 a
Water Regime	Low	13.10	12.18	11.75	12.35 a
	High	13.40	12.22	11.96	12.52 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	NS
Media	NS
Water Regime	NS
Time	
Linear	**
Quadratic	NS

Interactions

QFD x Temperature	NS
QFD X Media	NS
QFD X Time	**
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	NS
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 1% (**) level.

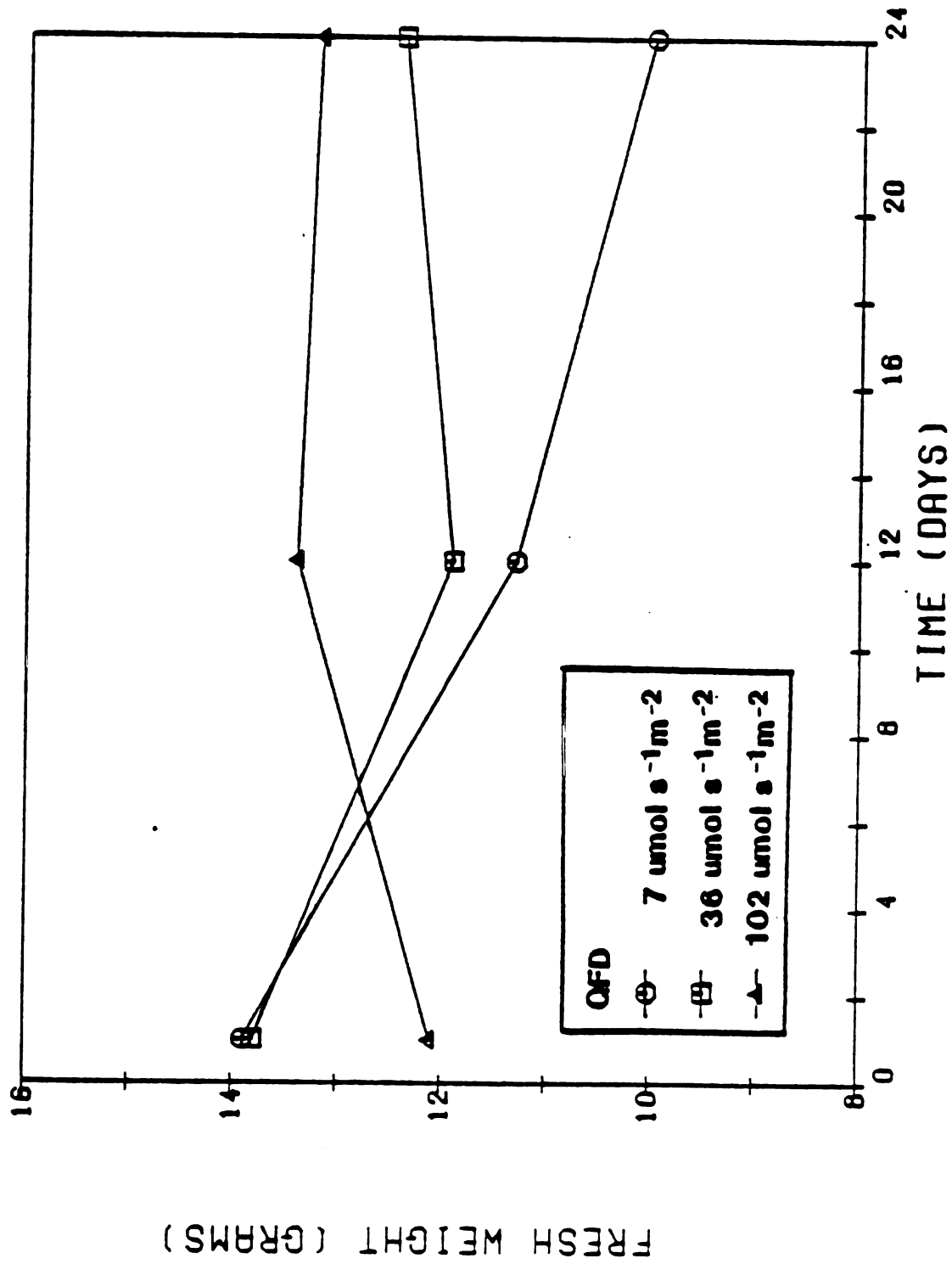


Figure 16. Influence of time and quantum flux density on fresh weight of geranium 'Sooner Red'.

Table 8 . Influence of postproduction environmental factors on leaf weight (g) of geranium 'Sooner Red'.

Environmental Factor	Level	Days Postproduction			Mean ^x
		0	12	24	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	6.12	4.28	3.96	4.79 a
	36	6.28	4.89	5.14	5.43 b
	102	5.35	5.32	5.25	5.31 b
Temperature (°C)	4.5	6.55	4.76	5.24	5.52 bc
	13	5.71	5.52	5.57	5.60 c
	21	5.71	4.88	3.96	4.85 a
	29	5.69	4.17	4.34	4.74 a
Media	VSP	5.69	4.87	4.99	5.18 a
	1:1:1	6.14	4.79	4.57	5.17 a
Water Regime	Low	5.78	4.89	4.64	5.10 a
	High	6.05	4.77	4.92	5.25 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	*
Temperature	
Linear	**
Quadratic	NS
Media	NS
Water Regime	NS
Time	
Linear	**
Quadratic	**

Interactions

QFD X Temperature	NS
QFD X Media	NS
QFD X Time	**
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

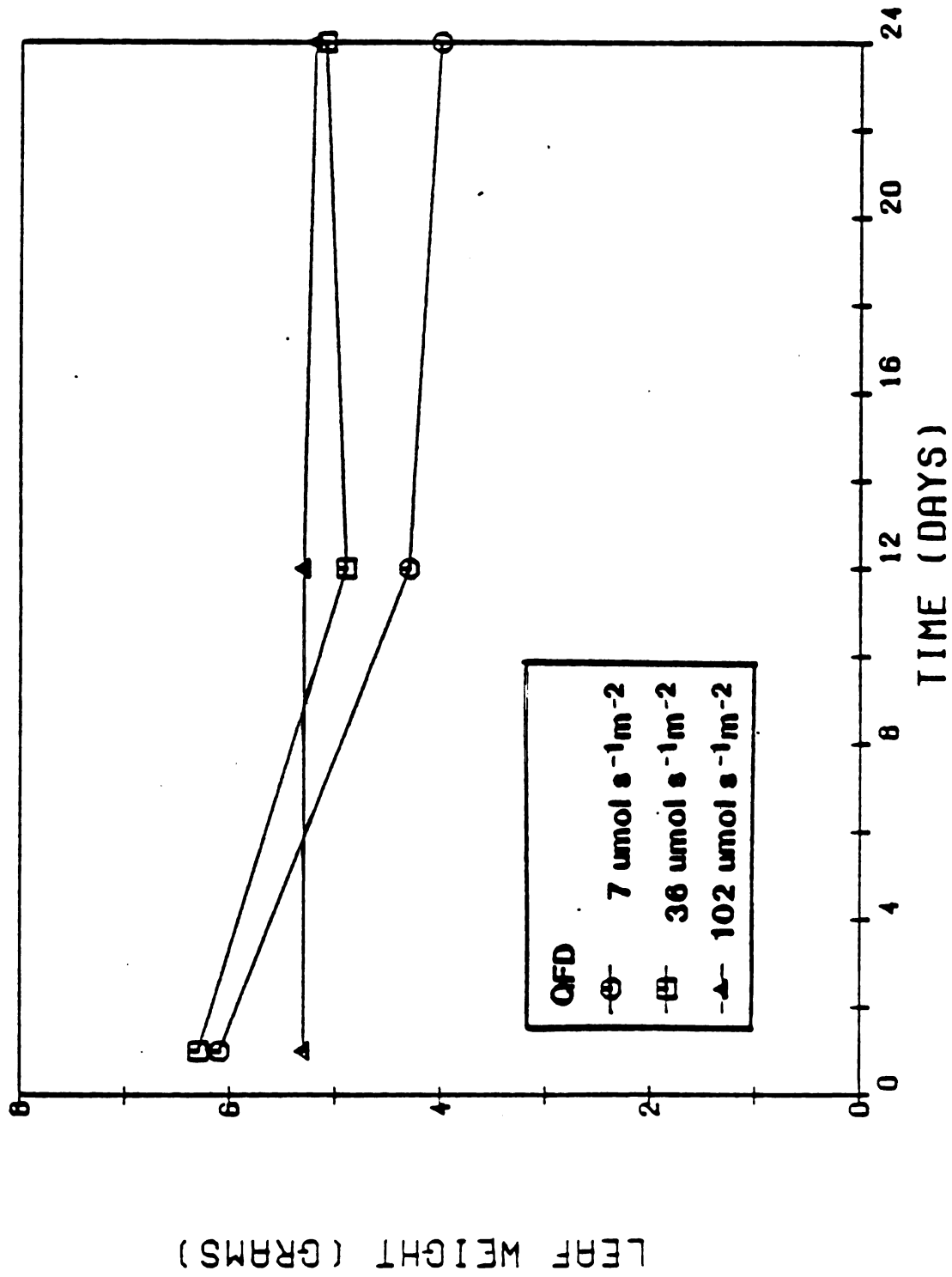


Figure 17. Influence of time and quantum flux density on leaf weight of geranium 'Sooner Red'.

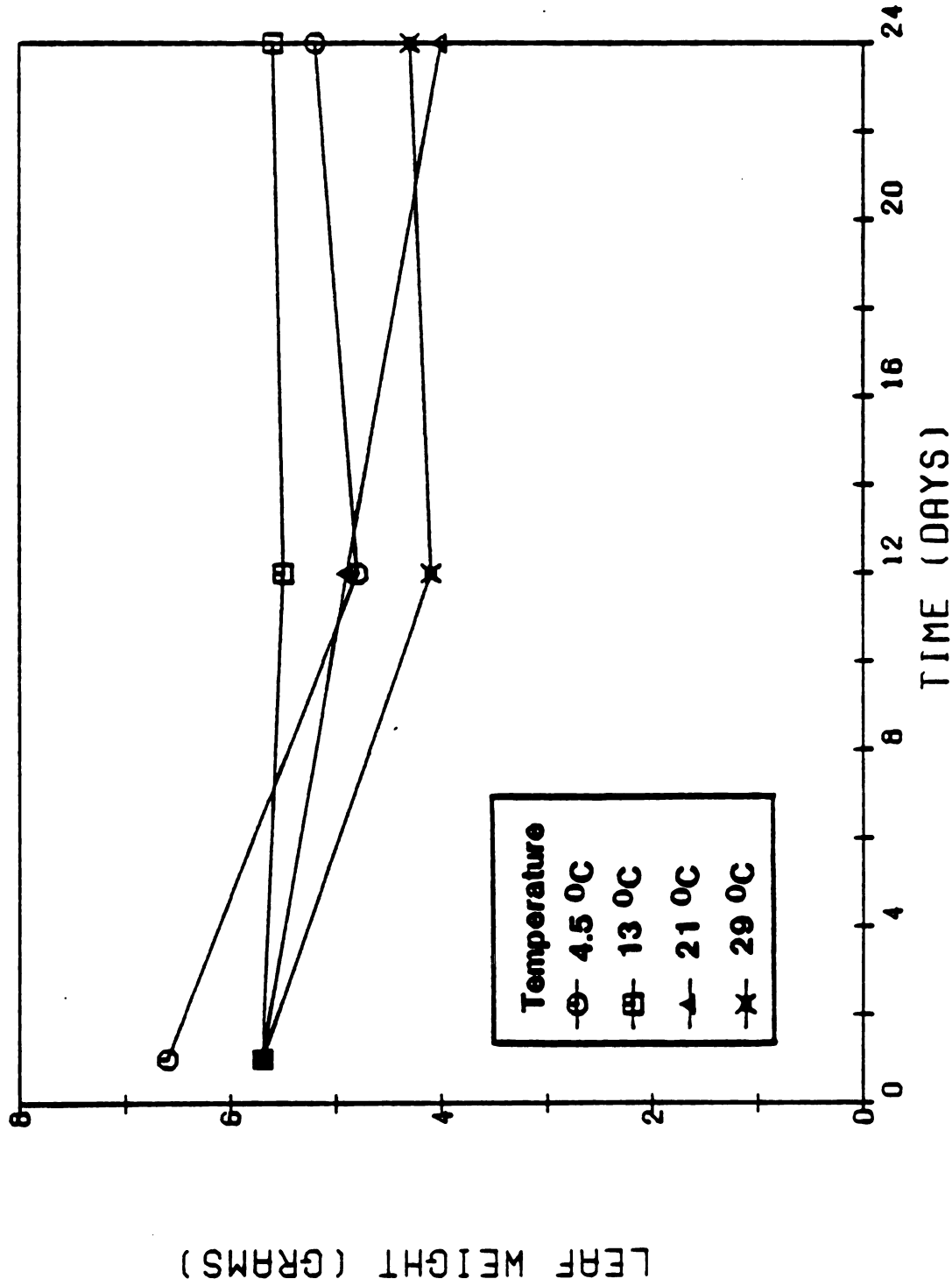


Figure 18. Influence of time and temperature on leaf weight of geranium 'Sooner Red'.

Table 9. Influence of postproduction environmental factors on leaf area (cm) of geranium 'Sooner Red'.

Environmental Factor	Level	Days Postproduction			Mean ^x
		0	12	24	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	21.19	14.66	13.56	16.47 a
	36	21.06	16.32	17.99	18.46 b
	102	18.61	18.51	18.34	18.49 b
Temperature (°C)	4.5	22.12	16.63	15.42	18.06 ab
	13	18.72	17.70	21.46	19.29 b
	21	20.62	15.90	14.33	16.95 a
	29	19.68	15.75	15.31	16.91 a
Media	VSP	19.66	16.61	16.73	17.67 a
	1:1:1	20.91	16.38	16.53	17.94 a
Water Regime	Low	20.05	16.47	15.77	17.43 a
	High	20.52	16.52	17.49	18.18 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	NS
Media	NS
Water Regime	NS
Time	
Linear	**
Quadratic	**

Interactions

QFD X Temperature	*
QFD X Media	NS
QFD X Time	**
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

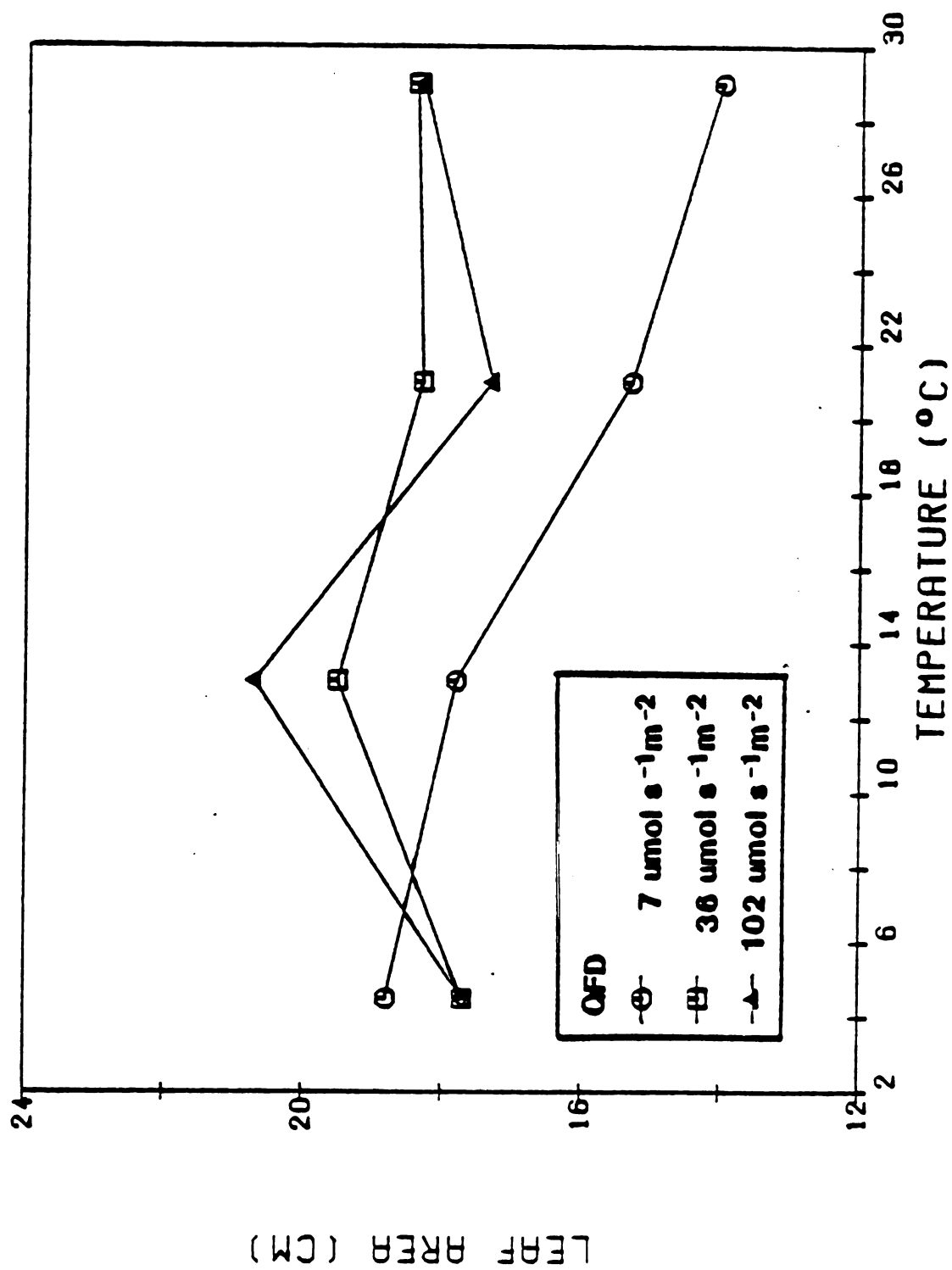


Figure 19. Influence of temperature and quantum flux density on leaf area of geranium 'Sooner Red'.

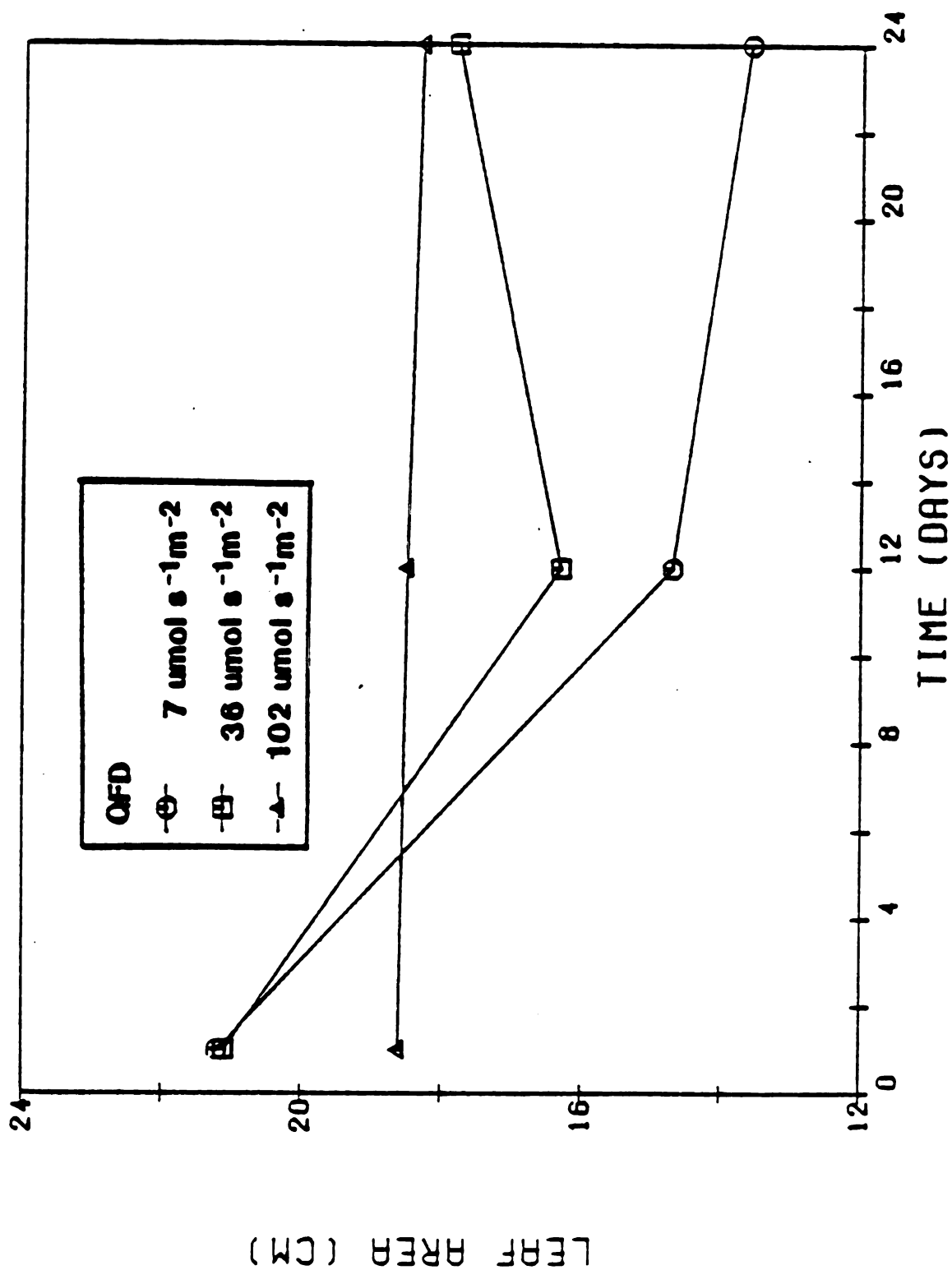


Figure 20. Influence of time and quantum flux density on leaf area of geranium 'Sooner Red'.

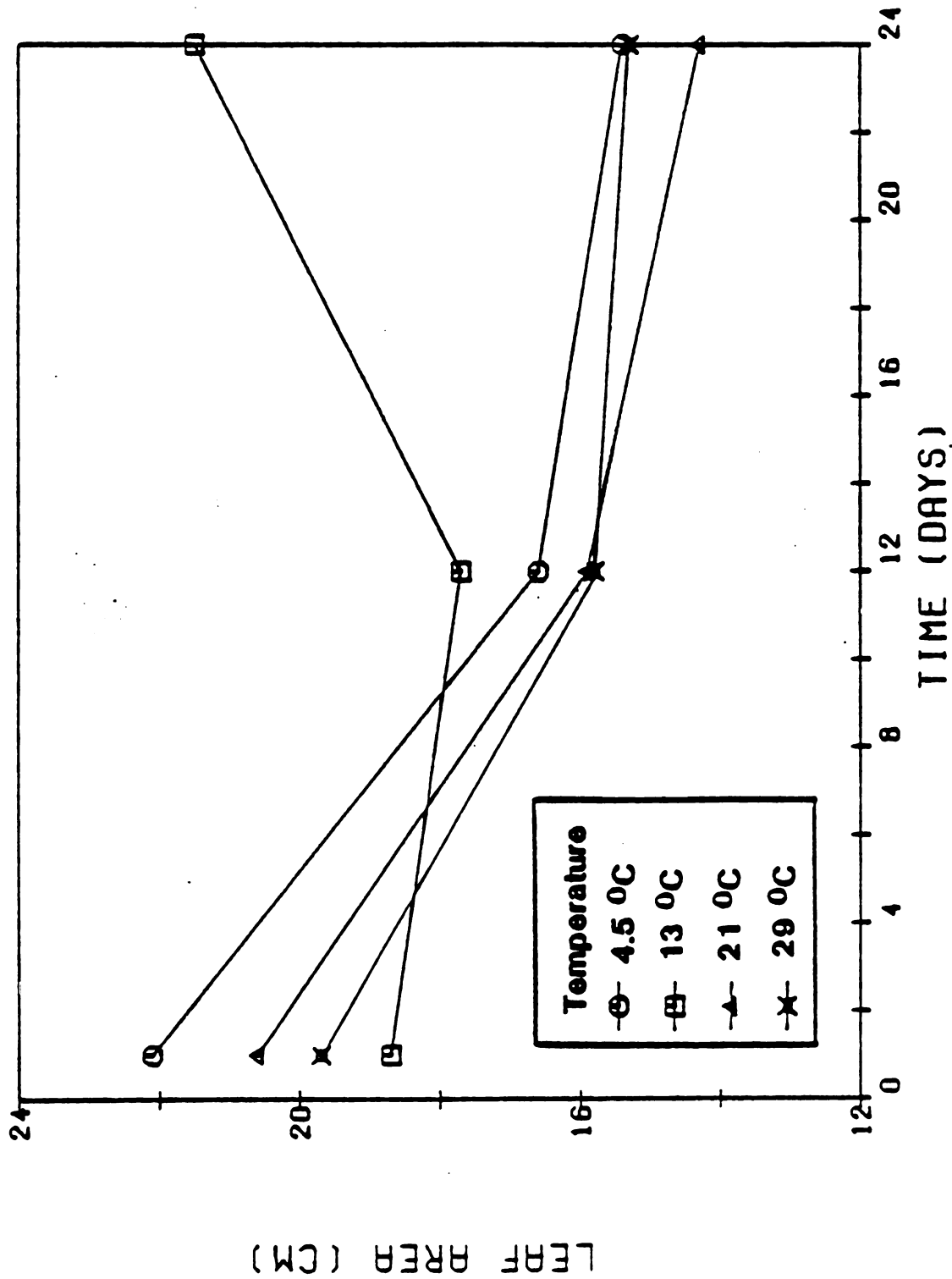


Figure 21. Influence of time and temperature on leaf area of geranium 'Sooner Red'.

