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**ANNUAL REPORT**

**Year 1**
**Chrysanthemums: The influence of daylength extension and supplementary lighting during flower maturation on the winter quality of pot chrysanthemums.**

**HDC PC 92b**
**1995/96**

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ANNUAL REPORT SEPTEMBER 1996
YEAR 1

HDC PC92b

# Chrysanthemums: The influence of supplementary lighting, length of night and spacings on the quality and economics of the winter production of pot chrysanthemums

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Co-Ordinator: Mr D Abbott

Commenced: October 1995

Completed: March 1996

Key words: Chrysanthemum, photoperiod, daylength, supplementary lighting, tungsten lighting, spacing, flower quality, plant stature, plant quality

## RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

## APPLICATION

Three lines of investigation were followed to address the decline in quality of pot chrysanthemums during the winter. Photoperiod was manipulated by reducing length of night which held promise for improving quality. Techniques using assimilation lighting and tungsten lighting were successful and will be further evaluated in year two. Supplementary lighting for the last three weeks of short days produced significant improvements in final quality at marketing and during shelf-life. Closer spacing slightly increased production time and reduced pot spread and flower count however it was feasible to reduce pot spacing to offset the cost of providing supplementary lighting.

## SUMMARY


### i. Background and trial details

Despite considerable research effort into improving the winter quality of pot chrysanthemums, this issue remains a major concern to the commercial grower. Supplementary lighting throughout production so far has given the best solution to the problem but is used by few growers, largely due to the expense of such a treatment. Two lines of investigation were therefore followed to address the problems of winter quality with the economics of the solution in mind.

Firstly, the effect of photoperiod was considered. An 11 hour day and 13 hour night is widely accepted commercially as optimum for speed of production. Reducing length of night should delay production and in doing so increase the accumulation of assimilates by the plant via photosynthesis prior to reaching maturity and therefore improve final quality. Photoperiod or reduced night length treatments were therefore evaluated.

Secondly, the use of supplementary lighting for just a short period of production was assessed. The advantage of lighting for a part of the total production time only is that it is more economical. This approach is already taken by growers who light at high intensity during the early stages of production only, but this regime improves speed of production rather than quality. HDC funded work with spray chrysanthemums has indicated that lighting during the end of production only will improve quality. This approach was therefore evaluated for pot chrysanthemums.

Finally as the economics of providing supplementary lighting is always a problem for the commercial grower, spacing treatments were also assessed. Closer pot spacing will reduce the

cost of lighting each pot and has been assessed in previous HDC funded studies on pot chrysanthemums. Closer spacing was evaluated with the two most widely used types of lighting regime to confirm results found in previous trials.

The objectives of the trial were therefore as follows:

- To evaluate the potential for improving quality of commercially grown pot chrysanthemum varieties through reducing night length in combination with commonly used lighting regimes.

- To investigate the use of assimilation lighting on the flower maturation period of production to improve quality of a range of commercial varieties whilst minimising electricity running costs.

- To assess the influence of closer pot spacings on quality, production time, shelf-life and the economics of production.

The influence of photoperiod was assessed using the three most commonly used lighting regimes in current commercial use i.e.:

a, no supplementary lighting
b, 4.8 $W/m^2$ throughout short days
c, 12 $W/m^2$ during weeks 1 - 3 of short days only.

Wherever supplementary lighting was in use, length of night was reduced by extending the length of lighting period given by the high pressure sodium lamps. Hence the following lighting periods were used:

| **Photoperiod treatment** | **Lighting interval using high pressure sodium lamps** |
|---|---|
| 11 hour day, 13 hour night | 0700 - 1800 hrs |
| 11.5 hour day, 12.5 hour night | 0700 - 1830 hrs |
| 12 hour day, 12 hour night | 0700 - 1900 hrs. |

Wherever supplementary lighting was not in use, length of night was reduced by turning on tungsten lighting at dusk and keeping it on until the following times:

| **Photoperiod treatment** | **Lighting interval using tungsten lights** |
|---|---|
| 11 hour day, 13 hour night | dusk - 1800 hrs |
| 11.5 hour day, 12.5 hour night | dusk - 1830 hrs |
| 12 hour day, 12 hour night | dusk - 1900 hrs. |

Two lighting intensities were compared with no supplementary lighting to evaluate the effectiveness of lighting at the end of short days only, as follows:

a, No supplementary lighting throughout

b, 4.8 $W/m^2$ during weeks 7, 8 and 9 of short days only

c, 12 $W/m^2$ during weeks 7, 8 and 9 of short days only.

To evaluate the impact of closer pot spacing the following treatments were compared:

| | | |
|---|---|---|
| 'Standard' spacing | = | 27 $pots/m^2$ intermediate spacing<br>13.5 $pots/m^2$ final spacing |
| 'Close' spacing | = | 32 $pots/m^2$ intermediate spacing<br>16 $pots/m^2$ final spacing. |

These two spacing treatments were evaluated for three lighting regimes which were:

No supplementary lighting
4.8 $W/m^2$ throughout production
12 $W/m^2$ during weeks 1 - 3 of short days only.

## ii. Results

The impact of photoperiod on total production time varied with lighting regime in use. Reducing night length of pots grown using 4.8 $W/m^2$ supplementary lighting throughout short days increased production time as expected. On the whole however these delays were small and of the order of two to three days. There were no delays in production time recorded however when either no supplementary lighting or lighting at 12 $W/m^2$ was given for the first three weeks of short days only. In fact production time actually decreased as night length was reduced using tungsten lighting on the pots grown without supplementary lighting. This unexpected result will be more fully investigated in the second year of the trial.

Despite the unusual production time results, records of vegetative growth (i.e. plant height and spread) indicate small increases as a result of reducing night length. The greatest effect was observed where reduced night length was combined with supplementary lighting at 12 $W/m^2$ weeks 1 - 3 SDs. Shorter nights also apparently increased bud count of plants given supplementary lighting at 12 $W/m^2$ weeks 1 - 3 SDs. These slight improvements in visual quality at marketing were maintained during the shelf-life period giving enhanced quality during shelf-life but no significant decrease in rate of deterioration during shelf-life.

Providing supplementary lighting during bud maturation (i.e. the last three weeks of short days) had a significant impact on visual quality. Improved foliage quality and petal colour were both observed with lighting at higher intensity (12 $W/m^2$) giving the most outstanding results. Increases in the number of buds and flowers produced per pot also resulted from providing supplementary lighting during flower maturation.

A slight reduction in production time also resulted from supplementary lighting at the end of short days. The greatest impact was found for plants developing flowers when solar radiation levels were poor (i.e. pots stuck in week 41 and week 45) and with the 12 $W/m^2$ weeks 7 - 9 treatment which reduced production time by about 3 days.

The benefits of these treatments recorded at marketing were found to continue during the shelf-life period giving enhanced visual quality throughout shelf-life. The improved petal colour held well during shelf-life, but as some flowers opened within the shelf-life environment the centre petals were pale in colour as they expanded.

Assessment of pot spacing confirmed the results of earlier trials. That is, closer spacing results in slight delays in production time (around 2 days) and slight decreases in pot spread and bud count. These factors would need to be assessed against the savings achieved in providing supplementary lighting to each pot. Pots grown using 4.8 $W/m^2$ supplementary lighting and close spacing were clearly superior to pots grown at standard spacing without supplementary lighting. Closer spacing did not significantly increase rate of deterioration in shelf-life testing.

## iii Conclusions

- Reducing night length is a promising technique for improving quality.

- This technique will be evaluated further in year two.

- Supplementary lighting when buds are developing and maturing into flowers provides a significant improvement in quality which gives enhanced visual pleasure at marketing and through shelf-life.

- Closer spacing may be used to reduce the cost of providing supplementary lighting, but individual growing systems must be carefully considered when decreasing the space available to individual pots.

## EXPERIMENTAL SECTION

## INTRODUCTION

Winter quality remains a key issue for the all year round pot chrysanthemum grower. Supplementary lighting regimes have been studied through HDC funded research over the winter period, identifying regimes which can improve quality and speed of production. To date significant improvements in winter quality require that supplementary lighting is used throughout the short day period which is of course expensive in terms of running costs.

HDC funded work (Wilson, 1995) has demonstrated that improvements in flower quality and shelf-life can be achieved through lighting at high intensity at the end of the short day period (or during flower maturation) but this treatment was combined with lighting at lower intensity for the remainder of short days. The potential of high intensity lighting during flower maturation alone has been demonstrated through HDC funded work on AYR spray chrysanthemums at HRI Efford in 1994/95 (Wilson, 1996) with improvements in petal colour and foliage quality recorded. It is therefore possible that lighting pot chrysanthemums during flower maturation alone may offer a suitable alternative to current 'best' lighting regimes. Along with ensuring good quality, sales of pot chrysanthemums in the winter period may also be improved if a wider range of varieties were available. At present, a number of summer grown varieties are unavailable for marketing in the winter due to questionable quality at this time of year. It is therefore important to assess 'end of short days' lighting treatments on both standard winter varieties such as Charm as well as other less common varieties in winter such as Akron and Miramar.

Another method for improving winter quality may be to extend the period of production, and hence total period of assimilation, by delaying maturity. One method of achieving such a delay is through decreasing the period which the plant perceives as night time. The standard night length used for maximum speed of flowering in the commercial production of pot chrysanthemums is 13 hours. Research in Holland has examined night length manipulation in winter for spray chrysanthemums and has demonstrated potential fresh weight increases (van der Hoeven, 1995). In winter, night length increases above even the standard 13 hours. Dutch growers may readily impose reduced night length treatments at this time of year as they generally have assimilation lighting available with which daylength can be increased. A majority of U.K. pot chrysanthemum growers may already have assimilation lights installed following recommendations from previous studies on assimilation lighting. Since there are also pot chrysanthemum growers without assimilation lighting available however, studies on reducing night length will be combined with production without assimilation lighting (but using tungsten lights to reduce night length) as well as with lighting at the two standard lighting regimes recommended in previous work.

Finally, closer pot spacing would increase throughput per square metre and offer a method for improving the economics of using supplementary lighting in the winter period. Observations in HDC funded work at HRI Efford in 1993/94 (Wilson, 1994) as well as more detailed studies in 1994/5 (Wilson, 1995) have indicated that closer spacing can be achieved but with small penalties in terms of total production time, pot spread and number of flowers. It is necessary however to repeat these studies to verify these findings, particularly as it was felt that plant vigour may have been slightly reduced in the 1994/95 studies.

Hence this report examines work on the effects of supplementary lighting during flower maturation, extended daylength and pot spacing to optimise on quality whilst reducing lighting costs and maximising returns in terms of throughput of pots.

## OBJECTIVES

The objectives were:

1) To evaluate the potential for improving the quality of commercially grown pot chrysanthemum varieties through extended daylength in combination with a range of lighting regimes.

2) To investigate the use of assimilation lighting on the flower maturation period of production only as a method to improve winter quality of a range of commercial varieties whilst minimising electricity running costs.

3) To assess the influence of closer pot spacings on quality, production time, shelf-life and the economics of production.

# MATERIALS AND METHODS

## 1. Treatments

### 1.1 The influence of night length treatments on winter quality

Supplementary lighting regimes and night length treatments were combined as follows:

| | | |
|---|---|---|
| No supplementary lighting | x | * Natural night |
| No supplementary lighting | x | 13 hour night |
| No supplementary lighting | x | 12.5 hour night |
| No supplementary lighting | x | 12 hour night |
| | | |
| 4.8 $W/m^2$ throughout SD | x | 13 hour night |
| 4.8 $W/m^2$ throughout SD | x | 12.5 hour night |
| 4.8 $W/m^2$ throughout SD | x | 12 hour night |
| | | |
| 12 $W/m^2$ weeks 1-3 SD only | x | * Natural night |
| 12 $W/m^2$ weeks 1-3 SD only | x | 13 hour night |
| 12 $W/m^2$ weeks 1-3 SD only | x | 12.5 hour night |
| 12 $W/m^2$ weeks 1-3 SD only | x | 12 hour night |

* The natural length of night varied from a minimum of 13½ hours to a maximum of 16 hours during these studies.

Where pots were receiving supplementary lighting (i.e throughout SD for the 4.8 $W/m^2$ treatment or during the first three weeks of SD for the 12 $W/m^2$), photoperiod treatments were achieved as follows:

| | | |
|---|---|---|
| 13 hour night | - | Luminaires on 0700-1800 hrs daily |
| 12.5 hour night | - | Luminaires on 0700-1830 hrs daily |
| 12 hour night | - | Luminaires on 0700-1900 hrs daily |

Where pots were not receiving supplementary lighting (i.e. throughout SD for the no supplementary lighting treatment or from week 4 of SD onwards for the 12 $W/m^2$ treatment), the night length treatments were achieved as follows:

| | | |
|---|---|---|
| * Natural night | - | Blackout from dusk to 0700 hrs daily |
| 13 hour night | - | Tungsten lighting from dusk to 1800 hrs daily |
| 12.5 hour night | - | Tungsten lighting from dusk to 1830 hrs daily |
| 12 hour night | - | Tungsten lighting from dusk to 1900 hrs daily |

**Varieties:** Charm and Cerise About Time

### 1.2 The influence of supplementary lighting during bud maturation on winter quality

Lighting at low (4.8 W/m$^2$) and high (12 W/m$^2$) intensity during the last three weeks of short days was compared with no supplementary lighting on five varieties of pot chrysanthemums as follows.

Supplementary lighting regimes:

No supplementary lighting throughout short days
4.8 W/m$^2$ during weeks 7, 8 and 9 of short days only
12 W/m$^2$ during weeks 7, 8 and 9 of short days only

**Varieties:** Charm, Cerise About Time, Yuba, Miramar and Akron

### 1.3 The influence of supplementary lighting and spacing on winter quality

Spacing was examined in combination with the standard lighting regimes of:

No supplementary lighting
4.8 W/m$^2$ throughout short days
12 W/m$^2$ during weeks 1-3 of short days

Standard and close pot spacings were compared as follows:

| | | |
|---|---|---|
| Standard spacing | - | 27 pots/m$^2$ intermediate spacing<br>(19.2 cm from pot centre to centre)<br>13.5 pots/m$^2$ final spacing<br>(27.2 cm from pot centre to centre) |
| Close spacing | - | 32 pots/m$^2$ intermediate spacing<br>(17.8 cm from pot centre to centre)<br>16 pots/m$^2$ final spacing<br>(25.0 cm from pot centre to centre) |

**Varieties:** Charm and Cerise About Time

## 2. Cultural details

### 2.1 Plant material

Unrooted cuttings of Charm, Yuba, Miramar and Akron were purchased from Yoder Toddington Limited (raised in Kenya).

Unrooted cuttings of Cerise About Time were purchased from Ficor Limited (raised in Brazil).

### 2.2 Propagation (long days)

Cuttings were stuck in Levington M2 compost in 140 mm half pots (14D) with five cuttings stuck in each pot. Bottom heating was applied to achieve a compost temperature of 20°C. After sticking, pots were covered with clear polythene which remained in place for 10 days before weaning the plants off. Night break lighting during the long day period (18 days from sticking) was supplied for 5 hours per night from 2230 to 0330 hrs using tungsten lamps (15 minutes on, 15 minutes off cycle) at 0.54 $W/m^2$ at plant height.

### 2.3 Short day environment

Heating set points were adjusted according to ambient conditions and lighting regimes to achieve equivalent averages in all compartments and a minimum of 18°C day and night in all compartments. Venting set points were also adjusted to achieve comparable temperature across all treatment compartments but were set in the region of 23°C.

Thermal screens and blackout covers were drawn across at 1800 hrs or dusk (whichever was earlier) daily and removed at 0700 hrs daily. Note, lighting treatments were given below blackout screens where necessary.

$CO_2$ enrichment was given to maintain levels to 1000 vpm when the vents were less than 5% open and to 500 vpm with vents at or above 5% open using pure $CO_2$.

## 2.4 Growth regulation

Plants were pinched back to 7 to 8 leaves when the growing tip was of sufficient size to handle.

Daminozide (as B-nine) was used to control plant height. Frequency and rate of application was tailored to each variety and its vigour under the different treatment regimes as follows:

| | Charm | Cerise About Time | Akron | Miramar | Yuba |
|---|---|---|---|---|---|
| **1. 24/48 hours after sticking (when cuttings are turgid):** | | | | | |
| | 0.75 g/l | 0.75 g/l | 0.75 g/l | none | none |
| **2. When breaks are 1.5-2.0 cm long:** | | | | | |
| | 2.50 g/l | 1.50 g/l | 1.50 g/l | 1.00 g/l (if required) | 1.50 g/l |
| **3. 7-10 days after 2 above (week 41 stick) or 10-14 days after 2 above (week 45 and 48 stick):** | | | | | |
| | 2.25 g/l (if required) | 1.50 g/l (if required) | 1.50 g/l (if required) | none | none |
| **4. 7 days after 3 above:** | | | | | |
| | 1.50 g/l (if required) | none | none | none | none |

(where g/l refers to concentration of formulated product.)

## 2.5 Pot spacing

Except for pots receiving spacing treatments as described above, pots were spaced at 41 pots/$m^2$ (i.e. pot thick) during the 18 day propagation period. On moving to the short day environment, pots were spaced at 27 pots/$m^2$ (19.2 cm from pot centre to centre) for the first 14 short days and were then moved to 13.5 pots/$m^2$ (17.8 cm from pot centre to centre) final spacing.

## 2.6 Nutrition

Liquid feeding commenced at the start of short days and continued at each irrigation. The dilute feed applied contained 300 mg/l N : 60 mg/l $P_2O_5$ (26 mg/l P) : 250 mg/l $K_2O$ (207 mg/l K).

### 2.7 Pest and disease control

A routine, preventative spray programme was maintained against Western Flower Thrips alternating the insecticides malathion (as MTM Malathion 60 at 1.8 ml/l), endosulfan (as Thiodan at 2 ml/l) and dichlorvos (as Nuvan 500 EC at 1 ml/l). Additional treatments included iprodione (as Rovral at 5 g/l) and *Verticillium lecannii* (as Mycotal at 1 g/l and Vertilec at 2 g/l).

## 3. Assessments

Pots were assessed at marketing stage three as defined in the pot chrysanthemum poster (i.e. 12 flowers all just bending outwards, 50% of petals at least 20 mm long). The following parameters were recorded:

i. Time taken to reach marketing stage three.

ii. Height of each plant in the pot to assess average plant height and uniformity of the pot.

iii. Maximum and minimum pot spread.

iv. Flower development recorded as separate figures of number of developing buds (i.e. bud stages 1-3 as defined by Cockshull and Hughes, 1972) and number of open buds (i.e. bud stages 4 and over as defined by Cockshull and Hughes, 1972).

v. Extent of leaf damage through a qualitative score based on severity of damage. That is, score 0 = no damage to score 3 = severe damage.

The effects of treatments on the keeping quality of pots were also assessed during a simulated shelf-life period. This included sleeving and boxing plants for holding in cold store (at 8 °C) for three days in darkness. Plants in sleeves were moved on the fourth day to a room lit with fluorescent lighting. After four days in this environment, sleeves were removed. Pots were then assessed for deterioration at regular intervals over a 4 week period as follows:

i. Pot deterioration score, where a qualitative score was assigned according to the overall condition of the pot. Score 0 = no deterioration, score 1 = minor deterioration (i.e. the first signs of deterioration beginning to show), score 2 = moderate deterioration and score 3 = severe deterioration (i.e. the pot would no longer be kept on display by the consumer).

ii. Leaf quality score using the same qualitative scores as for marketing records described above.

iii. Extent of flower development, recorded as number of open flowers (i.e. bud stages 4+) per pot.

iv. Extent of flower distortion, recorded as number of distorted flowers per pot to indicate where flowers were unable to open up properly.

Since records commenced after sleeves were removed from the pots, each weekly record corresponded to the following number of days in shelf-life:

| | | |
|---|---|---|
| Record 1 | = | 3 days in cold store + 4 days in sleeves |
| | = | 7 days from marketing |
| Record 2 | = | 14 days from marketing |
| Record 3 | = | 21 days from marketing |
| Record 4 | = | 28 days from marketing |

Pots were also inspected daily to produce an accurate figure of number of days taken to reach each of the deterioration stages noted above.

Additional records included:

- Analysis of growing media eight weeks after the start of short days.
- Continual monitoring of compartment environments and solar radiation levels.
- Photographs and observations as appropriate.

## 4. Statistical analyses

Analysis of variance was carried out to assess the significance of treatment effects on the data collected. Replication of treatments was based on time (stick dates) and varieties. Effects examined included night length treatments and their interaction with supplementary lighting regime, supplementary lighting at the end of short days treatments and their interaction with variety along with their comparison with standard lighting regimes, and spacing. Main effects will be presented as figures meaned across variety, sticking date and in some cases also night length, spacing or lighting treatment, depending on the comparison in question. The use of these means increases the power of the tests enabling more detailed analysis of the data. Individual treatment means are however presented graphically in the appendices so that results for different varieties and sticking dates can be examined independently with the main observations in mind from the statistical analyses.

Standard deviation of both plant height and maximum bud stage per pot were also analysed to indicate variability per pot relative to treatment (where a small standard deviation indicates greater uniformity).

Statistical terms used include:

| | |
|---|---|
| N.S. | Not significant |
| S.E.D. | Standard error of differences of means |
| L.S.D. | The least (minimum) difference when comparing two means within a given data set that is required for the means to be statistically different. |
| * | $P<0.05$, i.e. the probability of this result occurring by chance is equal to or less than 1 in 20 (0.05 = 5%). |
| ** | $P<0.01$, i.e. the probability of this result occurring by chance is equal to or less than 1 in 100 (0.01 = 1%). |
| *** | $P<0.001$, ie the probability of this result occurring by chance is equal to or less than 1 in 1000 (0.001 = 0.1%). |

## RESULTS AND DISCUSSION

Key observations from statistical analyses will be presented in the following section and hence data will represent means across various factors such as sticking date, variety, night length treatments, lighting regimes, etc. To supplement this information, individual treatment means are represented graphically in the appendices, to allow comparison of trends for each sticking date and variety.

### 1. The influence of night length treatments on winter quality.

### 1.1 Vegetative development and flower production.

#### 1.1.1 Production time (number of days from sticking to marketing).

a. Night length

Night length had a significant (**) influence on production time for data meaned across lighting regimes. The trend for this data is unexpected with the longest production time resulting from a 12.5 hour night length and no significant difference in production time of the 13 and 12 hour nights.

Mean number of days from sticking to marketing

| | **Night length** | |
|---|---|---|
| **13 hrs** | **12.5 hrs** | **12 hrs** |
| 81.1 | 82.2 | 80.9 |

S.E.D. = 0.252, L.S.D. (P = 0.05) = 0.58

This trend in fact appears to be a result of the interaction between night length and lighting regime discussed below.

b. Supplementary lighting regime

As found in previous trials (e.g. Finlay, 1993), supplementary lighting significantly (***) influenced production time. The longest production time resulted from no supplementary lighting. Lighting at 12 W/m$^2$ weeks 1-3 SD gave the biggest reduction in production time of 4.3 days averaged over varieties, sticking dates and night length treatments. Lighting at 4.8 W/m$^2$ throughout SD also gave an average reduction in production time of 1.8 days compared with no supplementary lighting.

Mean number of days from sticking to marketing

| No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD |
|---|---|---|
| 83.4 | 81.7 | 79.1 |

S.E.D. = 0.252, L.S.D. (P = 0.05) = 0.58

c. Night length x supplementary lighting regime

There was also a significant (***) interaction between night length and supplementary lighting as follows:

Mean number of days from sticking to marketing

| Night length | No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD |
|---|---|---|---|
| ND | 85.8 | - | 79.2 |
| 13 hrs | 84.2 | 80.0 | 79.2 |
| 12.5 hrs | 84.2 | 83.2 | 79.1 |
| 12 hrs | 81.2 | 81.9 | 78.9 |

S.E.D. = 0.616, L.S.D. (P = 0.05) = 1.42

In agreement with the mean data for lighting regime discussed above, the shortest production time resulted from lighting at 12 W/m$^2$ weeks 1-3 SD but lighting at 4.8 W/m$^2$ throughout SD also reduced production time compared with no supplementary lighting. Response to night length however varied with lighting regime.

Night length had no significant influence on the production time of the 12 W/m$^2$ weeks 1-3 SD lighting regime. For lighting at 4.8 W/m$^2$ throughout SD, production time was significantly increased by 12.5 and 12 hour nights compared with the standard 13 hour night length. There was however, no significant difference between the 12.5 and 12 hour treatments for this lighting regime. Reducing night length had the opposite effect on the production time of plants grown without supplementary lighting. Night lengths of 13 and 12.5 hours significantly reduced production time by an average of 1.6 days compared with natural day length. The shortest production time resulted from the 12 hour (or shortest) night length treatment which was, on average, 4.6 days faster than the 'standard' or natural day length treatment.

To summarise, the fastest of the 'standard' lighting regimes assessed (12 W/m$^2$ weeks 1-3 SD) was not significantly affected by reducing night length. Reducing night length using a longer period of assimilation lighting in the case of the 4.8 W/m$^2$ throughout SD regime had the expected result of significantly increasing production time. Reducing night length using tungsten lighting after dusk for plants receiving no supplementary lighting unexpectedly reduced production time.

It should be noted at this point that the use of tungsten lighting to either 1800 hrs, 1830 hrs or 1900 hrs would not, as planned, have produced the night lengths desired. This is because treatments did not account for the delay in sunrise, which in the depths of the winter, was later than 0700 hrs (i.e. the time from which the night lengths were calculated). This may, in part, account for the fact that significant delays did not occur as a result of even the shortest night length treatment. It is however difficult to explain why such treatments should significantly decrease production time.

The 4.8 W/m$^2$ throughout SD lighting regime was, in contrast, much more precise in the timing of the night and day periods since the luminaires were turned on continuously for either 11, 11.5 or 12 hours, and this treatment also produced the expected delay in reaching maturity.

The questions arising from these differences will be further addressed in the second year of the trial.

d. Night length x supplementary lighting regime x sticking data

There was also a significant (***) interaction between sticking date and the response of production time to night length and supplementary lighting.

Mean number of days from sticking to marketing

| **Night length** | **No supplementary lighting** | | | **4.8 W/m$^2$ throughout SD** | | | **12 W/m$^2$ weeks 1-3 SD** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **41** | **45** | **48** | **41** | **45** | **48** | **41** | **45** | **48** |
| ND | 82.4 | 90.4 | 84.7 | - | - | - | 79.9 | 81.4 | 76.2 |
| 13 hrs | 82.4 | 87.0 | 83.3 | 78.0 | 82.9 | 79.0 | 79.4 | 82.0 | 76.4 |
| 12.5 hrs | 82.0 | 86.4 | 84.3 | 79.7 | 87.5 | 82.5 | 79.3 | 81.5 | 76.5 |
| 12 hrs | 80.8 | 83.5 | 81.2 | 80.3 | 85.2 | 80.2 | 79.5 | 81.0 | 76.3 |

S.E.D. = 0.616, L.S.D. (P = 0.05) = 1.42

The influence of night length on the production time of the three lighting regimes clearly varied with sticking date.

As with the data meaned across sticking date, night length treatments did not significantly influence the production time of plants grown using supplementary lighting at 12 W/m$^2$ weeks 1-3 SD. Production time was, however, slower overall for pots stuck in week 45 (and therefore grown under the poorest solar radiation levels).

Shorter nights reduced the production time of the no supplementary lighting regime for all stick weeks, but the effect was greater for the week 45 stuck pots than the week 41 or 48 stuck pots. In fact, for the week 45 stuck pots even the 13 hour night treatment significantly reduced production time over the natural day length treatment.

Looking at individual treatment means (Appendix I, figures 1a - 2c, pages 61 - 66), reducing night length with tungsten lighting reduced production time by up to 7 days overall.

Mean production time resulting from lighting at 4.8 W/m$^2$ throughout SD was increased by shorter nights for all three stick weeks as it was for data meaned across stick weeks discussed above. However the trend for individual stick weeks varied. That is, for pots stuck in week 41, 12.5 and 12 hour nights significantly increased production time compared with the standard 13 hour night but were not significantly different to each other. For pots stuck in week 45 and 48 however, the 12.5 hour night treatment was significantly slower than both and 13 and 12 hour treatments. There is no obvious explanation for this unexpected trend but data in year 2 of the trial will be analysed to assess if it is repeated.

### 1.1.2 Plant height

a. Night length

Decreasing night length significantly (***) increased plant height data meaned across lighting regimes:

Mean plant height (cm)

| | Night length | |
|---|---|---|
| **13 hrs** | **12.5 hrs** | **12 hrs** |
| 15.5 | 16.1 | 16.6 |

S.E.D. = 0.164, L.S.D. (P = 0.05) = 0.38

b. Supplementary lighting regime

Lighting regime also had a significant (**) influence on plant height for data meaned across night length treatments. Lighting at 12 W/m$^2$ weeks 1-3 SD only, produced taller plants than no supplementary lighting or lighting at 4.8 W/m$^2$ throughout SD.

Mean plant height (cm)

| No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD |
|---|---|---|
| 15.8 | 16.0 | 16.5 |

S.E.D. = 0.164, L.S.D. (P = 0.05) = 0.38

c. Night length x supplementary lighting regime

There was also a significant (***) interaction between night length treatment and supplementary lighting regime.

Mean plant height (cm)

| Night length | No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD |
|---|---|---|---|
| ND | 15.2 | - | 15.2 |
| 13 hrs | 15.3 | 15.7 | 15.6 |
| 12.5 hrs | 16.2 | 15.7 | 16.3 |
| 12 hrs | 15.9 | 16.5 | 17.5 |

S.E.D. = 0.402, L.S.D. (P = 0.05) = 2.31

As discussed above, lighting at 12 W/m$^2$ weeks 1-3 SD was found to significantly increase height over the other two lighting regimes for data meaned across night length treatments. It is clear from the above table however that for 'standard' night length treatments there were no significant differences in plant height. This agrees with previous studies on these lighting regimes (e.g. Wilson, 1995) and is not surprising when it is considered that growth regulators were applied according to the vigour of these individual lighting treatments at standard night length.

There was no significant effect of night length on the height of plants grown either with no supplementary lighting or with lighting at 4.8 $W/m^2$ throughout SD. Night length did however influence the height of plants grown at 12 $W/m^2$ weeks 1-3 SD. As length of night decreased, mean plant height significantly increased by up to 2.3 cm overall.

The night length treatments were in fact designed to increase vegetative growth (which may for example be expressed as increase in height) and there is therefore some indication of this effect from these results. This will, however, require further support from plant spread data (which is discussed below) since height may also indicate plant stretching rather than extra growth. Visual observations also indicated that night length slightly increased the height of plants in the 12 $W/m^2$ weeks 1-3 lighting regime (plate 6, page 118). Some plants did appear to be stretched as a result of reducing night length using tungsten lighting but this was more noticeable for plants grown without supplementary lighting (where no significant differences were found in plant height) than those grown using 12 $W/m^2$ weeks 1-3 SD.

These results are perhaps surprising since it was anticipated that reducing night length would increase production time and that this delay would allow time for more vegetative growth to develop on the plant. Since there were no significant delays due to shorter night length with the 12 $W/m^2$ weeks 1-3 SD lighting regime, this treatment may be expected also to have no response in terms of vegetative growth. Furthermore, plant height of the only lighting regime where delays were recorded (i.e. 4.8 $W/m^2$ throughout SD) was not significantly influenced by night length.

When trends in individual treatment means are examined (Appendix I, figures 1 & 2) plant height consistently increased with reducing night length when lit at 12 $W/m^2$ weeks 1-3 SD. Shorter nights also increased the height of plants grown without supplementary lighting and at 4.8 $W/m^2$ throughout production but overall the response was less consistent and also less pronounced. There is however an indication from these data that plant height may also be influenced by more extreme treatments for all three lighting regimes assessed.

### 1.1.3 Plant spread

a. Night length

Maximum and minimum pot spread records were combined to produce average spread figures which were analysed statistically.

Decreasing night length significantly (***) increased average pot spread data meaned across lighting regimes.

Average pot spread (cm)

| Night length 13 hrs | 12.5 hrs | 12 hrs |
|---|---|---|
| 29.5 | 30.6 | 30.7 |

S.E.D. = 0.194, L.S.D. (P = 0.05) = 0.45

b. Supplementary lighting regime

Average pot spread was also significantly (***) influenced by lighting regime. No supplementary lighting produced the smallest average pot spread. Lighting at 12 $W/m^2$ weeks 1-3 SD increased average spread by 1.1 cm for data meaned across night length treatments. Lighting at 4.8 $W/m^2$ throughout SD produced the greatest average pot spread which was 2.5 cm wider overall than no supplementary lighting.

Average pot spread (cm)

| No supplementary lighting | 4.8 $W/m^2$ throughout SD | 12 $W/m^2$ weeks 1-3 SD |
|---|---|---|
| 29.1 | 31.5 | 30.2 |

S.E.D. = 0.194, L.S.D. (P = 0.05) = 0.45

c. Night length x sticking date

There was also a significant (*) interaction between sticking date and night length on pot spread data meaned across lighting treatments. That is, pots stuck in weeks 41 and 48 had significantly greater average pot spread as a result of shorter nights as observed for the data meaned across stick weeks above. There were however no significant differences between day length treatments in terms of average pot spread, for pots stuck in week 45.

Average pot spread (cm)

| | Night length (hrs) | | |
|---|---|---|---|
| | **13 hrs** | **12.5 hrs** | **12 hrs** |
| stick week 41 | 29.9 | 31.9 | 32.1 |
| stick week 45 | 29.0 | 29.1 | 29.8 |
| stick week 48 | 29.7 | 30.8 | 30.2 |

S.E.D. = 0.335, L.S.D. (P = 0.05) = 0.77

d. Night length x supplementary lighting regime

There was no significant interaction between lighting regime and night length on average pot spread. Hence for all lighting regimes average pot spread was increased by 12.5 and 12 hour nights compared with 13 hour nights.

Average pot spread (cm)

| **Night length** | **No supplementary lighting** | **4.8 W/m$^2$ throughout SD** | **12 W/m$^2$ weeks 1-3 SD** |
|---|---|---|---|
| ND | 29.5 | - | 30.0 |
| 13 hrs | 28.2 | 30.9 | 29.4 |
| 12.5 hrs | 29.7 | 31.7 | 30.3 |
| 12 hrs | 29.4 | 32.0 | 30.7 |

S.E.D. = 0.474, L.S.D. (P = 0.05) = 1.09

Overall trends in pot spread data support the indication from plant height data that reducing night length increased vegetative growth. The differences found although significant were overall small however and further investigations in year 2 will assess if more dramatic night length treatments will have a greater impact on vegetative growth.

### 1.1.4 Developing (stages 1-3) and open (stages 4+) buds/flowers

a. Night length

The mean number of developing buds per pot significantly (**) increased as night length decreased for data meaned across lighting regimes. That is, the 12.5 hour treatment produced significantly more developing buds than the 13 hour treatment and the 12 hour treatment produced significantly more developing buds than the 12.5 hour treatment.

Reducing night length also significantly (**) increased the number of open buds per pot. In this case however, there were significantly more open buds for the 12.5 and 12 hour treatments than the 13 hour treatment but there was no significant difference between the 12.5 and 12 hour treatments.

Mean number of buds/flowers per pot

| | | **Night length** | |
|---|---|---|---|
| | **13 hrs** | **12.5 hrs** | **12 hrs** |
| Stages 1-3 | 12.7 | 13.5 | 14.3 |
| Stages 4+ | 15.4 | 17.6 | 17.3 |

Stages 1-3 S.E.D. = 0.294, L.S.D. (P = 0.05) = 0.68

Stages 4+ S.E.D. = 0.534, L.S.D. (P = 0.05) = 1.23

b. Supplementary lighting regime

Lighting regime also influenced number of buds. Lighting at 4.8 W/m$^2$ throughout SD produced significantly (***) more developing and open buds than the no supplementary lighting and the 12 W/m$^2$ weeks 1-3 regimes (as found in previous trials with these regimes). There were also significantly more open flowers per pot resulting from no supplementary lighting than from lighting at 12 W/m$^2$ weeks 1-3 SD.

Mean number of buds/flowers per pot

| | No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD |
|---|---|---|---|
| Stages 1-3 | 10.74 | 19.60 | 10.14 |
| Stages 4+ | 16.28 | 19.93 | 14.08 |

Stages 1-3 S.E.D. = 0.294, L.S.D. (P = 0.05) = 0.68

Stages 4+ S.E.D. = 0.534, L.S.D. (P = 0.05) = 1.23

c. Night length x supplementary lighting regime

There was also a significant interaction (***) between night length and supplementary lighting regime on the number of developing buds produced per pot. For the lighting regime 12 W/m$^2$ weeks 1-3 SD night length had the same effect as discussed above for data meaned across lighting regimes. That is, a 12.5 hour night produced significantly more developing buds than a 13 hour night or natural night length. A 12 hour night further increased the number of developing buds produced over the 12.5 hour night treatment. For the no supplementary lighting regime however, the 13 hour treatment produced the fewest developing buds but there were no significant differences between the natural night length, 12.5 hour and 12 hour treatments.

Night length had no significant influence over the number of developing buds produced when lighting at 4.8 W/m$^2$ throughout SD.

There was no significant interaction between night length and supplementary lighting regime on the number of open buds produced.

Mean number of buds/flowers per pot

| Night length (hrs) | No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD |
|---|---|---|---|
| **Stages 1-3:** | | | |
| ND | 11.6 | - | 7.3 |
| 13 | 10.0 | 20.4 | 7.7 |
| 12.5 | 11.4 | 18.6 | 10.3 |
| 12 | 10.8 | 19.8 | 12.4 |
| S.E.D. = 0.509, L.S.D. (P = 0.05) = 1.17 | | | |
| **Stages 4+:** | | | |
| ND | 15.0 | - | 13.3 |
| 13 | 15.1 | 18.8 | 12.4 |
| 12.5 | 16.6 | 21.3 | 15.0 |
| 12 | 17.2 | 19.7 | 14.9 |

Night length and lighting regime had no significant influence over the average maximum bud stage per pot and there was also no significant interaction between these factors.

## 1.2 Shelf-life performance

As described previously in Materials and Methods (page 13), shelf-life was recorded following a 3 day cold store period and 4 days in sleeves. Hence the weekly records taken correspond to the following number of days from marketing:

| | | |
|---|---|---|
| Record 1 | = | 7 days from marketing |
| Record 2 | = | 14 days from marketing |
| Record 3 | = | 21 days from marketing |
| Record 4 | = | 28 days from marketing |

### 1.2.1 Leaf quality

a. Night length

At the point of removing sleeves (Record 1), night length had a significant (*) influence on leaf quality. Poorer leaf quality (indicated by a higher score) resulted from the 12 hour night length treatment than the 13 and 12.5 hour treatments. As length of time in shelf-life increased leaf quality deteriorated and significant differences between treatments disappeared. Overall however, leaf score figures remained favourable throughout shelf-life since they rose only slightly above the score 1 figure (indicating only minor deterioration) at the worst point.

Mean leaf damage score

| **Number of days from marketing** | | **Night length** | | **S.E.D.** | **L.S.D.** |
|---|---|---|---|---|---|
| | **13 hrs** | **12.5 hrs** | **12 hrs** | | **(P = 0.05)** |
| 7 (*) | 0.40 | 0.47 | 0.58 | 0.048 | 0.11 |
| 14 (NS) | 0.56 | 0.57 | 0.64 | - | - |
| 21 (NS) | 0.80 | 0.73 | 0.83 | - | - |
| 28 (NS) | 1.06 | 1.05 | 1.05 | - | - |

b. Supplementary lighting regime

Leaf quality was significantly influenced by supplementary lighting regime for most of the shelf-life period. For records taken 7, 21 and 28 days from marketing, lower scores (i.e. indicating less leaf damage) were associated with no supplementary lighting than either 4.8 $W/m^2$ throughout SD or lighting at 12 $W/m^2$ weeks 1-3 SD. Again leaf damage scores were low overall with the highest score of 1.18 relating to minor deterioration only.

