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CONTRACT REPORT

Chrysanthemums: Supplementary Lighting and Spacing for the Winter Production of AYR Spray Chrysanthemums

HDC PC 104
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RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

Application

Applying supplementary lighting for short phases of the total production period indicated that to produce increases in plant height over that achieved with current commercial practise, it is necessary to use lighting during vegetative growth (long days). Fresh weight however may be increased over that produced with current commercial practice through lighting during vegetative or generative phases of growth. The use of supplementary lighting during the last five weeks of short days was particularly beneficial with increases in fresh weight and grade one stems and decreases in grade three and waste stems. Visual improvements in foliage and flower quality were also observed. These treatments therefore offer a method to improve on the quality currently produced during the winter without the need to use lighting throughout the entire production period.

Summary

i. Background and trial details

With the ongoing need to improve winter quality of AYR spray chrysanthemums and the increasing pressure from imported produce either grown in Southern climates or under supplementary lighting in Holland for example, lighting for UK production during the winter period was investigated. The aim of the project was to investigate the impact of lighting on isolated key phases of production and then to further optimise on those treatments most effective for improving quality. The period of production from planting to harvesting was broken down into the following three key periods for this work:

1. From planting to the end of 28 long days
   (vegetative growth)

2. Day 1 to 35 of short days, including the interruption
   (flower initiation and development)

3. Day 36-70 of short days
   (flower maturation)

Spacing was also investigated as part of the programme to assess firstly if supplementary lighting can be made more economically attractive by offsetting costs against a higher number of stems per square metre. Secondly wider spacing with no supplementary lighting was assessed to compare the benefits of providing extra natural light through increased space per stem with the benefits of increasing light energy received via supplementary lighting.

The treatments for the first set of investigations (during the winter 1994/95 period) were as follows:

1) No supplementary lighting throughout production.

2) Supplementary lighting at 4.8 W/m^2 throughout production.
(or a total of 23.88 MJ/m^2 light energy supplied by the luminaires).

3) Supplementary lighting at 12 W/m^2 during 28 long days only.
(or a total of 22.96 MJ/m^2 light energy supplied by the luminaires).

4) Supplementary lighting at 12 W/m^2 day 1-35 of short days.
(or a total of 20.20 MJ/m^2 light energy supplied by the luminaires).

5) Supplementary lighting at 12 W/m^2 day 36-70 of short days.
(or a total of 16.80 MJ/m^2 light energy supplied by the luminaires).

The second set of treatments (1995/96) focused on lighting during the last five weeks of short days as follows:

1) No supplementary lighting throughout production.

2) Supplementary lighting at 4.8 W/m^2 throughout production
(or a total of 23.88 MJ/m^2 light energy supplied by the luminaires).

3) Supplementary lighting at 12 W/m^2 day 36-70 short days only
(or a total of 16.63 MJ/m^2 light energy supplied by the luminaires).

4) Supplementary lighting at 4.8 W/m^2 day 36-70 short days only
(or a total of 6.65 MJ/m^2 light energy supplied by the luminaires).

5) Supplementary lighting at 12 W/m^2 day 47-60 short days only
(or a total of 6.65 MJ/m^2 light energy supplied by the luminaires).

In both studies, treatments 1 and 2 represented standard commercial practice in the U.K. and Holland respectively. The remaining treatments then examined the impact of lighting on different key stages of production during the first year and concentrated on treatments during the last five weeks of production during the second year.

Luminaires were on continuously from 03.30 to 22.30 hrs (19 hrs) during long days (including the interruption) or from 07.00 to 18.00 hrs (11 hrs) during short days. Where treatments were not receiving supplementary lighting during the long day period, standard tungsten cyclic night break lighting was used from 22.30 to 03.30 hrs (5 hrs).

Spacing treatments compared standard winter spacing of 54 plants/m^2 with a closer treatment of 64 plants/m^2 where supplementary lighting was supplied or with a wider treatment of 45 plants/m^2 where no supplementary lighting was supplied.

The varieties Splendid Reagan and Dark Cerise Delta were used to assess the treatments in both years of the trial.

ii. Results

The use of supplementary lighting at the same intensity (12 W/m^2) but at different isolated stages of production (i.e. during the first year of the trial) illustrated the different effects that may be achieved by manipulating timing of the supplementary lighting treatment.

Lighting during long days only had a large impact on plant height with increases of 31-40% compared with standard UK winter production. This treatment therefore has potential to decrease the number of long days required during the winter when declining light levels increase the length of time required to produce a stem of sufficient length to allow short days to commence. Since a standard number of long days was used throughout these trials it was not possible to estimate the number of days which may be saved with such a treatment but it should be noted that turning the supplementary lighting off at the end of long days appeared to have a negative impact on development. Flower initiation and final harvest appeared to be delayed by this treatment compared with crops receiving no supplementary lighting. Furthermore final grade out figures were poorer from this treatment than from no supplementary lighting.

Lighting at 12 W/m^2 during day 1-35 of short days had little impact on height but did improve fresh weight. Speed of flower initiation was also increased with the interruption commencing 1-2 days earlier than standard production with no supplementary lighting and harvesting commencing up to 7 days earlier. This treatment also had some benefit on final grade out but did not match that achieved with the standard Dutch regime of lighting throughout production.

Lighting at 12 W/m^2 during day 36-70 of short days produced the greatest improvements in final quality of the treatments assessed in the first year of the trial. Stem fresh weight was increased by up to 35% over standard winter production and improvements in weight grading were also demonstrated. Furthermore, stem visual quality was markedly improved in comparison with production without supplementary lighting and was in fact comparable with that achieved through production under supplementary lighting throughout production (i.e. the standard Dutch regime).

Due to the significant improvements achieved through lighting during day 36-70 of short days, treatments in the second year of the trial concentrated on this five week period.

By repeating lighting at 12 W/m² day 36-70 of short days in the second year of the trial, it was possible to confirm that significant improvements can be achieved with this treatment and that comparable quality to that from lighting throughout production can be produced. These improvements were achieved on both week 40 and week 45 planting dates.

Reducing the intensity of lighting to 4.8 W/m² day 36-70 of short days also produced significant improvements in quality in comparison with no supplementary lighting. Visual quality was not equivalent to that produced with the higher light intensity but cost benefit assessments found this treatment to be the most favourable of those assessed. In fact these calculations found this treatment to improve returns over those from production without supplementary lighting even when the production costs incorporated the cost of supplying lighting (Table 1).

Lighting at 12 W/m² for just 14 days within the five week period at the end of short days (i.e. from day 47-60 SD) yielded improvements over production without supplementary lighting but was less effective than the other lighting treatments assessed in the second year of studies.

Table 1: Cost * - benefit analysis of supplementary lighting and spacing treatments

Lighting	Spacing (plants/m²)	Increased price required to cover standard winter production cost Week 40 planting (week 02 flower) (p/stem)	Week 45 planting (week 08 flower) (p/stem)
No Supplementary Lighting	45	0.12	0.25
	54	0.00	0.00
4.8 W/m² throughout production	54	4.84	3.38
	64	3.64	2.15
12 W/m² day 36-70 SD	54	3.42	1.44
	64	1.83	0.39
4.8 W/m² day 36-70 SD	54	1.31	0.62
	64	0.60	-1.48
12 W/m² day 47-60 SD	54	1.07	1.41
	64	1.82	0.21

* The costs of supplying lighting treatments assume a mobile rig is used where appropriate - fuller costings are presented in the main report.

Closer plant spacing was found to decrease the improvements achieved with supplementary lighting at standard winter spacing. Improvements over production without supplementary lighting at standard winter spacing were still produced using closer plant spacing with supplementary lighting and in fact the best treatment in the cost benefit analysis from the week 45 planting was 4.8 W/m^2 day 36-70 SD at 64 $plants/m^2$.

Wider spacing for plants grown without supplementary lighting also improved grade out and fresh weight. These improvements did not however match those achieved with supplementary lighting and did not produce the improvements in visual quality of foliage and flowers noted when using supplementary lighting.

Conclusions

These studies clearly show that improvements in winter quality may be achieved through using supplementary lighting during the last five weeks of production. Such a technique will have the advantage over lighting throughout production of reducing costs. At the least it will be possible to save on running costs using these treatments as well as improve the life of the lamp (and hence reduce the frequency with which purchase of replacement lamps will be necessary). If it is possible to install lamps on a mobile system the potential for savings using the supplementary lighting treatments identified increases greatly as illustrated in Table 1 above.

EXPERIMENTAL SECTION

INTRODUCTION

Even in the most favoured areas of the British Isles, there are three months of the winter when solar radiation levels are below the minimum required for satisfactory growth of chrysanthemums. Low light levels reduce the rate of growth and affect the rate of bud initiation, hence winter schedules are longer and quality is generally poorer compared with production in the summer. Timing the short day interruption in winter is also complicated by the low and variable solar radiation levels experienced.

Supplementary lighting has become a recognised technique for improving the production of pot chrysanthemums during the winter period. Trial work initially at Lee Valley EHS and latterly at HRI Efford has clearly demonstrated that high intensity supplementary lighting can be effective on a commercial scale for both increasing the rate of bud initiation and hence reducing cropping time and improving pot quality. This work has also identified suitable lighting protocols for a range of commercial varieties with full economic evaluations (Finlay, 1993, Wilson, 1994a & 1994b).

The two most effective protocols emerging from these studies are:

i. Lighting at 4.8 W/m^2 (2000 lux) throughout the short day period.
(Improves final quality and reduces production time by up to 5 days.)

ii. Lighting at 12 $W//m^2$ (5000 lux) for the first three weeks of short days.
(Reduces production time by up to 8 days and increases initial vegetative growth.)

The potential for improving winter quality of AYR Chrysanthemums through supplementary lighting is already well recognised and utilised in Holland to maintain the quality of product in the winter period when there is greater competition from Southern produced flowers. It is therefore important to assess how the UK industry may best compete with imports from both Holland grown under lighting as well from more Southerly latitudes.

If supplementary lighting is to be taken up by the U.K. industry for AYR production however, the use of this technique should be evaluated with the modern commercial spray varieties produced. Principally work is required to quantify the potential benefits of lighting on commercial varieties and to identify appropriate lighting protocols since intensity and timing have clearly been important in previous studies on pot chrysanthemums and offer potential savings in the considerable costs of such treatments. This two year project was therefore designed to screen a range of lighting treatments to identify the most profitable stages of production to supply lighting and then focus in and further optimize on the most appropriate treatments identified.

To reduce the impact of poor light levels on winter crops it is common practice for growers to plant at lower densities (typically around 54 plants/m^2 compared with 64-70 plants/m^2 in summer) to increase the light received by individual plants through reduced shading. Furthermore it has been demonstrated by work at HRI Littlehampton (Langton & Hammond, 1993) that the weight of a stem produced is directly related to spacing of plants in a bed. The potential benefits achieved with reduced plant spacing will also be assessed both economically and in terms of plant quality against that achieved with supplementary lighting. This will allow comparison between the benefits that may be achieved through spacing in comparison with the more expensive option of supplying supplementary lighting.

OBJECTIVES

The objectives were:

1. To evaluate supplementary lighting intensity and timing of application on the rate of growth and quality of AYR chrysanthemum varieties produced over the winter period.

2. To evaluate in more detail treatments identified in initial studies as being most suitable, in particular to optimise these treatments to determine the most cost efficient strategy.

3. To examine the interaction of spacing and lighting techniques on the rate of growth and quality of commercial AYR chrysanthemum varieties produced over the winter period.

4. To evaluate supplementary lighting and spacing treatments economically.

MATERIALS AND METHODS

1. Lighting Treatments

1994/95:

Standard lighting regimes to represent U.K. winter production (treatment 1 below) and Dutch winter production (treatment 2 below) were compared with high intensity supplementary lighting given for one of the three key periods during production (treatments 3-5). These periods included the long day period when plants were growing vegetatively, the first five weeks of short days including the period of bud initiation and the period of interrupted lighting, and finally the last five weeks of short days when buds were developing and maturing into flowers. These treatments may be summarised as follows:

1) No supplementary lighting throughout production.

2) Supplementary lighting at 4.8 W/m^2 throughout production (or a total of 23.88 MJ/m^2 light energy supplied by the luminaires).

3) Supplementary lighting at 12 W/m^2 during 28 long days only (or a total of 22.96 MJ/m^2 light energy supplied by the luminaires).

4) Supplementary lighting at 12 W/m^2 day 1-35 of short days (or a total of 20.20 MJ/m^2 light energy supplied by the luminaires).

5) Supplementary lighting at 12 W/m^2 day 36-70 of short days (or a total of 16.63 MJ/m^2 light energy supplied by the luminaires).

1995/96:

The two standard regimes described above (1 and 2) were also used for comparison in the second year of the trial. Lighting treatments in the second year however focused on just one of the three periods of production identified above, namely, the last five weeks of short days. Lighting at two different intensities were compared for the whole of this period (treatments 3 and 4 below) to examine the level of intensity required to produce significant benefits. A fifth treatment was designed to assess if a shorter period of lighting, given in the middle of the last five weeks of short days, could also produce a significant benefit (treatment 5 below). The intensity of this treatment was equivalent to that used for treatment three, but for a shorter time period. The total additional light supplied by this treatment however was designed to match that supplied by treatment four.

In summary the lighting treatments were:

1) No supplementary lighting throughout production.

2) Supplementary lighting at 4.8 W/m^2 throughout production (or a total of 23.88 MJ/m^2 light energy supplied by the luminaires).

3) Supplementary lighting at 12 W/m^2 day 36-70 short days (or a total of 16.63 MJ/m^2 light energy supplied by the luminaires).

4) Supplementary lighting at 4.8 W/m^2 day 36-70 short days only (or a total of 6.65 MJ/m^2 light energy supplied by the luminaires).

5) Supplementary lighting at 12 W/m^2 day 47-60 short days only (or a total of 6.65 MJ/m^2 light energy supplied by the luminaires).

Supplementary lighting was supplied by high pressure sodium lamps (SON/T agro). Where lighting treatments coincided with long days (i.e. either initial long days, or long days used to give the interruption), luminaires were turned on for 19 hours continuously from 03.30 hrs to 22.30 hrs daily. Due to the nature of the compartments it was not possible to use thermal screens while lighting was supplied during the long day period. Where lighting treatments coincided with short days, luminaires were turned on for 11 hours continuously from 07.00 hrs to 18.00 hrs daily.

For treatments where supplementary lighting was not supplied during long days, conventional cyclic tungsten lighting (at 0.5 W/m^2) was used to provide a night break from 22.30 hrs to 03.30 hrs daily.

2. Spacing Treatments

The same spacing densities were used in both years of the trial.

For treatments receiving supplementary lighting, standard winter spacing of **54 plants/m^2** (or 85%) was compared with a closer spacing of **64 plants/m^2** (or 100%) to assess if using supplementary lighting during the winter period could be made more economical by spreading the costs of lighting over more stems.

For treatments receiving no supplementary lighting, standard winter spacing of **54 plants/m²** (or 85%) was compared with a wider spacing of **45 plants/m²** (or 70%) to assess if the type of benefit achieved through supplementary lighting can be produced by increasing the natural light available to each plant through wider spacing.

In the first year (1994/95), the spacing treatments were achieved by giving plants equal spacing at planting to a pre-made grid set to give the following plants spacings:

Spacing (plants/m^2)	Space between adjacent plants (cm)
64	12.5
54	13.6
45	14.9

Plants were subsequently allowed to grow up through the standard chrysanthemum support net.

In the second year, commercial spacings rather than even spacings were employed to achieve the specified treatments. That is patterns were designed within the framework of the standard chrysanthemum support net as follows:

64 plants/m^2 - One plant in every net space.

