HIGH INTENSITY SUPPLEMENTARY LIGHTING OF POT CHRYSANTHEMUMS IN THE GREENHOUSE

Dissertation for the Degree of Ph. D.

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ABSTRACT

HIGH INTENSITY SUPPLEMENTARY LIGHTING OF
POT CHRYSANTHEMUMS IN THE GREENHOUSE

By

Gary Allen Anderson

Continuous supplementary lighting of pot cultivars of _Chrysanthemum morifolium_ Ramat. with Lucalox (400 W) sodium vapor and Multivapor (400 W) mercury lamps at 58 to 116 W/m^2 improved plant quality from Sept. to Apr. The benefits were measured during vegetative growth and at flowering from lighting stock plants, lighting during propagation, or lighting after transplanting. Maximum benefits from lighting determined by the increases in plant height, fresh and dry weight, flowering branch number and floral display diameter resulted from lighting during the 3 weeks after transplanting. Smaller benefits were found from lighting stock plants or during propagation.

Chrysanthemum stock plants lighted continuously with Multivapor and Lucalox lamps (100 W/m^2) produced larger numbers of cuttings with greater fresh and dry weight and

stem diameter than those receiving only seasonal daylight and photoperiodic lighting. Cuttings from plants receiving high intensity supplementary lighting rooted in fewer days, had greater root fresh and dry weights, and greater top fresh weight than plants lighted photoperiodically. After transplanting these cuttings became established more rapidly and developed into flowering plants of higher quality.

Continuous high intensity supplementary lighting of chrysanthemum vegetative cuttings during propagation from Oct. to Mar. at 116 W/m^2 reduced the number of days to rooting and increased root number, length and fresh weight over non-lighted cuttings. Lighting benefits were lost at 174 W/m^2 when foliar chlorosis developed which delayed rooting and reduced root growth.

Benefits were similar from supplemental lighting at 116 W/m^2 with combined Lucalox and Multivapor lamps and 58 W/m^2 with Lucalox lamps. Increasing light intensity by adding the Multivapor lamp to the Lucalox did not significantly improve chrysanthemum growth and quality over benefits from Lucalox lamps.

High intensity supplementary lighting: (1) increased the plant display diameter because more flowering branches developed from the pinch, (2) increased branch diameter resulting in a sturdier plant with less need for support and better shipping quality and (3) slightly increased plant height with significance depending on the cultivar. The prospect of greatly improving pot mum quality during the winter months by using a highly efficient light source should make installation of a Lucalox lighting system attractive to commercial growers.

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By

Gary Allen Anderson

A DISSERTATION

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To Cheryl

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INTRODUCTION

During short winter days natural greenhouse light intensities are low and the growth of many greenhouse crops is slowed. In Michigan, winter days are frequently cloudy and often less than one-half the potential sunlight is received. Artificial lighting has been used to control daylength (photoperiodic lighting) and to a lesser extent to promote growth rate and plant quality (photosynthetic lighting). In the greenhouse, photosynthetic lighting most frequently is used to supplement natural daylight but in some cases plants have been successfully grown entirely under artificial light.

The widespread use of photosynthetic lighting has been retarded by the lack of a highly efficient lamp source which could provide high light intensities at an economical cost. The advent of high intensity discharge lamps (HID) is making commercialization of horticultural lighting more promising. Lucalox sodium vapor and Multi-vapor lamps (HID) have the highest light producing efficiency of any commercial source of white light. The HID lamp is about 30% efficient in its use of electrical input, compared with about 20% for fluorescent lamps and only 8% to 10% for incandescent lamps.

The Lucalox (400 W) sodium vapor lamp produces 105 lumens per watt compared with 80 lumens per watt for a Multivapor (400 W) mercury lamp. For Lucalox lamps a sodium/mercury amalgam in a ceramic arc tube is vaporized to emit "golden white" light. For Multivapor lamps mercury and metallic iodides are vaporized in a quartz arc tube. The Multivapor lamp emits more blue light and less orange-red light than the Lucalox lamp (Figures A1 and A2).

The elliptical bulb shape for both lamps is very compact and permits optimum control of the direction of light. Long lamp lives and lumen maintenance characteristics contribute to significantly reduced costs of lighting maintenance. Their high efficacies make for low electric energy costs.

The Duraglow luminaire used with HID lamps is well suited for greenhouse applications (Figure A3). The faceted reflector design of the luminaire provides uniform, diverging light with no photometric crossovers or hot spots. The design also eliminates the redirection of radiant energy through the arc tube of the lamp and thus insures long lamp life. The reflector is lightweight and coated with a special glass finish to make it impervious to plant nutrients, insecticides and moisture.

This study was initiated to determine the possible benefits of supplemental lighting of pot chrysanthemums with HID lamps. Pot mums are an important greenhouse crop grown in quantity throughout the year. In northern latitudes, winter pot mum quality declines due to slower growth, less branching and weaker stem and foliage development. It was the aim of this study to determine the extent to which normal winter pot mum quality could be improved using Lucalox and Multivapor lamps.

NOTE TO COMMITTEE

This dissertation has been prepared in two sections. Section One, 'High Intensity Supplementary Lighting of Chrysanthemum Stock Plants,' is a paper in journal format that has been submitted for publication in HortScience.

Section Two is in the traditional thesis form. The body is divided into four parts for clarity and convenience in future publication.

SECTION ONE

High Intensity Supplementary Lighting of Chrysanthemum Stock Plants[1]

G. A. Anderson and W. J. Carpenter[2,3]

Michigan State University, East Lansing

Abstract. Stock plants of *Chrysanthemum morifolium* Ramat. cv. Bright Golden Anne lighted continuously from Sept. 30 to May 15 with Multivapor and Lucalox lamps (100 W/m^2) produced larger nos. of cuttings than those receiving only seasonal daylight and photoperiod lighting. Supplementary high intensity lighting improved cutting quality by increased fresh and dry wt and stem diameter. Cuttings from plants receiving high intensity lighting rooted in fewer days, had greater root fresh and dry wts, and greater top fresh wt than

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[1]Journal Article No. 6456 from the Michigan Agricultural Experiment Station.

[2]Graduate student and professor, Department of Horticulture.

[3]The authors wish to acknowledge the financial support and equipment from the General Electric Foundation and cuttings from Yoder Bros. Inc.

plants lighted photoperiodically. After transplanting these cuttings became established more rapidly and developed into flowering plants of higher quality.

Low greenhouse light intensities in winter limit the growth rate and quality of plants. Supplementary artificial radiation has been successfully used in northern climates to improve the growth rate and quality of greenhouse crops (6). Supplemental photoperiodic lighting of carnations with 75W and 150W incandescent reflector lamps allows the earlier flowering of shoots and increases flower yield (7). Supplementary high intensity greenhouse lighting using combinations of mercury vapor and incandescent lamps has increased plant top heights and dry wt and reduced the no. of days to flowering for peas, beans, tobacco, and snapdragon (2). Sodium vapor lamps are more efficient than others, producing larger plant tissue dry wt from equal energy in the visible region (1).

Flint reported geranium and chrysanthemum stock plants lighted 10 hrs nightly with color-corrected mercury vapor lamps produced 56% and 20% respectively more cuttings than photoperiodically lighted controls during Nov. and Dec. Benefits from high intensity lighting of chrysanthemum decline more rapidly in the spring than for geranium (3). Swain found that 4 cultivars of chrysanthemum stock plants lighted from Sept. 29 to Jan. 3 with mercury vapor lamps (300-600 ft-c at plant level) produced significantly more and heavier cuttings than photoperiodically lighted controls (6).

Our study determined chrysanthemum stock plant benefits from continuous high intensity supplementary lighting with Lucalox and Multivapor lamps and the later influence on cutting propagation and plant development. These high intensity discharge lamps are of particular interest because they have the highest light producing efficiency of any commercial sources of white light. Their compactness eliminates any significant shading from the lighting system and allows for good control of the direction of light. Long lamp life, lumen maintenance and high efficacies make for reduced costs of lighting maintenance.

Rooted cuttings (210) of chrysanthemum cv. Bright Golden Anne were planted in each of 2 adjacent north-south 4.5m by 1m raised benches Oct. 1. Above one bench 2 Lucalox (400W) sodium vapor lamps and a Multivapor (400W) mercury vapor lamp with reflectors were alternated, providing $100W/m^2$ 22 cm above the bench surface. High intensity lighting 24 hrs daily began Oct. 20 and continued to May 15. Light (50 ft-c) from incandescent lamps (60W) 4 hrs nightly kept plants in the adjoining bench vegetative. A black sateen cloth was hung vertically between the two benches. Cultural practices were followed as recommended for chrysanthemums (4), and a 1200-1500 ppm CO_2 level was maintained in the greenhouse air.

Twelve plots were established in each bench to compare cutting no. and quality beneath and between each lamp with plants lighted only photoperiodically. Records included cutting no. harvested monthly from each plot and cutting measurements of node no., basal diameter, and fresh and dry wt.

The rootability and subsequent development of cuttings from lighted stock plants was determined by propagations in Nov. and Jan. Terminal cuttings (8 cm) from each plot were propagated in a medium of coarse sand with bottom heat (24^{o}C) and intermittent misting 10 sec. each 10 min. Incandescent lighting 4 hrs nightly during propagation prevented flower bud initiation. Rooted cuttings from each plot were harvested Dec. 14 and Jan. 20 and the no. of days for rooting, root no., root fresh and dry wt, and top length, fresh wt, and node no. were determined. Other rooted cuttings from each treatment were potted 3 to a 6 inch clay pot in a medium of equal parts of soil, peat moss, and Turface and given recommended cultural practices (4). Plants were harvested 5, 10, 15, and 20 days after transplanting and at flowering to determine the lasting extent of the benefits found at propagation.

Cutting yield. Chrysanthemum stock plants receiving 100W/m^2 continuously from Lucalox and Multivapor lamps produced a larger no. of cuttings than those lighted photoperiodically during each of the 7 monthly periods (Fig. 1). Lighted stock plants yielded 43% more terminal cuttings in Nov.-Dec. than photoperiodic lighting, 102% in Jan.-Feb. and 33% in Mar.-Apr.

Cutting quality. Improved cutting quality resulted from high intensity lighting of stock plants. Cuttings from high intensity lighted plants had larger and thicker leaves and greater basal stem diameter than cuttings from photoperiodic lighting. In Jan. terminal stem cuttings (8 cm) from high intensity lighted stock plants had 64% greater fresh wt and 108% more dry wt with a 58% larger basal stem diameter. Similar differences in cutting size and wt were found during Nov. and Mar. (Table 1). The node no. per 8 cm terminal cutting was slightly greater from high intensity light than photoperiodic lighting of stock plants. No significant difference was found among cuttings from the various lighted plots.

Propagation. Cuttings from high intensity lighted ($100W/m^2$) stock plants developed roots 2 days earlier in Nov. and Dec. with thicker roots having 45% greater root fresh wt, and slightly larger top fresh wt and node no. (Table 2).

Growth after transplanting. Top and root measurements, 20 days after transplanting, showed plants derived from high intensity lighted stock plants had larger fresh

Table 1. Quality of 8 cm terminal cuttings from plots of chrysanthemum stock plants under various light regimes.

Trial	Lucalox	Multivapor	Luca./Mult.	Control
		Node no./cutting		
Nov.	4.26x[a]	4.67x	4.12x	3.69y
Jan.	4.17x	4.88x	3.75x	3.78x
Mar.	4.58x	4.58x	4.00x	3.33y
		Cutting base diam. (cm)		
Nov.	0.52x	0.49x	0.51x	0.37y
Jan.	0.49x	0.49x	0.50x	0.31y
Mar.	0.53x	0.51x	0.47x	0.30y
		Fresh wt (g)		
Nov.	4.26x	4.67x	4.12x	3.69y
Jan.	3.22x	3.58x	3.72x	2.21y
Mar.	4.64x	4.49x	3.68y	2.70z
		Dry wt (g)		
Nov.	0.54x	0.56x	0.51x	0.27y
Jan.	0.52x	0.53x	0.51x	0.25y
Mar.	0.61x	0.63x	0.52x	0.21y

[a]Figures based on 4 replications of 6 cuttings each. Figures on a given line followed by the same letter are not significantly different at the 5% level.

Table 2. Comparison of chrysanthemum plants propagated and grown under normal light conditions but originating from stock plants lighted 100W/m^2 with combined Lucalox and Multivapor lamps.[a]

	Nov./Dec. Lighted Stock	Nov./Dec. Unlighted Stock	Jan./Feb. Lighted Stock	Jan./Feb. Unlighted Stock
End of Propagation				
Days to root	11.50x	13.90y	11.80x	14.30y
No. of roots	32.56x	34.31x	27.91x	25.77x
Fr. root wt (g)	1.49x	1.03y	1.37x	1.19y
Dry root wt (g)	0.27x	0.19y	0.22x	0.15y
Top length (cm)	8.81x	8.47x	8.75x	8.86x
No. of nodes	4.32x	3.67y	3.92x	3.82x
Fr. top wt (g)	4.19x	3.57y	4.02x	2.97y
Day 10				
Fr. root wt (g)	3.56x	2.83y	3.31x	2.15y
Dry root wt (g)	0.52x	0.46y	0.49x	0.39y
Top length (cm)	10.94x	8.85y	9.94x	9.32y
No. of nodes	5.32x	4.39y	4.69x	4.41x
Fr. top wt (g)	5.95x	3.75y	4.92x	4.06y
Day 20				
Fr. root wt (g)	6.44x	5.47y	5.94x	4.82y
Dry root wt (g)	0.79x	0.71y	0.75x	0.64y
Top length (cm)	14.69x	12.02y	12.92x	11.93x
No. of nodes	7.44x	6.38y	6.21x	5.95y
Fr. top wt (g)	8.00x	6.32y	6.75x	6.04y
At Flowering				
Plant ht. (cm)	68.32x	62.49y	65.32x	61.77x
No. of fl. branches	3.24x	2.63y	3.12x	2.54y
Fr. top wt (g)	75.12x	70.41y	74.01x	69.36y
Dry top wt (g)	10.29x	9.90y	9.97x	8.65y
Flower diam. (cm)	9.76x	9.57x	9.52x	9.35x

[a]Figures based on 4 replications of 3 plants each. Figures on a given line followed by the same letter are not significantly different from the other value within the trial at the 5% level.

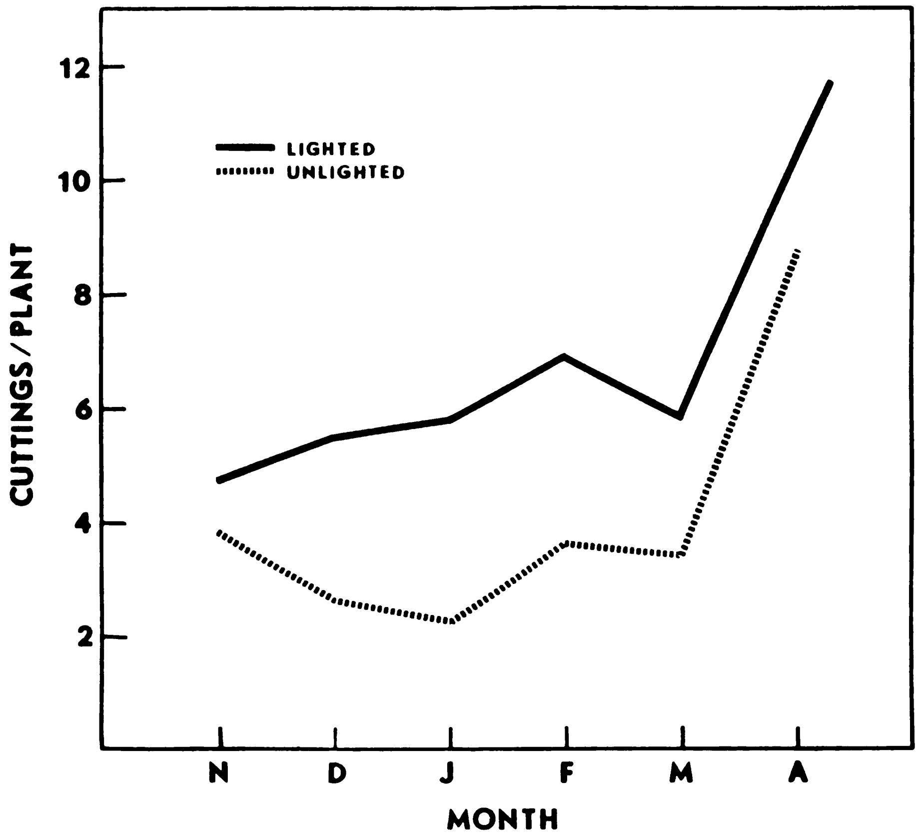

Fig. 1. Mean monthly no. of 8 cm terminal stem cuttings per chrysanthemum stock plant comparing treatments lighted continuously (100 W/m^2 from Lucalox and Multivapor lamps) with unlighted (only photoperiodic lighting).

wt, greater plant height, top fresh wt, and stem node no. (Table 2). At flowering, treatment differences were visible, and measurements showed these plants had 23% more flowering branches and were slightly taller and heavier than those from photoperiodically lighted stock (Table 2).

Terminal stem cutting numbers yielded by chrysanthemum stock plants from Oct. through May were increased greatly by continuous lighting with Multivapor and Lucalox lamps at $100W/m^2$. The increased cutting no. reflected a 4.7 day decrease (from 16.3 to 11.6 days during Dec. and Jan.) in the no. of days from cut-to-cut for high intensity lighted versus photoperiodic lighted plants. The no. of branches/m^2 in high intensity lighted plots was increased 110% and 68% in Jan. and Mar. respectively. High intensity lighting allows a greater density of branches while the limited photosynthesis at normal winter greenhouse daylight intensities is inadequate to support large nos. of branches.

High intensity supplemental lighting has been reported to increase the total reducing sugar level in rose leaves.[4] Chrysanthemum leaves probably also contain higher carbohydrate reserves after exposure to

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[4]Anderson, G. A. 1970. The Effect of High Intensity Supplemental Lighting of Roses in the Greenhouse. Master's Thesis. Michigan State University, East Lansing.

supplementary high light energy levels. Since chemical synthesis and plant growth are dependent on the amount of available photosynthate, this could explain the stockier cuttings with greater fresh wt from the high intensity lighting of stock plants. The greater carbohydrate reserve probably also accounts for the faster rooting and heavier root system.

The benefits in plant quality after propagation were found to continue through the first 20 days of growth after transplanting and provided for a slightly higher quality plant at flowering. Our results indicate that supplementary lighting of stock plants with high intensity discharge lamps during the winter months in northern latitudes increases cutting no. and improves chrysanthemum plant growth and development to flowering, and should have commercial application.

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SECTION TWO

REVIEW OF LITERATURE

Advancements in horticultural lighting

Many possible methods of supplementing greenhouse daylight during the winter months have been investigated since L.H. Bailey in 1893 used artificial light on growing plants. Enclosing a carbon arc lamp in glass to absorb the damaging ultraviolet radiation, he showed that electric light could benefit plant growth. Bailey called the new technique electro-horticulture (42).

Although scientists recognized that an increased light intensity increased assimilation in plants, its use in regulating plant growth received limited attention until Garner and Allard discovered the controlling influence of daylength on the flowering of plants (12, 32). Following this discovery, artificial lighting to control daylength was used in biological research and for commercial plant production. During the 1920's and 1930's research was begun to make qualitative measurements of light's effect on photosynthesis and subsequent plant growth (4, 14, 61, 64, 68). Researchers reported that carbohydrate levels in plant tissue could be changed by the light intensity or daylength (23, 26). Went (84) reported in 1941 that although qualitatively a number of effects were known, understanding of the quantitative relationship between wavelength, light intensity, and total energy and their physiological effects was still shockingly deficient.

Lighting equipment has two general uses in horticulture, photoperiodic and photosynthetic lighting. Photoperiodic control of chrysanthemum flowering is well known. The development of practical applications of daylength to chrysanthemum production was made by Laurie and his co-workers in 1930 (46).

Photoperiodic lighting is accomplished with relatively low intensities (10 foot-candles of incandescent light) at critical periods to produce desired responses. Incandescent lamps are superior to other types because they emit more orange-red radiation (600-700 nm) than most other lamps, and the orange-red rays are more effective in controlling the photoperiodic phenomena (46). Most fluorescent lamps emit lower intensities of orange-red radiation than incandescent lamps and therefore must operate for longer periods to achieve the same photoperiodic result. However, pink fluorescent lamps, which emit considerable orange-red radiation, can produce a desired photoperiodic response with half the duration of lighting each night than incandescent lamps (46).

Over the last forty years much information has been acquired regarding the specific ratios of light to dark periods that are required to manipulate the bloom of floriculture crops. The explanation of this phenomenon is intimately related to the action of the light-absorbing pigment, phytochrome. The chrysanthemum is perhaps the most extensive commercial greenhouse crop controlled in this way.

High intensity lighting for increased photosynthesis, while used by growers in Europe, has had less application by U.S. growers (10). Photosynthetic lighting of horticultural crops requires irradiation levels from ten to over a hundred times that needed for photoperiodic control of flowering. The need for photosynthetic lighting in the greenhouse is greatest at northern latitudes during the winter months when normal greenhouse light intensities are low. For maximum benefit, artificial lighting is used to supplement natural daylight with higher day temperatures and supplemental carbon dioxide throughout the lighting period (77).

Bickford stated that horticultural applications of lighting would be grossly impractical if it were necessary to duplicate the radiant intensity of natural spring or summer daylight (10). Fortunately much lower levels of light are sufficient to induce many plant photo-responses, including photosynthesis. It is upon this premise that horticultural lighting is based.