Mean leaf damage score

| Number of days from marketing | | No supplementary lighting | 4.8 W/m² throughout SD | 12 W/m² weeks 1-3 SD | S.E.D | L.S.D. (P = 0.05) |
|---|---|---|---|---|---|---|
| 7 | (*) | 0.42 | 0.46 | 0.57 | 0.048 | 0.11 |
| 14 | (NS) | 0.53 | 0.59 | 0.64 | - | - |
| 21 | (*) | 0.64 | 0.86 | 0.86 | 0.064 | 0.15 |
| 28 | (*) | 0.85 | 1.13 | 1.18 | 0.087 | 0.20 |

There was no significant interaction between night length and lighting regimes on leaf quality.

### 1.2.2 Flower opening

Records of number of open flowers were taken during shelf-life to indicate overall visual pleasure as well as to monitor if buds were developing into flowers.

a. Night length

In accordance with records taken at marketing, the 12.5 and 12 hours night length treatments had significantly more open flowers at each weekly record than the 'standard' 13 hour treatment. Comparison with the data recording at marketing (see Section 1.1.4 a, page 23), indicates that flower number increased during the cold store and sleeve period (i.e. the first 7 days after marketing). Flowers continued to open for up to 21 days after marketing after which numbers fell slightly. There were no obvious differences between night length treatments in the pattern with which flower numbers increased and decreased. It is therefore apparent that the significant differences in flower number recorded at marketing were maintained during shelf-life and would therefore continue to give the same relative levels of visual pleasure. Night length treatment did not however appear to influence how number of open flowers changed during shelf-life.

Mean number of flowers per pot

| Number of days from marketing | | Night length 13 hrs | 12.5 hrs | 12 hrs | S.E.D. | L.S.D. (P = 0.05) |
|---|---|---|---|---|---|---|
| 7 | (*) | 17.7 | 19.8 | 19.8 | 0.639 | 1.47 |
| 14 | (NS) | 18.4 | 21.1 | 20.8 | 0.549 | 1.27 |
| 21 | (NS) | 18.7 | 20.8 | 21.2 | 0.498 | 1.15 |
| 28 | (NS) | 17.9 | 20.8 | 20.4 | 0.693 | 1.60 |

b. Supplementary lighting regime

The influence of lighting regime on number of open flowers during shelf-life also follows the same trend as that observed when pots were ready for marketing. That is, pots lit at 4.8 W/m$^2$ throughout SD had the highest number of open flowers at each weekly assessment made. Numbers of open flowers per pot were closer for the no supplementary lighting and the 12 W/m$^2$ weeks 1-3 SD regimes but were in fact significantly higher for the no lighting treatment. Comparing the number of open flowers per treatment at marketing (Section 1.1.4 b above, page 23) again indicates that flowers did open post marketing and as noted above, the biggest increase in number occurred during the first 7 days of the shelf-life period. Pattern of flower opening was not apparently affected by supplementary lighting regime.

Mean number of flowers per pot

| Number of days from marketing | No supplementary lighting | 4.8 W/m$^2$ throughout SD | 12 W/m$^2$ weeks 1-3 SD | S.E.D | L.S.D. (P = 0.05) |
|---|---|---|---|---|---|
| 7 (***) | 17.7 | 24.1 | 15.6 | 0.639 | 1.47 |
| 14 (***) | 18.9 | 25.6 | 15.7 | 0.549 | 1.27 |
| 21 (***) | 18.5 | 25.9 | 16.2 | 0.498 | 1.15 |
| 28 (***) | 18.7 | 25.0 | 15.4 | 0.693 | 1.60 |

There was no significant interaction between night length and supplementary lighting regime on the number of open flowers per pot during shelf-life.

### 1.2.3 Flower distortion

Since flower opening can sometimes appear distorted (e.g. petals expanding on only part of the flower), the number of flowers appearing distorted during shelf-life was also recorded. However neither night length treatment nor supplementary lighting regime had a significant influence on the number of distorted flowers per pot. Furthermore the number of flowers appearing distorted did not exceed 2.1 per pot overall and was therefore generally low throughout.

Mean number of distorted flowers per pot

| Number of days from marketing | | 13 hrs | Night length 12.5 hrs | 12 hrs |
|---|---|---|---|---|
| **7** | (NS) | 1.5 | 1.7 | 1.5 |
| **14** | (NS) | 1.9 | 1.8 | 2.0 |
| **21** | (NS) | 1.6 | 1.4 | 1.6 |
| **28** | (NS) | 1.3 | 1.2 | 1.3 |

Mean number of distorted flowers per pot

| Number of days from marketing | | No supplementary lighting | 4.8 $W/m^2$ throughout SD | 12 $W/m^2$ weeks 1-3 SD |
|---|---|---|---|---|
| **7** | (NS) | 1.5 | 1.8 | 1.4 |
| **14** | (NS) | 1.6 | 2.1 | 2.0 |
| **21** | (NS) | 1.3 | 1.7 | 1.6 |
| **28** | (NS) | 1.1 | 1.3 | 1.3 |

The night length treatments and supplementary lighting regimes had no significant influence on the length of time pots lasted in shelf-life.

## 1.3 Compost Analyses

There were no consistent trends either in the analysis results from individual plots (Table 1, Appendix IV, pages 103-105) or for the mean results across sticking dates presented below to indicate that the nutrient status of the compost was influenced by night length treatments. Levels of potassium in the compost were unusually low across treatments, particularly for pots stuck in week 45. This was not reflected by any visual sysmptons of deficiency. Furthermore, the liquid feed composition and frequency of feeding was identical to that used in previous HDC winter pot chrysanthemum trials. There is, therefore, no obvious explanation for this discrepancy, and it does not appear to be a result of any treatment effects.

| Lighting regime | Night length (hrs) | Bulk density g/ml | pH | Ec (μS/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/1) | Ca (mg/l) | Mg (mg/1) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Variety: Charm** | | | | | | | | | | |
| No Supplementary Lighting | **ND** | 0.41 | 5.3 | 318 | 138 | 0.73 | 52 | 45 | 109 | 88 |
| | **13** | 0.41 | 5.3 | 309 | 123 | 0.70 | 46 | 61 | 103 | 71 |
| | **12.5** | 0.43 | 5.4 | 265 | 118 | 0.53 | 45 | 38 | 94 | 69 |
| | **12** | 0.40 | 5.4 | 250 | 114 | 0.87 | 39 | 39 | 85 | 68 |
| 4.8 W/m² throughout SD | **13** | 0.42 | 5.4 | 254 | 99 | 2.63 | 43 | 24 | 91 | 61 |
| | **12.5** | 0.44 | 5.5 | 216 | 85 | 0.73 | 37 | 20 | 77 | 56 |
| | **12** | 0.43 | 5.6 | 232 | 78 | 0.70 | 40 | 15 | 83 | 65 |
| 12 W/m² throughout SD | **ND** | 0.39 | 5.3 | 271 | 123 | 0.83 | 39 | 47 | 88 | 59 |
| | **13** | 0.39 | 5.2 | 297 | 93 | 0.57 | 47 | 31 | 110 | 77 |
| | **12.5** | 0.42 | 5.3 | 326 | 136 | 0.87 | 48 | 28 | 120 | 89 |
| | **12** | 0.41 | 5.5 | 228 | 90 | 0.73 | 37 | 25 | 79 | 59 |
| **Variety: Cerise About Time** | | | | | | | | | | |
| No Supplementary Lighting | **ND** | 0.44 | 5.1 | 355 | 183 | 1.10 | 62 | 90 | 146 | 114 |
| | **13** | 0.42 | 5.3 | 291 | 121 | 0.77 | 52 | 55 | 101 | 76 |
| | **12.5** | 0.45 | 5.2 | 282 | 118 | 0.63 | 53 | 51 | 101 | 77 |
| | **12** | 0.41 | 5.3 | 300 | 116 | 1.03 | 53 | 36 | 109 | 82 |
| 4.8 W/m² throughout SD | **13** | 0.44 | 5.4 | 251 | 100 | 0.80 | 46 | 29 | 91 | 66 |
| | **12.5** | 0.45 | 5.2 | 321 | 124 | 1.77 | 52 | 55 | 115 | 82 |
| | **12** | 0.45 | 5.5 | 259 | 83 | 0.77 | 49 | 24 | 94 | 70 |
| 12 W/m² throughout SD | **ND** | 0.41 | 5.2 | 296 | 123 | 0.67 | 46 | 53 | 103 | 72 |
| | **13** | 0.43 | 5.3 | 325 | 126 | 0.73 | 61 | 50 | 124 | 88 |
| | **12.5** | 0.43 | 5.4 | 283 | 101 | 0.90 | 54 | 20 | 108 | 85 |
| | **12** | 0.42 | 5.1 | 330 | 128 | 0.73 | 51 | 42 | 122 | 95 |

## 1.4 Summary - night length treatments

The objective of reducing length of night (or extending photoperiod) was to decrease the rate of production. The benefit of this would be to increase the length of time spent producing vegetative growth and hence improve the overall bulk of the pot. Quality would therefore be expected to benefit from improved vegetative growth and furthermore with greater photosynthetic potential, more energy should be available for the development and maturation of flowers.

Due to interaction with lighting regimes night length treatments produced some interesting and unexpected results.

Where night length treatments were combined with lighting at 4.8 $W/m^2$ throughout production, shorter nights had the expected effect of increasing production time with increases of up to 5 days on individual treatment means. This lighting regime was also the only one where sodium lamps were turned on for the whole of the day period (i.e. 11.5 and 12 hours depending on the treatment in question).

Shorter nights had no significant effect on the rate of production of pots lit at 12 $W/m^2$ weeks 1-3 SD. This lighting regime also resulted in the shortest production time figures of the three regimes assessed.

Combining shorter nights with no supplementary lighting (but using tungsten lighting to achieve the required photoperiod) had the unexpected result of speeding up rate of production. Savings of up to 7 days were recorded on individual treatment means with no obvious penalties in terms of quality. To date, no satisfactory explanation has been found to explain the effect observed and these treatments will be closely examined in the second year of the trial. This effect was more pronounced for pots stuck in week 45, and therefore during the poorest of winter light levels (and also the longest natural night lengths) and these factors may therefore be important. Furthermore, night length was reduced by using tungsten lighting which came on at dusk and stayed on until 1800 hrs, 1830 hrs or 1900 hrs. These treatments therefore assumed sufficient natural daylight would be available for the plants to perceive the start of day as 0700 hrs. The start of the day would in fact have been later than this time during the shortest winter days. It is therefore possible that night length was not sufficiently short to cause delays. Set points will be adjusted in the second year of the trial to ensure night lengths are as required and to assess if rate of production will still be decreased or if increases, as expected, will result. Furthermore night length treatments will be achieved using lighting pre-sunrise rather than post-sunset as in this first year of the work. Whatever the outcome of this second year, there is clearly potential during the shortest days in winter to increase rate of production of plants grown without supplementary lighting through using tungsten lighting at the end of natural daylight.

Measurements of plant development (height and spread) indicated that day length did influence the amount of vegetative growth produced. Again the results found were perhaps unexpected. The only treatment which may be predicted to be significantly affected by night length would be the one for which significant delays in production time were recorded (i.e. lighting at 4.8 W/m$^2$ throughout SD). In fact, significant increases in height resulting from shorter nights were only found for plants lit at 12 W/m$^2$ weeks 1-3 SD. However individual treatment means indicate a trend of increasing height with decreasing night length across all lighting regimes. This evidence of increased vegetative growth resulting from reducing night length was supported further by average pot spread data, although the differences found so far are small and more extreme treatments will be assessed in year 2.

There was also some indication of improving visual quality through reducing night length in that significantly more developing and open buds were produced by the shorter night length treatments. These effects were generally greater for the 12 W/m$^2$ weeks 1-3 SD lighting regime.

These slight improvements in visual quality were apparently maintained during shelf-life testing. Night length did not appear to influence the life of pots post-marketing and hence better quality pots at the start of shelf-life continued as better quality pots throughout the period of testing.

# 2. The influence of supplementary lighting during bud maturation on winter quality

## 2.1 Vegetative development and flower production

### 2.1.1. Production time (number of days from sticking to marketing)

a. Lighting treatment

Supplementary lighting during the last three weeks of short days significantly (**) influenced production time. For data meaned across stick weeks and varieties, lighting at 12 W/m$^2$ during weeks 7, 8 and 9 of short days reduced production time by 2.3 days in comparison with no supplementary lighting.

Mean number of days from sticking to marketing

| No supplementary lighting | 4.8 W/m$^2$ weeks 7-9 SD | 12 W/m$^2$ weeks 7-9 SD |
|---|---|---|
| 85.7 | 85.0 | 83.5 |

S.E.D. = 0.407, L.S.D. (P = 0.05) = 0.86

b. Lighting treatment x sticking week

There was a significant (**) interaction between sticking week and end of short days lighting treatment. For pots stuck in weeks 41 and 45 (and therefore maturing against low background light levels), lighting at 12 W/m$^2$ during weeks 7, 8 and 9 reduced production time by 3.4 and 2.2 days respectively in comparison with no supplementary lighting as observed for data meaned across sticking week discussed above.

There was however no significant difference in production time between these three lighting regimes for pots stuck in week 48 when background light levels during bud maturation were improving. The trends in individual treatment means (Appendix II, figures 1a-1c, pages 80-82) reflect these results with the greatest reduction in production time of 5 days resulting from lighting Akron at 12 W/m$^2$ weeks 7-9 SD and sticking in week 41.

Mean number of days from sticking to marketing

| | No supplementary lighting | 4.8 W/m$^2$ weeks 7-9 SD | 12 W/m2 weeks 7-9 SD |
|---|---|---|---|
| Stick week 41 | 82.4 | 79.8 | 79.0 |
| Stick week 45 | 89.8 | 91.4 | 87.6 |
| Stick week 48 | 85.0 | 83.7 | 83.8 |

S.E.D. = 0.705, L.S.D. (P = 0.05) = 1.49

c. Comparison with standard lighting regimes

There was no significant interaction between variety and end of short days lighting treatment. Data for end of short day lighting treatments are also compared below with the 'standard' lighting treatments 4.8 W/m$^2$ throughout SD and 12 W/m$^2$ weeks 1-3 SD (this data was available for the varieties Charm and Cerise About Time from the comparison of day length treatments discussed in Section 1).

Lighting for the last three weeks of short days was clearly not as effective as lighting either throughout SD at 4.8 W/m$^2$ or during weeks 1-3 SD at 12 W/m$^2$, in reducing production time. This may be explained by the stage of development during the period of lighting. That is, during the first three weeks of short days buds would be initiating and hence lighting would speed this process up giving large benefits in terms of reducing production time. Lighting during the last three weeks of short days would not speed up bud initiation but did produce smaller benefits in production time by increasing the speed of bud maturation. This reflects results observed from HDC funded work on spray chrysanthemums lit at different stages of production (Wilson, 1996).

Mean number of days from sticking to marketing

| Variety | No supplementary lighting | 4.8 W/m$^2$ throughout SD | 48 W/m$^2$ weeks 7-9 SD | 12 W/m$^2$ weeks 1-3 SD | 12 W/m$^2$ weeks 7-9 SD |
|---|---|---|---|---|---|
| Cerise About Time | 85.5 | 79.2 | 84.8 | 78.9 | 83.8 |
| Charm | 86.1 | 80.7 | 85.1 | 79.4 | 83.8 |

S.E.D. = 0.910, L.S.D. (P = 0.05) = 1.93

d. Lighting treatment x variety

Since the other three varieties assessed were not used in other parts of the trial, there is no data from 'standard' lighting regimes. Although, as discussed above, there was no significant interaction between variety and end of short days lighting treatment the mean data across stick weeks is presented below to complete the picture.

Mean number of days from sticking to marketing

| | **No supplementary lighting** | **4.8 W/m² weeks 7-9 SD** | **12 W/m2 weeks 7-9 SD** |
|---|---|---|---|
| Akron | 81.3 | 79.9 | 79.2 |
| Miramar | 86.3 | 85.9 | 84.3 |
| Yuba | 89.4 | 89.3 | 86.2 |

S.E.D. = 0.910, L.S.D. (P = 0.05) = 1.93

e. Variety

Variety also significantly (***) influenced length of production time. For data meaned across the three sticking weeks and lighting treatments, Akron was the fastest of the varieties assessed, and Yuba was the slowest. There was no significant difference between the length of production of Charm, Cerise About Time and Miramar.

Mean number of days from sticking to marketing

| **Akron** | **Cerise About Time** | **Charm** | **Miramar** | **Yuba** |
|---|---|---|---|---|
| 80.1 | 84.7 | 85.0 | 85.5 | 88.3 |

S.E.D. = 0.525, L.S.D. (P = 0.05) = 1.11

### 2.1.2. Plant height

a. Lighting treatment

Plant height was significantly (**) influenced by lighting during the last three weeks of short days. The height of plants lit at 12 $W/m^2$ during weeks 7-9 SD was significantly shorter than the other two treatments. There was however no difference in height between no supplementary lighting and lighting at 4.8 $W/m^2$ weeks 7-9 SD.

Mean plant height (cm)

| No supplementary lighting | 4.8 $W/m^2$ weeks 7-9 SD | 12 $W/m^2$ weeks 7-9 SD |
|---|---|---|
| 16.5 | 16.5 | 15.8 |

S.E.D. = 0.172, L.S.D. (P = 0.05) =0.36

b. Lighting treatment x sticking week

There was also a significant (*) interaction between lighting treatment and sticking date on plant height. Plants were shorter from lighting at 12 $W/m^2$ weeks 7-9 SD stuck in week 41 and 48 but there was no difference in plant height between the three treatments for plants stuck in week 45.

Mean plant height (cm)

| | No supplementary lighting | 4.8 $W/m^2$ weeks 7-9 SD | 12 $W/m^2$ weeks 7-9 SD |
|---|---|---|---|
| Stick week 41 | 18.1 | 18.4 | 17.0 |
| Stick week 45 | 15.8 | 15.3 | 15.5 |
| Stick week 48 | 15.8 | 15.7 | 15.0 |

S.E.D. = 0.298, L.S.D. (P = 0.05) = 0.63

Overall, whilst significant effects were found, the actual differences in height between treatments was small. This may be demonstrated by the individual treatment mean data (Appendix II, figures 1a-1c, pages 80-82). Differences between treatments do not exceed 2 cm in height for any of the varieties and sticking weeks assessed.

c. Variety

Plant height was also significantly (***) influenced by variety as may be expected. The tallest variety overall was Yuba whilst the shortest was Akron.

Mean plant height (cm)

| **Akron** | **Cerise About Time** | **Charm** | **Miramar** | **Yuba** |
|---|---|---|---|---|
| 14.2 | 15.2 | 14.7 | 17.1 | 20.3 |

S.E.D. = 0.222, L.S.D. (P = 0.05) = 0.47

### 2.1.3 Plant spread

a. Lighting treatment

There was a small increase in average pot spread resulting from lighting at 4.8 W/m$^2$ weeks 7-9 SD. However this increase was not repeated for the higher intensity of 12 W/m$^2$.

Average pot spread (cm)

| **No supplementary lighting** | **4.8 W/m$^2$ weeks 7-9 SD** | **12 W/m$^2$ weeks 7-9 SD** |
|---|---|---|
| 29.8 | 30.4 | 29.9 |

S.E.D. = 0.187, L.S.D. (P = 0.05) =0.40

There was no significant interaction between lighting treatments and stick week or lighting treatment and variety on average pot spread.

b. Variety

Variety significantly (***) influenced plant spread. The most compact varieties of those assessed were Charm and Akron. Yuba produced the greatest plant spread.

Average pot spread (cm)

| Akron | Cerise About Time | Charm | Miramar | Yuba |
|---|---|---|---|---|
| 29.2 | 30.6 | 29.1 | 34.4 | 31.0 |

S.E.D. = 0.417, L.S.D. (P = 0.05) = 0.88

Lighting at the end of short days had no significant influence on leaf damage score per pot.

### 2.1.4 Developing (stages 1-3) and open (stages 4+) buds/flowers

a. Lighting treatment

Lighting at both 4.8 $W/m^2$ and 12 $W/m^2$ significantly (***) increased the number of developing buds per pot by 8.2 and 10.1 buds per pot respectively (data meaned across varieties and sticking week) compared with no supplementary lighting.

There was however no significant difference between these treatments in terms of the number of open flowers per pot.

Mean number of buds/flowers per pot

| | No supplementary lighting | 4.8 $W/m^2$ weeks 7-9 SD | 12 W/m2 weeks 7-9 SD |
|---|---|---|---|
| Stages 1-3 | 15.0 | 23.2 | 25.1 |
| Stages 4+ | 17.9 | 18.6 | 18.0 |

Stages 1-3: S.E.D. = 1.908, L.S.D. (P = 0.05) = 4.04

b. Lighting treatment x sticking week

Sticking week significantly (*) interacted with lighting treatment in terms of the number of developing buds produced per pot. For pots stuck in week 41 and 45, lighting treatments had the same effect on number of developing buds per pot as that described above for data meaned across sticking week. These pots also matured during periods of low background solar radiation. Lighting regime did not however, influence the number of developing buds produced on pots stuck in week 48. This is probably due to the fact that these pots also matured towards the end of the winter period (week 8) when background light levels were improving.

There was no significant interaction between sticking week and lighting treatment on the number of open buds produced per pot. The mean number of open buds per pot does appear to increase for both the 4.8 W/m$^2$ weeks 7-9 and the 12 W/m$^2$ weeks 7-9 treatments for pots stuck in week 45, although this was not found to be significant.

Mean number of buds/flowers per pot

| | No supplementary lighting | 4.8 W/m$^2$ weeks 7-9 SD | 12 W/m2 weeks 7-9 SD |
|---|---|---|---|
| **Stages 1-3:** | | | |
| Stick week 41 | 8.2 | 13.5 | 15.8 |
| Stick week 45 | 16.7 | 32.5 | 35.6 |
| Stick week 48 | 20.0 | 23.6 | 23.7 |
| S.E.D. = 3.305, | L.S.D. (P = 0.05) = 7.01 | | |
| **Stages 4+:** | | | |
| Stick week 41 | 21.2 | 21.1 | 20.2 |
| Stick week 45 | 16.4 | 18.1 | 18.8 |
| Stick week 48 | 16.1 | 16.6 | 14.9 |

These trends are reflected in the individual treatment mean data (Appendix II, figures 3a-3c, pages 86-88, where the increase in number of developing buds due to lighting at the end of short days was consistent across all varieties for stick weeks 41 and 45 but was less pronounced and consistent for stick week 48. The maximum increase in number of developing buds produced compared with no supplementary lighting was 45.1 buds for the variety Akron stuck in week 45 and lit at 12 W/m$^2$ weeks 7-9 SD. Akron however produced large numbers of smaller flowers than the other varieties assessed (see below). Increases in individual treatment means ranged from 3.5 to 14.9 developing buds per pot across the other varieties assessed for lighting at

12 $W/m^2$ weeks 7-9 SD compared with no supplementary lighting, and sticking in weeks 41 and 45. Lighting at 12 $W/m^2$ weeks 7-9 SD also had a significant impact on the visual quality of the flowers with flower colour appearing much more intense than for pots grown without supplementary lighting. This effect was particularly pronounced for the variety Cerise About Time.

c. Variety

Variety significantly influenced the number of developing buds per pot. Akron produced the most developing buds but this variety also produced smaller flowers than the other varieties assessed. Miramar produced the lowest number of developing buds per pot at marketing stage 3.

The number of open buds per pot was also significantly (***) influenced by variety although the trend was different to that discussed above for developing buds. Along with developing buds Akron also produced one of the highest numbers of open buds per pot but there was no significant difference between Akron, Miramar and Cerise About Time in terms of the number of open buds produced. Charm produced the lowest number of open buds per pot at marketing stage 3 for data meaned across sticking weeks and lighting regimes.

Mean number of buds/flowers per pot

| | **Akron** | **Cerise About Time** | **Charm** | **Miramar** | **Yuba** |
|---|---|---|---|---|---|
| **Stages 1-3** | 31.1 | 12.2 | 20.7 | 14.4 | 27.0 |
| **Stages 4+** | 21.7 | 21.0 | 11.4 | 20.1 | 16.6 |

Stages 1-3: S.E.D. = 2.463, L.S.D. (P = 0.05) = 5.22
Stages 4+: S.E.D. = 1.132, L.S.D. (P = 0.05) = 2.40

Lighting at the end of short days had no significant influence on average maximum bud stage per pot.

## 2.2 Shelf-life performance

### 2.2.1 Leaf quality

a. Lighting treatment

Lighting during weeks 7-9 SD did not significantly influence the extent of leaf damage recorded per pot for any of the assessments made during shelf-life. This reflects the observations made at marketing discussed above.

Leaf damage score increased with length of time in shelf-life but the rate of increase in score (and therefore damage observed) was not apparently influenced by lighting treatment. Overall leaf damage score remained low since score 1 is equivalent to minor levels of deterioration.

Mean leaf damage score

| **Number of days from marketing** | **No supplementary lighting** | **4.8 W/m$^2$ weeks 7-9 SD** | **12 W/m$^2$ weeks 7-9 SD** |
|---|---|---|---|
| 7 | 0.83 | 0.73 | 0.64 |
| 14 | 1.07 | 1.01 | 0.83 |
| 21 | 1.26 | 1.28 | 1.00 |
| 28 | 1.38 | 1.43 | 1.36 |

There was no significant interaction between variety and lighting treatment on the leaf damage score during shelf-life.

Whilst no differences were recorded in terms of leaf damage, it should be noted that visual improvements in leaf quality were observed as a result of lighting at the end of short days. In particular, leaves at the top of the plant (i.e. those visible when the pot is sleeves for marketing) were darker green in colour as a result of lighting in comparison with no supplementary lighting. This effect was more pronounced for the 12 W/m$^2$ weeks 7-9 treatment but was also apparent for the 4.8 W/m$^2$ weeks 7-9 treatment.

### 2.2.2. Flower opening

a. Lighting regime

At marketing, there was no significant difference between lighting treatments in terms of number of open buds per pot. Throughout shelf-life however, there were significantly (***) more open buds per pot from lighting at 4.8 W/m$^2$ and at 12 W/m$^2$ weeks 7-9 SD than from no supplementary lighting.

Mean number of open flowers per pot

| No supplementary lighting | 4.8 W/m$^2$ weeks 7-9 SD | 12 W/m2 weeks 7-9 SD |
|---|---|---|
| 24.2 | 27.5 | 27.9 |

S.E.D. = 0.672, L.S.D. (P = 0.05) = 1.42

b. Lighting regime x stage of shelf-life

There was no significant interaction between lighting regime and stage of shelf-life. Pots treated with supplementary lighting at the end of short days therefore continued to have a higher number of flowers throughout shelf-life.

The increase in number of open flowers per pot was greater earlier in the shelf-life period. The largest increase was apparent for the day 7 assessment when number of open flowers per pot had increased by 4.7, 6.5 and 7.4 respectively for the treatments no supplementary lighting, 4.8 W/m$^2$ weeks 7-9 SD and 12 W/m$^2$ weeks SD, in comparison with the number of open flowers recorded at marketing (see section 2.1.4 a, page 38). Subsequent changes in number of open flowers per pot were smaller and not apparently influenced by lighting regime.

Mean number of open flowers per pot

| Number of days from marketing | No supplementary lighting | 4.8 W/m$^2$ weeks 7-9 SD | 12 W/m$^2$ weeks 7-9 SD |
|---|---|---|---|
| 7 | 22.6 | 25.1 | 25.4 |
| 14 | 24.3 | 27.7 | 28.4 |
| 21 | 24.9 | 28.4 | 29.0 |
| 28 | 25.2 | 28.7 | 28.9 |

S.E.D. = 0.859, L.S.D. (P = 0.05) = 1.70

Although lighting at the end of short days did not significantly influence the number of open flowers per pot at marketing, it did have a significant benefit on shelf-life. There were more open flowers per pot at the point of removing sleeves (i.e. 7 days from marketing) and flower numbers remained higher for the lit treatments (compared with no supplementary lighting) throughout the shelf-life period. Furthermore, the deeper petal colour resulting from lighting at 12 W/m$^2$ weeks 7-9 observed at marketing continued to be apparent during the shelf-life period. A problem was however observed with some pots in shelf-life in that as flowers opened within the shelf-life environment, the petals at the centre opened with very little colour. This was particularly noticeable for the variety Cerise About Time following lighting at 12 W/m$^2$ weeks 7-9 SD.

### 2.2.3 Flower distortion

a. Lighting treatment

There were significantly (*) fewer distorted flowers on pots which had been lit at the end of shelf-life than those which had received no supplementary lighting for data meaned across the weekly shelf-life assessments.

Mean number of open flowers per pot

| No supplementary lighting | 4.8 W/m$^2$ weeks 7-9 SD | 12 W/m2 weeks 7-9 SD |
|---|---|---|
| 1.1 | 0.6 | 0.5 |

S.E.D. = 0.225, L.S.D. (P = 0.05) = 0.45

b. Lighting treatment x stage of shelf-life

There was no significant interaction bettween lighting treatment and stage of shelf-life in terms of flower distortion. Throughout the shelf-life assessment period pots which had received lighting during weeks 7-9 SD had fewer distorted buds than those grown without supplementary lighting.

Mean number of distorted flowers per pot

| **Number of days from marketing** | **No supplementary lighting** | **4.8 W/m² weeks 7-9 SD** | **12 W/m² weeks 7-9 SD** |
|---|---|---|---|
| 7 | 1.1 | 0.6 | 0.4 |
| 14 | 1.2 | 0.8 | 0.7 |
| 21 | 1.3 | 0.7 | 0.5 |
| 28 | 0.8 | 0.4 | 0.5 |

S.E.D. = 0.275, L.S.D. (P = 0.05) = 0.55

b. Variety

Variety significantly (***) influenced the number of distorted flowers recorded during shelf-life. For data meaned across the four shelf-life records and the three lighting treatments taken, Charm produced the highest number of distorted buds during shelf-life. Yuba also produced significantly more distorted buds than the remaining varieties Akron, Cerise About time and Miramar.

Mean number of distorted flowers per pot

| **Akron** | **Cerise About Time** | **Charm** | **Miramar** | **Yuba** |
|---|---|---|---|---|
| 0.0 | 0.3 | 1.9 | 0.4 | 1.1 |

S.E.D. = 0.291, L.S.D. (P = 0.05) = 0.58

There was no significant interaction between variety and lighting treatment on the number of distorted flowers produced in shelf-life.

Supplementary lighting for the last three weeks of short days did not significantly influence the length of time pots lasted in shelf-life.

## 2.3 Compost Analyses

There were no consistent trends either in the analysis results from individual plots (Table 2, Appendix IV, pages 106-108) or for the mean results across sticking dates presented below to indicate that the nutrient status of the compost was influenced by lighting treatments at the end of short days. As noted in section 1, potassium levels in the compost were generally lower than expected but this does not appear to be the result of treatment effects.

Mean compost analyses (across sticking week):

| Variety | Lighting treatment | Bulk density | pH | Ec (μS/cm) | NO3-N (mg/l) | NH4-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm | No supplementary lighting | 0.41 | 5.3 | 652 | 138 | 0.73 | 52 | 45 | 109 | 88 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.44 | 5.3 | 276 | 129 | 0.57 | 48 | 47 | 96 | 84 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.44 | 5.2 | 396 | 202 | 0.77 | 54 | 82 | 132 | 112 |
| CAT | No supplementary lighting | 0.44 | 5.1 | 355 | 183 | 1.10 | 62 | 90 | 146 | 114 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.42 | 5.2 | 326 | 127 | 0.80 | 60 | 63 | 115 | 85 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.44 | 5.3 | 285 | 111 | 0.60 | 53 | 55 | 97 | 79 |
| Yuba | No supplementary lighting | 0.43 | 5.3 | 276 | 128 | 0.60 | 52 | 55 | 95 | 81 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.44 | 5.2 | 332 | 154 | 0.67 | 59 | 58 | 117 | 94 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.44 | 5.2 | 138 | 148 | 0.70 | 53 | 64 | 105 | 79 |
| Akron | No supplementary lighting | 0.42 | 5.2 | 341 | 157 | 0.63 | 53 | 54 | 122 | 88 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.41 | 5.1 | 368 | 175 | 0.70 | 54 | 61 | 126 | 89 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.42 | 5.2 | 367 | 175 | 0.67 | 58 | 58 | 132 | 101 |
| Miramar | No supplementary lighting | 0.41 | 5.1 | 429 | 203 | 0.77 | 67 | 76 | 154 | 111 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.42 | 4.9 | 488 | 220 | 0.83 | 66 | 108 | 166 | 135 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.43 | 5.1 | 393 | 186 | 0.60 | 61 | 84 | 133 | 105 |

## 2.4 Summary - lighting during weeks 7-9 of short days

Providing pots with supplementary lighting for the last three weeks of short days only produced some benefit in terms of reducing production time in comparison with no supplementary lighting throughout production. This type of lighting treatment was not however as effective as the more conventional regimes such as lighting at 4.8 W/m$^2$ throughout SD or at 12 W/m$^2$ weeks 1-3 SD in terms of speeding up production.

Significant differences were found in both plant height and vegetative growth due to lighting at the end of short days. These differences were however small and perhaps of little importance commercially (except that some compensation may be required in growth regulation treatments where lighting at 12 W/m$^2$ weeks 7-9 is used).

Larger differences were however recorded in number of buds and flowers produced. Both lighting treatments (i.e. 4.8 and 12 $W/m^2$ weeks 7-9 SD) improved the number of developing buds at marketing. Furthermore, as some of these buds opened while plants were in sleeves (during the seven days from marketing) greater visual pleasure may be expected at point of sale as a result of increased flower number due to lighting for the last three weeks of short days (compared with no supplementary lighting). Additional benefits, which enhanced visual quality, included darker coloured foliage and deeper petal colour due to lighting at the end of short days. These benefits were much clearer for the 12 $W/m^2$ weeks 7-9 treatment than the 4.8 $W/m^2$ weeks 7-9 treatment. These improvements were also noted throughout the shelf-life assessment period. Visual quality during shelf-life was also enhanced by the reduction in number of distorted flowers produced per pot due to lighting at the end of SD. The 4.8 $W/m^2$ and 12 $W/m^2$ treatments were equally effective in this respect.

Overall, lighting during weeks 7-9 SD clearly had a greater impact on generative growth (flower development) than on vegetative growth. This would be expected since the vegetative growth period occurs during long days and initial short days when plants were not receiving supplementary lighting. Thus while these treatments may not be expected to increase the vegetative bulk of the pot they would enhance its quality at marketing as well as during shelf-life and in speeding up flower development, also giving some benefits in reducing production time. To further improve quality at marketing it may be possible to combine the benefits achieved in flower quality through lighting at the end of short days with other treatments earlier in production to increase vegetative growth (and hence ensure specifications for height and spread are met). Such treatments may include extra long days, different pinching techniques or decreasing night length.

# 3. The influence of supplementary lighting and spacing on winter quality

## 3.1 Vegetative development and flower production

### 3.1.1 Production time

a. Spacing

Increasing the density of pots to 16 pots/$m^2$ (final spacing) significantly (*) increased production time in comparison with a standard spacing of 13.5 pots/$m^2$ (final spacing). The difference in time was 0.9 days overall for data meaned across sticking dates, lighting regimes and varieties.

Mean number of days from sticking to marketing

| **13.5 pots/$m^2$** | **16 pots/$m^2$** |
|---|---|
| 81.6 | 82.5 |

S.E.D. = 0.199, L.S.D. (P = 0.05) = 0.553

Delays recorded in individual treatment means (Figures 1a-1c, Appendix III, pages 90-92) were in the order of 1-2 days which, while longer than the differences in mean data above, are small overall.

b. Spacing x supplementary lighting regime

There was no significant interaction between supplementary lighting regime and spacing treatment in terms of production time. Therefore slight delays in production time may be expected from closer spacing pots grown either without supplementary lighting, with lighting at 4.8 W/$m^2$ throughout SD or with lighting at 12 W/$m^2$ weeks 1-3 SD.

Mean number of days from sticking to marketing

| Spacing | No supplementary lighting | 4.8 W/m² throughout SD | 12 W/m² weeks 1-3 SD |
|---|---|---|---|
| 13.5 pots/m² | 85.8 | 80.0 | 79.2 |
| 16 pots/m² | 86.2 | 81.1 | 80.3 |

S.E.D. = 0.345, L.S.D. (P = 0.05) = 0.96

There was no significant interaction between variety and spacing treatment or between sticking date and spacing treatment in terms of production time.

### 3.1.2 Plant height

a. Spacing

Reducing plant spacing had no significant effect on height for data meaned across sticking dates, varieties and lighting regimes.

Mean plant height (cm)

| 13.5 pots/m² | 16 pots/m² |
|---|---|
| 15.4 | 15.2 |

This is also clear in the individual treatment mean data (Figures 1a-1c, Appendix III, pages 90-92) where there is fluctuation in plant height but no consistent trends relating to spacing treatment.

There were no significant interactions found for plant height data.

### 3.1.3. Plant spread

a. Spacing

Average pot spread was significantly reduced by closer spacing. A reduction of 0.8 cm was recorded for data meaned across sticking weeks, varieties and lighting regimes.

Average pot spread (cm)

| 13.5 pots/m² | 16 pots/m² |
|---|---|
| 30.1 | 29.3 |

S.E.D. = 0.217, L.S.D. (P = 0.05) = 0.60

As with production time data discussed above, the influence of spacing on pot spread, although statistically significant, was only small and not likely to be of importance commercially. This is also reflected in the individual treatment mean data (Figures 2a-2c, Appendix III, pages 93-95).

There were no significant interactions found either with sticking week, lighting regime or variety and spacing for average plant spread.

### 3.1.4 Leaf quality

Closer pot spacing was expected to reduce leaf quality as a result of higher microclimate humidity and therefore greater risk from disease as well as mechanical damage. There was however no significant difference between 13.5 and 16 pots/m² final spacing in terms of the qualitative leaf damage score recorded, although a slightly higher mean score resulted from the closer spacing treatment.

Mean leaf damage score

| 13.5 pots/m² | 16 pots/m² |
|---|---|
| 0.28 | 0.37 |

This trend in mean data can also be observed in the individual treatment mean figures (Figures 4a-4c, Appendix III, pages 99-101) where higher leaf damage scores were associated with closer spacing for several treatment combinations particularly for sticking weeks 41 and 48. This data is however variable and also inconsistent in that higher leaf damage also results from the wider spacing treatment in some cases. Overall it is also clear the extent of leaf damage was low with treatment mean figures generally remaining below the score 1 figure relating to minor levels of damage only. These results confirm previous assessments of closer spacing treatments (Wilson, 1994 & 1995).

### 3.1.5 Developing (stages 1-3) and open (stages 4+) buds/flowers

a. Spacing

The number of developing buds per pot was significantly (*) influenced by spacing treatment with a lower number associated with spacing at 16 pots/m$^2$ final spacing than at 13.5 pots/m$^2$ final spacing for data meaned across sticking week, lighting regimes and varieties. The number of open flowers per pot however was not significantly influenced by spacing treatment.

Mean number of buds/flowers per pot

| | **13.5 pots/m$^2$** | **16 pots/m$^2$** |
|---|---|---|
| Stages 1-3 | 13.1 | 11.4 |
| Stages 4+ | 15.7 | 15.1 |

Stages 1-3: S.E.D. = 0.417, L.S.D. (P = 0.05) = 1.16

b. Spacing x supplementary lighting regime

There was no significant interaction between lighting regime and spacing on the number of developing or open buds produced per pot. Therefore, for each lighting regime there were fewer developing buds per pot from spacing at 16 pots/m$^2$ (final spacing) than at 13.5 pots/m$^2$ (final spacing) and no significant difference between spacing treatments in the number of open flowers produced per pot.

Mean number of buds/flowers per pot

| | **No supplementary lighting** | **4.8 W/m$^2$ throughout SD** | **12 W/m$^2$ weeks 1-3 SD** |
|---|---|---|---|
| **Stages 1-3** | | | |
| 13.5 pots/m$^2$ | 11.6 | 20.4 | 7.3 |
| 16 pots/m$^2$ | 10.4 | 16.9 | 6.9 |
| **Stages 4+** | | | |
| 13.5 pots/m$^2$ | 15.0 | 18.8 | 13.2 |
| 16 pots/m$^2$ | 14.6 | 18.5 | 12.1 |

Stages 1-3: S.E.D. = 0.722, L.S.D. (P = 0.05) = 2.00

There were no significant interactions between sticking date or variety and spacing treatment.

### 3.1.6 Maximum bud stage

a. Spacing

Average maximum bud stage was significantly (**) influenced by spacing treatment. That is average maximum bud stage was significantly reduced by closer pot spacing.