Table 10. Influence of postproduction environmental factors on change in stem height (cm) of geranium 'Sooner Red'.

Environmental Factor	Level	Days Postproduction ^x		Mean ^y
		12	24	
QFD ^z ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	0.8	1.2	1.0 A
	36	0.8	1.4	1.1 AB
	102	1.0	1.6	1.3 B
Temperature ($^{\circ}\text{C}$)	4.5	0.5	0.8	0.7 a
	13	0.9	1.5	1.2 b
	21	1.0	2.1	1.6 b
	29	1.1	1.3	1.2 b
Media	VSP	0.9	1.3	1.1 a
	1:1:1	0.8	1.5	1.2 a
Water Regime	Low	0.9	1.3	1.1 a
	High	0.9	1.6	1.2 a

^x Calculation of stem height at postproduction intervals as change from day 0.

^y Mean separation within environmental factors by HSD test, 5% (capitals) or 1% level.

^z QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	*
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	NS
Water Regime	NS
Time	
Linear	**

Interactions

QFD X Temperature	NS
QFD X Media	NS
QFD X Time	NS
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

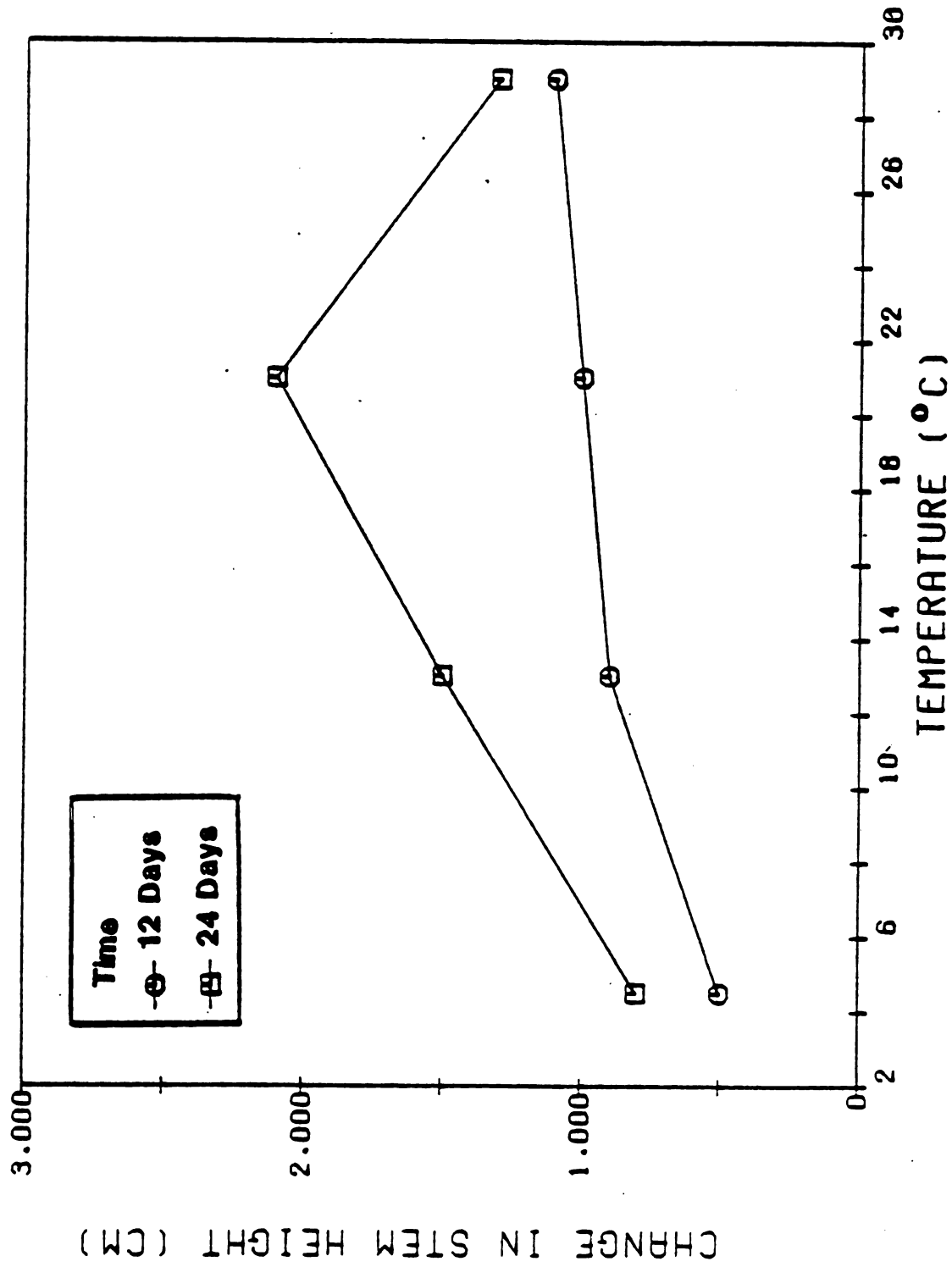


Figure 22. Influence of temperature and time on change in stem height of geranium 'Sooner Red'.

Table 11. Influence of postproduction environmental factors on new growth of geranium 'Sooner Red'.

Environmental Factor	Level	Days Postproduction			Mean ^x
		0	12	24	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	2.5	3.3	3.9	3.2 c
	36	2.4	3.0	3.2	2.9 b
	102	2.6	2.7	2.8	2.7 a
Temperature (°C)	4.5	2.5	3.9	4.2	3.5 c
	13	2.6	2.4	2.7	2.6 a
	21	2.4	3.0	2.9	2.8 ab
	29	2.5	2.7	3.5	2.9 b
Media	VSP	2.6	2.9	3.3	2.9 a
	1:1:1	2.5	3.1	3.3	3.0 a
Water Regime	Low	2.5	3.1	3.4	3.0 a
	High	2.5	3.0	3.3	2.9 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

New growth rating scale: 1= Rapid and strong 2 = Moderate and strong 3= Moderate but weak 4= Very weak 5= No growth

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	NS
Water Regime	NS
Time	
Linear	**
Quadratic	NS

Interactions

QFD X Temperature	**
QFD X Media	*
QFD X Time	**
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	*
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

IMPATIENS

MATERIALS AND METHODS

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Change in Stem Height

Chilling injury damage prevented measurement of stem height change at 4.5°C.

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

Number of New Flowers

Beginning on day 0, all flowers were removed except the youngest open flower on one plant for all replicates. Data were collected at the opening of all subsequent flowers at 2 to 3 day intervals for 36 days. The number of new flowers was determined after the 36 day period for all treatment combinations.

Visual Assessment

Plants were given a visual assessment at 12 day intervals describing flower and foliage quality as an overall indication of postharvest keeping quality.

RESULTS

Fresh Weight (FW)

Main Effects

Highest FW was shared at the medium and high QFD levels and at 13 and 21°C. FW was higher in the peat-lite medium and under high moisture conditions (Table 13).

Interactions

Over time (Figure 23), FW declined from day 0 to day 36 at both 4.5 and 29°C. Plants at 13 and 21°C maintained their day 0 FW over the 36 day testing period. Under both low and high moisture (Figure 24), FW was highest at 13 and 21°C. Over time (Figure 25), while the same trend of FW loss occurred at both moisture levels, the magnitude was greater under low moisture.

FW was highest (Figure 26) in both media at 13 and 21°C but the magnitude was larger in the peat-lite medium.

Change in Stem Height

Main Effects

The greatest gain in stem height was at the medium QFD level and at 13 and 21°C in the peat-lite medium. Water regime was not significant (Table 14).

Interactions

Over time (Figure 27), plants gained in stem height regardless of QFD level. However, low QFD level plants showed the least gain from day 12 to day 24. Over time (Figure 28), plants gained in stem height regardless of temperature. The gain over time was much less however for plants held at 29°C.

Plants held in the soil-based medium (Figure 29) were largely unaffected by QFD level, while those in the peat-lite medium were

tallest at the medium QFD level. The trend (Figure 30) for stem height increase over time was similar for both media but the magnitude of gain was larger in the peat-lite medium.

Number of New Flowers

Main Effects

There were more flowers in the 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$ QFD range and from 13 to 21°C in the peat-lite medium while water regime was not significant (Table 14).

Interactions

At 4.5 and 29°C (Figure 31), flowering was negligible regardless of QFD level. The greatest number of new flowers occurred at 13 and 21°C regardless of QFD level. At 7 $\mu\text{mol s}^{-1} \text{m}^{-2}$, flowering was minimal regardless of temperature.

Both media (Figure 32) supported minimal flowering at 4.5 and 29°C. However, while there was an average of 17 flowers at both 13 and 21°C in the peat-lite medium, there were only 12 and 6 respectively at 13 and 21°C in the soil-based medium.

Visual Assessment

4.5°C

After only 3 days at this temperature, plants displayed chilling injury with water soaked spots on the foliage, foliage fade, and shiny flower buds which failed to open at all QFD levels. Wilting, abscission and necrosis of the foliage became so severe that after only 12 days virtually all plants were dead over all treatments. Maximum marketability at this temperature was 2 days.

13°C

After 12 days, there were many flowers with intense color development at both the medium and high QFD levels and only a rare flower at the low QFD level. Flowers were larger in the peat-lite medium (3.5 cm) compared to the soil-based medium (2.8 cm). After 36 days, only a few buds remained at the low QFD level and stems were elongated. At the medium and high QFD levels, flowers remained abundant and were larger with the greatest color development and longevity over all other temperature and QFD treatment combinations.

21°C

After 12 days, plants at the medium and high QFD levels were taller, and flowers were fewer, smaller and had less color development as comparable QFD levels at 13°C. This pattern persisted for 36 days. There were more flowers under high moisture than low moisture. Stems of low QFD plants were elongated and new flowers were pink and small. After 36 days, it was noted that leaf size was larger in the peat-lite medium.

29°C

Flower formation declined after 5 days at this temperature at all QFD levels. The few flowers that opened were very small and pale pink. After 12 days, plants were spindly with sparse, dull foliage and chlorosis. Marketability was poor after 12 days.

DISCUSSION

This study revealed that while QFD level influenced keeping quality, temperature had a larger role in the postharvest life of impatiens within the ranges tested. Moderate temperatures prolonged keeping quality. There was approximately a 65 and 40% fresh weight

loss at 4.5 and 29°C respectively after 36 days, while plants at 13 and 21°C maintained their day 0 fresh weight level. We assume this to correlate directly with marketability.

Plants tested within the 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$ range displayed superior performance over those at the 7 $\mu\text{mol s}^{-1} \text{m}^{-2}$ QFD level with regard to fresh weight and visual assessment.

It is more difficult to recommend one medium type over the other since plants in the peat-lite medium were larger (25 gms) than those in the soil-based medium (17 gms) when they entered postharvest treatment due to a production influence. However, there were more flowers over all treatment combinations in the peat-lite medium and flower size was larger at 13°C in the peat-lite mix.

At 29°C after 24 days, stem height increase was minimal while plants at 13 and 21°C continued to gain for 36 days.

The number of new flowers over the 36 day testing period was dramatically affected by both QFD level and temperature. There were many more new flowers at 13 and 21°C regardless of QFD level. Flowering essentially ceased between 7 and 36 $\mu\text{mol s}^{-1} \text{m}^{-2}$. This would establish necessary QFD levels to maintain flowering to the bedding plant industry.

From this investigation, the following conditions are recommended for optimum 36 day postharvest marketability: a QFD range of 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$ and a 13 to 21°C temperature range under high moisture in a peat-lite medium.

Table 12. Influence of postproduction environmental factors on fresh weight (g) of impatiens 'Super Elfin Red'.

Environmental Factor	Level	Days Postproduction				Mean $\bar{x}$
		0	12	24	36	
QFD y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	20.87	17.83	16.66	13.30	17.16 a
	36	22.09	18.50	19.40	17.24	19.30 b
	102	21.17	18.36	18.84	16.93	18.83 b
Temperature ($^{\circ}\text{C}$)	4.5	21.36	13.46	12.84	7.61	13.82 a
	13	20.80	23.48	23.22	21.31	22.20 c
	21	21.47	20.82	22.71	21.10	21.52 c
	29	21.87	15.16	14.43	13.27	16.18 b
Media	VSP	25.13	22.94	22.55	19.34	22.49 b
	1:1:1	17.62	13.52	14.04	12.30	14.37 a
Water Regime	Low	21.95	17.18	17.51	15.26	17.98 A
	High	20.80	19.28	19.09	16.38	18.89 B

$\bar{x}$ Mean separation within environmental factors by HSD test, 5% (capitals) or 1% level.

y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	**
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	
Linear	*
Time	
Linear	**
Quadratic	NS

Interactions

QFD X Temperature	NS
QFD X Media	NS
QFD X Time	NS
QFD X Water	NS
Temperature X Media	**
Temperature X Time	**
Temperature X Water	*
Media X Time	NS
Media X Water	NS
Water X Time	*

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

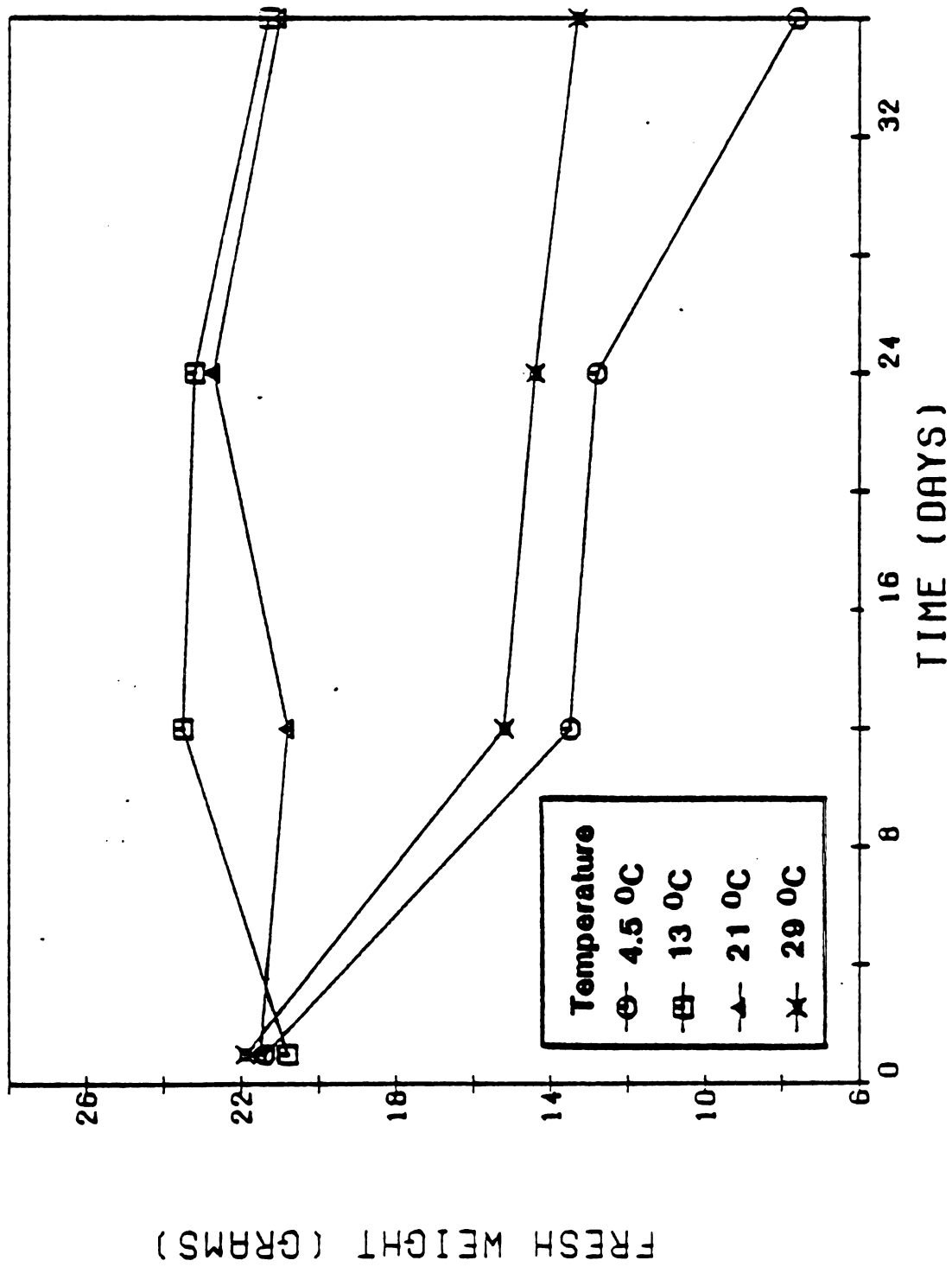


Figure 23. Influence of time and temperature on fresh weight of impatiens 'Super Elfin Red'.

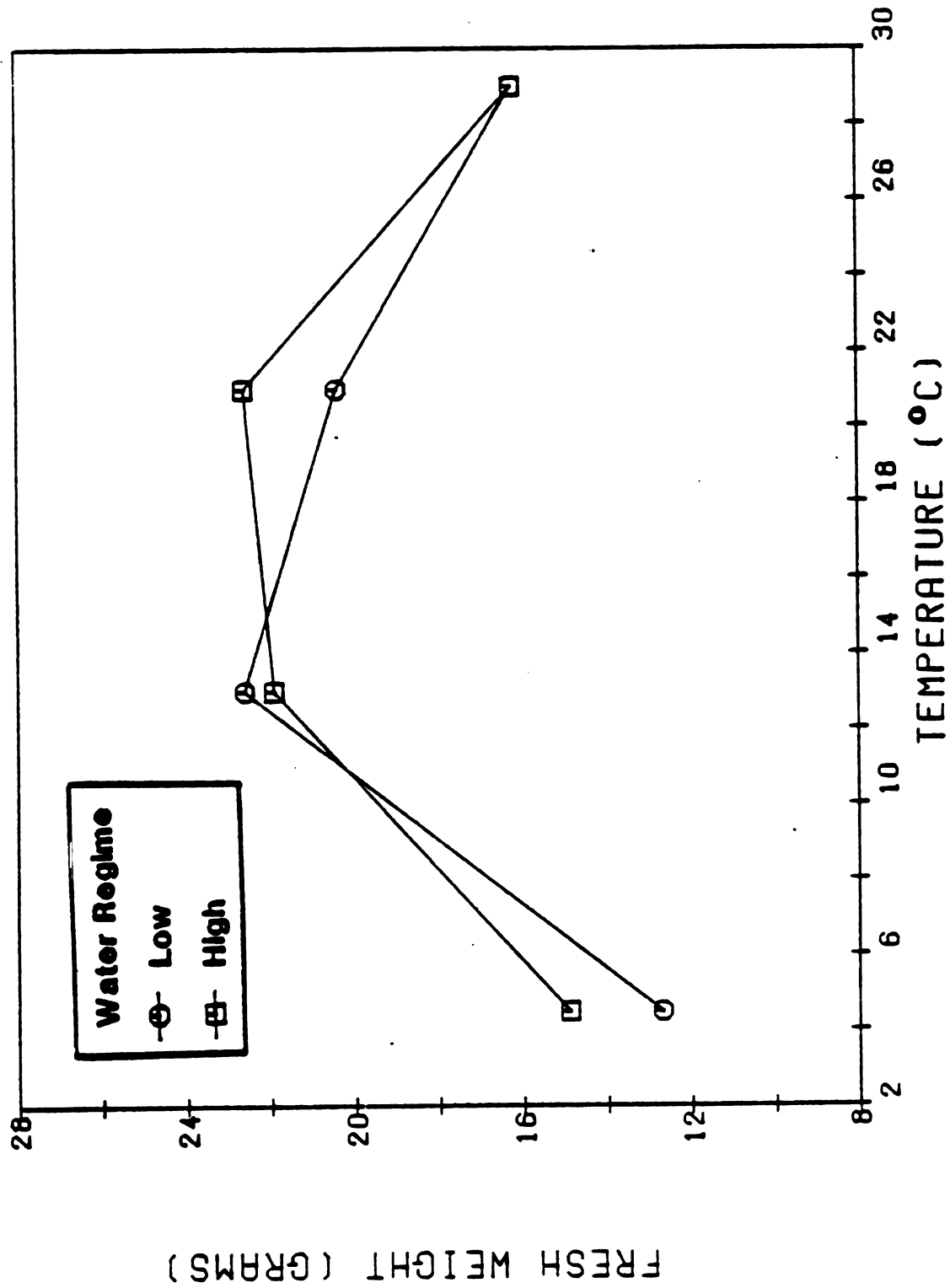


Figure 24. Influence of temperature and water regime on fresh weight of impatiens 'Super Elfin Red'.

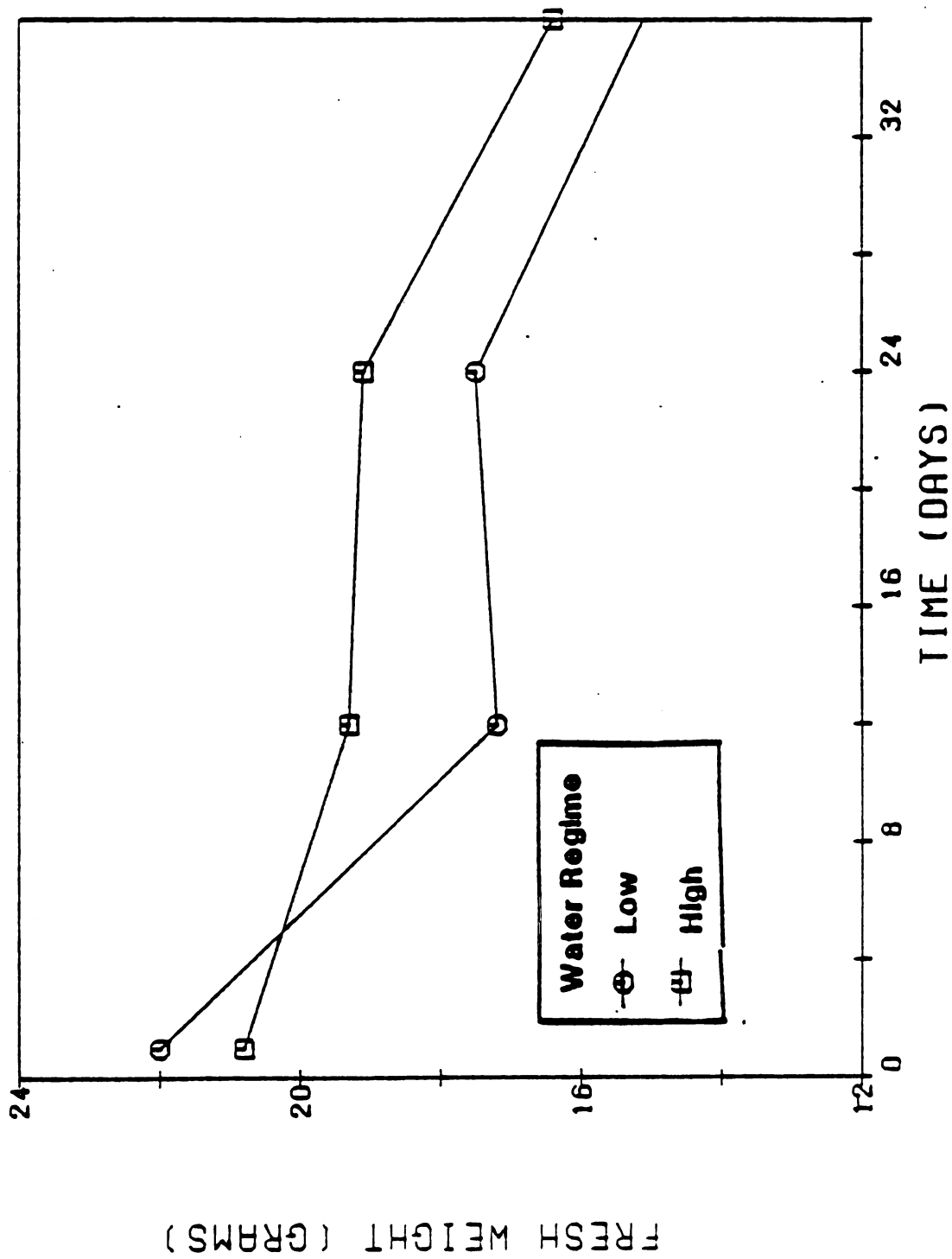


Figure 25. Influence of time and water regime on fresh weight of impatiens 'Super Elfin Red'.