Canham summarized the desirable properties of a lamp to supplement daylight and accelerate plant vegetative growth as: (1) The spectral flux distribution must give the maximum increase in the rate of plant growth per unit of incident flux; (2) It should permit the plant to grow and develop normally, e.g. does not cause excessive elongation or soft growth; (3) The intensity of incident flux per unit area should be as high as possible for a given input; (4) The capital and running costs per plant irradiated should be as low as possible; (5) The lamp life should be as long as possible; (6) The lamp and fitting should be as compact as possible to reduce shading of natural daylight; (7) The fitting should stand greenhouse conditions without deterioration; (8) The distribution of radiant flux over the bench area should be as uniform as possible (16). Basic and applied research and practical applications indicate that those lamps most efficient in radiating energy in the 580 to 800 nm spectral region are most effective and most widely used in horticulture.

The spectral distribution of energy is just as important as the total energy emitted. Studies of the effect of different spectral regions on various plant responses show red and blue light control most plant processes (26, 74). Therefore, a greater percentage of energy should be in the 600-700 nm region with lesser percentages in the 700-800 nm and 400-500 nm regions.

Lamps in horticultural use today include incandescent lamps, standard "white" and plant growth fluorescent lamps and mercury vapor lamps. The suitability of lamps for lighting plants has been studied in many research projects. Seasonal and geographic variations in natural daylight and differences among species and varieties in response to lighting treatments have made comparisons of supplemental lighting studies difficult.

Incandescent lamps have wider use because of a lower initial cost and simplicity. Unfortunately they have a low energy conversion and a short lamp life, about one-tenth that of a standard fluorescent lamp (10). However, a larger part of the visible energy emitted by these lamps is in the red region. There is also a substantial portion of energy emitted in the far-red region which has been shown by Roodenburg to cause undesirable formative effects with many plants (67).

The fluorescent lamp is a diffuse light source with a relatively high energy conversion efficiency, long life and spectral flexibility. The ultra-violet part of the radiant energy is absorbed by a fluorescent powder on the inside of the glass envelope, where it is converted to visible radiation. The spectral emission depends upon the particular fluorescent powder which coats the inside of the lamp (81). Plant growth lamps are used when high emission in the 600-700 nm region is desired. W.S. Gro-Lux lamps emit more energy in the far-red 700-800 nm than any other fluorescent lamp (16). Although fluorescent lamps may provide a more ideal distribution of light for greenhouse benches, the acceptance of fluorescent lamps for greenhouse lighting has been hindered by equipment and installation costs and by the form and bulk of available industrial fixtures that produce excess shading of plants (10).

Plants lighted with high intensity discharge lamps have been shown to produce normal growth (65). However there have been reports of excessive ultra-violet emission from clear mercury lamps (16). The uniform distribution of light energy over a growing area is a problem in greenhouse lighting. Mercury fixtures or mercury reflector lamps manufactured for commercial use may not provide a suitable light distribution for greenhouses where low mounting heights exist (10).

Bickford and Dunn (10) list four general applications of photosynthetic lighting for greenhouses: (1) overbench and overbed lighting, (2) inter-plant lighting, (3) under bench lighting, and (4) growth (propagation) room lighting. Overbench and overbed lighting with incandescent, fluorescent or mercury lamps is the most widely used method.

Perhaps the first commercial all fluorescent photosynthetic lighting system was installed in a greenhouse in

Alaska (10). The very short Alaskan daylight period (only about four hours in winter) was extended to fifteen hours to promote the growth of salad crops (tomatoes, lettuce, cucumbers, radishes, and peppers). Since Alaskan greenhouses normally close down during winter because of low natural light intensities and extremely low temperatures, this became the first continuously productive commercial greenhouse operation. The lighting system consisting of W.S. Gro-Lux lamps mounted at twelve inch spacing in socket strips with ballasts remotely mounted provided 20 W/ft^2. Lamps were at fixed mounting $6\frac{1}{2}$ feet above beds and $3\frac{1}{2}$ feet above the propagation benches.

Canham (16) describes another technique for providing photosynthetic lighting that involves mounting the lighting equipment on movable runners so that it can be easily moved from one area to another. This efficient use of equipment, called "double batching" permits lighting of two groups of plants for twelve hours each during a single day.

Inter-plant lighting is efficient from the standpoint that shaded leaves are exposed to radiation levels much higher than would be possible with overhead lighting. Plants responding well to this treatment include tall-growing plants which require high intensity light at all leaf levels. Carpenter and Anderson have shown that inter-plant lighting of roses with W.S. Gro-Lux lamps improved flower yields by increasing bottom breaks, stimulating axillary shoot development after flower removal, and slightly reducing the days from cut-to-cut (17). Plant contact with 80^{o}-100^{o}F W.S. Gro-Lux lamp surfaces results in little or no tissue burn.

Underbench lighting utilizes greenhouse space more efficiently. Total growing area can be doubled or tripled when fluorescent lamps are mounted beneath benches. Plants with short growing habits as African violet, foliage plants, gloxinias, geraniums, and chrysanthemums are possibilities for underbench areas.

Growth (propagation) room lighting is of interest because it permits lighting of a small area yet can affect the later growth of most plants. Lighting during seed germination, seedling growth, rooting and growth of cuttings, and bulb forcing for a relatively short time has the potential to improve plant quality and hasten plant development (81).

Little work has been done on the effects of photosynthetic lighting on the growth and cutting yield from chrysanthemum stock plants and on the subsequent rooting of cuttings. In 1964, Swain used clear mercury lamps at 27 W/ft^2 to provide light each day (8 a.m. to 8 p.m.) from September to April for growing chrysanthemum stock plants in Nova Scotia. He found lighted plants grown from September to January produced 22% more cuttings of greater fresh weight than plants grown in the unlighted plots.

Lighted plants grown from January to April produced heavier cuttings but not a greater number than from the unlighted controls (77). Flint (30) using mercury lamps nightly (10 hours) for chrysanthemum stock plants found a 20% increase in cutting yield over unlighted controls in November and December.

Lindstrom found that chrysanthemum cv. Shoesmith produced significant increases in height, fresh weight, dry weight, stem diameter, and flower diameter when exposed to higher supplemental light and carbon dioxide levels in the greenhouse during the pre-flower induction period. He compared cool white and W.S. Gro-Lux fluorescent lamps installed at about 20 W/ft^2 to provide an 18 hour photoperiod with daylength extension lighting to midnight for the first four weeks of growth. He compared light sources with supplemental carbon dioxide (2000 ppm), without supplemental carbon dioxide, and with the usual incandescent control treatment used for chrysanthemums. The results show that the combination of supplemental light and carbon dioxide is better than either applied alone. Without supplemental carbon dioxide, plants under W.S. Gro-Lux lamps produced greater growth than those under cool white and the incandescent control. With supplemental carbon dioxide the same relationship was evident except that plants under the cool white treatment were taller than those under Gro-Lux (50).

Payne and others (56) studied fluorescent lighting of chrysanthemums in Oklahoma and found that greenhouse grown plants receiving supplementary lighting from Standard Gro-Lux and W.S. Gro-Lux lamps in the spring were significantly heavier in dry weight of flowers and vegetation than the control plants. Other differences were not significant. During the summer trial the number of breaks and the dry weight of flowers were significantly higher with a daytime supplementary lighting treatment than for control plants in the greenhouse. Since there were few easily observed quality differences among plants in the various lighting treatments, it was concluded that daytime supplementary fluorescent lighting of chrysanthemums in Oklahoma appears to be of questionable value.

Reports from growers in areas of low winter greenhouse light intensity differ from those of Payne. Kenneth Maekowa, pot-mum specialist of Seattle, Washington, reported they now use 600 foot-candles from 1 a.m. to 6 p.m. daily for the first 19 days after potting. They found the improved quality of their dark-weather crop justified the expense (8).

Photomorphogenesis in chrysanthemum

The ability of light intensity, duration and quality to influence plant growth, development, differentiation, and reproduction has been recognized for some time (48).

Stem elongation is of major importance when considering the morphological manifestation of plant growth resulting from variation in environmental factors. It is well known that excessive plant stem elongation occurs in continuous darkness. Light depresses this internode extension and far-red radiation in the 700-800 nm range as well as visible light in the red and blue regions can elicit this response.

Supression of stem elongation is not, however, directly correlated with an increased light intensity. Inadequate light intensities limit the development of many species, particularly of high light requiring plants as chrysanthemums. This is evident in the reduced vegetative growth of greenhouse crops during the winter months in northern latitudes compared with growth during spring and autumn when natural light intensities are higher (46).

In 1872 Sachs recognized light inhibition of growth when he observed that many plant species are inhibited in stem elongation during daylight hours (48). A high light intensity inhibits cell elongation and limits growth in most higher plants. Yet in spite of such inhibition, overall maximum growth, as determined by shoot elongation and leaf expansion, is made by most high light requiring plants in full sunlight of 10,000 foot-candles or more (80). At these high light intensities sufficient light of perhaps 2,000 to 3,000 foot-candles is available to the inner, shaded parts of the plants.

Treshow reports that sun-loving plants grown in full sunlight have thicker stems, with well developed xylem and supporting tissues and internodes relatively shorter than when grown in the shade (80). In summer's high light intensities, stems of greenhouse grown roses and carnations may be shorter than desired. If the light intensity is reduced to some extent, leaves may become quite dark green, the stems somewhat longer, and the leaves thinner (46).

Craig (22) found that several greenhouse crops, including peas, beans, tobacco, snapdragon, and strawberry responded well to mercury vapor, mercury fluorescent and incandescent supplementary illumination during the winter months in Nova Scotia. Plant height and plant top dry weights were greater for lighted than unlighted plants. Swain reported that four cultivars of chrysanthemum stock plants lighted from September to January with mercury vapor lamps (300-600 foot-candles at plant level) produced significantly more and heavier cuttings than unlighted controls (77). No information was given as to whether the increased cutting production was attributed to more rapid vegetative growth or increased branching of stock plants. Carpenter and Anderson found that roses lighted 20 hours with 31.3 lamp watts/ft^2 with W.S. Gro-Lux lamps to supplement natural daylight responded with improved flower yields by increasing bottom breaks, stimulating axillary shoot development after flower removal, and slightly reducing the days from cut-to-cut. Development of additional axillary buds was the principal factor in the improved branching of lighted plants (17).

Stimulation of chrysanthemum axillary bud development has the potential of increasing cutting production from stock plants as well as improving the floral show of pot mums at flowering. Vegetative growth and branching of chrysanthemums grown under normal greenhouse light conditions is much improved after April 1, when solar radiation levels are higher than during the winter months (62).

Another morphological response to light is the development and ultimate expansion of the leaves. Smaller but denser and heavier leaves are often produced in full sunlight, while shading results in much larger, thinner leaves with thinner epidermis, less palisade, more intercellular space and spongy parenchyma, and more numerous stomata (80). When shading reduces the light intensity to 2,000 foot-candles, the ultimate leaf area may be increased 15% to 55% while the plant weight is reduced nearly in half (53). The palisade cells, which contain the principal supply of chloroplasts, are formed in larger numbers with increasing light intensity during leaf development (48). The morphological response to bright light seems to offer a basis for the physiological adaptation of leaves to high light intensity. It is commonly observed in the greenhouse during winter that plants easily wilt on a sunny day which has been preceeded by several cloudy days (46). This is evidence that plants can rapidly adapt to changing light intensity levels.

Individual cells of the leaf blade are usually smaller at high light intensities than in subdued light or shade. The result is smaller but thicker leaf blades, denser but smaller stomata, and more conducting and mechanical tissue. The cuticle and cell walls are generally thicker, intercellular spaces smaller, and blades of a harder texture. From an evolutionary viewpoint, these morphological modifications help make the plant more resistant to temperature and drought stress and infection by fungus and bacterial parasites (80). Plants grown at lower light intensities are characterized by more weakly developed spongy parenchyma and a better-developed palisade layer.

Light quality may also influence leaf expansion. The effect of different wavelengths on size and shape of expanded leaves varies considerably among species. While the situation regarding chrysanthemum is not well documented, cells in the under surface of tomato leaves expand irregularly and incompletely in red light, so that the mature leaves are curled (80).

Leaf color can also be influenced by light quality and duration. Prolonged daily exposure to light can prevent chlorophyll formation. The result is chlorosis due to the revealing of more of the yellow caratenoid. Wolf has shown that in seedlings the biosynthesis of carotenoid pigments is greatly stimulated in light compared with that of seedlings in darkness (90). Anthocyanin is known to be formed only in the presence of light and may be excessive in unshaded plants grown for their green foliage color. Anthocyanin synthesis in many plants requires prolonged irradiation at moderately high intensities (10).

Shirley's controlled studies with ultraviolet light showed that plant growth was inhibited by high light intensities, but once light intensity was reduced, normal growth was resumed and there was no permanent damage to the plants (68). High intensity of radiation in the far ultraviolet and shorter wavelengths is usually negligible in sunlight, since it is absorbed by ozone in the atmosphere. When sunlight passes through glass most of the ultraviolet rays are removed (46). Therefore the action of ultraviolet on plants in the greenhouse becomes important only if radiations of very short wavelength are produced artificially. Although such radiations could have an injurious effect on lighted plants, they are not produced to any significant extent by lamps used in horticultural lighting (10). Furthermore plant tissue is quite insensitive to the near ultraviolet spectral region of wavelengths (those longer than 290 nm). Radiation is active only to the extent it can be absorbed and ultraviolet cannot penetrate to the interior of the plant, like the visible and near-infra-red (78). Since the greatest part of the ultraviolet radiation which strikes plant surfaces is absorbed by the directly exposed cells, the immediate reaction may be only superficial. However, it is possible that significant repercussions may ultimately develop from such exposure (78).

In some plants continuous lighting has been found to produce considerable morphological alterations (3, 26). Continuous illumination of tomato produces a very poorly developed plant which does not bear fruit. However, many plants, including begonia, cotton, and geranium, show excellent leaf color and normal development and flowering (3, 62). There is no evidence in the literature of unfavorable effects on chrysanthemum as a result of lighting 24 hours daily.

Light affects root initiation and growth of leafy cuttings. Light intensity and duration must be great enough so that carbohydrates will accumulate in excess of those used in respiration. Stoutemyer and Close have shown that light intensities of 150 to 200 foot-candles 18 hours daily provided by white fluorescent lamps were sufficient for satisfactory rooting in some species of greenwood cuttings (75). These intensities are low compared with 10,000 foot-candles in full sunlight, but woody cuttings are much more dependent upon stored carbohydrates than herbaceous cuttings.

Stoutemyer and Close have shown that radiation in the orange-red portion of the spectrum favors rooting of cuttings more than the blue region (76). However, when stock plants of Gordonia axillaris were exposed for six weeks to light sources of different quality before taking the cuttings, best rooting resulted for cuttings taken from plants exposed to blue light (76).

Waxman and Nitsch reported that long days increased and short days decreased the rooting quality for a number of species of cuttings (83). It is likely that in some cases long light periods may have contributed to photosynthate production rather than to any direct photoperiodic effect. Chrysanthemums must be given long days during propagation to keep the cuttings vegetative (46). This is commonly accomplished with 60 W or 100 W incandescent lamps lighted four hours nightly to break the dark period.

In chrysanthemum the formation of adventitious roots takes place after the cutting is made (36). The origin of these roots is a group of cells in the interfascicular region which are capable of becoming meristematic. The small groups of cells, the root initials, divide forming groups of many small cells which develop into root primordia. As cell division continues a vascular system develops in the new root primordium and becomes connected to the adjacent vascular bundle (29). The root tip grows outward, through the cortex, emerging from the epidermis of the stem. Because the roots originate within the stem tissue and grow outward, they are said to arise endogenously. Root initials were observed microscopically in terminal stem cuttings of chrysanthemum after three days in the propagation bench (72). At least ten days is normally required for visible roots to emerge.

After chrysanthemum stem cuttings are placed in the propagation bench, callus will develop at the basal end of the cutting. The callus is an irregular mass of parenchyma cells which arises from the region of the vascular cambium and adjacent phloem. Formation of callus and formation of roots are independent of each other, however they often occur simultaneously due to their dependence upon similar internal and environmental conditions (36).

Light and photosynthesis

A number of environmental factors, including light, temperature, carbon dioxide, water and nutrients can affect the rate of photosynthesis and the amount of photosynthate subsequently produced. A deficiency of any one of these factors can limit growth and reduce plant vigor. Light is of great importance to the plant because it provides the energy necessary for the conversion of carbon dioxide and water by chlorophyll-containing plants into carbohydrates in the photosynthetic process. Seventy-five percent of the total photosynthate may be incorporated in polysaccharide, much of which is used to build cell walls; fifteen to twenty percent may be consumed in respiration; and the remaining serves as substrate for carbohydrate, fat, and protein metabolism (80). Thus all chemical synthesis, energy and plant growth depend on adequate photosynthesis to provide the needed photosynthate.

Many plants are structurally organized to receive the greatest amount of light possible. Maximum light absorption is facilitated by the large surface/volume ratio of the leaf, coupled with the large intercellular surface area and lamellar chloroplast structure (80).

According to estimates made by Brown and Escombe, about seventy percent of the sunlight striking a leaf surface is absorbed, the remaining thirty percent being transmitted or reflected. Twenty percent of the light energy may be transformed into heat and re-emitted by radiation while nearly fifty percent may be used for evaporation. Only about one percent of the light energy is used for photosynthesis (78).

There are several methods available for determining quantitatively the amount of photosynthesis that has taken place. The dry weight method is commonly used. Increase in the dry weight of test plants in comparison with appropriate control plants is often used as an overall measure of photosynthetic efficiency. Another method is standard analytic determination of carbohydrate present in leaves at the start and at the end of a photosynthetic period. Anderson has shown that high intensity supplemental lighting of rose leaves (31.3 W/ft^2 with W.S. Gro-Lux lamps) increases the total reducing sugar level compared with leaves exposed to winter's normal greenhouse light intensities. The amount of photosynthesis, as determined by the total sugar content of the tissue, may in turn be correlated with morpho-physiologic changes in the plant (1).

Light quality, intensity, and duration are all vital to normal plant development, but the intensity is the most critical variable influencing photosynthesis (80). Photosynthesis increases with increasing light intensity in a linear manner, up to a certain level with sufficiently high temperatures and carbon dioxide supply. Beyond that point there is no further increase and the curve flattens into a plateau with greater intensities of light. However, most of the work relating light intensity to photosynthesis has been done using lower plants. Therefore the measurement of the saturation effect of light intensity on higher plants is at best rather empirical (10).

The intensity required for light saturation is different for different kinds of plants and varies with the age of the same plant. Shading of lower leaves by upper ones accounts for large differences in light requirements. Increasing light intensity usually results in greater photosynthesis in plants which have many shaded leaves. Since many leaves on chrysanthemums are shaded by adjoining foliage because of close planting, as much sunlight as possible should be admitted to permit maximum photosynthesis without damaging the plants from excessive intensities (46). Insufficient light limits the radiant energy available for photosynthesis, causing food reserves to be depleted faster than they can be stored. Gerhold showed that the photosynthetic rate of Scotch pine decreased in direct proportion to decreasing light intensity from 6,400 to 1,800 foot-candles. Below 1,800 foot-candles the photosynthetic rate dropped still more steeply (34).

Competition for light as a result of shading or crowding can substantially reduce the growth rate of plants. Shiroya and others attributed poor root growth of shaded pine seedlings to limited photosynthate translocated to the roots (69). The effect of low light intensities in reducing root growth helps explain the difficulty unadapted species have competing for nutrients and water in a low light intensity situation.

Too high a light intensity may reduce photosynthesis by rapidly photo-oxidizing chlorophyll, so that the remaining supply is inadequate to absorb sufficient light energy. Leaf color fades as the old chlorophyll is destroyed in the upper palisade cells. A pale green or yellowish cast results because chlorophyll breakdown by intense illumination is faster than chlorophyll synthesis (80). Chlorophyll synthesis may also be inhibited by high light intensities. Leaves have a limited protective mechanism against chlorophyll loss. Chloroplasts may migrate to the center of the cell under conditions of light stress (80). High light intensities may also affect photosynthesis by the oxidizing of the enzymes participating in photosynthesis. These explanations are somewhat theoretical because plants vary so greatly in their response to light and the optimum light requirements are unknown for most plant species. Gerhold found that photosynthetic activity in Scotch pine was inhibited only when the light intensity reached 9,300 foot-candles (34). Shirley found that maximum dry weight increase of red pine seedlings occurred at 98 percent of full sunlight, although maximum growth was reached at half this light intensity (68).

Leaves adapted to winter's low light intensities may respond quite differently to increase in light intensity than summer grown plants. Barua studied the photosynthetic rates of detached tea leaves as influenced by various light intensities (9). He found significantly different assimilation rates for the various light intensities which could not be explained by the thickness of the leaf lamina or the chlorophyll concentration of the leaves. Shade adapted leaves had significantly higher rates of photosynthesis in the weakest light and lower rates in the higher intensities than the corresponding sun adapted leaves. Therefore it is likely that tissues adapt to specific conditions and their response at any particular time is influenced by their previous conditioning.

The effect of various wavelengths of light on photosynthesis has been difficult to determine precisely. Many observers find that the red and blue portions of the spectrum are most effective in photosynthesis with red light causing the best yield under intensities of equal energy (38, 52). In 1970 Balegh and Biddulph measured the photosynthetic action spectrum for bean leaf (7). Their graph shows a peak in the blue region about 440 nm and two peaks (at about 670 and 630 nm) in the region of longer wavelengths.