Average maximum bud stage

| **13.5 pots/m²** | **16 pots/m²** |
|---|---|
| 7.97 | 7.69 |

S.E.D. = 0.050, L.S.D. (P = 0.05) = 0.139

b. Spacing x supplementary lighting regime

This slight reduction in average bud stage was also recorded for each of the lighting regimes assessed.

Average maximum bud stage

| | **No supplementary lighting** | **4.8 W/m² throughout SD** | **12 W/m² weeks 1-3 SD** |
|---|---|---|---|
| 13.5 pots/m² | 7.88 | 8.07 | 7.97 |
| 16 pots/m² | 7.47 | 7.95 | 7.67 |

S.E.D. = 0.087, L.S.D. (P = 0.05) = 0.24

These reductions in average maximum bud stage reflect the slight delays in production time and decreases in numbers of developing buds discussed above. There were no significant interactions between sticking weeks, varieties or lighting regimes and spacing treatment.

## 3.2 Shelf-life performance

### 3.2.1 Leaf quality

In accordance with results found at marketing, spacing did not significantly influence leaf damage score during shelf-life. There was however a trend throughout shelf-life of higher leaf damage score due to closer spacing. Leaf damage score increased with length of time in shelf - life but change with time was not apparently influenced by spacing treatment.

Mean leaf damage score

| Number of days from marketing | 13.5 pots/m$^2$ | 16 pots/m$^2$ |
|---|---|---|
| 7 | 0.43 | 0.63 |
| 14 | 0.60 | 0.82 |
| 21 | 0.88 | 1.00 |
| 28 | 1.11 | 1.15 |

Overall leaf damage score was low for both spacing treatments throughout shelf-life reaching minor levels of damage only at the end of the assessment period for data meaned across sticking weeks, varieties and lighting regimes. There were no significant interactions between sticking weeks, varieties or lighting regimes and spacing treatment.

Spacing treatment also had no significant influence over the number of open flowers or distorted flowers recorded during shelf-life. Total length of viable shelf-life was also not significantly influenced by spacing.

## 3.3 Compost analyses

Compost analysis results for individual plots (Table 3, Appendix IV, page 109) and mean results across sticking weeks presented below both indicate that closer spacing was generally associated with lower nutrient levels within the compost after 8 weeks of short days. All nutrients except for phosphorus followed this general trend for all three lighting regimes and both varieties. It is difficult to offer a definite explanation of this trend - possibilities include higher microclimate, humidity from closer spacing may have reduced transpiration and therefore watering frequency however such a trend was not apparent in the day to day maintenance of the trial. Spacing of the pots may have artificially influenced irrigation practise with pots being more difficult to reach (since all pots were watered from above by hand).

Mean compost analyses

| | Spacing (pots/m$^2$) | Bulk density g/ml | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/1) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No Supplementary lighting | 13.5 | 0.41 | 5.3 | 318 | 138 | 0.73 | 52 | 45 | 109 | 88 |
| | 16.0 | 0.41 | 5.3 | 285 | 128 | 0.63 | 45 | 53 | 91 | 71 |
| 4.8 W/m$^2$ throughout SD | 13.5 | 0.44 | 5.4 | 254 | 99 | 2.63 | 43 | 24 | 91 | 61 |
| | 16.0 | 0.46 | 5.5 | 192 | 72 | 0.60 | 36 | 26 | 65 | 45 |
| 12 W/m$^2$ weeks 1-3 SD | 13.5 | 0.39 | 5.3 | 504 | 123 | 0.83 | 39 | 47 | 88 | 59 |
| | 16.0 | 0.41 | 5.4 | 234 | 101 | 0.57 | 39 | 33 | 81 | 62 |
| Cerise About Time: | | | | | | | | | | |
| No Supplementary lighting | 13.5 | 0.44 | 5.1 | 355 | 183 | 1.10 | 62 | 90 | 146 | 114 |
| | 16.0 | 0.42 | 5.1 | 323 | 142 | 0.83 | 58 | 78 | 118 | 94 |
| 4.8 W/m$^2$ throughout SD | 13.5 | 0.44 | 5.4 | 251 | 100 | 0.80 | 46 | 29 | 91 | 66 |
| | 16.0 | 0.46 | 5.3 | 226 | 89 | 0.77 | 45 | 31 | 79 | 61 |
| 12 W/m$^2$ weeks 1-3 SD | 13.5 | 0.41 | 5.2 | 296 | 123 | 0.67 | 46 | 53 | 103 | 72 |
| | 16.0 | 0.42 | 5.4 | 247 | 88 | 0.70 | 50 | 37 | 87 | 64 |

### 3.4 Summary - spacing treatments

Spacing was found to have a statistically significant influence on plant development and flower production. These effects were detrimental with, for example, increases in production time of 1-2 days, reduction in average pot spread of 0.8 cm and decreases in number of developing buds of 0.4 to 3.5 buds per pot associated with closer plant spacing.

Given the size of these changes however, their impact on commercial production is likely to be small. These results reflect those found for spacing treatments assessed in the winter 1994/95 period under the HDC funded project PC92a (Wilson, 1995) which examined spacing treatments in combination with four supplementary lighting regimes. It was unclear at the end of the 1994/95 project however whether close spacing was only possible in winter if plants were receiving additional light energy in the form of supplementary lighting. It was therefore suggested that closer spacing may cause greater problems for crops grown without supplementary lighting. Comparison of spacing treatments under the three lighting regimes in the current project (i.e. no supplementary lighting, 4.8 $W/m^2$ throughout SD and 12 $W/m^2$ weeks 1-3 SD) indicated, however, that there was no interaction between lighting regime and the closer spacing treatment assessed. The impact of closer spacing was therefore the same for all lighting regimes assessed.

It is clearly possible to reduce pot spacing in the winter and therefore increase returns on a $m^2$ basis. This will result in some quality penalties as outlined above which would need to be balanced against desired specification and the improvements in returns due to increased volume of sales. The impact of pot spacing is also likely to be specific to different growing systems and the vigour of varieties grown. Systems which produce higher humidity levels combined with dense leaf canopies may be expected to suffer more from closer spacing. The growing system involved in the current trial utilised rolling benches covered with fibre glass matting and aquafol with benches on concrete floors. Floors and matting were frequently damped to maintain high humidity but this system would still be expected to produce lower humidities than some commercial systems in use.

## 4. Economic Evaluation

In this interim report costings only of the treatments have been calculated. As with calculations carried out for spray chrysanthemum work (e.g. Wilson, 1996) it is envisaged that a cost-benefit approach can be taken for these figures for inclusion in the final project report. The full costing calculations are presented in Appendix VI (page 122).

### 4.1 The cost of night length treatments

The cost of reducing night length depends on the lighting regime in question. For example where lighting is provided at 4.8 $W/m^2$ throughout short days reducing night length requires a small increase in electricity consumed only. As a consequence the increase in price relative to the 'standard' treatment (i.e. of a 13 hour night) is 0.7p/pot or 2% for the shortest night given. To reduce night length for the remaining lighting regimes studied, installation and use of tungsten lighting is required for part or all of the production period. As a consequence these options are more expensive relative to the standard treatment, e.g. a 12 hour night with no supplementary lighting requires an extra 2p per pot, but the overall cost of the treatments is low.

Summary of the cost of providing lighting for different night length treatments

| | Cost p/pot | | |
|---|---|---|---|
| | **Capital** | **Running** | **Total** |
| 1. No supplementary lighting | | | |
| Natural night | 0.0 | 0.0 | 0.0 |
| 13 hour night | 2.1 | 0.6 | 2.7 |
| 12.5 hour night | 2.1 | 0.7 | 2.8 |
| 12 hour night | 2.1 | 0.9 | 3.0 |
| 2. 4.8 $W/m^2$ throughout SD | | | |
| 13 hour night | 6.1 | 7.9 | 14.0 |
| 12.5 hour night | 6.1 | 8.2 | 14.3 |
| 12 hour night | 6.1 | 8.6 | 14.7 |
| 3. 12 $W/m^2$ week 1.3 SD | | | |
| Natural night | 3.6 | 4.6 | 8.2 |
| 13 hour night | 5.1 | 5.0 | 10.1 |
| 12.5 hour night | 5.1 | 5.3 | 10.4 |
| 12 hour night | 5.1 | 5.7 | 10.8 |

## 4.2 The cost of lighting at the end of short days

As detailed in the table below, lighting at the end of short days only was costed at 5.3p/pot for an intensity of 4.8 W/m$^2$ and 12.2p/pot for 12 W/m$^2$. Both treatments are therefore less expensive than the lighting regime of 4.8 W/m$^2$ throughout short days which is the better of the standard lighting regimes for improving quality. It is possible that further study on lighting intensities between the two examined in this study would provide a better economic option to improving quality through lighting at the end of short days only.

Since the importance of cost of treatment and the benefits produced will vary according to the type of end product desired, the table below summarises final cost against a brief description of the benefits of lighting given at the end of short days only in comparison with the two more conventional lighting regimes. The comments all assume a comparison between the lighting regime in question and no supplementary lighting.

| TREATMENT | COMMENTS ON TREATMENT EFFECTS | COST (P/POT) |
|---|---|---|
| 4.8 W/m$^2$ throughout SD | Average production time reduced by around 4-5 days. Produced highest bud count and improved foliage quality. | 14.0 |
| 12 W/m$^2$ weeks 1-3 SD | Average production time reduced by around 7-8 days. No significant improvements in foliage quality or bud count. | 8.2 |
| 4.8 W/m$^2$ weeks 7, 8 & 9 SD | Average production time reduced by around 1-2 days. Some improvement in foliage quality and bud count. | 5.3 |
| 12 W/m$^2$ weeks 7, 8 & 9 SD | Average production time decreased by up to 3-4 days. Foliage quality improved at the top of the plant in particular, and bud count increased. Significant improvement in flower colour which was maintained during shelf-life | 12.2 |

## 4.3 Savings produced with closer spacing

As in previous studies closer spacing had a small negative impact on production (as detailed in section 3). The benefits of closer spacing, in terms of reducing the cost of supplying lighting on a cost per pot basis, as detailed below would need to be balanced against the final product desired.

| Treatment | Capital | Cost p/pot<br>Running | Total |
|---|---|---|---|
| **4.8 W/m$^2$ throughout SD** | | | |
| Standard spacing<br>(13.5 pots/m$^2$ final spacing) | 6.1 | 7.9 | 14.0 |
| Close spacing<br>(16 pots/m$^2$ final spacing) | 5.1 | 6.6 | 11.7 |
| **12 W/m$^2$ weeks 1-3 SD** | | | |
| Standard spacing<br>(13.5 pots/m$^2$ final spacing) | 3.6 | 4.6 | 8.2 |
| Close spacing<br>(16 pots/m$^2$ final spacing) | 3.0 | 3.8 | 6.8 |

As always it must be emphasized that these costings have to assume certain figures such as the cost of a unit of electricity etc. Therefore while they are suitable for treatment comparisons they do not provide a definitive figure for individual nurseries. The methods used to calculate these figures are detailed in Appendix VI (page 122).

## 5. Discussion

The photoperiod, or length of night treatments produced some unexpected results in this first year of the trial. The only treatments to cause significant delay were those using supplementary lighting throughout the short day period with 12.5 hour and 12 hour night lengths. Surprisingly, reducing night length by providing tungsten lighting from dusk until 18.00 hrs, 18.30 hrs or 19.00 hrs actually reduced total production time.

The objective of reducing length of night was to increase vegetative growth on the pot to enhance final pot shape and quality. Records of vegetative growth and flower development indicate there is potential to achieve this objective. However, more extreme reductions in length of night would appear necessary which will be evaluated in year two.

Supplementary lighting for the last three weeks of short days only clearly had a beneficial impact on final quality. In particular, bud number was increased, flower colour enhanced and foliage quality improved. This treatment did not prolong the life of the pot during shelf-life but the quality improvements achieved at marketing did provide enhanced visual quality throughout shelf-life testing.

Lighting at the end of short days also reduced production time in comparison with no supplementary lighting. For maximum speed of production, however, lighting at 12 $W/m^2$ weeks 1-3 of short days was the most favourable treatment. Looking at the relative costs of these lighting regimes (page 56) lighting for weeks 1-3 of short days is also less expensive than lighting for weeks 7-9 of short days since pots are at a closer spacing for at least part of the former treatment. However this treatment will only improve speed of production and a more effective use of lighting at 12 $W/m^2$ for just three weeks of the short day period to improve quality is to time this treatment to correspond with the last three weeks of short days.

As in previous years, closer spacing has been found to be a suitable method for reducing the costs of providing supplementary lighting. The penalties of growing at closer spacing (including longer production time of 1-2 days, reduced pot spread and bud count) will need to be balanced against the savings in terms of providing supplementary lighting to each pot. It is difficult to suggest the closest spacing which may be achieved when growing with supplementary lighting, however, since individual growing systems will undoubtedly have an influence. The trial growing system is likely to represent commercial systems with low relative humidity. Systems with higher humidity are likely to be more susceptible to lower leaf damage and disease problems as spacing density increases.

## 6. Conclusions

- Reducing night length is a promising technique for improving quality.

- This technique will be evaluated further in year two.

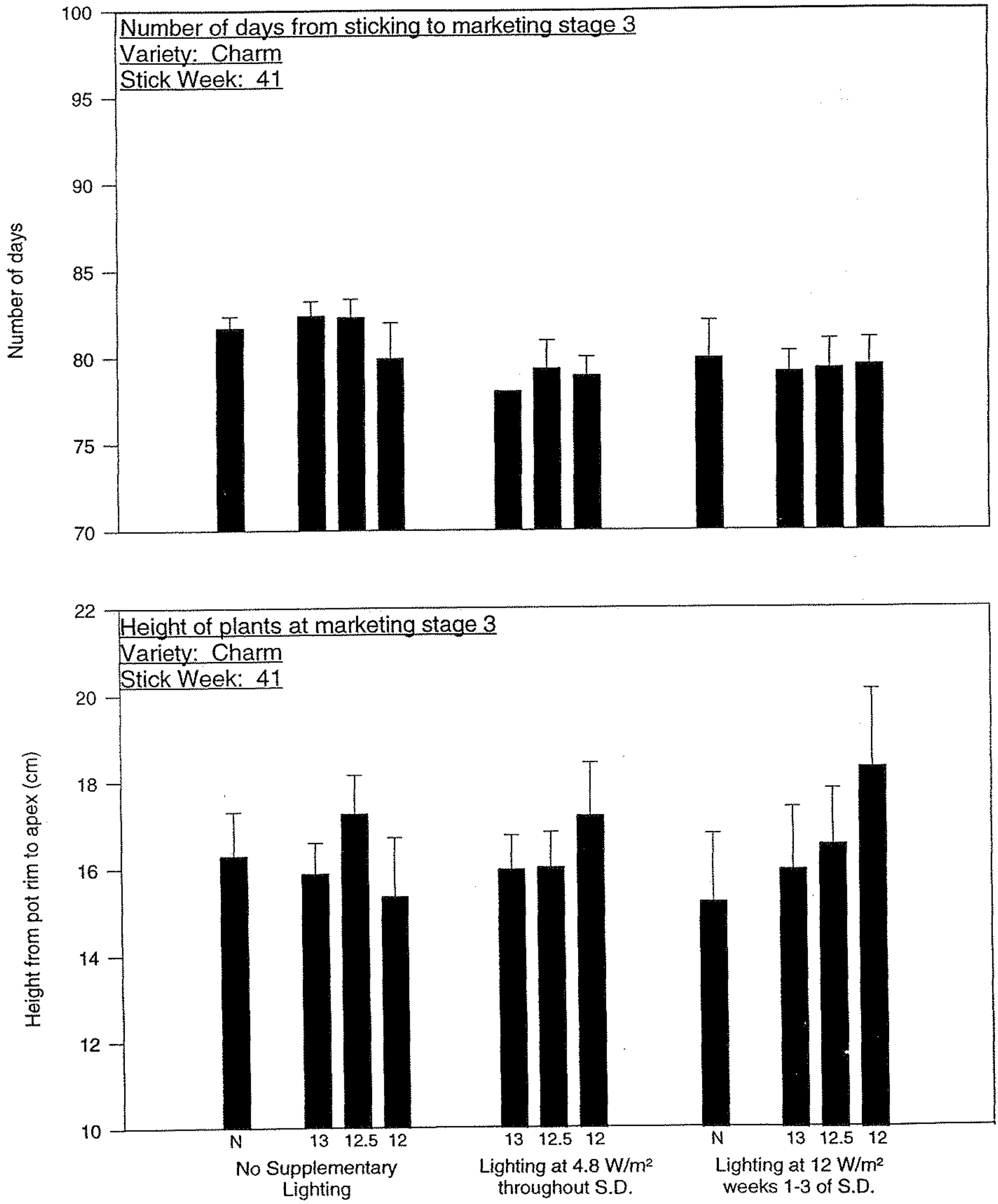
- Supplementary lighting when buds are developing and maturing into flowers provides a significant improvement in quality which gives enhanced visual pleasure at marketing and through shelf-life.

- Closer spacing may be used to reduce the cost of providing supplementary lighting, but individual growing systems must be carefully considered when decreasing the space available to individual pots.

## APPENDIX I

**Treatment means: reduced night length treatments**

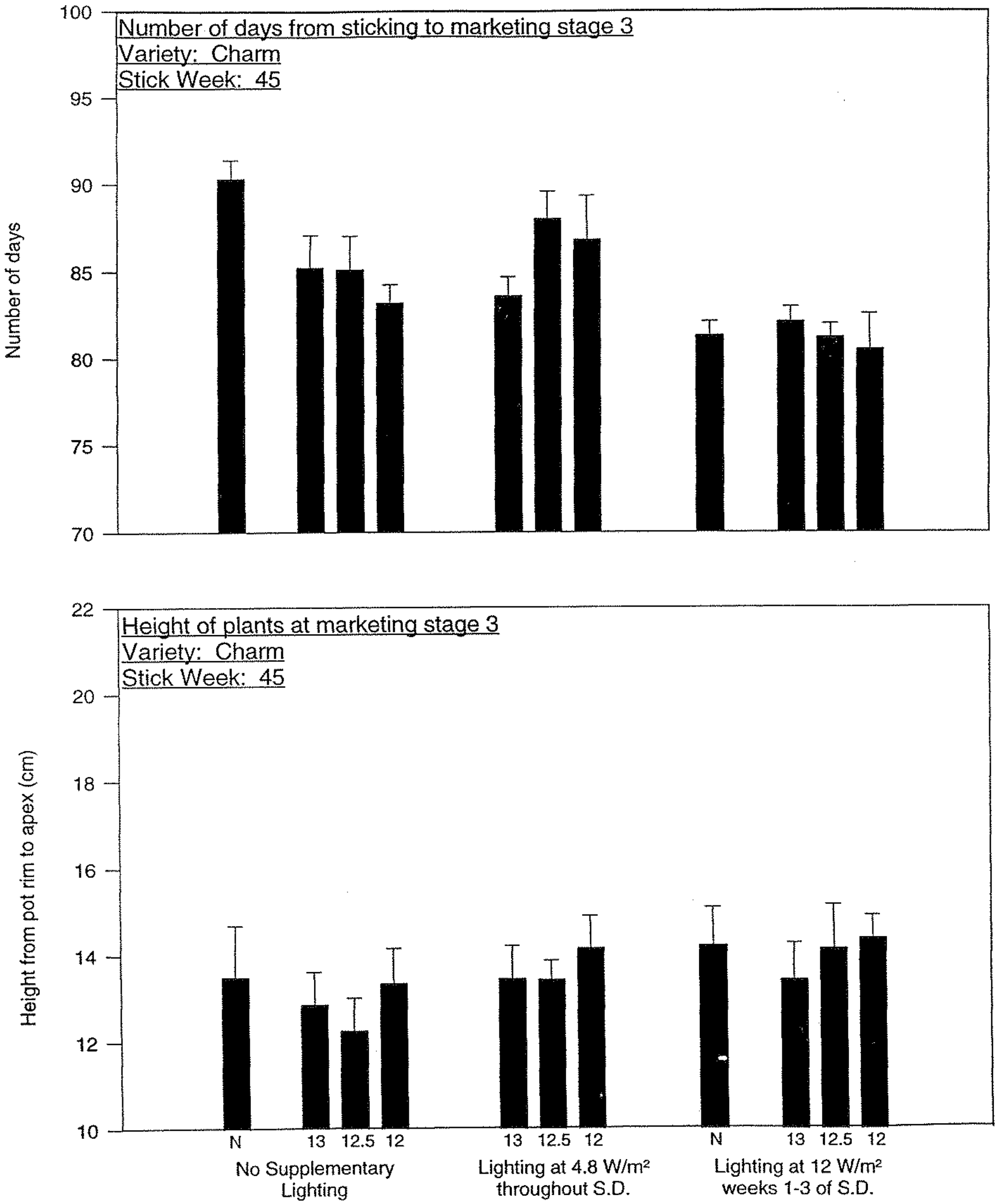
# Figure 1a: The Influence of Supplementary Lighting and Length of Night on Production time and Plant Height




**KEY TO LENGTH OF NIGHT TREATMENTS:**

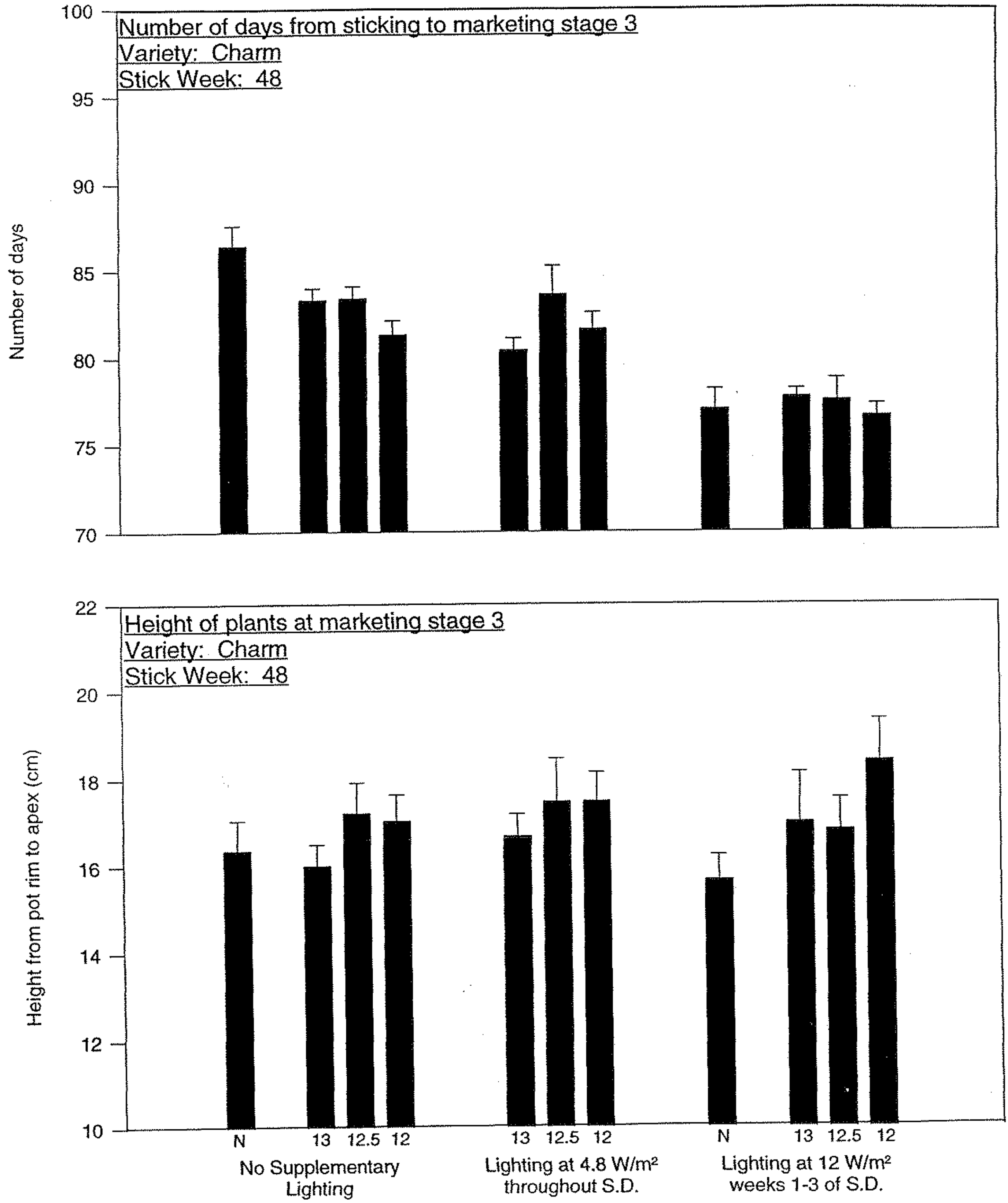
N = Natural Nightlength (i.e. blackout dusk to 0700)
13 = 13 hour dark period
12.5 = 12.5 hour dark period
12 = 12 hour dark period

## Figure 1b: The Influence of Supplementary Lighting and Length of Night on Production Time and Plant Height



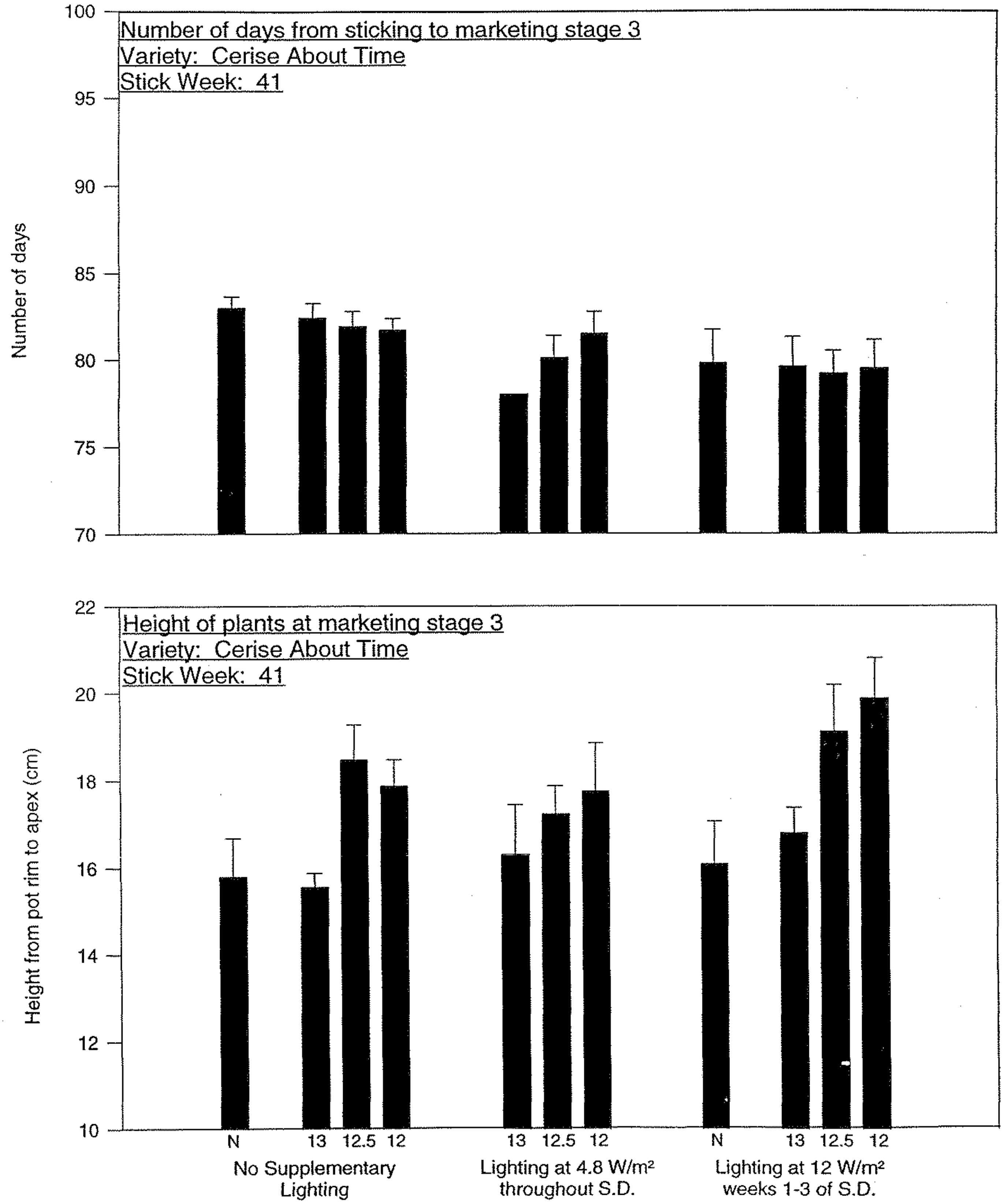

**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk to 0700)
13 = 13 hour dark period
12.5 = 12.5 hour dark period
12 = 12 hour dark period

## Figure 1c: The Influence of Supplementary Lighting and Length of Night on Production Time and Plant Height



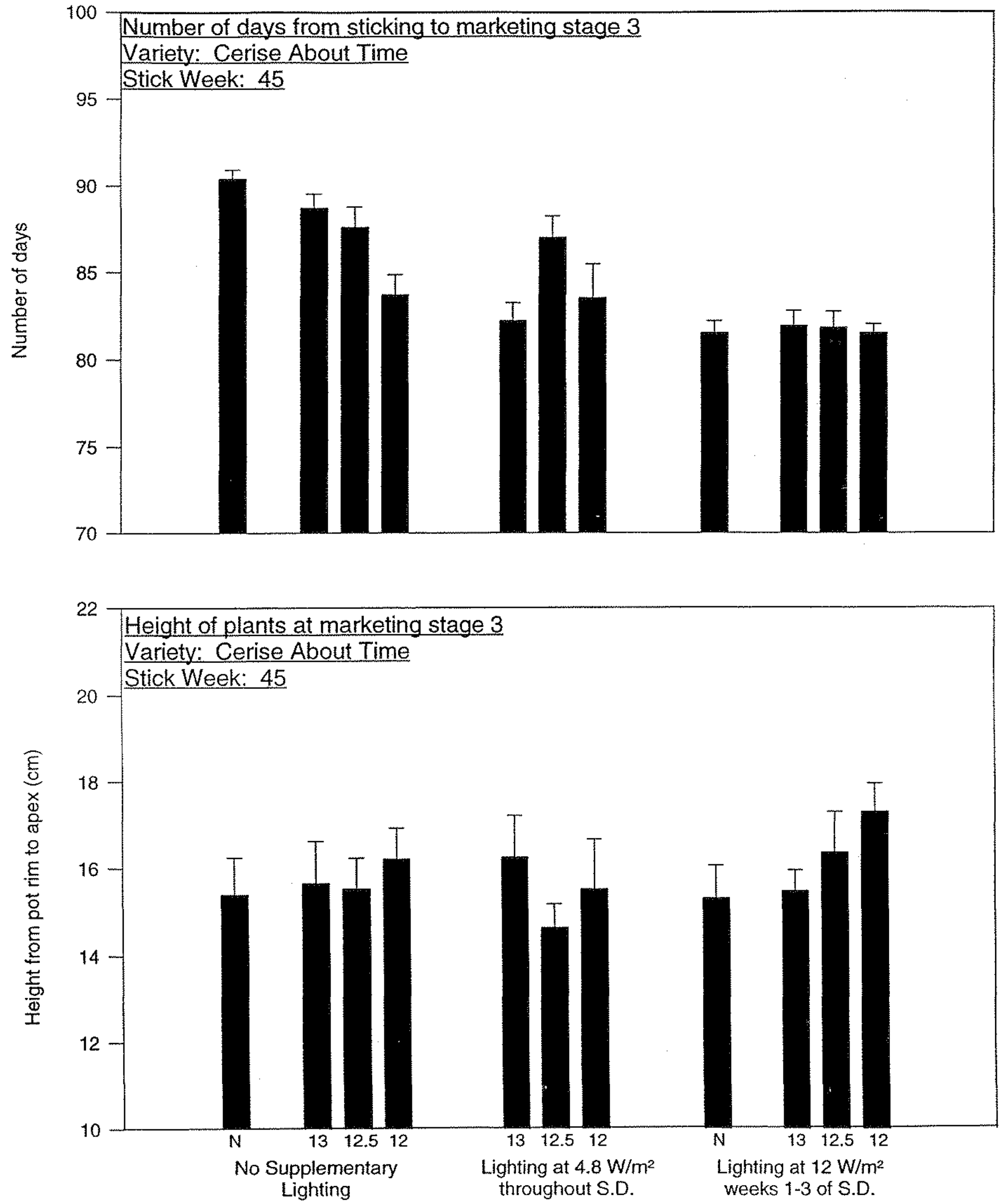

**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk to 0700)
13 = 13 hour dark period
12.5 = 12.5 hour dark period
12 = 12 hour dark period

**Figure 2a: The Influence of Supplementary Lighting and Length of Night on Production Time and Plant Height**



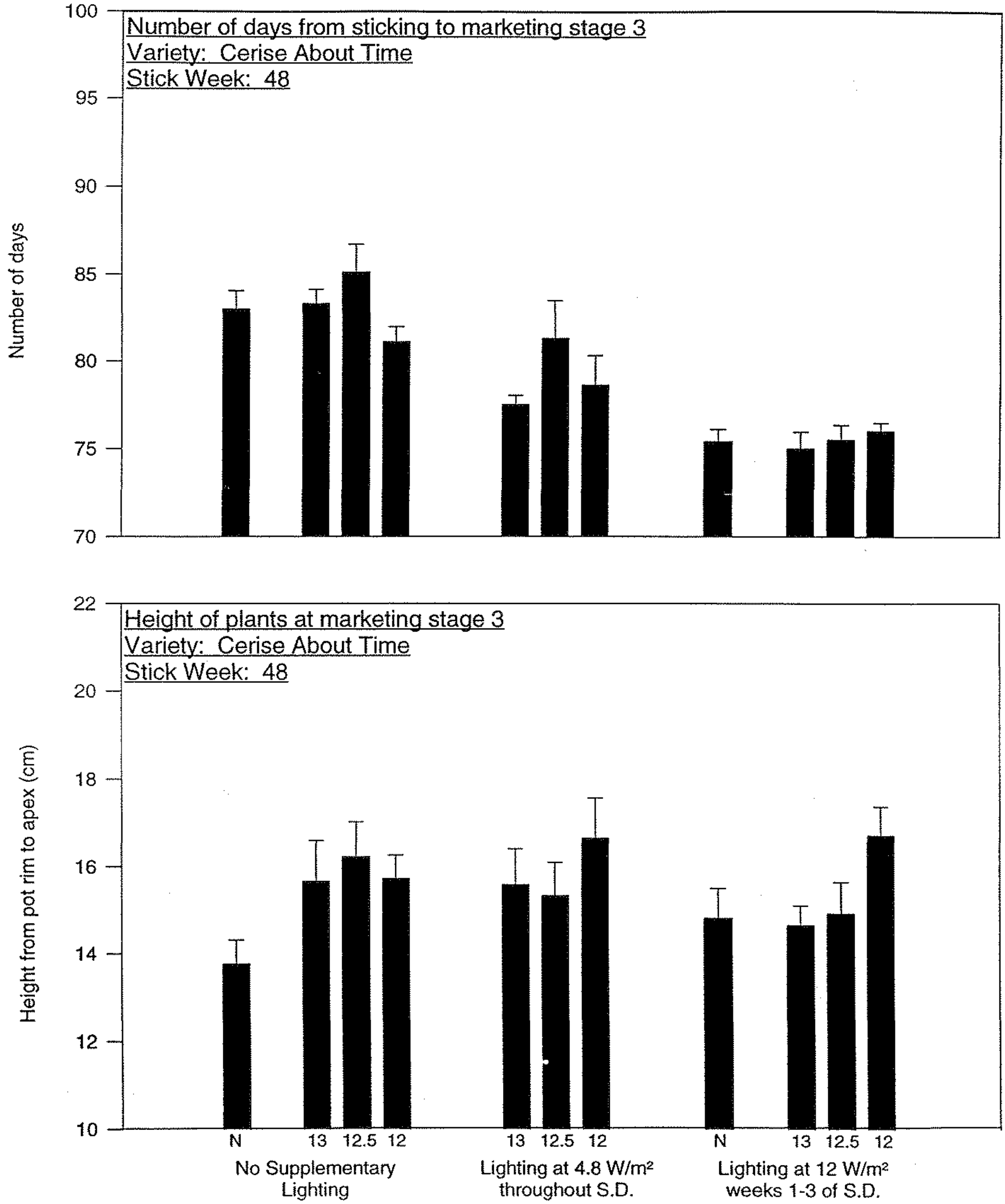

| **KEY TO LENGTH OF NIGHT TREATMENTS:** | |
|---|---|
| N = Natural Nightlength (i.e. blackout dusk til 0700) | 13 = 13 hour dark period |
| 12.5 = 12.5 hour dark period | 12 = 12 hour dark period |

## Figure 2b: The Influence of Supplementary Lighting and Length of Night on Production Time and Plant Height



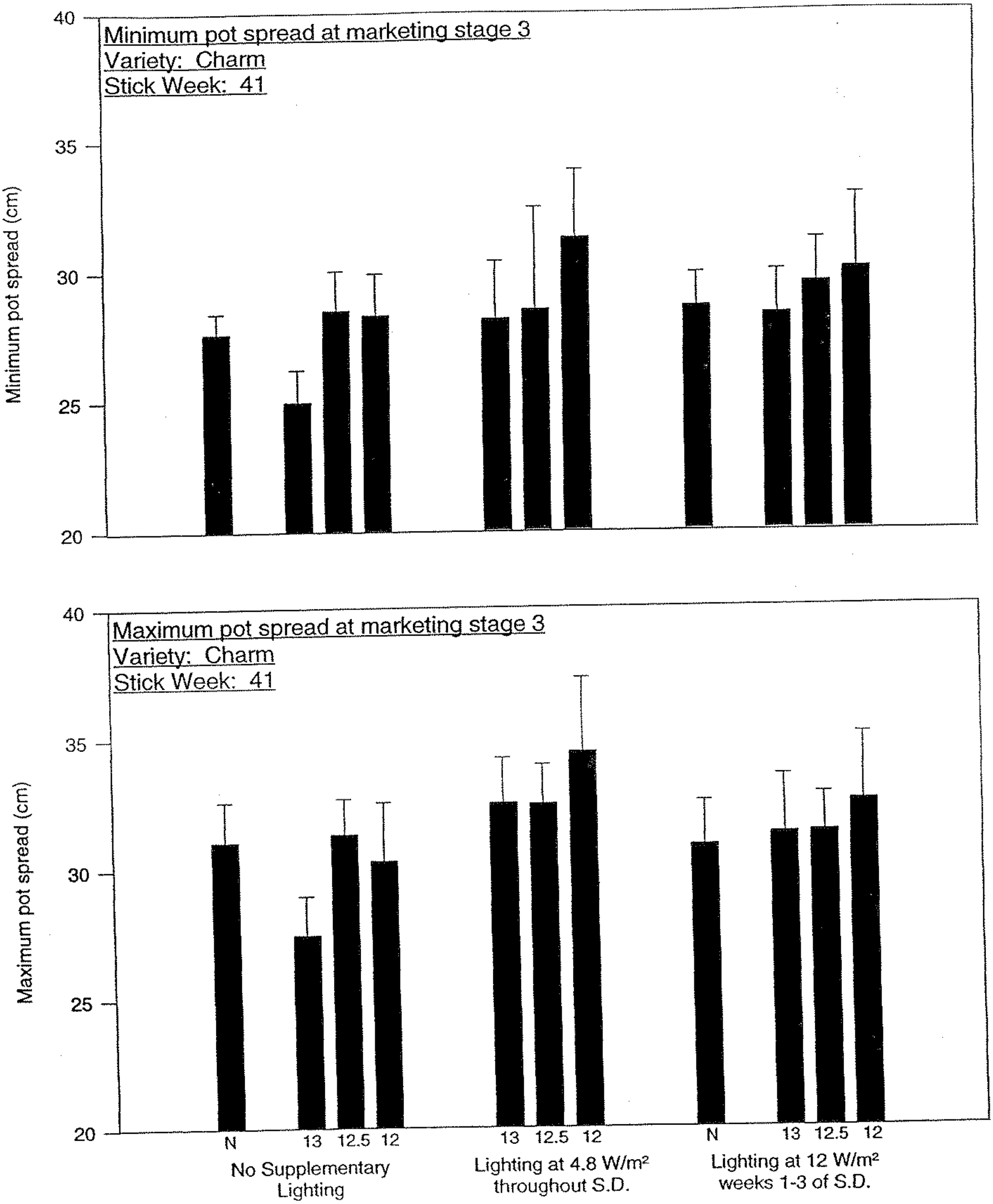

**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700) 13 = 13 hour dark period
12.5 = 12.5 hour dark period 12 = 12 hour dark period