54 plants/m^2 - A repeating unit of three rows where every net space was planted in rows one and two but only alternate net spaces were planted in row three, i.e.:

row 1	x	x	x	x	x	x	x	x	x	x	x	x
row 2	x	x	x	x	x	x	x	x	x	x	x	x
row 3	x	o	x	o	x	o	x	o	x	o	x	o

(where x = 1 plant and o = 1 space)

45 plants/m^2 - A repeating unit of three rows where every net space was planted in row one but only alternate net spaces were planted in rows two and three (and the spaces in row two were next to plants in row three), i.e.:

row 1	x	x	x	x	x	x	x	x	x	x	x	x
row 2	x	o	x	o	x	o	x	o	x	o	x	o
row 3	o	x	o	x	o	x	o	x	o	x	o	x

(where x = 1 plant and o = 1 space).

Note: When planting within the framework of the chrysanthemum support net, peat blocks were placed close to the nearest irrigation line (where one line was placed between every two rows of plants) rather than in the centre of the net space, as is standard practice.

3. Cultural Methods and Conditions

i. Plant material

Cuttings of Splendid Reagan and Dark Cerise Delta were purchased unrooted from Yoder Toddington Limited and Ficor Limited (and raised in Kenya and Brazil respectively) to represent single varieties grown commercially during the winter period.

ii. Propagation

In both years of the trial, two planting dates were compared. These were:

1. Sticking in week 38 with planting in week 40.

and

2. Sticking in week 43 with planting in week 45.

The unrooted cuttings were stuck in peat blocks (5 cm x 5 cm x 3 cm) made from Levington blocking compost with Etridiazole (as Aaterra WP) at 37 g/m^3 at mixing, on each occasion. Bottom heat was used to achieve a compost temperature of 20°C. After sticking, blocks were covered with clear polythene which was sealed down at the edges to maintain humidity. Covers were removed after 7 days to wean the plants. Plants were propagated for 14 days in this environment with night break lighting supplied for 5 hours per night using 100 watt tungsten lamps (15 minutes on, 15 minutes off cycle) to achieve a minimum light level of 0.5 W/m^2.

iii. Schedule

A common schedule was maintained for all plantings to allow comparison between results. This included 28 initial long days, sufficient short days according to light levels to permit interruption (by comparison with critical light integrals from Langton, 1992), 10 days of interruption lighting followed by a return to short day conditions. Since some of the treatments in both years provided supplementary lighting during flower initiation, the light energy supplied by the luminaires was added to the solar radiation received to calculate light integrals for appropriate timing of the interruption, hence some treatments commenced interruption earlier than others as summarised below:

1994/95:

Treatment	**Number SD to interruption (days)**		**Cumulative light during SD to interruption (MJ/m²)**	
	Stick week 38	**Stick week 43**	**Stick week 38**	**Stick week 43**
No supplementary lighting	16	17	58.3	41.5
4.8 W/m² throughout	15	16	59.6	42.9
12 W/m² during LD	16	17	58.3	41.5
12 W/m² days 1-35 SD	15	15	64.0	43.0
12 W/m² days 36-70 SD	16	17	58.3	41.5

1995/96:

Treatment	Number SD to interruption (days)		Cumulative light during SD to interruption (MJ/m^2)	
	Stick week 38	Stick week 43	Stick week 38	Stick week 43
No supplementary lighting	15	19	65.5	34.5
4.8 W/m^2 throughout	14	18	64.0	36.4
12 W/m^2 days 36-70 SD	15	19	65.5	34.5
4.8 W/m^2 days 36-70 SD	15	19	65.5	34.5
12 W/m^2 days 47-60 SD	15	19	65.5	34.5

iv. Glasshouse environment

Heating set points were adjusted according to ambient conditions and light levels to achieve equivalent averages in all compartments and a minimum of 18°C during the day and 19°C during the night period in all compartments. Venting set points were set at 23°C. Thermal screens and blackout covers were drawn across at 18.00 hrs daily and removed at 07.00 hrs daily (except where supplementary lighting was in use for long days when it was not possible to close the screens).

Enrichment with pure CO_2 was given to 1000 v.p.m. when the vents were less than 5% open and to 500 v.p.m. with vents at or above 5% open.

v. Nutrition, growth regulation and pest and disease control

A standard winter feed of 150 mg/l N : 200 mg/l K_2O (166 mg/l K) was applied at each irrigation, commencing two weeks after planting.

Daminozide (as B-nine) was applied at 1 g/l product after two weeks of long days and at 1.5 g/l product after three weeks of short days to Splendid Reagan only. Note: due to high levels of solar radiation following week 40 in 1995, an additional application of B-nine at 1 g/l product was applied to the week 40 planting in the 1995/96 trial at the end of long days.

Verticillium lecanii (as 1g/l Mycotel and 2 g/l Vetilec) was applied immediately after sticking cuttings on each occasion. A drench of iprodione (as Rovral flo) was also applied at 0.5 g/l when the polythene sheets were removed from the trays to wean the plants.

A routine programme alternating high volume sprays of dichlorvos (as Nuvan 500 EC), malathion and endosulfan (as Thiodan) was used for the prevention and control of WFT with spot treatments of pirimicarb (as Pirimor) and deltamethrin (as Decis) for aphid control as necessary. Methiocarb (as Draza pellets) was also used to control slugs and snails.

4. Assessments

In both years, assessments were conducted at the following three key stages:

1. At the end of long days.

2. After 35 short days.

3. At maturity.

On each occasion a full row of plants was removed* and recorded for the following parameters:

i. Stem length from the top of the peat block (cm).

ii. Stem fresh weight (g).

iii. Bulk dry weight of all plants sampled per plot (g).

iv. Number of expanded true leaves.

v. Leaf mineral status (through chemical analysis).

* In the 1994/95 trial plots at 54 plants/m^2 and 45 plants/m^2 spacing contained only 10 plants per row due to the even spacing arrangement. In the 1995/96 trial, planting was arranged so that a full row of 12 plants would be sampled on each occasion.

To assess plant variability on a larger sample of plants, *in situ* assessments of plant height were also made on each sampling date. Fifteen plants were tagged and measured on each occasion with their position in the bed recorded.

Additional records taken at maturity included:

i. Fresh weight and number of flowers per plant for the 12 plants sampled destructively. Where flowers with petals just expanding or above were removed from the pedicel immediately below the sepals for weighing and counting. (1995/96 only.)

ii. Number of harvests per plot and date of each harvest.

iii. Grade out of harvested stems per plot recording number and weight of wraps produced in the grades 1, 2 and 3 as defined below, plus the number and bulk weight of stems below grade 3 (categorised as waste).

Grade 1: At least five open flowers with at least three buds with potential to open post-harvest.

Grade 2: At least three open flowers with at least three buds with potential to open post-harvest.

Grade 3: At least two open flowers with at least two buds with potential to open post-harvest.

iv. Shelf-life evaluation (1995/96 only) where the first wrap of grade one flowers cut from each plot was placed in a cut flower box and dry stored for 1 day at 2-5°C (cold room). This was followed by a further 1 day storage at 10-15°C (packing shed environment). Stems were then removed from sleeves and re-cut to remove 3-5 cm from the base and placed in tap water (striping away any leaves which would be below the water level) on day 3 and lit with fluorescent lighting for 12 hours per day with temperatures of 18-20°C day and night and ambient humidity in the range 70-80%. Records involved checking stems daily and recording the interval from fresh looking flowers to the first stage of minor deterioration (stage 1) and to severe deterioration (stage 2) at which point stems were considered to no longer give visual pleasure.

Photographic records of treatment differences were taken as appropriate. Environmental data monitored throughout the trial included:

i. Daily light sum with records adjusted for Photosynthetically Active Radiation (PAR) reaching treatment plots including solar radiation and light from the luminaires when in use.

ii. Compartment temperatures.

5. Statistical Analysis

Recording of guard plots as well as treatment plots permitted an analysis of variance to be carried out on the data. These comparisons are however limited in that they are based on bed to bed variability and it is recommended by the statistician that this approach must be viewed with some caution. Furthermore temperature gradients across guard beds clearly affected response to interruption lighting indicating that guard bed treatment responses may have been affected by small temperature differences in comparison with treatment beds. To this end guard and treatment bed effects have been compared through analysis of variance but it is not possible to produce valid probability values from this test (since there is no replication of plots in this case). This test has been used to check the validity of any main significant differences identified but it does not identify where treatment differences may have been masked by variability between the guard and treatment plots.

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 column, that is required for the means to be statistically different. (All L.S.D. values were calculated from the t value representing a probability value of 0.05).
*	$P<0.05$, 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%).
***	$P<0.001$, i.e. the probability of this result occurring by chance is equal to or less than 1 in 1000 (0.001 = 0.1%).

RESULTS AND DISCUSSION

1. Year 1

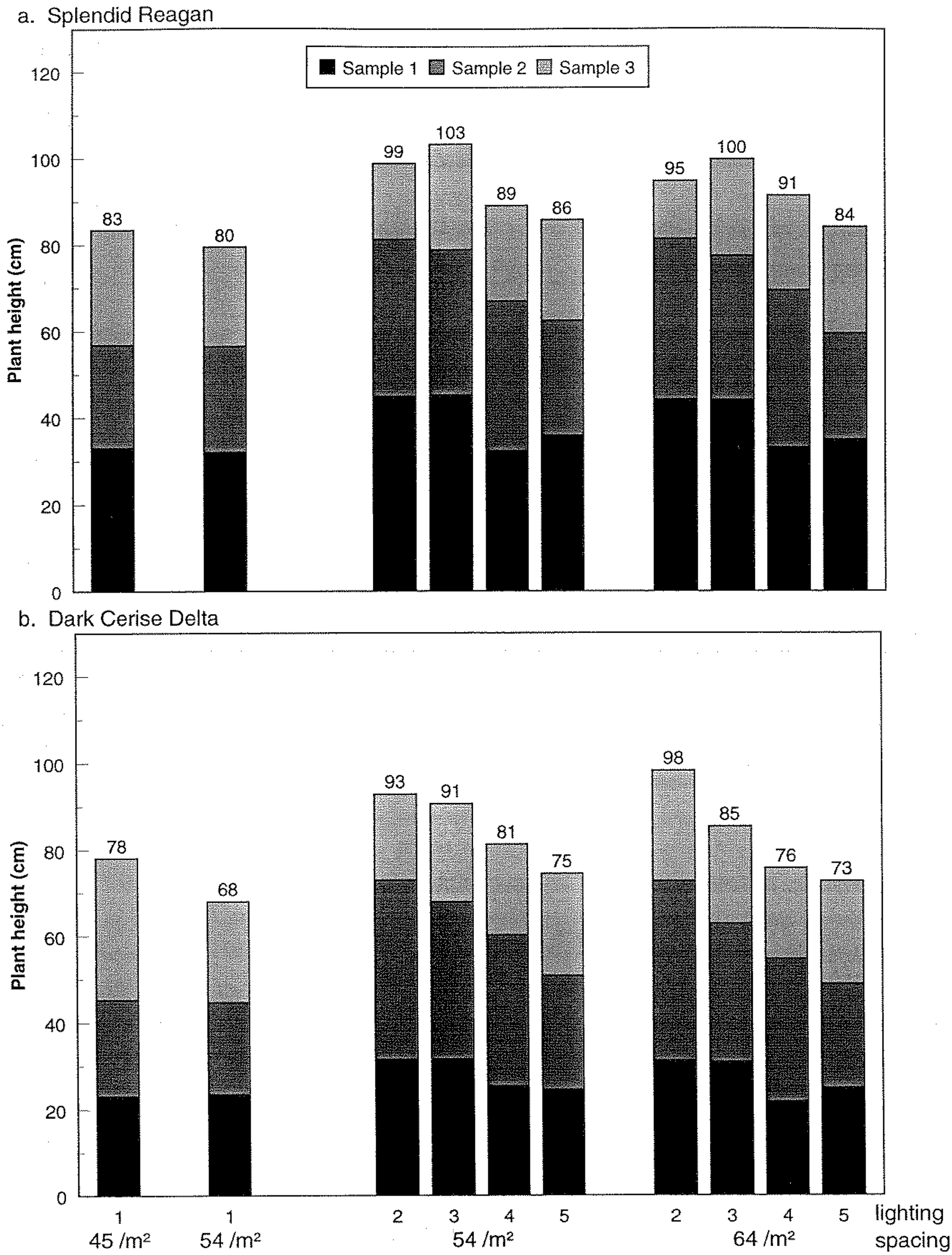
Uneven plant establishment, due to elevated soil conductivities, resulted in a high level of plant variability within and between plots making interpretation of the first year's results difficult. These problems were more notable with the first planting and as a result of soil flooding had less impact on the second planting. It was therefore agreed that only records from the second planting would be taken and that these should be viewed with the variability problems in mind. Statistical analysis was not carried out on this data due to the variability discussed but general trends will be examined.

It is worth noting that the while the results discussed below were collected on three occasions, namely at the end of long days, after 35 short days and at maturity; not all treatments had commenced on each of these occasions. Therefore the first sample allows comparison of no supplementary lighting, lighting at 4.8 W/m^2 during long days or lighting at 12 W/m^2 during long days. The second sample allows comparison of no supplementary lighting, lighting at 4.8 W/m^2 during long days plus the first 35 short days (including the interruption), lighting at 12 W/m^2 during long days only and lighting at 12 W/m^2 during the first 35 short days (including the interruption) only. All five treatments can be compared from data collected during the final sample.

1.1 The Influence of Supplementary Lighting on Plant Development

Plant height was increased by supplementary lighting (figure 1, page 18). The increase in height was influenced by the period of plant development during which the treatment was given. When the first destructive sample was taken at the end of long days, only two of the lighting treatments had commenced i.e. treatment 2 - 4.8 W/m^2 throughout production and treatment 3 - 12 W/m^2 during long days. Therefore plants had received either 4.8 W/m^2 supplementary lighting for 28 long days, 12 W/m^2 supplementary lighting for 28 long days or no supplementary lighting for 28 long days. The increase in height at 31-40% over the standard treatment was comparable for these two treatments. It is notable that at maturity (i.e. sample 3) lighting at 12 W/m^2 during long days produced either taller plants or equivalent plant height to lighting at 4.8 W/m^2 throughout production, despite the fact that no additional lighting was supplied to this treatment for the remainder of production.

Figure 1. The Influence of Supplementary Lighting and Spacing on Plant Height
Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting 2 = 4.8 W/m² throughout production 3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD 5 = 12 W/m² 36-70 SD

Lighting at 12 W/m² day 1-35 of short days (including the interruption) also increased plant height as recorded after 35 short days (i.e. sample 2) in comparison with no supplementary lighting. This treatment did not however compare in height with that resulting from the same lighting intensity given during long days. Furthermore, plant height by the end of production (i.e. sample 3) was generally comparable with that resulting from no supplementary lighting. Lighting at 12 W/m² day 36-70 of short days did not influence plant height.

In terms of increasing plant height therefore, supplementary lighting was most effective when timed during the period of vegetative growth.

Trends in leaf number data (figure 2, page 21) largely reflect those discussed above for plant height indicating that the increases in height noted resulted from increased plant growth rather than internode stretching. It is clear from these data that there was little change in leaf number between samples 2 and 3 (i.e. after 35 short days or at maturity), which may be expected since buds were initiated before sample 2 was taken and hence no new leaves would be produced. Fluctuations in leaf number between these two samples therefore reflects variability within samples. This observation highlights the limitation of influencing plant height through supplementary lighting during the last part of the short day period as discussed above.