Dunn and Went have plotted micrograms of photosynthetic yield of tomato seedlings per foot-candle of light from various portions of the spectrum as emitted by colored fluorescent lamps. The contours of this graph are very similar to the action spectrum of chlorophyll (26).

Light intensity, temperature and rate of photosynthesis are inter-related. Plants differ considerably in the range of temperatures in which photosynthesis can proceed. Emerson and Green used Barcroft-Warburg manometers to measure rate of Gigartina photosynthesis under various light intensity and temperature regimes. Banks of incandescent lamps of unspecified intensity were shielded with filters to produce lower light intensities. At low light intensities and high carbon dioxide photosynthesis is independent of temperature. With strong light and abundant carbon dioxide, photosynthesis increases with higher temperatures (27). As temperature increases so do respiration rates. Increased respiration reduces carbohydrate reserves resulting from photosynthesis. Too high temperature (above 32°C) can cause stretching of chrysanthemum plants and delayed development of flower buds. Too low temperatures (below 16°C) can retard or cause uneven development of chrysanthemum flowers. Chrysanthemums are usually grown at a night temperature of not less than 18°C (46).

The carbon dioxide content of the air is approximately 0.03 percent, and during periods of high light intensity and warm temperatures when plants are well supplied with water, it may be a limiting factor in photosynthesis (46). In general, the rate of photosynthesis increases in proportion to increase in carbon dioxide content of the air, up to a point where some other factors become limiting. It is a common greenhouse practice to enrich the air with carbon dioxide (1200-1500 ppm) to help increase photosynthesis. Higher intensities from supplemental lighting would increase the utilization of carbon dioxide added to the greenhouse atmosphere.

I

EVALUATING SUPPLEMENTARY LIGHTING DURING AND AFTER PROPAGATION

The regulatory effect of lighting for photoperiodic control has shown long days (LD) cause earlier and better rooting for many species (25, 45, 70), but delay the rooting of others (40). Leshem and Schwartz (49) found LD reduced chrysanthemum rooting, but this response was prevented by exogenously applied IBA. Stoutemyer and Close (76) propagated various plant species under equal intensities (150 to 200 lm/ft^2) of each light color and found pink light was superior to white, which was better than blue. MacDonald (51) reported 400 ft-c or higher is needed to supplement the natural daylight if photosynthesis is to be increased sufficiently to influence carbohydrate levels in many plant species.

The objective of this study was to determine if high intensity supplemental lighting during some critical period between sticking cuttings and short-day (SD) treatment was as beneficial as lighting during the entire period. Groups of plants were harvested at the beginning of the SD treatment, 5 weeks later (half-way to flowering) and at flowering. Since treatment differences occurred during the early stages of growth, it was important to see the duration and extent of the differences as the plants matured.

Materials and Methods

Adjoining 4.6 m by 7.7 m greenhouse sections oriented E-W were divided by aluminum foil covered paper to create four 4.6 m by 3.85 m sections. Beginning in Oct. 1971, a Lucalox (400 W) sodium vapor and a Multivapor (400 W) mercury vapor lamp were placed below the greenhouse ridge in one section 2 m apart, while in the other section 2 Lucalox and a Multivapor lamp were spaced 1 m apart. After Dec. only 2 lamps were used in each lighted section. Lamp luminaires were 1.4 m above the propagation bench, each lamp emitting 58 W/m^2 of light. A coarse sharp sand medium was maintained 21^{o}C with buried Famco propagation mats while the air temperature was 16^{o}C nights and 21^{o}C days.

Ninety-six cuttings of Chrysanthemum morifolium Ramat. cv. Bright Golden Anne were propagated in each section monthly from Oct. to Mar. All cuttings received intermittent mist (6 sec. per 6 min., 24 hours daily) and 2 applications of a complete fertilizer solution (100 ppm) weekly. In a preliminary study, all cuttings receiving supplementary light without misting became dehydrated and many died. Twenty-four chrysanthemum cuttings in each lighted and unlighted replicate were removed 14 days after placement in the propagation bench. After Dec. 1971 cuttings were harvested when root lengths became 2 cm. Records for individual cuttings included number of days to root, root number, length and fresh weight, and top length and fresh weight.

The remainder (72) of the rooted cuttings from each plot were potted 4 to a 6 inch clay pot in a medium of equal parts of soil, peat moss, and Turface. A randomized block experimental design was established to permit 36 plants from each section to continue receiving high intensity supplemental lighting (116 W/m^2) 24 hours daily during the 3 week vegetative period from potting until the SD treatment began (referred to as stage 2). A second group received only incandescent lighting 4 hours nightly during stage 2 to prevent flower bud initiation. The 4 treatments included: (a) continuous lighting (116 W/m^2) during propagation and stage 2, (b) only photoperiodic lighting during propagation and stage 2, (c) lighted (116 W/m^2) during propagation but only photoperiodic lighting during stage 2, (d) only photoperiodic lighting during propagation but lighted (116 W/m^2) during stage 2. Recommended cultural practices for chrysanthemum were followed (46) and no supplemental lighting was used after the SD treatment began.

Twelve plants from each replication were harvested at: (a) the end of stage 2 (3 weeks after potting), (b) half-way to flowering (5 weeks after SD treatment began) and (c) at flowering. Records at the end of stage 2 included the length and fresh and dry weight for both roots and shoots. After 5 weeks of short days, major and minor nodes (nodes showing evidence of producing a flowering shoot and nodes not likely to produce a flowering shoot) were counted and recorded in addition to other data. Flowering data included plant height and fresh top weight, and flower number, diameter and fresh weight were determined when the second circle of petals expanded.

From Jan. to Mar. 1973 the propagation studies were repeated using two cultivars, 'Bright Golden Anne' and 'Puritan.' The experimental design was identical to the previous year. Only one Multivapor lamp emitting 58 W/m^2 was used since earlier studies had indicated that a Lucalox (400 W) sodium vapor lamp alone was as effective in promoting rooting as the Lucalox and Multivapor lamps in combination. The daily lighting duration was reduced from 24 to 20 hours to overcome a slight foliar chlorosis, but this did not significantly decrease rootability of the cuttings. When root lengths became 2 cm rooting measurements were made that included days from planting to harvest; root number, length and fresh weight; and top length and fresh weight. Data were analyzed statistically according to Duncan's Multiple Range Test.

Greenhouse air temperatures were measured on the propagation benches receiving 0, 116, and 174 W/m^2 of supplementary light using thermocouples and a 24-point recording potentiometer. Leaf temperatures under mist were measured in Dec. using a temperature radiometer.

East Lansing's incident solar radiation during the course of the study was obtained from the U.S. Weather Service. Greenhouse light intensities during nights, cloudy days and sunny days were measured by a Weston 756 Illumination Meter. Total radiation input from natural daylight and lamps during the trial period was calculated in $KW\text{-}hrs/m^2$ according to guidelines by Noesen and Spacil (54).

When chrysanthemum cuttings under 174 W/m^2 of supplemental light developed foliar chlorosis, leaf tissue samples were prepared for foliar analysis and leaf sections were prepared and examined under a light microscope. Leaf tissue was killed and fixed in FAA and prepared by the paraffin technique according to Knobloch (41). A double Safranin-Fast Green stain enhanced the visibility of the sections.

Results

Propagation

Rooting. Cuttings receiving 116 W/m^2 of supplementary light from combined Lucalox and Multivapor lamps during propagation had larger numbers of roots, longer roots from earlier initiation, and higher root fresh weights than those non-lighted or lighted at 174 W/m^2 (Table 3). In Oct. the roots of cuttings lighted at 116 W/m^2 were 37% heavier than cuttings unlighted during the 14 days in the propagation bench. Lighting at 174 W/m^2 during the same trial reduced cutting weight 34% below unlighted cuttings. Differences in fresh root weight between cuttings lighted 174 W/m^2 and unlighted were smaller during Nov. and Dec. than in Oct. (Figure 2). When cuttings were harvested after a standard root length had been reached, those receiving 116 W/m^2 of supplementary light had significantly larger fresh root weight than the unlighted controls.

During the second year's trials only Lucalox lamps (58 W/m^2) were used. The number of days needed to initiate and develop roots of 2 cm from Jan. to Mar. was reduced 3 to 4 days by supplementary lighting compared with cuttings propagated under normal greenhouse light conditions (Table 4). Cvs. Bright Golden Anne and Puritan responded well to high intensity supplemental lighting.

Table 3.--The influence of supplementary light intensity on the vegetative propagation of chrysanthemum, cv. Bright Golden Anne, comparing 0, 116, and 174 W/m^2 of light from combined Lucalox and Multivapor lamps (14 days after cuttings were placed in the propagation bench).[z]

Propagation month	Added light W/m^2	Root			Top	
		no.	length (cm)	fr. wt (g)	length (cm)	fr. wt (g)
Oct.	0	21.5b	3.0b	1.85b	8.63a	3.69a
	116	30.2a	3.6a	2.54a	9.87b	3.84a
	174	16.9b	2.1c	1.22b	10.02b	3.72a
Nov.	0	18.8b	2.3b	1.32b	8.72a	3.82a
	116	24.2a	3.3a	2.37a	9.89b	3.91a
	174	19.3b	2.7b	1.22b	10.13b	3.85a
Dec.	0	14.2c	1.8c	1.09b	8.75a	3.95a
	116	27.1a	3.9a	2.38a	9.65b	3.89a
	174	20.6b	2.3b	1.47b	10.03b	3.74a

[z]Mean separation of values in columns within a month by Duncan's Multiple Range Test, 5%.

Table 4.--The influence of supplementary light from Lucalox lamps on the vegetative propagation of chrysanthemums.[z]

Cultivar	Propagation month	Added light (W/m^2)	No. days to harvest	Root no.	Root length (cm)	Root fr. wt (g)	Top length (cm)	Top fr. wt (g)
						1971 Trial		
'Bright Golden Anne'	Jan.	0	14	19.5b	1.7b	0.82b	7.79b	2.58a
		116	14	24.2a	3.1a	1.67a	9.06a	3.23a
	Feb.	0	14	20.3b	2.1b	0.62b	7.32b	3.07a
		116	14	31.3a	3.6a	1.36a	9.27a	3.59a
	Mar.	0	14	22.8b	2.0b	1.04b	8.54a	3.32a
		116	14	35.9a	3.7a	2.26a	9.97a	3.75a
						1972 Trials		
'Bright Golden Anne'	Jan.	0	15	23.1b	2.0a	0.54b	8.02b	3.21a
		58	11	34.2a	2.0a	1.13a	9.57a	3.75a
	Feb.	0	14	19.0b	2.0a	0.34b	8.47b	3.47a
		58	11	26.8a	2.0a	0.55a	9.74a	3.92a
	Mar.	0	12	19.2b	2.0a	0.39b	8.69b	3.84a
		58	9	26.9a	2.0a	0.59a	10.32a	4.05a
'Puritan'	Jan.	0	14	20.6b	2.0a	0.53b	7.41b	2.94a
		58	11	31.5a	2.0a	1.07a	8.75a	3.21a
	Feb.	0	14	17.7b	2.0a	0.30b	7.67b	3.17a
		58	10	23.9a	2.0a	0.49a	8.94a	3.59a
	Mar.	0	12	18.3b	2.0a	0.37b	7.75b	3.47a
		58	9	26.4a	2.0a	0.54a	9.59a	3.76a

[z]Mean separation of values in columns within a month by Duncan's Multiple Range Test, 5%.

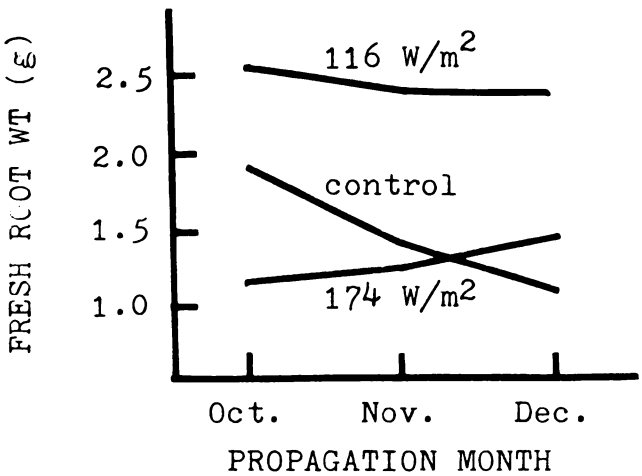

Figure 2.--Fresh root wt of chrysanthemum cuttings propagated under 0, 116, 174 W/m^2 of supplementary light from combined Lucalox and Multivapor lamps.

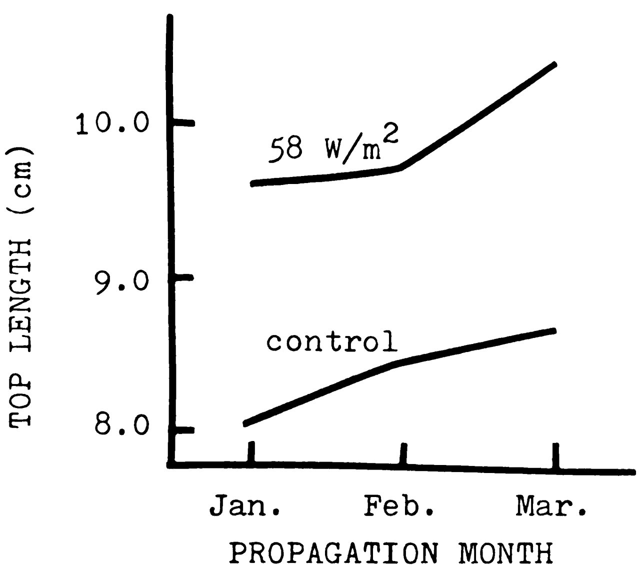

Figure 3.--Top length of chrysanthemum cuttings propagated under 0 and 58 W/m^2 of supplementary light from Lucalox lamps.

Lighted 'Puritan' cuttings had 35% more roots and 63% heavier roots than unlighted cuttings during the Feb. trial. Lighted and unlighted cuttings averaged 23.9 and 17.7 roots per cutting with a fresh weight of 0.49 g and 0.30 g respectively. Similar increases in root number and root fresh weight were observed for cv. Bright Golden Anne. The consistent benefit from lighting over the trial period was seen graphically when the monthly averages of fresh root weight were plotted (Figure 3).

Top growth. Growth of cuttings in length during propagations from Oct. to Dec. was 10% and 15% larger for lighted 116 W/m^2 and 174 W/m^2 respectively than unlighted cuttings. Top fresh weights were not significantly different (Table 3). These data were supported by Jan. to Mar. trials comparing cuttings lighted 116 W/m^2 from combined Lucalox and Multivapor lamps and unlighted cuttings (Table 4). Cuttings lighted 58 W/m^2 from Jan. to Mar. with a Lucalox lamp had significantly greater top length but non-significant top fresh weight compared with unlighted controls (Table 4).

Cuttings lighted 24 hours daily at 174 W/m^2 from combined Lucalox and Multivapor lamps developed foliar chlorosis during propagation. In certain leaves this culminated in the development of necrotic areas before the 14th day in the propagation bench.

Temperature and light measurements. Air temperatures among cuttings were 1.2°C and 1.7°C warmer in sections receiving 116 W/m^2 and 174 W/m^2 respectively than in non-lighted sections. Cuttings under 116 W/m^2 and 174 W/m^2 of light had leaf temperatures 1.3°C and 2.5°C higher at night and 2.7°C and 5.1°C higher on sunny days in Dec. than those in non-lighted sections (Figure 4).

Greenhouse light intensities during nights, cloudy days and sunny days in late Dec. were increased 1000 and 1500 ft-c from 116 W/m^2 and 174 W/m^2 of irradiation (Table 5). Mean radiation values from sunlight averaged 237, 104 and 178 calories of sunlight per cm^2 per min. for Oct., Dec. and Feb. respectively (Appendix B). Total radiation input from natural daylight and lamps during the trial period is listed in Tables 6 to 8.

Anatomical observations. Chrysanthemum cuttings propagated under 174 W/m^2 of supplementary light from combined Lucalox and Multivapor lamps developed foliar chlorosis with dispersed necrotic areas after 2 weeks in the propagation bench. Examination of leaf cross sections through necrotic areas under the light microscope at 10x showed disorganization and death of pallisade cells and dissolution of the spongy mesophyll.

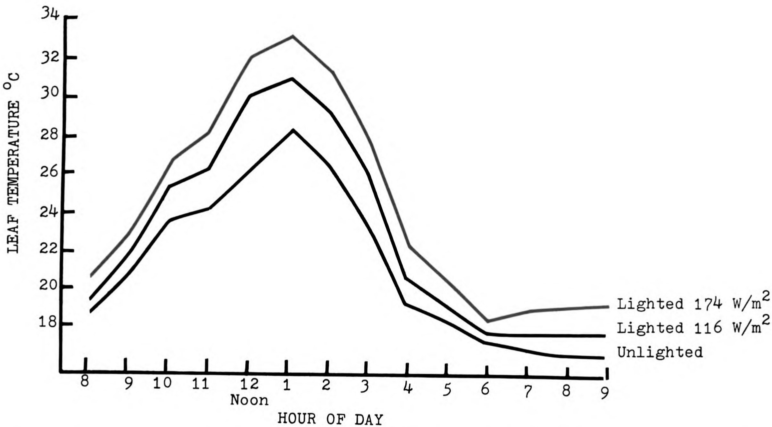

Figure 4.--Chrysanthemum leaf temperatures during propagation under intermittent misting comparing those receiving no supplementary light during a sunny day with 116 and 174 W/m^2 in late December.

Table 5.--Mean light intensities in late December in non-lighted and lighted greenhouses at night and cloudy and sunny days.

Treatment	Night Intensities (ft-c)	Light intensities ft-c Cloudy	Sunny
Greenhouse	0	725	2450
Greenhouse + 116 W/m^2	1050	1675	3610
Greenhouse + 174 W/m^2	1490	2100	4175

Growth after transplanting

Root length and weight. Chrysanthemum plants continuously lighted 116 W/m^2 with combined Lucalox and Multivapor lamps during propagation and from transplanting to SD treatment had fresh root weights 26%, 36%, 34%, and 34% greater than unlighted plants during Nov., Dec., Jan. and Feb. respectively. Plants harvested at the beginning of SD treatment that only had been lighted during propagation or after transplanting had fresh and dry root weights of intermediate values between those lighted continuously and unlighted (Table 6).

Plants harvested 5 weeks after initiating the SD treatment had fresh and dry root weight differences similar to those of the same treatment at the beginning of short days (Table 7). Lighting continuously during a Jan. propagation and from transplanting to short days increased dry root weight 32% over unlighted plants harvested halfway from starting short days to flowering. Results were consistent during the 4 trial periods (Figure 5). Significantly greater root length was found for continuously lighted plants than unlighted at the beginning of short days for plants propagated in Nov. and Dec. Root lengths could not be accurately measured 5 weeks after short days began.

Top length and weight. Plants lighted 116 W/m^2 continuously during Dec. propagation and from transplanting

Table 6.--Supplementary lighting (116 W/m^2) effects on chrysanthemum vegetative growth from lighting during propagation, or from transplanting to SD treatment, or during both periods.[z]

Month	Lighting treatment	Total light input $KW\text{-}hr/m^2$	Root length (cm)	Root fr. wt (g)	Root dry wt (g)	Top length (cm)	Top fr. wt (g)	Top dry wt (g)
Nov.	prop. and after	1118	10.3a	13.4a	1.23a	24.4a	17.3a	1.17a
	propagation	509	9.9a	12.6ab	1.21ab	22.6a	16.1ab	0.97ab
	after transplant	774	9.7a	11.9ab	1.19ab	22.4a	15.9bc	0.94bc
	control	265	9.4a	10.6b	1.06b	20.7a	14.4c	0.88c
Dec.	prop. and after	1054	9.5a	12.6a	0.88a	21.6a	16.5a	1.01a
	propagation	536	9.1ab	11.4b	0.82ab	20.0a	14.1ab	0.92b
	after transplant	700	8.8ab	10.9b	0.81ab	19.7a	14.4ab	0.85b
	control	182	8.4b	9.7c	0.74b	18.1a	12.3b	0.77c
Jan.	prop. and after	1064	8.8a	11.9a	0.79a	22.4a	15.7a	0.96a
	propagation	552	8.3ab	10.2b	0.72b	19.2a	13.4ab	0.89b
	after transplant	718	8.1ab	9.6b	0.69b	18.6a	12.6ab	0.83b
	control	208	7.6b	8.9c	0.62c	17.4a	11.4b	0.72c
Feb.	prop. and after	1104	9.2a	12.5a	0.85a	23.9a	15.0a	0.93a
	propagation	595	8.9a	10.4b	0.74b	19.4a	13.9b	0.89ab
	after transplant	760	8.6a	9.9bc	0.73c	18.3a	13.4b	0.83b
	control	252	8.3a	9.3c	0.67d	17.3a	11.7c	0.74c

[z]Mean separation of values in columns within a month by Duncan's Multiple Range Test, 5%.

Table 7.--Supplementary lighting (116 W/m^2) effects at bud development from lighting during propagation, or lighting from transplanting to SD treatment, or during both periods on chrysanthemums.[z]

Month	Lighting treatment	Total light input KW-hr/m^2	Root length (cm)	Root fr. wt (g)	Root dry wt (g)
Dec.	prop. and after	1118	16.8a	18.3a	2.33a
	propagation	509	16.2a	17.1ab	2.17ab
	after transplant	774	15.9a	16.3ab	2.13ab
	control	265	15.3a	14.2b	1.83b
Jan.	prop. and after	1054	16.3a	17.9a	2.29a
	propagation	536	15.6a	15.7ab	1.92ab
	after transplant	700	15.2a	15.2ab	1.89ab
	control	182	14.7a	13.3b	1.74b
Feb.	prop. and after	1064	15.7a	17.4a	2.17a
	propagation	552	15.1a	15.6ab	1.83ab
	after transplant	718	14.9a	14.3ab	1.74b
	control	208	14.3a	13.6b	1.62b
Mar.	prop. and after	1104	15.9a	16.5a	1.96a
	propagation	595	15.3a	14.9ab	1.82ab
	after transplant	760	15.1a	14.7ab	1.73ab
	control	252	14.7a	13.2b	1.57b

[z]Mean separation of values in columns within a month by Duncan's Multiple Range Test, 5%.