**Figure 2c: The Influence of Supplementary Lighting and Length of Night on Production Time and Plant Height**



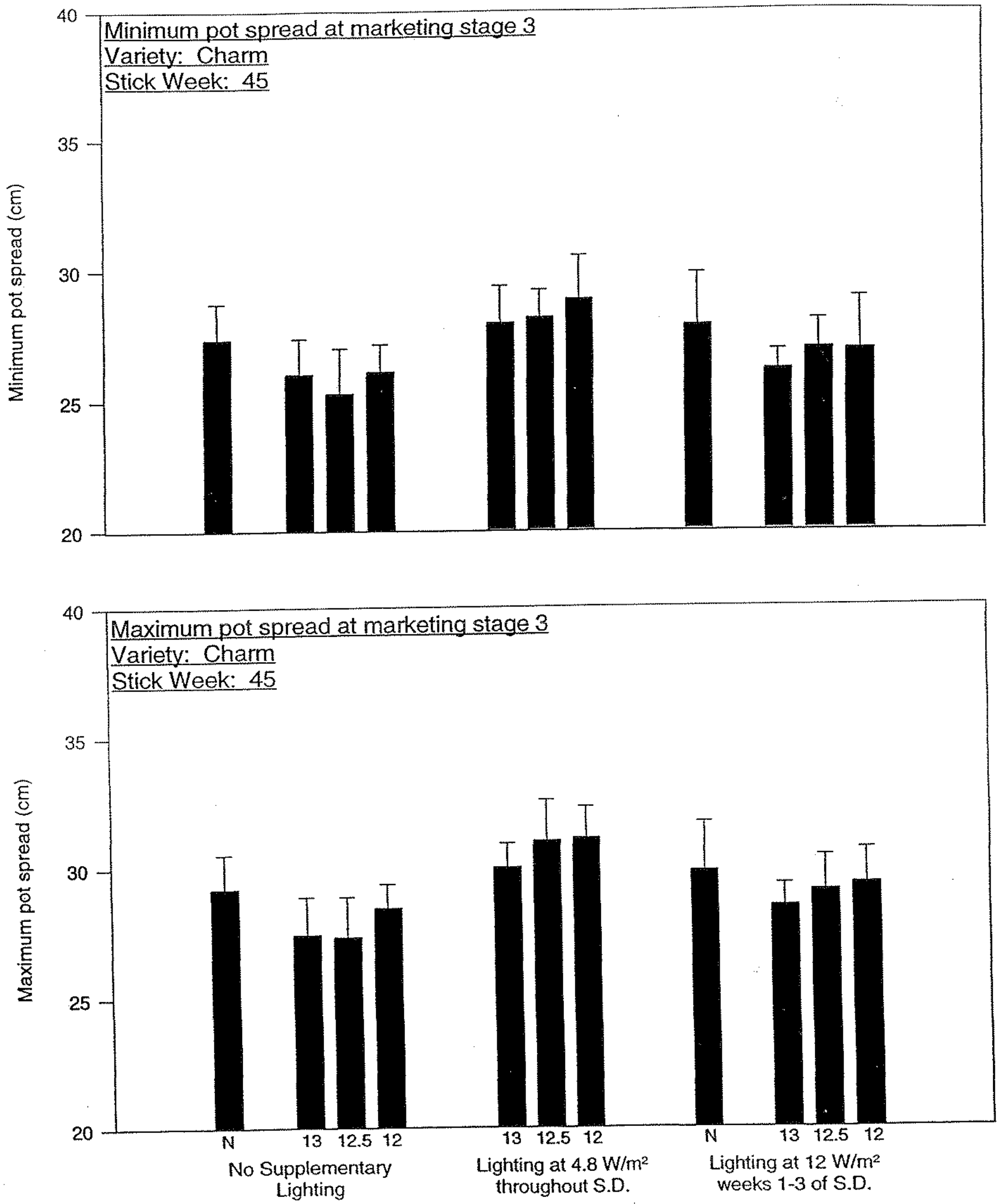

**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
13 = 13 hour dark period
12.5 = 12.5 hour dark period
12 = 12 hour dark period

## Figure 3a: The Influence of Supplementary Lighting and Length of Night on Maximum and Minimum Pot Spread




**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
13 = 13 hour dark period
12 = 12 hour dark period

## Figure 3b: The Influence of Supplementary Lighting and Length of Night on Maximum and Minimum Pot Spread




**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
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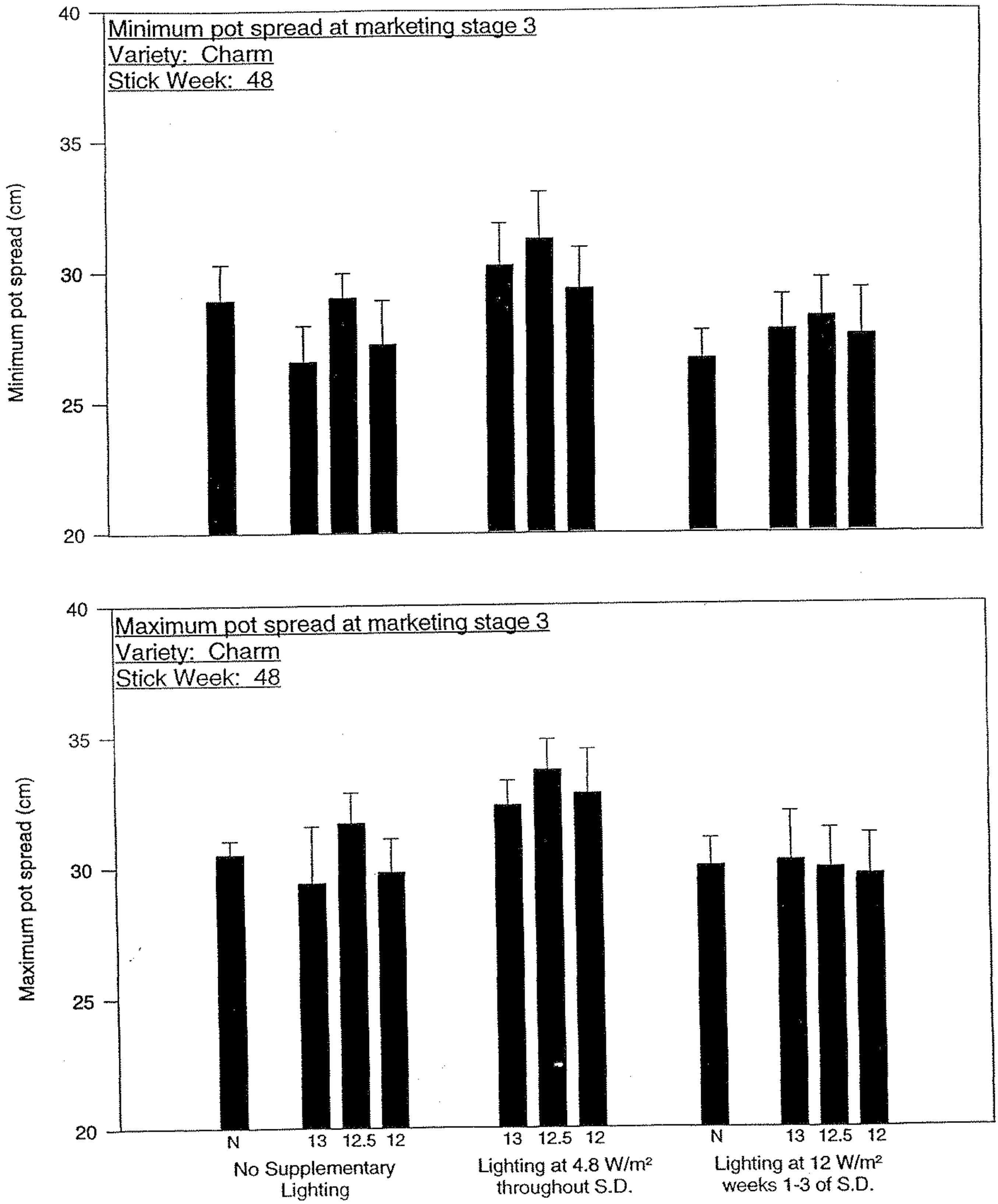
12 = 12 hour dark period

## Figure 3c: The Influence of Supplementary Lighting and Length of Night on Maximum and Minimum Pot Spread




**KEY TO LENGTH OF NIGHT TREATMENTS:**

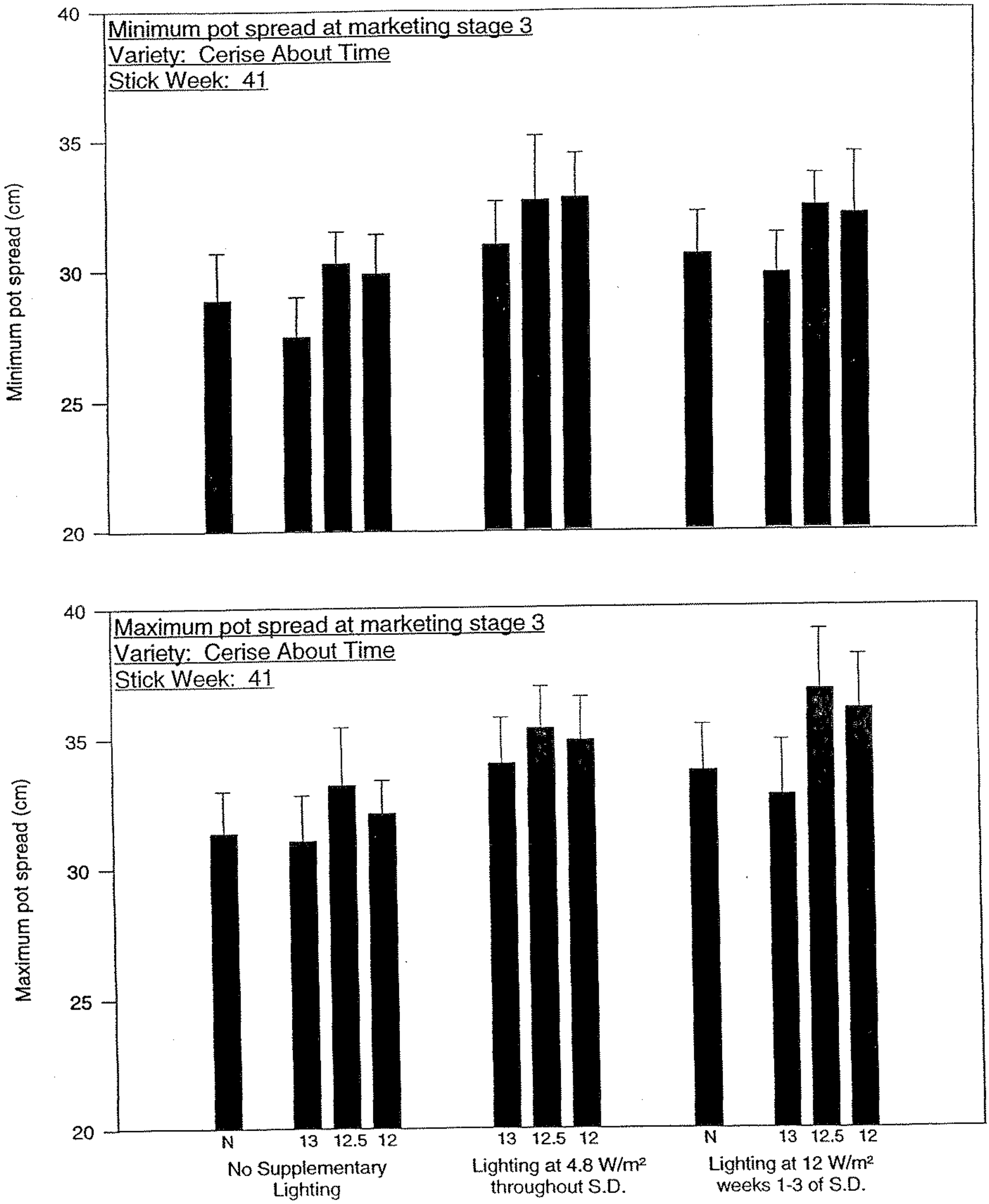
N = Natural Nightlength (i.e. blackout dusk til 0700)

12.5 = 12.5 hour dark period

13 = 13 hour dark period

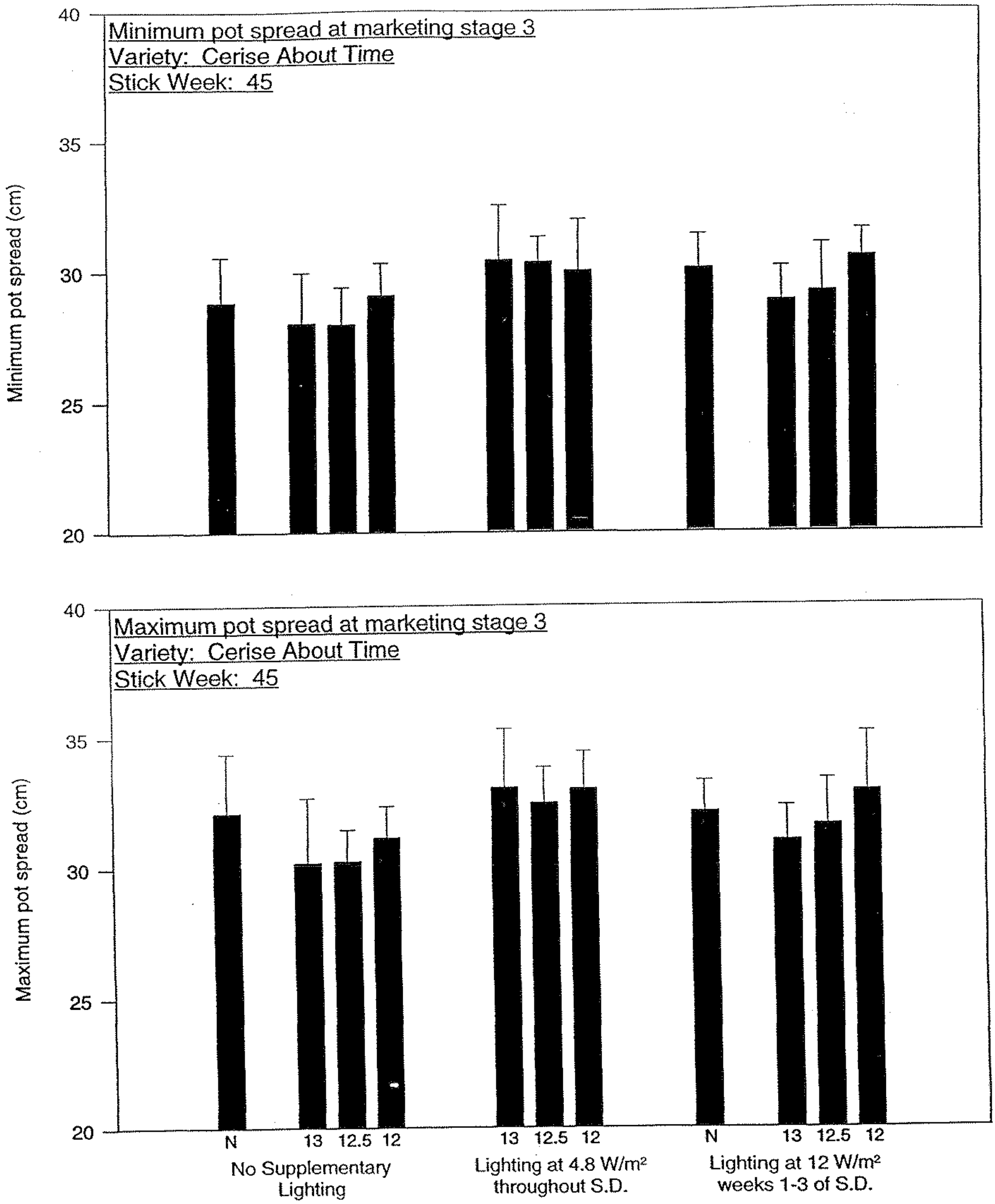
12 = 12 hour dark period

## Figure 4a: The Influence of Supplementary Lighting and Length of Night on Maximum and Minimum Pot Spread




**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
13 = 13 hour dark period
12 = 12 hour dark period

## Figure 4b: The Influence of Supplementary Lighting and Length of Night on Maximum and Minimum Pot Spread




**KEY TO LENGTH OF NIGHT TREATMENTS:**

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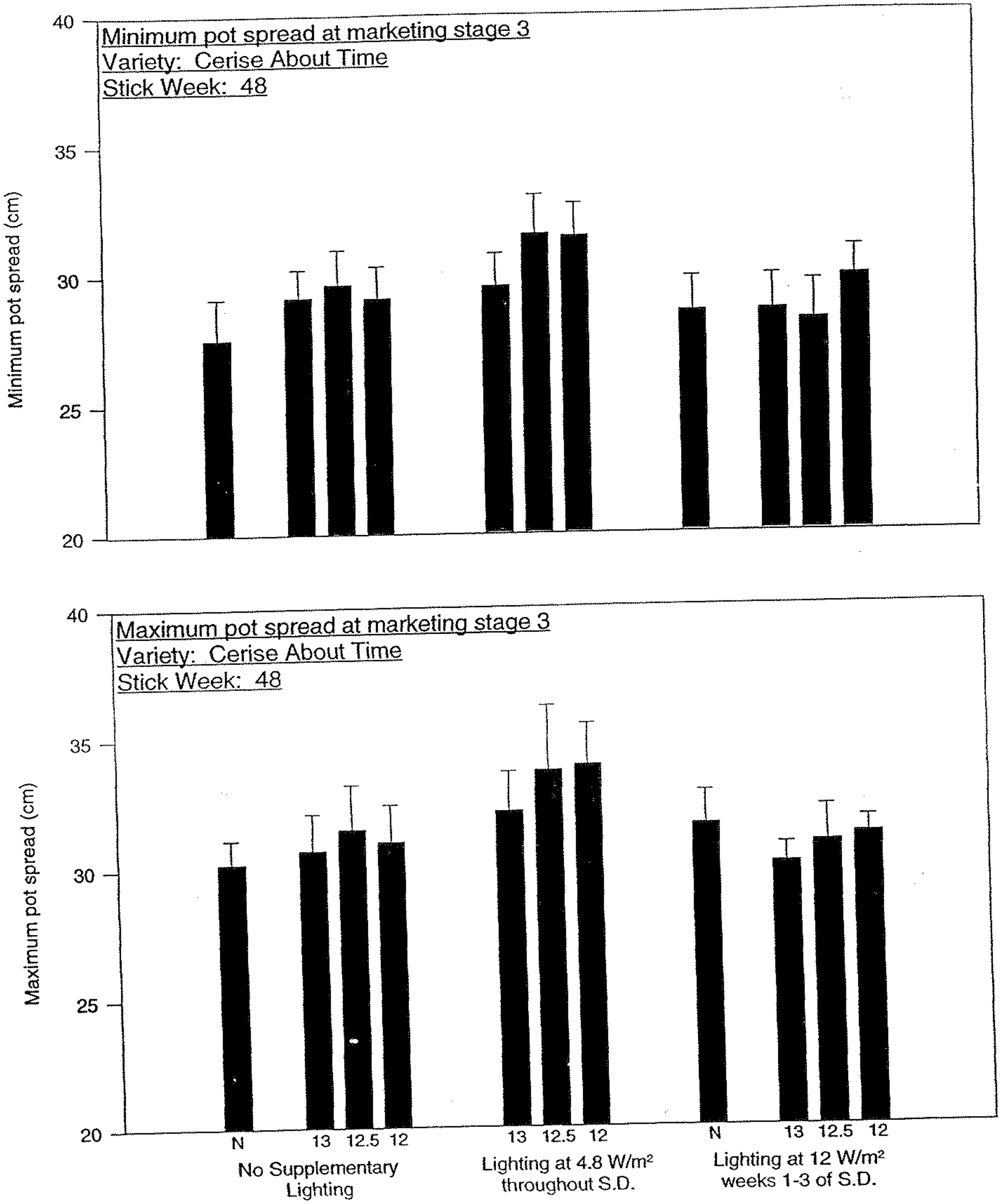
12 = 12 hour dark period

## Figure 4c: The Influence of Supplementary Lighting and Length of Night on Maximum and Minimum Pot Spread




**KEY TO LENGTH OF NIGHT TREATMENTS:**

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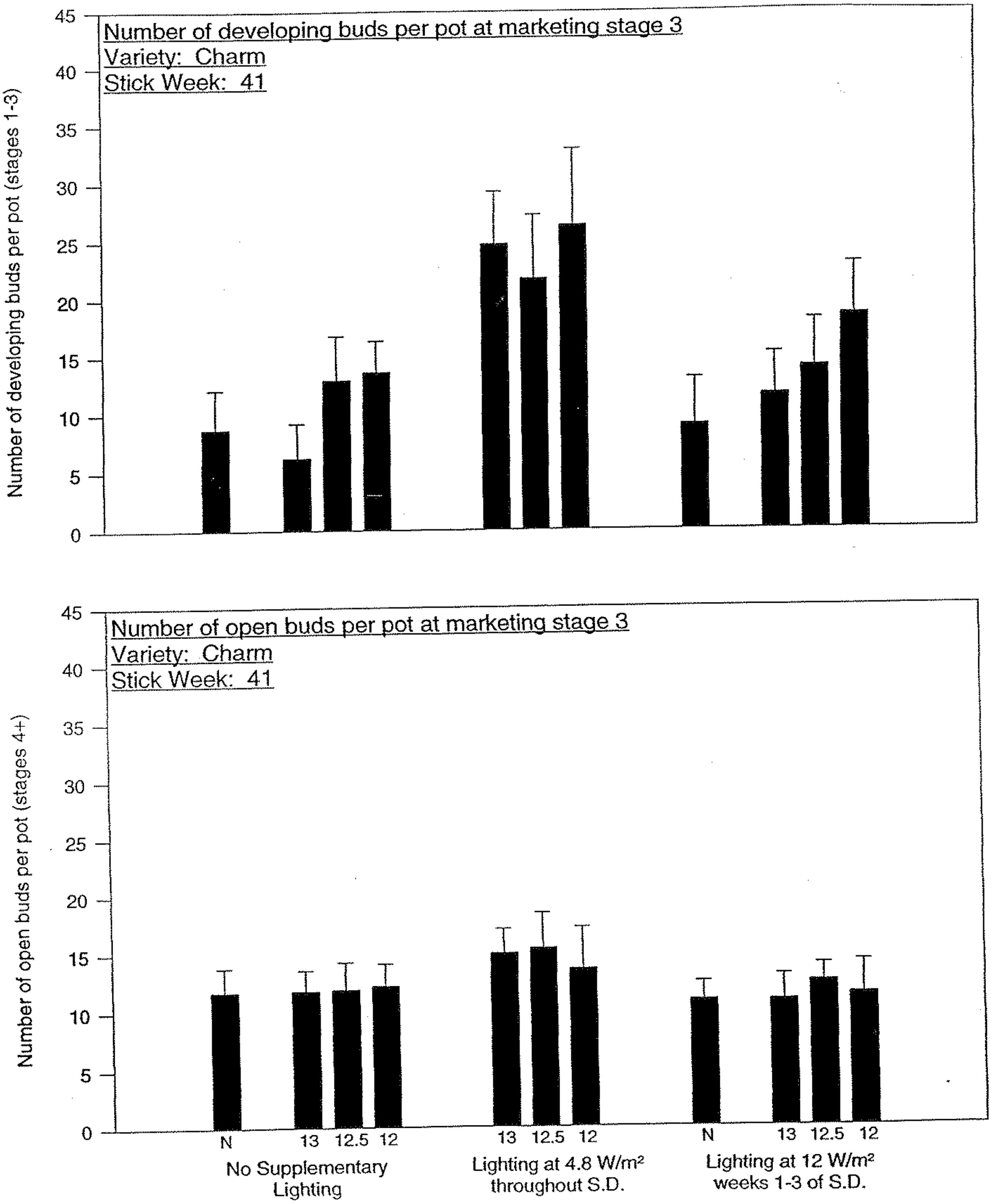
12 = 12 hour dark period

**Figure 5a: The Influence of Supplementary Lighting and Length of Night on Flower Development**




**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
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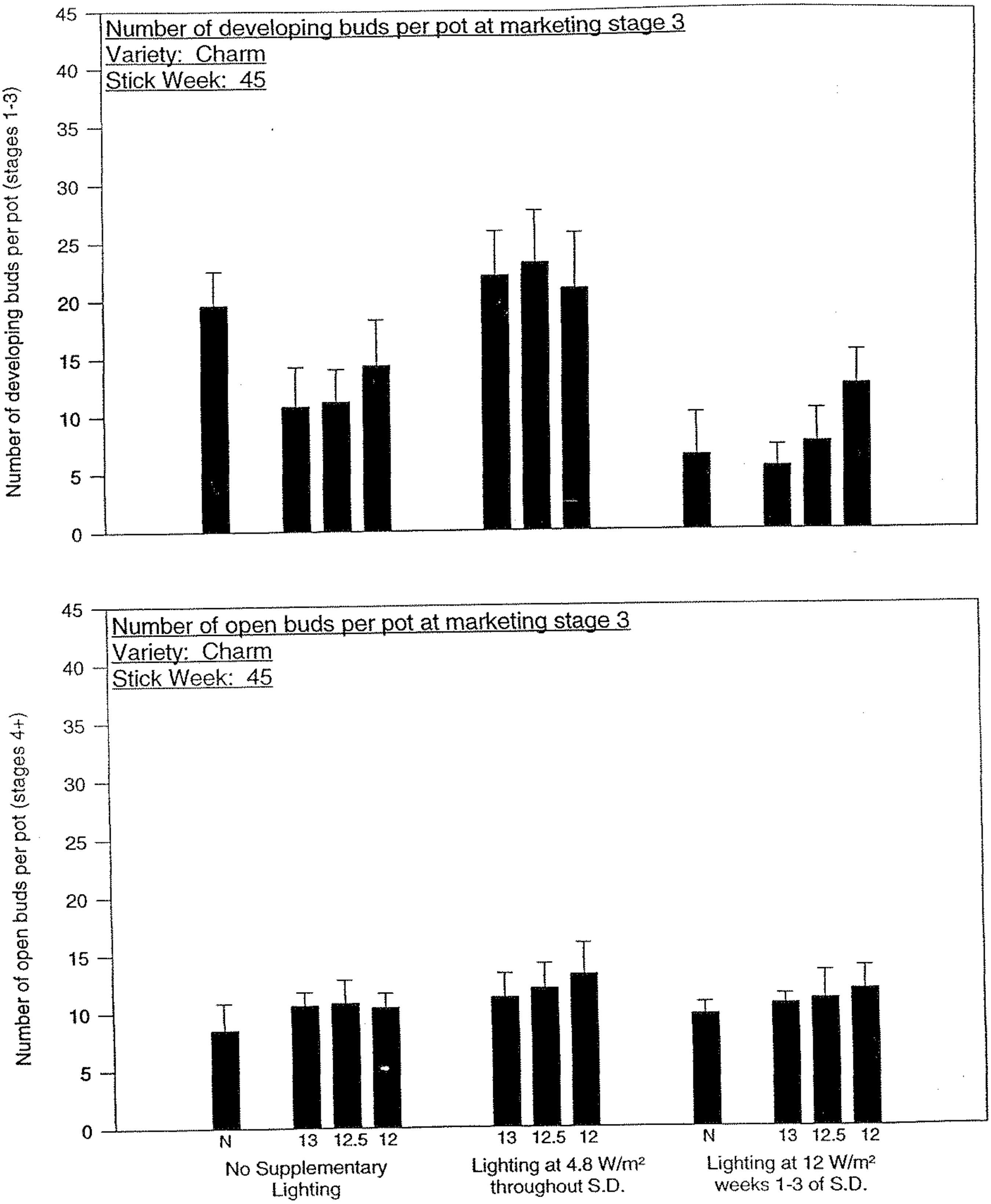
12 = 12 hour dark period

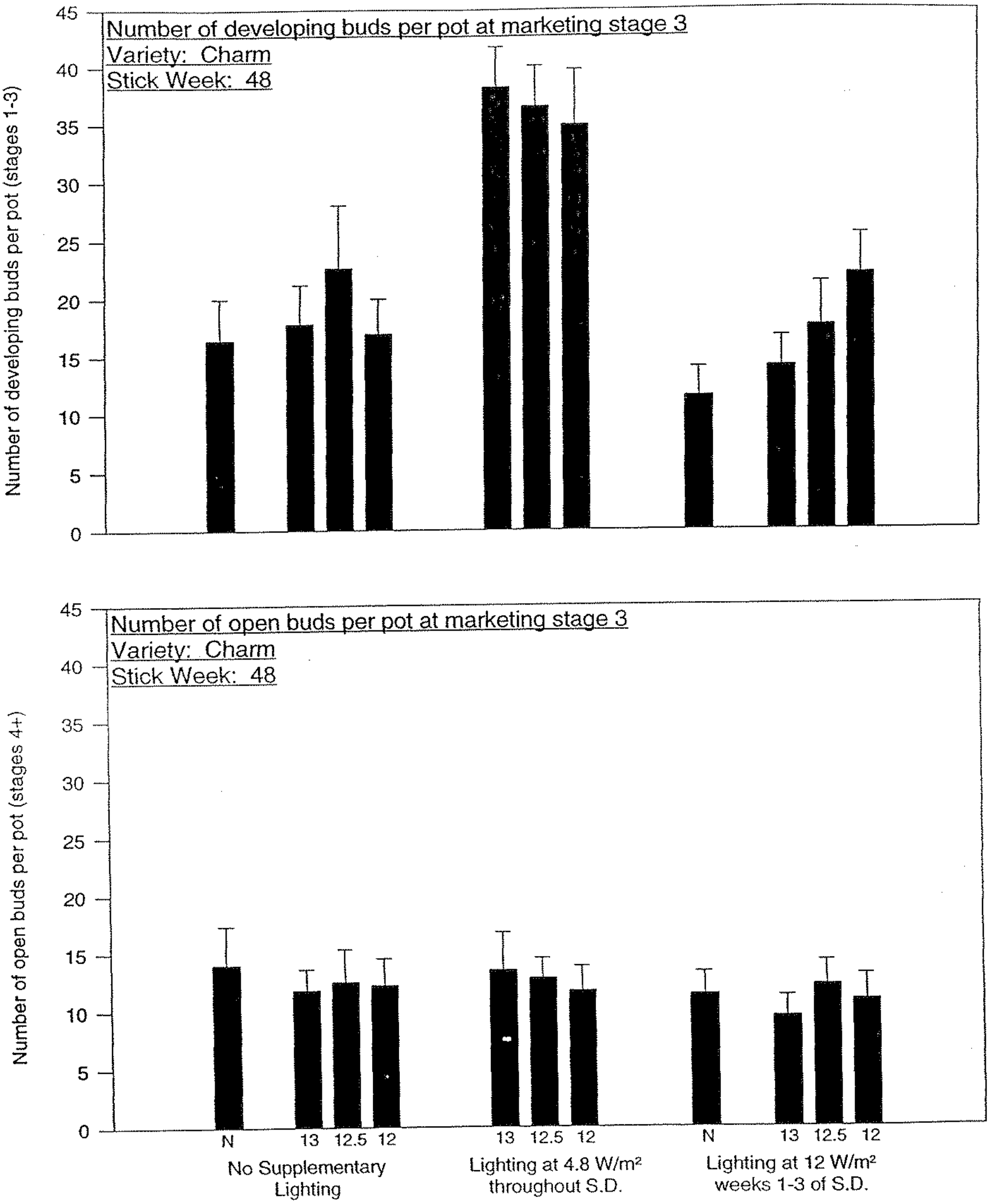
## Figure 5b: The Influence of Supplementary Lighting and Length of Night on Flower Development




**KEY TO LENGTH OF NIGHT TREATMENTS:**

N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
13 = 13 hour dark period
12 = 12 hour dark period

**Figure 5c: The Influence of Supplementary Lighting and Length of Night on Flower Development**




**KEY TO LENGTH OF NIGHT TREATMENTS:**

N = Natural Nightlength (i.e. blackout dusk til 0700)
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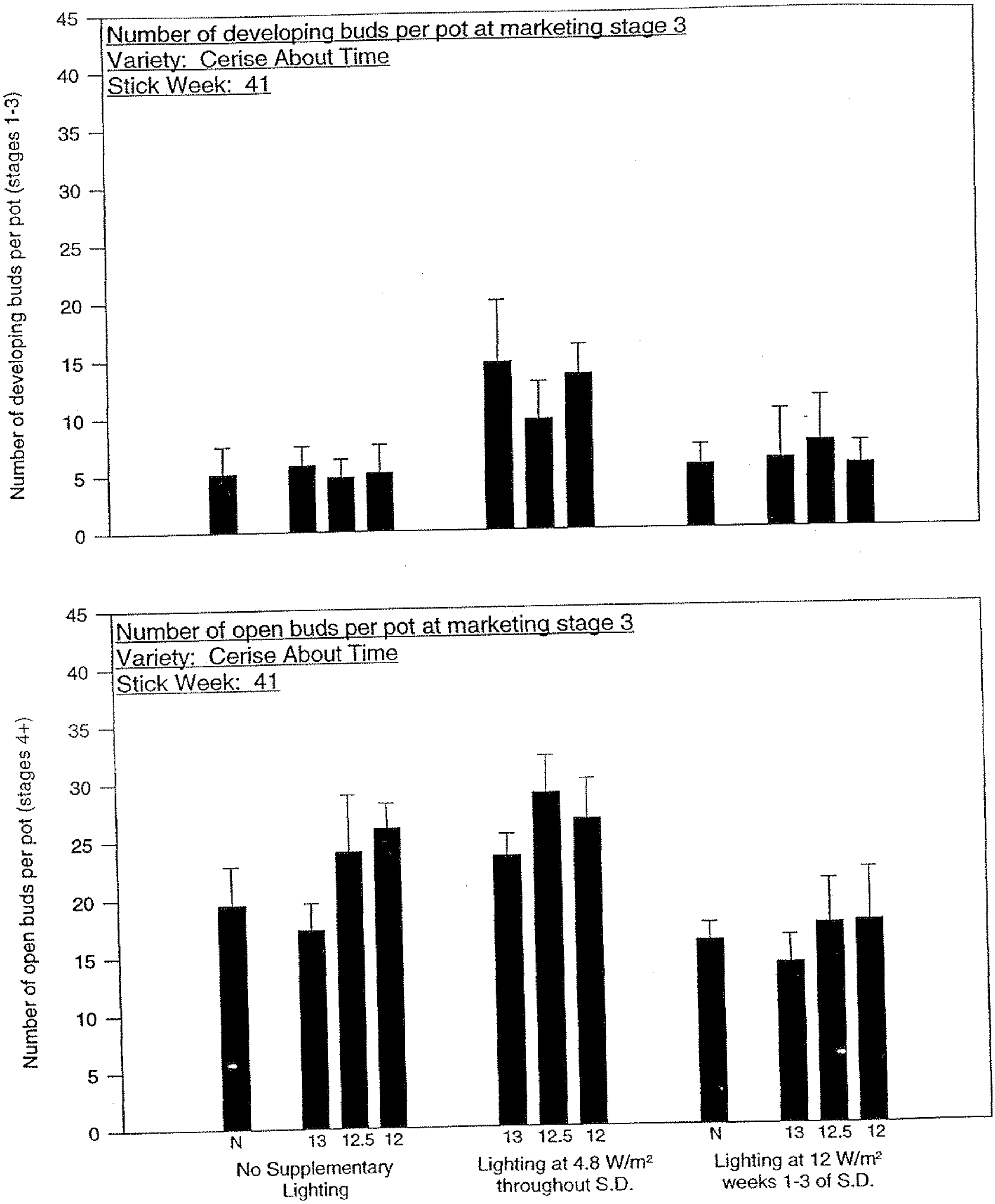
12.5 = 12.5 hour dark period
12 = 12 hour dark period

**Figure 6a: The Influence of Supplementary Lighting and Length of Night on Flower Development**




**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
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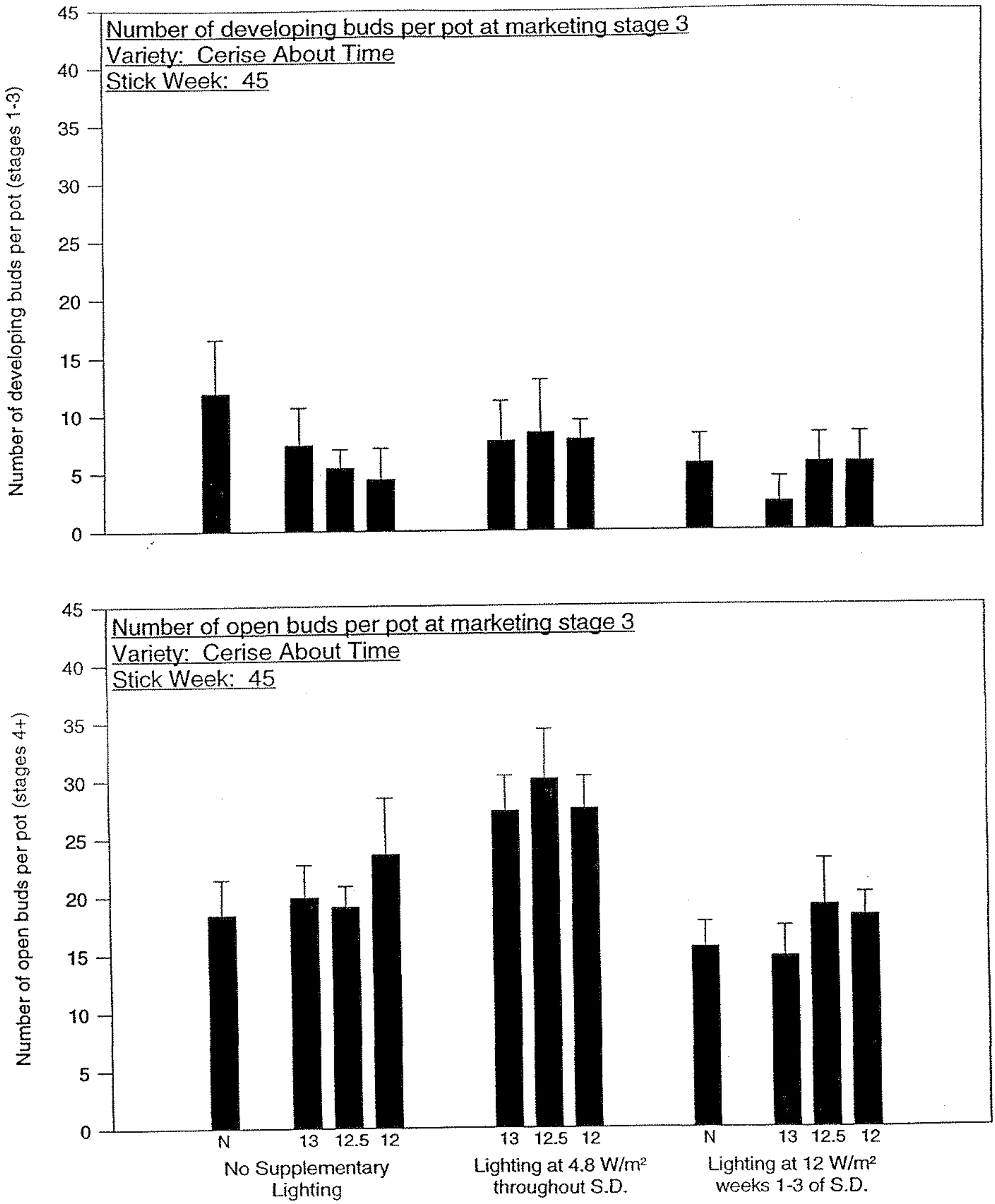
12 = 12 hour dark period