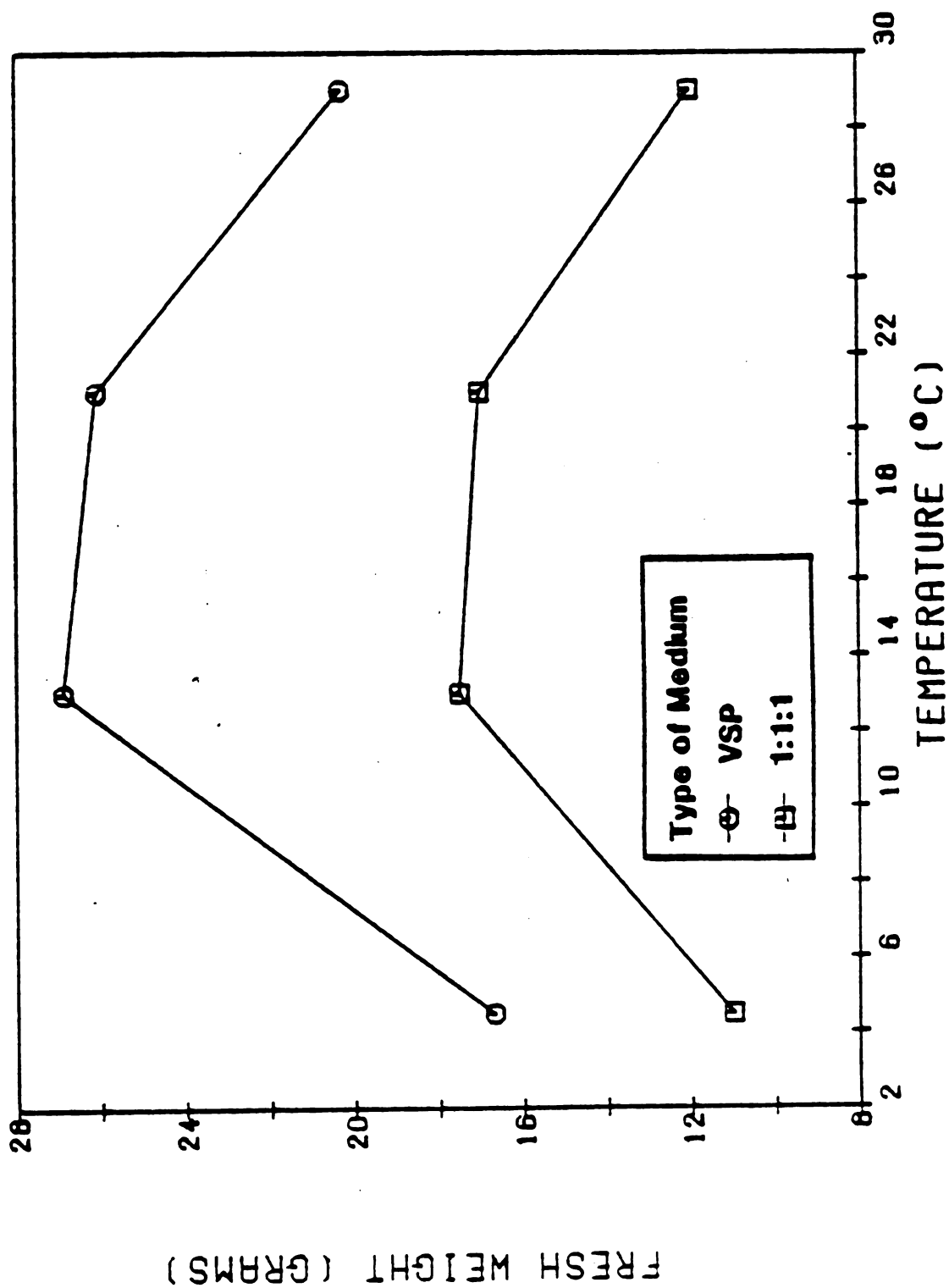


Figure 26. Influence of temperature and media on fresh weight of impatiens 'Super Elfin Red'.

Table 13. Influence of postproduction environmental factors on change in stem height of impatiens 'Super Elfin Red'.

Environmental Factor	Level	Days Postproduction ^x			Mean ^y
		12	24	36	
QFD ^z ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	0.8	1.4	2.5	1.6 A
	36	0.7	1.8	2.9	1.8 B
	102	0.6	1.7	2.5	1.6 A
Temperature (°C)	13	0.5	1.6	3.1	1.7 B
	21	0.4	1.7	3.0	1.7 B
	29	1.1	1.6	1.8	1.5 A
Media	VSP	0.6	1.9	3.0	1.8 b
	1:1:1	0.7	1.4	2.3	1.5 a
Water Regime	Low	0.7	1.5	2.6	1.6 a
	High	0.6	1.8	2.6	1.7 a

^x Calculation of stem height at postproduction intervals as change from day 0.

^y Mean separation within environmental factors by HSD test, 5% (capital) or 1% level.

^z QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	NS
Quadratic	*
Temperature	
Linear	*
Quadratic	NS
Media	**
Water Regime	NS
Time	
Linear	**
Quadratic	NS

Interactions

QFD X Temperature	NS
QFD X Media	**
QFD X Time	*
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	**
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

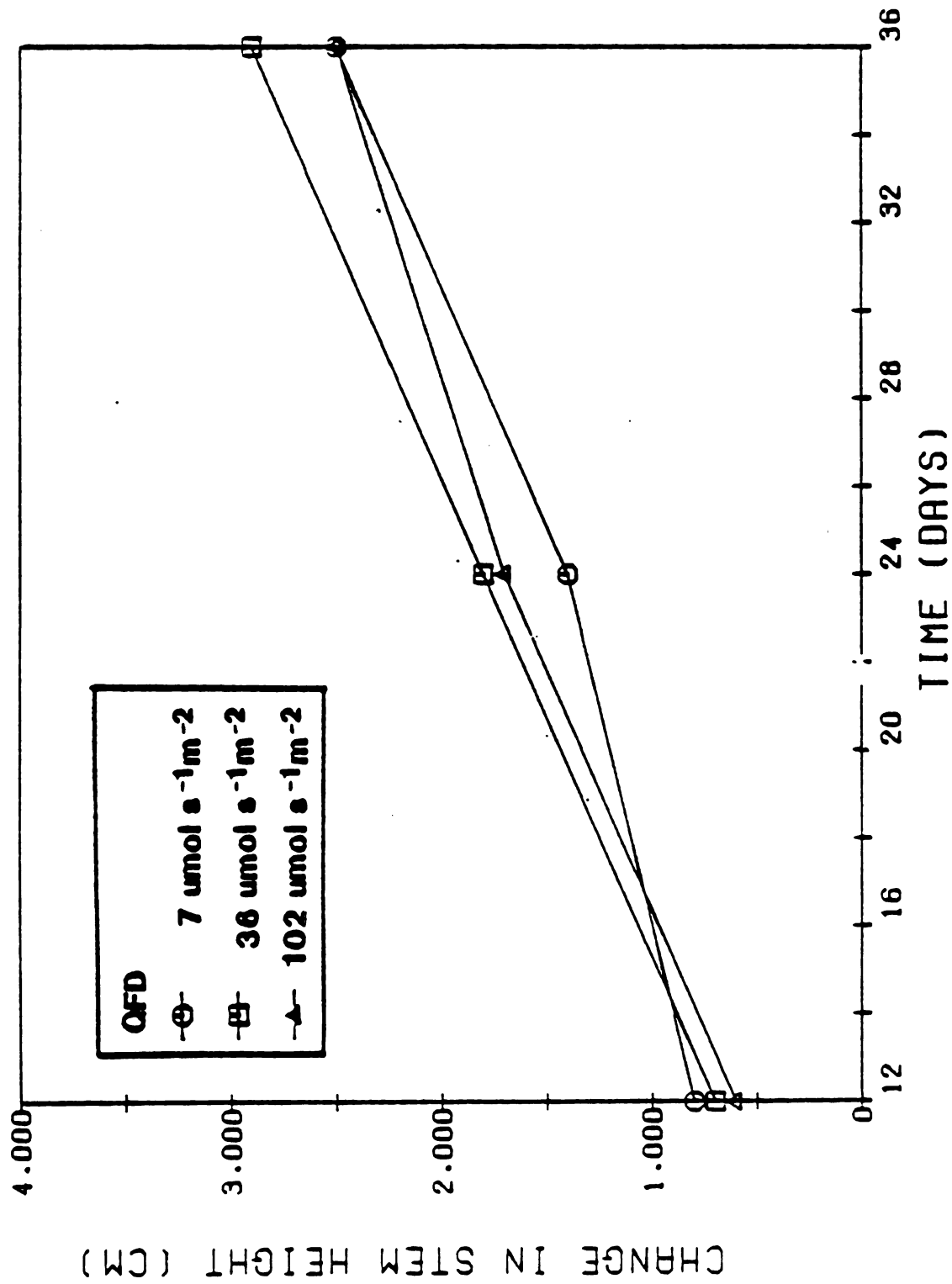


Figure 27. Influence of time and quantum flux density on change in stem height of impatiens 'Super Elfin ed'.

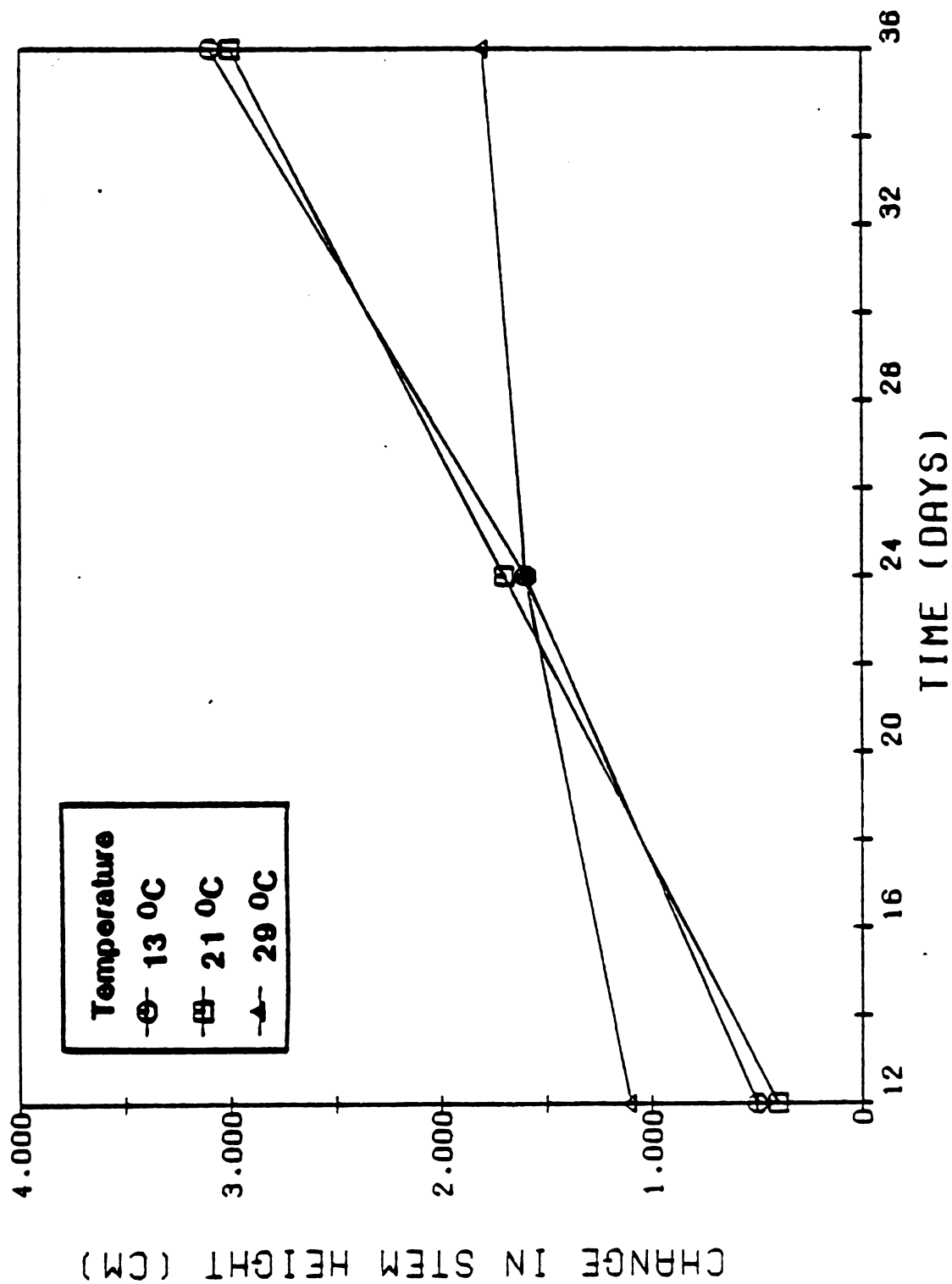


Figure 28. Influence of time and temperature on change in stem height of impatiens 'Super Elfin Red'.

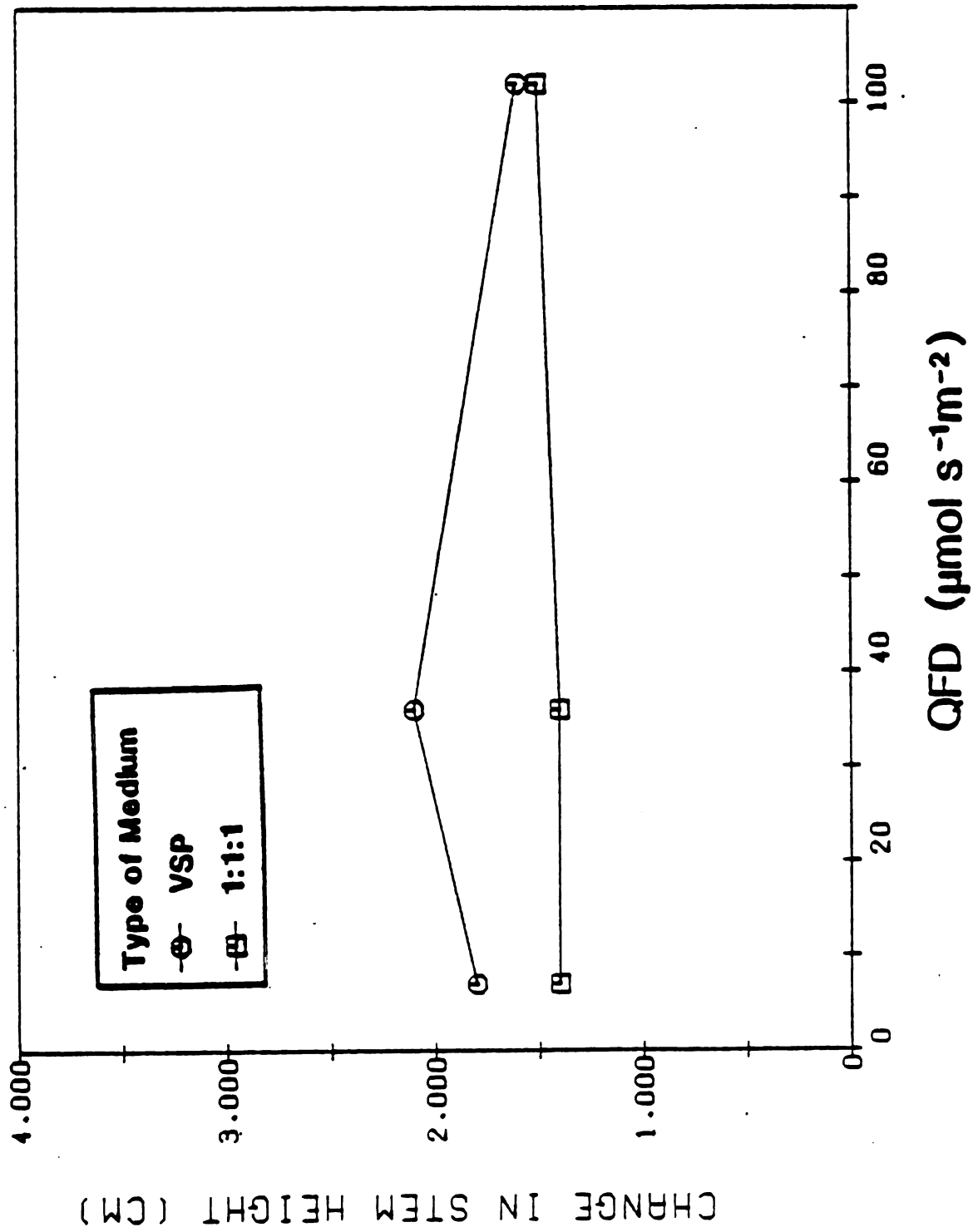


Figure 29. Influence of quantum flux density and media on change in stem height of impatiens 'Super Elfin Red'.

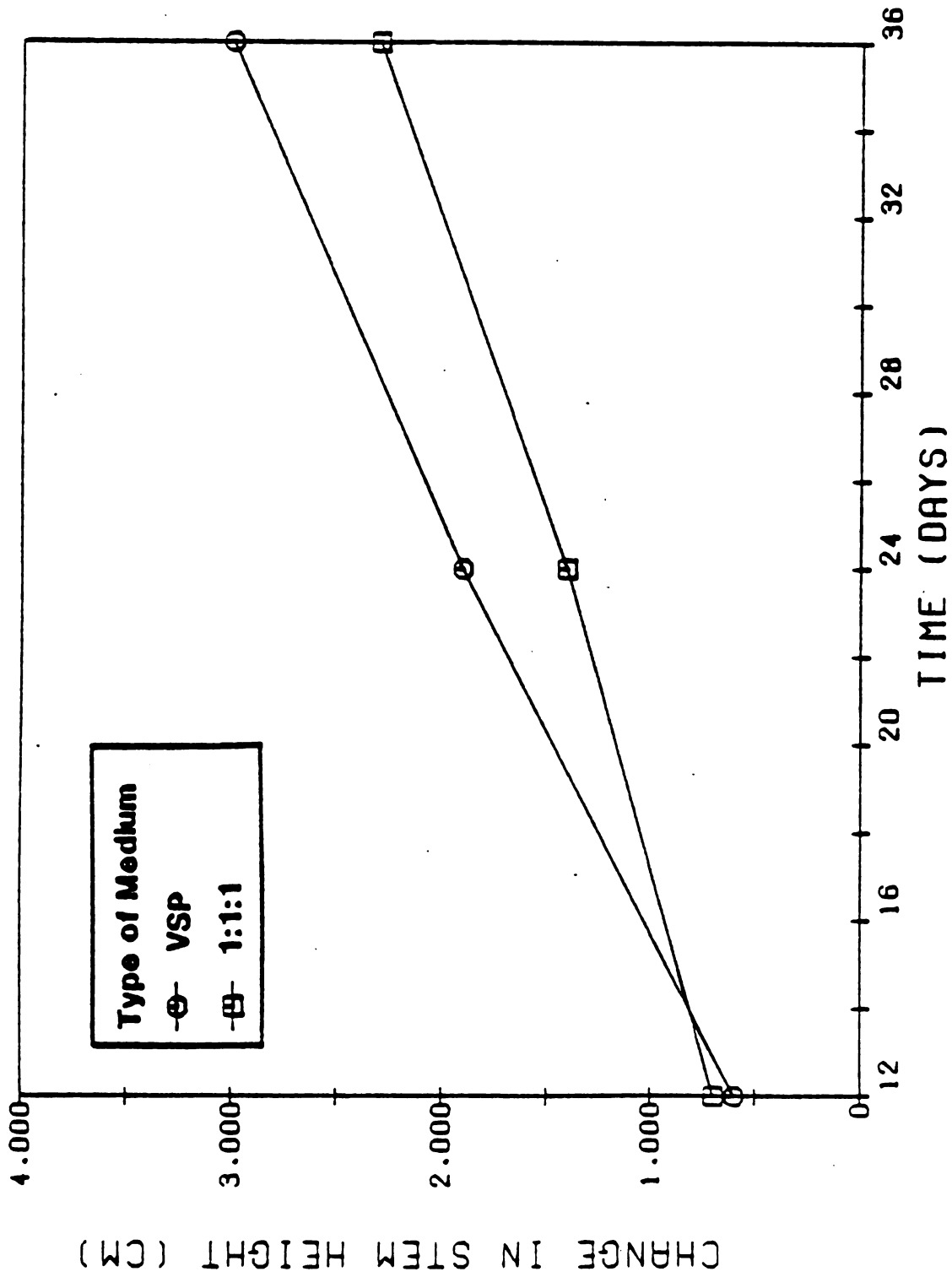


Figure 30. Influence of time and media on change in stem height of impatiens 'Super Elfin Red'.

Table 14. Influence of postproduction environmental factors after 36 days on number of new flowers in impatiens 'Super Elfin Red'.

Environmental Factor	Level	Mean ^x
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	2.40 a
	36	8.87 b
	102	10.21 b
Temperature ($^{\circ}\text{C}$)	4.5	0.61 a
	13	14.58 b
	21	11.72 b
	29	1.72 a
Media	VSP	9.29 b
	1:1:1	5.03 a
Water Regime	Low	6.83 a
	High	7.49 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	**
Temperature	
Linear	NS
Quadratic	**
Media	**
Water Regime	
Linear	NS

Interactions

QFD X Temperature	**
QFD X Media	NS
QFD X Water	NS
Temperature X Media	**
Temperature X Water	NS
Media X Water	NS

Nonsignificant (NS) or significant at 1% level.

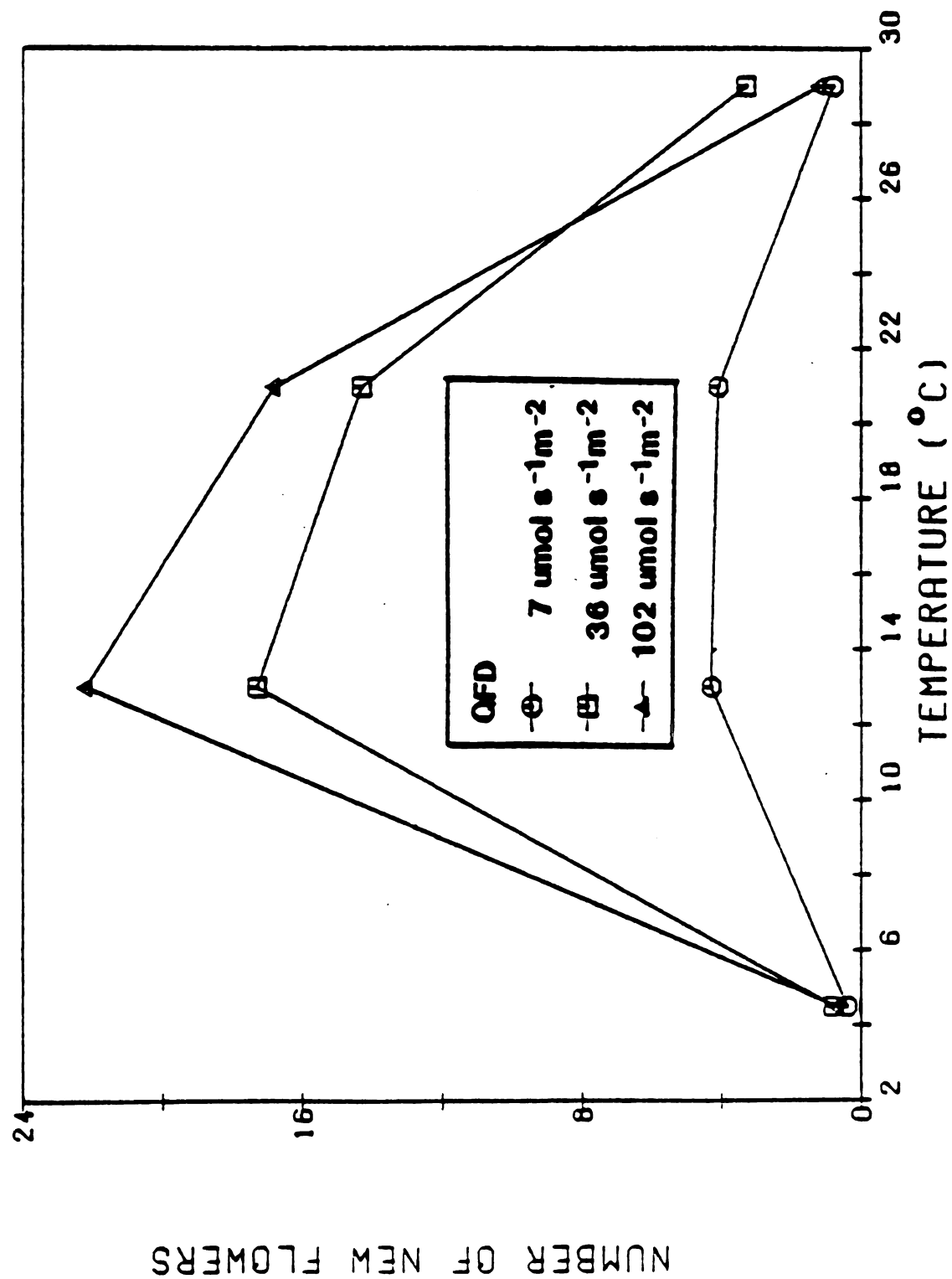


Figure 31. Influence of temperature and quantum flux density on number of new flowers after 36 days inimpatiens 'Super Elfin Red'.