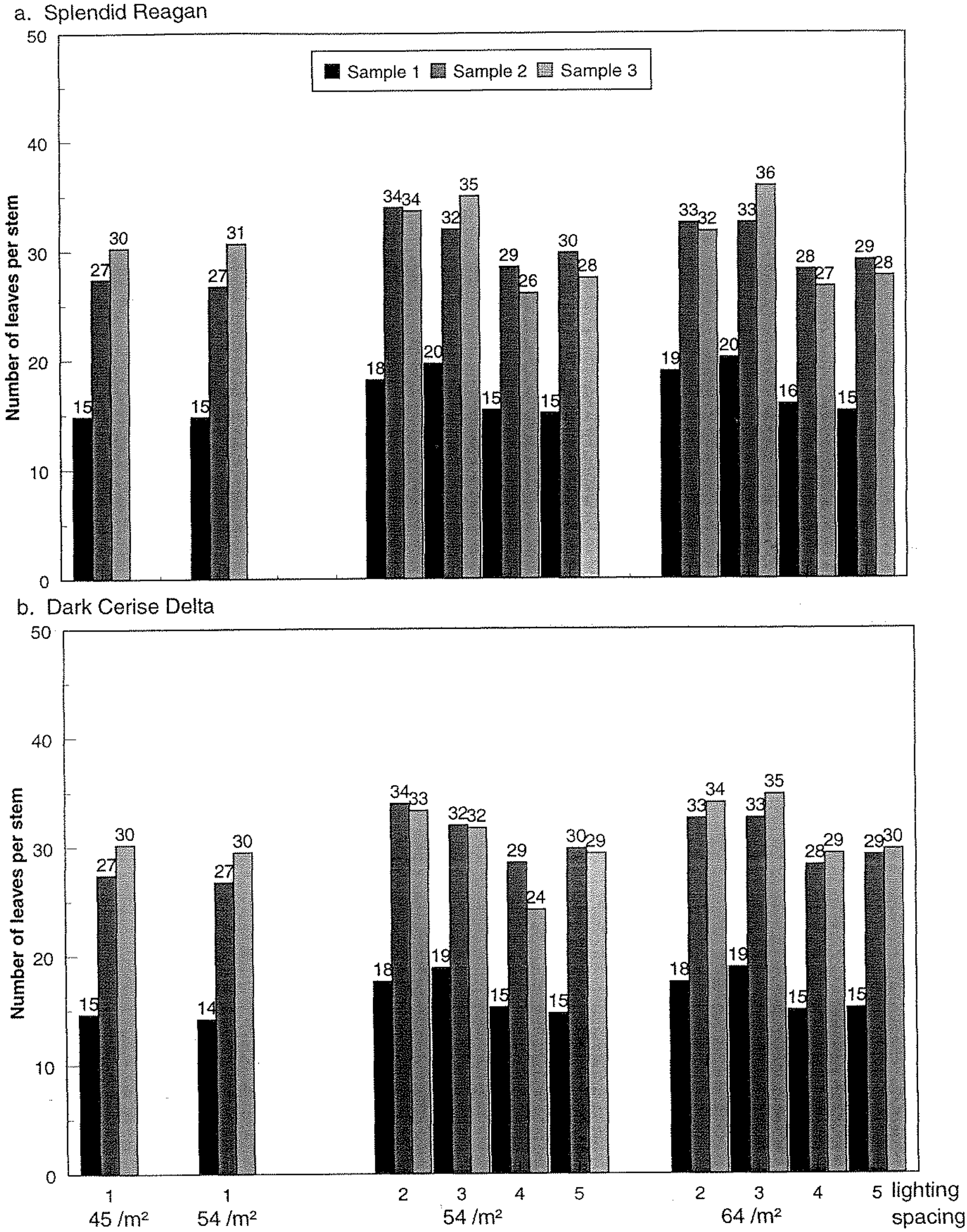
Fresh weight was also increased by supplementary lighting (figure 3, page 22) and the change in weight was influenced both by lighting intensity and timing of treatment.

At the end of long days (sample 1), the greatest fresh weight resulted from lighting at 12 W/m² during long days. Lighting at 4.8 W/m² also increased fresh weight in comparison with no supplementary lighting.

Lighting at 12 W/m² during days 1-35 SD had a significant effect on fresh weight and overall produced the greatest fresh weight when sampled after 35 short days (i.e. the second sample). The impact that lighting during this period had on fresh weight can be assessed by comparing the change in fresh weight between each of the three periods over which assessments were made. For example, the increase in mean fresh weight for Splendid Reagan between sample 1 and sample 2 (i.e. the period over which the supplementary lighting was supplied to this treatment) was 44-46g. In comparison weight increased by only 9g between planting and sample 1 and by 2g between sample 2 and sample 3. Lighting at 12 W/m² during days 36-70 short days had a similar impact on fresh weight with the greatest increase in fresh weight occurring during this last period of growth. It is therefore clearly possible to have a large impact on stem fresh weight by lighting at high intensity for short phases of the total production period when plants are no longer growing vegetatively. This conflicts with the results noted for stem length where increases in stem length were much greater where the period of lighting treatment corresponded with vegetative growth.

There was no consistent evidence that percentage dry matter was affected by the supplementary lighting treatments assessed (figure 4, page 23).

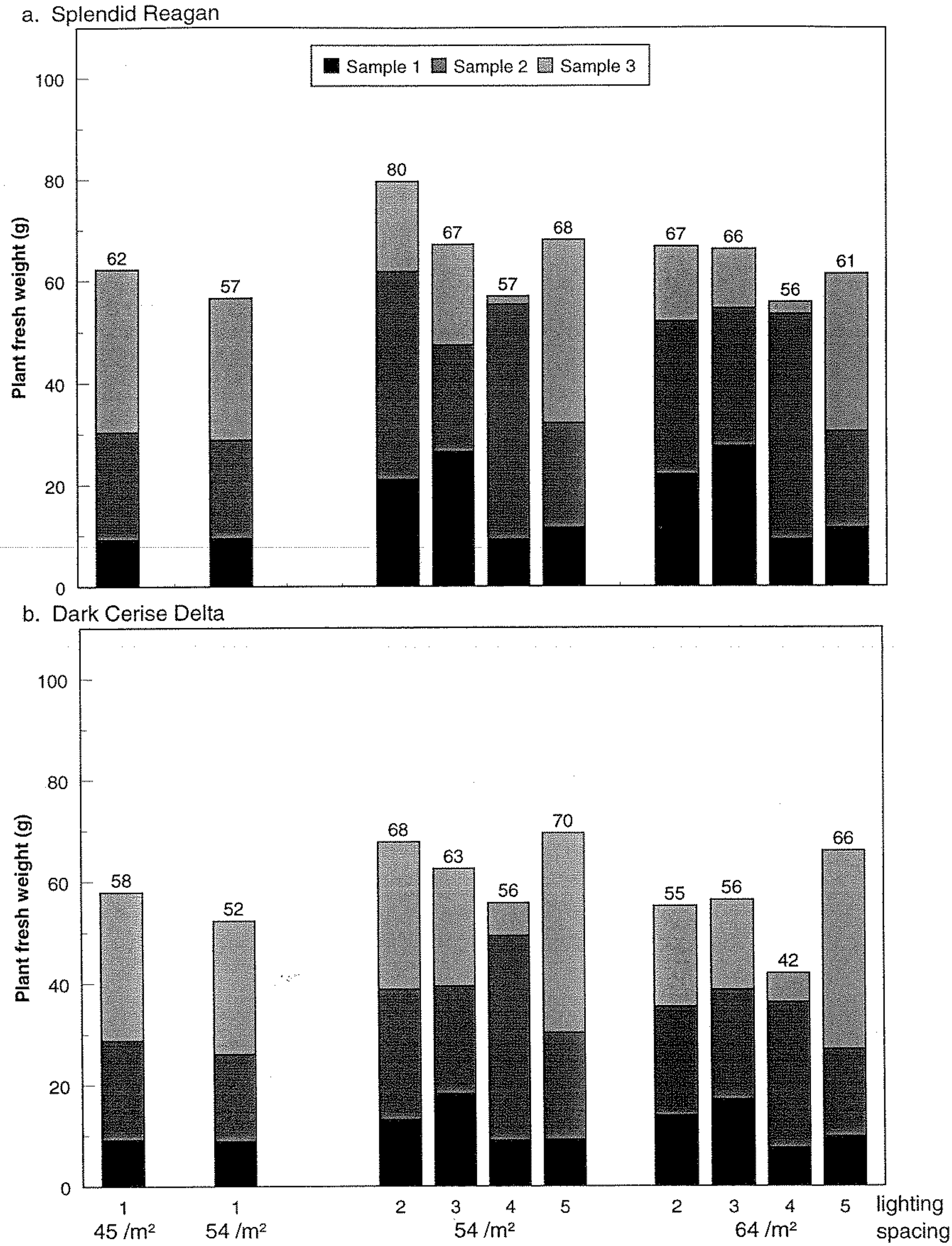
Figure 2. The Influence of Supplementary Lighting and Spacing on Leaf Number
Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

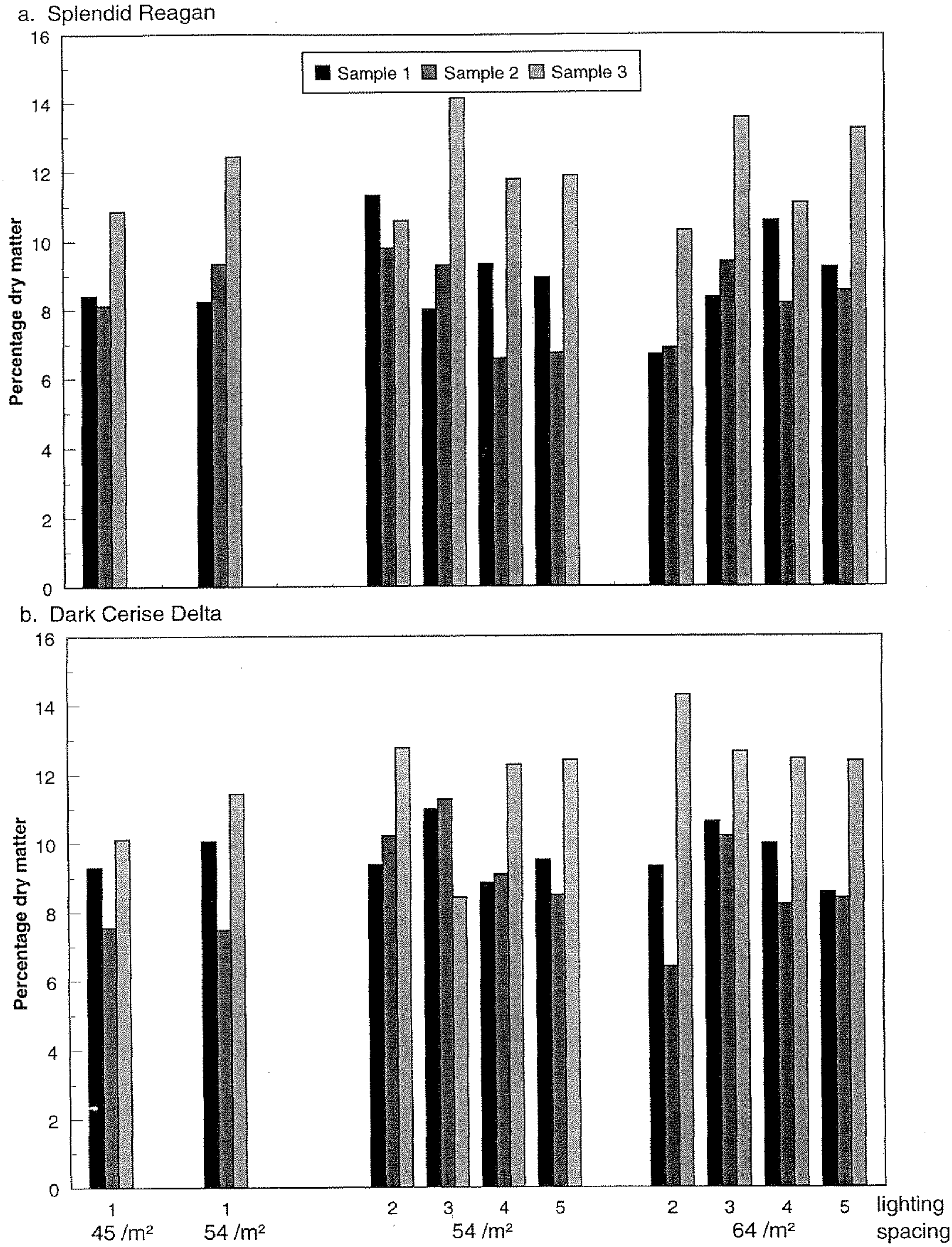
Figure 3. The Influence of Supplementary Lighting and Spacing on Plant Fresh Weight
Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

Figure 4. The Influence of Supplementary Lighting and Spacing on Percentage Dry Matter Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

1.2 The Influence of Supplementary Lighting on Final Product

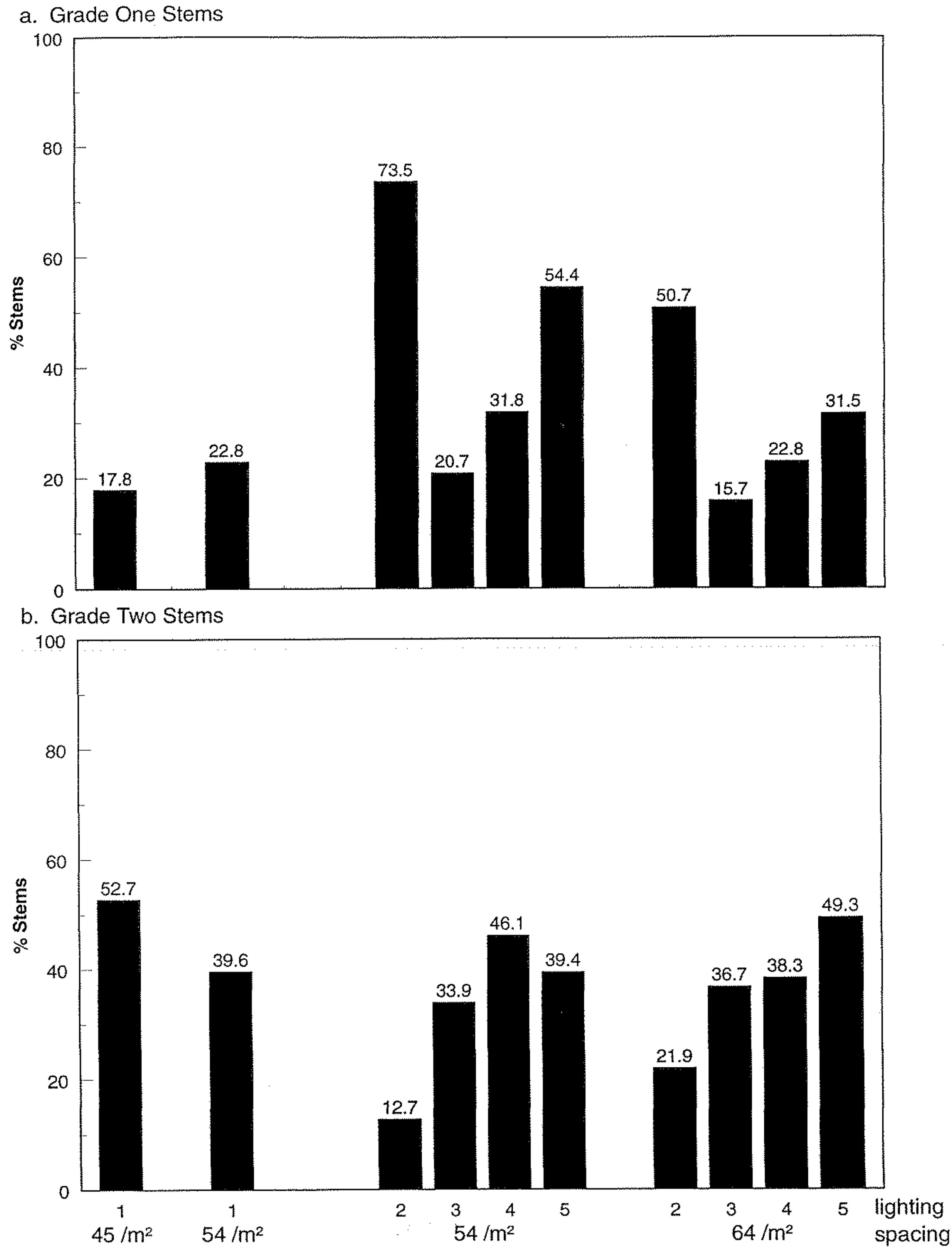
Variability within plots made it difficult to accurately assess production time relative to treatment. It was however observed that treatments did have some impact on rate of production. Lighting at 12 W/m^2 during long days alone for example appeared to decrease the rate of flower initiation in comparison with no supplementary lighting. This was indicated by the speed with which buds first became visible as illustrated in plate 2 (Appendix IV, page 143). Furthermore, the first harvest on these plots was 2-3 days later than that on plots receiving no supplementary lighting. It seems possible that switching the environment from one of high light intensity through the use of supplementary lighting at 12 W/m^2 during long days to a low light intensity with no supplementary lighting from the start of short days, may have produced a type of shock which impacted on flower initiation and subsequent maturity.