## Figure 6b: The Influence of Supplementary Lighting and Length of Night on Flower Development




**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
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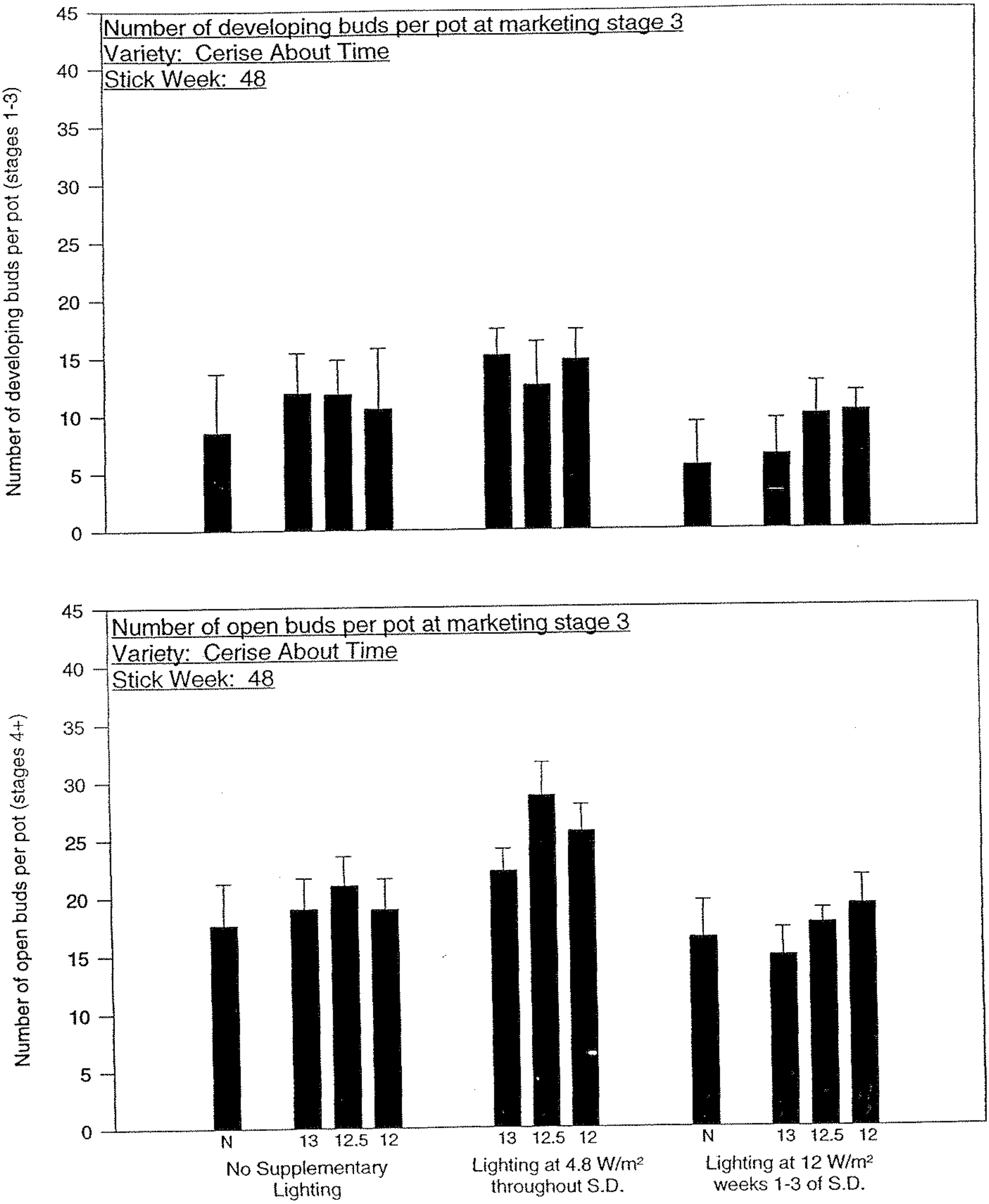
12 = 12 hour dark period

## Figure 6c: The Influence of Supplementary Lighting and Length of Night on Flower Development

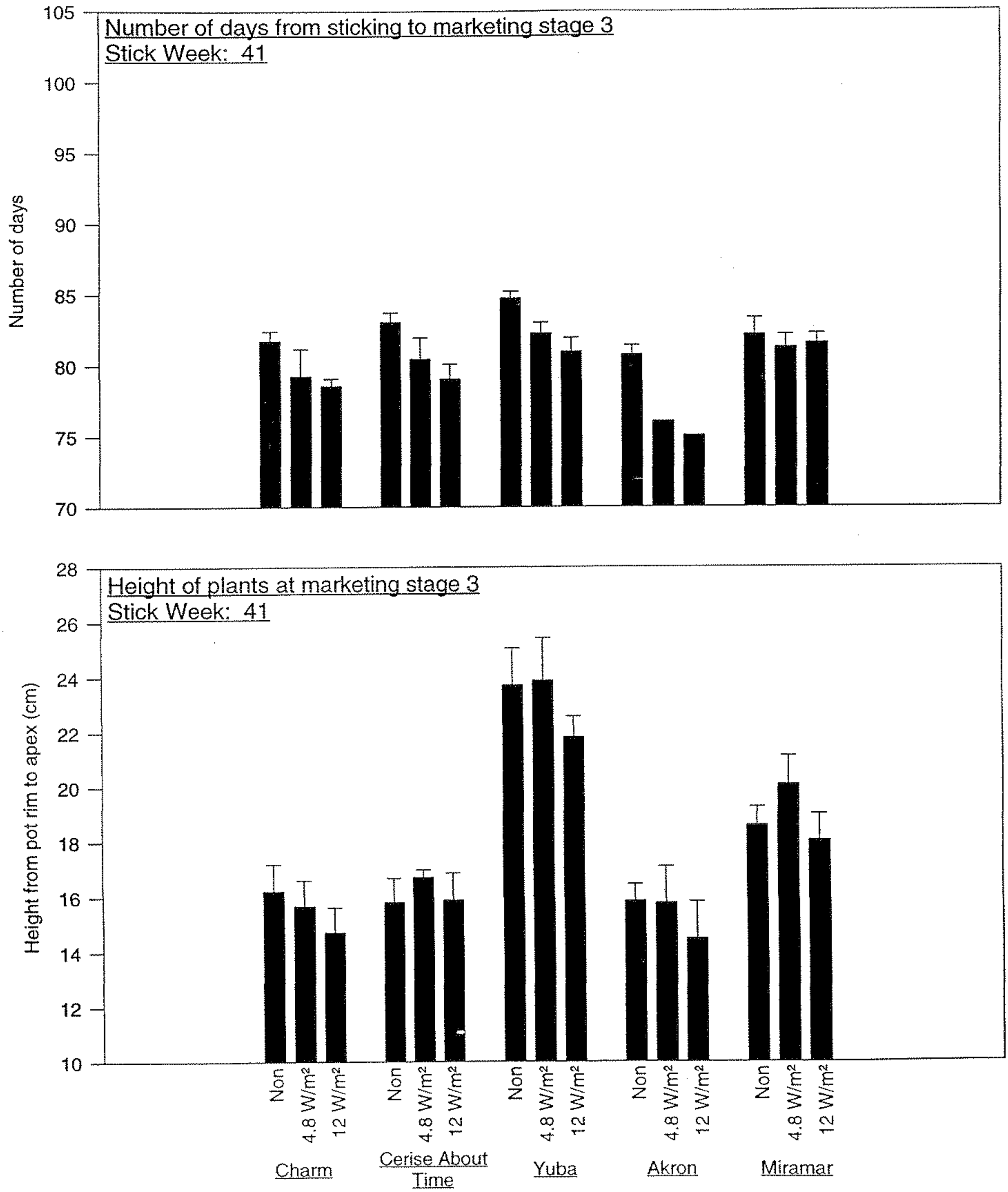



**KEY TO LENGTH OF NIGHT TREATMENTS:**
N = Natural Nightlength (i.e. blackout dusk til 0700)
12.5 = 12.5 hour dark period
13 = 13 hour dark period
12 = 12 hour dark period

## APPENDIX II

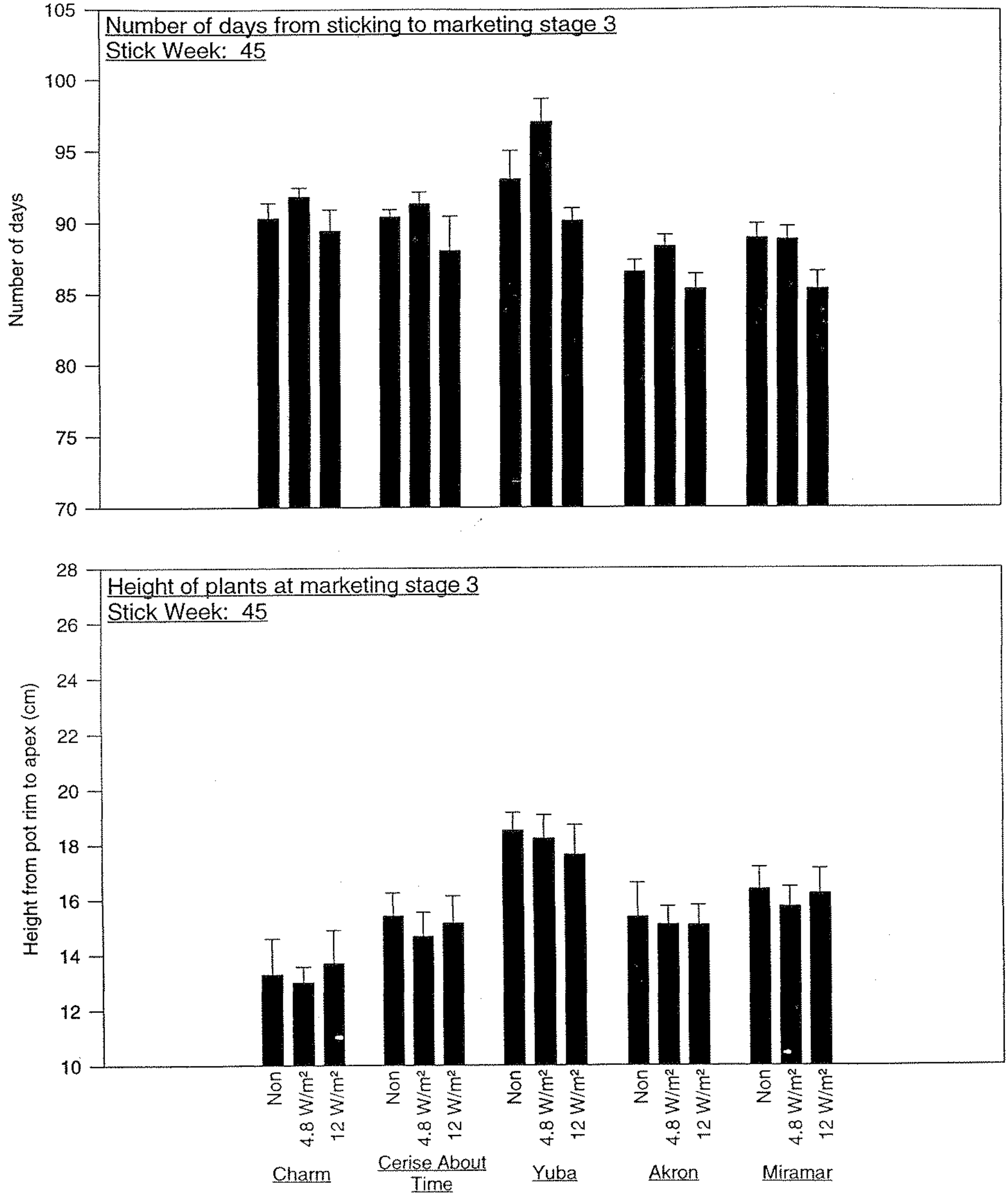
**Treatment means: supplementary lighting at the end of short days**

**Figure 1a: The Influence of Supplementary Lighting During Flower Maturation on Production Time and Plant Height**




**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**
Non = No Supplementary Lighting
4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.
12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

## Figure 1b: The Influence of Supplementary Lighting During Flower Maturation on Production Time and Plant Height



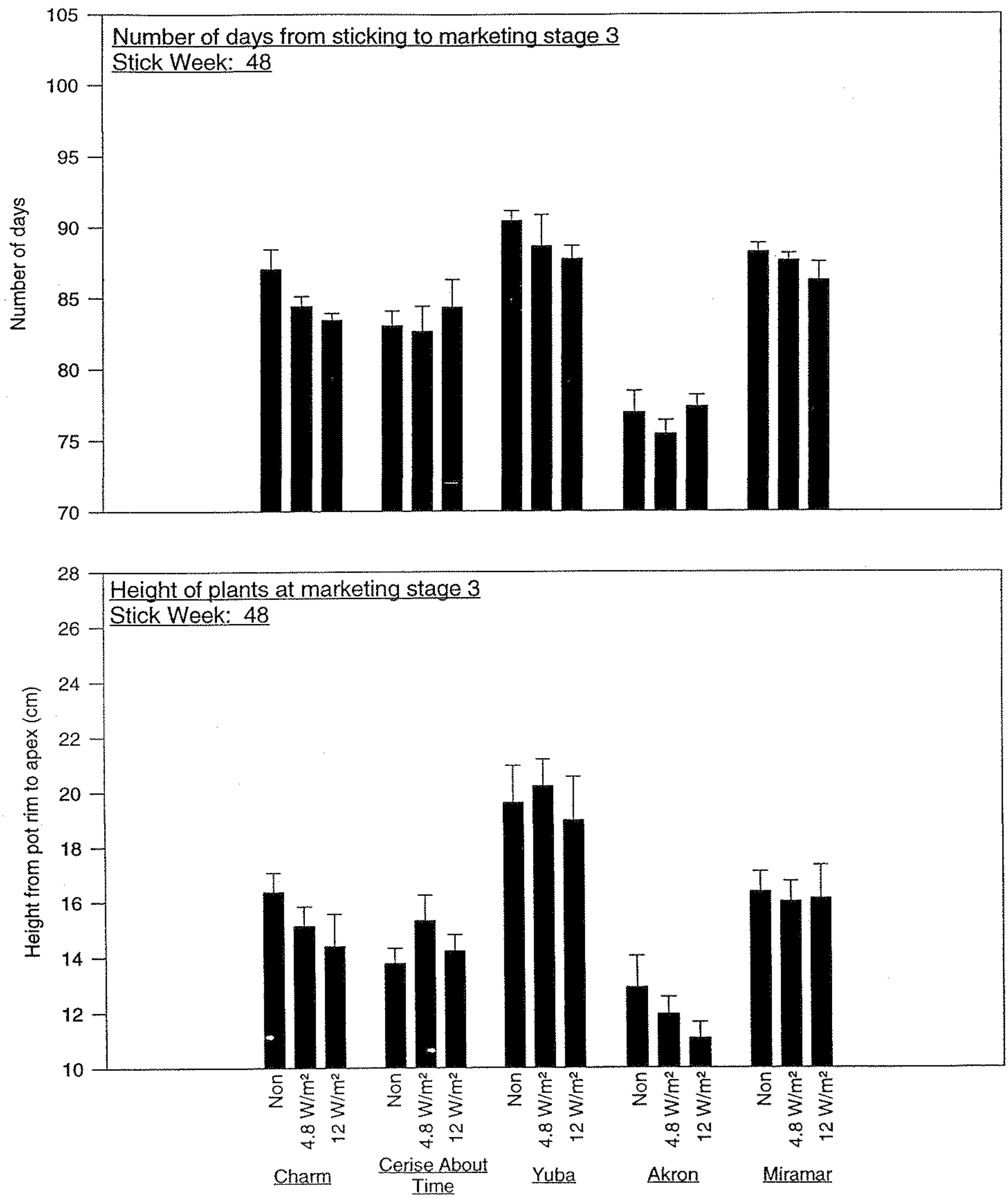

**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**

Non = No Supplementary Lighting

4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.

12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

## Figure 1c: The Influence of Supplementary Lighting During Flower Maturation on Production Time and Plant Height



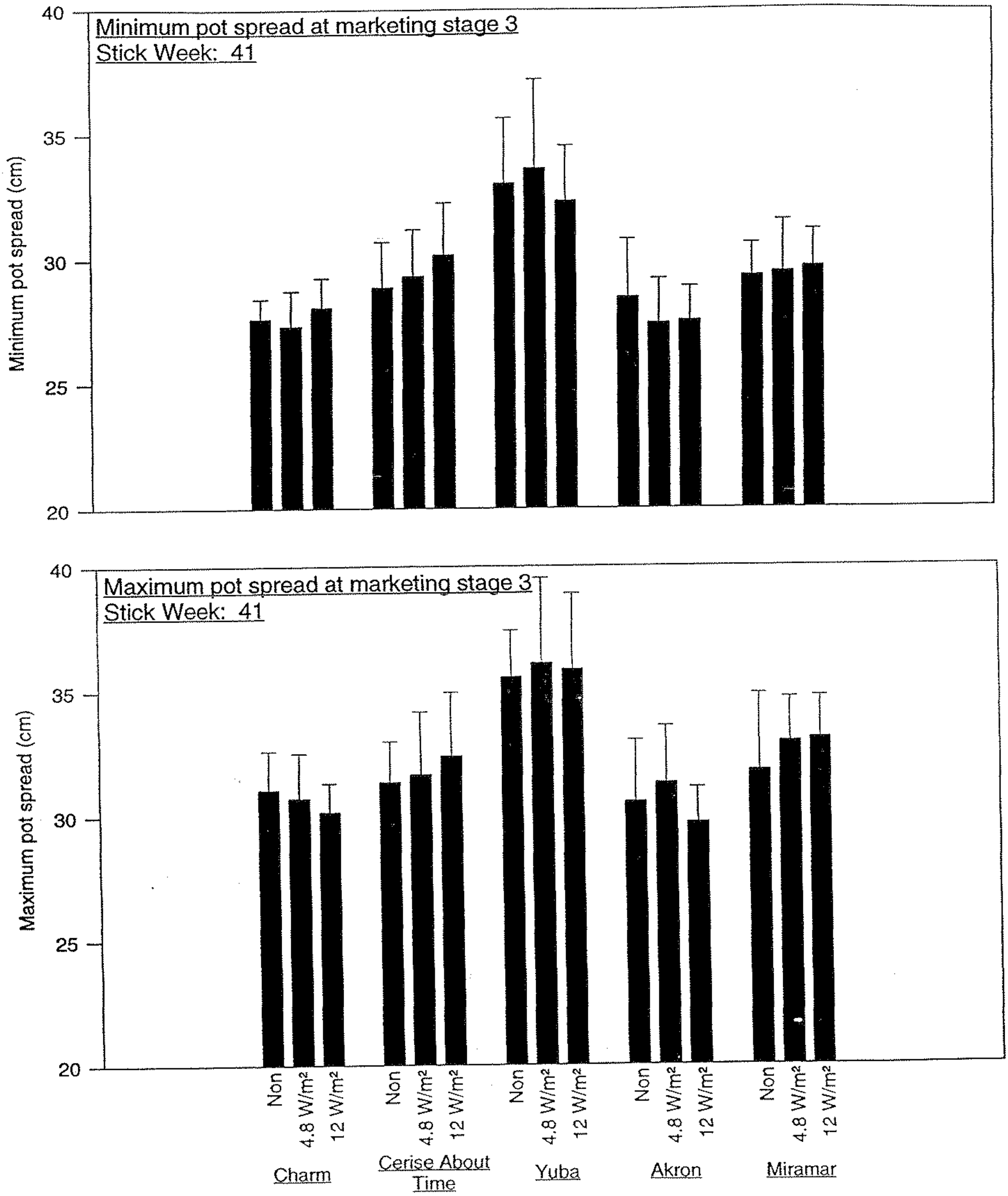

**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**

Non = No Supplementary Lighting

4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.

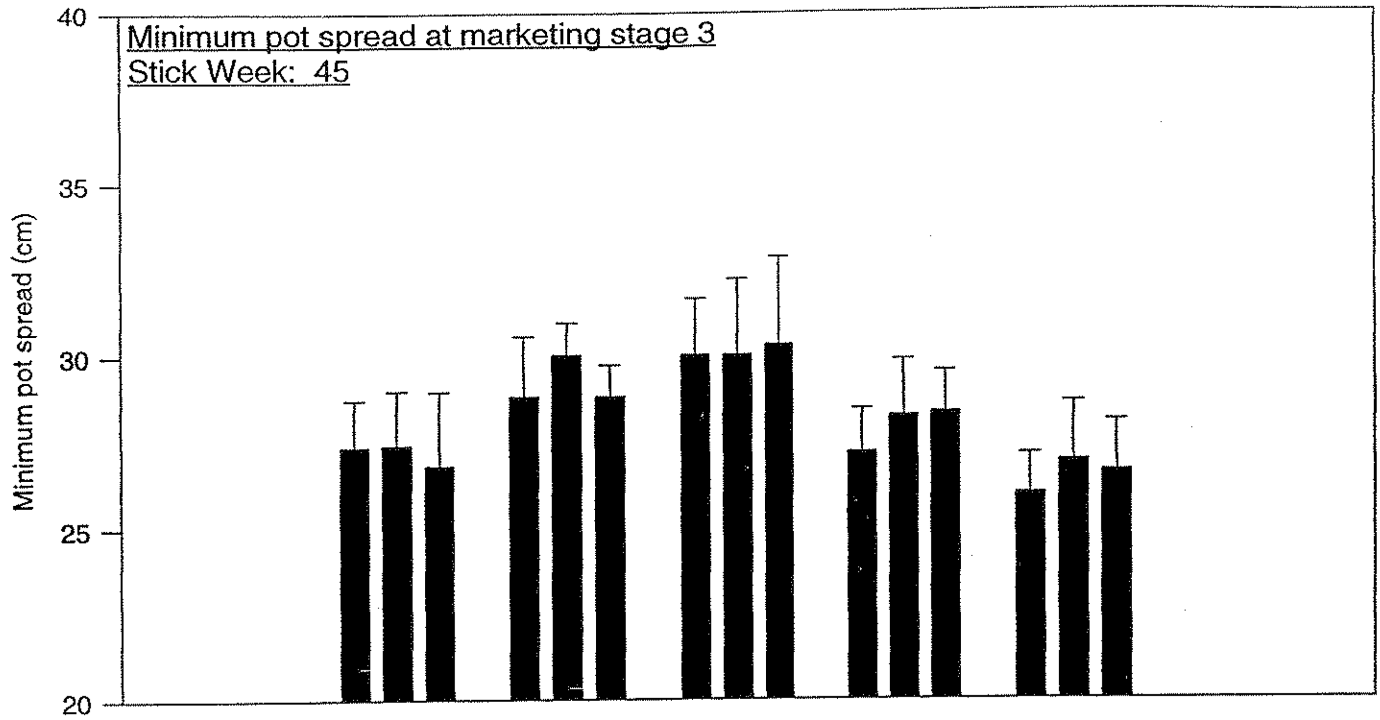
12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

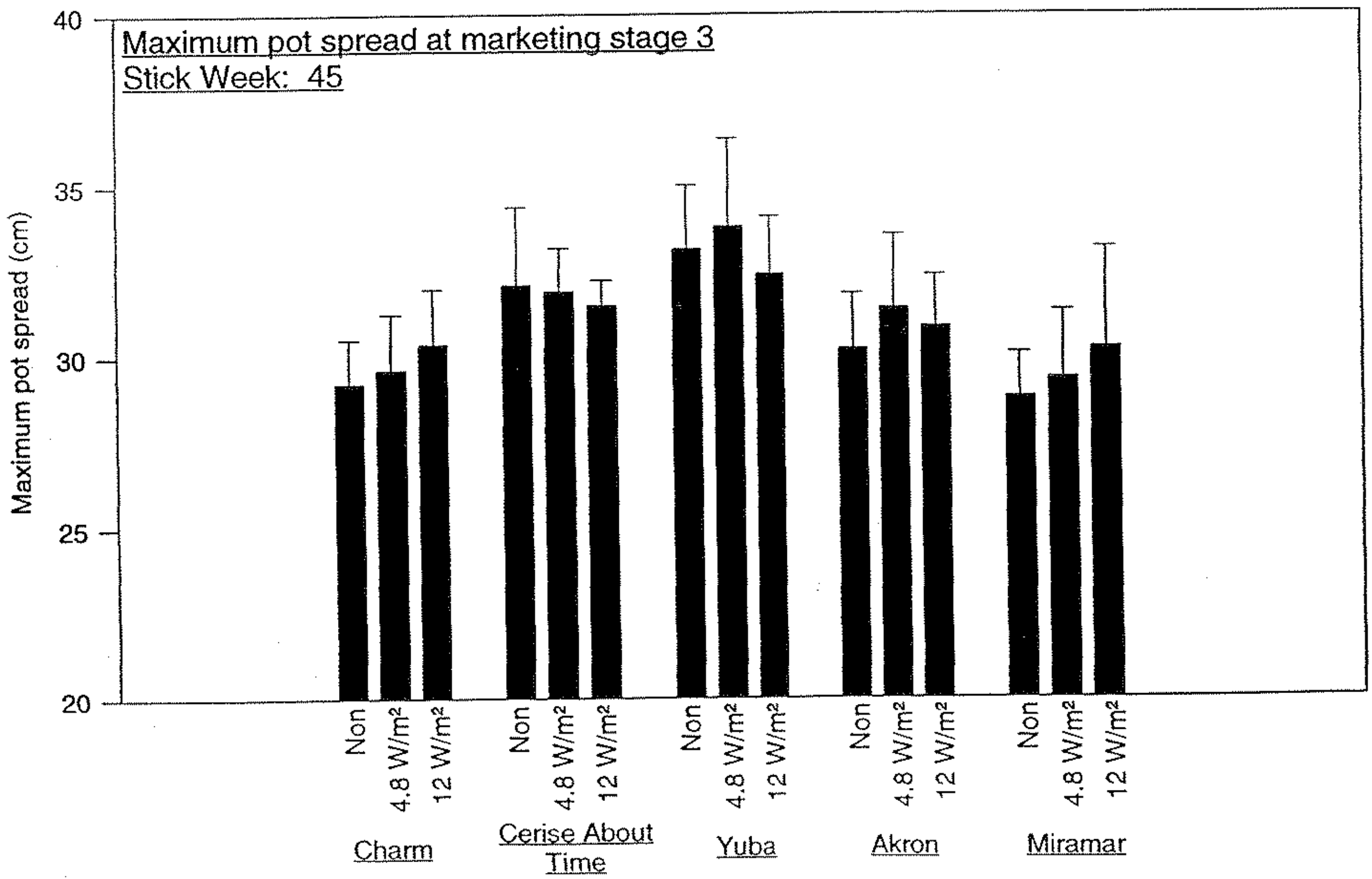
**Figure 2a: The Influence of Supplementary Lighting During Flower Maturation on Maximum and Minimum Pot Spread**




**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**
Non = No Supplementary Lighting
4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.
12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

# Figure 2b: The Influence of Supplementary Lighting During Flower Maturation on Maximum and Minimum Pot Spread



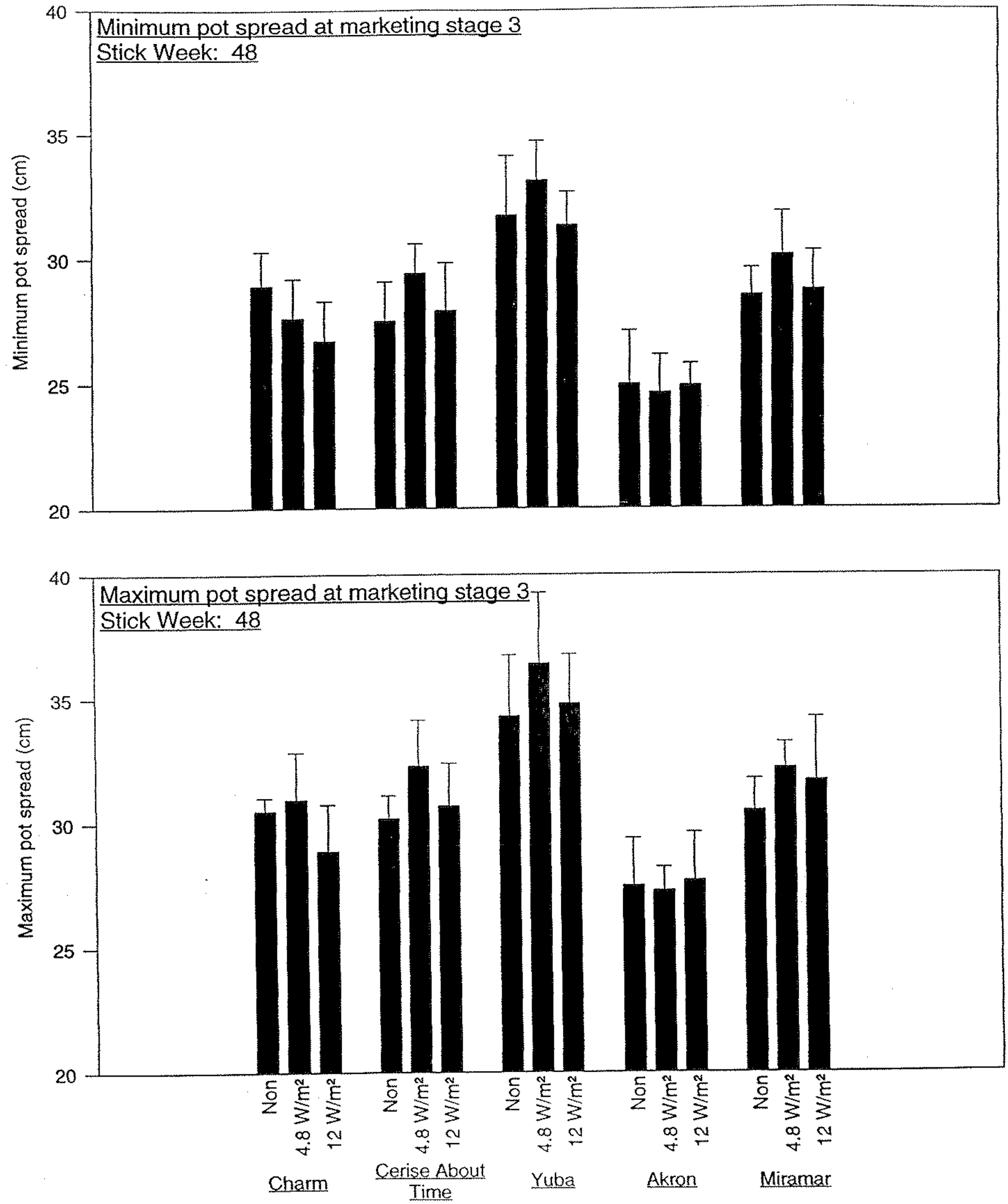

**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**

Non = No Supplementary Lighting

4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.

12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

## Figure 2c: The Influence of Supplementary Lighting During Flower Maturation on Maximum and Minimum Pot Spread




**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**

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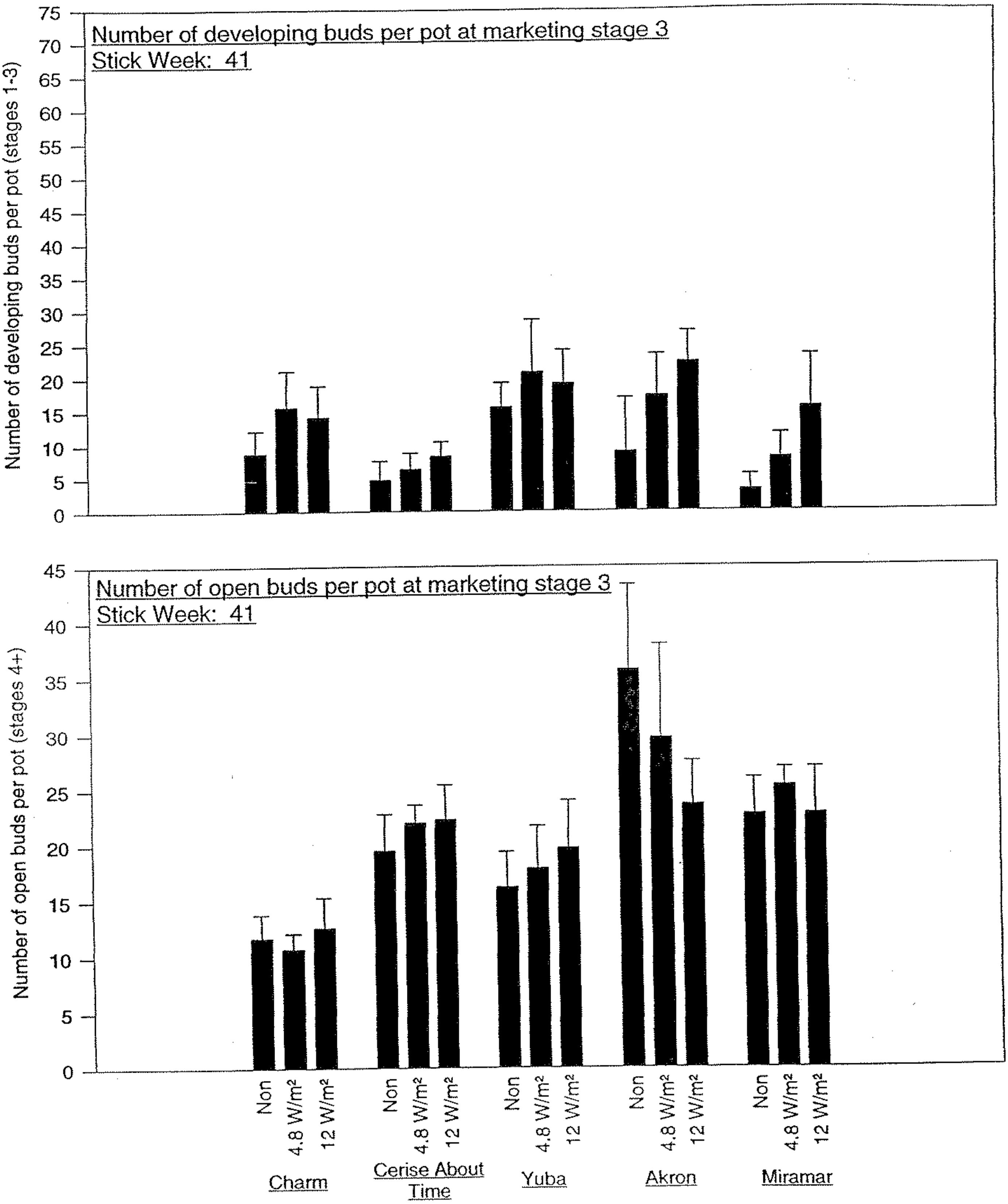
4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.
12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

## Figure 3a: The Influence of Supplementary Lighting During Flower Maturation on Flower Development




**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**

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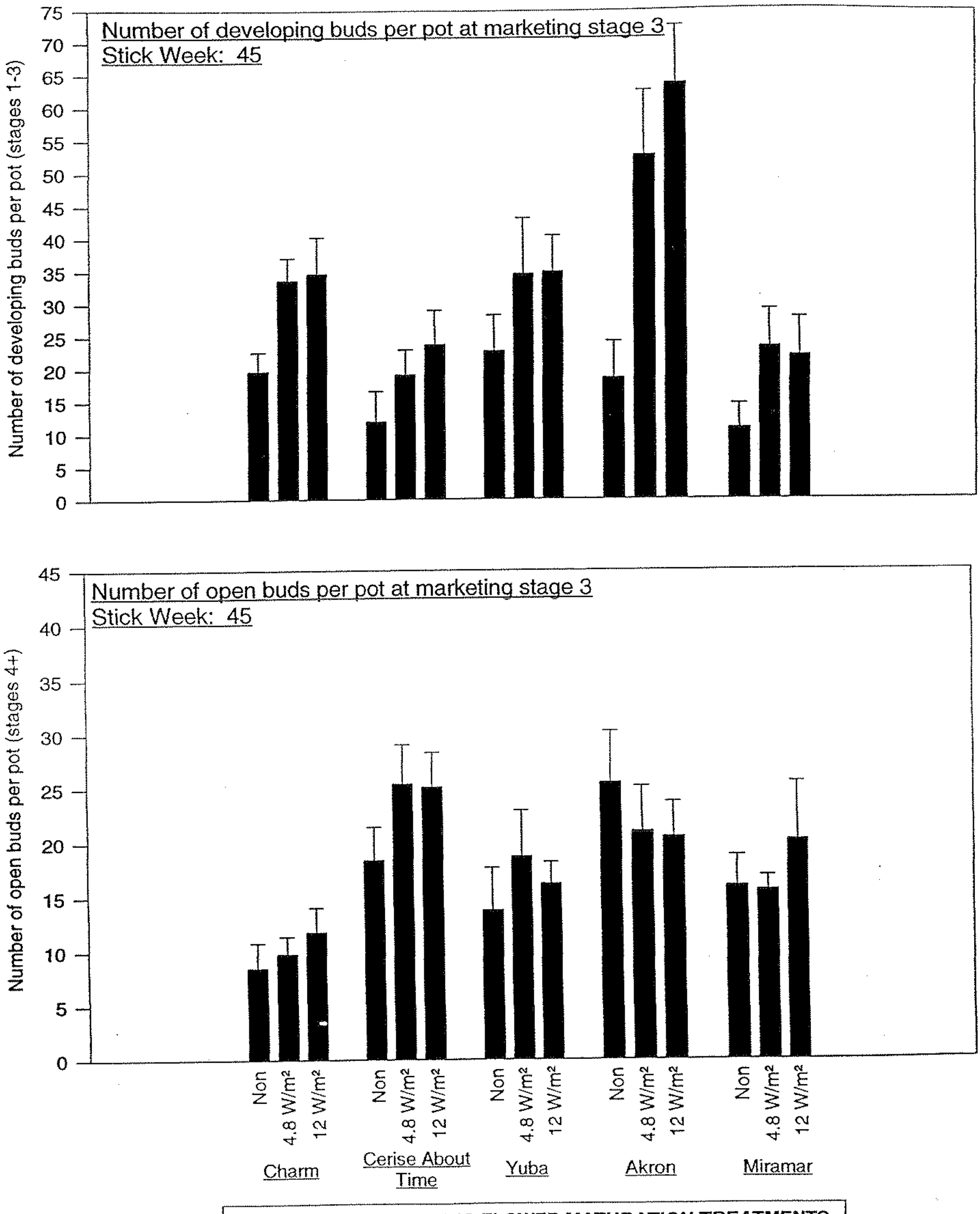
4.8 W/m$^2$ = Lighting at 4.8 W/m$^2$ weeks 7, 8 & 9 of S.D.