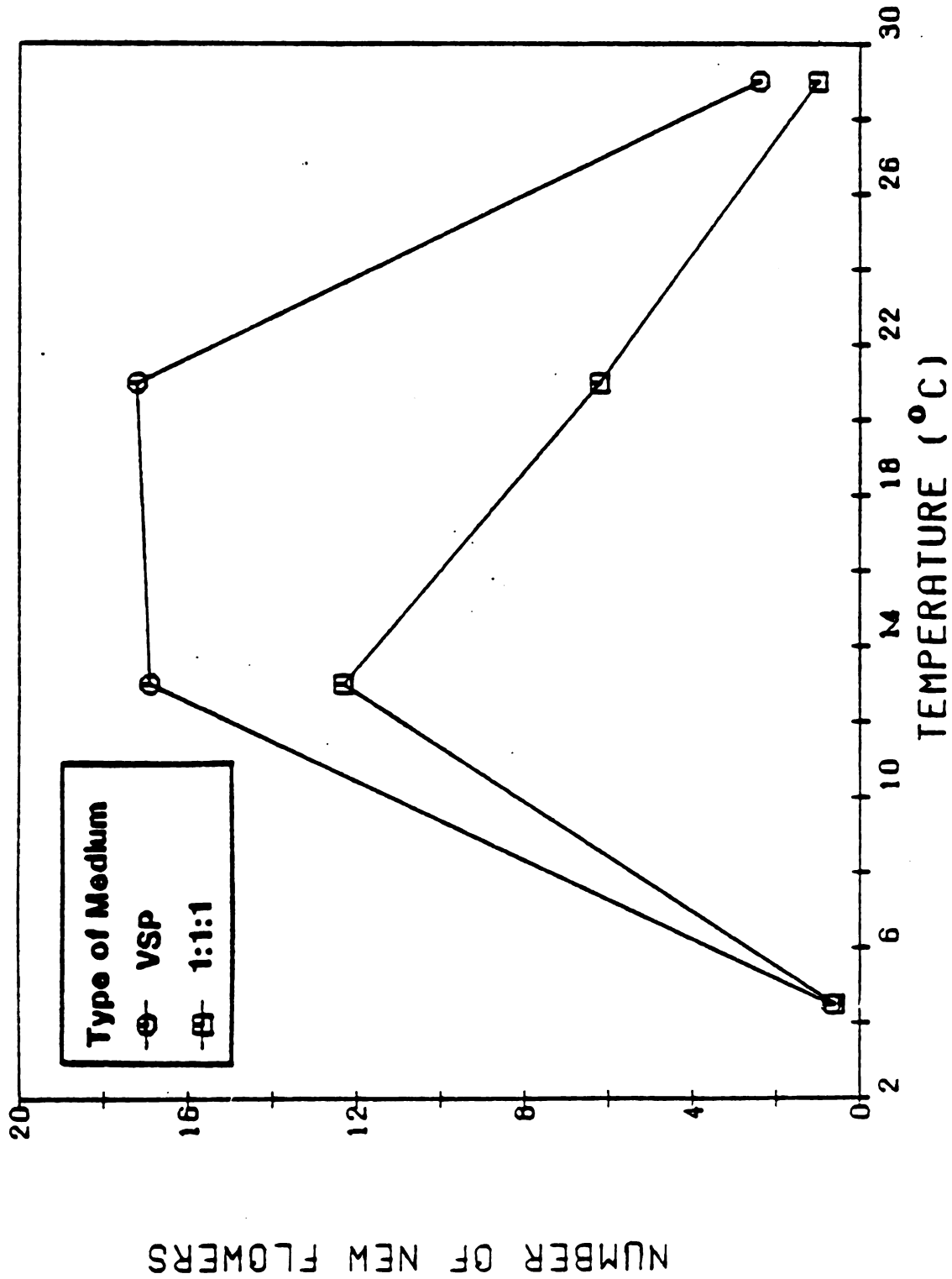


Figure 32. Influence of temperature and media on number of new flowers after 36 days in impatiens 'Super Elfin Red'.

PETUNIA

MATERIALS AND METHODS

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Change in Stem Height

Due to early decline of plants held at the low QFD level at 29°C, analysis of variance was determined in two ways. Plants were analyzed 4.5, 13 and 21°C over all QFD levels and at the medium and high QFD levels over all temperatures.

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

Flower Development

On day 0, stage of flowering was recorded for the two uppermost flowers on the central stem on one plant for all replicates (0= no bud, 1= visible bud, 2= 1/4" bud, 3= 1/2" bud, 4= fully elongated bud, 5= open flower, 6= mature flower, 7= senesced flower). Stages were recorded at 3 day intervals. The number of flowers to reach maturity was determined after 36 days over all treatment combinations.

Visual Assessment

Plants were given a visual assessment at 12 day intervals describing flower and foliage quality as an overall indication of

postharvest keeping quality.

RESULTS

Fresh Weight (FW)

Main Effects

FW increased with increasing QFD level and was highest at both 13 and 21°C in the peat-lite medium while water regime was not significant (Table 15).

Interactions

Plants gained FW (Figure 33) as temperature increased from 4.5 to 21°C at both the low and medium QFD levels and then declined to 29°C with a much greater loss occurring at the low QFD level. At the high QFD level, plants added a considerable amount of FW from 4.5 to 13°C and essentially maintained that weight as temperature increased.

Over time (Figure 34), low QFD level plants remained stable to day 12, declined the most from day 12 to day 24 and then stabilized to day 36. At the medium QFD level, plants gradually lost FW from day 0 to day 24 and then gained to day 36. At the high QFD level, plants lost FW to day 12 and then gained to day 36 above their day 0 level. Over time (Figure 35), plants held at 4.5°C lost FW to day 24 and then gained to day 36. At 13°C, plants lost FW to day 12 and then recovered that loss gradually to day 36. At 21°C, plants essentially demonstrated no FW gain or loss over the 36 day treatment while at 29°C, FW was gradually lost from day 0 to day 36.

The trend for FW gain (Figure 36) as temperature increased was the same for both media with a larger magnitude in the peat-lite medium. Over time (Figure 37), plants held in the peat-lite medium

lost FW to day 24 and then gained to their day 0 level by day 36, while those in the soil-based medium gradually lost FW throughout the testing period.

Change in Stem Height

All QFD Levels

Main Effects

The greatest gain in stem height was shown at the low QFD level, at 21°C, in the peat-lite medium and under both medium and high moisture levels (Table 16).

Interactions

At 4.5 and 13°C (Figure 38), minimal change occurred over time. At 21°C, there was a significant gain in stem height between day 12 and day 24 with a lesser increase to day 36.

All Temperatures

Main Effects

The greatest gain in stem height was demonstrated at the medium QFD level, at 29°C, in the peat-lite medium under medium and high moisture (Table 17).

Interactions

There was minimal stem height gain (Figure 39) between 4.5 and 13°C at both the medium and high QFD levels followed by a sharp gain as temperature increased to 29°C. The increase was larger between 21 and 29°C for the medium QFD level.

After 36 days (Figure 40), plants held at 4.5 and 13°C gained approximately 2 cm while those at 21 and 29°C gained 6 and 11 cm respectively.

Flower Development

Main Effects

More flowers matured with increasing QFD level and with increasing temperature up to 21°C. At 21 and 29°C, values were similar. Medium type and water regime were not significant (Table 18).

Interactions

Regardless of QFD level (Figure 41), flowers did not mature at 4.5°C. There was negligible maturation at the low QFD level regardless of temperature. With the medium QFD level, there was minimal maturation from 4.5 to 13°C, a substantial increase from 13 to 21°C and then a dramatic decline from 21 to 29°C. The number of flowers to mature at the high QFD level increased sharply as temperature increased from 4.5 to 29°C. Flower maturity (Figure 42) increased marginally from the low to the medium QFD level regardless of water regime. Above $36 \mu \text{mol s}^{-1} \text{m}^{-2}$, more flowers matured under high moisture.

Visual Rating

4.5°C

After 12 days, there were fewer flowers as QFD level decreased and flowers and leaves were smaller at the low QFD level. By day 24, plants developed an overall chlorosis and flowering declined markedly at all QFD levels. After 36 days, plants were compact and chlorotic with no flowers and many aborted buds with necrosis of the lower leaves at the low QFD level.

13°C

After 12 days, there were more flowers at the high QFD level.

After 24 days, chlorosis developed. Flowering declined as QFD level decreased. There were no flowers at the low QFD level with stem elongation. This pattern persisted through 36 days.

21°C

After 12 days, there were more flowers at the high QFD level. After 24 days, the number of flowers declined as QFD level decreased and there was stem elongation at the low and medium QFD levels.

After 36 days, flowers remained abundant at the high QFD level with a decline to 2 flowers per plant at the medium QFD level and no flowers at the low QFD level. Plants under low moisture were more compact and had larger leaves than plants at medium and high moisture.

29°C

Plants held at the high QFD level were very tall with many flowers at this temperature after 12 days. At the medium QFD level, flowers were fewer and smaller with the central stem more elongated than the laterals in many cases. At the low QFD level, stem elongation was very pronounced with chlorosis and necrosis of the lower leaves and virtually no flowers. After 24 days, plants at the high QFD level remained tall with many flowers. New flowers exhibited purple streaking. At the medium QFD level, shoots displayed a vining type of growth habit and were spindly and chlorotic with no flowers. At the low QFD level, there were no flowers and considerable bud abortion with many dead plants.

After 36 days, the foliage was chlorotic, growth habit was vining and leaves were small at the high QFD level. Flowers were abundant and small. At the medium QFD level, foliage habit and color

were similar to plants at the high QFD level. Flowers were rare and all new ones displayed purple streaking. Many plants were dead at the low QFD level.

DISCUSSION

This study revealed that at the low QFD level and at a temperature of 29°C, fresh weight loss was 25% after 36 days indicating negative 36 day marketability. It also indicated that at 4.5°C fresh weight loss was nearly the same regardless of QFD level, but above 21°C, the lower the QFD level, the greater the fresh weight loss. This is in agreement with a recent similar simulated postproduction study with petunia by Armitage and Kowalski (15) who found that at QFD levels of 300, 600 and 900 $\mu\text{mol s}^{-1} \text{m}^{-2}$ along with temperatures of 10, 20 and 30°C, QFD level is more important at high temperatures but has little effect at low temperatures.

This study also indicated that at the low QFD level and in the 21 to 29°C range, stem elongation becomes very pronounced indicating inferior marketability.

Flowering is of paramount importance for consumer marketability. This investigation indicates that within the QFD ranges tested, there would be no flowering at 4.5°C. At the medium QFD level sufficient flowers for salability would occur only between 13 and 21°C. At the high QFD level, the number of flowers to mature increased with temperature. Armitage, in the study cited earlier in this discussion, found new flower development over a 15 day postharvest period to be fastest at the hot postproduction temperature (30°C), followed by moderate (20°C) and then by cool (10°C) conditions.

This postproduction study indicates that best 36 day marketability would require the following conditions: a QFD range of 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$, a temperature range of 13 to 21°C while water regime is not significant.

With this bedding plant species, plants in both media entered the postharvest treatments with approximately the same fresh weight. However, 36 days postharvest, plants in the peat-lite medium maintained their day 0 fresh weight, but there was a 20% fresh weight loss for plants in the soil-based medium. The peat-lite medium appears to offer superior marketability for this plant species.

Table 15. Influence of postproduction environmental factors on fresh weight (g) of petunia 'White Magic'.

Environmental Factor	Level	Days Postproduction				Mean ^x
		0	12	24	36	
QFD Y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	14.29	14.08	10.60	10.42	12.36 a
	36	14.96	13.73	12.91	13.89	13.87 b
	102	14.91	13.44	14.58	15.61	14.84 c
Temperature (°C)	4.5	14.06	12.64	10.48	12.59	12.44 a
	13	14.64	13.51	14.07	14.66	14.22 bc
	21	14.92	14.82	14.27	14.64	14.66 c
	29	15.26	14.02	12.01	11.34	13.17 ab
Media	VSP	15.14	14.10	13.33	15.00	14.39 b
	1:1:1	14.30	13.40	12.09	11.62	12.86 a
Water Regime	Low	14.64	13.50	11.79	13.61	13.39 a
	Med	14.77	13.00	13.26	13.09	13.53 a
	High	14.75	14.76	13.09	13.22	13.95 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects		Interactions	
QFD		QFD X Temperature	**
Linear	**	QFD X Media	*
Quadratic	NS	QFD x Time	**
Temperature		QFD X Water	NS
Linear	*	Temperature X Media	NS
Quadratic	**	Temperature X Time	**
Media	**	Temperature X Water	NS
Water Regime	NS	Media X Time	**
Time		Media X Water	NS
Linear	**	Water X Time	NS
Quadratic	**		

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

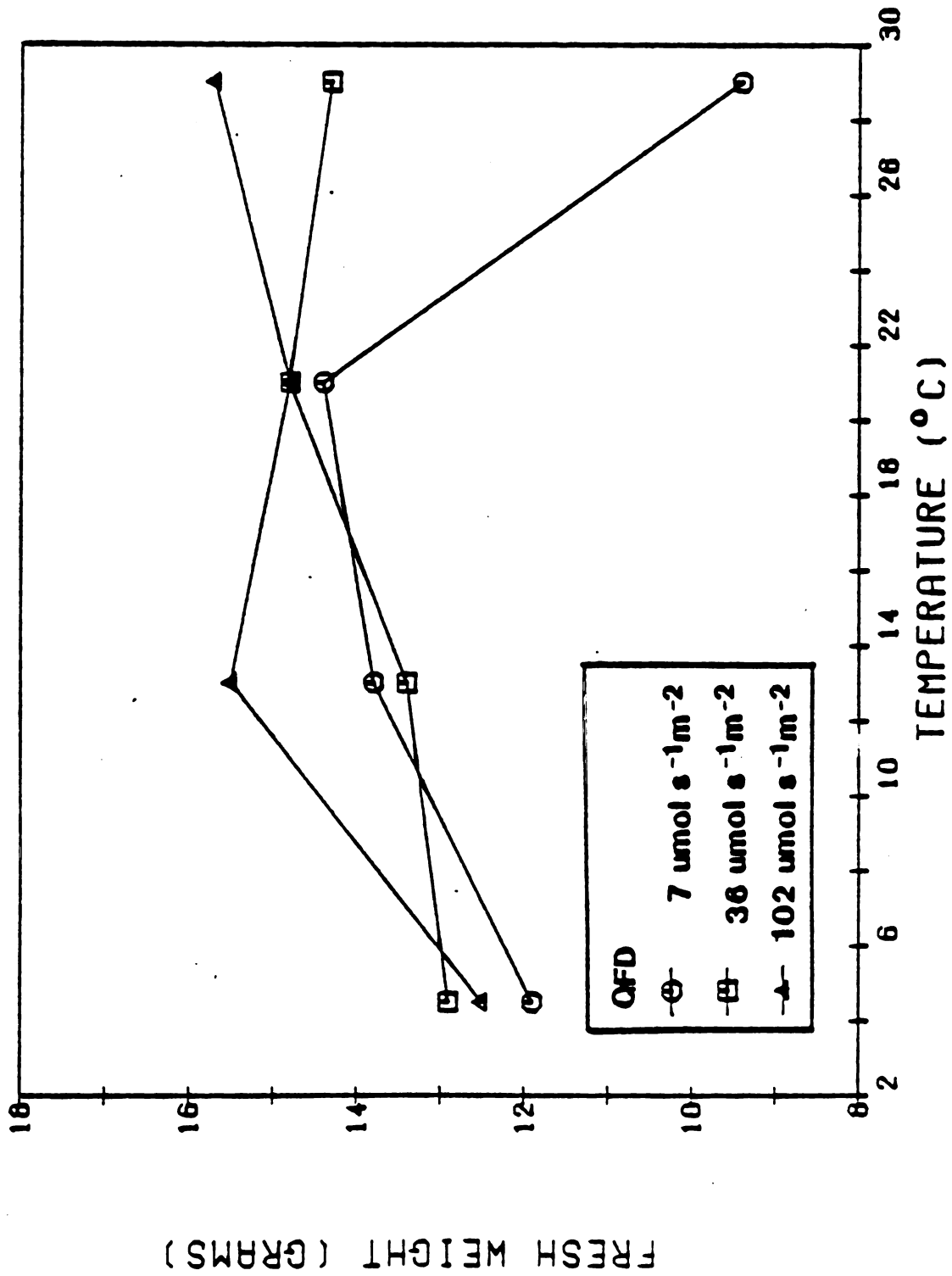


Figure 33. Influence of temperature and quantum flux density on fresh weight of petunia 'White Magic'.

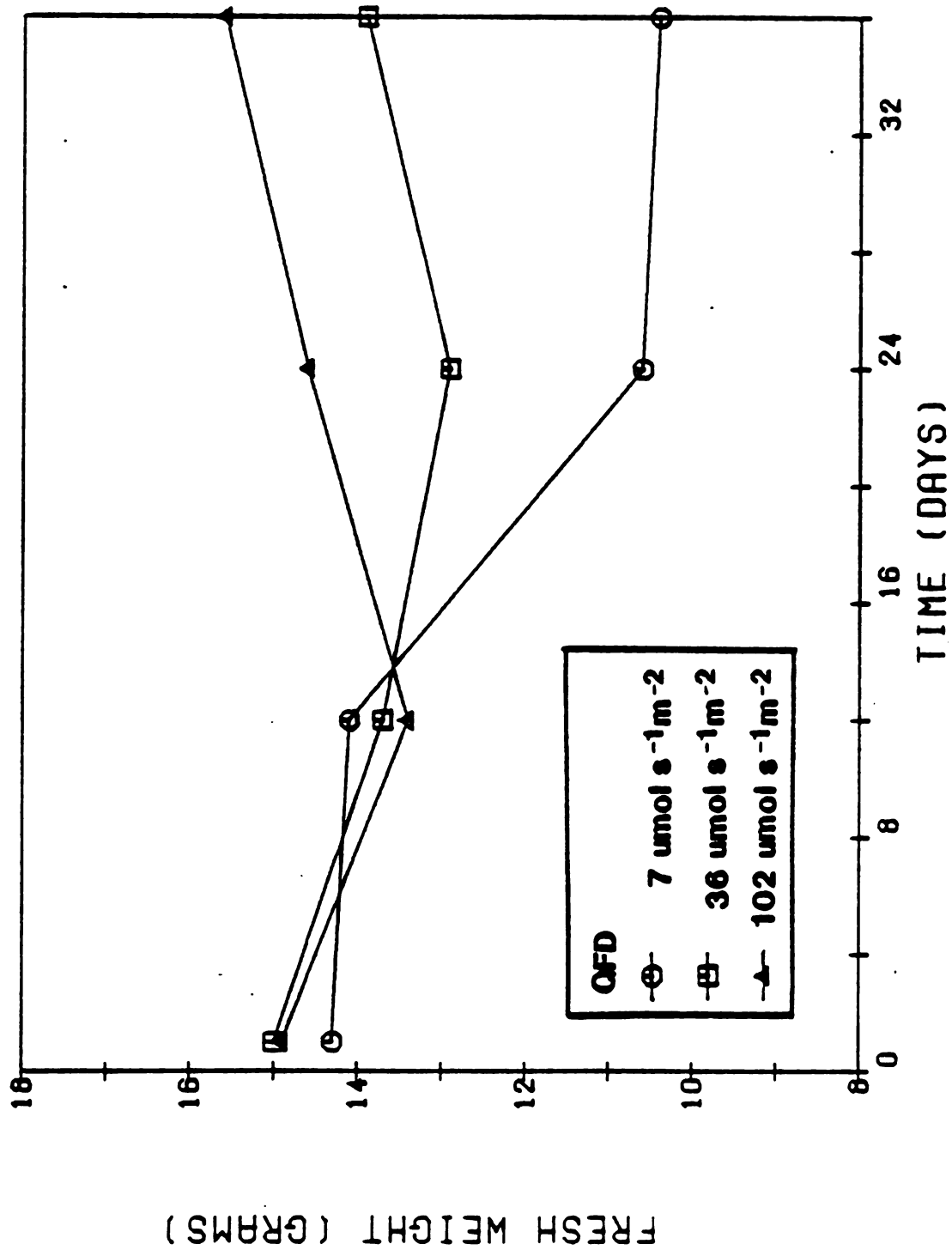


Figure 34. Influence of time and quantum flux density on fresh weight of petunia 'White Magic'.

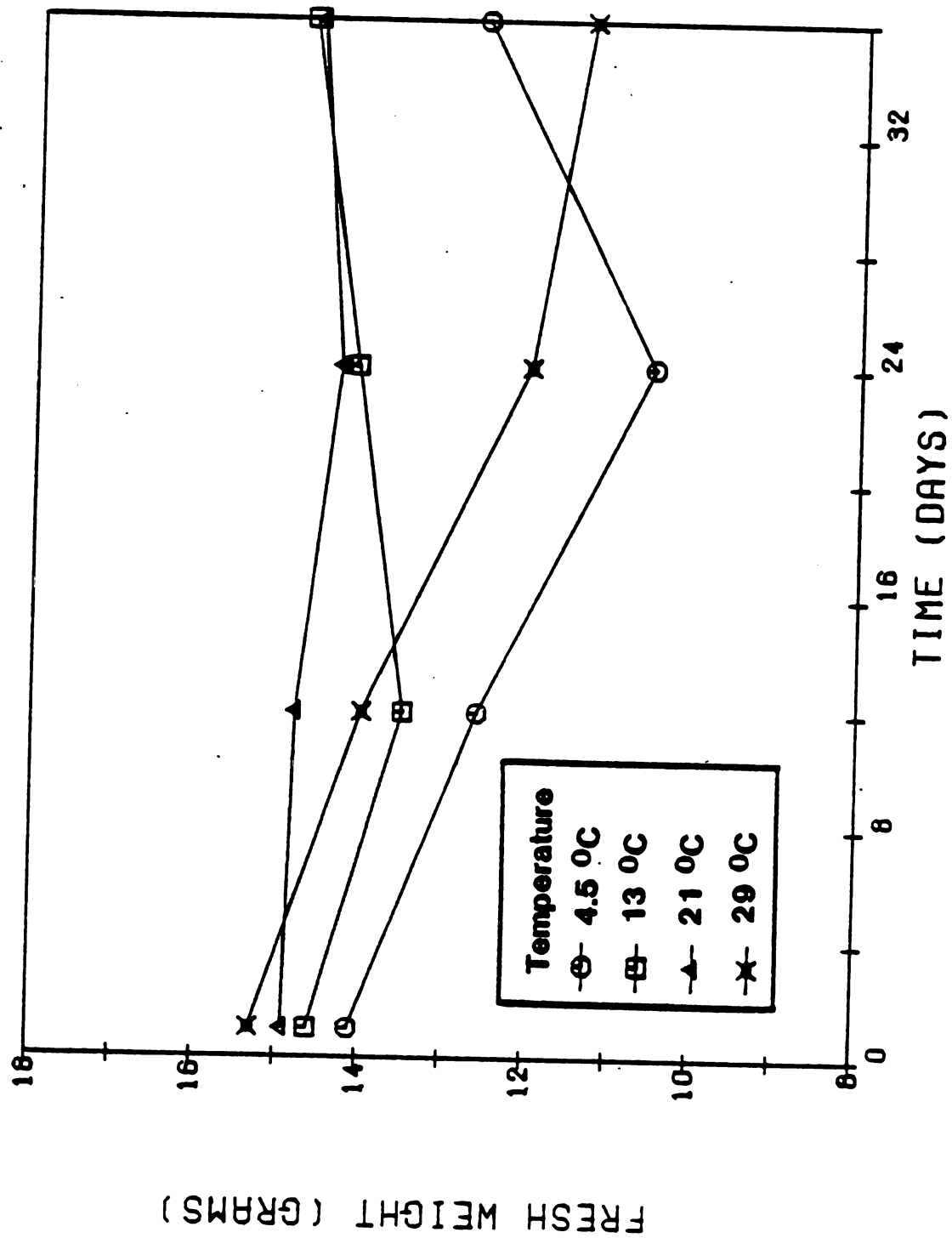


Figure 35. Influence of time and temperature on fresh weight of petunia 'White Magic'.

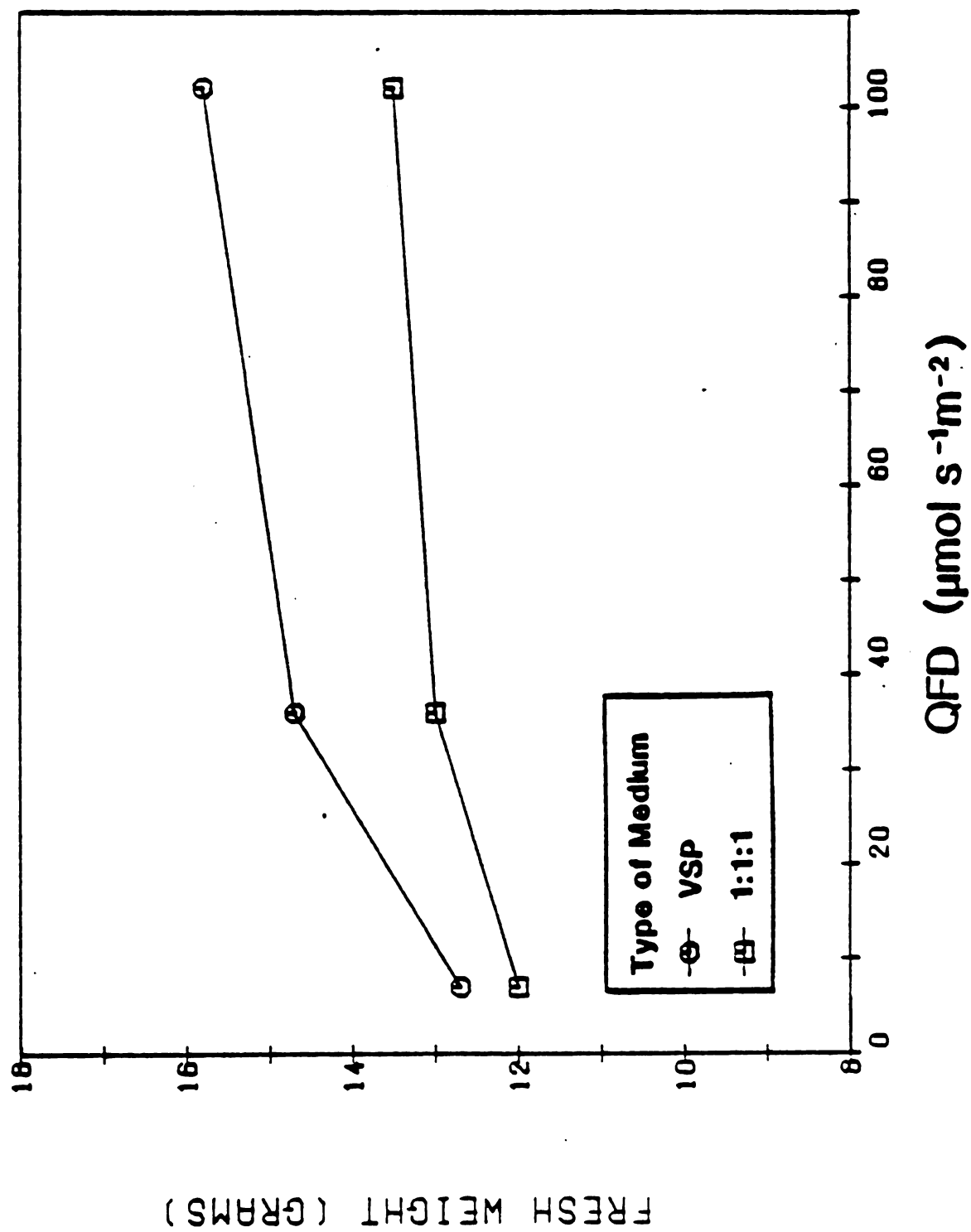


Figure 36. Influence of quantum flux density and media on fresh weight of petunia 'White Magic'.