In contrast, production time was apparently reduced by providing supplementary lighting during flower initiation i.e. the treatments 4.8 W/m^2 throughout production or 12 W/m^2 day 1-35 short days, by approximately one week. With the variability experienced, it was difficult to assess if one of these treatments was faster than the other in this trial but it seems likely that any differences between them would have been small (i.e. two or three days) for the planting date assessed. This result corresponds with that observed in HDC funded work on pot chrysanthemums (e.g. Finlay, 1993) receiving supplementary lighting at these two intensities during flower initiation. It was also notable that the treatment 12 W/m^2 days 36-70 short days reduced production time in comparison with no supplementary lighting by approximately 5 days. Thus placement of lighting influenced overall production time by at least 8 days.

Product quality as assessed by grading mature stems (figures 5 and 6, pages 25-28) was clearly improved by supplementary lighting, depending on treatment. The most favourable grade out resulted from the treatments 4.8 W/m^2 throughout short days and 12 W/m^2 day 36-70 short days. These two treatments both increased the proportion of grade one stems produced in comparison with no supplementary lighting, and also decreased the proportion of grade three and waste stems produced.

Along with increasing the speed of production, lighting at 12 W/m^2 during day 1-35 short days had a slight impact on final quality, producing higher proportions of high grade stems and lower proportions of low grade stems in comparison with plants receiving no supplementary lighting. This treatment was not, however, as effective as lighting at 12 W/m^2 day 36-70 short days described above. Lighting at 12 W/m^2 during long days only however appeared to decrease product quality with a reduction in proportion of grade one and two stems as well as an increase in the proportion of grade three and waste stems.

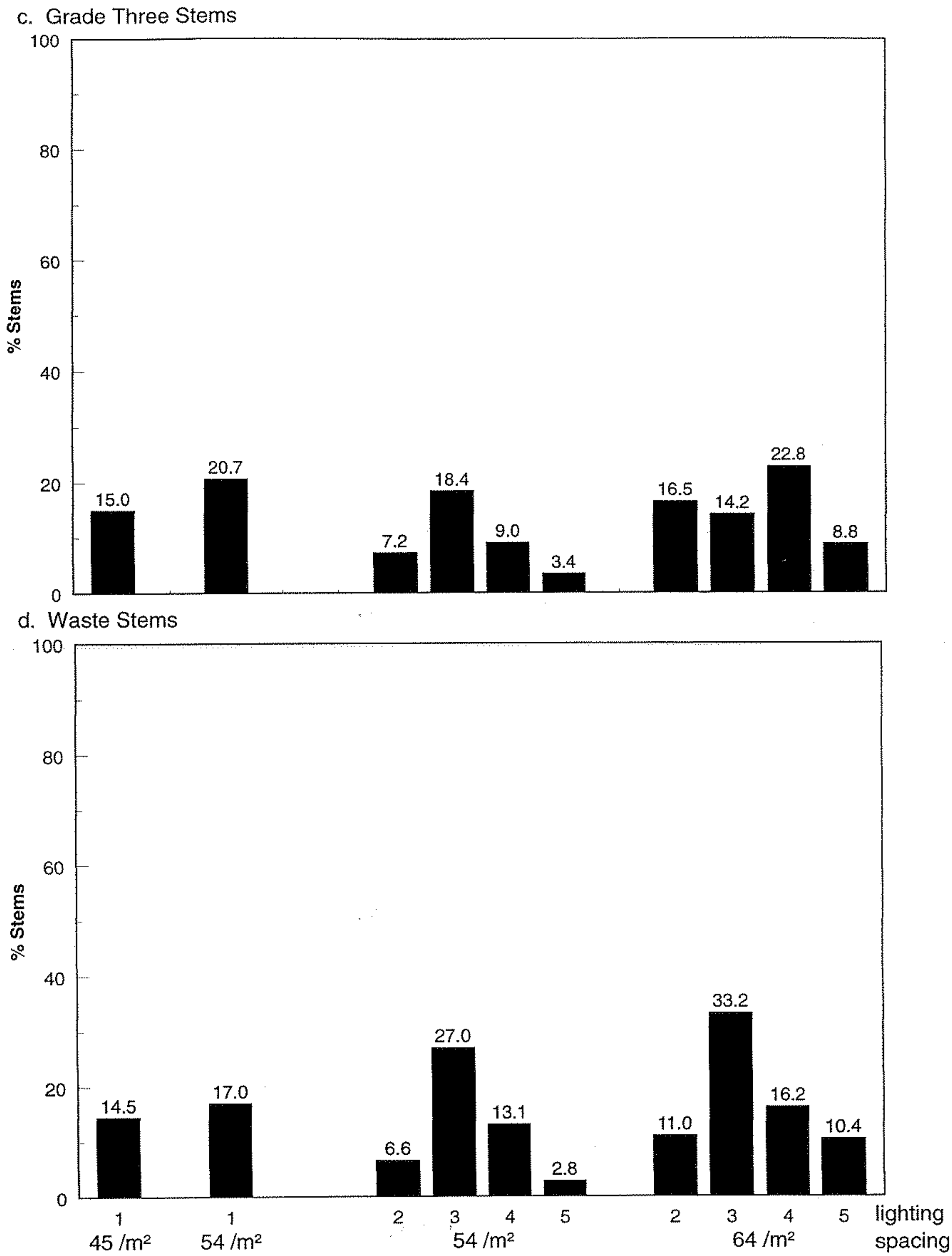
Figure 5. The Influence of Supplementary Lighting and Spacing on Grade Out of Splendid Reagan - Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

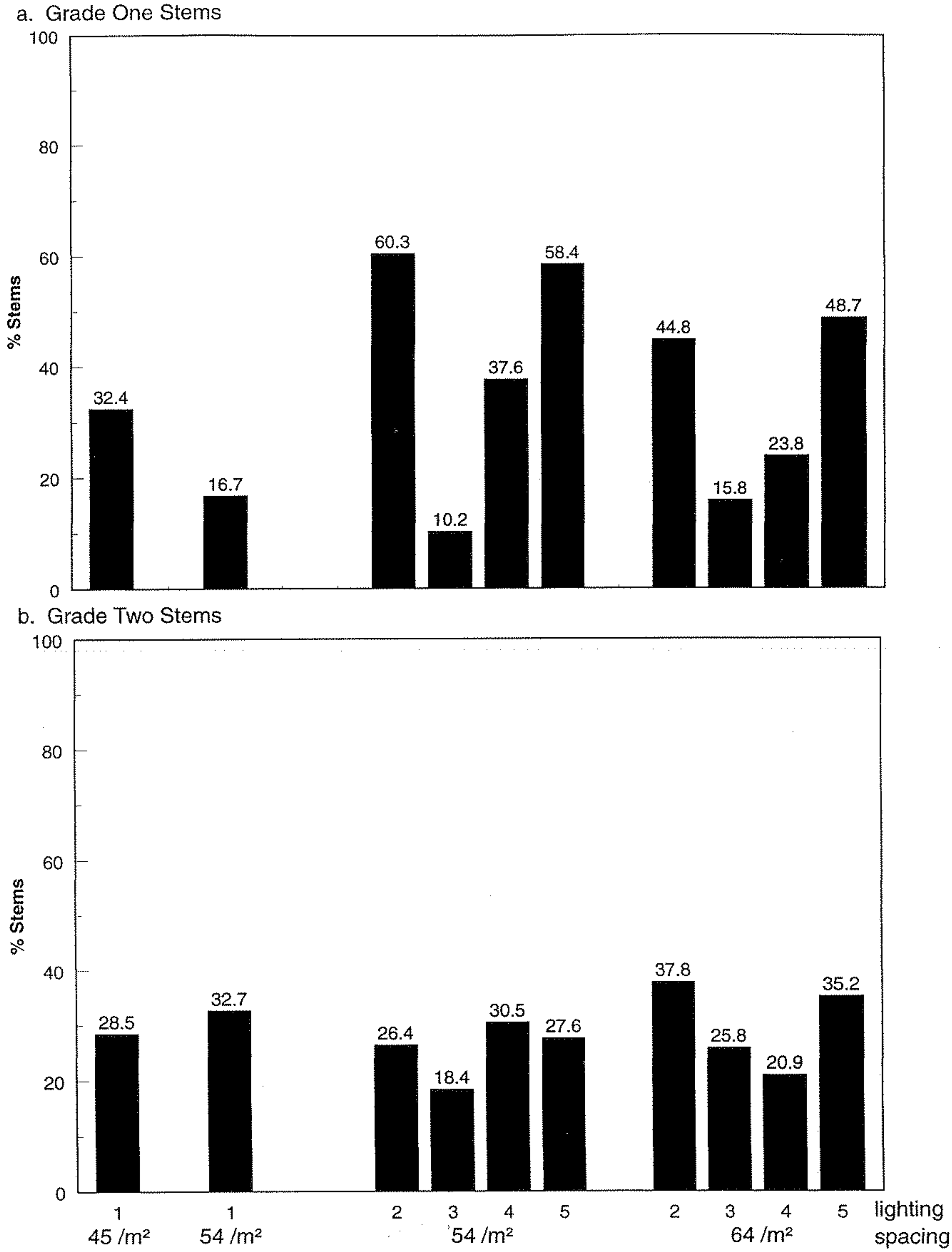
Figure 5. The Influence of Supplementary Lighting and Spacing on Grade Out of Splendid Reagan - Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

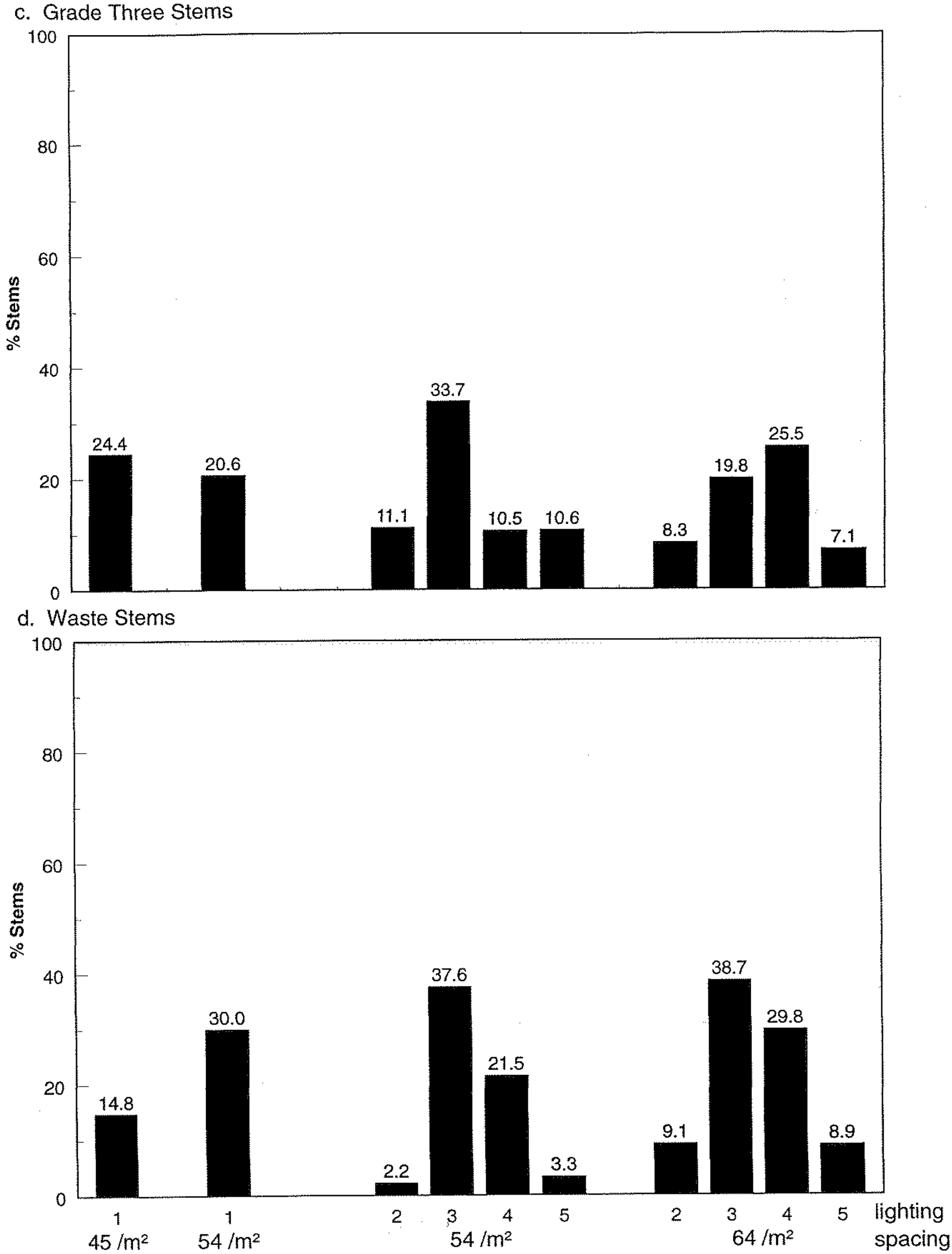
Figure 6. The Influence of Supplementary Lighting and Spacing on Grade Out of Dark Cerise Delta - Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

Figure 6. The Influence of Supplementary Lighting and Spacing on Grade Out of Dark Cerise Delta - Week 45 Planting - 1994/95



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² LD
4 = 12 W/m² 1-35 SD
5 = 12 W/m² 36-70 SD

In agreement with stem fresh weight data assessed on full stems (i.e. cut off at the peat block), average wrap weight (i.e. of a wrap of 5 stems cut to 70cm length and sleeved) was also improved by supplementary lighting. This may be illustrated by representing the results of grade out according to bunch weight categories rather than the qualitative grading system as reviewed above (figure 7, pages 30 and 31). Weight grading is already established in Holland and the top weight grade is represented by the top category used in these figures (i.e. stems over 75g). Stems over 55g would be considered suitable to meet supermarket specifications. It is therefore apparent that as well as improving the proportion of grade one stems produced, the lighting treatments 4.8 W/m^2 throughout SD and 12 W/m^2 day 36-70 SD produced higher proportions of stems in the higher weight categories.