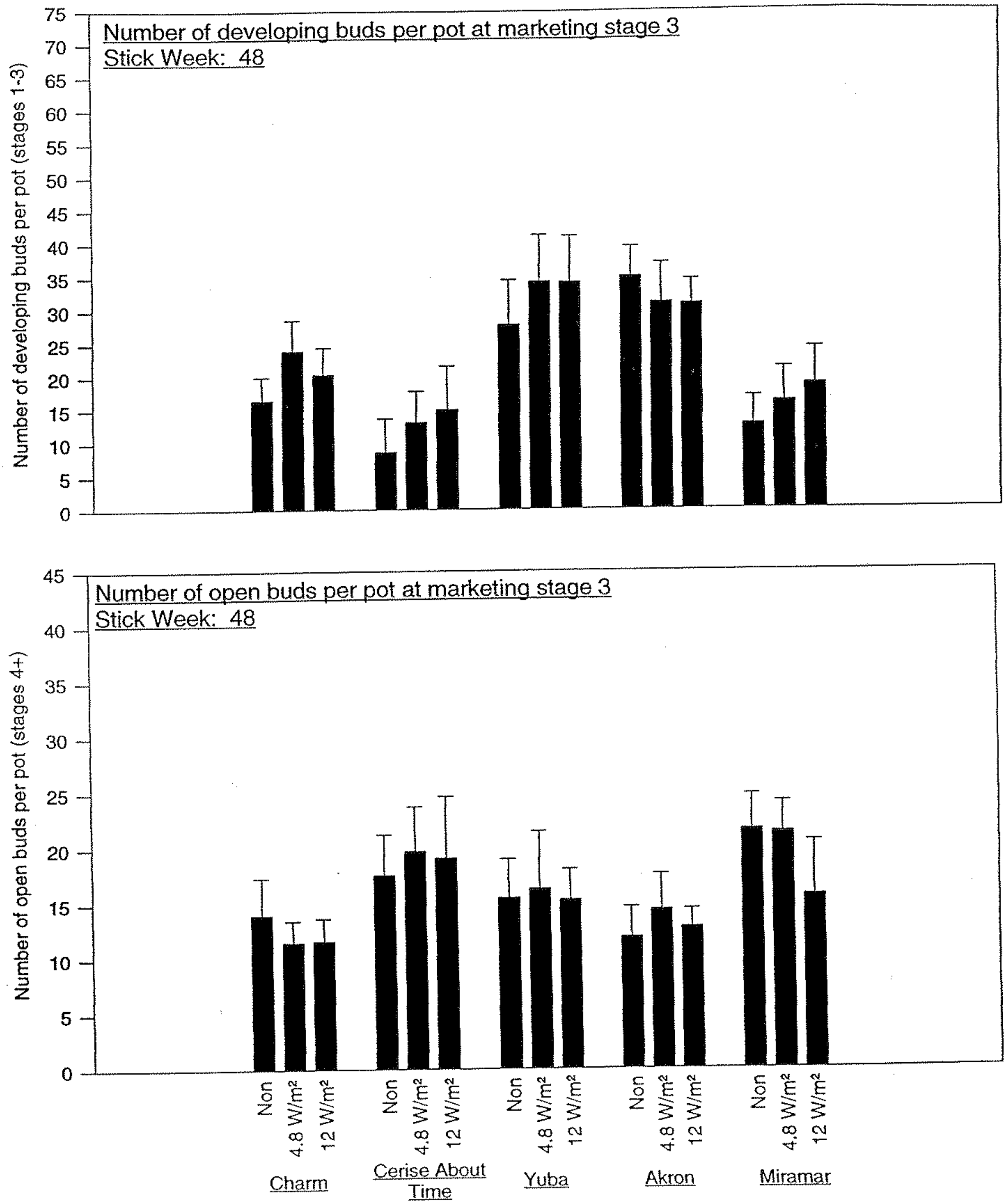
12 W/m$^2$ = Lighting at 12 W/m$^2$ weeks 7, 8 & 9 of S.D.

## Figure 3b: The Influence of Supplementary Lighting During Flower Maturation on Flower Development




| KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS: | | |
|---|---|---|
| Non | = | No Supplementary Lighting |
| 4.8 W/m² | = | Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D. |
| 12 W/m² | = | Lighting at 12 W/m² weeks 7, 8 & 9 of S.D. |

## Figure 3c: The Influence of Supplementary Lighting During Flower Maturation on Flower Development



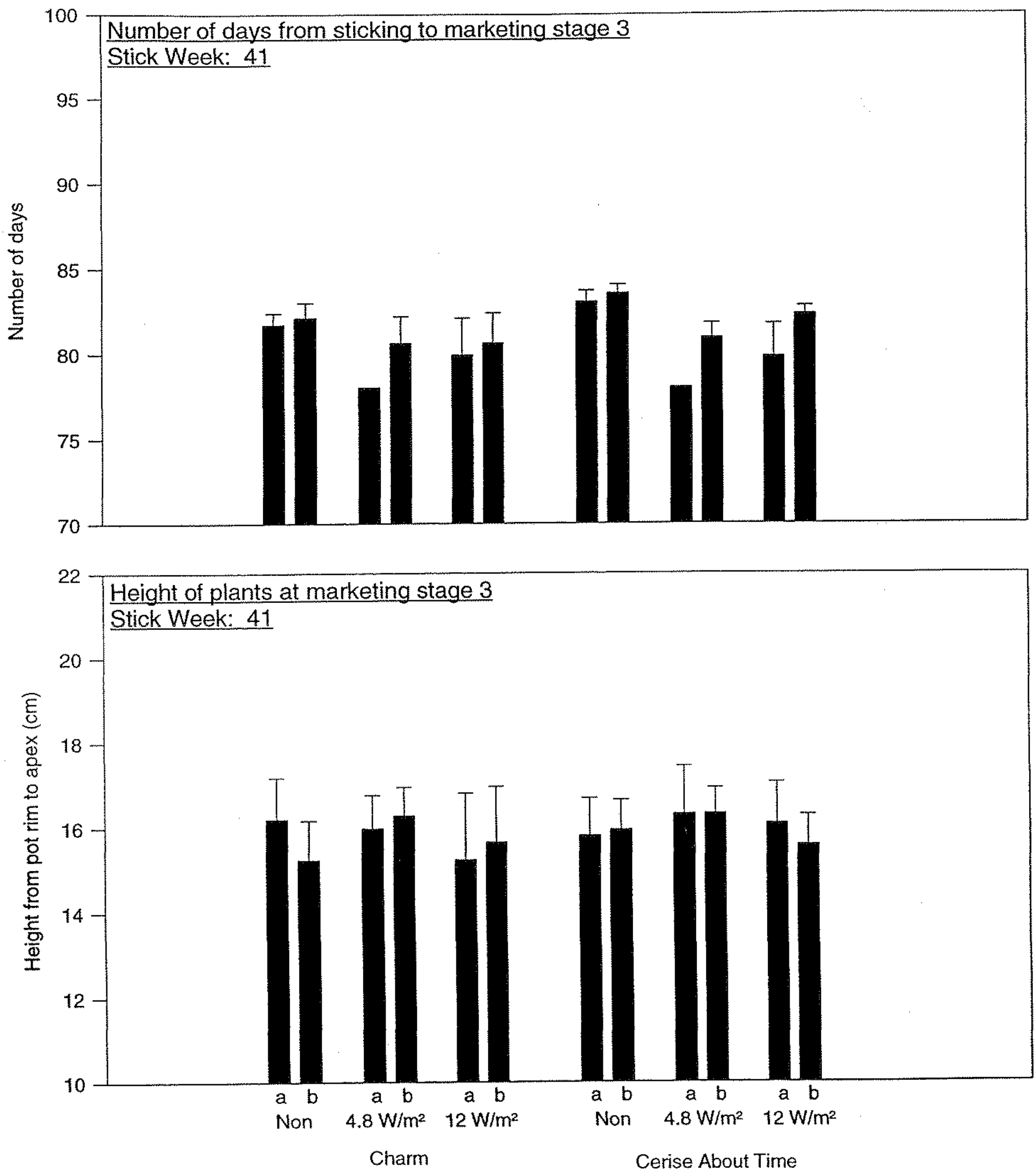

**KEY TO LIGHTING DURING FLOWER MATURATION TREATMENTS:**

Non = No Supplementary Lighting
4.8 W/m² = Lighting at 4.8 W/m² weeks 7, 8 & 9 of S.D.
12 W/m² = Lighting at 12 W/m² weeks 7, 8 & 9 of S.D.

## APPENDIX III

## Treatment means: closer spacing treatments

# Figure 1a: The Influence of Supplementary Lighting and Spacing on Production Time and Plant Height

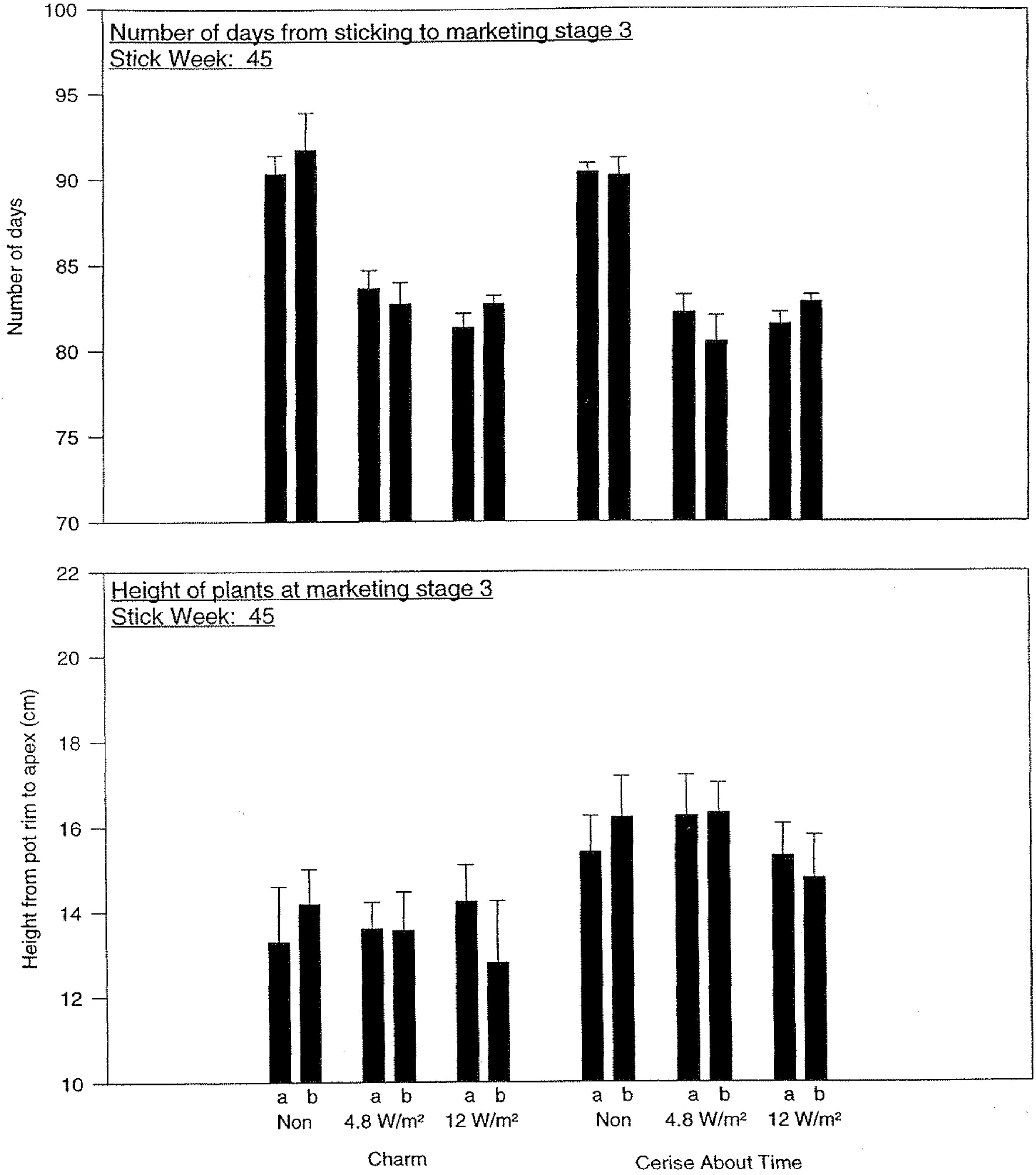



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/$m^2$ = 4.8 W/$m^2$ throughout S.D.
12 W/$m^2$ = 12 W/$m^2$ weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/$m^2$ at final spacing
b = 16 pots/$m^2$ at final spacing

# Figure 1b: The Influence of Supplementary Lighting and Spacing on Production Time and Plant Height

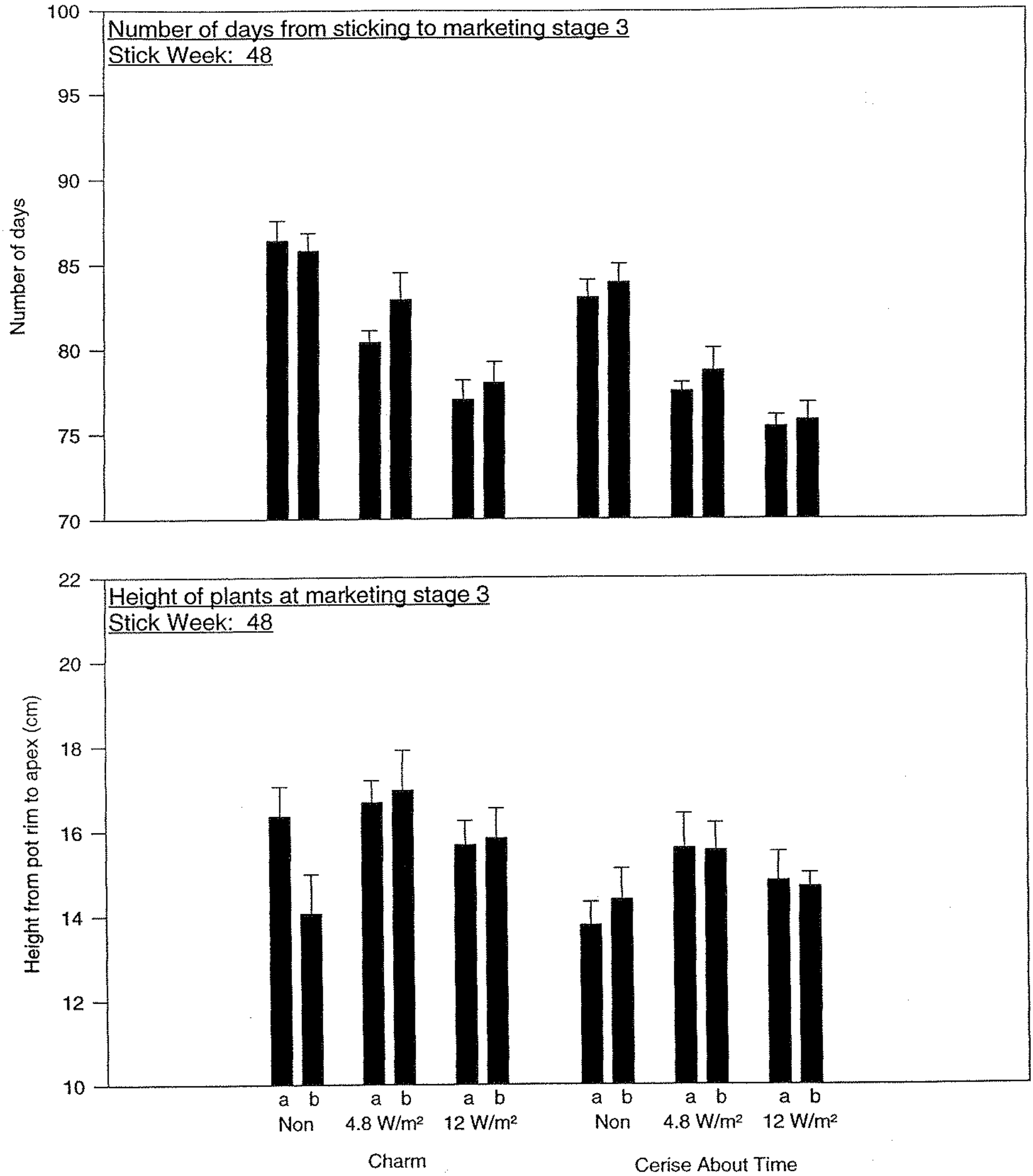



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

## Figure 1c: The Influence of Supplementary Lighting and Spacing on Production Time and Plant Height

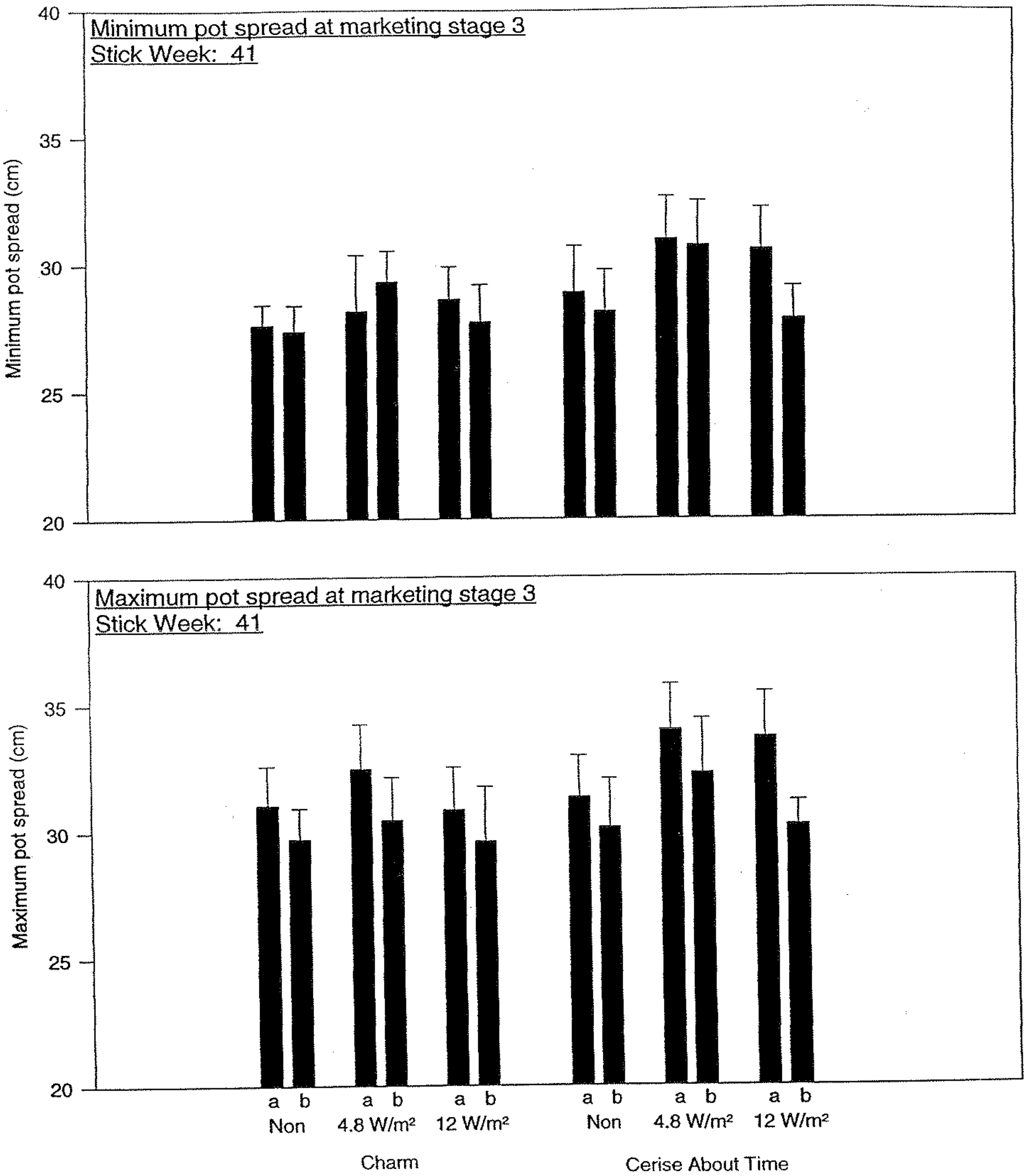



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

# Figure 2a: The Influence of Supplementary Lighting and Spacing on Maximum and Minimum Pot Spread

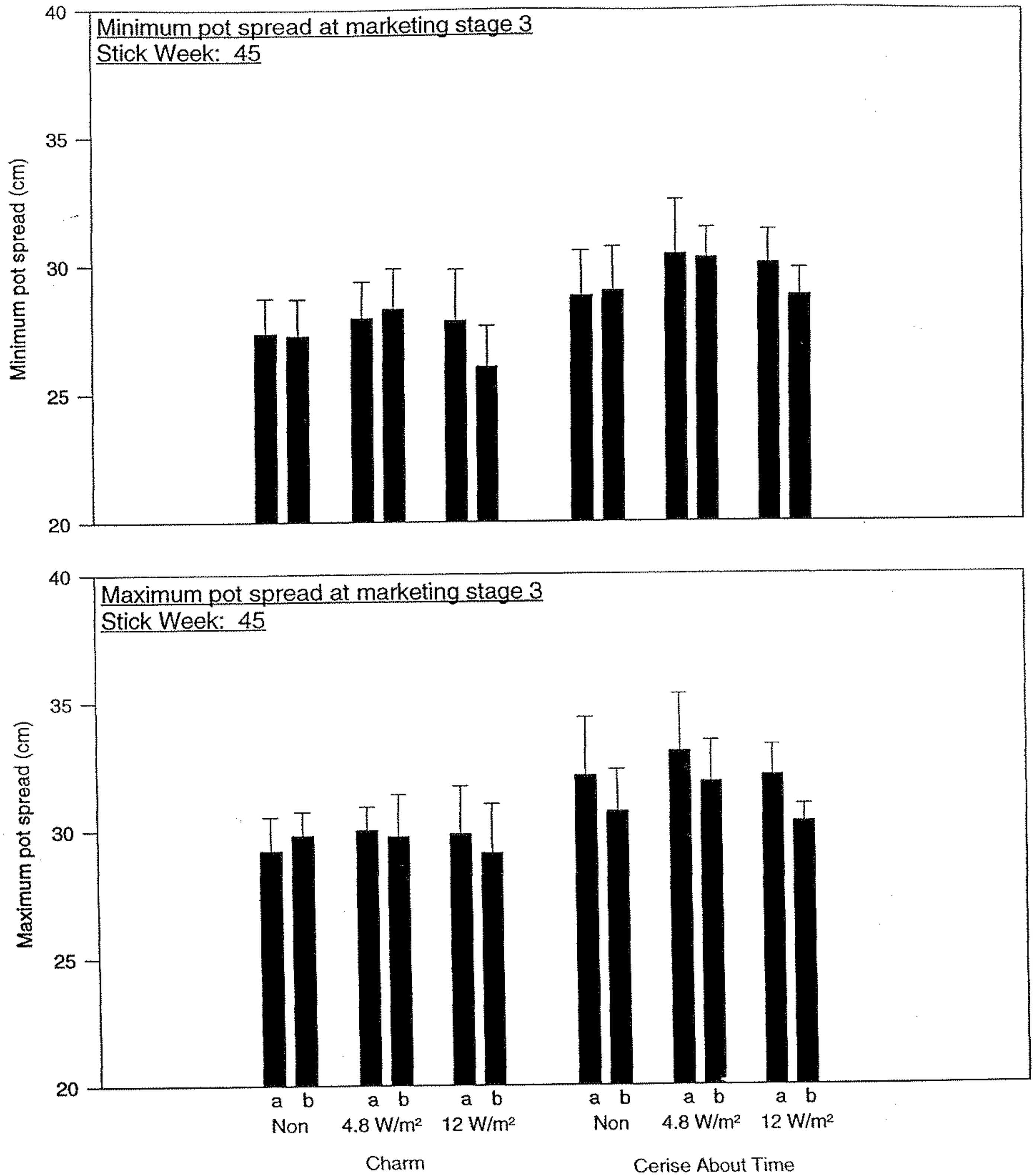



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

## Figure 2b: The Influence of Supplementary Lighting and Spacing on Maximum and Minimum Pot Spread

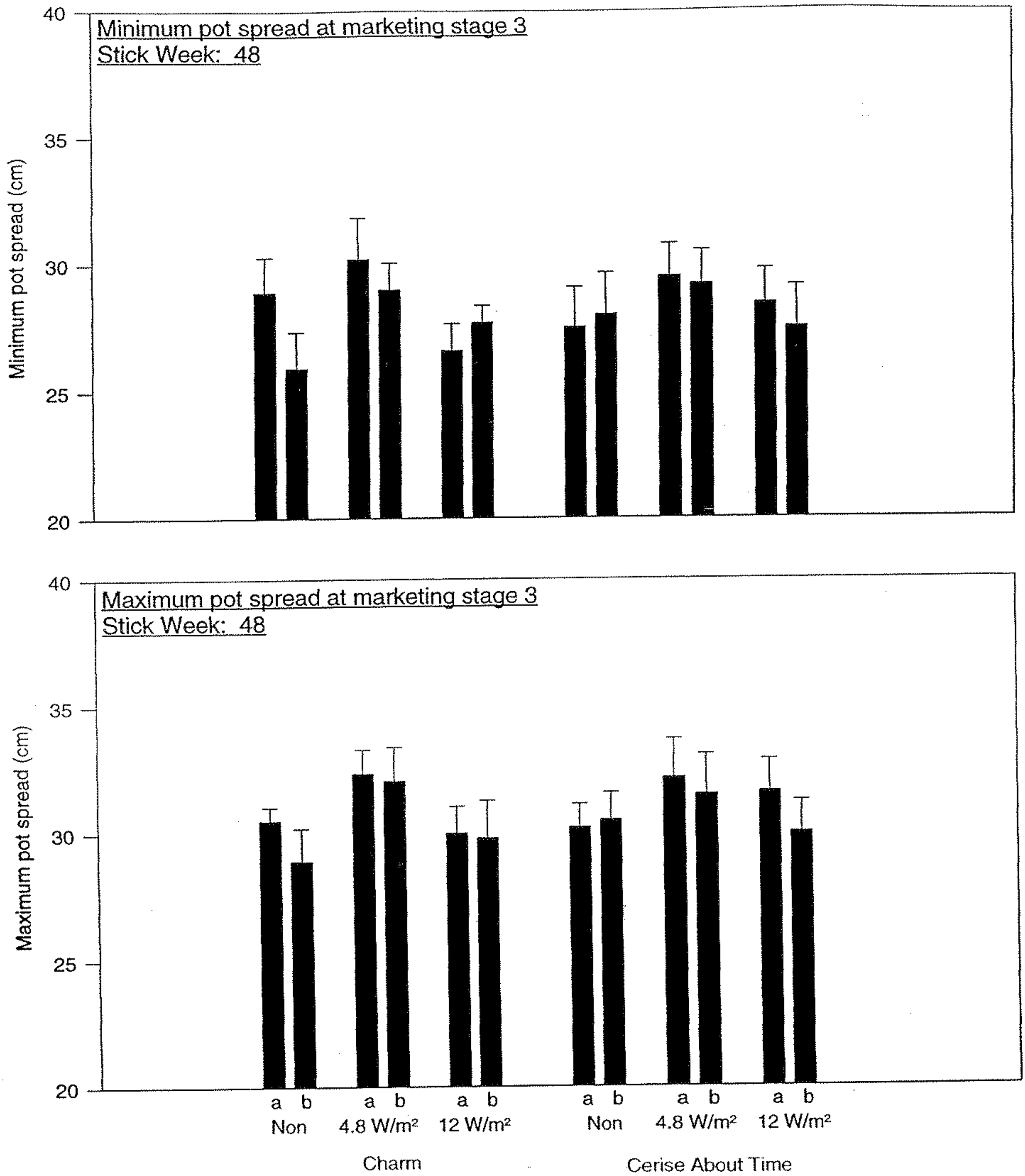



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m$^2$ = 4.8 W/m$^2$ throughout S.D.
12 W/m$^2$ = 12 W/m$^2$ weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m$^2$ at final spacing
b = 16 pots/m$^2$ at final spacing

## Figure 2c: The Influence of Supplementary Lighting and Spacing on Maximum and Minimum Pot Spread

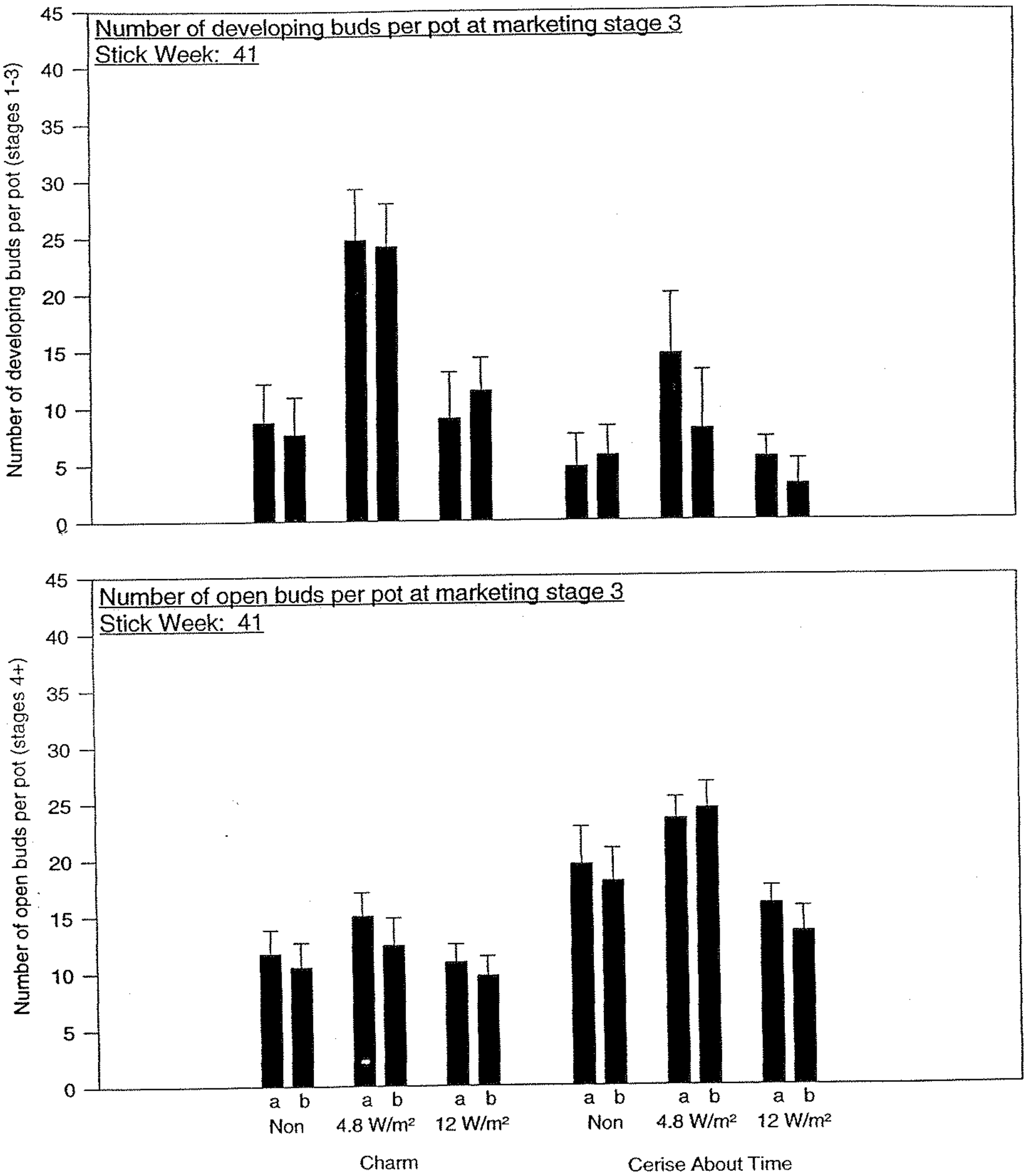



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

## Figure 3a: The Influence of Supplementary Lighting and Spacing on Flower Development

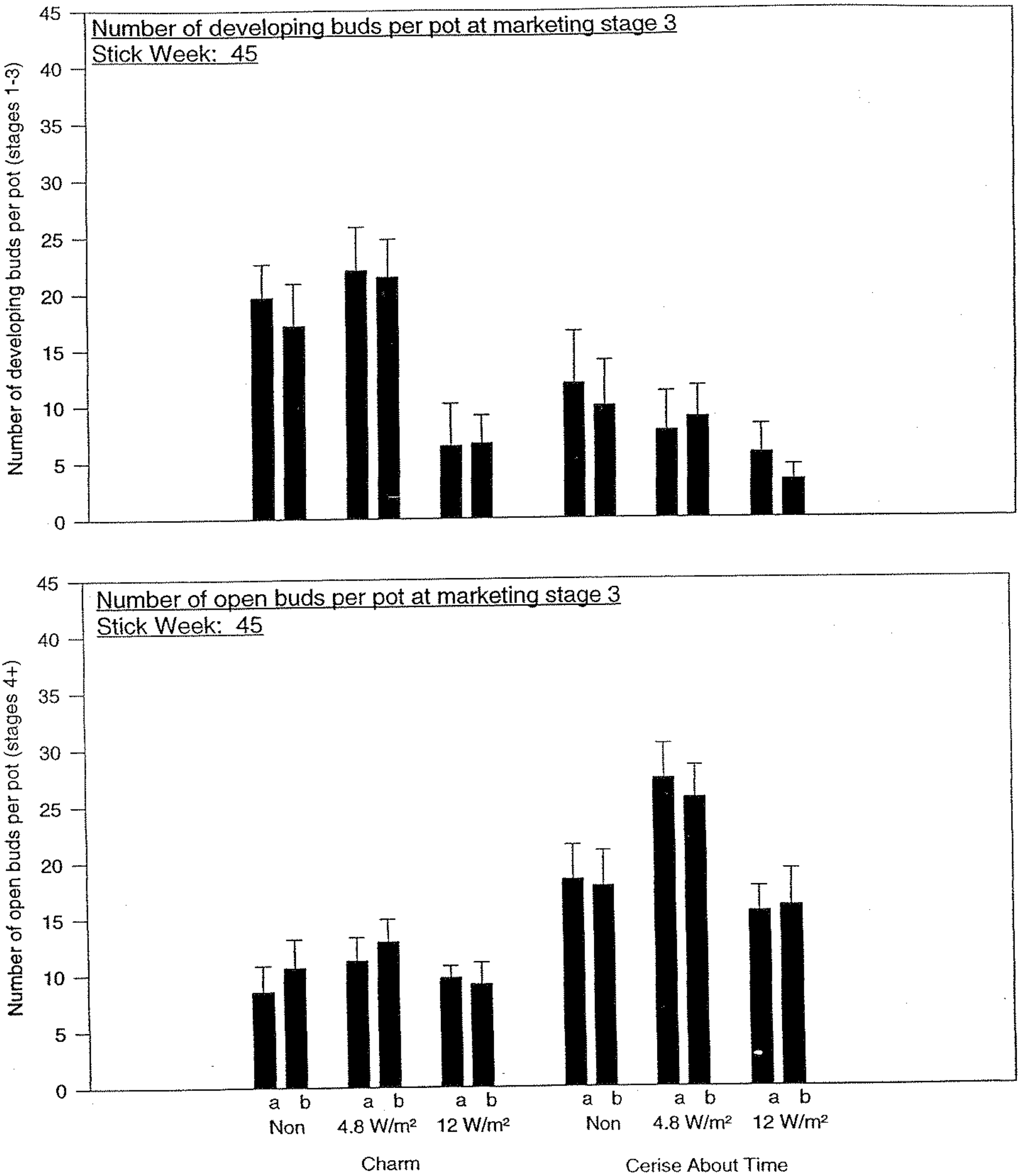



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

## Figure 3b: The Influence of Supplementary Lighting and Spacing on Flower Development

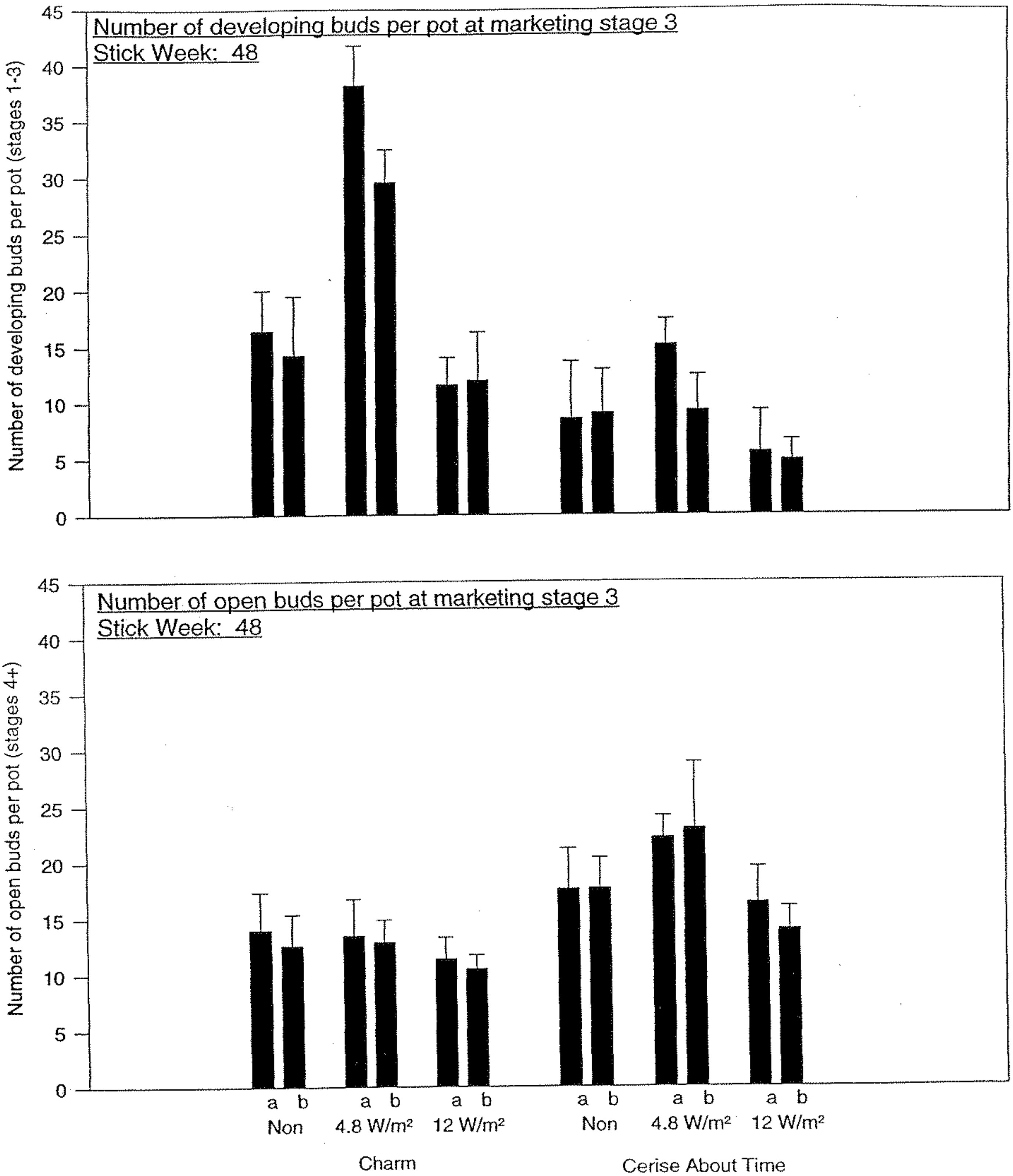



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

# Figure 3c: The Influence of Supplementary Lighting and Spacing on Flower Development

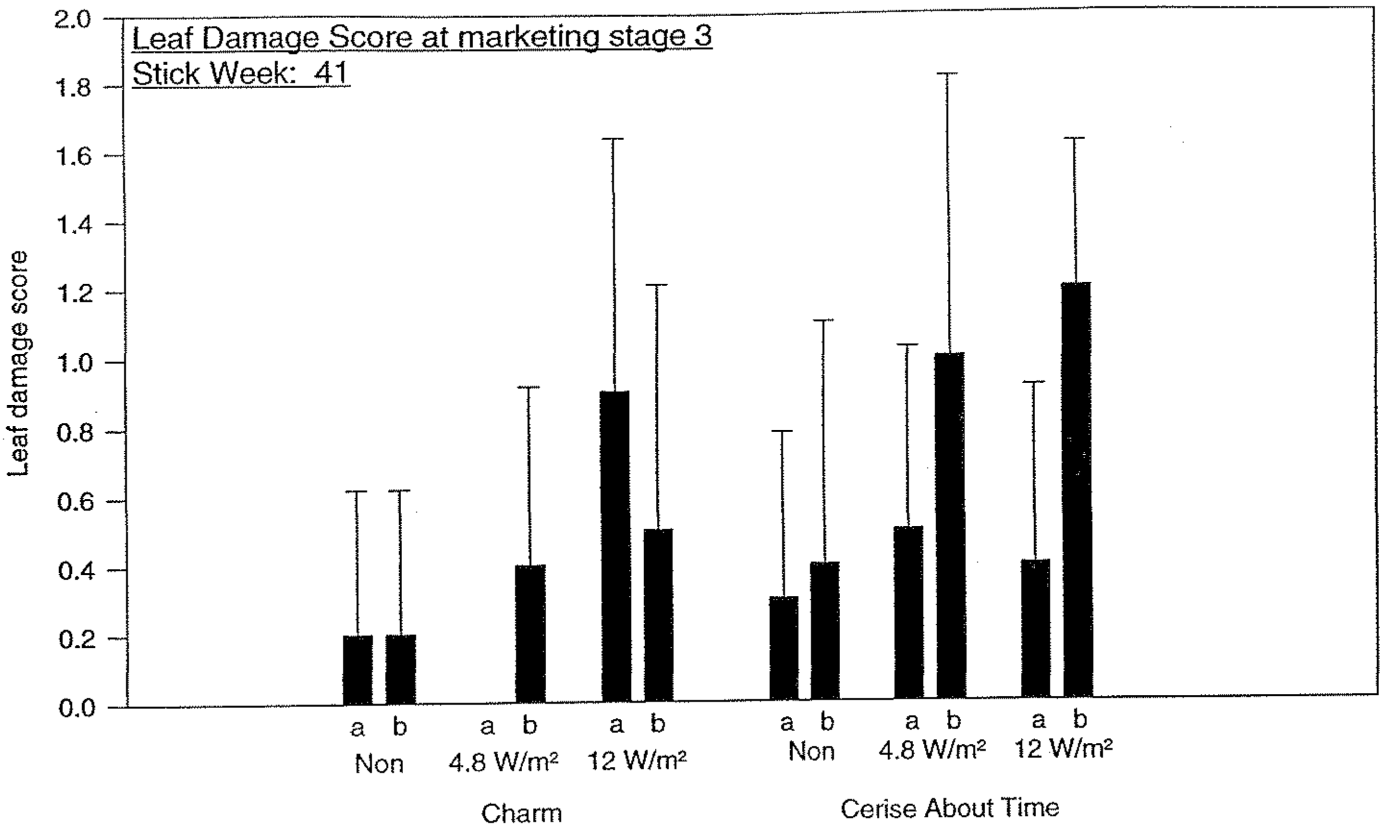



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

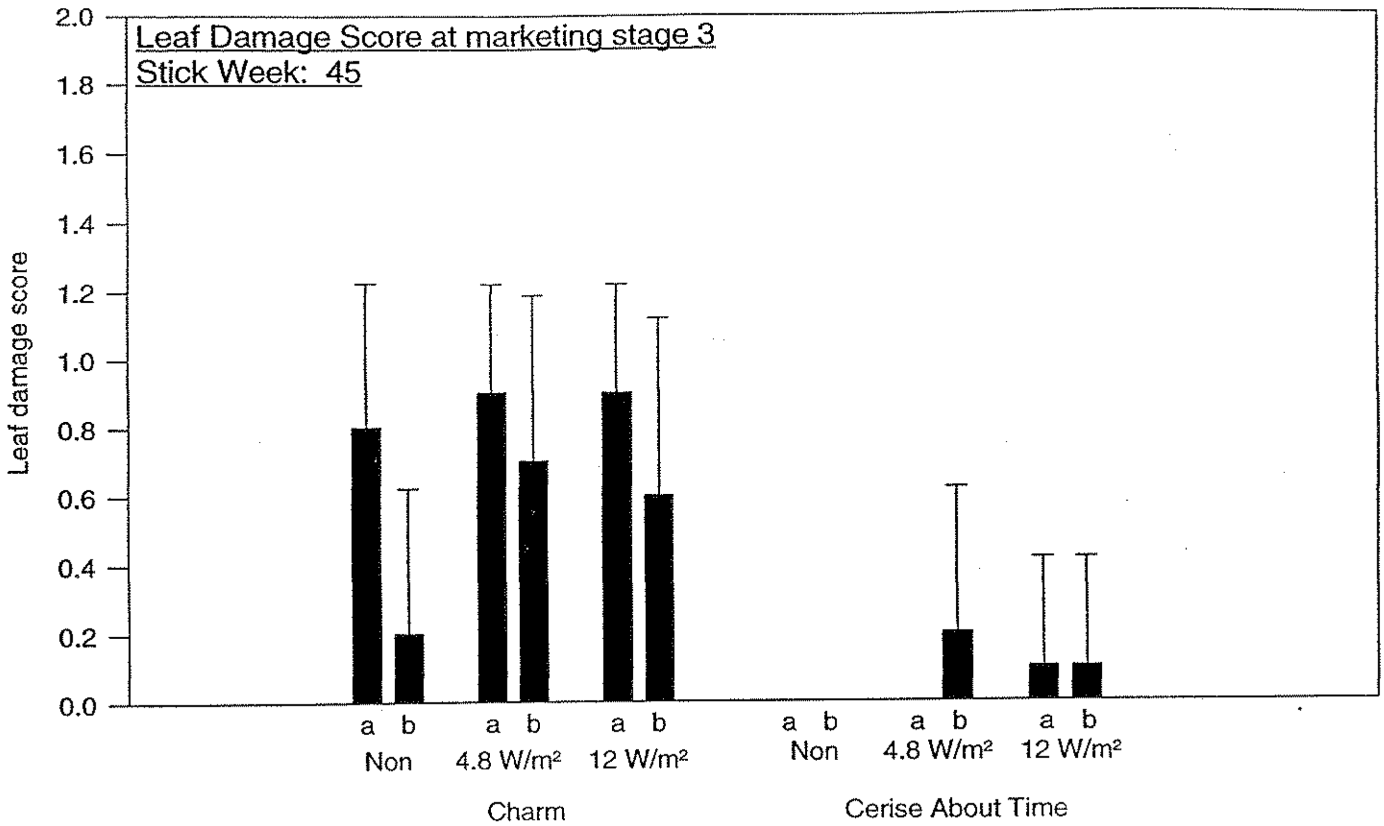
**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