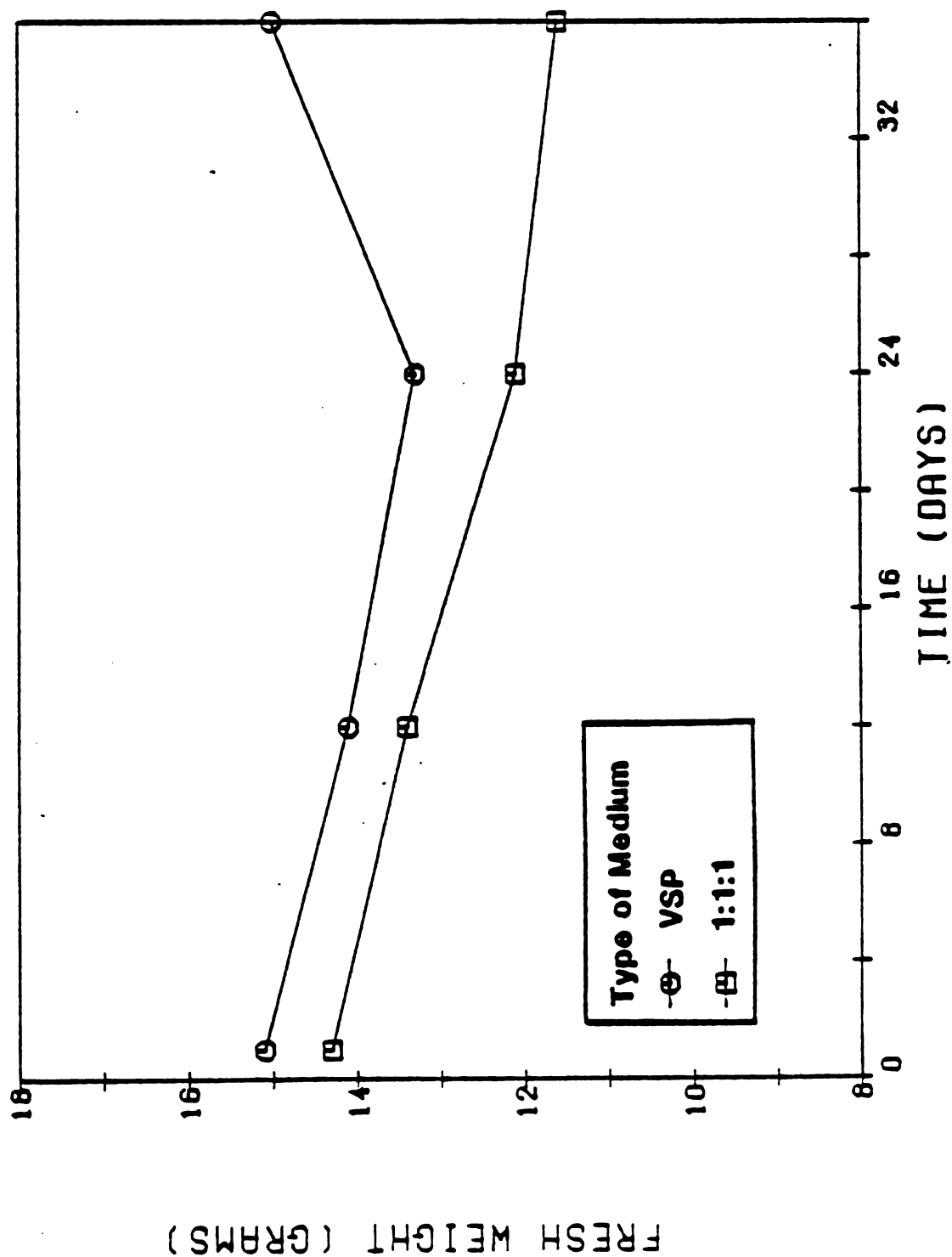


Figure 37. Influence of time and media on fresh weight of petunia 'White Magic'.

Table 16. Influence of postproduction environmental factors on change in stem height (cm) of petunia 'White Magic'.

Environmental Factor	Level	Days Postproduction ^x			Mean ^y
		12	24	36	
QFD ^z ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	2.2	3.6	4.3	3.4 b
	36	2.0	3.6	3.3	3.0 ab
	102	1.9	3.0	3.4	2.8 a
Temperature (°C)	4.5	1.3	1.8	1.6	1.6 a
	13	1.8	2.2	2.4	2.1 b
	21	3.0	6.2	7.0	5.4 c
Media	VSP	2.3	3.8	4.1	3.4 b
	1:1:1	1.8	3.0	3.3	2.7 a
Water Regime	Low	1.7	3.0	3.6	2.8 A
	Med	2.1	3.8	3.6	3.2 B
	High	2.2	3.4	3.9	3.2 B

^x Calculation of stem height at postproduction intervals as change from day 0.

^y Mean separation within environmental factors by HSD test, 5% (capitals) or 1% level.

^z QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	*
Time	
Linear	**
Quadratic	**

Interactions

QFD X Temperature	NS
QFD X Media	NS
QFD X Time	NS
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) Level.

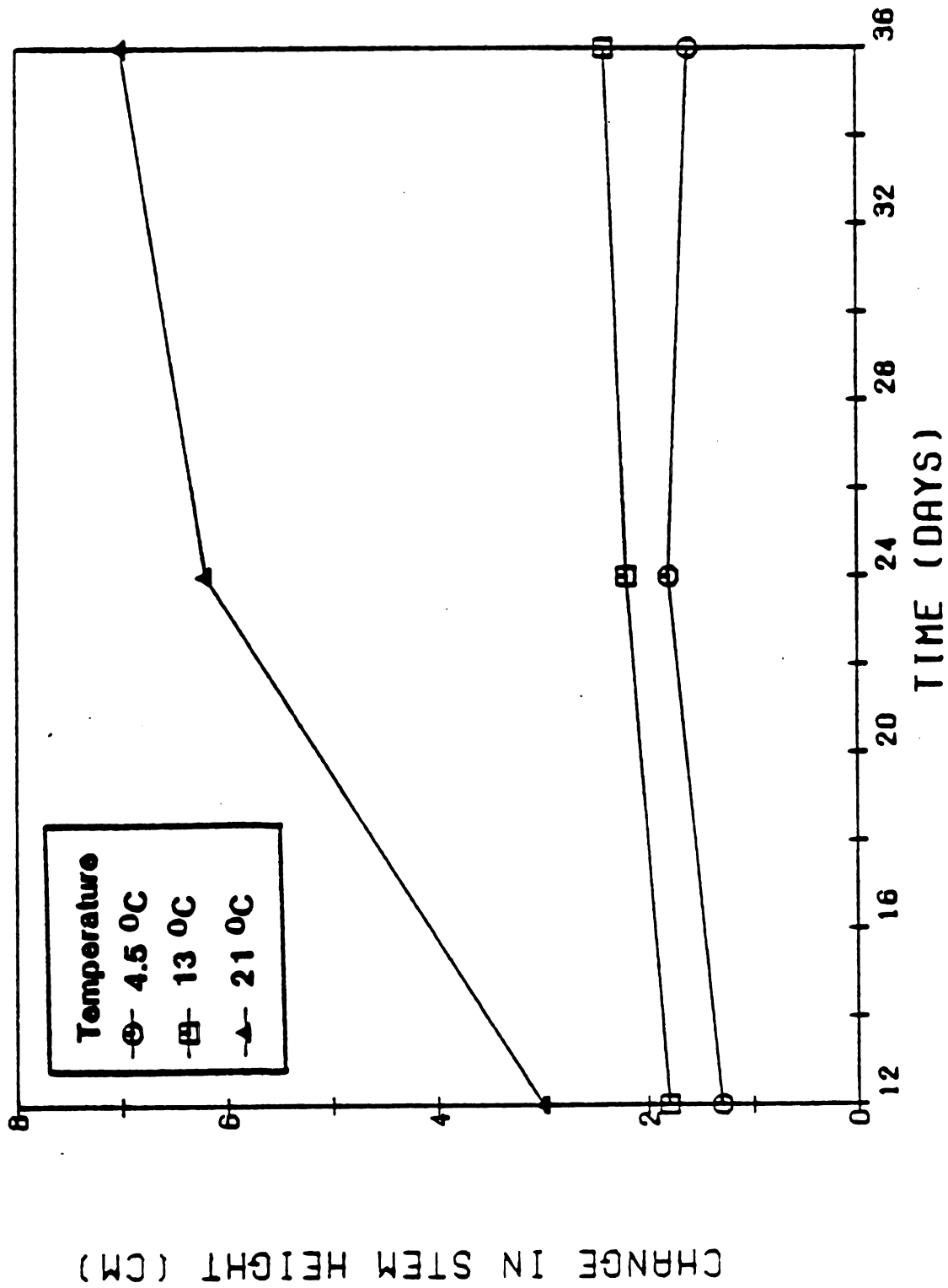


Figure 38. Influence of time and temperature on change in stem height of petunia 'White Magic'.

Table 17. Influence of postproduction environmental factors on change in stem height (cm) of petunia 'White Magic'.

Environmental Factor	Level	Days Postproduction ^x			Mean ^y
		12	24	36	
QFD ^z ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	36	2.6	5.2	6.0	4.6 b
	102	2.4	4.3	4.8	3.8 a
Temperature (°C)	4.5	1.1	1.9	1.5	1.5 a
	13	1.5	2.0	2.2	1.9 a
	21	3.2	5.1	6.3	5.2 b
	29	4.3	9.0	11.5	8.3 c
Media	VSP	2.9	5.0	6.0	4.6 b
	1:1:1	2.2	4.4	4.8	3.8 a
Water Regime	Low	2.3	3.8	4.8	3.6 a
	Med	2.4	5.5	5.3	4.4 b
	High	2.9	4.9	6.0	4.6 b

^x Calculation of stem height at postproduction intervals as change from day 0.

^y Mean separation within environmental factors by HSD test, 1% level.

^z QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	**
Time	
Linear	**
Quadratic	**

Interactions

QFD X Temperature	**
QFD X Media	NS
QFD X Time	NS
QFD X Water	NS
Temperature X Media	NS
Temperature X Time	**
Temperature X Water	NS
Media X Time	NS
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 1% (**) level.

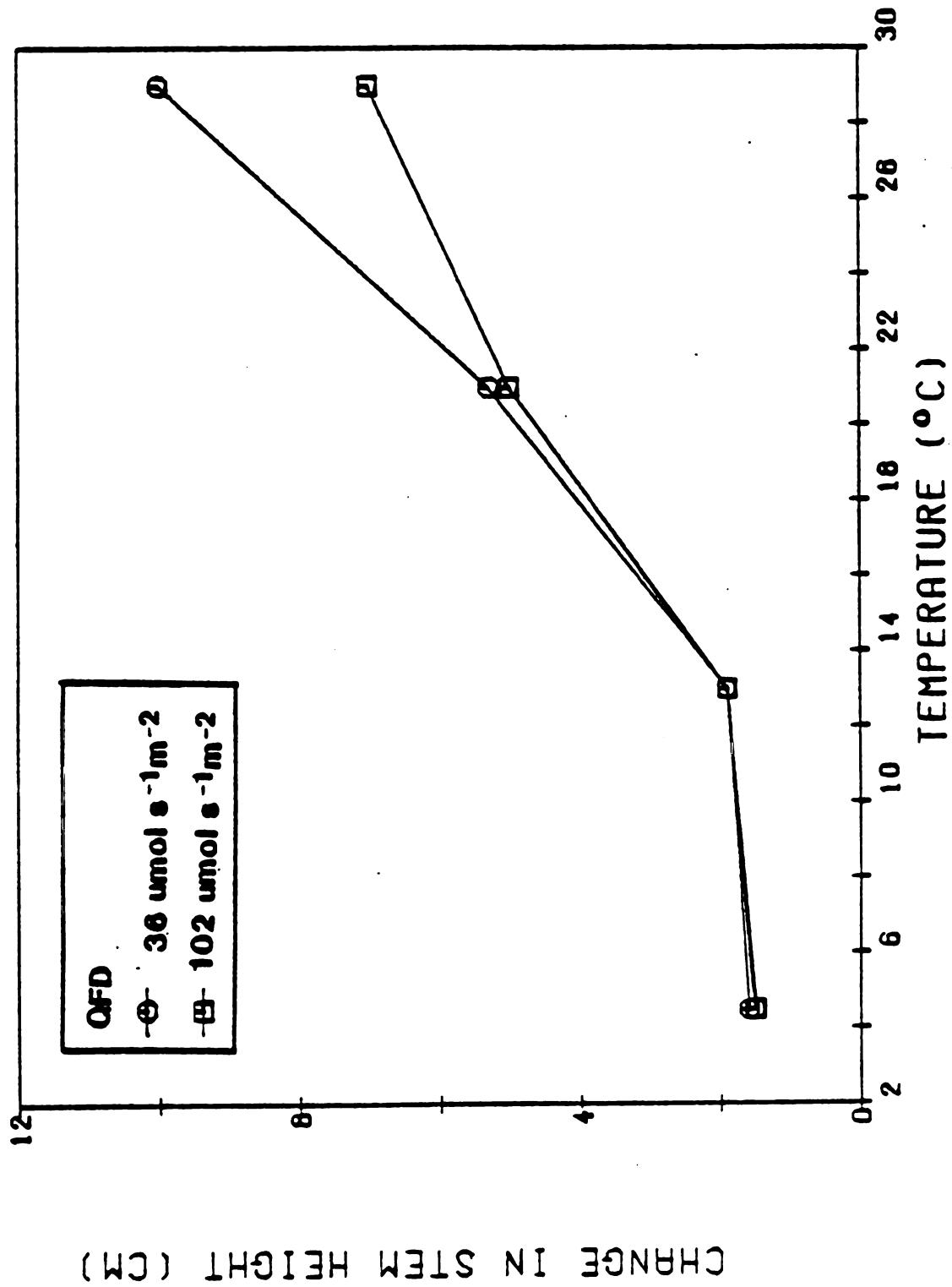


Figure 39. Influence of temperature and quantum flux density on change in stem height of petunia 'White Magic'.

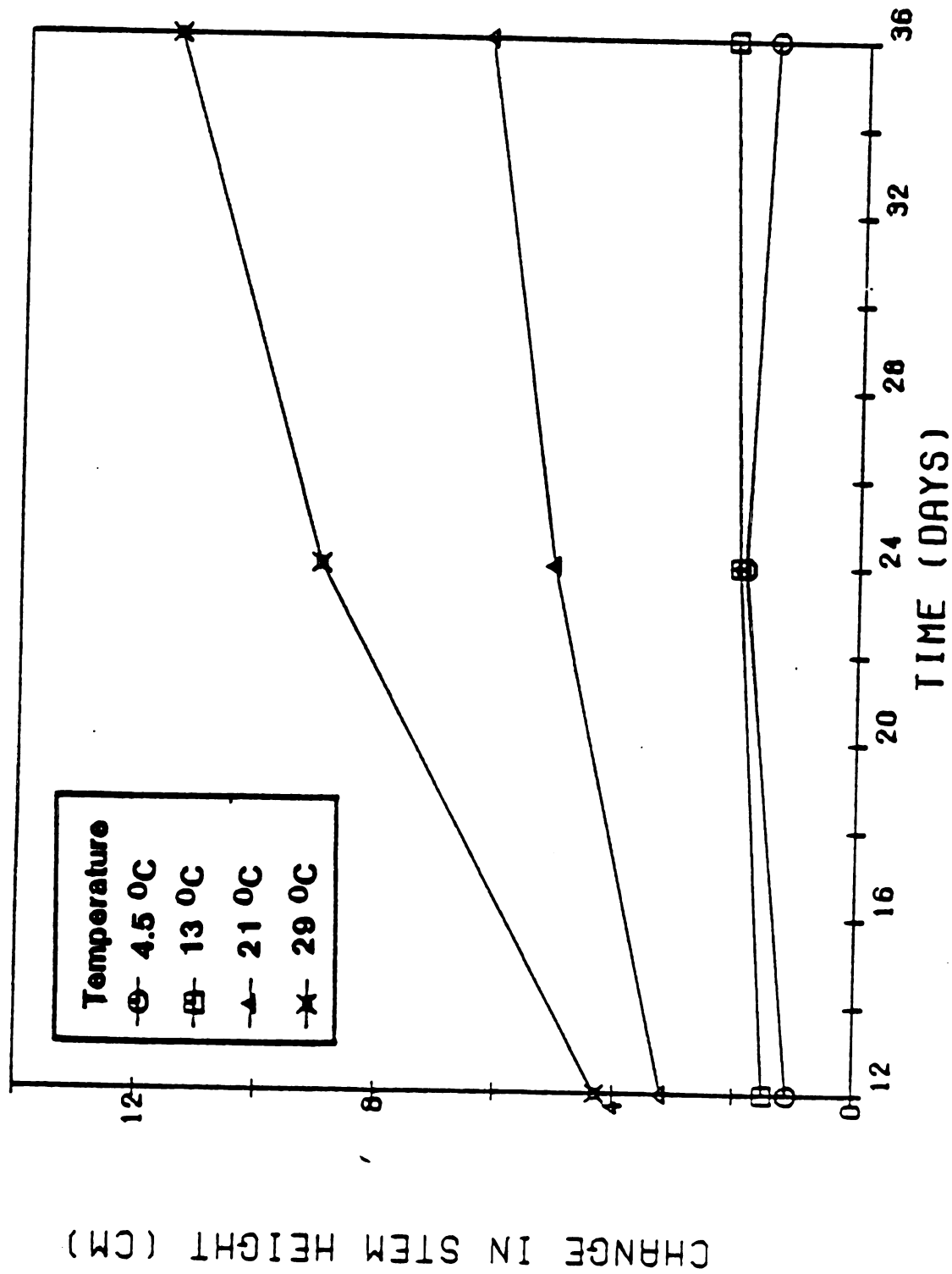


Figure 40. Influence of time and temperature on change in stem height of petunia 'White Magic'.

Table 18. Influence of postproduction environmental factors after 36 days on number of flowers to mature in petunia 'White Magic'.

Environmental Factor	Level	Mean ^x
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	0.85 a
	36	1.46 b
	102	3.07 c
Temperature (°C)	4.5	0.76 a
	13	1.41 a
	21	2.78 b
	29	2.22 b
Media	VSP	1.70 a
	1:1:1	1.89 a
Water Regime	Low	1.69 a
	Med	1.75 a
	High	1.93 a

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	**
Temperature	
Linear	**
Quadratic	**
Media	NS
Water Regime	NS

Interactions

QFD X Temperature	**
QFD X Media	NS
QFD X Water	*
Temperature X Media	NS
Temperature X Water	NS
Media X Water	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

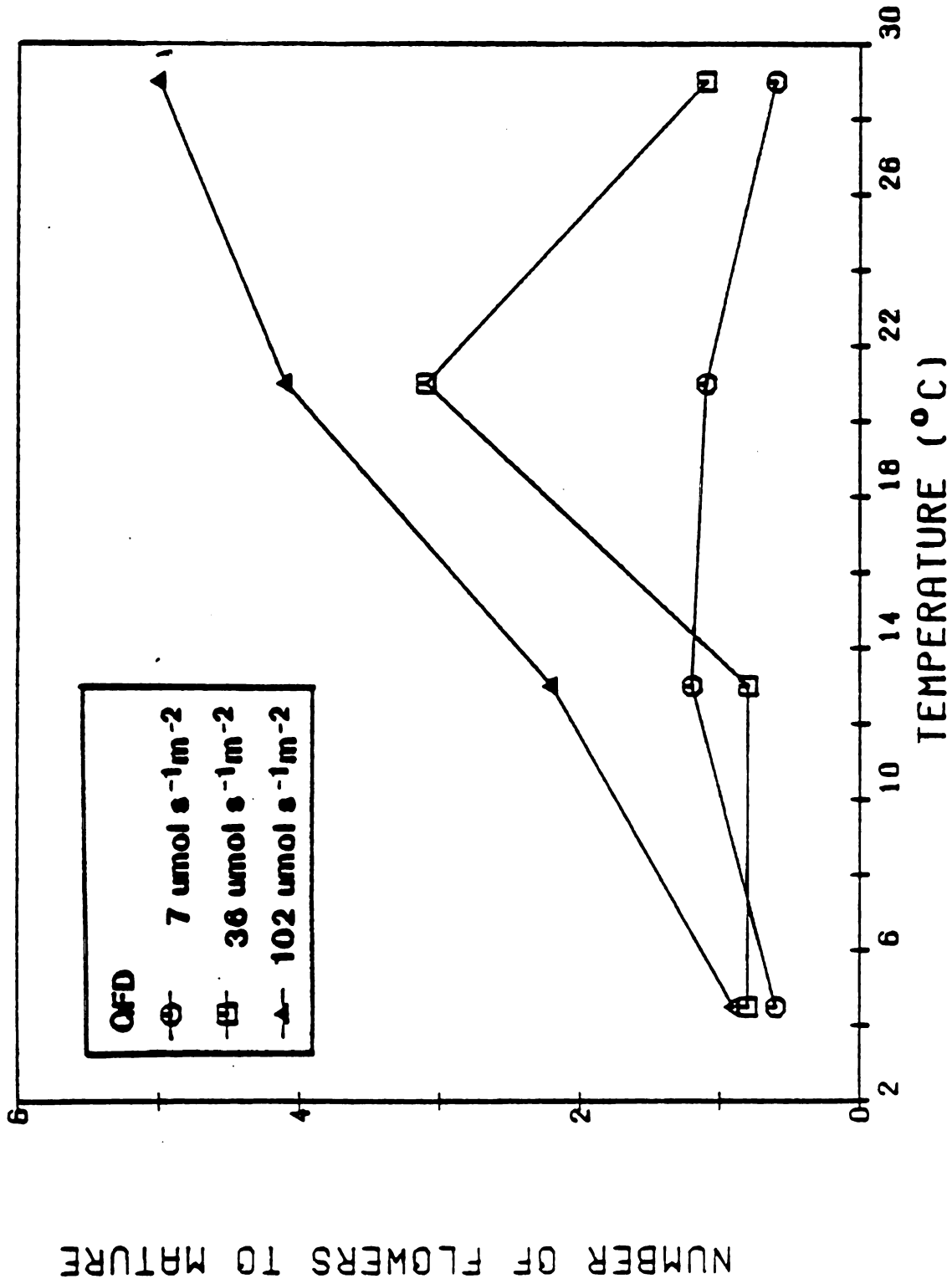


Figure 41. Influence of temperature and quantum flux density after 36 days on number of flowers to mature in petunia 'White Magic'.

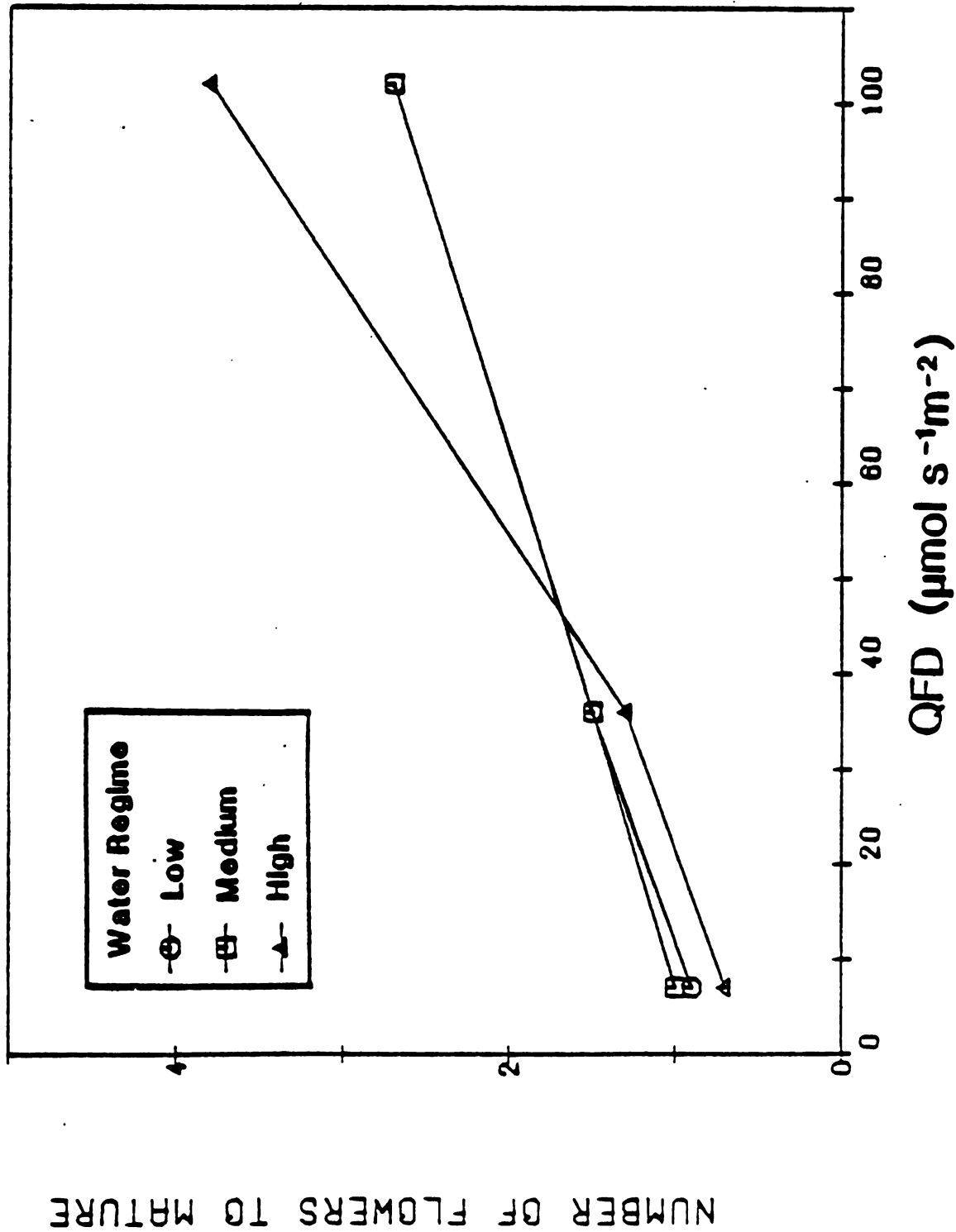


Figure 42. Influence of quantum flux density and water regime after 36 days on number of flowers to mature in petunia 'White Magic'.