Along with the quantifiable improvements in stem quality outlined above, visual quality was also improved by some of the supplementary lighting treatments. Lighting at 4.8 W/m^2 throughout production, as expected produced stems with darker green foliage and increased bud counts as well as stronger looking stems. Of more surprise was the significant improvement in quality achieved by providing supplementary lighting at 12 W/m^2 day 36-70 of short days only. Despite spending the larger proportion of its production period with no supplementary lighting, plants began to produce darker green foliage within the first week of the treatment commencing. This was also apparent in other treatments where supplementary lighting at 12 W/m^2 was first turned on. The benefit of this particular treatment however is that the foliage benefiting most from these improvements in visual quality due to lighting is that at the top of the plant which is on display within the sleeve at point of sale. Furthermore improvements in flower colour were also noted when flowers matured during periods of low solar radiation levels resulting in pale coloured flowers where no lighting or lighting at only 4.8 W/m^2 were used. These visual improvements are illustrated in plates 3 and 4 (Appendix IV, pages 144 and 145).

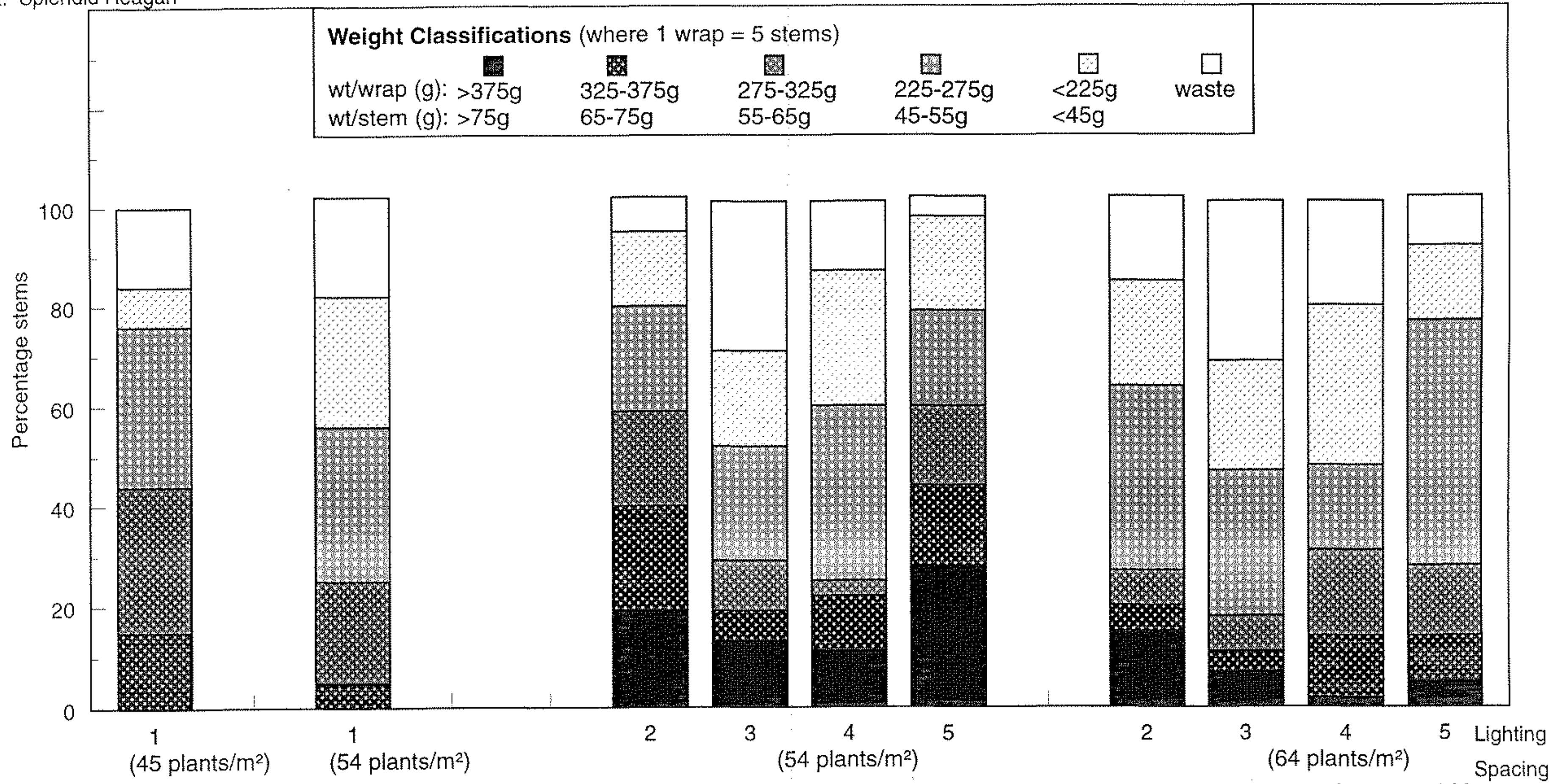
1.3 The Impact of Supplementary Lighting Treatment on Leaf Mineral Status

There were no obvious treatment effects on leaf mineral status at the three stages of growth assessed (Table 1, Appendix I, page 86). These data may also be expected to be affected by the high soil conductivity problems highlighted previously. Mineral nutrient levels were however generally within the ranges required for chrysanthemums. Nitrogen levels were low in comparison with the slightly high potassium levels. Boron levels were generally low for all treatments while manganese levels were high overall compared with the desired ranges.

Given the variability in plant establishment comparison of spacing treatments has not been made on the 1994/95 data.

Figure 7. Summary of the Influence of Supplementary Lighting and Spacing on Weight Grading - Week 45 Planting - 1994/95 (stems cut to 70 cm length for sleeving)

a. Splendid Reagan



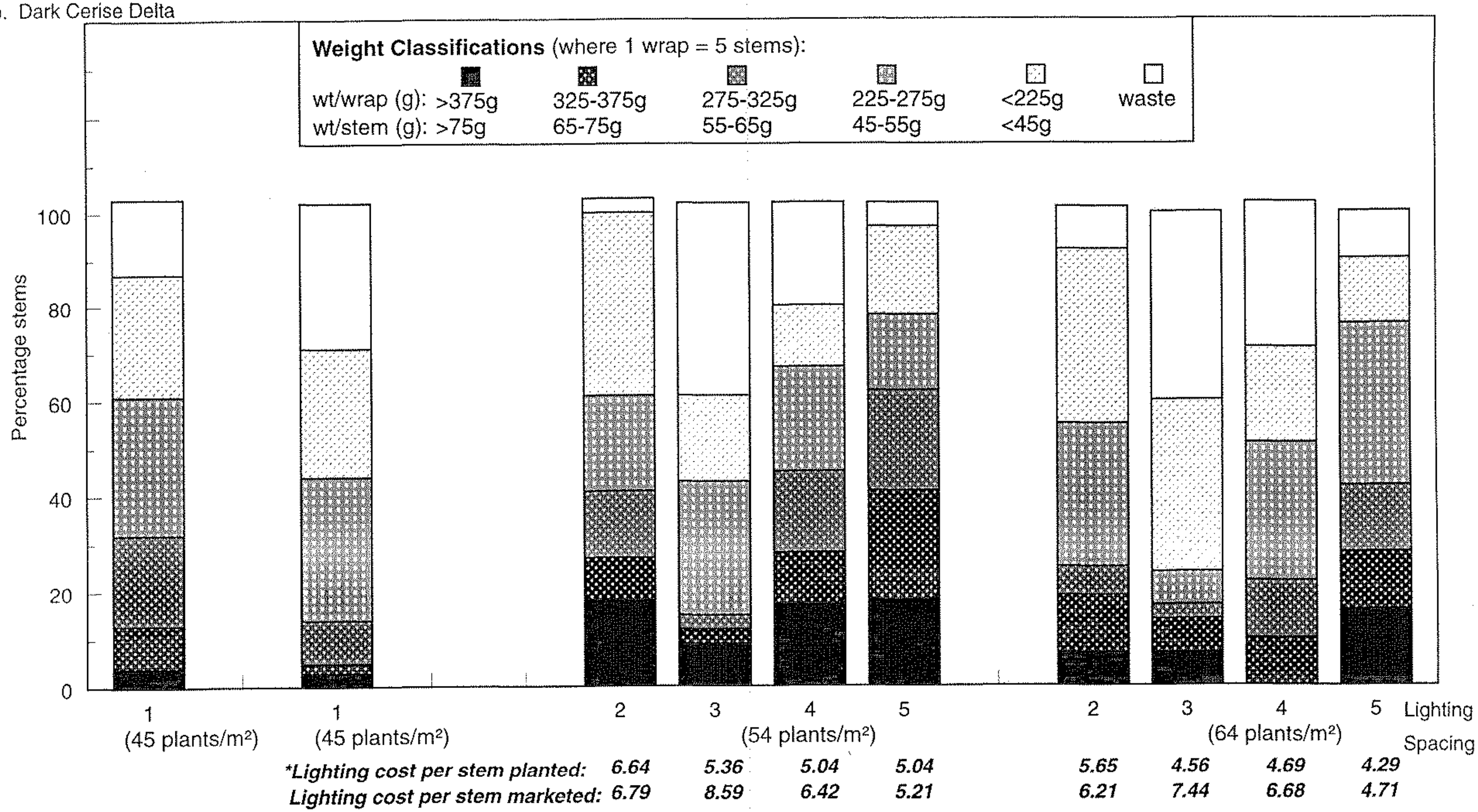
***Lighting cost per stem planted:**	**6.64**	**5.36**	**5.04**	**5.04**	**5.65**	**4.56**	**4.69**	**4.29**
Lighting cost per stem marketed:	**7.11**	**7.34**	**5.80**	**5.22**	**6.72**	**6.62**	**5.80**	**4.76**

KEY TO LIGHTING TREATMENTS:
1 = No supplementary lighting
2 = 4.8 W/m² throughout SD
3 = 12 W/m² LD only
4 = 12 W/m² day 1-35 SD only
5 = 12 W/m² day 36-60 SD only

Refer to page 75 for further details of costings calculated

Figure 7. Summary of the Influence of Supplementary Lighting and Spacing on Weight Grading - Week 45 Planting - 1994/95 (stems cut to 70 cm length for sleeving)

b. Dark Cerise Delta



KEY TO LIGHTING TREATMENTS:
1 = No supplementary lighting
2 = 4.8 W/m² throughout SD
3 = 12 W/m² LD only
4 = 12 W/m² day 1-35 SD only
5 = 12 W/m² day 36-60 SD only

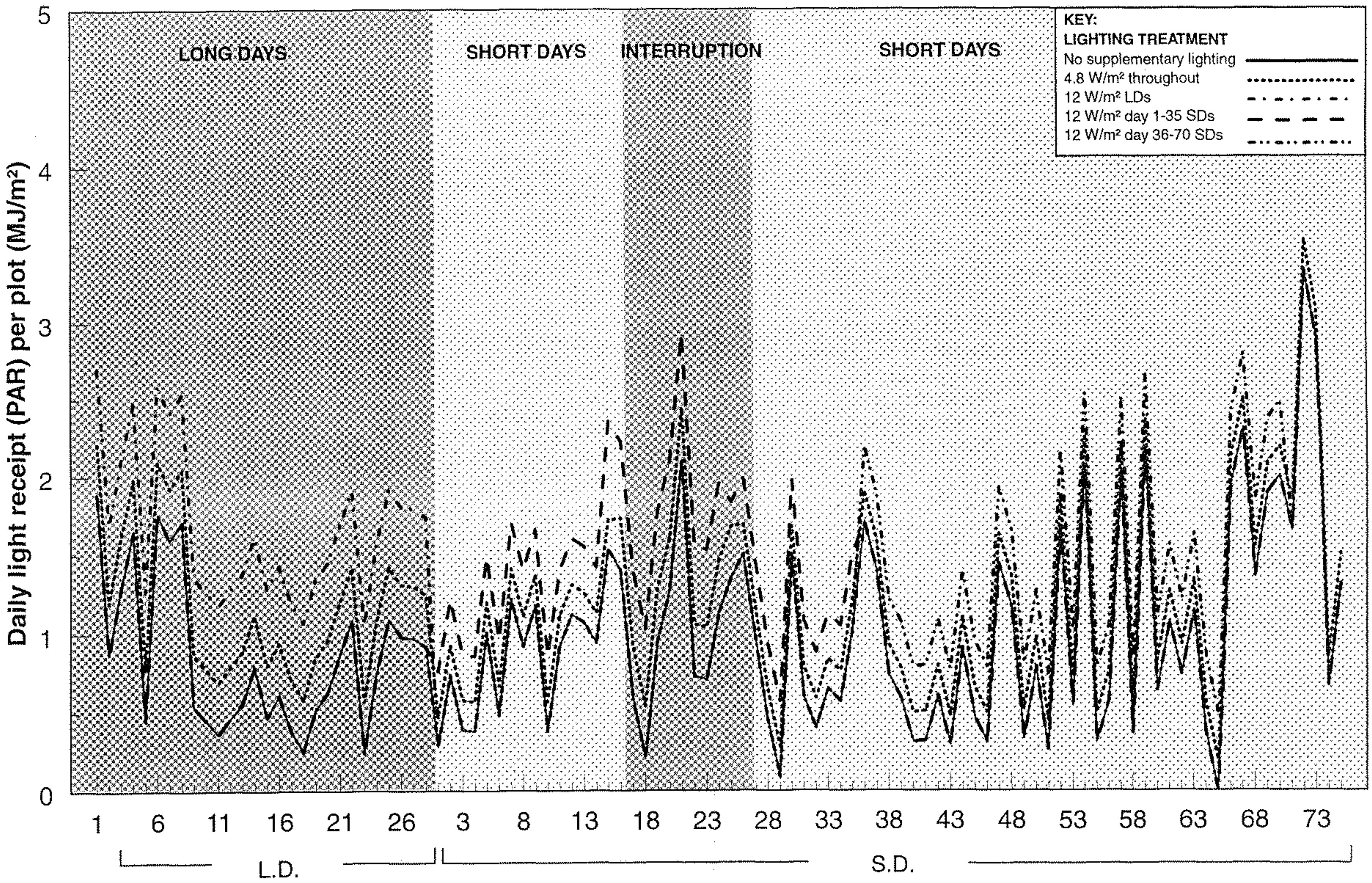
** Refer to page 75 for further details of costings calculated*

1.4 The Impact of Supplementary Lighting on Total Light Receipt

The light received daily per treatment calculated by adding external solar radiation, corrected for transmission (i.e. 70% in this trial) and Photosynthetically active radiation (PAR = 50% of total solar radiation) is illustrated in Figure 8, page 33. Clearly the PAR figure was increased where supplementary lighting was given and was greater as higher lighting intensities and longer lighting periods (i.e. long days).

It should also be noted that, due to low background solar radiation and the length of time lights are used for during long days, a larger percentage increase in light receipt per plot resulted from lighting during long days than during the last five weeks of short days. However the impact that lighting had on final quality was much greater through lighting during the last five weeks of short days than during long days. This emphasises further the importance of timing the use of supplementary lighting on maximising the efficiency with which it is used.