## Figure 4a: The Influence of Supplementary Lighting and Spacing on Leaf Quality




| **KEY TO TREATMENTS** | |
|---|---|
| **Supplementary Lighting:** | **Spacing:** |
| Non = No Supplementary Lighting | a = 13.5 pots/m² at final spacing |
| 4.8 W/m² = 4.8 W/m² throughout S.D. | b = 16 pots/m² at final spacing |
| 12 W/m² = 12 W/m² weeks 1-3 of S.D. only | |

## Figure 4b: The Influence of Supplementary Lighting and Spacing on Leaf Quality

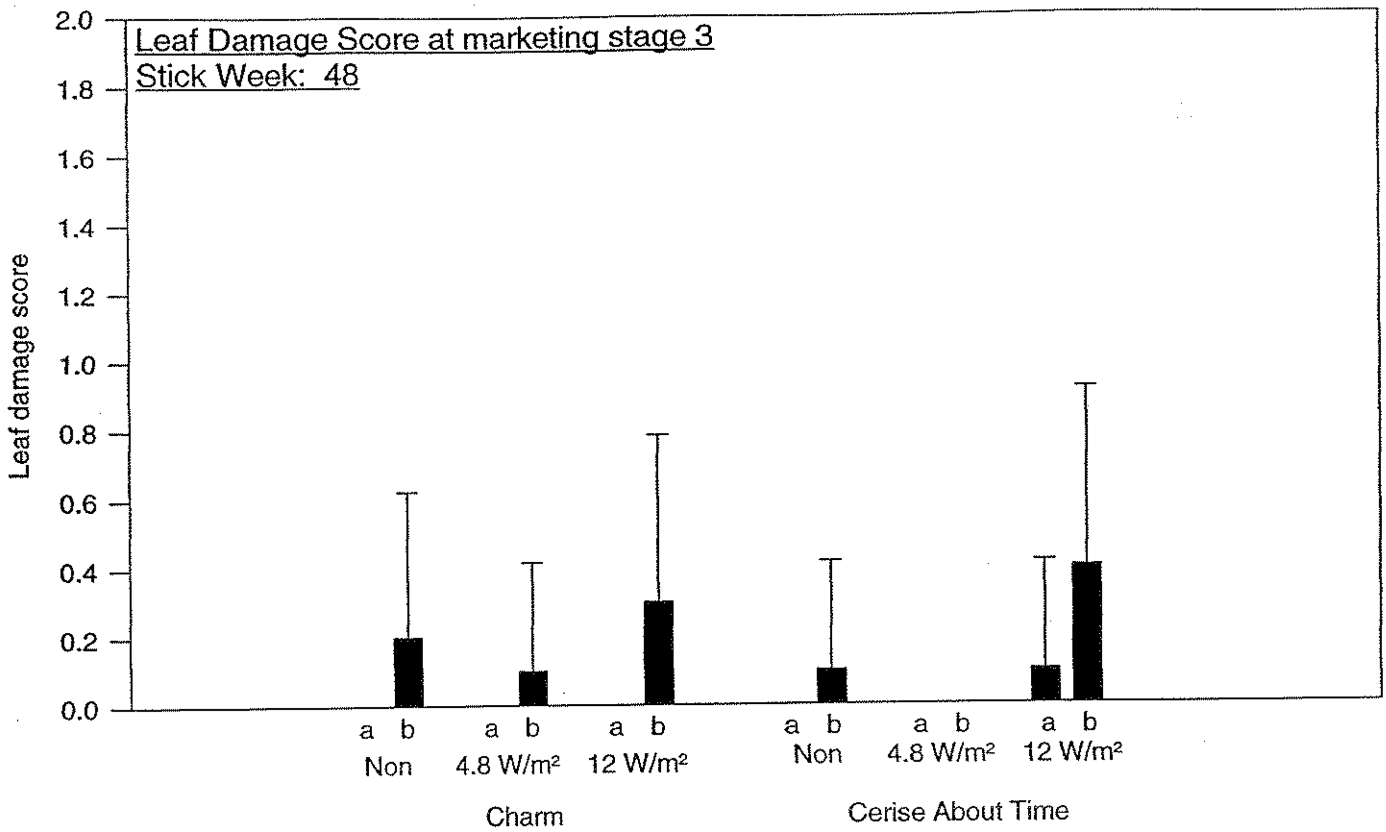



**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

# Figure 4c: The Influence of Supplementary Lighting and Spacing on Leaf Quality




**KEY TO TREATMENTS**

**Supplementary Lighting:**
Non = No Supplementary Lighting
4.8 W/m² = 4.8 W/m² throughout S.D.
12 W/m² = 12 W/m² weeks 1-3 of S.D. only

**Spacing:**
a = 13.5 pots/m² at final spacing
b = 16 pots/m² at final spacing

# APPENDIX IV
## Compost Analyses

Table 1a: **The influence of night length treatments on compost analyses - stick week 41**

| Lighting Regime | Night Length (hrs) | Bulk density | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/1) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No supplementary lighting | ND | 0.442 | 5.3 | 310 | 150 | 1.0 | 45 | 46 | 106 | 71 |
| | 13 | 0.435 | 5.2 | 267 | 90 | 1.0 | 32 | 68 | 83 | 50 |
| | 12.5 | 0.424 | 5.2 | 306 | 152 | 0.8 | 38 | 52 | 105 | 63 |
| | 12 | 0.412 | 5.4 | 227 | 120 | 0.7 | 26 | 48 | 68 | 39 |
| 4.8 W/m² throughout SD | 13 | 0.430 | 5.3 | 258 | 131 | 1.0 | 30 | 35 | 86 | 48 |
| | 12.5 | 0.437 | 5.4 | 226 | 111 | 0.9 | 23 | 20 | 74 | 38 |
| | 12 | 0.433 | 5.4 | 299 | 125 | 0.7 | 41 | 17 | 109 | 76 |
| 12 W/m² weeks 1-3 SD | ND | 0.430 | 5.0 | 297 | 179 | 1.0 | 32 | 78 | 99 | 50 |
| | 13 | 0.432 | 5.1 | 337 | 166 | 1.0 | 36 | 47 | 119 | 58 |
| | 12.5 | 0.426 | 5.3 | 339 | 162 | 0.8 | 40 | 32 | 122 | 64 |
| | 12 | 0.480 | 5.4 | 235 | 113 | 1.0 | 32 | 38 | 76 | 43 |
| Cerise About Time: | | | | | | | | | | |
| No supplementary lighting | ND | 0.504 | 5.1 | 360 | 176 | 1.0 | 61 | 43 | 133 | 74 |
| | 13 | 0.476 | 5.0 | 376 | 189 | 0.9 | 51 | 76 | 132 | 66 |
| | 12.5 | 0.483 | 5.0 | 299 | 151 | 1.0 | 44 | 61 | 104 | 66 |
| | 12 | 0.429 | 5.2 | 311 | 150 | 1.0 | 41 | 38 | 111 | 65 |
| 4.8 W/m² throughout SD | 13 | 0.498 | 5.3 | 298 | 142 | 1.5 | 44 | 31 | 105 | 61 |
| | 12.5 | 0.482 | 5.0 | 329 | 145 | 1.5 | 52 | 41 | 121 | 75 |
| | 12 | 0.494 | 5.4 | 284 | 123 | 0.9 | 46 | 36 | 96 | 59 |
| 12 W/m² weeks 1-3 SD | ND | 0.492 | 4.9 | 364 | 189 | 1.1 | 38 | 86 | 123 | 55 |
| | 13 | 0.459 | 4.9 | 466 | 236 | 1.1 | 64 | 61 | 184 | 104 |
| | 12.5 | 0.459 | 5.2 | 325 | 151 | 1.4 | 48 | 23 | 125 | 79 |
| | 12 | 0.479 | 4.9 | 404 | 181 | 1.4 | 60 | 50 | 153 | 99 |

Table 1b: **The influence of night length treatments on compost analyses - stick week 45**

| Lighting Regime | Night Length (hrs) | Bulk density | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No supplementary lighting | ND | 0.347 | 5.4 | 214 | 84 | 0.8 | 41 | 19.0 | 74 | 66 |
| | 13 | 0.384 | 5.4 | 233 | 91 | 0.7 | 40 | 19.0 | 79 | 60 |
| | 12.5 | 0.446 | 5.4 | 222 | 93 | 0.5 | 43 | 36.0 | 80 | 67 |
| | 12 | 0.392 | 5.4 | 180 | 73 | 1.4 | 31 | 17.0 | 61 | 56 |
| 4.8 W/m² throughout SD | 13 | 0.373 | 5.7 | 128 | 27 | 6.5 | 28 | 7.0 | 43 | 31 |
| | 12.5 | 0.415 | 5.7 | 99 | 22 | 0.8 | 23 | 10.0 | 34 | 21 |
| | 12 | 0.380 | 5.8 | 106 | 16 | 0.6 | 18 | 7.0 | 32 | 19 |
| 12 W/m² weeks 1-3 SD | ND | 0.326 | 5.5 | 182 | 67 | 1.1 | 34 | 26.0 | 61 | 43 |
| | 13 | 0.333 | 5.3 | 277 | 14 | 0.4 | 47 | 25.0 | 107 | 88 |
| | 12.5 | 0.459 | 5.2 | 299 | 128 | 1.3 | 43 | 29.0 | 107 | 89 |
| | 12 | 0.355 | 5.7 | 153 | 49 | 0.5 | 24 | 6.0 | 50 | 42 |
| Cerise About Time: | | | | | | | | | | |
| No supplementary lighting | ND | 0.393 | 5.3 | 251 | 56 | 1.3 | 58 | 35.0 | 93 | 80 |
| | 13 | 0.377 | 5.6 | 137 | 40 | 0.7 | 31 | 19.0 | 45 | 33 |
| | 12.5 | 0.433 | 5.3 | 214 | 73 | 0.5 | 43 | 32.0 | 76 | 64 |
| | 12 | 0.416 | 5.3 | 243 | 62 | 1.4 | 45 | 25.0 | 85 | 74 |
| 4.8 W/m² throughout SD | 13 | 0.382 | 5.7 | 107 | 16 | 0.6 | 23 | 8.0 | 37 | 25 |
| | 12.5 | 0.430 | 5.4 | 202 | 36 | 0.5 | 45 | 7.0 | 77 | 56 |
| | 12 | 0.407 | 5.5 | 211 | 34 | 0.5 | 47 | 6.0 | 82 | 68 |
| 12 W/m² weeks 1-3 SD | ND | 0.332 | 5.5 | 143 | 21 | 0.5 | 35 | 8.0 | 50 | 40 |
| | 13 | 0.362 | 5.4 | 178 | 29 | 0.5 | 45 | 60.0 | 67 | 56 |
| | 12.5 | 0.426 | 5.4 | 213 | 52 | 0.7 | 47 | 14.0 | 82 | 72 |
| | 12 | 0.392 | 5.0 | 327 | 108 | 0.5 | 39 | 40.0 | 121 | 101 |

Table 1c: **The influence of night length treatments on compost analyses - stick week 48**

| Lighting Regime | Night Length (hrs) | Bulk density | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No supplementary lighting | ND | 0.434 | 5.2 | 431 | 181 | 0.4 | 70 | 71 | 146 | 128 |
| | 13 | 0.405 | 5.2 | 426 | 188 | 0.4 | 67 | 96 | 147 | 103 |
| | 12.5 | 0.431 | 5.5 | 268 | 108 | 0.3 | 53 | 26 | 97 | 77 |
| | 12 | 0.397 | 5.3 | 344 | 150 | 0.5 | 60 | 52 | 127 | 109 |
| 4.8 W/m² throughout SD | 13 | 0.460 | 5.3 | 375 | 139 | 0.4 | 71 | 29 | 144 | 105 |
| | 12.5 | 0.480 | 5.4 | 324 | 122 | 0.5 | 65 | 31 | 122 | 109 |
| | 12 | 0.491 | 5.5 | 292 | 93 | 0.8 | 62 | 20 | 108 | 100 |
| 12 W/m² weeks 1-3 SD | ND | 0.419 | 5.3 | 334 | 122 | 0.4 | 50 | 36 | 105 | 83 |
| | 13 | 0.397 | 5.3 | 278 | 100 | 0.3 | 58 | 20 | 103 | 85 |
| | 12.5 | 0.380 | 5.4 | 339 | 118 | 0.5 | 62 | 23 | 131 | 115 |
| | 12 | 0.390 | 5.4 | 297 | 108 | 0.7 | 55 | 31 | 110 | 93 |
| Cerise About Time: | | | | | | | | | | |
| No supplementary lighting | ND | 0.408 | 5.0 | 453 | 317 | 1.0 | 68 | 193 | 211 | 188 |
| | 13 | 0.411 | 5.4 | 361 | 135 | 0.7 | 75 | 70 | 127 | 128 |
| | 12.5 | 0.427 | 5.4 | 333 | 129 | 0.4 | 73 | 61 | 123 | 100 |
| | 12 | 0.389 | 5.4 | 347 | 136 | 0.7 | 73 | 46 | 130 | 108 |
| 4.8 W/m² throughout SD | 13 | 0.454 | 5.3 | 349 | 142 | 0.3 | 71 | 49 | 130 | 111 |
| | 12.5 | 0.439 | 5.3 | 433 | 191 | 3.3 | 60 | 116 | 146 | 115 |
| | 12 | 0.456 | 5.5 | 283 | 92 | 0.9 | 55 | 31 | 105 | 84 |
| 12 W/m² weeks 1-3 SD | ND | 0.418 | 5.3 | 381 | 159 | 0.4 | 65 | 65 | 136 | 120 |
| | 13 | 0.464 | 5.5 | 330 | 112 | 0.6 | 74 | 29 | 122 | 103 |
| | 12.5 | 0.393 | 5.5 | 310 | 99 | 0.6 | 68 | 23 | 118 | 104 |
| | 12 | 0.374 | 5.4 | 259 | 96 | 0.3 | 53 | 35 | 93 | 84 |

Table 2a: The influence of supplementary lighting at the end of short days on compost analyses - stick week 41

| Variety | Lighting treatment | Bulk density | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm | No supplementary lighting | 0.442 | 5.3 | 310 | 150 | 1.0 | 45 | 46 | 106 | 71 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.552 | 5.3 | 255 | 140 | 0.8 | 34 | 53 | 84 | 55 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.472 | 5.2 | 298 | 164 | 0.9 | 32 | 66 | 95 | 53 |
| Cerise About Time | No supplementary lighting | 0.504 | 5.1 | 360 | 176 | 1.0 | 61 | 43 | 133 | 74 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.447 | 4.9 | 378 | 192 | 1.1 | 56 | 92 | 135 | 75 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.479 | 5.2 | 255 | 135 | 0.9 | 37 | 60 | 83 | 51 |
| Yuba | No supplementary lighting | 0.478 | 5.3 | 199 | 94 | 0.8 | 30 | 30 | 65 | 38 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.454 | 5.1 | 288 | 136 | 1.0 | 37 | 29 | 102 | 59 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.456 | 5.2 | 270 | 135 | 0.9 | 37 | 64 | 84 | 39 |
| Akron | No supplementary lighting | 0.476 | 5.2 | 329 | 162 | 0.8 | 41 | 36 | 119 | 57 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.417 | 5.0 | 404 | 214 | 1.1 | 46 | 68 | 150 | 73 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.453 | 5.0 | 437 | 223 | 0.9 | 62 | 70 | 169 | 98 |
| Miramar | No supplementary lighting | 0.429 | 5.0 | 475 | 224 | 1.1 | 68 | 41 | 187 | 82 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.434 | 5.0 | 402 | 219 | 1.0 | 48 | 59 | 145 | 77 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.464 | 5.0 | 368 | 185 | 0.8 | 46 | 85 | 122 | 63 |

Table 2b: **The influence of supplementary lighting at the end of short days on compost analyses - stick week 45**

| Variety | Lighting treatment | Bulk density | pH ($\mu$S/cm) | Ec (mg/l) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm | No supplementary lighting | 0.347 | 5.4 | 214 | 84 | 0.8 | 41 | 19 | 74 | 66 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.374 | 5.4 | 185 | 73 | 0.5 | 42 | 24 | 66 | 63 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.410 | 5.4 | 207 | 77 | 0.8 | 43 | 20 | 71 | 57 |
| Cerise About Time | No supplementary lighting | 0.393 | 5.3 | 251 | 56 | 1.3 | 58 | 35 | 93 | 80 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.418 | 5.4 | 251 | 48 | 0.7 | 53 | 38 | 89 | 68 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.409 | 5.4 | 229 | 42 | 0.5 | 51 | 35 | 80 | 62 |
| Yuba | No supplementary lighting | 0.397 | 5.3 | 169 | 76 | 0.4 | 42 | 20 | 58 | 48 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.445 | 5.3 | 268 | 116 | 0.5 | 56 | 46 | 96 | 82 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.424 | 5.4 | 138 | 68 | 0.5 | 34 | 17 | 48 | 43 |
| Akron | No supplementary lighting | 0.376 | 5.0 | 249 | 125 | 0.5 | 44 | 43 | 91 | 76 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.411 | 5.2 | 275 | 131 | 0.5 | 51 | 48 | 99 | 84 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.384 | 5.2 | 263 | 122 | 0.5 | 46 | 23 | 98 | 83 |
| Miramar | No supplementary lighting | 0.372 | 5.1 | 297 | 141 | 0.5 | 53 | 56 | 110 | 92 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.372 | 4.7 | 565 | 274 | 0.9 | 66 | 151 | 192 | 170 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.390 | 5.2 | 301 | 134 | 0.5 | 56 | 48 | 112 | 97 |

Table 2c: The influence of supplementary lighting at the end of short days on compost analyses - stick week 48

| Variety | Lighting treatment | Bulk density | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm | No supplementary lighting | 0.434 | 5.2 | 1431 | 181 | 0.4 | 70 | 71 | 146 | 128 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.403 | 5.3 | 389 | 173 | 0.4 | 68 | 64 | 138 | 134 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.426 | 5.0 | 82 | 364 | 0.6 | 87 | 161 | 231 | 226 |
| Cerise About Time | No supplementary lighting | 0.408 | 5.0 | 453 | 317 | 1.0 | 68 | 193 | 211 | 188 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.407 | 5.3 | 348 | 142 | 0.6 | 72 | 60 | 120 | 113 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.430 | 5.4 | 372 | 156 | 0.4 | 72 | 70 | 127 | 123 |
| Yuba | No supplementary lighting | 0.408 | 5.2 | 460 | 213 | 0.6 | 84 | 114 | 162 | 157 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.422 | 5.1 | 441 | 211 | 0.5 | 83 | 100 | 154 | 142 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.452 | 5.1 | 455 | 242 | 0.7 | 88 | 112 | 182 | 155 |
| Akron | No supplementary lighting | 0.411 | 5.3 | 445 | 185 | 0.6 | 75 | 82 | 156 | 131 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.396 | 5.2 | 426 | 179 | 0.5 | 65 | 66 | 129 | 111 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.428 | 5.3 | 400 | 1790 | 0.6 | 67 | 82 | 130 | 121 |
| Miramar | No supplementary lighting | 0.414 | 5.1 | 514 | 244 | 0.7 | 81 | 132 | 166 | 160 |
| | 4.8 W/m$^2$ weeks 7-9 SD | 0.467 | 5.1 | 497 | 168 | 0.6 | 83 | 114 | 160 | 158 |
| | 12 W/m$^2$ weeks 7-9 SD | 0.423 | 5.1 | 509 | 240 | 0.5 | 80 | 118 | 165 | 155 |

Table 3a: **The influence of supplementary lighting and spacing on compost analyses - stick week 41**

| Lighting Regime | Spacing (pots/m$^2$) | Bulk density g/ml | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No supplementary lighting | 13.5 | 0.442 | 5.3 | 310 | 150 | 1.0 | 45 | 46 | 106 | 71 |
| | 16.0 | 0.472 | 5.2 | 200 | 118 | 0.9 | 26 | 49 | 62 | 35 |
| 4.8 W/m$^2$ throughout SD | 13.5 | 0.473 | 5.3 | 258 | 131 | 1.0 | 30 | 35 | 86 | 48 |
| | 16.0 | 0.489 | 5.4 | 198 | 93 | 0.9 | 29 | 31 | 62 | 40 |
| 12 W/m$^2$ weeks 1-3 SD | 13.5 | 0.430 | 5.0 | 297 | 179 | 1.0 | 32 | 78 | 99 | 50 |
| | 16.0 | 0.492 | 5.3 | 218 | 118 | 0.7 | 27 | 55 | 69 | 38 |
| Cerise About Time: | | | | | | | | | | |
| No supplementary lighting | 13.5 | 0.504 | 5.1 | 360 | 176 | 1.0 | 61 | 43 | 133 | 74 |
| | 16.0 | 0.477 | 5.0 | 312 | 179 | 1.0 | 54 | 76 | 127 | 78 |
| 4.8 W/m$^2$ throughout SD | 13.5 | 0.498 | 5.3 | 298 | 142 | 1.5 | 44 | 31 | 105 | 61 |
| | 16.0 | 0.517 | 5.3 | 227 | 111 | 1.1 | 36 | 50 | 72 | 42 |
| 12 W/m$^2$ weeks 1-3 SD | 13.5 | 0.492 | 4.9 | 364 | 189 | 1.1 | 38 | 86 | 123 | 55 |
| | 16.0 | 0.521 | 5.2 | 347 | 158 | 1.1 | 54 | 61 | 119 | 62 |

Table 3b: The influence of supplementary lighting and spacing on compost analyses - stick week 45

| Lighting Regime | Spacing (pots/m$^2$) g/ml | Bulk density | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No supplementary lighting | 13.5 | 0.347 | 5.4 | 214 | 84 | 0.8 | 41 | 19 | 74 | 66 |
| | 16.0 | 0.350 | 5.5 | 194 | 75 | 0.7 | 38 | 20 | 64 | 52 |
| 4.8 W/m$^2$ throughout SD | 13.5 | 0.373 | 5.7 | 128 | 27 | 0.5 | 28 | 7 | 43 | 31 |
| | 16.0 | 0.397 | 5.8 | 111 | 18 | 0.5 | 24 | 8 | 36 | 27 |
| 12 W/m$^2$ weeks 1-3 SD | 13.5 | 0.326 | 5.5 | 182 | 67 | 1.1 | 34 | 26 | 61 | 43 |
| | 16.0 | 0.346 | 5.5 | 167 | 56 | 0.5 | 31 | 10 | 56 | 44 |
| Cerise About Time: | | | | | | | | | | |
| No supplementary lighting | 13.5 | 0.393 | 5.3 | 251 | 56 | 1.3 | 58 | 35 | 93 | 80 |
| | 16.0 | 0.399 | 5.2 | 222 | 52 | 0.9 | 45 | 49 | 76 | 67 |
| 4.8 W/m$^2$ throughout SD | 13.5 | 0.382 | 5.7 | 107 | 16 | 0.6 | 23 | 8 | 37 | 25 |
| | 16.0 | 0.368 | 5.3 | 155 | 50 | 0.8 | 31 | 6 | 60 | 43 |
| 12 W/m$^2$ weeks 1-3 SD | 13.5 | 0.332 | 5.5 | 143 | 21 | 0.5 | 35 | 8 | 50 | 40 |
| | 16.0 | 0.351 | 5.4 | 148 | 21 | 0.5 | 38 | 17 | 53 | 43 |

Table 3c: **The influence of supplementary lighting and spacing on compost analyses - stick week 48**

| Lighting Regime | Spacing (pots/$m^2$) | Bulk density g/ml | pH | Ec ($\mu$S/cm) | $NO_3$-N (mg/l) | $NH_4$-N (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Charm: | | | | | | | | | | |
| No supplementary lighting | **13.5** | 0.434 | 5.3 | 431 | 181 | 0.4 | 70 | 71 | 146 | 128 |
| | **16.0** | 0.420 | 5.2 | 462 | 191 | 0.3 | 71 | 91 | 147 | 127 |
| 4.8 W/$m^2$ throughout SD | **13.5** | 0.460 | 5.3 | 375 | 139 | 0.4 | 71 | 29 | 144 | 105 |
| | **16.0** | 0.491 | 5.3 | 267 | 105 | 0.4 | 56 | 40 | 97 | 67 |
| 12 W/$m^2$ weeks 1-3 SD | **13.5** | 0.419 | 5.3 | 1034 | 122 | 0.4 | 50 | 36 | 105 | 83 |
| | **16.0** | 0.405 | 5.4 | 317 | 129 | 0.5 | 60 | 34 | 119 | 103 |
| Cerise About Time: | | | | | | | | | | |
| No supplementary lighting | **13.5** | 0.408 | 5.0 | 453 | 317 | 1.0 | 68 | 193 | 211 | 188 |
| | **16.0** | 0.398 | 5.2 | 434 | 196 | 0.6 | 76 | 108 | 150 | 137 |
| 4.8 W/$m^2$ throughout SD | **13.5** | 0.454 | 5.3 | 349 | 142 | 0.3 | 71 | 49 | 130 | 111 |
| | **16.0** | 0.483 | 5.4 | 295 | 105 | 0.4 | 69 | 38 | 105 | 97 |
| 12 W/$m^2$ weeks 1-3 SD | **13.5** | 0.418 | 5.3 | 381 | 159 | 0.4 | 65 | 65 | 136 | 120 |
| | **16.0** | 0.392 | 5.5 | 246 | 86 | 0.5 | 57 | 32 | 88 | 87 |

# APPENDIX V
## Photographic records

**Plate 1**
**Illustration of leaf damage scores for assessments at marketing and during shelf-life**

Score 0

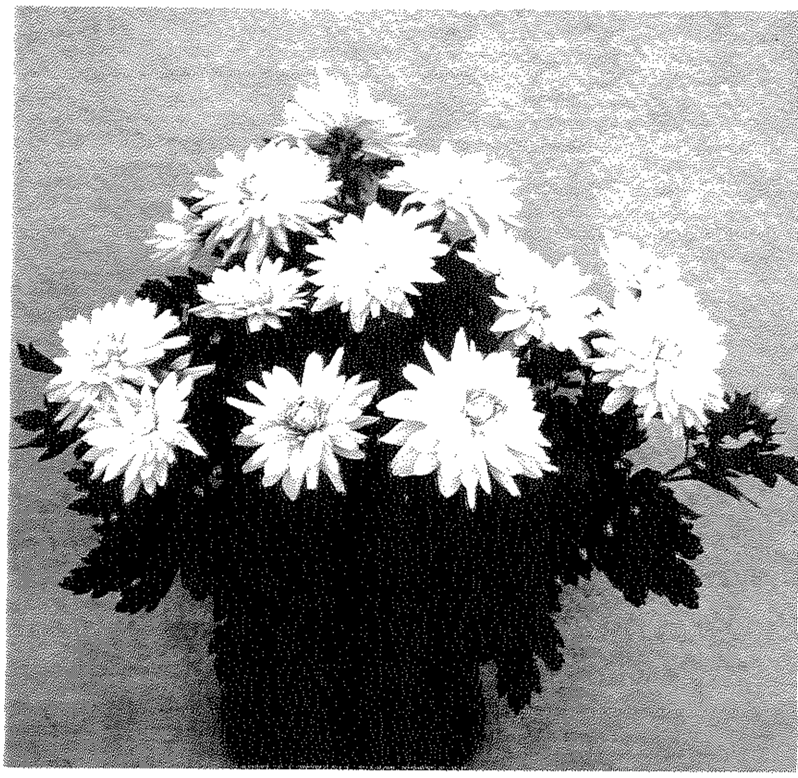
Score 1

Score 2

Note: Damage above score 2 was not observed for any treatments

**Plate 2**
**Illustration of deterioration scores for shelf-life assessment of Charm**

Score 1



Score 2

Score 3

**Plate 3**
**Illustration of leaf deterioration scores for shelf-life assessment of Cerise About Time**

Score 1

Score 2

Score 3

**Plate 4**
**The influence of reducing night length on plants grown without supplementary lighting**

Charm

Natural night | 13 hr night | 12.5 hr night | 12 hr night

Cerise About Time

Natural night | 13 hr night | 12.5 hr night | 12 hr night

**Plate 5**

**The influence of reducing night length on plants grown with supplementary lighting at 4.8 W/m$^2$ throughout short days**

Charm

13 hr night 12.5 hr night 12 hr night

Cerise About Time

13 hr night 12.5 hr night 12 hr night

**Plate 6**

**The influence of reducing night length on plants grown with supplementary lighting at 12 W/m$^2$ during weeks 1 to 3 of short days**

Charm

Natural night | 13 hr night | 12.5 hr night | 12 hr night

Cerise About Time

Natural night | 13 hr night | 12.5 hr night | 12 hr night

**Plate 7**
**The influence of supplementary lighting at the end of short days**

Charm

Cerise About Time

Yuba

| No supplementary lighting | 4.8 W/m² weeks 7-9 SD | 12 W/m² weeks 7-9 SD |
|---|---|---|

**Plate 7a**

**The influence of supplementary lighting at the end of short days**

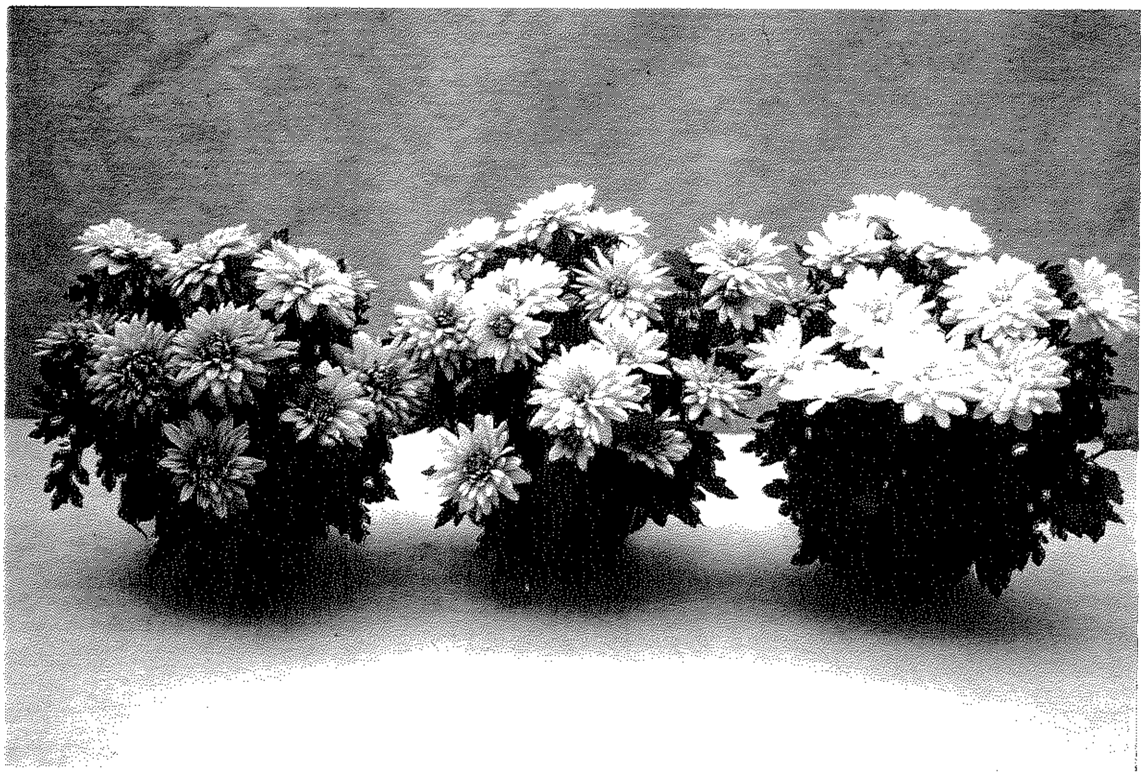
Miramar

Akron

| No supplementary lighting | 4.8 W/m² weeks 7-9 SD | 12 W/m² weeks 7-9 SD |
|---|---|---|

**Plate 8**

An example of the unevenness which resulted on some pots from tungsten lighting to reduce night length.



Comparison of flower colour fade during shelf-life with improved colour retention from lighting at the end of short days (taken after 21 days in shelf-life).

# APPENDIX VI
## Economic appraisal of treatments

## COST OF SUPPLEMENTARY LIGHTING FOR POT CHRYSANTHEMUMS

The following presents calculations for the costs of the lighting treatments assessed in this trial. There are a number of variables which will affect final costing. These include the lighting regime itself and the density of pot spacing. Decreasing the length of night also affects lighting costs and calculations have therefore been presented for each of the treatment combinations assessed to illustrate how they influence final cost.

The final cost of lighting will also be affected by items such as the capital cost of lamps, electricity charges and interest rates on loans. To illustrate the impact that changes in the cost of these basic items can have on final costs, all calculations have been based on two separate sets of assumptions. The first set is based on costings calculated for the 1991/92 HDC funded work PC13b (Finlay, 1993). The second set is based on updated figures collected from the Electricity Association and Royal Bank of Scotland. (The latter set of figures are presented in italics to separate them from the former set.)

**Assumptions**

1. Capital cost of 400W SON/T lamp and installation = £160 or *£150*°

   Capital cost of 150W tungsten lamp and installation, including spare bulbs at a replacement of 1 bulb per year = £6.18°

2. Illuminance

| | |
|---|---|
| 12 $W/m^2$ | 1 lamp covers $6m^2$ |
| 4.8 $W/m^2$ | 1 lamp covers $14m^2$ |
| 5 $W/m^2$ (tungsten) | 1 bulb covers $9.6m^2$ |

3. Annual capital cost per luminaire assuming amortized over 5 years at 14%* *(or 9%°)*

   $\frac{£160}{5\ yrs} + \frac{(80 \times 14\%)}{100} = £43.20$ *or* $\frac{£150}{5\ yrs} \times \frac{(80 \times 9\%)}{100} = £37.20$

4. Annual capital cost per tungsten bulb (including installation and spare bulbs) assuming amortized over 5 years at 9%°.

   $\frac{£6.18}{5\ yrs} + \frac{(80 \times 9\%)}{100} = £8.44$

5. Annual capital cost per $m^2$
   SON/T lighting

   at 12 $W/m^2$ = $\frac{43.2}{6}$ = £7.20/$m^2$/year or $\frac{37.2}{6}$ = £6.20/$m^2$/year

   at 4.8 $W/m^2$ = $\frac{43.2}{6}$ = £3.09/$m^2$/year or $\frac{37.2}{6}$ = £2.66/$m^2$/year

   Tungsten lighting

   at 5 $W/m^2$ = $\frac{8.44}{9.6}$ = £0.88/$m^2$/year

6. Period of lighting during SD (including extended daylength treatments) with SON/T lamps:

| | |
|---|---|
| 11 hours/day | - 0700 to 1800 hrs |
| 11.5 hours/day | - 0700 to 1830 hrs |
| 12 hours/day | - 0700 to 1900 hrs |

Period of lighting during SD to extend daylength, assuming dusk commences at 1630 hrs on average over the winter period, with tungsten lighting:

| | | | | |
|---|---|---|---|---|
| 13 hour night | - | 1630 to 1800 hrs | = | 1.5 hrs |
| 12.5 hour night | - | 1630 to 1830 hrs | = | 2.0 hrs |
| 12 hour night | - | 1630 to 1900 hrs | = | 2.5 hrs |

7. Lighting period - October-February = 20 weeks

Trial period = 20 weeks but commercial winter production period = 26 weeks. Hence calculations are based on commercial standard of 26 weeks.