TOMATO

MATERIALS AND METHODS

Fresh Weight

At 12 day intervals, the above ground portion of the plant was weighed on one plant per each replication for all treatment combinations.

Change in Stem Height

Change in stem height was calculated as change from day 0. Measurement was from the soil line to the apex of the tallest meristem at 12 day intervals on one plant per each replication for all treatment combinations.

Visual Assessment

Plants were given a visual assessment at 12 day intervals describing flower and foliage quality as an overall indication of postharvest keeping quality.

RESULTS

Fresh Weight (FW)

Main Effects

FW increased with increasing QFD level and was highest at 13°C, in the peat-lite medium under high moisture (Table 19).

Interactions

Highest FW was at 13°C regardless of QFD level (Figure 43). Above 13°C, plants held at both low and high QFD levels lost FW to 21°C and then remained stable to 29°C, while those at the medium QFD

level continued to decline as temperature increased. Over time (Figure 44), plants at the low QFD level lost FW from day 0 to day 36, those at the medium QFD level gained FW from day 0 to day 12 and then stabilized to day 36 while those at the high QFD level gained FW from day 0 to day 36. Over time (Figure 45), plants held at 4.5°C lost FW throughout the testing period while those at 13°C added FW. Plants held at 21 and 29°C gained approximately one gram after 36 days.

At 4.5°C (Figure 46), plants in both media exhibited low FW but showed a sharp gain to 13°C. Plants in the peat-lite medium lost FW from 13 to 29°C, while those in the soil-based medium lost FW from 13 to 21°C and then gained at 29°C. Over time (Figure 47), plants in the peat-lite medium demonstrated a 20% FW gain after 36 days while soil-based medium plants lost nearly 10%.

Change in Stem Height

Main Effects

Stem height increased with increasing QFD level and had the largest increase at 21°C in the peat-lite medium under high moisture (Table 20).

Interactions

Stem height gain (Figure 48) was minimal at 4.5°C regardless of QFD level and least at the low QFD level regardless of temperature. At the medium QFD level, stem height gain was approximately 7 cm at 13°C, 10 cm at 21°C and 7.5 cm at 29°C. At the high QFD level, stem height gain was approximately 9 cm at 13°C, 14.5 cm at 21°C and 8 cm at 29°C. The trend was the same for plants in both media (Figure 49). Stem height change was least at 4.5°C from day 0. Stem height increased as

temperature increased from 4.5 to 21°C but the change from day 0 was less between 21 and 29°C.

Visual Assessment

4.5°C

After 8 days, chilling injury was evident. Even though the foliage was wilted, the meristems still appeared viable at all QFD levels. Marketability at this temperature would be limited after approximately one week.

13°C

After 12 days, plants at the high QFD level were compact with dark green foliage and anthocyanin pigmentation on the stems. The pattern was similar at the medium QFD level but with less anthocyanin. Plants at the low QFD level were much lighter green with dessication of the leaves and marked stem elongation. After 24 days at the high QFD level, anthocyanin was visible on the foliage as well as the stems and flower buds were visible. At the medium QFD level, anthocyanin was remained confined to the stems and floral buds were less developed. At the low QFD level, leaf margins were necrotic and there were no buds. This pattern persisted for the 36 day testing period.

21°C

The foliage was dark green with anthocyanin traces on the upper stems at the high QFD level after 12 days. The pattern was similar at the medium QFD level with absence of anthocyanin. Plants were lighter green and stems were elongated at the low QFD level. After 36 days no change was evident at the high QFD level while medium and low QFD level plants were elongated with chlorosis.

29°C

Foliage color was dark green at the high QFD level but became lighter as QFD level decreased with stem elongation at the low QFD level. Anthocyanin pigmentation and floral bud development did not take place at this temperature over the 36 day testing period.

DISCUSSION

This study agrees with well known information on the chilling sensitivity of this plant species. Regardless of QFD level, within the ranges tested, fresh weight was lowest at 4.5°C. By the 12th day of the testing period, plants at this temperature had lost nearly one-third of their day 0 fresh weight indicating marketability of short duration. It was also clear, based on fresh weight, that a QFD level of $7 \mu\text{mol s}^{-1} \text{m}^{-2}$ was not sufficient for keeping quality of this sun species. In the temperature range from 13 to 29°C, fresh weight increased as QFD level increased suggesting best keeping quality at the high QFD level. The large stem height increase at 21°C is an unfavorable response for marketability.

For this plant species, the peat-lite medium appears to offer better 36 day marketability than the soil-based medium. After 36 days, plants in the peat-lite medium increased fresh weight three grams while soil-based medium plants lost nearly one gram even though plants in both media entered the treatment period at approximately the same fresh weight.

Tomato requires the following conditions for 36 day marketability: a QFD level in the $100 \mu\text{mol s}^{-1} \text{m}^{-2}$ range, temperature from 13 - 21°C under high moisture in the peat-lite medium.

Table 19. Influence of postproduction environmental factors on fresh weight (g) of tomato 'Better Boy'.

Environmental Factor	Level	Days Postproduction				Mean ^x
		0	12	24	36	
QFD ^y ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	10.56	9.57	6.70	5.75	8.15 a
	36	10.57	11.85	11.54	11.01	11.24 b
	102	9.47	13.16	15.59	16.30	13.63 c
Temperature (°C)	4.5	10.69	7.93	6.37	4.52	7.38 a
	13	10.83	15.09	15.97	16.89	14.70 c
	21	9.31	11.65	12.28	11.61	11.21 b
	29	9.98	11.43	10.49	11.06	10.74 b
Media	VSP	10.69	13.16	12.77	13.45	12.52 b
	1:1:1	9.72	9.90	9.78	8.59	9.50 a
Water Regime	Low	9.78	10.47	11.17	10.02	10.36 a
	High	10.62	12.58	11.38	12.02	11.65 b

^x Mean separation within environmental factors by HSD test, 1% level.

^y QFD (Quantum Flux Density).

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	
Linear	**
Time	
Linear	NS
Quadratic	*

Interactions

QFD X Temperature	**
QFD X Media	NS
QFD X Time	**
QFD X Water	NS
Temperature X Media	*
Temperature X Time	**
Temperature X Water	NS
Media X Time	**
Media X Water	NS
Water X Time	NS

Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

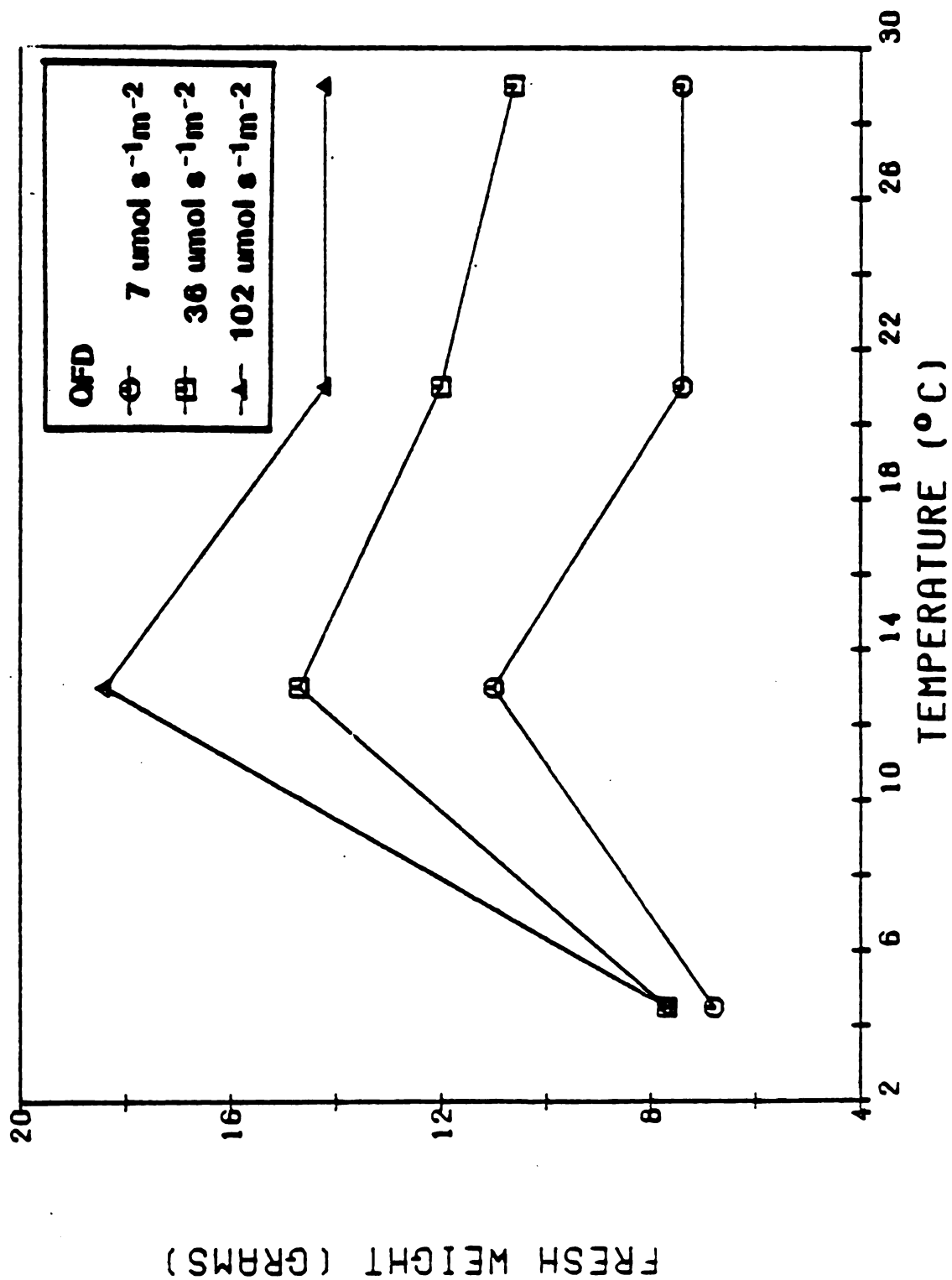


Figure 43. Influence of temperature and quantum flux density on fresh weight of tomato 'Better Boy'.

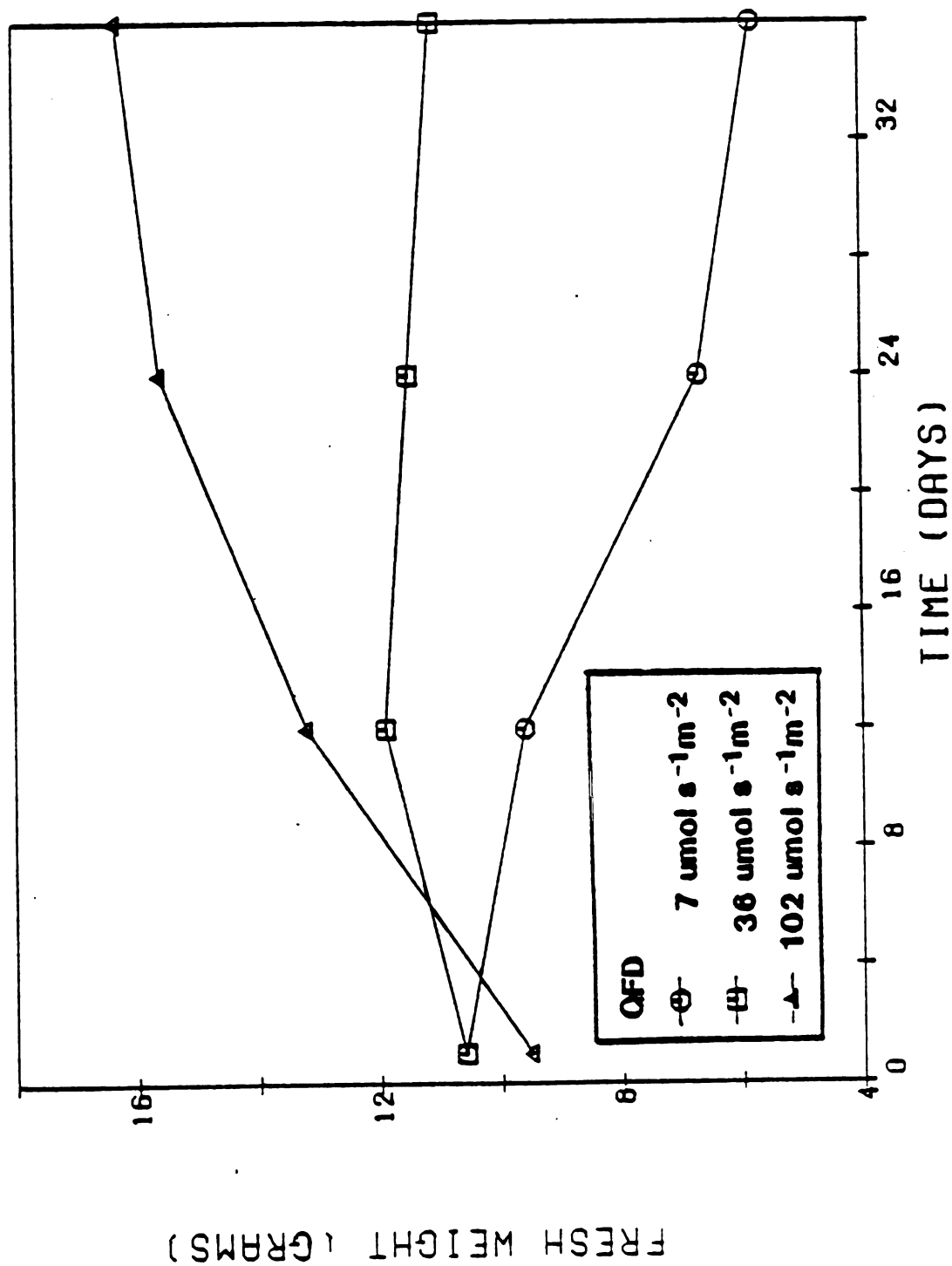


Figure 44. Influence of time and quantum flux density on fresh weight of tomato 'Better Boy'.

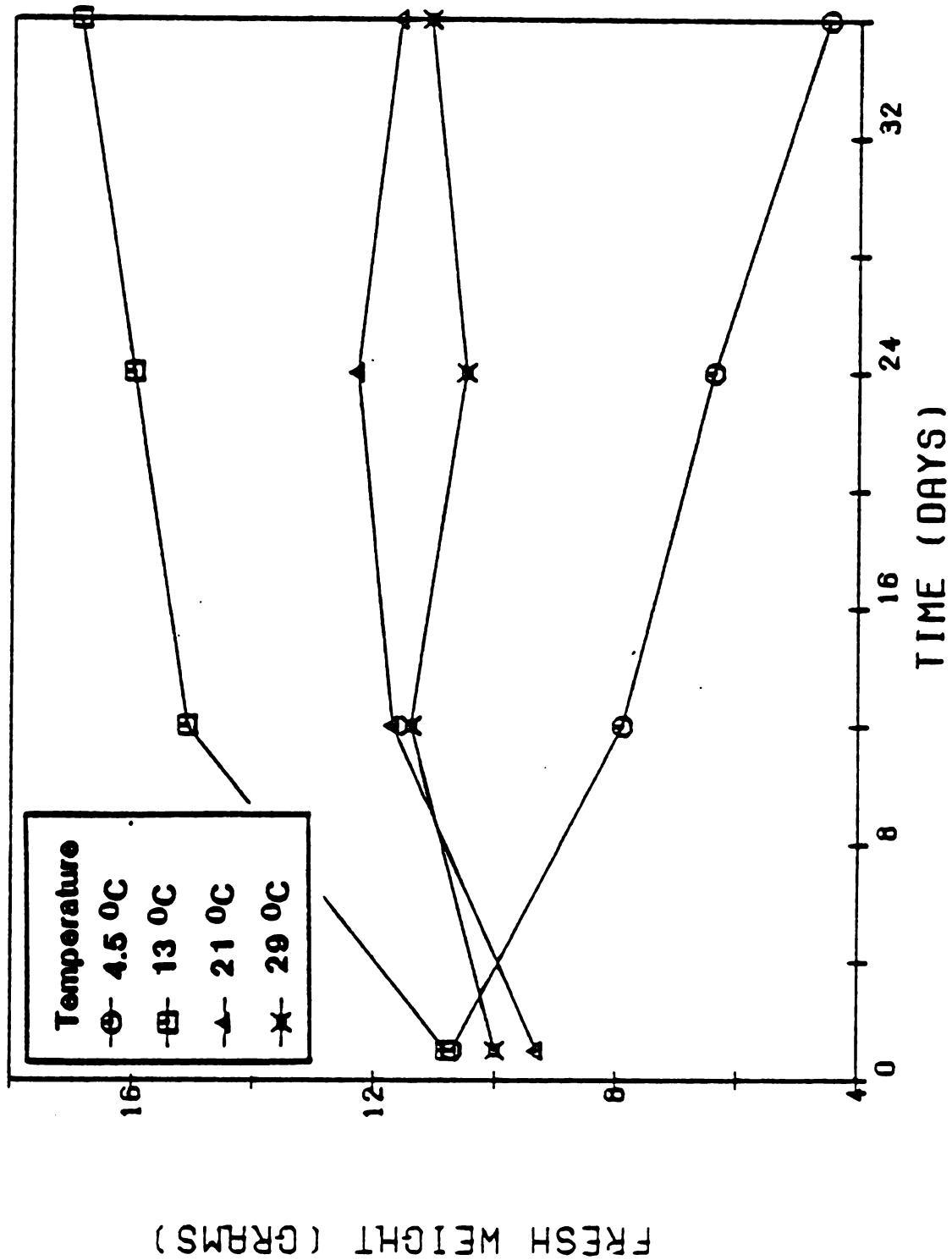


Figure 45. Influence of time and temperature on fresh weight of tomato 'Better Boy'.

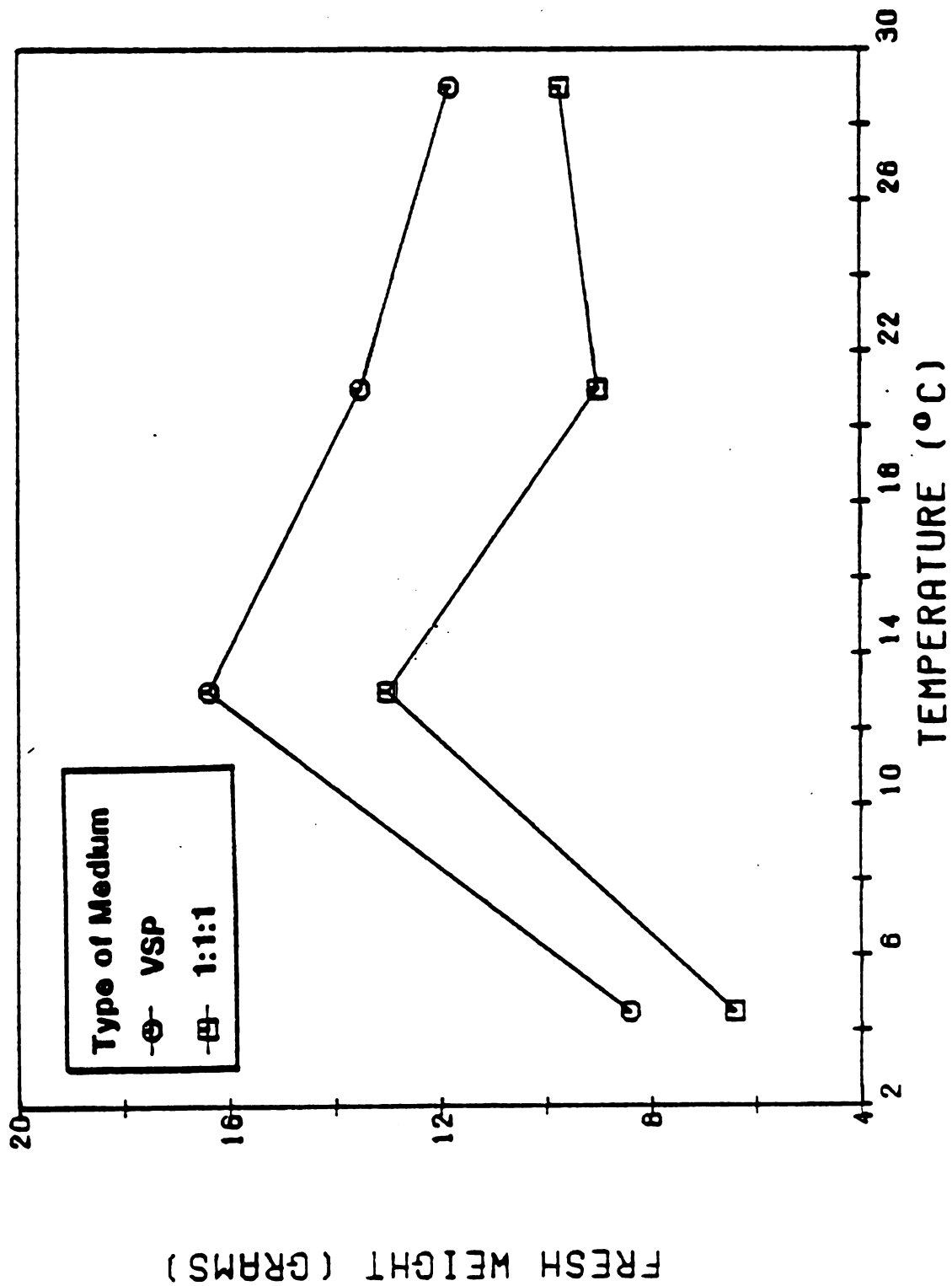


Figure 46. Influence of temperature and media on fresh weight of tomato 'Better Boy'.

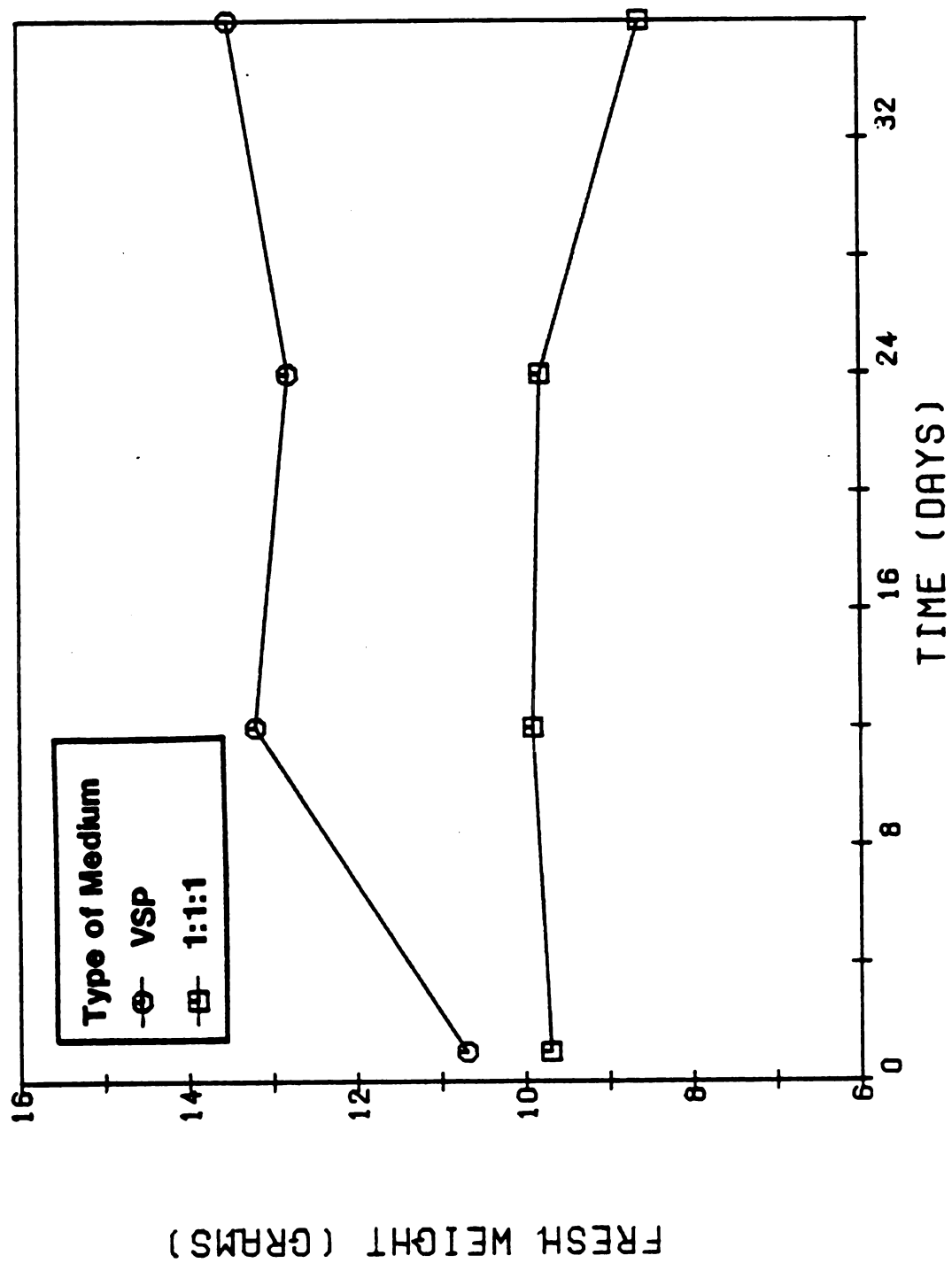


Figure 47. Influence of time and media on fresh weight of tomato 'Better Boy'.