Figure 8. PAR light levels received per treatment corrected for transmission and additional light supplied by luminaires
Week 45 Planting - 1994/95



2. Year 2

Despite the difficulties experienced, there were clear indications from the work carried out in year 1 that improvements in quality could be achieved through providing supplementary lighting for a short period at the end of production. The treatments assessed in the second year therefore focused on the last five week period of short days through assessing light intensity and also a shorter period of lighting within this 5 week interval.

While the results discussed below were collected on three occasions, namely at the end of long days, after 35 short days and at maturity; not all treatments had commenced on each of these occasions. In fact, only the treatment providing lighting at 4.8 W/m^2 throughout production had commenced by both the first and the second sample dates. By the third sample date however, all treatments had been given and can be compared in this data set.

The design of the trial permits the following statistical comparisons :

- the mean of the lit treatments* and the mean of the no supplementary lighting treatment.
- the means of each of the four supplementary lighting treatments.
- the mean of 45 plants/m^2 spacing and of 54 plants/m^2 spacing in the absence of supplementary lighting.
- the mean of 54 plants/m^2 spacing and of 64 plants/m^2 spacing for each supplementary lighting treatment.

Further comparisons can only be made on interactions as follows:

- variety x the mean of lit treatments* and no supplementary lighting.
- variety x each supplementary lighting treatment.
- variety x the mean of 45 plants/m^2 and of 54 plants/m^2 in the absence of supplementary lighting .
- variety x the mean of 54 plants/m^2 and of 64 plants/m^2 for each supplementary lighting treatment.

Since the statistical analysis is not able to separate each lighting and spacing treatment combination for each variety, these individual treatment means have also been recorded graphically and trends in these data will be discussed alongside the significant effects noted from the statistical analyses described above.

* Since only one of the lighting treatments (i.e. 4.8 W/m^2 throughout production) had commenced when the first and second destructive samples were taken, it would be unrealistic to expect the mean of the four lighting treatments to be significantly different from the mean of the no supplementary lighting treatment (since three of the treatments contributing to the first mean would also be representing the effects of no supplementary lighting).

2.1 The Influence of Supplementary Lighting and Spacing on Plant Development

2.1.1 Plant Height and Leaf Number

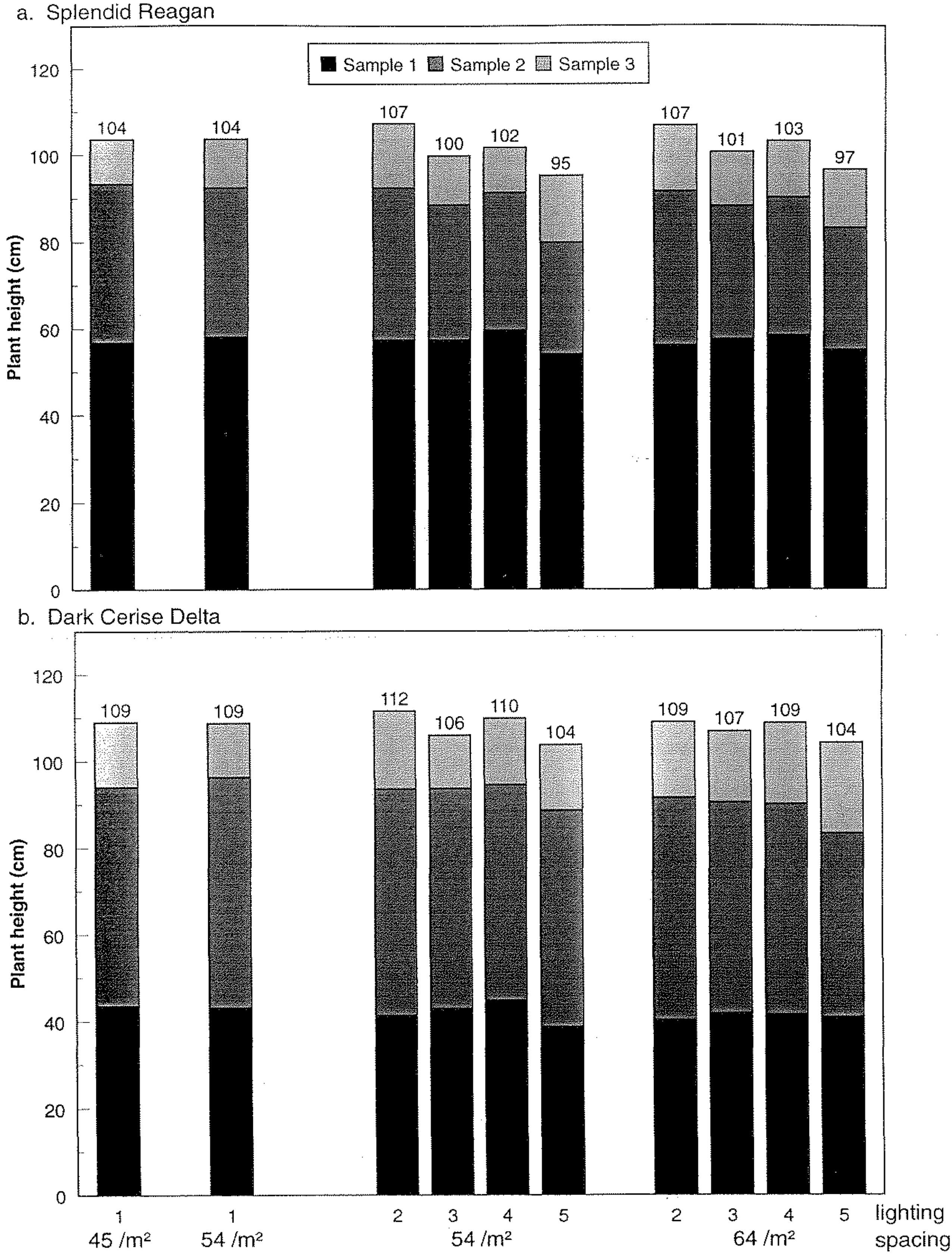
In contrast with year 1, treatments in year 2 largely focused on providing lighting during the last part of the short day period when plants were no longer growing vegetatively. Given therefore the observations made in year 1 that only lighting given during vegetative growth increased plant height, few of the year 2 treatments would be expected to increase plant height.

This is supported by the results from year 2 where supplementary lighting treatments had little impact on mean plant height for either the week 40 or the week 45 plantings (figures 9 and 10, pages 36 and 37).

It is apparent from the treatment means presented in figures 9 and 10 (pages 36 and 37), that the treatment 4.8 W/m^2 throughout SD (i.e. including the long day period) produced slightly taller plants; particularly for the second planting when solar radiation levels were declining. This was also the only treatment in year 2 which provided supplementary lighting during long days. The height of the three samples taken was also consistently higher from planting in week 40 than in week 45, this reflects the high levels of solar radiation received during the 28 long day period following planting in week 40 (in fact plants were taller than would normally be expected at the end of the long day period but for experimental purposes the long day period had been fixed at 28 days).

These observations are largely supported by the statistical analysis where no significant increase in height was found as a result of lighting at 4.8 W/m^2 throughout production from the first planting (week 40). A significant increase in height was associated with this lighting treatment from the second planting however when background light levels during the vegetative phase of production were declining (table 1). Overall height was increased by 4-21% over the three samples assessed in comparison with the remaining lighting treatments. It is therefore apparent that, in agreement with the results found in year 1, supplementary lighting given during long days increased height but had little impact on height when given during the last 5 weeks of short days.

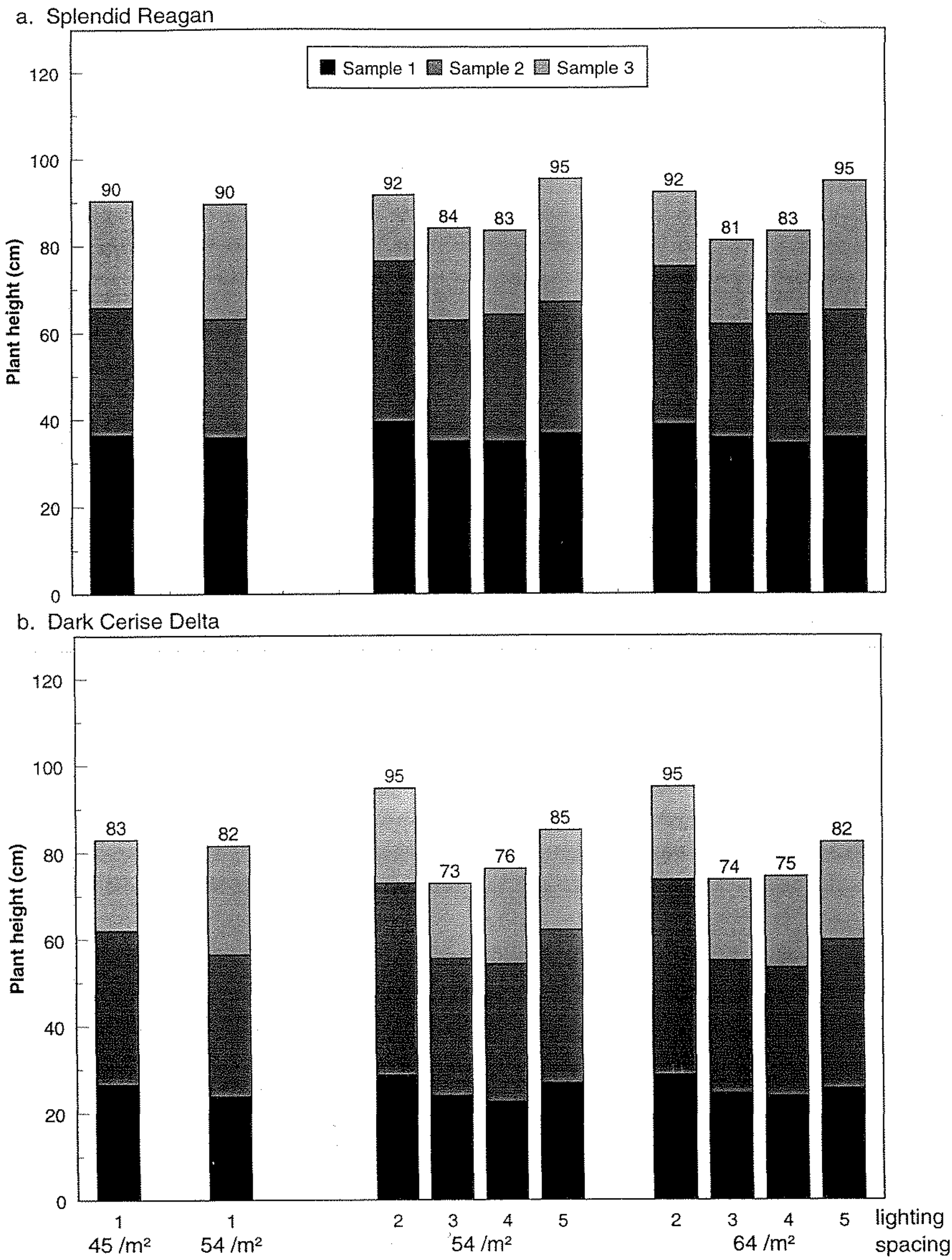
Figure 9. The Influence of Supplementary Lighting and Spacing on Plant Height
Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Figure 10. The Influence of Supplementary Lighting and Spacing on Plant Height
Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Table 1: Effect of supplementary lighting on plant height (week 45 planting)

Lighting	Sample 1	Sample 2	Sample 3
4.8 W/m² throughout	33.95	74.61	93.41
12 W/m² 36-70 SD	29.84	58.87	77.94
4.8 W/m² 36-70 SD	28.95	59.03	79.37
12 W/m² 47-60 SD	31.28	63.58	89.43
Significance	**	**	***
SED (5 d.f.)	*0.692*	*1.992*	*1.826*
LSD (5%)	*1.78*	*5.12*	*4.69*

Plant height was also apparently increased with the treatment 12 W/m² 47-60 SD. However, timing the interruption from this data was based on light integral using data for the variety Delta in reference tables calculated from work carried out by Allen Langton (1992). Revegetation occurred in some areas of the treatment compartments in the second planting of the trial due to localised marginal temperatures (since the interruption for Reagan varieties is more sensitive to temperature than for Deltas). In particular effects were noted on plants from the treatment 12 W/m² 47-60 SD. In the light of the other data produced this treatment would therefore not be expected to increase plant height.

The impact this problem may have had on mean plant height figures can be illustrated by examining the analysis of interaction effects between variety and the supplementary lighting treatments (Table 2). Height of the variety Delta from the treatment 4.8 W/m² throughout production, after 35 short days and at maturity was significantly greater than the other lighting treatments assessed. The height of Reagan plants lit at 4.8 W/m² throughout SD was also significantly greater than the lighting treatments 12 W/m² 35-70 SD and 4.8 W/m² 35-70 SD but was not significantly different to that from the treatment 12 W/m² 47-60 SD (i.e. where the effects of revegetation were most pronounced).

Table 2: **Interaction between variety and supplementary lighting on plant height (week 45 planting)**

Lighting	Sample 1	Sample 2	Sample 3
Splendid Reagan			
4.8 W/m² throughout	39.18	75.85	91.95
12 W/m² 36-70 SD	35.42	62.41	82.58
4.8 W/m² 36-70 SD	34.67	64.19	83.34
12 W/m² 47-60 SD	36.35	66.10	95.10
Significance	*NS*	**	***
SED (5 d.f.)	-	*2.183*	*1.943*
LSD (5%)	-	4.72	4.20
Dark Cerise Delta			
4.8 W/m² throughout	28.73	73.36	94.88
12 W/m² 36-70 SD	24.27	55.33	73.29
4.8 W/m² 36-70 SD	23.23	53.87	75.40
12 W/m² 47-60 SD	26.21	61.05	83.75
Significance	*NS*	**	***
SED (5 d.f.)	-	*2.183*	*1.943*
LSD (5%)	-	*4.72*	*4.20*

There is little evidence, either from the treatment means (figures 9 and 10, pages 36 and 37) or the statistical comparisons made, that spacing influenced plant height. The standard deviation of plant height data, both from the destructive samples taken and from *in situ* measurements on a larger sample size, indicated that spacing and lighting treatments did not significantly influence variability.

As illustrated by the mean data presented in figures 11 and 12 (pages 41 and 42), the trends in leaf number largely followed those in plant height with few differences arising due to the supplementary lighting treatments other than an increase in leaf number concurrent with the increase in stem length resulting from supplementary lighting at 4.8 W/m^2 throughout production. This may be further supported by the 'leaf number ratio' data (figures 13 and 14, pages 43 and 44) which was calculated by dividing leaf number by plant height. The ratios calculated are largely constant for each sample taken, with differences mainly arising from age of sample, variety or planting date. That is, the ratio decreased (and hence internode length increased) with age of sample. Dark Cerise Delta had a larger ratio (and hence shorter internodes) overall than Splendid Reagan. Planting in week 45 (i.e. under poorer light levels) also increased the ratio (i.e. produced shorter internodes).