8. Electricity running costs

| | | | | |
|---|---|---|---|---|
| Standard | 7 am - midnight | 7.78p/kWhr* | *or* | *5.50p/kWhr*° |
| Off-Peak | Midnight - 7 am | 2.61p/kWhr* | *or* | *3.00p/kWhr*° |

Each luminaire requires 0.44 kW per hour i.e. 400 watts per lamp plus 40 watts for starter equipment. Each tungsten bulb requires 0.15 kW per hour i.e. 150 watts per lamp.

9. Average production time (to marketing stage 3)

at 12 W/m² weeks 1-3 SD = 75 days (including 14 days in propagation)

at 4.8 W/m² throughout SD = 77 days (including 14 days in propagation)

Therefore assume an average of 9 weeks in short days (will vary according to variety and solar radiation levels).

* Assumed cost in original costings calculated for the 1991/92 HDC funded work.
° *Assumed cost according to average figures in 1995*

## A. Capital Cost

**Treatment 1a** **No supplementary lighting (13 hour night)**

(NOTE: Since using tungsten lighting is a new treatment costs will only be calculated on current assumptions of capital etc)

Tungsten lighting at intermediate spacing (weeks 1-2 SD) at 5 $W/m^2$, $1m^2$ will service 13 crops.

27 pots x 13 crops = 351 pots

Capital cost per pot:

$$\frac{88}{351} = 0.3p/pot$$

Tungsten lighting at final spacing (weeks 3-9 SD) at 5 $W/m^2$, $1m^2$ will service 3.7 crops.

13.5 pots x 3.7 crops = 50 pots

Capital cost per pot

$$\frac{88}{50} = 1.8p/pot$$

Total capital cost

$$0.3 + 1.8 = 2.1p/pot$$

**Treatment 1b** **No supplementary lighting (12.5 hour night)**

Capital costs as for treatment 8 apply.

**Treatment 1c** **No supplementary lighting (12 hour night)**

Capital costs as for treatment 8 apply.

**Treatment 2a** **4.8 $W/m^2$ throughout SD (13 hour night)**

At intermediate spacing (weeks 1-2) and 4.8 $W/m^2$, $1m^2$ will service 13 crops at the following densities:

a. 27 $pots/m^2$ x 13 crops = 351 pots
b. 32 $pots/m^2$ x 13 crops = 416 pots

Capital cost per pot:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| a. | = | $\frac{309}{351}$ | = | 0.9p/pot | *or* $\frac{266}{351}$ | = | *0.8p/pot* |
| b. | = | $\frac{309}{416}$ | = | 0.7p/pot | *or* $\frac{266}{416}$ | = | *0.6p/pot* |

At final spacing (weeks 3-9) and 4.8 W/m², 1m² will service 3.7 crops at the following densities:

| | | | |
|---|---|---|---|
| a. | 13.5 pots/m² x 3.7 crops | = | 50.0 pots |
| b. | 16 pots/m² x 3.7 crops | = | 59.2 pots |

Capital cost per pot:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| a. | = | $\frac{309}{50}$ | = | 6.2p/pot | *or* $\frac{266}{50}$ | = | *5.3p/pot* |
| b. | = | $\frac{309}{59.2}$ | = | 5.2p/pot | *or* $\frac{266}{59.2}$ | = | *4.5p/pot* |

Total capital cost per density:

| | | | |
|---|---|---|---|
| a. | = | 0.9 + 6.2 = 7.1p/pot | *or 0.8 + 5.3 = 6.1p/pot* |
| b. | = | 0.7 + 7.2 = 5.9p/pot | *or 0.6 + 4.5 = 5.1p/pot* |

**Treatment 2b** **4.8 W/m² throughout SD (12.5 hour night)**

Capital costs as for treatment 1 apply.

**Treatment 2c** **4.8 W/m² throughout SD (12 hour night)**

Capital costs as for treatment 1 apply.

**Treatment 3a** **12 W/m² weeks 1-3 SD (13 hour night weeks 1-3 SD, natural night weeks 4+ SD))**

At intermediate spacing (weeks 1-2) and 12 W/m², 1m² will service 13 crops at the following densities:

| | | | |
|---|---|---|---|
| a. | 27 pots/m² x 13 crops | = | 351 pots |
| b. | 32 pots/m² x 13 crops | = | 416 pots |

| | | | | | | |
|---|---|---|---|---|---|---|
| a. | $\frac{720}{351}$ | = | 2.1p/pot | *or* | $\frac{620}{351}$ | = *1.8p/pot* |

b. $\frac{720}{416}$ = 1.7p/pot *or* $\frac{620}{416}$ = *1.5p/pot*

At final spacing (week 3) and 12 W/m², 1m² will service 26 crops at the following densities:

a. 13.5 pots/m² x 26 crops = 351 pots
b. 16 pots/m² x 26 crops = 416 pots

a. $\frac{720}{351}$ = 2.1p/pot *or* $\frac{620}{351}$ = *1.8p/pot*

b. $\frac{720}{416}$ = 1.7p/pot *or* $\frac{620}{416}$ = *1.5p/pot*

Total capital cost

a. = 2.1 + 2.1 = 4.2p/pot *or 1.8 + 1.8 = 3.6p/pot*
b. = 1.7 +1.7 = 3.4p/pot *or 1.5 + 1.5 = 3.0p/pot*

**Treatment 3b** **12 W/m² weeks 1-3 SD (13 hour night)**

(NOTE: Since using tungsten lighting is a new treatment costs will only be calculated on current assumptions of capital etc)

Capital costs for SON/T lighting during weeks 1-3 SD as for treatment 4 above, i.e:

*3.6p/pot*

Capital cost for tungsten lighting weeks 4-9 SD at 1m² will service 4.3 crops.

At final spacing:

*13.5 pots/m² x 4.3 crops* = *58.1 pots*

Capital cost per pot:

(NB: Prices current to date only since this costing was not carried out in the 1991/92 report)

$\frac{88}{58.1}$ = *1.5p/pot*

Total capital cost

*3.6 + 1.5* = *5.1p/pot*

**Treatment 3c** **12 W/m² weeks 1-3 SD (12.5 hour night)**

Capital costs as for treatment 5 apply.

**Treatment 3d** **12 W/m² weeks 1-3 SD (12 hour night)**

Capital costs as for treatment 5 apply.

**Treatment 4** **4.8 W/m² weeks 7-9 SD only**

At final spacing (weeks 7-9) and 4.8 W/m², 1m² will service 8.7 crops:

13.5 pots/m² x 8.7 crops = 117 pots

Capital cost

$\frac{309}{117}$ = 2.6p/pot *or* $\frac{266}{117}$ = *2.3p/pot*

**Treatment 5 12 W/m² weeks 7-9 SD only**

At final spacing (weeks 7-9) and 12 W/m², 1m² will service 8.7 crops:

13.5 pots/m² x 8.7 crops = 117 pots

Capital cost

$\frac{720}{117}$ = 6.2p/pot *or* $\frac{620}{117}$ = *5.3p/pot*

## B. Running Cost

**Treatment 1a  No supplementary lighting (13 hour night)**

(NOTE: Since using tungsten lighting is a new treatment, costs will be calculated on current assumptions of capital etc)

2 weeks at intermediate spacing plus 7 weeks at final spacing with tungsten lighting to extend daylength

At intermediate spacing for 2 weeks (12 $W/m^2$) =

$$\frac{0.15\ kW \times 1.5\ hrs \times 14\ days \times 5.50p/kWhr}{9.6m^2} = 1.8p/m^2$$

At 27 pots/$m^2$:

$$\frac{1.8}{27} = 0.1p/pot$$

At final spacing for 7 weeks =

$$\frac{0.15\ kW \times 1.5\ hrs \times 49\ days \times 5.50p/kWhr}{9.6m^2} = 6.3p/m^2$$

At 13.5 pots/$m^2$:

$$\frac{6.3}{13.5} = 0.5p/pot$$

Total Running Costs:

$$0.1 + 0.5 = 0.6p/pot$$

**Treatment 1b  No supplementary lighting (12.5 hour night)**

(NOTE: Since using tungsten lighting is a new treatment, costs will be calculated on current assumptions of capital etc)

2 weeks at intermediate spacing plus 7 weeks at final spacing with tungsten lighting to extend daylength

At intermediate spacing for 2 weeks =

$$\frac{0.15\ kW \times 2\ hrs \times 14\ days \times 5.50p/kWhr}{9.6m^2} = 2.4p/m^2$$

At 27 pots/m²:

$$\frac{2.4}{27} = 0.1p/pot$$

At final spacing for 7 weeks =

$$\frac{0.15\ kW \times 2\ hrs \times 49\ days \times 5.50p/kWhr}{9.6m^2} = 8.4p/m^2$$

At 13.5 pots/m²:

$$\frac{8.4}{13.5} = 0.6p/pot$$

Total Running Costs:

$$0.1 + 0.6 = 0.7p/pot$$

**Treatment 1c** **No supplementary lighting (12 hour night)**

(NOTE: Since using tungsten lighting is a new treatment, costs will be calculated on current assumptions of capital etc)

2 weeks at intermediate spacing plus 7 weeks at final spacing with tungsten lighting to extend daylength

At intermediate spacing for 2 weeks =

$$\frac{0.15\ kW \times 2.5\ hrs \times 14\ days \times 5.50p/kWhr}{9.6m^2} = 3.0p/m^2$$

At 27 pots/m²:

$$\frac{3.0}{27} = 0.1p/pot$$

At final spacing for 7 weeks =

$$\frac{0.15\ kW \times 2.5\ hrs \times 49\ days \times 5.50p/kWhr}{9.6m^2} = 10.5p/m^2$$

At 13.5 pots/m²:

$$\frac{10.5}{13.5} = 0.8p/pot$$

Total Running Costs:

$$0.1 + 0.8 = 0.9p/pot$$

**Treatment 2a 4.8 W/m² throughout SD (13 hour night)**

i. Based on costings used in the 1991/92 HDC funded work (PC13b)

2 weeks at intermediate spacing plus 7 weeks at final spacing.

At intermediate spacing for 2 weeks (4.8 W/m²) =

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 14 \text{ days x } 7.78\text{p/kWhr}}{14\text{m}^2} = 37.7\text{p/m}^2$$

Running cost per density:

a. $= \frac{37.7}{27} =$ 1.4p/pot

b. $= \frac{37.7}{32} =$ 1.2p/pot

At final spacing for 7 weeks (4.8 W/m²) =

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 49 \text{ days x } 7.78\text{p/kWhr}}{14\text{m}^2} = 131.8\text{p/m}^2$$

Running cost per density:

a. $= \frac{131.8}{13.5} =$ 9.8p/pot

b. $= \frac{131.8}{16} =$ 8.2p/pot

Total running cost per density:

a. 1.4 + 9.8 = 11.2p/pot
b. 1.2 + 8.2 = 9.2 p/pot

or

ii. Based on average figures current in 1995

At intermediate spacing for 2 weeks (4.8 W/m²) =

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 14 \text{ days x } 5.50\text{p/kWhr}}{14\text{m}^2} = 26.6\text{p/m}^2$$

Running cost per density:

a. $= \frac{26.6}{27} =$ *1.0p/pot*

b. = $\frac{26.6}{32}$ = *0.8p/pot*

At final spacing for 7 weeks (4.8 $W/m^2$) =

$$\frac{0.44\ kW \times 11\ hrs \times 49\ days \times 5.50p/kWhr}{14m^2} = 93.2p/m^2$$

Running cost per density:

*a.* = $\frac{93.2}{13.5}$ = *6.9p/pot*

*b.* = $\frac{93.2}{16}$ = *5.8p/pot*

Total running cost per density:

*a.* *1.0 + 6.9* = *7.9p/pot*
*b.* *0.8 + 5.8* = *6.6 p/pot*

**Treatment 2b 4.8 $W/m^2$ throughout SD (12.5 hour night)**

i. Based on costings used in the 1991/92 HDC funded work (PC13b)

2 weeks at intermediate spacing plus 7 weeks at final spacing.

At intermediate spacing for 2 weeks (4.8 $W/m^2$) =

$$\frac{0.44\ kW \times 11.5\ hrs \times 14\ days \times 7.78p/kWhr}{14m^2} = 39.4p/m^2$$

At 27 $pots/m^2$

$\frac{39.4}{27}$ = 1.5p/pot

At final spacing for 7 weeks (4.8 $W/m^2$) =

$$\frac{0.44\ kW \times 11.5\ hrs \times 49\ days \times 7.78p/kWhr}{14m^2} = 137.8p/m^2$$

At 13.5 $pots/m^2$

$\frac{137.8}{13.5}$ = 10.2p/pot

Total running cost:

a. 1.5 + 10.2 = 11.7p/pot

or

ii. Based on average figures current in 1995

At intermediate spacing for 2 weeks (4.8 W/m²) =

$$\frac{0.44\ kW \times 11.5\ hrs \times 14\ days \times 5.50p/kWhr}{14m^2} = 27.8p/m^2$$

At 27 pots/m²:

$$\frac{27.8}{27} = 1.0p/pot$$

At final spacing for 7 weeks (4.8 W/m²) =

$$\frac{0.44\ kW \times 11.5\ hrs \times 49\ days \times 5.50p/kWhr}{14m^2} = 97.4p/m^2$$

At 13.5 pots/m²:

$$\frac{97.4}{13.5} = 7.2p/pot$$

Total Running Cost:

*1.0 + 7.2 = 8.2p/pot*

**Treatment 2c 4.8 W/m² throughout SD (12 hour night)**

i. Based on costings used in the 1991/92 HDC funded work (PC13b)

2 weeks at intermediate spacing plus 7 weeks at final spacing.

At intermediate spacing for 2 weeks (4.8 W/m²) =

$$\frac{0.44\ \text{kW} \times 12\ \text{hrs} \times 14\ \text{days} \times 7.78\text{p/kWhr}}{14\text{m}^2} = 41.0\text{p/m}^2$$

At 27 pots/m²:

$$\frac{41}{27} = 1.5\text{p/pot}$$

At final spacing for 7 weeks (4.8 $W/m^2$) =

$$\frac{0.44 \text{ kW x } 12 \text{ hrs x } 49 \text{ days x } 7.78\text{p/kWhr}}{14\text{m}^2} = 143.8\text{p/m}^2$$

At 13.5 pots/$m^2$:

$$\frac{143.8}{13.5} = 10.7\text{p/pot}$$

Total Running Cost:

$$1.5 + 10.7 = 12.2\text{p/pot}$$

or

ii. Based on average figures current in 1995

At intermediate spacing for 2 weeks (4.8 $W/m^2$) =

$$\frac{0.44 \text{ kW x } 12 \text{ hrs x } 14 \text{ days x } 5.50\text{p/kWhr}}{14\text{m}^2} = 29.0\text{p/m}^2$$

At 27 pots/$m^2$:

$$\frac{29}{27} = 1.1\text{p/pot}$$

At final spacing for 7 weeks (4.8 $W/m^2$) =

$$\frac{0.44 \text{ kW x } 12 \text{ hrs x } 49 \text{ days x } 5.50\text{p/kWhr}}{14\text{m}^2} = 101.6\text{p/m}^2$$

At 13.5 pots/$m^2$:

$$\frac{101.6}{13.5} = 7.5\text{p/pot}$$

Total Running Cost:

$$1.1 + 7.5 = 8.6\text{p/pot}$$

**Treatment 3a** **12 $W/m^2$ weeks 1-3 SD (13 hour night weeks 1-3 SD, natural night weeks 4+ SD)**

i. Based on costings used in the 1991/92 HDC funded work (PC13b)

2 weeks at intermediate spacing plus 1 week at final spacing.

At intermediate spacing for 2 weeks (12 $W/m^2$) =

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 14 \text{ days x } 7.78\text{p/kWhr}}{6\text{m}^2} = 87.9\text{p/m}^2$$

Running cost per density:

a. = $\frac{87.9}{27}$ = 3.3p/pot

b. = $\frac{87.9}{32}$ = 2.7p/pot

At final spacing for 1 week (12 $W/m^2$) =

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 49 \text{ days x } 7.78\text{p/kWhr}}{6\text{m}^2} = 43.9\text{p/m}^2$$

Running cost per density:

a. = $\frac{43.9}{13.5}$ = 3.3p/pot

b. = $\frac{43.9}{16}$ = 2.7p/pot

Total running cost per density:

a. 3.3 + 3.3 = 6.6p/pot
b. 2.7 + 2.7 = 5.4 p/pot

or

ii. Based on average figures current in 1995

At intermediate spacing for 2 weeks (12 $W/m^2$) =

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 14 \text{ days x } 5.50\text{p/kWhr}}{6\text{m}^2} = 62.1\text{p/m}^2$$

Running cost per density:

a. = *$\frac{62.1}{27}$* = *2.3p/pot*

b. $= \frac{62.1}{32} = 1.9p/pot$

At final spacing for 1 week (12 W/m²) =

$$\frac{0.44\ kW \times 11\ hrs \times 7\ days \times 5.50p/kWhr}{6m^2} = 31.1p/m^2$$

Running cost per density:

*a.* $= \frac{31.1}{13.5} = 2.3p/pot$

*b.* $= \frac{31.1}{16} = 1.9p/pot$

Total Running Cost per Density:

*a.* $2.3 + 2.3 = 4.6p/pot$
*b.* $1.9 + 1.9 = 3.8\ p/pot$

**Treatment 3b 12 W/m² weeks 1-3 SD (13 hour night)**

(NOTE: Since using tungsten lighting is a new treatment, costs will be calculated on current assumptions of capital etc)

2 weeks at intermediate spacing plus 1 week at final spacing with SON/T lighting

At intermediate spacing for 2 weeks (12 W/m²) =

$$\frac{0.44\ kW \times 11\ hrs \times 14\ days \times 5.50p/kWhr}{6m^2} = 62.1p/m^2$$

At 27 pots/m²:

$$\frac{62.1}{27} = 2.3p/pot$$

At final spacing for 1 week (12 W/m²) =

$$\frac{0.44\ kW \times 11\ hrs \times 7\ days \times 5.50p/kWhr}{6m^2} = 31.1p/m^2$$

At 13.5 pots/m²:

$$\frac{31.1}{13.5} = 2.3p/pot$$

6 weeks at final spacing with tungsten lighting to extend daylength

$$\frac{0.15\ kW \times 1.5\ hrs \times 42\ days \times 5.50p/kWhr}{9.6m^2} = 5.4p/m^2$$

At 13.5 pots/m²:

$$\frac{5.4}{13.5} = 0.4p/pot$$

Total Running Costs:

$$2.3 + 2.3 + 0.4 = 5.0p/pot$$

**Treatment 3c 12 W/m² weeks 1-3 SD (12.5 hour night)**

(NOTE: Since using tungsten lighting is a new treatment, costs will be calculated on current assumptions of capital etc)

2 weeks at intermediate spacing plus 1 week at final spacing with SON/T lighting

At intermediate spacing for 2 weeks (12 W/m²) =

$$\frac{0.44\ kW \times 11.5\ hrs \times 14\ days \times 5.50p/kWhr}{6m^2} = 64.9p/m^2$$

At 27 pots/m²:

$$\frac{64.9}{27} = 2.4p/pot$$

At final spacing for 1 week (12 W/m²) =

$$\frac{0.44\ kW \times 11.5\ hrs \times 7\ days \times 5.50p/kWhr}{6m^2} = 32.5p/m^2$$

At 13.5 pots/m²:

$$\frac{32.5}{13.5} = 2.4p/pot$$

6 weeks at final spacing with tungsten lighting to extend daylength

$$\frac{0.15\ kW \times 2.0\ hrs \times 42\ days \times 5.50p/kWhr}{9.6m^2} = 7.2p/m^2$$

At 13.5 pots/m$^2$:

$$\frac{7.2}{13.5} = 0.5p/pot$$

Total Running Costs:

$$2.4 + 2.4 + 0.5 = 5.3p/pot$$

**Treatment 3d** **12 W/m$^2$ weeks 1-3 SD (12 hour night)**

(NOTE: Since using tungsten lighting is a new treatment, costs will be calculated on current assumptions of capital etc)

2 weeks at intermediate spacing plus 1 week at final spacing with SON/T lighting

At intermediate spacing for 2 weeks (12 W/m$^2$) =

$$\frac{0.44\ kW \times 12\ hrs \times 14\ days \times 5.50p/kWhr}{6m^2} = 67.8p/m^2$$

At 27 pots/m$^2$:

$$\frac{67.8}{27} = 2.5p/pot$$

At final spacing for 1 week (12 W/m$^2$) =

$$\frac{0.44\ kW \times 12\ hrs \times 7\ days \times 5.50p/kWhr}{6m^2} = 33.9p/m^2$$

At 13.5 pots/m$^2$:

$$\frac{33.9}{13.5} = 2.5p/pot$$

6 weeks at final spacing with tungsten lighting to extend daylength

$$\frac{0.15\ kW \times 2.5\ hrs \times 42\ days \times 5.50p/kWhr}{9.6m^2} = 9.0p/m^2$$

At 13.5 pots/m$^2$:

$$\frac{9.0}{13.5} = 0.7p/pot$$

Total Running Costs:

$$2.5 + 2.5 + 0.7 = 5.7p/pot$$

**Treatment 4 4.8 W/m² weeks 7-9 SD only**

3 weeks at final spacing under lighting

i. Based on costings used in the 1991/92 HDC funded work (PC13b)

At final spacing for 3 weeks (4.8 W/m²) =

$$\frac{\text{0.44 kW x 11 hrs x 21 days x 7.78p/kWhr}}{14m^2} = 56.5p/m^2$$

At 13.5 pots/m²:

$$\frac{56.5}{13.5} = 4.2p/pot$$

or

ii. Based on average figures current in 1995

At final spacing for 3 weeks (4.8 W/m²) =

$$\frac{\textit{0.44 kW x 11 hrs x 21 days x 5.50p/kWhr}}{\textit{14m}^2} = \textit{39.9p/m}^2$$

At 13.5 pots/m²:

$$\frac{39.9}{13.5} = \textit{3.0p/pot}$$

**Treatment 5 12 W/m² weeks 7-9 SD only**

3 weeks at final spacing under lighting

i. Based on costings used in the 1991/92 HDC funded work (PC13b)

At final spacing for 3 weeks (12 W/m²) =

$$\frac{\text{0.44 kW x 11 hrs x 21 days x 7.78p/kWhr}}{6m^2} = 131.8p/m^2$$

At 13.5 pots/m²:

$$\frac{131.8}{13.5} = 9.8p/pot$$

or

ii. Based on average figures current in 1995

At final spacing for 3 weeks (12 $W/m^2$) =

$$\frac{0.44\ kW \times 11\ hrs \times 21\ days \times 5.50p/kWhr}{6m^2} = 93.2p/m^2$$

At 13.5 $pots/m^2$:

$$\frac{93.2}{13.5} = 6.9p/pot$$

## C. Summary of the cost of providing lighting for the treatments assessed

| | Cost p/pot | | | | | |
|---|---|---|---|---|---|---|
| | Capital | | Running | | Total | |
| **1. No supplementary lighting** | | | | | | |
| 13 hour night | | *(2.1)*° | | *(0.6)*° | | **(2.7)**° |
| 12.5 hour night | | *(2.1)* | | *(0.7)* | | **(2.8)** |
| 12 hour night | | *(2.1)* | | *(0.9)* | | **(3.0)** |
| **2. 4.8 W/m² throughout SD** | | | | | | |
| 13 hour night: | | | | | | |
| Standard spacing | 7.1* | *(6.1)*° | 11.2* | *(7.9)*° | **18.3*** | ***(14.0)***° |
| Close spacing | 5.9 | *(5.1)* | 9.4 | *(6.6)* | **15.3** | ***(11.7)*** |
| 12.5 hour night | 7.1 | *(6.1)* | 11.7 | *(8.2)* | **18.8** | ***(14.3)*** |
| 12 hour night | 7.1 | *(6.1)* | 12.2 | *(8.6)* | **19.3** | ***(14.7)*** |
| **3. 12 W/m² weeks 1-3 SD** | | | | | | |
| Natural night length0 | | | | | | |
| Standard spacing | 4.2* | *(3.6)*° | 6.6* | *(4.6)*° | **10.8*** | ***(8.2)***° |
| Close spacing | 3.4 | *(3.0)* | 5.4 | *(3.8)* | **8.8** | ***(6.8)*** |
| 13 hour night | | *(5.1)* | | *(5.0)* | | ***(10.1)*** |
| 12.5 hour night | | *(5.1)* | | *(5.3)* | | ***(10.4)*** |
| 12 hour night | | *(5.1)* | | *(5.7)* | | ***(10.8)*** |
| **4. 4.8 W/m² weeks 7-9 SD** | 2.6* | *(2.3)*° | 4.2* | *(3.0)*° | ***6.8**** | **(5.3)**° |
| **5. 12 W/m² weeks 7-9 SD** | 6.2 | *(5.3)* | 9.8 | *(6.9)* | **16.0** | ***(12.2)*** |

* Based on costings calculated in the 1991/92 HDC funded work (PC13b)

° *Based on figures current in 1995*

## APPENDIX VII

## REFERENCES

Cockshull, K. E. and Hughes, A. P. (1971) The effects of light intensity at different stages in flower initiation and development of *Chrysanthemum morifolium*. Ann Bot. 35, 915-926

Cockshull, K. E. and Hughes, A. P. (1972) Flower formation in *Chrysanthemum morifolium* - the influence of light level. Journal of Horticultural Science, 47, 113.

Finlay, A. R. (1993) Chrysanthemums: Supplementary lighting for winter production of pot chrysanthemums. Contract Report HDC PC13b.

van der Hoeven, A. P. (1994) Effecten kortere nacht chrysantenteelt onderzocht. Vakblad voor de Bloemisterij, 40, 32-33 & 35.

Wilson, D. P. (1994) Chrysanthemums: The influence of supplementary lighting and DROP regimes on the winter quality of American bred varieties of pot chrysanthemums. Contract Report HDC PC92.

Wilson, D. P. (1995) Chrysanthemums: The influence of combined supplementary lighting regimes and pot spacings on the quality and economics of the winter production of pot chrysanthemums. Contract Report HDC PC92a.

Wilson, D. P. (1996) Chrysanthemums: Supplementary lighting and spacing for the winter production of AYR spray chrysanthemums. Contract Report HDC PC104 and 104b.

# APPENDIX VIII

(Contract, Terms and Conditions)

# HORTICULTURAL DEVELOPMENT COUNCIL R & D CONTRACT

**Contract Number: PC 92b**
**Contract Date: Feb., 1996**

1. This is a contract between the Horticultural Development Council (hereinafter called the 'Council') and HRI (hereinafter called the 'Contractor').

2. It is for carrying out a research and development project and delivering the results obtained to the 'Council'.

3. The title of the project is

   CHRYSANTHEMUMS : THE INFLUENCE OF DAY LENGTH EXTENSION AND SUPPLEMENTARY LIGHTING DURING FLOWER MATURATION ON THE WINTER QUALITY OF POT CHRYSANTHEMUMS

   Details of the project are listed in the Schedule which is attached.

4. This contract will commence on 1 October, 1995 and will last for 10 months.

5. The final report of the study will be supplied to the Council no later than 31 July, 1996.

6. The contractor agrees to attend such project review meetings that the 'Council deem' appropriate.

7. The contractor agrees to supply one written item per year about the project for HDC 'Project News' (or an appropriate technical publication agreed with the HDC), and to attend one conference or field-day per year to present results.

8. The total price for this work will be £15,555.

9. Terms of payment will be that the Council will pay quarterly, in arrears, according to the following schedule:

Finally, closer pot spacing would increase throughput per square metre and offer a method for improving the economics of using supplementary lighting in the winter period. Observation studies in HDC funded work at HRI Efford in 1993/94 (PC92) as well as more detailed studies in 1994/95 (PC92a) have indicated that closer spacing can be achieved but with small penalties in terms of total production time, pot spread and number of flowers. It is necessary however to repeat these studies to verify these findings, particularly as it was felt that plant vigour may have been slightly reduced in the 1994/95 studies.

Hence the investigation outlined here proposes to examine the effects of supplementary lighting during flower maturation, extended daylength and pot spacing to optimise on quality whilst reducing lighting costs and maximising returns in terms of throughput of pots. These issues will be addressed through the following objectives:

a) to evaluate the potential for improving the quality of commercially grown pot mum varieties through extended daylength in combination with a range of lighting regimes.

b) to investigate the use of assimilation lighting on the flower maturation period of production only as a method to improve winter quality of a range of commercial varieties whilst minimising electricity running costs.

c) to assess the influence of closer pot spacings on quality, production time, shelf life and the economics of production.

## 2. POTENTIAL FINANCIAL BENEFITS TO THE INDUSTRY

The influence of supplementary lighting during flower maturation, extended daylengths and pot spacings on commercially produced pot mum varieties may:

a) identify techniques to further improve winter quality and expand the diversity of the product and hence assist growers to at least maintain their position in the marketing of pot plants in the winter period.

b) reduce the running costs of supplementary lighting (through lighting during flower maturation only) whilst producing the means to seek premium returns via improved flower quality.

c) further improve the economic viability of supplementary lighting techniques through reduced space allocation per pot.

To assist in the interpretation of the results by the grower, all lighting regimes will be presented in terms of economic costing to allow comparisons of treatments against each other. The means to tailor these costs to individual circumstances will also be provided.

## 3. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

Extended daylength treatments will compare the effects of manipulating period of assimilation and length of photoperiod on plant form, rate and quality of bud initiation, flowering uniformity, production time and post production longevity. The influence of assimilation lighting during flower maturation (against a range of background levels of solar radiation experienced during the winter period) will be also quantified against plant form, rate and quality of bud initiation, flowering uniformity, production time and post production longevity. Records (including photographs) will also be kept of qualitative effects which are more difficult to demonstrate through quantifiable results.

# SCHEDULE FOR PC 92b

## 1. BACKGROUND AND COMMERCIAL OBJECTIVE

Winter quality remains a key issue for the all year round pot chrysanthemum grower. This problem is highlighted by the fact that, due to poor quality and lack of interest by the consumer, sales of pot mums over the winter period are declining. Supplementary lighting regimes have formed the focus of attention of HDC funded research over the winter period with regimes identified which can improve quality and speed of production. To date regimes which have produced significant improvements in winter quality require that supplementary lighting is used throughout the short day period which is of course expensive in terms of running costs. In addition still further improvements in winter quality have been demanded by the industry in general (as voiced through the U.K. pot mum study group).

HDC funded work in 1994/95 (PC92a) demonstrated that improvements in flower quality and shelf life can be achieved through lighting at high intensity (12 $W/m^2$) at the end of the short day period (or during flower maturation). This treatment was however combined with lighting at lower intensity (4.8 $W/m^2$) for the earlier period of short days. The potential of high intensity lighting during flower maturation alone was however demonstrated through HDC funded work on AYR spray chrysanthemums at HRI Efford in 1994/95 (PC104). Petal colour was again found to be improved as well as the quality of foliage at the top of the stem compared with unlit treatments as well as other lit treatments. It is therefore possible that lighting pot mums during flower maturation alone may offer a cheaper alternative to current 'best' lighting regimes. Strategic work conducted at the Unit of Flower Crop Physiology of Reading University in the late 1960's to early 1970's supports the potential of such a treatment for improving flower quality.

Along with ensuring good quality, sales of pot mums in the winter period may also be improved if a wider range of varieties were available. At present, a number of summer grown varieties are unavailable for marketing in the winter due to questionable quality at this time of year. It is therefore important to assess 'end of short days' lighting treatments on both standard winter varieties such as Charm as well as other varieties such as Akron and Miramar.

An additional method for improving winter quality may be to extend the period of production, and hence total period of assimilation, by delaying maturity. One method of achieving such a delay is through extending the period which the plant perceives as daytime. The standard daylength used for maximum speed of flowering in the commercial production of pot mums is 11 hours. Research in Holland has examined daylength manipulation in winter for spray chrysanthemums and has demonstrated potential fresh weight increases by extending daylength. In winter, daylength drops below even the standard short day daylength of 11 hours. Dutch growers may readily impose extended daylength treatments at this time of year as they generally have assimilation lighting available with which daylength can be increased. Similarly a majority of the U.K. pot chrysanthemum growers may already have assimilation lights installed following recommendations from previous studies on assimilation lighting. Since there are also pot mum growers without assimilation lighting available however, studies on extended daylength will be combined with production without assimilation lighting (but using tungsten lights to extend daylength) as well as with lighting at the two standard lighting regimes recommended in previous work.

## 4. CLOSELY RELATED WORK

HDC funded work at HRI Efford over recent years has investigated supplementary lighting regimes, formerly on pot chrysanthemums (e.g. PC13a, b & c) and latterly on spray chrysanthemums (PC104). In addition, work on supplementary lighting, specifically during flower maturation forms the subject of investigation for ongoing HDC funded work at HRI Efford in the 1995/96 period (PC104b).

MAFF funded studies at HRI Efford will also examine the effects of increasing solar radiation on spray chrysanthemums through the use of reflective ground cover materials and manipulating crop spacing. AFRC funded strategic work at the Unit of Flower Crop Physiology of Reading University during the later 1960's to early 1970's, established the principals of response of varieties such as Bright Golden Anne to high intensity lighting during flower maturation.

## 5. DESCRIPTION OF THE WORK

### a) The influence of daylength on winter quality

The potential of daylength extension to improve quality, will be assessed under ambient (i.e. no supplementary lighting) conditions as well as the two 'standard' supplementary lighting regimes determined in previous studies using, the following treatments:

Lighting regimes:

i) No supplementary lighting (unlit) throughout short days (S.D.)

ii) 4.8 W/m$^2$ throughout short days (S.D.)

iii) 12 W/m$^2$ for the first three weeks of S.D. followed by no supplementary lighting for the remaining S.D. period

Daylength Treatments:

i) 11 hours

ii) 11.5 hours

iii) 12 hours

Each daylength treatment will be combined with each of the lighting regimes above. Daylength extension will be achieved using SONT lamps during the lit period of the lighting regime or using tungsten lamps (set up to supply 0.4 W/m$^2$ at crop height) during unlit periods.

Controls:

Since natural daylength during the winter period falls below 11 hours, growers without supplementary lighting would not be achieving the shortest of the daylength treatments described above (i.e. 11 hours). Hence the unlit treatment and the unlit period of the treatment 12 W/m$^2$ weeks 1-3 S.D. only also require controls where natural daylength is used as follows:

i) Unlit throughout S.D. with natural daylength

ii) 12 W/m$^2$ weeks 1-3 S.D. (using 11 hour daylengths) to unlit conditions using natural daylength for remaining S.D.

Plants will receive no supplementary lighting during the long day period.

Supplementary lighting during S.D. Will be provided continuously by 400W high pressure sodium (SONT/T) lamps for 11, 11.5 or 12 hours as appropriate from 0700 hrs daily. Daylengths 11, 11.5 or 12 hours as appropriate from 0700 hours will be maintained for all unlit periods using tungsten lamps where necessary.

Temperature will be set at 18°C day and night with venting at 23°C day and 21°C night.

$CO_2$ will be applied to 1000 v.p.m. with vents less than 5% open and to 500 v.p.m. with vents at or above 5% open.

Chemical growth regulation using daminozide (as B-Nine) will be applied as appropriate for the standard regime (i.e. 11 hour daylength) for each variety to allow any differences in plant height due to the influence of extended daylength be recorded. Observations will also be made on selected pots from guard rows treated with B-Nine "as required" per treatment to demonstrate the final result that would be achieved commercially.

Standard winter feed will be applied to all pots at each irrigation.

Varieties: Charm, Cerise About Time.

Sticking dates : Weeks 41, 45, 48.

Assessments:

The effect of treatments on production time and plant quality will be assessed at marketing stage 3 (i.e. 12 flowers all just bending outwards, 50% of petals at least 20mm long) by recording:

1. Time taken to reach marketable stage.
2. Uniformity of flower development.
3. Plant height - of 5 plants per pot.
4. Maximum and minimum plant spread per pot.
5. Leaf damage.
6. Environmental and solar radiation measurements.
7. Photographic record as appropriate.

The effect of treatments on the shelf life performance of plants will be assessed on a sub sample of pots selected at marketing stage 3. Pots will be sleeved and boxed before storing in a cool chamber for three days, sleeves will be removed after four days in the shelf life environment and assessed for deterioration at regular intervals over a four week period.

b) **Evaluation of closer spacing treatments on the quality and economics of production**

Closer pot spacings will be assessed in combination with supplementary lighting to investigate the potential for decreasing the cost per pot of providing lighting. The impact of closer spacing will be investigated on the quality of the final product. Closer pot spacing will also be investigated on pots receiving no supplementary lighting to assess if there is an interaction between light level and pot spacing on final quality (i.e.

whether or not it is necessary to have additional light input via supplementary lighting to maintain adequate quality when pots are spaced closer together).

Lighting regimes:

i) No supplementary lighting (unlit) throughout short days (S.D.)

ii) 4.8 W/m$^2$ throughout short days (S.D.)

iii) 12 W/m$^2$ for the first three weeks of S.D. followed by no supplementary lighting for the remaining S.D. period

These lighting regimes will be repeated for both standard and close spacings as follows:

i) Intermediate - 27 pots/m$^2$, Final - 13.5 pots/m$^2$ (standard)

ii) Intermediate - 32 pots/m$^2$, Final - 16 pots/m$^2$ (close)

Plants will receive no supplementary lighting during the long day period.

Supplementary lighting during S.D. will be provided continuously by 400W high pressure sodium (SONT/T) lamps for 11 hours from 0700 hrs daily. Natural daylength (i.e. blackout from dusk to dawn) will be used where pots are not receiving supplementary lighting.

Temperature will be set at 18°C day and night with venting at 23°C day and 21°C night.

$CO_2$ will be applied to 1000 v.p.m. with vents less than 5% open and to 500 v.p.m. with vents at or above 5% open.

Chemical growth regulation using daminozide (as B-Nine) will be applied as appropriate for the standard regime ~~(i.e. 11 hour daylength) for each variety to allow any differences in plant height due to the influence of extended daylength be recorded.~~

Standard winter feed will be applied to all pots at each irrigation.

Varieties: Charm, Cerise About Time

Sticking date : Weeks 41, 45, 48

Assessments : As for a. above.

c) **The influence of supplementary lighting during flower maturation on winter quality**

Supplementary lighting during flower maturation will be assessed against two lighting intensities over the same period of time (i.e. for a total of 21 days over weeks 7, 8 and 9 of S.D.) as follows:

Lighting Regimes:

i) No supplementary lighting (unlit) throughout short days (S.D.)

ii) Unlit weeks 1-6 S.D. inclusive, followed by lighting at 4.8 W/m$^2$ during weeks 7, 8 and 9 of short days (S.D.)

iii) Unlit weeks 1-~~7~~6 S.D. followed by lighting at 12 W/m$^2$ during weeks 7, 8 and 9 of short days (S.D.)

Plants will receive no supplementary lighting during the long day period.

Supplementary lighting during S.D. will be provided continuously by 400W high pressure sodium (SONT/T) lamps for 11 hours from 0700-1800 hrs. Unlit periods will consist of natural daylength according to time of year.

Temperature will be set at 18°C day and night with venting at 23°C day and 21°C night.

$CO_2$ will be applied to 1000 v.p.m. with vents less than 5% open and to 500 v.p.m. with vents at or above 5% open.

Chemical growth regulation using daminozide (as B-Nine) will be applied as appropriate for the standard regime ~~(i.e. 11 hour daylength) for each variety to allow any differences in plant height due to the influence of extended daylength be recorded.~~

Standard winter feed will be applied to all pots at each irrigation.

Varieties: Charm, Cerise About Time, Yuba, Akron, Miramar

Sticking dates : Weeks 41, 45, 48

Assessments : As for a. above.

All the experimental work will be completed by February 1996.

## 6. STAFF RESPONSIBILITIES

Project Leader: Dr. Debbie Wilson, HRI Efford
Project Co-ordinator: Mr. David Abbott, Swallowfield Horticultural Enterprises

## 7. LOCATION

HRI Efford (K-Block)

**Contract No:**

## TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)

Signature ...............................
Position Commercial Manager HRI
Date 26/4/96

Signed for the Contractor(s)

Signature ...............................
Position ...............................
Date ...............................

Signed for the Contractor(s)

Signature ...............................
Position ...............................
Date ...............................

Signed for the Council

Signature ...............................
Position: RESEARCH MANAGER
Date 22.4.96