Table 7 (cont'd.)

Month	Lighting treatment	Top: length (cm)	no. of major nodes	no. of minor nodes	fr. wt (g)	dry wt (g)
Dec.	prop. and after	36.5a	3.7a	3.4a	33.7a	5.1a
	propagation	36.2a	3.3ab	3.1a	30.4ab	4.2ab
	after transplant	36.5a	2.9b	2.9a	32.6ab	4.5ab
	control	37.4a	2.5b	2.1b	25.4b	3.8b
Jan.	prop. and after	36.9a	3.2a	3.0a	31.6a	4.9a
	propagation	36.5a	2.6ab	2.3ab	25.3ab	3.5ab
	after transplant	36.7a	3.1a	2.9ab	27.9ab	4.2ab
	control	37.4a	2.2b	1.8b	22.4b	3.2b
Feb.	prop. and after	35.4a	3.5a	2.9a	30.7a	4.6a
	propagation	37.2a	2.7ab	2.0ab	24.3b	3.3ab
	after transplant	35.2a	3.2a	2.5a	28.2ab	4.0ab
	control	36.4a	2.1b	1.7b	21.7b	2.9b
Mar.	prop. and after	36.2a	3.1a	3.2a	30.2a	4.7a
	propagation	36.0a	2.2b	2.2ab	24.7b	3.5b
	after transplant	35.9a	3.0a	2.7a	28.5ab	4.2a
	control	35.4a	1.9b	1.9b	20.3b	3.0b

Table 8.--Supplementary lighting (116 W/m^2) effects at flowering comparing plants lighted only during propagation, or from transplanting to SD treatment, or lighting during both periods on chrysanthemums.[z]

Month	Lighting treatment	Total light input $KW\text{-}hr/m^2$	Plant		Flowers		
			height (cm)	fr. top wt (g)	number	diameter (cm)	fr. wt (g)
Feb.	prop. and after	1118	66.2a	74.1a	3.3a	9.8a	12.6a
	propagation	509	65.9a	67.4ab	2.7bc	9.5a	12.0a
	after transplant	774	66.0a	69.2ab	3.2ab	9.7a	12.4a
	control	265	65.8a	65.3b	2.5c	9.4a	11.8a
Mar.	prop. and after	1054	70.9a	70.8a	3.1a	10.4a	14.6a
	propagation	536	68.4a	65.2ab	2.5bc	9.5a	12.1a
	after transplant	700	69.2a	67.4ab	2.8ab	9.8a	13.7a
	control	182	68.0a	63.6b	2.3c	9.3a	11.3a
Apr.	prop. and after	1064	67.8a	80.1a	3.0a	9.8a	13.5a
	propagation	552	65.2a	69.2b	2.5bc	8.9a	11.5a
	after transplant	718	66.7a	75.4b	2.8ab	9.4a	12.6a
	control	208	64.2a	60.2c	2.2c	8.6a	10.9a
May	prop. and after	1104	65.1a	84.5a	3.5a	10.0a	14.2a
	propagation	595	63.5a	72.3b	2.8bc	9.5a	12.9a
	after transplant	760	64.8a	79.7b	3.2ab	9.8a	13.7a
	control	252	62.4a	63.9c	2.5c	9.2a	12.3a

[z]Mean separation of values in columns within a month by Duncan's Multiple Range Test, 5%.

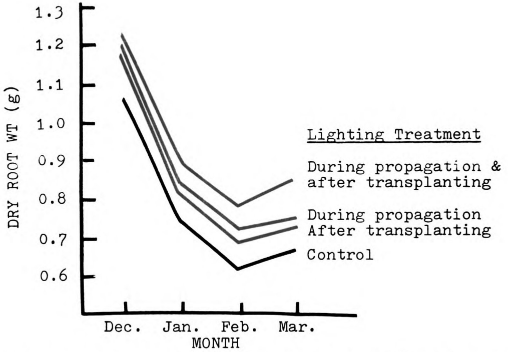

Figure 5.--Supplementary lighting (116 W/m^2) effects on dry root wt at SD treatment from lighting during propagation, or lighting from transplanting to SD treatment, or during both periods.

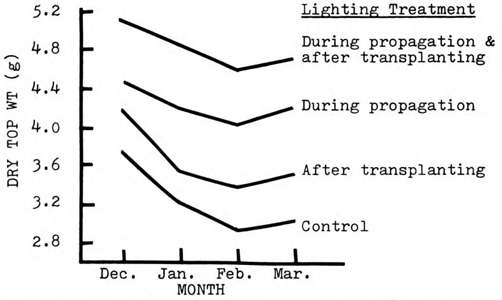

Figure 6.--Supplementary lighting (116 W/m^2) effects on dry top wt at bud development from lighting during propagation, or lighting from transplanting to SD treatment, or during both periods.

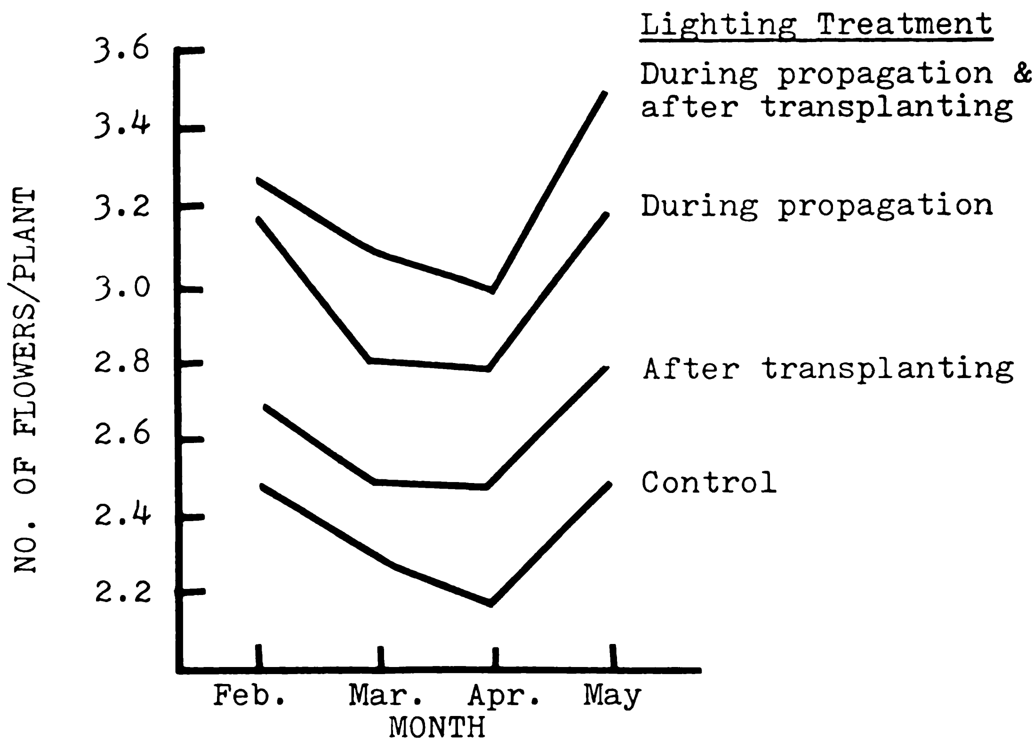

Figure 7.--No. of flowers per plant comparing those receiving supplementary light (116 W/m^2) 24 hrs. daily during propagation, or from potting to SD treatment, or during both periods.

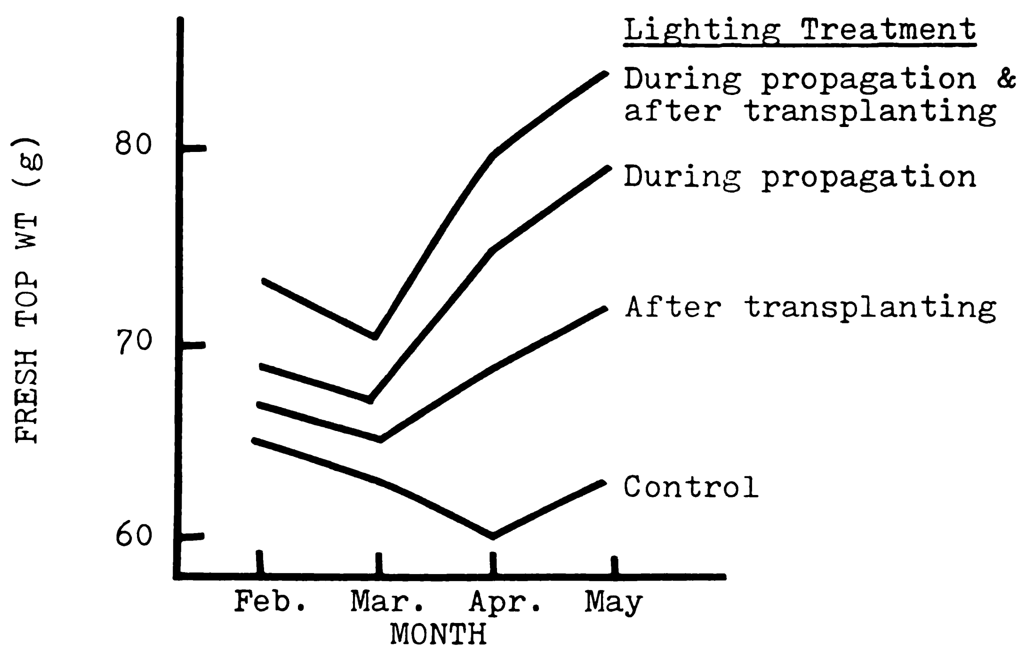

Figure 8.--Fresh top wt at flowering comparing plants receiving supplementary light (116 W/m^2) 24 hrs. daily during propagation, or from potting to SD treatment, or during both periods.

to SD treatment had 44%, 34%, and 30% greater fresh top weight at the beginning of short days, 5 weeks after short days began and at flowering respectively than unlighted controls. Differences in fresh top weight were significant and consistent for all trial periods from Nov. to May. Plants lighted only during propagation or only after transplanting had intermediate top fresh weights between continuously lighted and unlighted plants (Tables 6, 7, and 8). Top height at flowering for cv. Bright Golden Anne was not significantly different for any of the lighting treatments.

Flower number and size. A significant difference in node numbers was found between plants lighted continuously during propagation and from transplanting to short days, and those not lighted. Lighted plants had 48%, 69%, 70% and 52% more nodes with the potential of developing flowering branches than unlighted plants during Dec., Jan., Feb. and Mar. respectively (Table 7).

At flowering the number of flowering branches was significantly greater for plants continuously lighted to short days than unlighted plants (Table 8). Plants lighted continuously during propagation in Dec. and up to short days, only during propagation, and only after transplanting had 3.1, 2.5 and 2.8 flowering branches per plant respectively compared with 2.3 branches for unlighted plants. This was a 36%, 14% and 27% increase over unlighted controls. Differences were consistent throughout the 4 trial periods (Figure 7).

Individual flower diameters for plants lighted during propagation and after transplanting averaged 9.8 cm in Feb. compared with 9.4 cm for unlighted plants. These differences were small and not significant.

Discussion

Chrysanthemum cuttings receiving 116 W/m^2 of supplementary light from combined Lucalox and Multivapor lamps root faster and develop into rooted cuttings of higher quality than cuttings receiving only seasonal greenhouse daylight or those receiving supplementary lighting at 174 W/m^2. Benefits from supplemental lighting during propagation in northern latitudes are possible since plant growth rates and quality are substantially reduced during winter's low greenhouse light intensities.

Post (62) has shown the seasonal variation in natural light intensity correlates with seasonal differences in growth and quality of greenhouse crops. The marked decline in fresh root weight for rooted chrysanthemum cuttings propagated Oct. to Feb. under seasonal daylight conditions in this study is in accord with Post's observations. During the same period cuttings receiving 116 W/m^2 of supplementary light from Lucalox and Multivapor lamps continued to produce stocky roots of nearly constant fresh weight. High intensity supplementary lighting can compensate for seasonal decline in natural light energy values and is of greatest benefit when seasonal daylight values are lowest (Dec.-Feb.).

Plants grown in the greenhouse during dark winter days may be injured if transferred to growth chambers. The development of foliar chlorosis and necrosis has been attributed to high intensities in the short-wave region (81).

Since chrysanthemum cuttings in this study had not been exposed to comparable energy levels prior to sticking in the propagation bench, the leaves may have had no wax and little or no cutin which normally shield the leaf cells from incident radiation. With poorly developed protective layers the leaves were subject to injury by exposure to the higher light intensity (174 W/m^2). This speculation was supported by observations of much reduced chlorosis and no necrotic areas on cuttings originating from lighted stock (100 W/m^2) and propagated under 174 W/m^2 of supplemental light. Furthermore, slightly injured rooted cuttings when potted and transferred to 116 W/m^2 of supplemental light recovered within 10 days and developed normally. Older leaves became greener and new growth was normal and more rapid than unlighted controls.

Foliar injury was also reduced when the daily lighting period was reduced from 24 to 16 hours. This may be related to the balance between chlorophyll production and breakdown. Chlorophyll is continually being replenished; however its breakdown by intense illumination may be sufficiently fast that renewal fails to keep pace with destruction. A daily dark period may allow a surplus of chlorophyll to be produced which in turn prevents the development of a pale green or yellowish cast in the leaves. Concurrently, a dark period with the accompanying reduction in leaf temperature may allow for more efficient utilization of photosynthate with less energy being used for respiration. The larger amount of photosynthate available within the cutting for root development would be tied directly to improved rooting.

This study indicates that if supplementary high intensity lighting at 174 W/m^2 from Lucalox and Multivapor lamps was used for the propagation of chrysanthemums it must be accompanied by an 8 hour dark period to prevent foliar injury. However, this would be an impractical approach since at lower intensities (116 W/m^2 and 58 W/m^2) lighting 20 or 24 hours daily produces high quality rooting without significant foliar injury. From an economic standpoint Lucalox (400 W) sodium vapor lamps spaced 3 m apart with luminaires 1.4 m above the propagation bench and lighted 20 hours daily to supplement natural greenhouse light from Oct. to Mar. is satisfactory for the propagation of chrysanthemum cuttings.

This study has shown the cumulative value of high intensity supplementary lighting of pot chrysanthemum cv. Bright Golden Anne during propagation and up to short days. Large and important improvements in pot mum quality have been achieved when winter daylight intensities are continuously supplemented for a total of 5 weeks, 2 weeks during propagation and 3 weeks after transplanting, with high intensity discharge lamps. Benefits from lighting only during propagation or only after transplanting are similar, but intermediate between plants lighted 5 weeks and those unlighted.

Plants lighted continuously during Dec. propagation and after transplanting received a total light energy input of 1118 KW-hrs/m^2 during the 5 week period compared with 265 KW-hrs/m^2 for unlighted plants, 509 KW-hrs/m^2 for plants lighted only during propagation and 774 KW-hrs/m^2 for plants lighted only after transplanting. The greater the total light energy input that is made during propagation and up to short days (using combined Lucalox and Multivapor lamps at 116 W/m^2) the higher the quality of the pot plant. The benefits of lighting cv. Bright Golden Anne only during propagation or only for 3 weeks after transplanting remain at flowering. The highest quality plant at flowering is obtained by further increasing the total energy input by continuous lighting during propagation and for 3 weeks after transplanting.

Differences in plant quality among the various treatments were observed from Nov. to Mar. Plants receiving higher total energy levels during propagation and after transplanting had greater fresh and dry top weights and more flowers than those receiving less light energy. Presumably this was a result of increased availability of photosynthate for plant growth.

The quality of plant growth during propagation and early stages of development is often related to the subsequent quality of a horticultural commodity. For example, tall spindly petunia plants grown from seed under low greenhouse light conditions and planted outdoors fail to develop into well-branched floriferous plants during the summer months, while stocky well-branched plants quickly form showy mounds of color. In a similar way this study has shown that high quality chrysanthemum plants with a well-developed root system at the time SD treatment begins will proceed to develop into higher quality flowering plants with more flowers and denser foliage than plants with less developed stem and root systems.

Plants lighted (116 W/m^2) continuously throughout propagation and up to short days had as many as 70% more potential flowering branches than unlighted plants. The subsequent development of flower buds resulted in a larger floral display for lighted plants, increasing their beauty and retail value. Lighted plants should bring at least 50 cents more on the wholesale market for a 6 inch pot chrysanthemum than for unlighted. The cost of lighting for the 5 weeks in question is less than 7 cents per 6 inch pot thus making the lighting operation economically feasible.

II

SHORT-TERM SUPPLEMENTARY LIGHTING OF POT CHRYSANTHEMUMS AFTER TRANSPLANTING

Greenhouse high intensity supplementary lighting using mercury vapor and incandescent lamps has been found to increase plant top height and dry weight and reduce the number of days to flowering for peas, beans, tobacco, and snapdragon (22). Supplemental lighting with W.S. Gro-Lux fluorescent lamps at 29 lamp W/ft^2 has improved the development of newly planted dormant and cut-back rose plants by increasing the number of flowering stems developing after a hard pinch and increasing the number of bottom breaks (20). High intensity supplemental lighting of greenhouse roses from Sept. to Apr. has increased the cut flower yield by 70% to 80% without a significant decline in quality (17, 58). The objective of this study was to determine high intensity supplemental lighting's effect during the 5 week period following transplanting of rooted cuttings on pot chrysanthemum vegetative growth and flowering.

Materials and Methods

Four hundred and eight chrysanthemum terminal stem cuttings (8 cm) cv. Bright Golden Anne were harvested Nov. 1971 and Jan. 1972 from stock plants grown under normal greenhouse light conditions and propagated in a medium of coarse sand with bottom heat (24^{o}C) and misted intermittently 10 sec. each 10 min. Incandescent lighting 4 hours nightly during propagation prevented flower bud initiation. After 14 days in the propagation bench, 48 cuttings were harvested and root number, length and fresh and dry weight and fresh top weight were determined. The remaining rooted cuttings were potted 4 to a 6 inch clay pot in a medium of equal parts of soil, peat moss, and Turface.

Thirty pots were assigned to each of 3 lighting treatments: (1) lighted 24 hours daily with combined Lucalox (400 W) sodium vapor lamps and Multivapor (400 W) mercury vapor lamps at 116 W/m^2, (2) lighted 24 hours daily with a Lucalox (400 W) lamp at 58 W/m^2 and (3) only incandescent photoperiodic lighting 4 hours nightly. Each treatment had 2 replications in separate greenhouses.

Lucalox and Multivapor lamps with reflectors were alternated 1.5 m above a bench in each greenhouse to provide 116 W/m^2 22 cm over the bench surface and Lucalox lamps were similarly placed above another bench in each house to provide 58 W/m^2. Control plants were lighted with incandescent lamps (60 W) 4 hours nightly to keep the plants vegetative. Cultural practices were followed as recommended for chrysanthemums (46) and a 1200-1500 ppm CO_2 level was maintained in the greenhouse.

Twelve plants were harvested weekly from each plot for 5 weeks. Plant records included root length, fresh and dry root weight, top height and fresh top weight.

Results

Root length and weight. Root growth, length and fresh and dry weight, was greater for plants lighted 2 weeks at 116 W/m^2 or 58 W/m^2 than for plants lighted only photoperiodically during the same period after potting (Table 9). No significant differences were found in root length or weight between plants lighted 116 W/m^2 with combined Lucalox and Multivapor lamps and plants lighted at 58 W/m^2 with Lucalox lamps (Figure 9). Similar results were found after 5 weeks of lighting in Dec. and Jan. when fresh root weights averaged 9.96 g and 9.84 g for 116 W/m^2 and 58 W/m^2 respectively compared with 7.33 g for unlighted plants.

Top height and weight. Top height and weight were significantly greater for plants lighted for 3 weeks after potting than those not lighted (Table 9). There were no significant differences in top height and weight between

Table 9.--Weekly evaluation of chrysanthemum plants, cv. Bright Golden Anne, comparing plants lighted 24 hours daily after transplanting with Lucalox and Multivapor lamps (116 W/m^2), only Lucalox (58 W/m^2) and unlighted.[a]

	Nov.-Dec.			Jan.-Feb.		
	Lucalox & Multi-vapor 116 W/m^2	Lucalox 58 W/m^2	Unlighted	Lucalox & Multi-vapor 116 W/m^2	Lucalox 58 W/m^2	Unlighted
Total light energy KW-hr/m^2/week	219	133	47	214	128	42
After propagation						
Root length (cm)	2.53x	2.53x	2.53x	2.03x	2.03x	2.03x
Fr. root wt (g)	1.27x	1.27x	1.27x	1.15x	1.15x	1.15x
Dry root wt (g)	0.20x	0.20x	0.20x	0.19x	0.19x	0.19x
Top length (cm)	8.46x	8.46x	8.46x	8.42x	8.42x	8.42x
Fr. top wt (g)	3.92x	3.92x	3.92x	3.54x	3.54x	3.54x
Week 1						
Root length (cm)	3.17x	3.14x	2.99x	3.29x	3.25x	3.13x
Fr. root wt (g)	2.12x	2.07x	1.94x	2.05x	1.98x	1.87x
Dry root wt (g)	0.30x	0.26x	0.22x	0.29x	0.23x	0.21x
Top length (cm)	9.24x	9.15x	9.11x	9.35x	9.24x	9.03x
Fr. top wt (g)	3.80x	3.72x	3.75x	3.75x	3.70x	3.69x
Week 2						
Root length (cm)	5.01x	4.96x	3.63y	4.26x	4.53x	3.53y
Fr. root wt (g)	3.31x	3.25x	2.56y	3.24x	3.31x	2.23y
Dry root wt (g)	0.53x	0.49x	0.45y	0.51x	0.53x	0.40y
Top length (cm)	10.87x	10.56x	9.41x	10.91x	10.73x	9.59y
Fr top wt (g)	4.80x	4.54x	4.01x	4.37x	4.29x	3.92y

Table 9 (cont'd.)