Table 20. Influence of postproduction environmental factors after 36 days on change in stem height (cm) of tomato 'Better Boy'.

Environmental Factor	Level	Mean $\bar{x}$
QFD $\bar{y}$ ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	7	3.5 a
	36	6.6 b
	102	8.4 c
Temperature ($^{\circ}\text{C}$)	4.5	2.1 a
	13	6.2 b
	21	9.7 c
	29	6.7 b
Media	VSP	7.2 b
	1:1:1	5.2 a
Water Regime	Low	5.2 a
	High	7.2 b

$\bar{x}$ Mean separation within environmental factors by HSD test, 1% level.

$\bar{y}$ QFD (Quantum Flux Density).

Calculation of stem height after 36 days as change from day 0.

Significance:

Main Effects

QFD	
Linear	**
Quadratic	NS
Temperature	
Linear	**
Quadratic	**
Media	**
Water Regime	
Linear	**

Interactions

QFD X Temperature	**
QFD X Media	NS
QFD X Water	NS
Temperature X Media	**
Temperature X Water	NS
Media X Water	NS

Nonsignificant (NS) or significant at 1% (**) level.

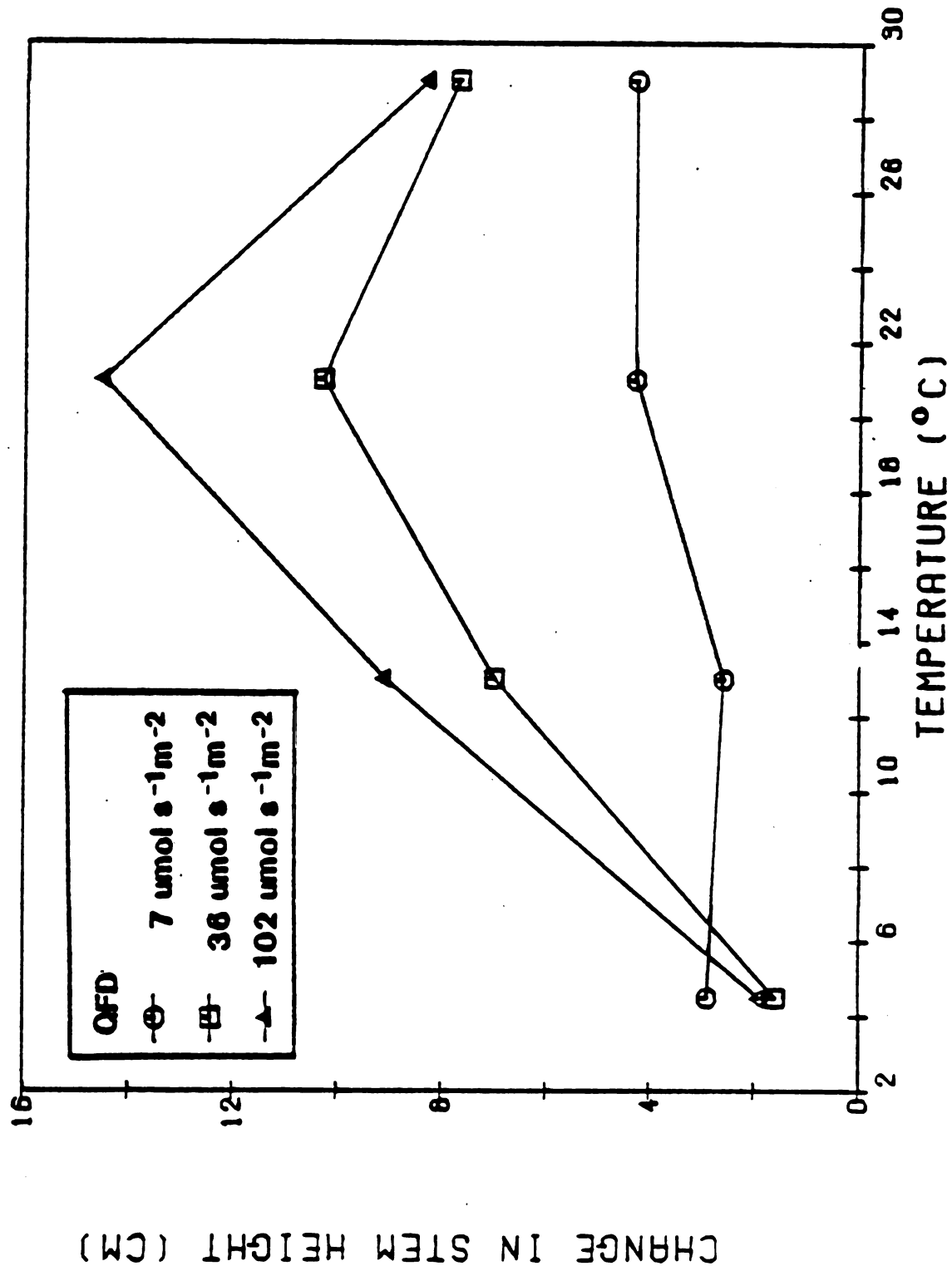


Figure 48. Influence of temperature and quantum flux density on change in stem height of tomato 'Better Boy'.

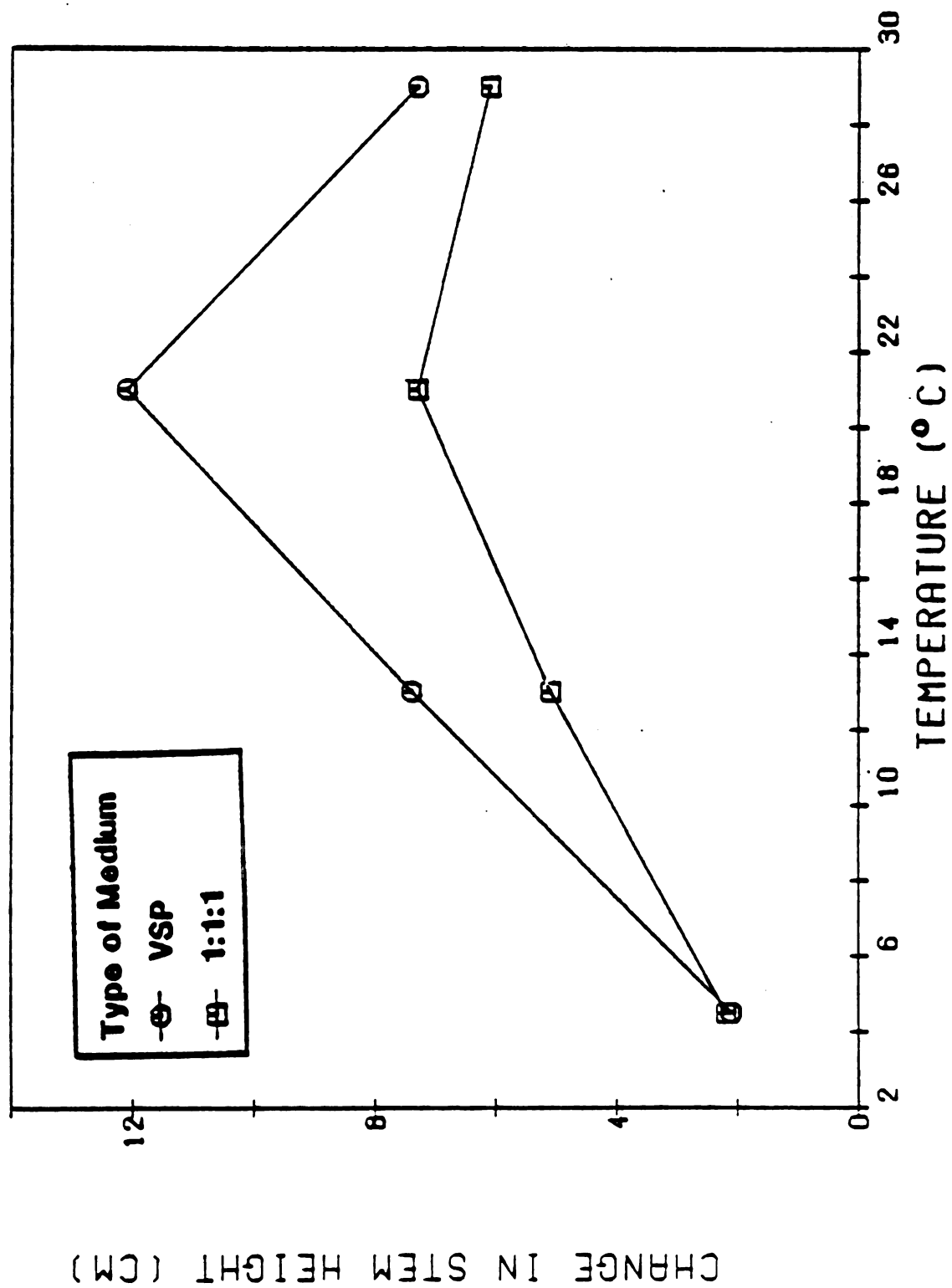


Figure 49. Influence of temperature and media on change in stem height of tomato 'Better Boy'.

CONCLUSION

In general, for the seven species tested, based on their fresh weight, change in stem height and visual assessment, marketability could best be maintained for 36 days at a 36 to 102 $\mu\text{mol s}^{-1} \text{m}^{-2}$ QFD range, a 13 to 21°C temperature range under high moisture in either type of medium.

Clearly, a QFD level of 7 $\mu\text{mol s}^{-1} \text{m}^{-2}$ was insufficient for maintaining keeping quality of any plant species. Flowering was negligible for both impatiens and petunia at this QFD level.

Alyssum, begonia, coleus and geranium had similar keeping quality in either a soil-based or a peat-lite medium while a peat-lite medium provided better keeping quality for impatiens, petunia and tomato.

Alyssum, begonia, coleus, impatiens and tomato exhibited the best keeping quality under the high moisture level while geranium and petunia responded similarly under all moisture levels.

Recommendations are provided for optimum 36 day postharvest marketability of the seven bedding plant species tested (Table 21).

Table 21. Recommendations for optimum 36 day marketability of seven bedding plant species.

Plant species	QFD ($\mu\text{mol s}^{-1}\text{m}^{-2}$)	Temperature ($^{\circ}\text{C}$)	Moisture Level	Medium Type
Alyssum	102	4.5 - 13	Medium to High	Peat-lite, Soil-based
Begonia	36 - 102	21	High	Peat-lite, Soil-based
Coleus	102	21 - 29	High	Peat-lite, Soil-based
Geranium	36 - 102	4.5 - 13	Low to High	Peat-lite, Soil-based
Impatiens	36 - 102	13 - 21	High	Peat-lite
Petunia	36 - 102	13 - 21	Low to High	Peat-lite
Tomato	102	13 - 21	High	Peat-lite

SECTION II

INFLUENCE OF ETHYLENE ON POSTPRODUCTION
KEEPING QUALITY OF BEDDING PLANTS

INTRODUCTION

The objective of this study was to determine sensitivity of nine popular bedding plant species to ethylene levels commonly encountered in the shipping environment when plants are transported from the greenhouse to the retail center.

MATERIALS AND METHODS

Seeds of the following bedding plant species were sown in March and germinated at 24°C under intermittent mist:

COMMON NAME	SCIENTIFIC NAME	CULTIVAR
Alyssum	<u>Lobularia maritima</u>	'Midnight'
Begonia	<u>Begonia</u> <u>semperflorens</u>	'Scarlanda'
Coleus	<u>Coleus X hybridus</u>	'Seven Dwarfs Scarlet'
Impatiens	<u>Impatiens wallerana</u>	'Novette Scarlet'
Marigold	<u>Tagetes erecta</u>	'Moonshot'
Pepper	<u>Capsicum annuum</u>	'Midway'
Petunia	<u>Petunia X hybrida</u>	'Red Flash'
Salvia	<u>Salvia splendens</u>	'Red Hot Sally'
Tomato	<u>Lycopersicon</u> <u>lycopersicum</u>	'Red Glo'

Seedlings were selected for uniformity and transplanted into a peat-lite mix containing 50% sphagnum peat, 20% vermiculite and 30% perlite with a nutritive charge consisting of nitrogen, potassium and phosphorus plus trace elements. Dolomitic limestone was added to

adjust pH to 5.5.

Plants were placed in a greenhouse environment and grown under a natural photoperiod at 21°C DT and 17°C NT $\pm$ 3°. Supplemental light was provided (40-80 μ mol s⁻¹ m⁻²) for 16 hours with HPS 400 watt lamps 4 feet from the plant canopy.

Nutrition was maintained using a 20-20-20 soluble fertilizer to provide 200 ppm nitrogen. Plants were leached with tap water every fourth watering. Plants were sprayed with a foliar application of 8-9 at 2500 ppm two weeks after transplant.

The following production schedule was used for each plant species:

PLANT SPECIES	DAYS IN GERMINATION ENVIRONMENT	WEEKS FROM SEEDING TO TRANSPLANT	WEEKS FROM TRANSPLANT TO BLOOM OR SALE
Alyssum	3	4	3
Begonia	14	8	7
Coleus	7	3	5
Impatiens	7	4	4
Marigold	3	3	3
Pepper	7	3	4
Petunia	5	4	5
Salvia	5	3	6
Tomato	5	3	3

Two to three weeks before start of the ethylene experiment, night temperature was lowered to 13°C.

POSTHARVEST

When plants reached anthesis (or in the case of pepper and tomato when the plants were deemed salable, they were enclosed in ten gallon plexiglass containers and gassed with 1 and 10 ppm of ethylene supplied by a baristatic flowboard system in a controlled environment

for 6,12, 24 and 48 hours. 6 plants from each species were tested at each ethylene level. Constant temperature was 25°C and a 12 hour photoperiod was provided with $10 \mu\text{mol s}^{-1} \text{m}^{-2}$ QFD from 40 watt cool-white fluorescent lamps.

After treatment, plants were observed for epinasty, abscission of floral parts, chlorosis and necrosis. Alyssum and impatiens were subsequently returned to the greenhouse and observed again after two weeks to decide whether treatment inflicted permanent damage or plants would recover.

RESULTS

Ethylene damage is described (Table 22) after 6,12,24 and 48 hours after treatment.

DISCUSSION

It was evident from this study that as little as a 1 ppm ethylene dosage for only 6 hrs can severely damage sensitive plant species. This study also demonstrated poor recovery from ethylene damage two weeks after exposure for alyssum and impatiens. Alyssum failed to produce new flowers at 1 or 10 ppm and plants treated with 10 ppm became necrotic. There was new bud development in impatiens at 1 ppm but not at 10 ppm. Epinasty was still evident at 10 ppm.

In 1917, Doupt (60) reported leaf abscission, epinasty and tissue proliferation of tomato, salvia and hibiscus when exposed to illuminating gas. This study showed early sensitivity of both salvia and tomato. The tomato is commonly used as an indicator plant for ethylene detection. It is well known that marigold is highly sensitive to ethylene exposure. Symptoms were not observed in this study until

after 48 hrs of exposure.

Dean (59) found in a simulated shipping study with geraniums, that transit at cooler ($2 - 10^{\circ}\text{C}$) temperatures slows senescence and ethylene synthesis and that shipping containers with ventilation reduce synthesis. She also showed that transit time should be as short as possible because darkness has been shown to enhance damage while delaying flowering as much as 1 week.

CONCLUSION

This study demonstrated early sensitivity of several bedding plant species to ethylene and failure to recover after exposure. This would indicate substantial monetary loss to the bedding plant industry.

It should be recommended from this investigation that growers meticulously examine their plant material prior to shipping for disease problems, ventilate shipping containers and ship at cool temperatures to control ethylene synthesis. To prevent ethylene action, vehicle exhaust must be avoided and absorbants can be used. This study confirmed the hazards of ethylene.

Table 22. Symptom development over time after ethylene treatment of nine bedding plant species.

PPM		HOURS			
		6	12	24	48
Alyssum	1	—	—	—	chlorosis
	10	—	—	—	floret abscission and severe chlorosis
Begonia	1	—	—	floret absciss.	complete floret abscission
	10	—	floret absciss.	floret absciss.	complete floret and bud abscission
Coleus	1	—	—	leaf abscission	leaf abscission
	10	—	leaf absciss.	leaf abscission	severe leaf absciss
Impatiens	1	floret absciss.	floret absciss.	floret absciss.	complete floret absciss. bud abscission epinasty
	10	complete floret absciss.	complete floret absciss.	complete floret absciss.	complete floret and bud abscission severe epinasty
Marigold	1	—	—	—	epinasty
	10	—	—	—	epinasty
Pepper	1	—	—	—	epinasty
	10	—	—	—	severe epinasty
Petunia	1	—	—	floral wilt	complete floret absciss.
	10	—	—	floral wilt	complete floret absciss.
Salvia	1	floret absciss. and epinasty	floret absciss. and epinasty	floret absciss. and epinasty	complete floret absciss. severe epinasty
	10	severe floret abscission & epinasty	severe floret abscission & epinasty	severe floret abscission & epinasty	complete floret absciss. complete defoliation
Tomato	1	epinasty	epinasty	epinasty	severe epinasty
	10	epinasty	epinasty	epinasty	severe epinasty

LITERATURE CITED

LITERATURE CITED

1. Abeles, F.B., 1973 Ethylene in plant biology. N.Y., London: Acad.
2. _____. 1982. Ethylene as an air pollutant. Agriculture and forestry bulletin. Vol. 5 no. 1 p. 4-12.
3. _____. and F.B. Abeles. 1972. Biochemical pathway of stress induced ethylene. Plant Physiol. 50: 496-498.
4. _____, R.E. Holm and H.E. Gahagan. 1967 Abscission: The role of aging. Plant Physiol. 42: 1351-1356.
5. _____ and J. Lonski. 1969. Stimulation of lettuce seed germination by ethylene. Plant. Physiol. 44: 277-280.
6. Addicott, F.T. 1977. Flower behavior in *Linum lewissii*: Some ecological and physiological factors in opening and abscission of petals. Am. Midl. Nat. 97: 321-332.
7. Adelusi, S.A. and A.O. Lawanson. 1978. Heat-induced changes in dry weight, leaf size and number of chloroplasts per cell in maize and cowpea shoots. J. Agric. Sci. 91: 349-357.
8. Aharoni, N., A. Blumenfeld and A.E. Richmond. 1977. Hormonal activity in detached lettuce leaves as affected by leaf water content. Plant Physiol. 59: 1169-1173.
9. Amer, F.A. and W.T. Williams. 1957. Leaf area growth in *Pelargonium zonale*. Ann. Bot. N.S. 21: 339-342.
10. Anderson, J.M., D.J. Goodchild and N.K. Boardman. 1973. Composition of the photosystems and chloroplast structure in extreme shade plants. Biochim. Biophys. Acta 325: 573-585.
11. Anonymous. 1978. Floriculture crops: production area and sales, 1976 and 1977. Intentions for 1978 Econ., Statistics and Coop. Service, Crop Reporting Board, U.S. Dept. Agr. sp.(r. 6-1 (78).
12. Armitage, A.M. 1980. Effects of light and temperature on physiological and morphological responses in hybrid geranium and marigold. Dissertation, Ph.D. Mich. State Univ.

13. _____. 1981. Maintaining quality bedding plants. *Amer. Veg. Grow and Greenhouse Grow.* 29(11): 98-100.
14. _____, R. Heins, S. Dean and W. Carlson. 1980. Factors influencing flower petal abscission in the seed propagated geranium. *J. Amer. Soc. Hort. Sci.* 105(4): 562-564.
15. _____ and T. Kowalski. 1983. Effects of light intensity and air temperature in simulated postproduction environment on *Petunia hybrida* Vilm. *J. Amer. Soc. Hort. Sci.* 108(1): 115-118.
16. _____ and T. Kowalski. 1983. Effect of irrigation frequency during greenhouse production on the postproduction quality of *Petunia hybrida* Vilm. *J. Amer. Soc. Hort. Sci.* 108(1) 118-121.
17. _____, H.M. Vines, Zeng-Ping Tu and C.C. Black. 1983. Water relations and net photosynthesis in hybrid geranium. *J. Amer. Soc. Hort. Sci.* 108(2): 310-314.
18. Asen, S. 1976. Known factors responsible for infinite flower color variations. *Acta. Hortic.* 63: 217-223.
19. _____, R.N. Stewart and K.H. Norris. 1975. Anthocyanin flavanol co-pigments and pH responsible for larkspur flower color. *Phytochemistry.* 14: 2677-2682.
20. Bartlett, R.U. 1961. Iron oxidation proximation to plant roots. *Soil Sc.* 92: 372-379.
21. Bauer, H. and M. Senser. 1979. Photosynthesis of ivy leaves (*Hedera helix* L.) after heat stress. II. Activity of ribulose bis-phosphate carboxylase, Hill reaction and chloroplast ultrastructure. *Z. Pflanzenphysiol.* 91: 359-369.
22. Benedict, M.B., C.J. Miller and J.S. Smith. 1973. Stanford Res. Inst. Proj. LSU-1503. Final Report. Stanford Res. Inst., Stanford Calif.
23. Berry, J. and O. Bjorkman. 1980. Photosynthetic response and adaptation to temperature in higher plants. *Ann. Rev. Plant Physiol.* 31: 491-543.
24. Beyer, E.M. and P.W. Morgan. 1971. Abscission. The role of ethylene modification of auxin transport. *Plant Physiol.* 48: 208-212.
25. Bickford, E.D. and S. Dunn. 1972. Lighting for plant growth. Kent State Univ. Press. Kent. OH.

26. Bjorkman, O. 1968. Carboxydismutase activity in shade adapted and sun adapted species of higher plants. *Physiol. Plant.* 21: 1-10.
27. _____. 1970. Characteristics of the photosynthetic apparatus as revealed by laboratory measurements. Prediction and measurement of photosynthetic productivity. Wageningen Cent. Agric. Publ. Doc. p. 267-281.
28. _____, N.K. Boardman, J.M. Anderson, S.W. Thorne, D.J. Goodchild and N.A. Pyliotis. 1972. Effect of light intensity during growth of *Atriplex patula* on the capacity of photosynthetic reactions, chloroplast components and structure. *Carnegie Inst. Washington Yearb.* 71: 115-135.
29. Blanpied, G.D. 1972. A study of ethylene in apple, red raspberry and cherry. *Plant Physiol.* 49: 627-630.
30. Boardman, N.K. 1977. Comparative photosynthesis of sun and shade plants. *Ann. Rev. Plant. Physiol.* 28: 355-377.
31. _____, J.M. Anderson, O. Bjorkman, D.J. Goodchild, L.H. Grimme and S.W. Thorne. 1974. Chloroplast differentiation in sun and shade plants: relationship between chlorophyll content, grana formation, photochemical activity and fractionation of the photosystems. *Port. Acta Biol. Ser A* 14: 213-236.
32. _____, J.M. Anderson, S.W. Thorne and O. Bjorkman. 1972. Photochemical reactions of chloroplasts and components of the photosynthetic electron transport chain in two rainforest species. *Carnegie Inst. Washington Yearb.* 71: 107-114.
33. _____, O. Bjorkman, J.M. Anderson, D.J. Goodchild and S.W. Thorne. 1975. Photosynthetic adaptation of higher plants to light intensity: relationship between chloroplast structure, composition of the photosystems and photosynthetic rates. *Proc. Third Int. Congr. Photosynthesis*. Ed., M. Avron. Amsterdam:Elsevier
34. Bohning, R.H. and C.A. Burnside. 1957. The effect of light intensity on rate of apparent photosynthesis in leaves of sun and shade plants. *Am. J. Bot.* 43: 557-561.
35. Boodley, J.W. 1981. *The Commercial Greenhouse*. Delmar Publ., N.Y.
36. Borochoy, A., A.H. Halevy and M. Shinitzky. 1976. Increase in microviscosity with aging in protoplast plasmalemma of rose petals. *Nature (London)* 2(3): 158-159.