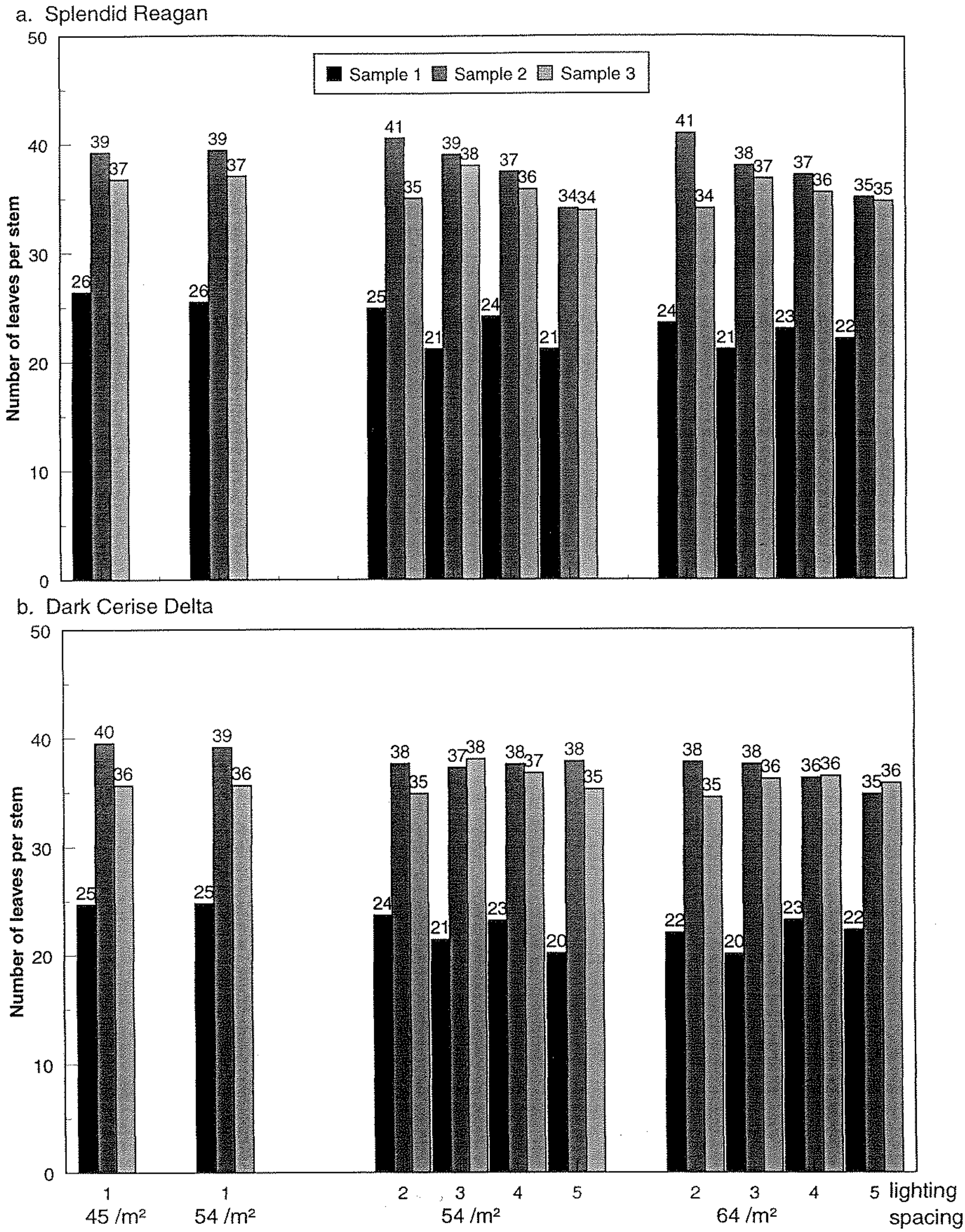
2.1.2. Fresh Weight

Supplementary lighting treatments had a greater impact on plant fresh weight, again reflecting observations made on the data from year 1 where fresh weight was more responsive than plant height to supplementary lighting treatments given while plants were growing generatively (i.e. during the last 5 weeks of the short day period).

Comparing trends in individual treatment means (figure 15 and 16, pages 45 and 46), lighting at 4.8 W/m^2 throughout production increased stem fresh weight compared with no supplementary lighting, particularly when solar radiation levels during early development (long days in particular) were declining (i.e. from planting in week 45). This effect was most pronounced for samples taken after 35 short days.

Statistical comparisons of supplementary lighting treatments with each other confirm the observation that lighting at 4.8 W/m^2 throughout production significantly increased fresh weight of plants sampled both at the end of long days and after 35 short days (table 3). As mentioned previously, the other three lighting treatments had not commenced by the time these first two samples were taken and hence were 30 to 40% lower in fresh weight than from lighting at 4.8 W/m^2 throughout production. By the final sample however, there were no longer any significant differences between the lighting treatments. Hence all three of the lighting treatments given during the last five weeks of short days compensated for the lower initial fresh weight such that stems at final harvest were of equivalent fresh weight to those lit throughout production. Furthermore, the weight gain achieved through using supplementary lighting during the last five weeks of short days will be on the part of the stem which is acutally marketed rather than in leaves and parts of the stem which are removed before sleeving wraps.

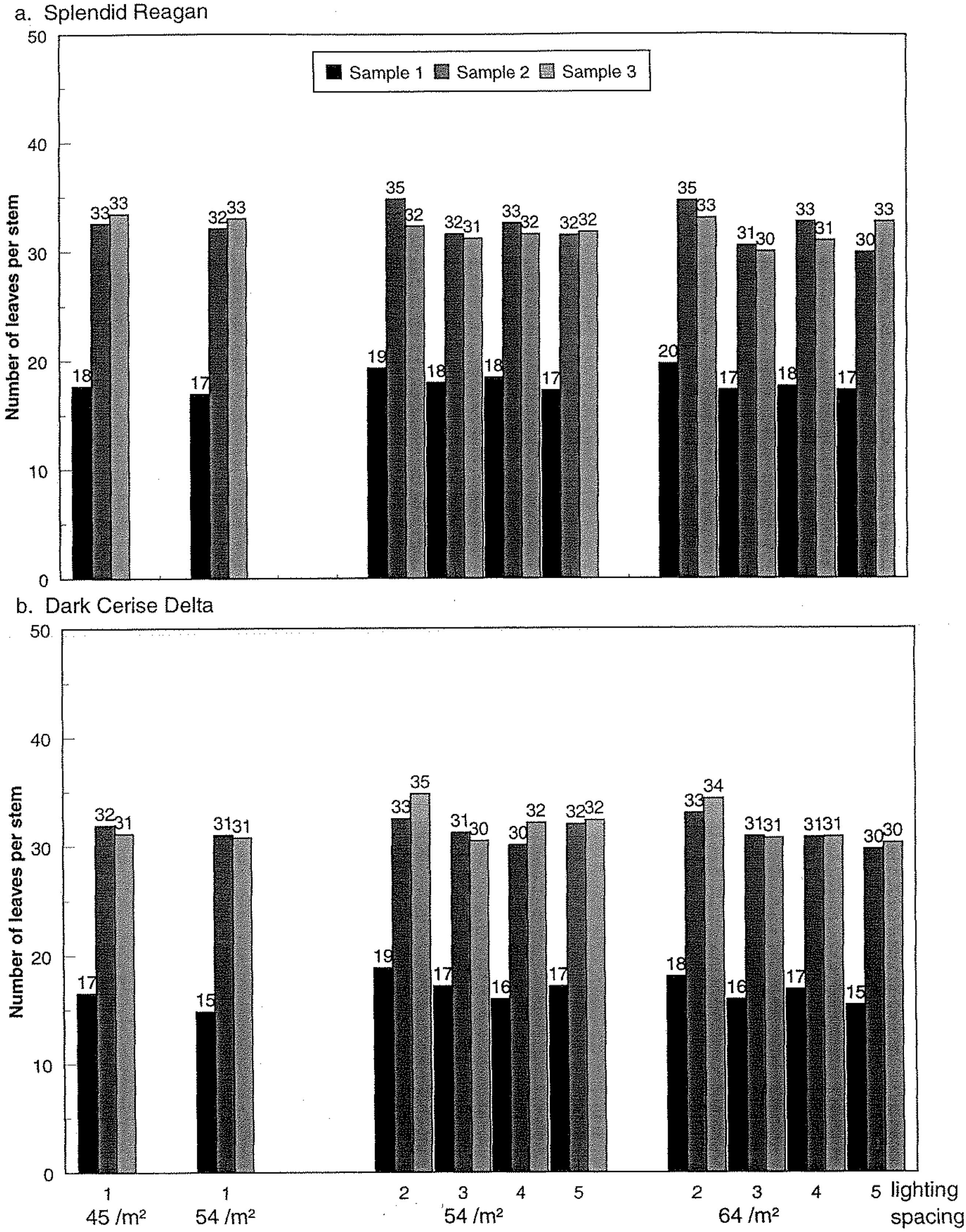
Figure 11. The Influence of Supplementary Lighting and Spacing on Leaf Number
Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting 2 = 4.8 W/m² throughout production 3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD 5 = 12 W/m² 47-60 SD

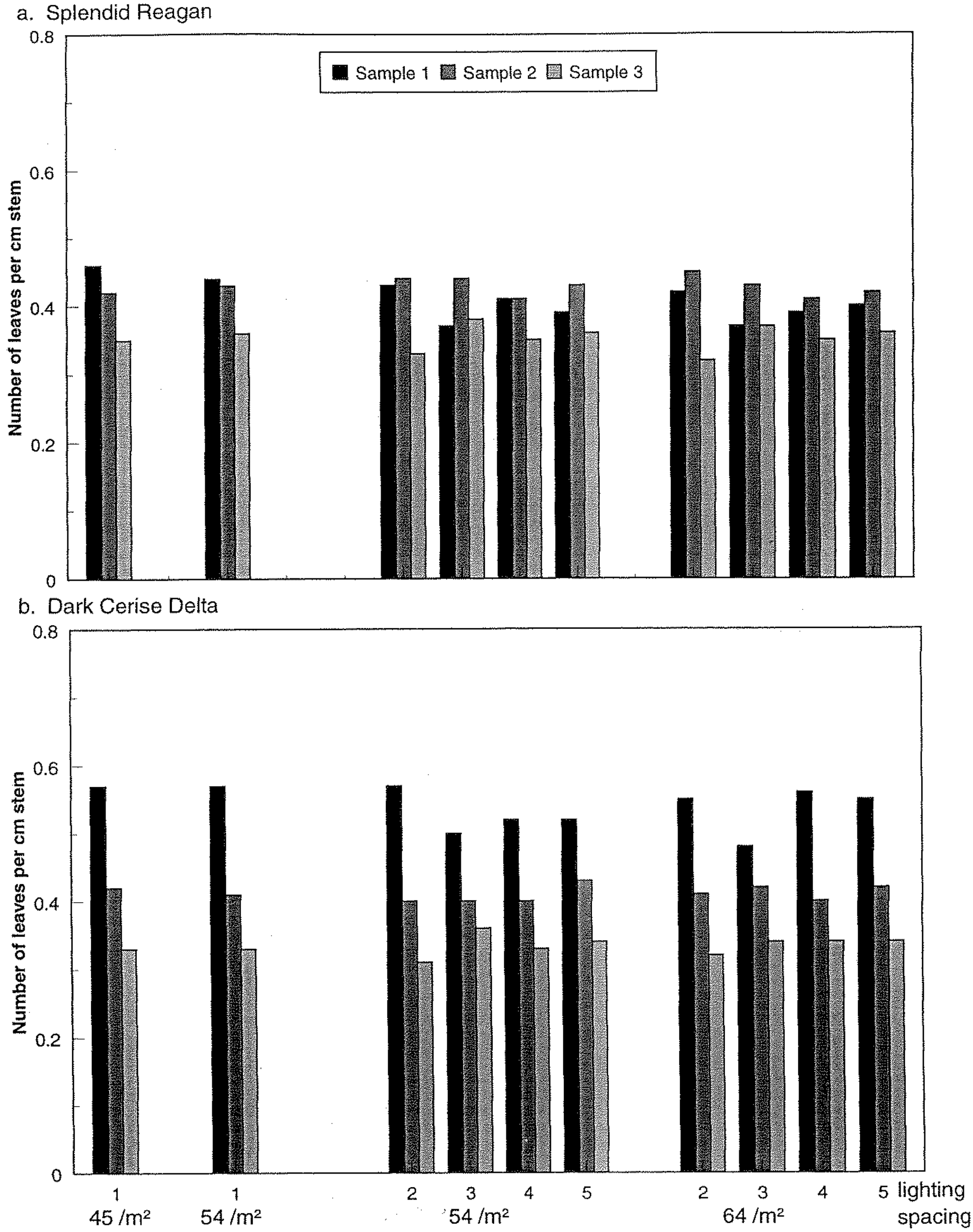
Figure 12. The Influence of Supplementary Lighting and Spacing on Leaf Number
Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

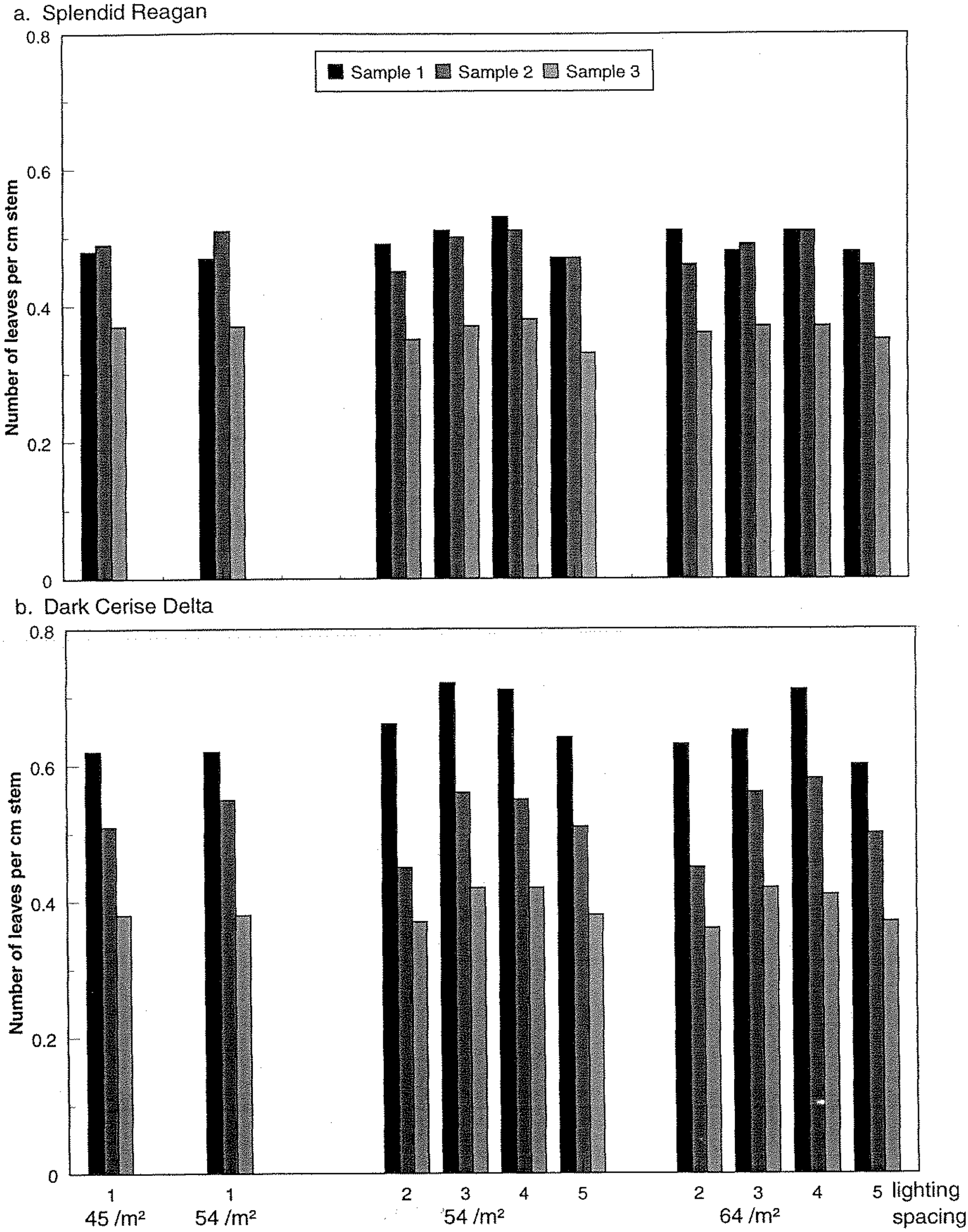
Figure13. The Influence of Supplementary Lighting and Spacing on Leaf Number Ratio Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