	Nov.-Dec.			Jan.-Feb.		
	Lucalox & Multi-vapor 116 W/m^2	Lucalox 58 W/m^2	Unlighted	Lucalox & Multi-vapor 116 W/m^2	Lucalox 58 W/m^2	Unlighted
Week 3						
Root length (cm)	6.00x	6.12x	4.71y	5.98x	5.89x	3.83y
Fr. root wt (g)	4.42x	4.37x	3.21y	4.39x	4.29x	3.01y
Dry root wt (g)	0.75x	0.70x	0.50y	0.72x	0.67x	0.46y
Top length (cm)	12.43x	12.47x	10.31y	12.68x	12.48x	9.43y
Fr. top wt (g)	6.71x	6.51x	5.21y	6.65x	6.74x	5.05y
Week 4						
Root length (cm)	7.54x	7.42x	5.31y	6.73x	7.04x	4.54y
Fr. root wt (g)	6.52x	6.31x	4.91y	6.42x	6.22x	4.47y
Dry root wt (g)	0.90x	0.86x	0.67y	0.87x	0.81x	0.64y
Top length (cm)	16.91x	15.71x	12.07y	16.07x	15.47x	11.72y
Fr. top wt (g)	8.57x	8.42x	6.11y	8.31x	8.29x	6.22y
Week 5						
Root length (cm)	9.96x	9.84x	7.33y	9.04x	8.84x	7.12y
Fr. root wt (g)	8.22x	8.01x	5.23y	8.31x	7.97x	5.94y
Dry root wt (g)	0.95x	0.92x	0.72y	1.02x	0.94x	0.82y
Top length (cm)	21.40x	22.64x	16.31y	20.13x	19.93x	15.42y
Fr. top wt (g)	10.64x	10.47x	8.13y	10.59x	9.98x	7.93y

[a]Mean separation of values in rows within a trial by Duncan's Multiple Range Test, 5%.

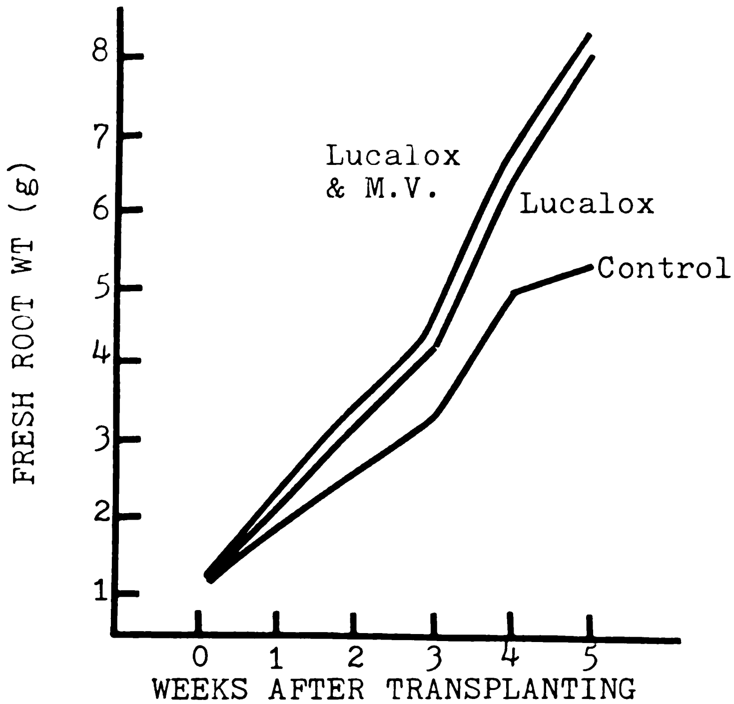

Figure 9.--Weekly evaluation of chrysanthemum fresh root wt comparing plants lighted 24 hrs. daily after transplanting with Lucalox and Multivapor lamps (116 W/m^2), only Lucalox (58 W/m^2) and unlighted.

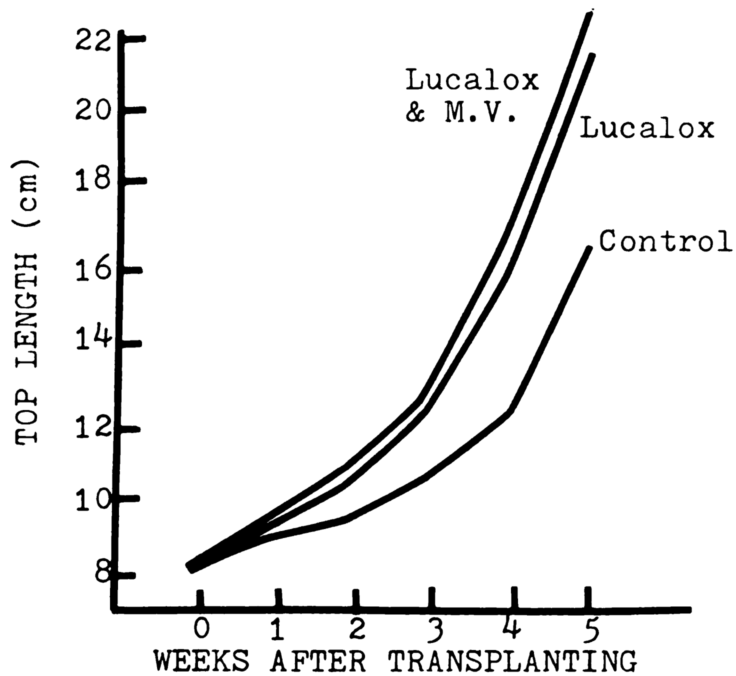

Figure 10.--Weekly evaluation of chrysanthemum top length comparing plants lighted 24 hrs. daily after transplanting with Lucalox and Multivapor lamps (116 W/m^2), only Lucalox (58 W/m^2) and unlighted.

plants lighted 116 W/m^2 with Lucalox and Multivapor lamps and plants lighted 58 W/m^2 with only Lucalox lamps (Figure 10). Chrysanthemum plants during 5 weeks of high intensity supplemental lighting in Dec. and Jan. increased in height almost 13 cm and were about 7 g heavier compared with an 8 cm increase in height and a 4 g increase in weight for unlighted plants.

Discussion

In these trials high intensity supplementary lighting at 116 W/m^2 and 58 W/m^2 significantly increased the rate and quality of plant growth from Nov. to Feb. Later studies have shown that pot chrysanthemum quality is improved by high intensity lighting from Sept. to Mar. (Part IV). Similar benefits were found from supplemental lighting at 116 W/m^2 from combined Lucalox and Multivapor lamps and 58 W/m^2 from a Lucalox lamp alone. Increasing light intensity by adding the Multivapor lamp to the Lucalox does not improve the quality of chrysanthemum cv. Bright Golden Anne.

The Multivapor lamp emits a larger portion of blue wavelengths and less red than the Lucalox lamp. During cloudy winter days there are proportionately more blue wavelengths than red in natural greenhouse light since water vapor in the air filters out red wavelengths from sunlight. The red part of the spectrum is more active in promoting photosynthesis than the same energy of blue light. Therefore adding more blue wavelengths to greenhouse light from Multivapor lamps may not greatly affect the rate of photosynthesis and thus be of little benefit to plant growth.

Noesen and Spacil (54) have shown that Lucalox (400 W) lamps can provide considerably more visible light than sunlight inside the greenhouse from Nov. to Mar. Lighting 24 hours daily in Dec. with a Lucalox (400 W) lamp can result in a total energy input of 30 KW-hrs/m^2/day from lamp and daylight compared with 7 KW-hrs/m^2/day from daylight alone.

Increasing the light energy 4-fold over natural light conditions results in faster growth of high quality for chrysanthemum cv. Bright Golden Anne. Differences in total light energy levels received since transplanting for lighted and unlighted plants increase over time and so do the benefits from supplemental lighting. The improved growth of lighted plants over unlighted probably results from greater net photosynthate being produced under higher energy levels.

Lighting chrysanthemums after transplanting with a Lucalox lamp at 58 W/m^2 should have commercial application if improvements in plant quality are maintained until flowering or if the pinch and SD treatment can be moved ahead to produce earlier flowering. The addition of a Multivapor lamp to a Lucalox to double the light intensity appears to be uneconomical since initial lamp cost and operating expenses are doubled without a significant improvement in growth rate or quality.

III

INTERACTION OF STOCK PLANT LIGHTING AND SUPPLEMENTARY LIGHTING OF POT CHRYSANTHEMUMS AFTER TRANSPLANTING

Supplementary lighting during the winter improves the growth rate and quality of chrysanthemum stock plants (2, 77). Anderson and Carpenter (2) have shown that chrysanthemum cuttings propagated from high intensity lighted stock plants become established more rapidly after transplanting and develop into a slightly higher quality plant at flowering than unlighted plants.

The growth after transplanting for chrysanthemum is improved when natural greenhouse light intensities are supplemented with high intensity discharge lamps at 58 W/m^2 or 116 W/m^2 (SECTION TWO, Part II). This study was initiated to compare the separate and cumulative benefit from high intensity supplemental lighting of pot chrysanthemums after transplanting with cuttings from similarly lighted stock plants.

Materials and Methods

In Dec. 1971 and Feb. 1972, 164 chrysanthemum terminal cuttings (8 cm) of cv. Bright Golden Anne were harvested from both lighted (100 W/m^2 combined Lucalox and Multivapor lamps) and unlighted stock plants. All cuttings were propagated under normal greenhouse light intensities. Root length, fresh and dry root weight, top length and fresh top weight of 36 cuttings originating from both lighted and unlighted stock were measured after propagation. The remainder of the rooted cuttings were potted 4 to a 6 inch clay pot in a medium of equal parts of soil, peat moss, and Turface.

After transplanting pots were divided between supplementary light (100 W/m^2) and natural light conditions resulting in 4 lighting treatments: (1) lighted as stock and after transplanting, (2) lighted as stock but not after transplanting, (3) unlighted as stock but lighted after transplanting, and (4) unlighted as stock and after transplanting. Pots were randomized within 2 identical lighted plots in separate greenhouses which provided 100 W/m^2 of light 24 hours daily 22 cm above the bench surface. At the initiation of SD treatment (3 weeks after transplanting), 8 pots from each treatment were harvested and root length, root fresh and dry weight, top length, fresh top weight and node number were determined.

The remainder of the pots were given SD treatment and normal greenhouse daylight until flowering. At flowering plant height, number of flowering branches, fresh and dry top weight and flower diameter were measured. Data were

Table 10.--Evaluation of chrysanthemum plants, cv. Bright Golden Anne, comparing plants lighted 100 W/m^2 as stock and after transplanting, lighted 100 W/m^2 after transplanting only, lighted 100 W/m^2 as stock and unlighted.[a]

	Dec.-Jan.				Feb.-Mar.			
	Lighted stock & after trans-plant	Lighted after trans-plant	Lighted stock	Un-lighted	Lighted stock & after trans-plant	Lighted after trans-plant	Lighted stock	Un-lighted
After propagation								
Root length (cm)	2.74x	2.31y	2.74x	2.31y	2.51x	2.17y	2.51x	2.17y
Fr. root wt (g)	1.52x	1.23y	1.52x	1.23y	1.46x	1.13y	1.46x	1.13y
Dry root wt (g)	0.32x	0.21y	0.32x	0.21y	0.29x	0.18y	0.29x	0.18y
Top length (cm)	8.86x	8.35x	8.86x	8.35x	8.82x	8.40x	8.82x	8.40x
Fr. top wt (g)	4.27x	3.86y	4.27x	3.86y	4.13x	3.67y	4.13x	3.67y
At short days								
Root length (cm)	6.74x	6.32x	5.12xy	4.58y	6.54x	6.21x	5.39xy	4.16y
Fr. root wt (g)	5.96x	5.79x	4.47y	3.24z	5.59x	5.13x	4.42y	3.05z
Dry root wt (g)	0.86x	0.82x	0.61y	0.57z	0.79x	0.72x	0.56y	0.43z
Top length (cm)	14.02x	13.41x	11.88y	10.57z	13.93x	13.24x	12.01y	10.14z
Fr. top wt (g)	7.94x	7.04x	6.14y	5.34z	7.76x	6.99xy	5.92y	5.17y
Node number	8.92x	8.69x	7.21y	6.10z	8.85x	8.32x	6.84y	5.93z
At flowering								
Plant ht. (cm)	68.54x	66.71xy	62.74y	61.43y	69.27x	67.32xy	64.61y	62.31y
No. fl. branches	4.19x	4.07x	3.17y	2.51z	4.29x	4.14x	3.24y	2.67z
Fr. top wt (g)	79.41x	77.32x	70.41y	63.93z	79.32x	78.47x	72.64y	65.42z
Dry top wt (g)	10.02x	9.71x	8.92y	8.04z	10.44x	10.32x	9.68y	8.57z
Flower diam. (cm)	9.57x	9.61x	9.41x	9.32x	9.71x	9.52x	9.49x	9.46x
Display diam. (cm)	44.71x	42.43x	36.39y	32.61z	42.62x	41.75x	35.42y	30.37z

[a]Mean separation of values in rows within a trial by Duncan's Multiple Range Test, 5%.

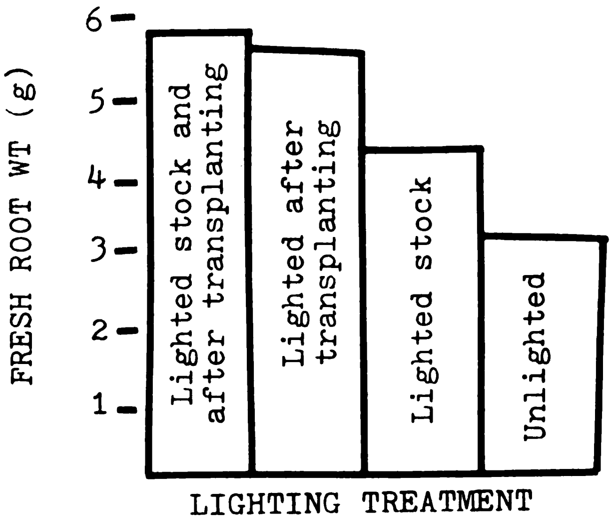

Figure 11.--Fresh root wt of chrysanthemum plants, 3 weeks after transplanting, lighted with HID lamps for various combinations of time as stock plants and 3 weeks after transplanting.

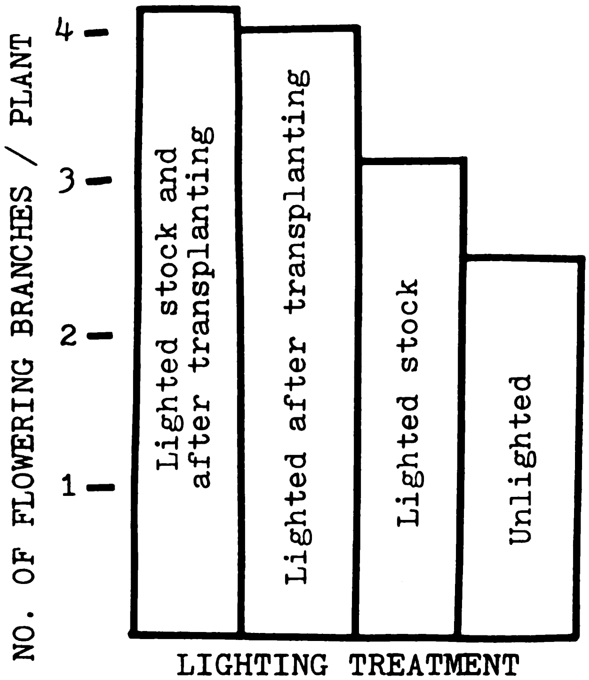

Figure 12.--No. of flowering branches per chrysanthemum plant lighted various combinations of time as stock plants and 3 weeks after transplanting.

analyzed statistically using Duncan's Multiple Range Test (73).

Results

<u>Measurements at short days</u>. Top and root measurements, 3 weeks after transplanting, showed plants derived from high intensity lighted stock plants and lighted 3 weeks after transplanting had larger fresh and dry root weight, greater plant height, top fresh weight, and stem node number than control plants (Table 10). Plants lighted only after transplanting (3 weeks) were of nearly equal quality to plants lighted both after transplanting and as stock plants. Plants lighted only as stock plants had significantly smaller fresh and dry root weight, fresh top weight, stem node number and shorter plant height than plants lighted for 3 weeks after transplanting but were of higher quality than plants not lighted during any phase of development (Figure 11).

<u>Plants at flowering</u>. At flowering treatment differences were visible. Measurements showed that plants lighted both as stock plants and after transplanting (3 weeks in late Dec. and early Jan.) were 7 cm taller at flowering than controls compared with a 5 cm increase and 1 cm increase in height over controls for plants lighted only after transplanting and only as stock

plants (Table 10). Fresh and dry top weights averaged 79 g and 10.0 g respectively for plants lighted both as stock and after transplanting compared with 77 g and 9.7 g for plants lighted only after transplanting, 70 g and 8.9 g for plants lighted only as stock plants and 64 g and 8.0 g for control plants.

Plants lighted both as stock plants and after transplanting (3 weeks in late Dec. and early Jan.) had 17 flowering branches per pot compared with 16 for plants lighted only after transplanting (3 weeks), 13 for plants lighted only as stock and 10 for control plants (Table 10). Flower diameter averaged 9.5 cm and was not significantly different among the treatments. Plants lighted both as stock plants and after transplanting (3 weeks in late Dec. and early Jan.) had plant display diameters averaging 44 cm compared with 42 cm for plants lighted only after transplanting (3 weeks), 36 cm for plants lighted only as stock and 33 cm for control plants.

Discussion

Chrysanthemum cuttings from stock plants lighted 100 W/m^2 with high intensity discharge lamps have significantly greater fresh and dry root weights after propagation than cuttings from unlighted stock, and differences continue to flowering (Table 10). Lighting cuttings from lighted stock plants for 3 weeks following transplanting resulted in still larger increases in fresh and dry root weight, fresh top weight, top length, and node number over unlighted controls. High intensity lighting for 3 weeks after transplanting produced plants of similar quality at the beginning of short days and at flowering regardless of whether the cuttings were from lighted or unlighted stock plants. Plants lighted as stock plants and after transplanting had a larger floral display than those lighted only after transplanting.

Plants derived from unlighted stock but lighted 3 weeks after transplanting were of better quality than plants derived from lighted stock but not lighted after transplanting. This study shows that lighting for 3 weeks after transplanting is more beneficial in improving plant quality at flowering than only lighting stock plants. However best results are obtained from lighting stock and after transplanting. Since most northern growers obtain cuttings produced and propagated under the higher light conditions of southern latitudes during the winter, they can achieve the combined benefits of high light energy levels by only lighting for 3 weeks after transplanting.

Although the additional benefits of lighting stock plants are small when plants are also lighted after transplanting, the lighting of stock plants may be worthwhile since the cost per cutting is low. Anderson and Carpenter

(2) have found that terminal stem cutting numbers yielded by chrysanthemum stock plants were greatly increased by continuous high intensity lighting from Oct. through May. Increased cutting yield from lighted stock plants in addition to small increases in flowering plant quality both are positive factors for stock plant lighting.

IV

BENEFITS AT FLOWERING FROM LIGHTING AFTER TRANSPLANTING

High intensity lamps can provide considerably more visible light than sunlight inside the greenhouse from Nov. to Mar. (54). High intensity supplemental lighting of greenhouse roses from Sept. to Apr. has increased yield by 70% to 80% without a significant decline in quality (17, 58). Seed propagated geraniums, under constant high intensity supplemental light, flowered 24-55 days earlier than those receiving no supplemental light. The growth after transplanting of chrysanthemum was improved from Nov. to Jan. when natural greenhouse light intensities were supplemented with 58 W/m^2 or 116 W/m^2 from high intensity discharge lamps (SECTION TWO, Part II). This study was initiated to determine the effect of 1 to 3 weeks of high intensity supplemental lighting from transplanting to SD treatment on the vegetative growth and flowering of 3 chrysanthemum cultivars.

Materials and Methods

One hundred rooted cuttings (10 cm) each of pot chrysanthemum cultivars Torch (9 week), Goldstar (10 week) and Deep Cristal (11 week) were received from Yoder Bros. at 3 week intervals from Aug. 11, 1972 through Mar. 8, 1973. Cuttings were planted 4 to a 6 inch clay pot in a medium of equal parts of soil, peat moss and Turface. Plants received varying lengths (0 to 3 weeks) of high intensity supplementary lighting between planting and the SD treatment. A cultivar requiring 3 weeks from potting to SD treatment was divided into 4 treatments: 0, 7, 14, and 21 days of supplementary lighting. In Aug. cv. Goldstar required only one week of long-day (LD) treatment before SD, and included only 2 treatments: control plants and those receiving one week of supplementary high intensity lighting. Subsequent trials with 'Goldstar' included 3 lighting treatments: 0, 7, and 14 days of supplementary light.