37. Bradford, K.J. and S.F. Yang. 1981. Physiological responses of plants to waterlogging. *HortScience* 16(1): 25-30.
38. Brady, C.J., N.S. Scott and R. Munns. 1974. Interaction of water stress with the senescence pattern of leaves. *R. Soc. N.Z. Bull.* 12: 403-409.
39. Brown, O.D.R. and E.R. Emino. 1981. Response of container grown plants to six consumer growing media. *HortScience* 16(1): 78-80.
40. Bunt, A.C. 1961. Some physical properties of pot plant composts and their effect on plant growth. I. Bulky physical conditioners. *Plant and Soil* 13 no. 4: 322-332.
41. _____. 1976. *Modern potting Composts*. A.C. Bunt, London.
42. Burg, S.P. 1962. Physiology of ethylene formation. *Ann. Rev. Plant Physiol.* 13: 265-302.
43. _____, A. Apelbaum, W. Eisinger and B.G. Kang. 1971. Physiology and mode of action of ethylene. *HortScience* 6: 359-364.
44. _____ and M.J. Dijkman. 1967. Ethylene and auxin participation induced fading of vanda orchid blossoms. *Plant Physiol.* 42: 1648-1650.
45. _____ and K.V. Thimann. 1959. The physiology of ethylene formation in apples. *Proc. Natl. Acad. Sci.* 45: 335-344.
46. Butler, R.D. 1967. The fine structure of senescing cotyledons of cucumber. *J. Exp. Bot.* 18: 535-543.
47. Chadwick, A.V. and S.P. Burg. 1967. An explanation of the inhibition of root growth caused by indole-3-acetic acid. *Plant Physiol.* 42: 415-420.
48. Chin, S.T.Y. and L. Beavers. 1970. Changes in endogenous growth regulators in nasturtium leaves during senescence. *Nature (London)* 92a : 178-188.
49. Collins, P.C. and T.M. Blessington. 1983. Postharvest effects of shipping temperature and subsequent interior keeping quality of *Ficus benjamina*. *HortScience* 18(5): 757-758.
50. Conover, C.A. and R.T. Poole. 1975. Growing acclimatized plants. *Fla. Foliage Grower* 12(9): 1-7.

51. _____ and R.T. Poole. 1981. Light acclimatization of african violet. HortScience 16(1): 92-93.
52. _____, R.T. Poole and R.W. Henley. 1975. Growing acclimatized foliage plants. Fla. Flower Grower 12(9): 1-4.
53. Cooper, A.J. 1973. Root temperature and plant growth. Commonwealth Bureau of Horticulture and Plantation Crops Res. Rev. no. 4.
54. Cooper, W.C. and P.C. Reece. 1942. Induced flowering of pineapples under Florida conditions. Proc. Fla. State Hort. Soc. 54: 132-138.
55. Craker, L.E. and F.B. Abeles. 1969. Abscission: Role of abscisic acid. Plant Physiol. 44: 1144-1149.
56. Crocker, W.C. and L.I. Knight. 1908. Effect of illuminating gas and ethylene upon flowering carnations. Bot. Gaz. 46: 259-276.
57. _____, P.W. Zimmerman and A.E. Hitchcock. 1932. Ethylene induced epinasty of leaves and the relation of gravity to it. Contrib. Boyce Thompson Inst. 4: 177-218.
58. Davidson, O.W. 1949. Effects of ethylene on orchid flowers. Proc. Amer. Soc. Hort. Sci. 53: 440-446.
59. Dean, M.J. 1979. A study of simulated environmental shipping conditions on senescence and transplant recovery of seedling geranium (*Pelargonium X hortorum* Bailey) Thesis, Mich. State Univ.
60. Doupt, L.S. 1917. The response of plants to illuminating gas. Bot. Gaz. 63: 209-224.
61. Dyer, T.A. and D.J. Osborne. 1971. Leaf nucleic acids. II. Metabolism during senescence and effect of kinetin. J. Exp. Bot. 22: 552-560.
62. Ecke, P.Jr. 1975. Poinsettia culture. Ball Red Book. Geo. J. Ball, Inc.
63. Eder, A. and W. Huber. 1977. Zur Wirkung von ABA und kinetin auf biochemische veran derungen in Pennisetum typhoides unter stress-einwirkungen. Z. Pflanzenphysiol. 84: 303-311.
64. Engelbrecht, L. and K. Mothes. 1964. Ueitere Untersuchungen zur experimentellen Beeinflussung der Hitzewirk ung bei Blattern von *Nicotiana rustica*. Flora 154: 279-298.

65. Esau, K. 1965. Plant Anatomy. John Wiley, N.Y.
66. Fitter, A.H. and R.K. Hay. 1981. Environmental Physiology of Plants. Academic Press, N.Y.
67. Fitting, H. 1911. Untersuchungen ueber die varzeitige Entbatterung von Blumen. Jahrb. Wiss. Bot. 49: 187-263.
68. Fletcher, R.A. and D.J. Osborne. 1966. Gibberellin as a regulator of protein and RNA synthesis during senescence in leaf cells of *Taraxacum officinale*. Can. J. Bot. 44: 739-745.
69. Frank, S. and A.L. Kenney. 1955. Chlorophyll and carotenoid destruction in the absence of light in seedlings of *Zea mays* L. Plant Physiol. 30: 413-418.
70. Frey-Wyssling, A. and F. Blank. Unter uber die physiologie de anthocyans in Reimblingen von *Brassica oleracea* L. var. *capitata* L. f. *rubra* (L). Ber. Schweiz Bot. Ges. 53: 550-578.
71. Funke, G.L., F. de Coeyer, A. deDecker and J. Maton. 1938. Response time to ethylene in tomato. Biol. Jaarb. 5: 335.
72. Gaastra, O. 1959. Photosynthesis of crop plants as influenced by light, carbon dioxide, temperature and stomatal diffusion resistance. Meded. Landbouwhoges. Wageningen 59: 1368.
73. Galston, A.W., P.J. Davies and R.L. Satter. 1980. The Life of the Green Plant. Prentice - Hall, N.J.
74. Garber, M.P. 1977. Effect of light and chilling temperatures on chilling sensitive and chilling resistant plants. Plant Physiol. 59: 981-985.
75. Goeschl, J.D., H.K. Pratt and B.A. Bonner. 1967. An effect of light on the production of ethylene and the growth of the plumular portion of etiolated pea seedling. Plant Physiol. 42: 1077-1080.
76. Goldthwaite, J.J. and Laetsch. 1967. Regulation of senescence in bean leaf discs by light and chemical growth regulators. Plant P hysiol. 42: 1757-1762.
77. Goodchild, D.J., O.Bjorkman and N.A. Pyliotis. 1972. Chloroplast ultrastructure, leaf anatomy and content of chlorophyll and soluble protein in rain forest species. Carnegie Inst. Washington Yearb. 71: 102-107.

78. Halevy, A.H. and A.M. Kofranek. 1976. The prevention of flower bud and leaf abscission in pot roses during simulated transport. *J. Amer. Soc. Hort. Sci.* 101(6): 658-660.
79. Hanan, J.J., W.D. Holley and K.L. Goldsberry. 1978. *Greenhouse Management*. Springer Verlag.
80. Hanisch ten Cate, Ch. H. and J. Bruinsma. 1973. Abscission of flower bud pedicels in begonia. I. Effects of plant growth regulator substances on the abscission with intact plants and explants. *Acta Bot. Neerl.* 22: 666-674.
81. _____, J.J.L. VanderPloeg-Voogd and J. Bruinsma. 1973. Abscission of flower bud pedicels in begonia. III. Anatomical pattern of abscission. *Acta Bot. Neerl.* 22: 681-685.
82. Hanson, A.D. and H. Kende. 1976. Biosynthesis of wound ethylene in morning-glory flower tissue. *Plant Physiol.* 57: 538-541.
83. Haborne, J.B. 1967. *Comparative Biochemistry of the Flavenoids*. Academic Press, N.Y.
84. Hardwick, K., M. Wood and H.W. Woolhouse. 1968. Photosynthesis and respiration in relation to leaf age in *Perilla frutescens* (L.) Britt. *New Phytol.* 67: 79-86.
85. Hasek, R.F., H.A. James and R.H. Sciaroni. 1969. Ethylene -- its effect on flower crops. *Flor. Rev.* 144: 21.
86. Hatch, M.D., C.R. Slack and T.A. Bull. 1969. Light induced changes in the content of some enzymes of the C₄ dicarboxylic acid pathway of photosynthesis and its effect on other characteristics of photosynthesis. *Phytochemistry* 8: 697-706.
87. Heck, W.W. and G.E. Pires. 1962. Effects of ethylene on horticultural and agronomic plants. *Texas Agr. Exp. Sta. MP* 613: 1-12.
88. Hernanday, G.R. and M. Schaedle. 1973. Functional and structural changes in senescing *Populus deltoides* chloroplasts. *Plant Physiol.* 51: 245-249.
89. Hitchcock, A.E., W. Crocker and P.W. Zimmerman. 1932. Effect of illuminating gas on the lily, narcissus, tulip and hyacinth. *Contrib. Boyce Thompson Inst.* 4: 155-176.
90. Holmgren, P., P.G. Jarvis and M.S. Jarvis. 1965. Resistances to carbon dioxide and water vapour transfer in leaves of different plant species. *Physiol. Plant.* 18: 557-573.

91. Horie, K. 1961. The behavior of the petals in the fading of the flowers of *Tradescantia reflexa*. *Protoplasma* 53: 377-386.
92. James, H.A. 1963. Bay area Pollut. Cont. Dist. Info. Bull. 8-63. 939 Ellis St. San Francisco, CA 94105.
93. Johnson, C.R., T.A. Nell, S.E. Rosenbaum and J.A. Lauritis. 1982. Influence of light intensity and drought stress on *Ficus benjamina* L. *J. Amer. Soc. Hort. Sci.* 107(2): 252-255.
94. Kaltaler, R.E.L. 1962. Environmental factors and chemical treatments affecting premature senescence of *Pelargonium X hortorum* Bailey during shipment. Thesis. Penn. State Univ.
95. Kang, B.G., C.S. Yocum, S.P. Burg and P.M. Ray. 1967. Ethylene and carbon dioxide -- mediation of hypocotyl hook-opening response. *Science* 156: 958-959.
96. Kaufmann, M.R. 1981. Development of water stress in plants. *HortScience* 16(1): 34-36.
97. Kozlowski, T.T. 1964. *Water Metabolism in Plants*. Harper, N.Y.
98. Kramer, P.J. 1940. Causes of decreased absorption of water by plants in poorly aerated media. *Am. J. Bot.* 27: 216-220.
99. _____. 1951. Causes of injury to plants resulting from flooding of the soil. *Plant Physiol.* 26: 722-736.
100. Kriedemann, P.E. and R.E. Smart. 1971. Effects of irradiance, temperature and leaf water potential on photosynthesis of vine leaves. *Photosynthetica* 5: 6-15.
101. Krone, P.R. 1937. The reaction of greenhouse plants to gas in the atmosphere and the soil. *Mich. Exp. Sta. Spe. Bull.* 285; 1-5.
102. Kumpf, J.F., Horton and Langhans. 1966. Seedling storage. *N.Y. State Flower Growers' Bull.* 244: 1-3.
103. Lahiri, A.N. and S. Singh. 1969. Effect of hypothermia on the nitrogen metabolism of *Pennisetum typhoides*. *Proc. Natl. Inst. Sci. India Pt. B.* 35: 131-138.
104. Larson, R.A., J.W. Love, D.L. Strider, R.K. Jones, J.R. Baker and K.F. Horn. 1978. Commercial poinsettia production. *N. C. State Agr. Ext. Ser.* p. 9-10, 17-19.

105. Leopold, A.C. 1961. Senescence in plant development. *Science* 134: 1727-1732.
106. _____. 1980. *Senescence in Plants*. Thimann, K.V., Ed., CRC Press
FLA
107. _____, and P.E. Kriedmann. 1975. *Plant Growth and Development*.
2nd Ed. McGraw Hill, N.Y.
108. Levitt, J. 1972. *Responses of Plants to Environmental Stresses*.
Academic Press, N.Y.
109. Ludlow, C.J. 1968. Photosynthesis of sun and shade ferns. Ph.D.
Thesis. Vanderbilt Univ., Nashville TN.
110. Lyon, C.J. 1970. Ethylene inhibition of auxin transport by gra-
vity in leaves. *Plant Physiol.* 45: 644-646.
111. Lyons, J.M. 1973. Chilling injury in plants. *Ann. Rev. Plant*
Physiol. 24: 445-466.
112. _____ and J.K. Raison. 1970. Oxidative activity of mitochon-
dria isolated from plant tissues sensitive and resistant to
chilling injury. *Plant Physiol.* 45: 386-389.
113. Manning, C.E., D.G. Miller and I.D. Teare. 1977. Effect of mois-
ture stress on leaf anatomy and water use efficiency of peas.
J. Amer. Soc. Hort. Sci. 102(6): 756-760.
114. Margulies, M.M. 1972. Effect of cold-storage of bean leaves on
photosynthetic reactions of isolated chloroplasts. Inability to
donate electrons to photosystem II and relation to manganese
content. *Biochim. Biophys. Acta* 267: 96-103.
115. Marousky, F.J. and B.K. Harbaugh. 1979. Interactions of ethylene,
temperature, light and CO₂ on leaf and stipule abscission and
chlorosis in *Philodendron scandens* subsp. *oxycardium*. *J. Amer.*
Soc. Hort. Sci. 104(6): 876-880.
116. _____ and B.K. Harbaugh. 1981. Influence of temperature, light
and ethylene on seedlings of geranium (*Pelargonium X hortorum*
Bailey) during simulated shipping conditions. *J. Amer. Soc. Hort.*
Sci. 106(5): 527-530.
117. Mastalerz, J. W. 1977. *The Greenhouse Environment*. John Wiley and
Sons, Inc., N.Y.

118. Mayak, S. and A.H. Halevy. 1980. Senescence in Plants. Thimann, K.V., Ed. CRC Press, FLA.
119. McGlasson, W.B., B.W. Poovaiah and H.C. Dostal. 1975. Ethylene production and respiration in aging leaf segments and in discs of fruit tissue of normal and mutant tomatoes. *Plant Physiol.* 56: 547-549.
120. Metwally, A.W., Struckmeyer, B. and G.E. Beck. 1970. Effect of three soil moisture regimes on the growth and anatomy of *Pelargonium X hortorum*. *J. Amer. Soc. Hort. Sci.* 95(6): 803-808.
121. Milbrath, J.A. and Hartman. 1949. The cause and control of defoliation in cut holly. *Oregon Agr. Exp. Sta. Bull.* 413, 11p.
122. Minina, E.G. 1938. Ethylene and female flower production on cucumbers. *Dokl. Akad. Nauk SSSR* 21: 298.
123. Misra, G. and U.C. Biswal. 1973. Factors concerned in leaf senescence. I. Effects of age, chemicals, petiole and photoperiod on senescence in detached leaves of *Hibiscus rosa-sinensis* L. *Bot. Gaz.* 138: 5-11.
124. Mittelheuser, C.J. and R.E.M. vanSteveninck. 1969. Stomatal closure and inhibition of transpiration induced by abscisic acid. *Nature (London)* 221: 281-282.
125. Molisch, H. 1938. The Longevity of Plants (*Die Lebensdauer der Pflanze*) Trans. E.H. Fulling, N.Y.
126. Morton, A.G. and D.J. Watson. 1948. A physiological study of leaf growth. *Ann. Bot.* 12(47): 281-310.
127. Mothes, K. 1928. Die Wirkung des wasser mangels auf den Eiweissumsatz in höheren Pflanzen *Ber. Dtsch. Bot. Ges.* 46: 59-67.
128. _____ and L. Engelbrecht. 1961. Kinetin induced directed transport of substances in excised leaves in the dark. *Phytochem.* 1: 58-62.
129. Nell, T.A., J.J. Allen, J.N. Joiner and L.G. Albrigo. 1981. Light, fertilizer and water level effects on growth, yield, nutrient composition and light compensation point of *chrysanthemum*. *HortScience* 16(2): 222-223.
130. Nelson, L.J. A.M. Armitage and W.H. Carlson. 1980. Keeping quality of marigolds and impatiens as affected by night temperature and duration. *Flor. Rev.* 167: no. 4318.

131. Osborne, D.J. and H.M. Halloway. 1960. Auxin control of protein levels in detached autumn leaves. *Nature (London)* 188: 240-241.
132. Park, R.B. and P.V. Sane. 1971. Distribution of function and structure in chloroplast lamellae. *Ann. Rev. Plant Physiol.* 22: 395-430.
133. Parups, E.V. and A.P. Chan. 1973. Extension of vase life of cut flowers by use of isoascorbate containing preservative solution. *J. Amer. Soc. Hort. Sci.* 98: 22-26.
134. Paull, R.E. 1981. Temperature induced leakage from chilling sensitive and chilling resistant plants. *Plant Physiol.* 68: 149-153.
135. Penfound, W.T. 1931. Plant anatomy as conditioned by light intensity and soil moisture. *Am. J. Bot.* 18: 558-572.
136. Pertuit, A.J.Jr. and A.R. Mazur. 1981. Development of growth media for poinsettias. *HortScience* 16(2): 216-218.
137. Petrie, A.H., J.F. Arthur and J.G. Wood. 1943. Physiological ontogeny in the tobacco plant. *Austr. J. Expt. Biol. Med. Sci.* 21: 191-200.
138. Poole, H.A. and T.A. Fretz. 1978. Aggregated fly ash as an amendment for container grown plants. *Ohio Flor. Assoc. Bul. no.* 583.
139. Poole, R.T. and C.A. conover. 1981. Influence of maximum air temperatures and irrigation frequency during high temperature periods on the growth of four foliage plants. *HortScience* 16(4): 556-557.
140. _____ and C.A. Conover. 1983. Influence of simulated shipping environments on foliage plant quality. *HortScience* 18(2): 191-193.
141. Poovaiah, B.W. and A.C. Leopold. 1973. Deferral of leaf senescence with calcium. *Plant Physiol.* 52: 236-239.
142. Porter, O.A. and J.T. Moraghan. 1975. Differential response of two corn inbreds to varying root temperatures. *Agron. J.* 67: 515-518.
143. Precht, H., J. Christopherson, H. Hensel and W. Larcher. 1973. *Temperature and Life.* Springer Verlag, Berlin.

144. Richardson, S.D. 1957. The effect of leaf age on rate of photosynthesis in detached leaves. *Acta Bot. Neerl.* 6: 445-457.
145. Sacher, J.A. 1957. Relationship between auxin and membrane integrity in tissue senescence and abscission. *Science* 125: 1199-1200.
146. _____. 1959. Studies of auxin membrane permeability relations in fruit and leaf tissues. *Plant Physiol.* 13: 365-372.
147. _____ and S.O. Salminen. 1969. Comparative studies of effect of auxin and ethylene on permeability and synthesis of RNA and protein. *Plant Physiol.* 44: 1371-1377.
148. Salin, M.L. and P.H. Homann. 1971. Changes of photorespiratory activity with leaf age. *Plant Physiol.* 48: 193-196.
149. Seeley, J.G. 1979. Advancements in commercial floriculture during the past 75 years. *HortScience* 14(3): 364-368.
150. Sestak, A. and J. Catsky. 1962. Intensity of photosynthesis and chlorophyll content as related to leaf age in *Nicotiana*. *Biol. Plant.* 4: 131-140.
151. Shaw, M. and M.S. Manocha. 1965. Fine structure in detached wheat leaves. *Can. J. Bot.* 43: 742-755.
152. Simons, R.K. 1973. *Shedding of Plant Parts*. Kozlowski, T.T., Ed. Academic Press, N.Y.
153. Singleton, V.L. 1972. *The Chemistry of Plant Pigments*. Chichester, C.O., Ed. Academic Press, N.Y.
154. Slavik, B. 1965. The influence of decreasing hydration level on photosynthetic rate in the thalli of the hepatic *Conocephallum conicum*. *Proc. Symp. Water stress in plants*, B.Slavic (ed.) Czech. Acad. Sci., Prague.
155. Smillie, R.M. 1962. Photosynthetic and respiratory activities of growing pea leaves. *Plant Physiol.* 37: 716-721.
156. _____ and R. Nott. 1979. Assay of chilling injury in wild and domestic tomatoes based on photosystem activity of the chilled leaves. *Plant Physiol.* 63: 796-801.
157. Spencer, P.W. and J.J. Titus. 1972. Biochemical and enzymatic changes in apple leaf tissue during autumnal senescence. *Plant Physiol.* 49: 746-750.

158. Spomer, A.L. 1979. Container soils are different. Horticulture Facts, Univ. Ill. at Urbana, Champaign, Coll. of Agr. Coop. Exten. Serv. Fl-4.
159. _____. 1979. Physical properties of a good container soil amendment. Horticulture Facts, Univ. Ill. at Urbana, Champaign, Coll. of Agr. Coop. Exten. Serv. Fl-5.
160. _____ and L.R. Nelms. 1979. Water retention of transplanted container soils. Horticulture Facts, Univ. Ill. at Urbana, Champaign, Coll. of Agr. Coop. Exten. Serv. Fl-7.
161. Staby, G.L. and A.M. Kofranek. 1979. Production conditions as they affect harvest and postharvest characteristics of poinsettia. J. Amer. Soc. Hort. Sci. 104(1): 88-92.
162. _____, J.F. Thompson and A.M. Kofranek. 1978. Postharvest characteristics of poinsettias as influenced by handling and storage procedures. J. Amer. Soc. Hort. Sci. 103(6) 712-715.
163. Stocker, O. 1960. Physiological and morphological changes in plants due to water deficiency. Arid Zone Research UNESCO 15: 63-104.
164. Stuart, N.W., S. Asen and C.J. Gould. 1966. Accelerated flowering of bulbous iris after exposure to ethylene. HortScience 1(1): 19-20.
165. Stuart, R.N., K.H. Norris and S. Asen. 1975. Microspectrophotometric measurement of pH and pH effect on color of petal epidermal cells. Phytochem. 14: 937-942.
166. Tan, Soon Chye. 1979. Relationships and interactions between phenylalanine ammonia-lyase, phenylalanine ammonia-lyase inactivating system and anthocyanin in apples. J. Amer. Soc. Hort. Sci. 104(5) 581-586.
167. Taylor, A.O. and A.S. Craig. 1971. Plants under climatic stress II. Low temperature, high light effects on chloroplast ultrastructure. Plant Physiol. 47: 719-725.
168. _____ and J.A. Rowley. 1971. Plants under climatic stress. I. Low temperature, high light effects on photosynthesis. Plant Physiol. 47: 713-718.
169. Taylor, H.M. and B. Klepper. 1978. The role of rooting characteristics in the supply of water to plants. Adv. Agron. 39: 99-128.

170. Thimann, K.V. 1980. Senescence in Plants. Thimann, K.V. Ed. CRC Press, FLA
171. Thomas, H. and J.L. Stoddart. 1980. Leaf senescence. Ann. Rev. Plant Physiol. 31: 83-111.
172. Tija, B.O.S., M.N. Rogers and D.E. Hartley. 1969. Effects of ethylene on morphology and flowering of *Chrysanthemum morifolium* Ramat. J. Amer. Soc. Hort. Sci. 94: 35-39.
173. Tingey, D.T. 1980. Stress ethylene production --- a measure of plant response to stress. HortScience 15(5): 630-633.
174. Valdovinos, J.G., L.C. Ernest and E.W. Henry. 1967. Effects of ethylene and gibberellic acid on auxin synthesis in plant tissues. Plant Physiol. 42: 1803-1806.
175. Vickery, H.B., C.W. Pucher, A.J. Wakeman and C.S. Leavenworth. 1937. Chemical investigations of the tobacco plant. VI. Chemical changes that occur in leaves during culture in light and darkness. Conn. Agr. Exp. Sta., New Haven, Bull. 399: 757-832.
176. Walker, J.M. 1969. One degree increments in soil temperatures affect maize seedling behavior. Soil Sc. Soc. Am. Proc. 33: 729-736.
177. Wang, C.Y. 1982. Physiological and biochemical responses to chilling stress. HortScience 17(2): 173-186.
178. _____, W.M. Mellenthin and E. Hansen. 1971. Effect of temperature on development of premature ripening of Bartlett pears. J. Amer. Soc. Hort. Sci. 96: 122-126.
179. Warncke, D.D. and D.M. Krauskopf. 1983. Greenhouse growth media: Testing and nutrient guidelines. M.S.U. Ag Facts. M.S.U. Coop. Exten. Serv. Bull. E-1736.
180. White, J.W. 1976. Bedding Plants. Pennsylvania Flower Growers.
181. Wiemken, C.V., A. Wiemken and Matile. 1974. Mobilisation von Zellwandstoffen in der Welkenden Blaten von *Ipomoea tricolor*. Planta 115: 297-307.
182. Wollgiehn, R. 1967. Nucleic acid and protein metabolism of excised leaves. Symp. Soc. Exp. Biol. 21: 321-266.

183. Woolhouse, H.W. 1967. Aspects of the biology of aging. Woolhouse, H.W. Ed., Symp. Soc. Exper. Biol. Vol. 21, Academic press, London and N.Y.
184. _____. 1978. Senescence processes in the life cycle of flowering plants. BioScience vol. 28 no. 1.
185. Worrall, R.J. 1981. Comparison of composted hardwood and peat based media for production of seedlings, foliage and flowering plants. Scientia Horticulturae 15: 311-319.
186. Wright, S.T.C. and R.U.P. Hiron. 1972. Plant Growth Substances. Carr, D.J. Ed. Springer, Berlin.
187. Yang, S.F. and H.K. Pratt. 1978. Biochemistry of Wounded Plant Storage Tissues. Kahl, G., Ed. deGruyter, Berlin.
188. Yarwood, E. 1977. Sensitization of leaves and pathogens to cold. Phytopathology 67: 637-647.
189. Yemm, E.W. 1935. Respiration of barley leaves. II. Carbohydrate concentration and CO₂ production in starving leaves. Proc. R. Soc. London. Ser. B., 117: 504-525.
190. _____. 1937. Respiration of barley leaves. III. Protein catabolism in starving leaves. Proc. R. Soc. London. Ser. B., 123: 243-273.
191. Zhdanova, L.P. 1950. Ethylene and flowering of Perilla and cocklebur. Dokl. Akad. Nauk SSSR 70: 715.
192. Zimmerman, P.W., A.E. Hitchcock and W. Crocker. 1931. The effect of ethylene and illuminating gas on roses. Contrib. Boyce Thompson Inst. 3: 459-481.
193. Zimmerman, R.P. and L.T. Kardos. 1961. Effect of bulk density on root growth. Soil Sc. 91: 280-288.