Three Lucalox (400 W) sodium vapor lamps with luminaires were mounted 1.5 m above each of 3 separate N-S oriented raised benches to emit 54 W/m^2 of light 22 cm above the bench surface for 24 hours daily. Three other greenhouse benches received light (50 ft-c) from incandescent lamps (60 W) 4 hours nightly to keep plants vegetative. Two pots per bench (a total of 6 pots) were placed immediately after transplanting under natural greenhouse light conditions with only photoperiodic lighting. Pots of the lighted treatments were randomized on the 3 high intensity lighted benches. Plants receiving shorter periods of high intensity lighting were given photoperiodic LD lighting until the SD treatment began. Cultural practices followed were as recommended for chrysanthemums (46), and a 1200-1500 ppm CO_2 level was maintained in the greenhouse. During SD treatment black sateen cloth was pulled nightly to prevent light contamination and promote flowering.

Measurements at flowering were collected when the second circle of petals unfurled on the earliest flower of each plant. Other measurements included the height of plant from the soil, diameter (all 4 plants considered) of the plant display, number of flowers per pot, diameter of the third largest flower, and fresh and dry weight of the individual plants. All data were analyzed statistically according to Duncan's Multiple Range Test (73).

Light input in the 380-700 nm band inside the greenhouse due to natural daylight and to the light from lamps was calculated from daily solar radiation values (Appendix B) and the lamp values according to the guidelines by Noesen and Spacil (54). Total light energy input (daylight and lamps) within the greenhouse is given for each lighting treatment during the trial period (Tables 11-13).

Results

Days to flower. The number of days to flower for chrysanthemum cvs. Goldstar, Torch and Deep Cristal was unaffected by high intensity supplementary lighting between potting and SD treatment (Tables 11-13). No significant differences in number of days to flower were shown within any of the 11 trials for each cultivar.

Size of flowering plant. The 3 cultivars 'Deep Cristal,' 'Torch,' and 'Goldstar' differed in their response to high intensity supplementary lighting. Cv. Deep Cristal lighted 21 days after transplanting from Aug. to Mar. developed into a taller flowering plant than plants unlighted (Table 13). Lighting 'Deep Cristal' 21 days after transplanting in Oct., Dec. and Feb. resulted in flowering plants 33.7, 35.8 and 36.8 cm tall compared with 26.0, 29.7 and 28.7 cm for unlighted plants. Lighting cv. Torch 21 days after transplanting from Nov. to Jan. resulted in a 12%-18% increase in height over controls (controls averaged 32 cm tall). Lighting cv. Torch before Nov. and after Jan. did not result in significant differences from controls in plant height at flowering. Lighting cv. Goldstar 14 days following potting from Aug. to Mar. resulted in a slight increase in height for the flowering plant but differences were not significant.

Table 11.--Evaluation of flowering chrysanthemum plants, cv. Goldstar, which had been lighted continuously for 0, 7, and 14 days after potting with a Lucalox lamp (58 W/m^2).[z]

Trial	Potting date	Days lighted	Light input to SD $KW\text{-}hr/m^2$	Days to fl.	Height of plant (cm)	Diam. of plant (cm)	No. of fls./ plant	Diam. of fl. (cm)	Fr. wt of plant (g)	Dry wt of plant (g)
1	8/11	0	65.4	68.0a	27.6a	40.3a	13.3a	9.7a	45.7a	6.8a
		7	107.2	67.0a	27.4a	41.7a	15.2a	10.0a	48.1a	7.7b
2	8/30	0	125.5	71.0a	28.3a	40.0a	11.3a	9.0a	43.3a	6.5a
		7	208.6	72.3a	28.3a	40.3a	14.0ab	9.3a	47.3ab	7.5ab
		14	297.7	70.3a	28.3a	41.3a	15.3b	9.4a	50.7b	8.1b
3 (Mt. Sun)	9/20	0	119.8	90.7a	32.5a	37.3a	14.5a	9.4a	72.9a	9.7a
		7	202.9	91.0a	34.0a	42.0b	17.3b	11.1b	82.3b	11.8b
		14	292.0	93.3a	37.0b	49.7c	20.3c	11.8b	104.0c	14.0c
4	10/11	0	110.5	73.4a	27.3a	37.3a	11.0a	8.5a	42.7a	5.6a
		7	192.6	72.6a	28.3a	41.3ab	13.3ab	8.4a	44.3a	6.5b
		14	282.7	72.1a	29.0a	44.0b	15.3b	9.0a	50.3b	6.6b
5	11/1	0	98.7	74.5a	27.7a	36.3a	11.3a	8.4a	42.2a	5.4a
		7	181.8	74.1a	28.0a	39.7ab	13.0ab	8.3a	44.4a	6.4b
		14	270.9	73.4a	29.3a	43.0b	15.7b	8.9a	50.1b	6.7b
6	11/22	0	83.2	73.3a	28.0a	36.0a	11.0a	8.9a	40.6a	5.6a
		7	166.3	73.5a	27.7a	40.7ab	13.7ab	8.9a	43.5ab	5.9b
		14	255.4	72.9a	27.7a	42.7b	15.0b	9.1a	48.9b	6.0b

Table 11 (cont'd.)

Trial	Potting date	Days lighted	Light input to SD KW-hr/m^2	Days to fl.	Height of plant (cm)	Diam. of plant (cm)	No. of fls./ plant	Diam. of fl. (cm)	Fr. wt of plant (g)	Dry wt of plant (g)
7 (Sun-Star)	12/19	0	73.1	74.0a	25.6a	36.7a	12.0a	8.4a	38.3a	4.4a
		7	156.2	72.6a	24.3a	37.0a	12.0a	8.4a	40.2ab	4.6a
		14	245.3	72.1a	24.7a	37.3a	13.7a	8.3a	43.6a	4.7a
8	1/4	0	81.7	74.4a	27.7a	37.7a	10.7a	8.9a	36.3a	4.9a
		7	164.8	73.1a	27.3a	41.3ab	12.0ab	9.0a	42.8ab	5.7b
		14	253.9	73.2a	27.0a	43.0b	14.7b	9.0a	47.2b	5.8b
9	1/24	0	83.3	72.3a	27.5a	38.0a	11.0a	8.7a	38.3a	5.1a
		7	167.4	71.5a	28.9a	40.3ab	12.3ab	9.0a	43.5ab	5.6ab
		14	256.5	70.8a	28.3a	43.7b	13.7b	9.2a	48.1b	6.0b
10	2/14	0	100.7	72.1a	26.0a	38.7a	11.7a	8.6a	40.2a	5.3a
		7	183.8	71.4a	27.3a	41.7ab	13.0ab	8.8a	45.5ab	5.7ab
		14	272.9	70.2a	27.8a	43.3b	14.0b	9.0a	50.3b	5.9b
11	3/8	0	115.2	70.4a	26.3a	40.3a	12.3a	8.7a	45.3a	5.6a
		7	198.3	69.5a	27.7a	42.2a	13.7ab	9.0a	49.8ab	5.8a
		14	287.4	68.0a	28.2a	44.0a	15.4b	9.2a	51.3b	6.0a

[z]Mean separation of values in columns within a trial by Duncan's Multiple Range Test, 5%.

Table 12.--Evaluation of flowering chrysanthemum plants, cv. Torch, which had been lighted continuously for 0, 7, 14, and 21 days after potting with a Lucalox lamp (58 W m^{-2}).[z]

Trial	Potting date	Days lighted	Light input to SD $KW\text{-}hr/m^2$	Days to fl.	Height of plant (cm)	Diam. of plant (cm)	No. of fls./ plant	Diam. of fl. (cm)	Fr. wt of plant (g)	Dry wt of plant (g)
1	8/11	0	133.4	73.7a	28.7a	34.7a	13.3a	7.9a	45.4a	5.6a
		7	216.5	72.0a	29.7a	38.0b	14.7ab	8.5a	51.9ab	6.1ab
		14	305.6	70.3a	30.3a	39.3b	16.3b	8.5a	58.9b	6.3b
2	8/30	0	188.2	81.3a	31.0a	36.0a	12.0a	7.7a	40.7a	5.8a
		7	268.7	79.5a	32.3a	39.3b	13.7ab	8.0a	46.4ab	5.9ab
		14	447.0	80.8a	33.0a	39.7b	15.3bc	7.6a	55.2b	6.0ab
		21	576.4	79.3a	33.7a	41.3b	16.7c	8.2a	62.4c	6.3b
3	9/20	0	179.7	83.3a	31.7a	36.3a	11.3a	7.8a	37.2a	5.4a
		7	260.2	82.0a	33.0a	39.7b	12.7ab	7.7a	51.7b	5.7a
		14	349.5	82.5a	34.0a	42.3c	15.3b	8.2a	59.3c	6.3c
		21	434.4	83.8a	34.7a	43.3c	16.3b	8.5a	62.3c	6.5b
4	10/11	0	165.7	82.4a	31.3a	35.0a	12.0a	7.5a	40.6a	5.3a
		7	246.2	82.0a	33.3ab	39.3b	13.3ab	7.6a	49.2b	5.9b
		14	335.5	81.7a	33.0ab	41.7bc	14.3bc	7.7a	57.9c	6.2bc
		21	420.4	81.3a	36.3b	43.6c	15.7c	7.9a	60.7c	6.4c
5	11/1	0	148.0	83.5a	30.3a	34.3a	11.3a	7.3a	39.5a	5.2a
		7	228.5	82.7a	33.7ab	37.0b	12.3ab	7.4a	46.8b	6.1b
		14	317.4	82.5a	34.3ab	40.6c	13.7bc	7.6a	54.2c	6.3b
		21	402.7	81.0a	35.7b	43.3d	15.3c	7.8a	58.7c	6.7b
6	11/22	0	124.8	83.6a	31.0a	33.3a	11.0a	7.4a	40.9a	5.3a
		7	205.3	83.5a	33.7ab	36.2b	13.0ab	8.0a	49.3b	5.8b
		14	294.6	82.3a	34.8ab	38.7c	13.5bc	7.9a	53.4bc	6.1b
		21	379.5	81.9a	36.3b	40.7d	15.8c	7.8a	60.1c	6.6c

Table 12 (cont'd.)

Trial	Potting date	Days lighted	Light input to SD $KW\text{-}hr/m^2$	Days to fl.	Height of plant (cm)	Diam. of plant (cm)	No. of fls./ plant	Diam. of fl. (cm)	Fr. wt of plant (g)	Dry wt of plant (g)
7	12/19	0	109.1	83.8a	31.8a	30.0a	10.4a	7.5a	38.7a	5.1a
		7	189.6	83.2a	33.3ab	35.2b	12.0ab	7.8a	47.2b	5.8b
		14	278.9	82.5a	33.8ab	38.3bc	12.3bc	7.9a	50.4bc	6.0bc
		21	367.9	81.7a	35.8b	41.2c	14.3c	7.9a	59.2c	6.2c
8	1/4	0	122.5	84.3a	31.0a	31.2a	10.0a	7.7a	40.7a	5.3a
		7	203.0	83.4a	34.8ab	35.8b	12.3ab	7.9a	55.3b	6.4b
		14	292.3	82.6a	34.3ab	38.0bc	13.5bc	7.9a	60.5bc	6.7bc
		21	377.2	80.9a	36.5b	40.7c	14.8c	8.0a	63.9c	6.9c
9	1/24	0	124.9	85.6a	31.8a	32.3a	11.3a	7.7a	45.7a	5.6a
		7	205.4	84.9a	32.3ab	35.8b	13.7ab	7.9a	57.3b	6.5b
		14	294.7	83.4a	33.0ab	39.0c	14.8bc	8.0a	61.7b	6.9bc
		21	379.6	81.2a	35.3b	40.3c	16.6c	8.1a	69.4c	7.2c
10	2/14	0	151.0	84.7a	32.3a	33.8a	12.6a	7.8a	47.9a	5.8a
		7	231.5	83.9a	32.8a	36.3b	14.3ab	7.7a	54.2ab	6.3b
		14	320.8	81.4a	33.3a	39.3c	15.7bc	7.9a	63.9bc	6.9bc
		21	405.7	80.9a	34.0a	40.2c	17.4c	8.0a	70.5c	7.5c
11	3/8	0	172.8	83.6a	33.0a	35.7a	14.0a	7.7a	55.2a	6.0a
		7	253.3	82.0a	33.3a	38.2b	15.5ab	7.8a	62.5b	7.0b
		14	342.6	81.3a	33.8a	40.6c	17.3bc	7.8a	67.7b	7.4b
		21	427.5	80.4a	34.3a	41.6c	18.8c	7.9a	71.9c	9.2c

[z]Mean separation of values in columns within a trial by Duncan's Multiple Range Test, 5%.

Table 13.--Evaluation of flowering chrysanthemum plants, cv. Deep Cristal, which had been lighted continuously for 0, 7, 14, and 21 days after potting with a Lucalox lamp (58 W/m^2).[z]

Trial	Potting date	Days lighted	Light input to SD $KW\text{-}hr/m^2$	Days to fl.	Height of plant (cm)	Diam. of plant (cm)	No. of fls./ plant	Diam. of fl. (cm)	Fr. wt of plant (g)	Dry wt of plant (g)
1	8/11	0	133.4	80.0a	25.0a	33.7a	13.0a	8.0a	47.8a	5.0a
		7	216.5	79.7a	26.7a	35.7ab	14.3ab	8.1a	54.8ab	5.7b
		14	305.6	78.3a	30.0b	39.3b	15.7b	8.6a	60.7b	6.4c
2	8/30	0	188.2	84.5a	26.3a	34.3a	12.3a	7.9a	46.2a	5.4a
		7	268.7	85.0a	29.0b	38.3b	13.7b	8.7a	52.1ab	5.9b
		14	447.0	85.8a	30.0bc	40.0b	14.0b	8.4a	60.0bc	6.1b
		21	576.4	86.3a	32.0c	44.3c	15.3c	8.7a	67.7c	6.4c
3	9/20	0	179.7	84.3a	25.3a	34.3a	12.7a	7.5a	38.4a	4.9a
		7	260.2	86.5a	31.0b	36.3ab	13.7b	8.0a	42.6ab	5.3b
		14	349.5	86.7a	31.3b	40.0b	14.0b	8.2a	56.0ab	6.4c
		21	434.4	85.8a	32.7b	44.0c	15.0c	8.6a	67.8c	7.2d
4	10/11	0	165.7	86.3a	26.0a	34.0a	11.4a	7.4a	37.3a	4.5a
		7	246.2	85.9a	31.7b	35.7a	12.7b	8.0a	42.7b	5.4b
		14	335.5	84.2a	33.0b	39.3b	13.3b	8.1a	53.4c	6.3c
		21	420.4	85.7a	33.7b	43.7c	14.7c	8.3a	64.9d	7.1d
5	11/1	0	148.0	87.2a	25.4a	32.3a	10.3a	7.5a	36.4a	4.3a
		7	228.5	86.4a	28.5b	36.9b	11.3b	7.9a	44.7b	5.4b
		14	317.8	85.2a	29.4bc	40.7b	12.0b	8.1a	54.9c	6.6c
		21	402.7	86.1a	31.7c	45.6c	13.7c	8.4a	68.7d	7.3d
6	11/22	0	124.8	88.4a	27.3a	33.4a	11.4a	7.7a	35.3a	4.4a
		7	205.3	87.9a	29.5ab	35.6a	12.5b	7.8a	46.4b	5.0b
		14	294.6	87.0a	30.0ab	37.9ab	13.3b	7.8a	57.2c	6.3c
		21	379.5	86.3a	33.3b	44.0b	14.8c	7.9a	65.4d	7.2d

Table 13 (cont'd.)

Trial	Potting date	Days lighted	Light input to SD KW-hr/m^2	Days to fl.	Height of plant (cm)	Diam. of plant (cm)	No. of fls./ plant	Diam. of fl. (cm)	Ft. wt of plant (g)	Dry wt of plant (g)
7	12/19	0	109.1	87.3a	29.7a	32.5a	10.7a	7.7a	34.7a	4.3a
		7	189.6	86.2a	30.0a	34.7ab	12.8b	7.9a	44.1b	5.0b
		14	278.9	86.9a	32.5b	37.6b	13.3b	8.0a	52.9c	6.3c
		21	367.9	85.6a	35.8b	40.3c	14.0c	8.2a	64.2d	7.1d
8	1/4	0	122.5	89.2a	30.2a	33.9a	11.3a	7.8a	32.1a	4.0a
		7	203.0	87.4a	32.8b	34.3ab	13.8b	7.8a	46.9b	5.4b
		14	292.3	86.9a	35.3bc	36.5b	14.3b	8.0a	55.7c	6.3c
		21	377.2	85.2a	36.7c	41.8c	15.8c	8.1a	62.8d	7.0d
9	1/24	0	124.9	87.5a	29.6a	34.6a	12.3a	7.9a	36.2a	4.4a
		7	205.4	87.2a	32.2b	37.2a	14.6b	8.0a	48.2b	5.3b
		14	294.7	85.3a	34.9bc	39.7ab	15.3b	8.1a	56.9c	6.5c
		21	379.6	84.9a	35.4c	42.4b	16.0c	8.3a	64.7d	7.4d
10	2/14	0	151.0	84.7a	28.7a	35.7a	12.7a	8.0a	41.4a	4.6a
		7	231.5	83.8a	32.4b	37.5a	14.3b	8.1a	52.7ab	5.5b
		14	320.8	82.9a	33.6b	39.6ab	15.0b	8.3a	60.4bc	6.7c
		21	405.7	83.0a	36.8c	43.9b	16.7c	8.5a	66.2c	7.6d
11	3/8	0	172.8	83.1a	29.4a	36.2a	13.0a	7.9a	52.4a	5.6a
		7	253.3	82.9a	30.2ab	37.4a	14.6b	8.2a	57.2ab	5.8b
		14	342.6	81.7a	32.4ab	40.4ab	15.4b	8.5a	64.9bc	6.9c
		21	427.5	80.4a	34.9b	44.7b	17.3c	8.7a	68.3c	7.8d

[z]Mean separation of values in columns within a trial by Duncan's Multiple Range Test, 5%.

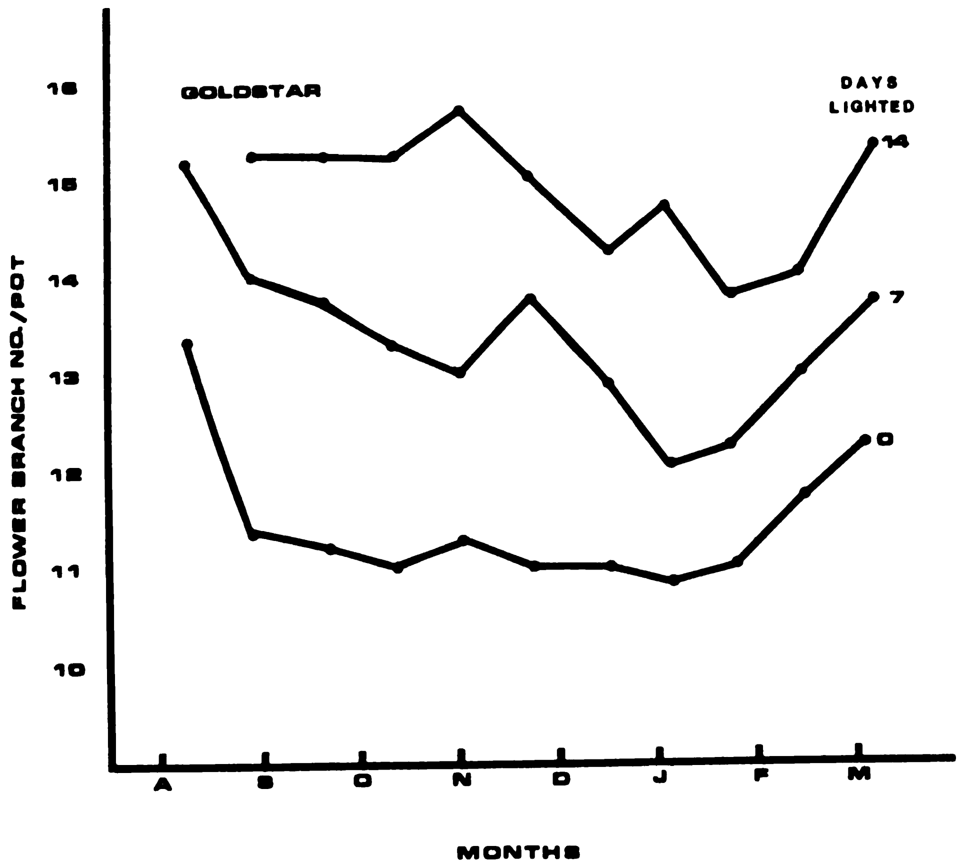

Figure 13.--No. of flowering branches per pot for cv. Goldstar comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, and 14 days after transplanting.

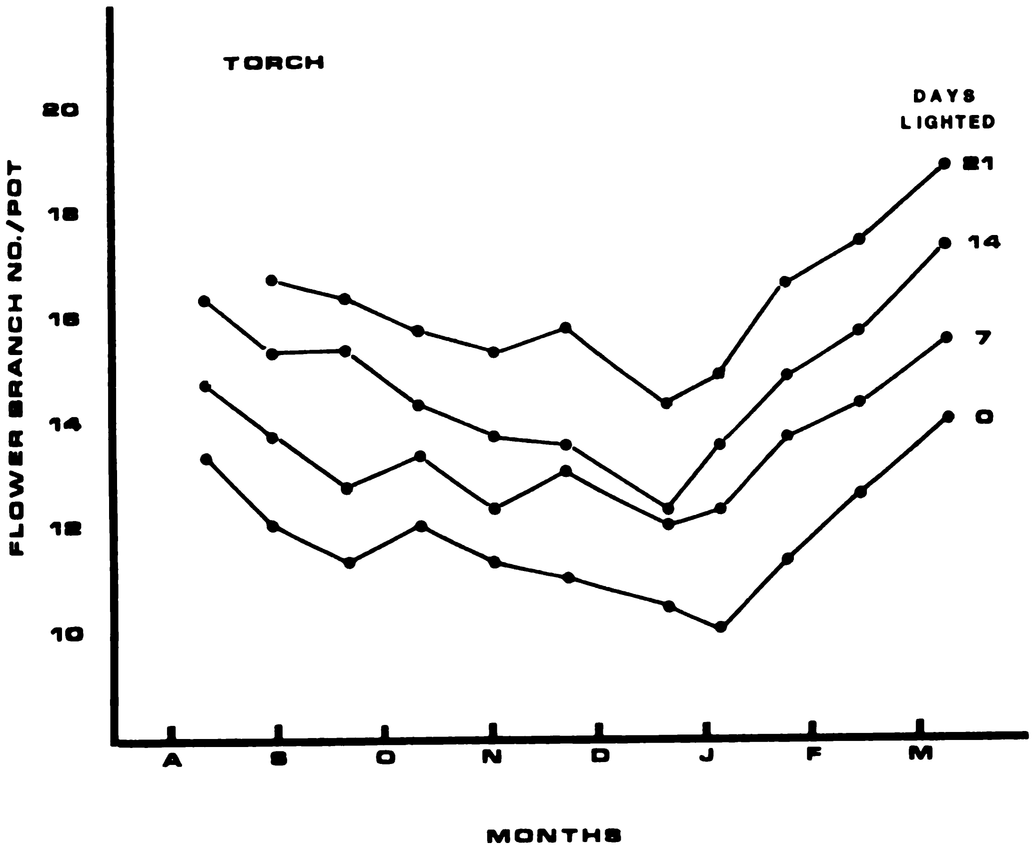

Figure 14.--No. of flowering branches per pot for cv. Torch comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, 14, and 21 days after transplanting.

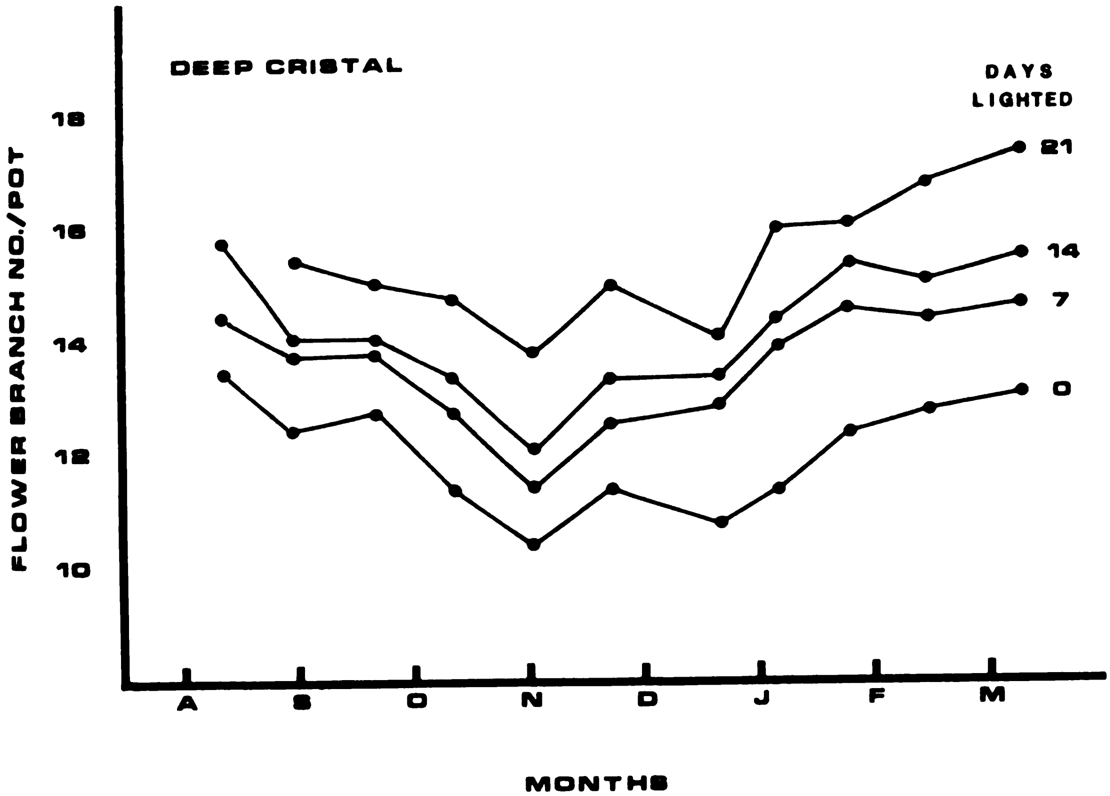

Figure 15.--No. of flowering branches per pot for cv. Deep Cristal comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, 14, and 21 days after transplanting.

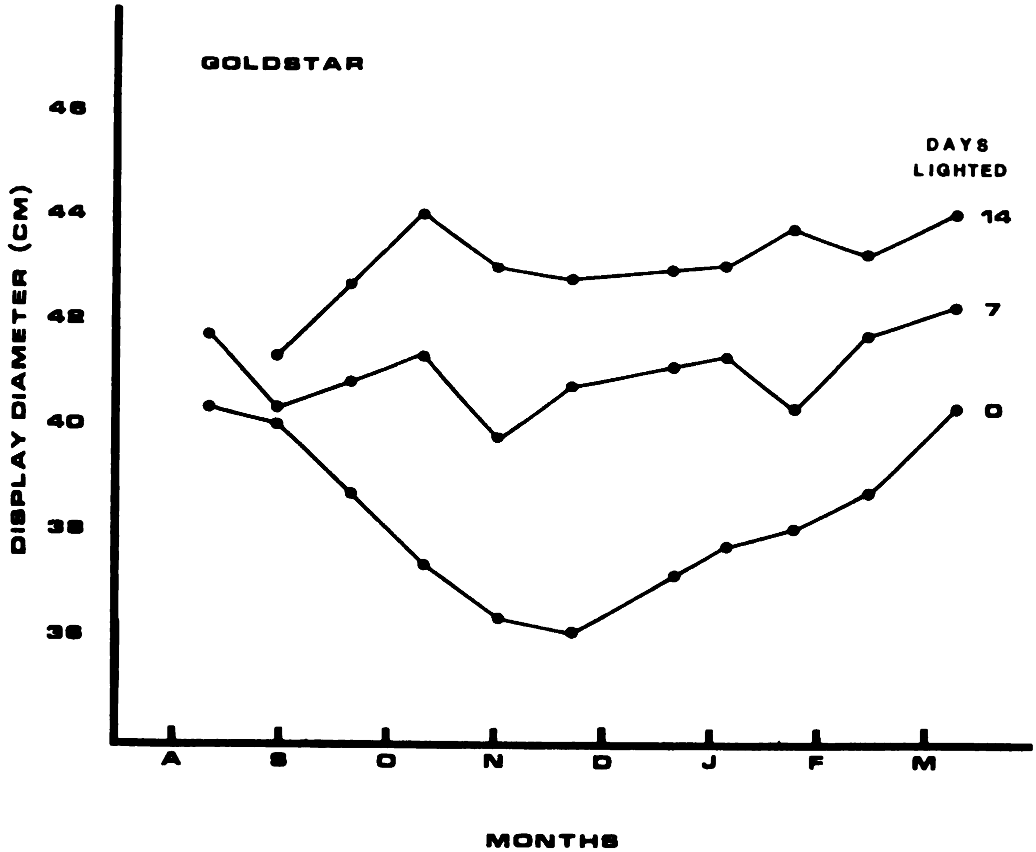

Figure 16.--Display diameter of cv. Goldstar comparing plants lighted 58 W/m2 with Lucalox lamps for 0, 7, and 14 days after transplanting.

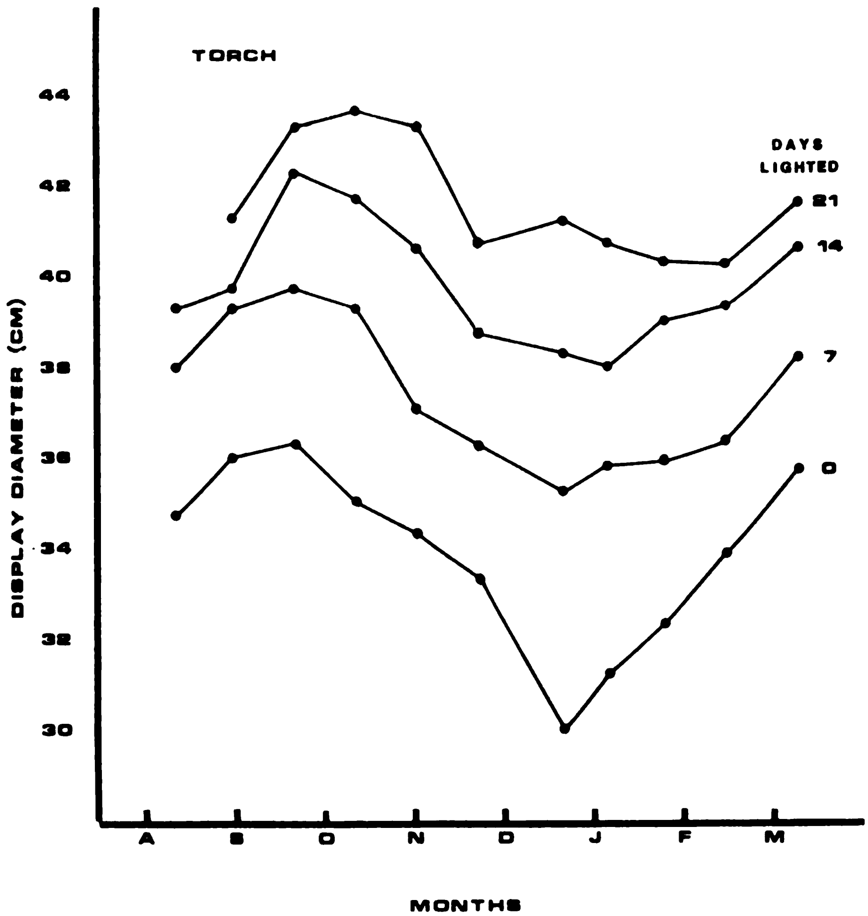

Figure 17.--Display diameter of cv. Torch comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, 14, and 21 days after transplanting.

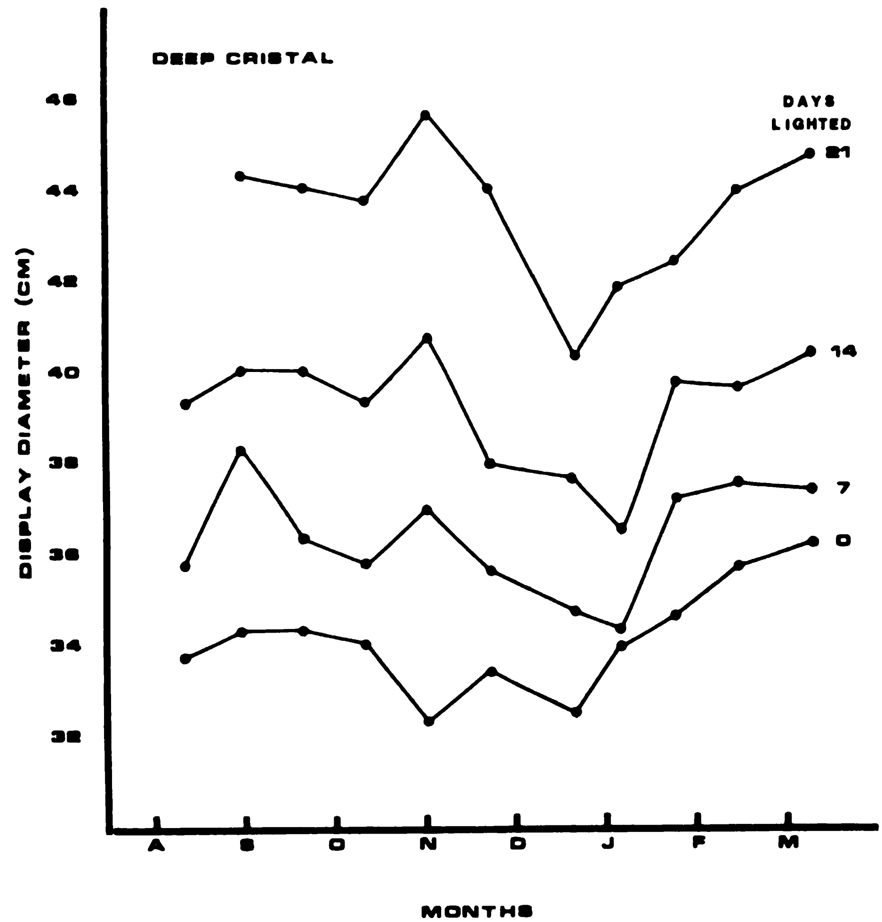

Figure 18.--Display diameter of cv. Deep Cristal comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, 14, and 21 days after transplanting.

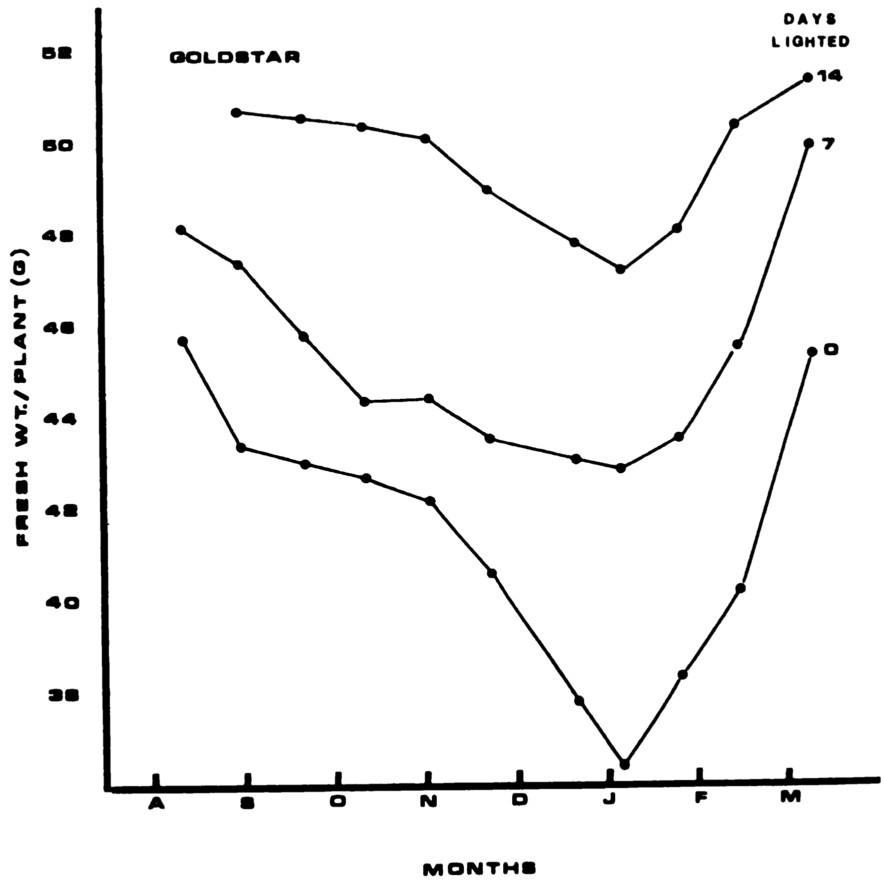

Figure 19.--Fr. wt of individual plants at flowering for cv. Goldstar comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, and 14 days after transplanting.

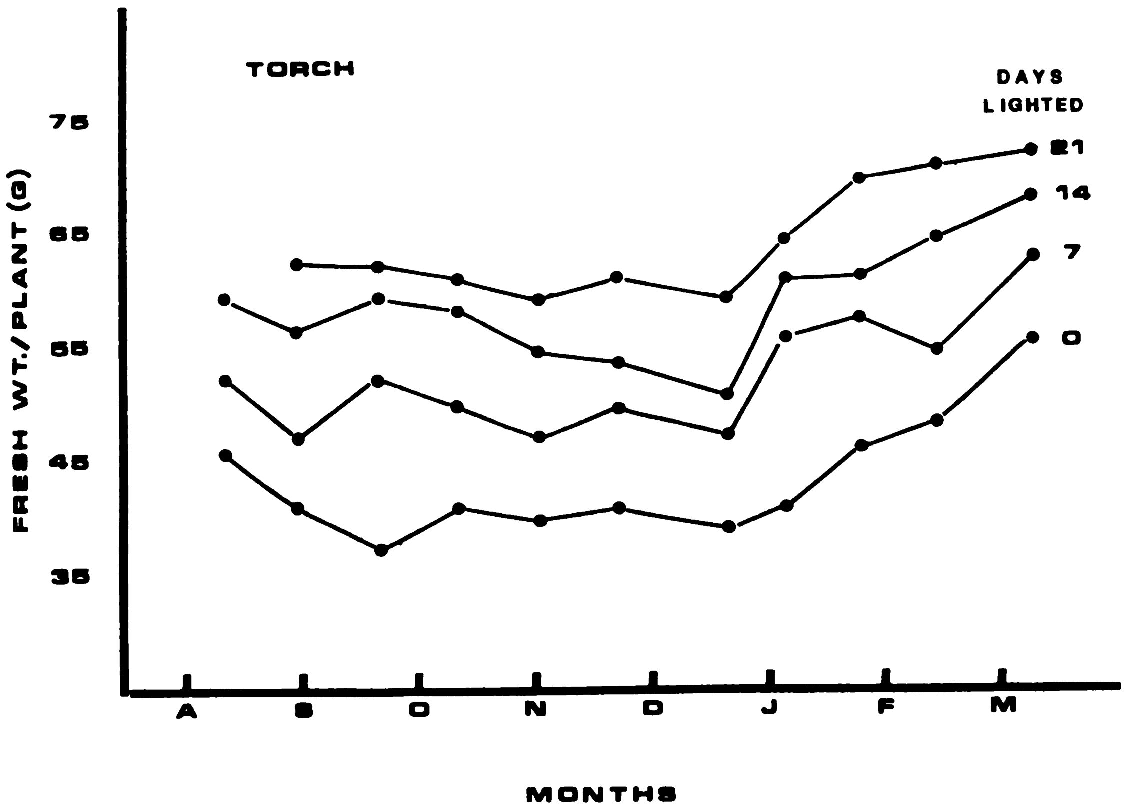

Figure 20.--Fr. wt of individual plants at flowering for cv. Torch comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, 14, and 21 days after transplanting.

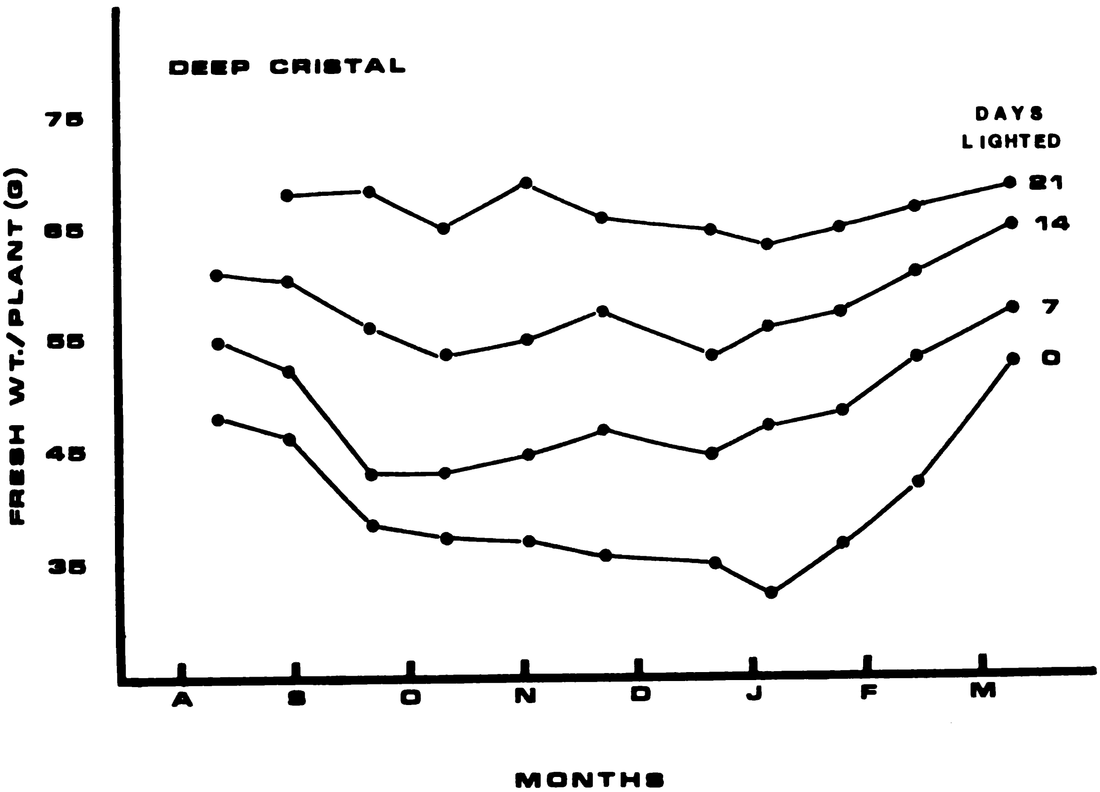

Figure 21.--Fr. wt of individual plants at flowering for cv. Deep Cristal comparing plants lighted 58 W/m^2 with Lucalox lamps for 0, 7, 14, and 21 days after transplanting.

All 3 cultivars lighted 14 or 21 days following potting from Sept. to Feb. developed into flowering plants with greater plant display diameter than those unlighted (Tables 11-13). Cv. Deep Cristal lighted 21 days between potting and SD treatment in Oct., Dec. and Feb. had floral display diameters 26%, 24% and 23% respectively greater than unlighted plants (unlighted plant means were: 34.0, 32.5 and 35.7 cm respectively).

Cv. Torch lighted 21 days after potting in Oct., Dec. and Feb. developed into flowering plants with plant display diameters of 43.6, 41.2 and 40.2 cm (a 25%, 37% and 19% increase over unlighted plants). Cv. Goldstar lighted 14 days between potting and SD treatment in Oct., Dec. and Feb. developed into plants with average plant display diameters of 44.0, 36.0 and 38.7 cm (an 18%, 18% and 12% increase over unlighted plants).

Weight of flowering plant. All 3 cultivars lighted Sept. through Mar. at 58 W/m^2 with Lucalox lamps for 14 to 21 days between potting and SD treatment developed into flowering plants of significantly greater fresh and dry weight than unlighted controls (Tables 11-13).

Cv. Deep Cristal lighted 21 days between potting and SD treatment in Oct., Dec. and Feb. developed into flowering plants with 74%, 84% and 60% respectively greater fresh top weight than unlighted plants (unlighted plant means were: 37.3, 34.7 and 41.4 g respectively).

Cv. Torch lighted 21 days after potting in Oct., Dec. and Feb. developed into flowering plants with top weights of 60.7, 59.2 and 69.4 g (a 50%, 53% and 48% increase over unlighted plants). Cv. Goldstar lighted 14 days between potting and SD treatment in Oct., Dec. and Feb. developed into plants with average fresh weights of 50.3, 48.9, and 50.3 g (an 18%, 30% and 25% increase over unlighted plants). Cvs. Deep Cristal and Torch lighted fewer than 21 days and cv. Goldstar lighted fewer than 14 days developed into flowering plants of intermediate fresh and dry weight between those lighted the full period between transplanting and short days and those not lighted (Figures 19-21).

Number and size of flowers. Chrysanthemum cultivars 'Goldstar,' 'Torch' and 'Deep Cristal' lighted 58 W/m^2 with Lucalox lamps between potting and SD treatment from Sept. through Mar. developed more flowers per 6 inch pot than those not lighted (Tables 11-13). Plants of cv. Goldstar lighted for 14 days in Nov. between potting and SD treatment produced an average of 15.3, 15.0 and 14.0 flowers per pot in Oct., Dec. and Jan. respectively (a 39%, 36% and 20% increase over unlighted plants). Increase in number of flowers per pot resulted in a larger floral display.

Cvs. Torch and Deep Cristal responded to lighting between potting and SD treatment with an increased flower number per pot (Figures 14 and 15). Cv. Torch lighted 21 days after potting in Oct., Dec., and Feb. developed into plants with 15.7, 14.3 and 17.4 flowers per pot respectively compared with 12.0, 10.4 and 12.6 respectively on unlighted plants. Cv. Deep Cristal lighted 21 days after potting in Oct., Dec. and Feb. developed into plants with 14.7, 14.0 and 16.0 flowers per pot respectively. This was approximately a 30% increase over unlighted controls. Plants lighted 7 and 14 days between potting and short days produced an intermediate number of flowers per pot between those plants lighted 21 days and unlighted controls.

The size of the individual flowers was unaffected by the lighting treatment. No significant difference in flower diameter was shown for any of the trials from Aug. through Mar. for cvs. Goldstar, Torch or Deep Cristal (Tables 11-13).

Discussion

The quality of pot chrysanthemum flowering from Oct. to May was increased when natural greenhouse light intensities from potting to short days were supplemented with Lucalox lamps at 58 W/m^2. Lighting improved pot mum quality by increasing plant display diameter resulting from a 20%-40% increase in number of flowering branches developing from the pinch (Figure 22). The development of 4 to 5 additional flowers per plant without a reduction in individual flower size was the principal factor in the improved floral display for lighted plants.

A stockier plant resulted from lighting due to a proportionately greater increase in fresh top weight than in top height. A 40%-50% increase in flowering branch diameter gave a sturdier plant with less need for support and better shipping quality.

A slight increase in plant height resulted from high intensity supplementary lighting with significance depending on cultivar and season. Lighted 'Torch' and 'Deep Cristal' had a greater increase in top height than lighted 'Goldstar.' 'Torch' and 'Deep Cristal' are classified as 'short' by growers because they require a longer vegetative period (long days) before SD treatment is begun than the more vigorous growing 'medium' or 'tall' cultivars. 'Goldstar' is classified as 'medium.' It may be that cultivars which normally grow slowly during the winter months show greater increases in height due to lighting than cultivars which normally grow more rapidly under natural greenhouse light conditions.

Slightly taller lighted plants with larger floral displays and dense dark green foliage are more appealing to consumers than the lower winter quality of unlighted plants. Winter 6 inch pot mum wholesale price can range

Figure 22.--Cv. Deep Cristal at bud development showing a plant lighted 58 W/m^2 for 3 weeks after transplanting (left) and an unlighted control (right).

Figure 22

from $1.75 to $2.25 depending upon plant quality and retail outlet. The higher quality plant resulting from lighting should bring the higher price and may even exceed it. Because of high lamp efficacies for Lucalox lamps and close spacing of pot mums during the first 3 weeks after potting, 21 days of light can be given pot mums for about 5 cents per pot. Although lighting results in a small increase in production costs (which may average about $1.35 per 6 inch pot during the winter months), the possibility of raising the wholesale price 50 cents should make installation of a Lucalox lighting system attractive to growers.

Increased quality of flowering chrysanthemums was related to the total radiant energy input during the vegetative growth period from potting to short days. Daily light input in the 380-700 nm band from the sun and Lucalox lamp in the greenhouse was calculated (Figure 23). This shows the ability of the Lucalox lamp to provide more total daily radiant energy than sunlight inside the greenhouse during the late fall, winter, and early spring months. This is due to low seasonal light levels, filtering by the greenhouse glass, and differences in daily duration of lighting (8-12 hours of daylight versus 24 hours of supplemental lighting).

Yield of greenhouse roses has been increased by increasing the total greenhouse light energy level with Lucalox lamps (54). Noesen and Spacil lighted 18 hours

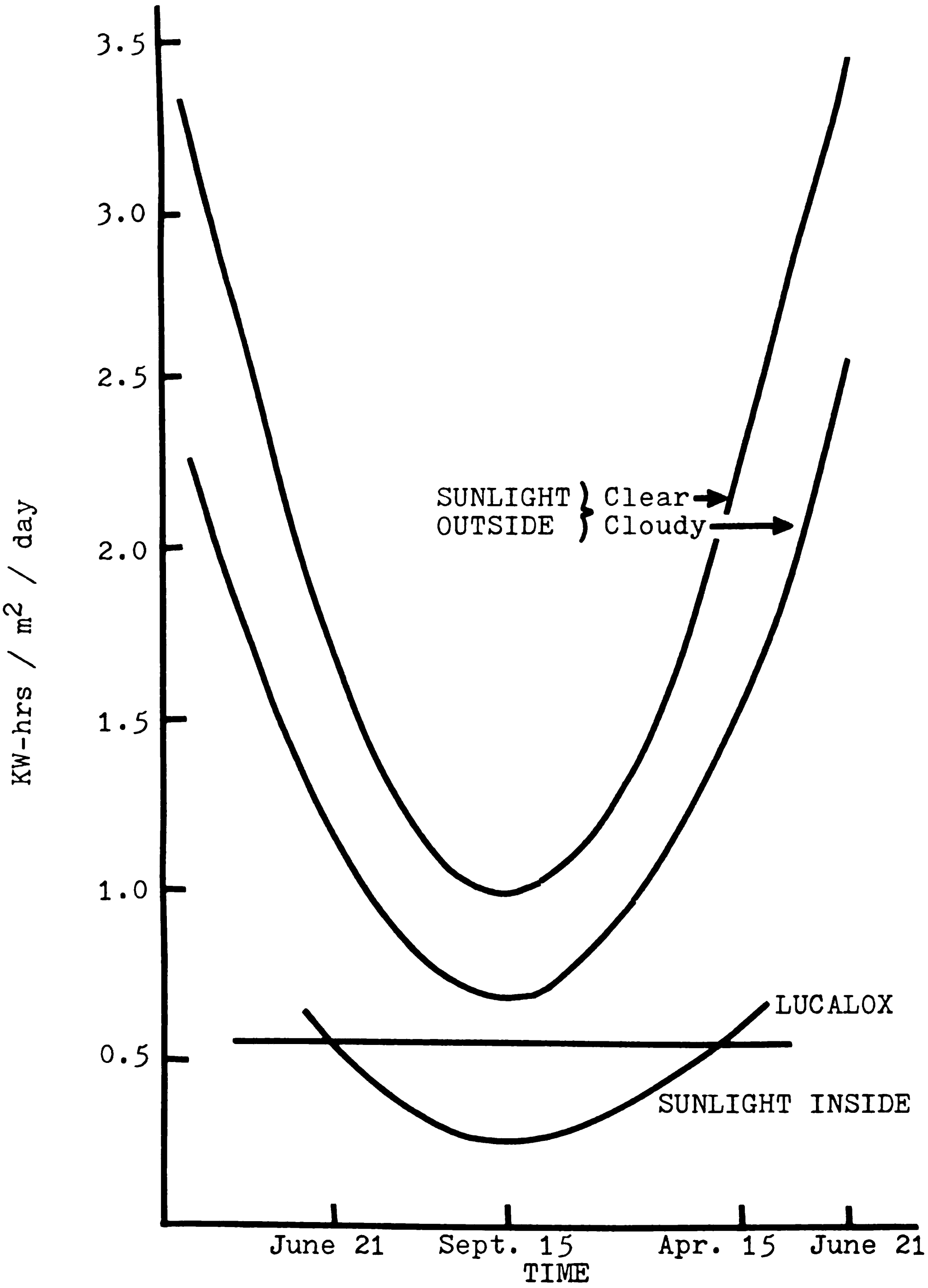

Figure 23.--Calculated daily natural light inputs outside the greenhouse for clear and typically cloudy days at East Lansing, Michigan, and natural and supplemental daily light inputs inside the greenhouse. Modified from Noesen and Spacil (54).

daily with Lucalox lamps, whose radiant energy approximated that of sunlight in the greenhouse, to double the total light energy input. This was correlated with a doubling of the yield of greenhouse roses. The improved quality of pot chrysanthemums may also be correlated with an increased total energy input in the greenhouse from supplemental lighting. This study has shown that factors which reflect plant quality at flowering, including number of flowers per plant, plant display diameter and fresh and dry plant weight, are increased by an increase in total energy input from natural daylight and Lucalox lamps during the period from potting to SD treatment.

SUMMARY

A study of high intensity supplementary lighting's effect on vegetative growth and flowering of pot chrysanthemum cultivars was made using high intensity discharge (HID) lamps. The separate and cumulative benefits of lighting plants as stock, during propagation, and after transplanting from Aug. to May were studied.

Chrysanthemum stock plants lighted continuously from Sept. to May with Multivapor and Lucalox lamps at 100 W/m^2 produced larger numbers of cuttings than those receiving only seasonal daylight and photoperiodic lighting. Cuttings from plants receiving high intensity lighting rooted in fewer days, had greater fresh and dry root weights, and greater top fresh weight than plants lighted only photoperiodically. After transplanting these cuttings became established more rapidly and developed into flowering plants of higher quality.

High intensity supplementary lighting at 116 W/m^2 during vegetative propagation of chrysanthemums from Oct. to Mar. reduced the number of days to root and increased root number, length and fresh weight over non-lighted cuttings. Lighting benefits were lost at 174 W/m^2 when

foliar chlorosis developed which delayed rooting and reduced root growth.

Benefits were similar from supplemental lighting at 116 W/m^2 with combined Lucalox and Multivapor lamps and 58 W/m^2 from Lucalox lamps. Increasing light intensity by adding the Multivapor lamp to the Lucalox does not significantly improve chrysanthemum growth and quality.

High intensity supplementary lighting of chrysanthemum plants after transplanting: (a) increased the plant display diameter because more branches developed from the pinch, (b) increased branch diameter resulting in a sturdier plant with less need for support and better shipping quality and (c) slightly increased plant height with significance depending on the cultivar. Slight additional benefits were observed when plants were also lighted during propagation and as stock plants. Increased quality of flowering pot chrysanthemums was related to the total radiant energy input during the vegetative growth period and during propagation.

High intensity supplemental lighting results in a larger floral display for lighted plants, increasing their beauty and retail value. The high efficiency of Lucalox lamps and the close spacing of pot chrysanthemums through the third week after transplanting should make commercial lighting economically feasible.

Future work with high intensity supplemental lighting might include an attempt to reduce the number of days to flower without reducing plant quality. This study showed rapid vegetative growth following transplanting. It may be possible to move the pinch and SD schedule ahead to produce a good quality plant in less time.

Another area not explored in this study is the possibility of producing pot chrysanthemums entirely under artificial light. Although exclusive use of artificial light does not utilize natural daylight, the environmental conditions of light, temperature, humidity and CO_2 could be more easily controlled with a substantial savings from reduced heat loss.

APPENDIX A

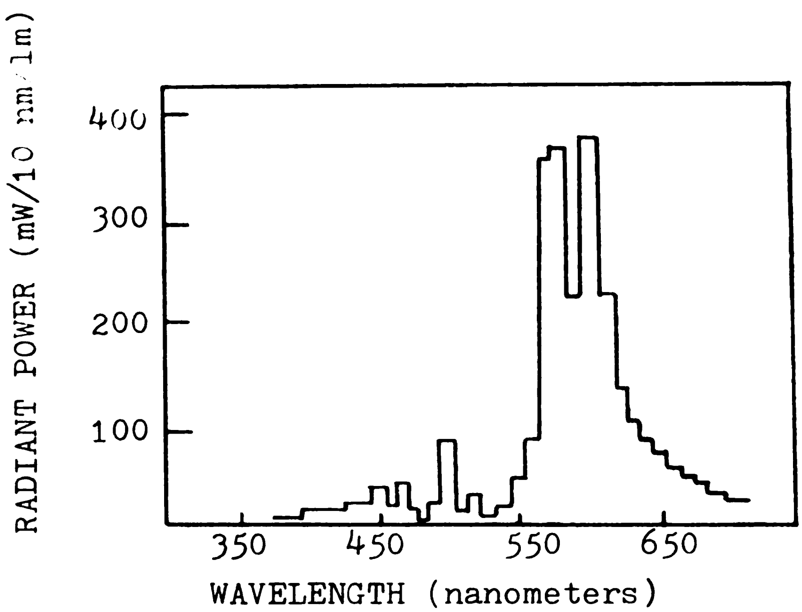

Figure A1.--Spectral distribution for typical 400-watt Lucalox lamps.

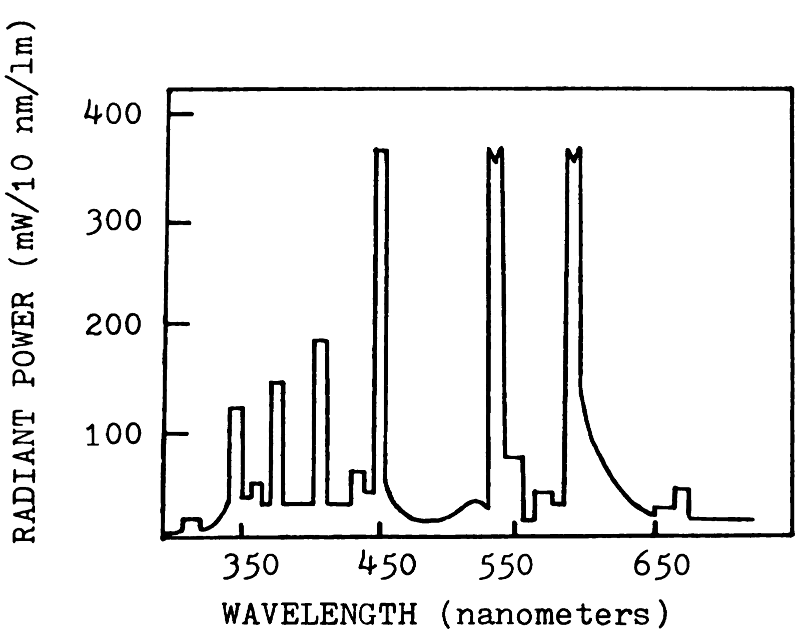

Figure A2.--Spectral distribution for typical 400-watt Multivapor lamps.

Figure A3.--HID luminaire showing mounting arrangement, ballast, and faceted reflector.

Figure A3

APPENDIX B

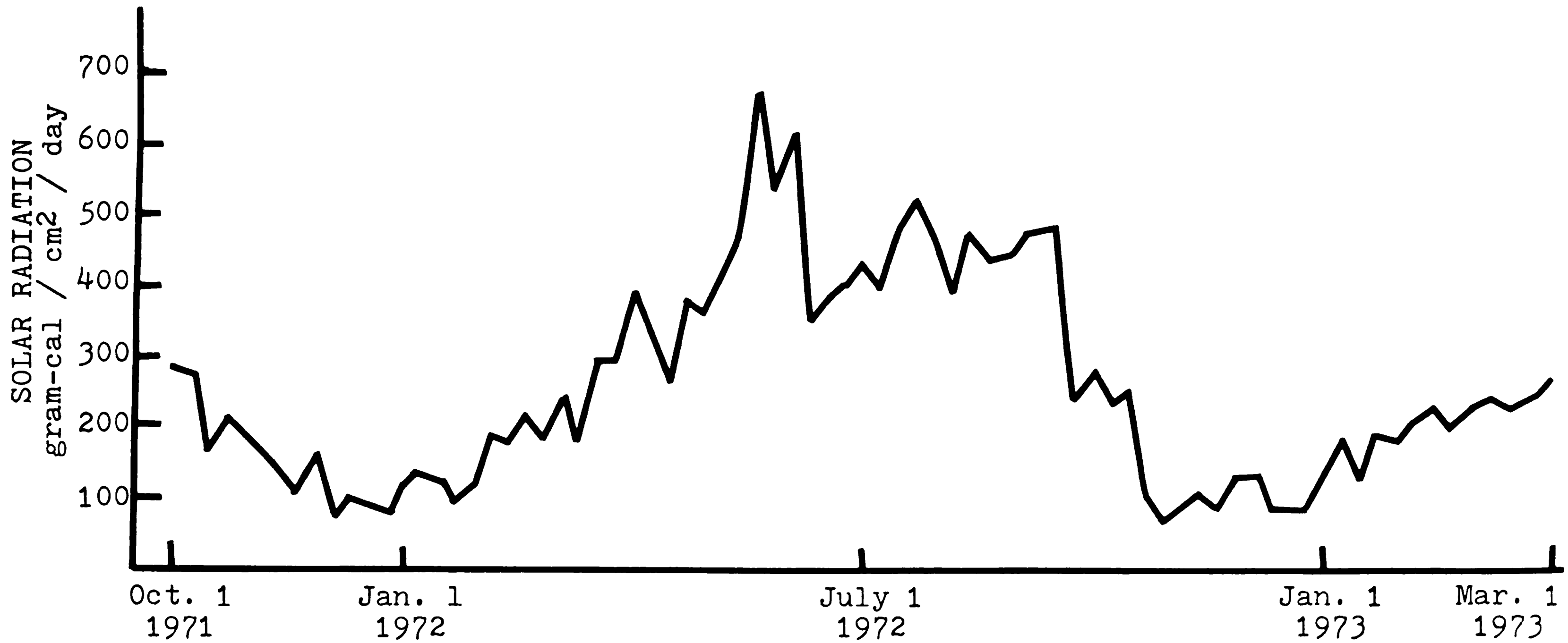

Figure B1.--Weekly mean solar radiation values for East Lansing, Michigan from Oct. 1971 to Mar. 1973.

DEFINITION OF TECHNICAL TERMS

Botanical

Chrysanthemum morifolium Ramat. belongs to the Compositae, a plant family having a flowering head which is made up of many small separate flowers clustered together. In accord with common horticulutral usage and for ease of reading, the flowering head has been referred to as a "flower" in this dissertation.

Electrical

A lighting installation can be described in terms of lamp watts per square meter (W/m^2). This information serves as a guide in lighting layouts planned without a light measuring device. The number of lamps required for a large area can be calculated, after the number of lamp watts per square meter is determined, using the formula:

$$\text{No. of lamps} = \frac{\text{Growing area } (m^2) \times \text{ required lamp } W/m^2}{\text{Individual lamp watts}}$$

APPENDIX C

The term luminous flux is given to the radiant energy evaluated according to its ability to produce a visual response. The unit of luminous flux is called the lumen, which is equal to the flux in a unit solid angle from a uniform point source of one candle. One candle is the unit of luminous intensity of a radiator producing one lumen per solid angle. The rate of luminous flux is often expressed in lumen-hours. If the luminous flux of one lumen is uniformly distributed on the area of one square foot, the illumination or unit of illuminance is one foot-candle (ft-c or fc).

The metric unit of work done at the rate of one joule per second is the watt. The lamp efficiency for both light sources in this dissertation is expressed in lumens per watt. With this information it is possible to relate the terminology used within this paper and that used by other authors.

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BIBLIOGRAPHY

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