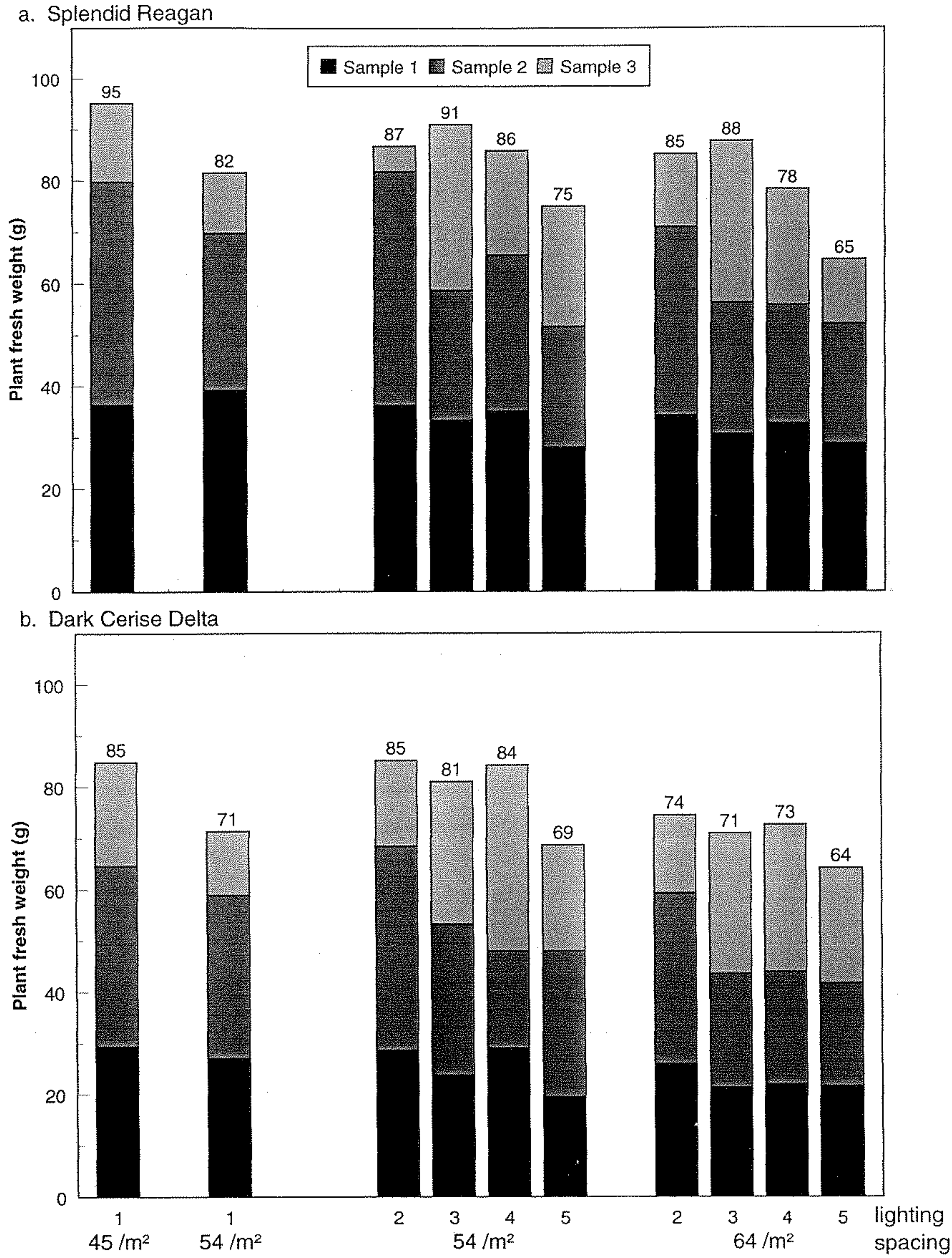
Figure 14. The Influence of Supplementary Lighting and Spacing on Leaf Number Ratio
Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

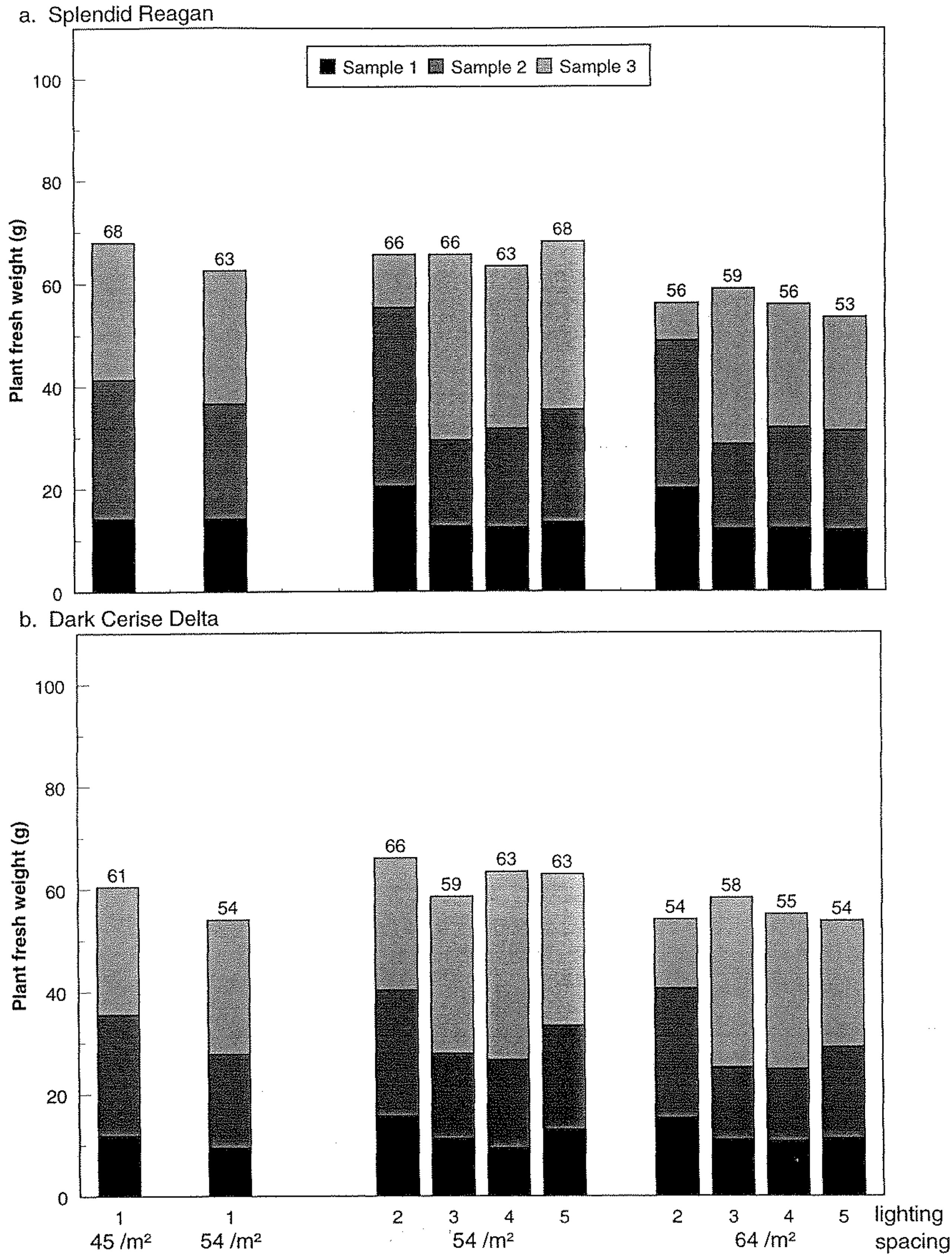
Figure 15. The Influence of Supplementary Lighting and Spacing on Plant Fresh Weight Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Figure 16. The Influence of Supplementary Lighting and Spacing on Plant Fresh Weight Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Table 3: Effect of supplementary lighting on fresh weight (week 45 planting)

Lighting	Sample 1	Sample 2	Sample 3
4.8 W/m² throughout	17.90	46.35	60.50
12 W/m² 36-70 SD	11.80	27.83	60.36
4.8 W/m² 36-70 SD	11.23	28.83	59.45
12 W/m² 47-60 SD	12.43	32.33	59.58
Significance	***	***	*NS*
SED (5 d.f.)	*0.742*	*1.807*	-
LSD (5%)	1.91	4.65	-

Planting at a wider spacing where no supplementary lighting was used increased fresh weight of samples from both planting dates (figures 15 and 16, pages 45 and 46). This observation is supported by the statistical comparison of these spacing treatments meaned across varieties (Table 4). There was no significant difference between the two spacing treatments at the first sample from planting in week 40, but as explained previously solar radiation levels were very favourable during this period and hence the closer spacing would be expected to be less important. In all other cases however increases of 10 to 19% in mean fresh weight resulted from spacing at 45 plants/m² rather than the conventional winter treatment of 54 plants/m².

Table 4: Effect of plant spacing on fresh weight in the absence of supplementary lighting

Spacing	Sample 1	Sample 2	Sample 3
Week 40 planting			
45 plants/m²	32.92	72.25	90.06
54 plants/m²	33.21	64.42	76.48
Significance	*NS*	*	**
SED (5 d.f.)	-	*3.269*	*3.262*
LSD (5%)	-	*7.06*	*7.05*
Week 45 planting			
45 plants/m²	13.06	38.54	64.29
54 plants/m²	11.88	32.29	58.35
Significance	*	***	*
SED (5 d.f.)	*0.442*	*1.132*	*2.198*
LSD (5%)	*0.95*	*2.45*	*4.75*

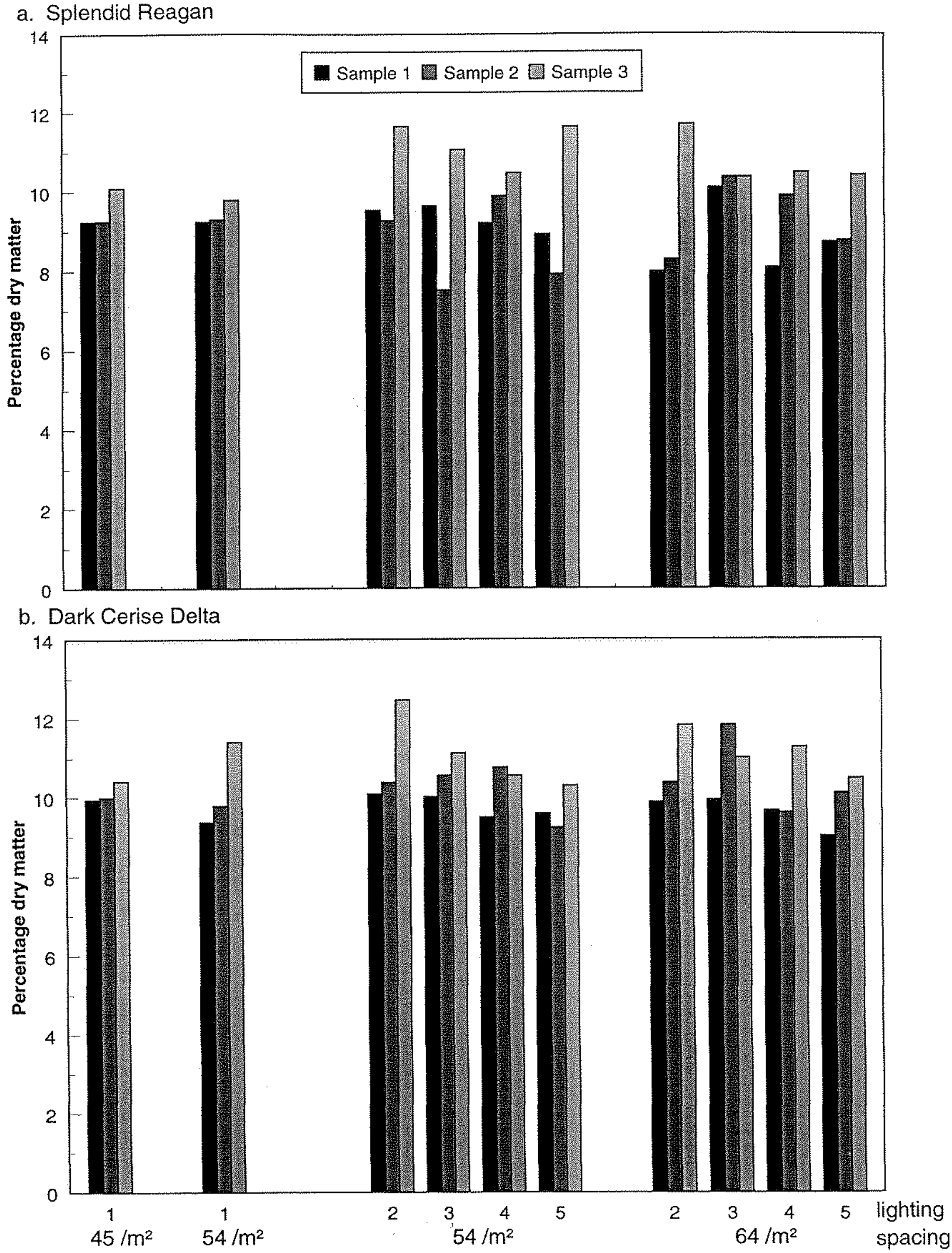
Closer spacing of plants receiving supplementary lighting reduced plant fresh weight overall for both plantings (figure 15 and 16, pages 45 and 46). This is generally supported by the statistical comparison of the data meaned across varieties (Table 5) with decreases ranging from 2 to 18% in fresh weight, depending on treatment and sample date, resulting from spacing at 64 plants/m² rather than 54 plants/m². Although the statistics do not compare no supplementary lighting directly with the supplementary lighting treatments it is clear by comparing the data from sample 3 between Tables 4 and 5 that at standard winter spacing, fresh weight was improved by all supplementary lighting treatments (except for 12 Wm/² 47-60 SD planted in week 40). This observation is further reinforced by the wrap weight data collected during grade out which is discussed below (section 2.2.3, page 68).

Table 5: Effect of plant spacing combined with supplementary lighting treatments on fresh weight

Lighting	Plants/m²	Sample 1	Sample 2	Sample 3
Week 40 planting				
4.8 W/m² throughout	54	32.44	75.06	85.94
	64	30.10	65.13	79.83
12 W/m² 36-70 SD	54	28.52	55.98	85.98
	64	26.00	49.94	79.31
4.8 W/m² 36-70 SD	54	32.08	56.71	85.02
	64	27.35	49.90	75.48
12 W/m² 47-60 SD	54	23.77	49.79	71.79
	64	25.23	47.00	64.46
Significance		**	**	**
SED (5 d.f.)		*1.039*	*3.269*	*3.262*
LSD (5%)		*2.24*	*7.06*	*7.05*
Week 45 planting				
4.8 W/m² throughout	54	18.10	47.92	65.85
	64	17.69	44.79	55.15
12 W/m² 36-70 SD	54	12.00	28.73	62.10
	64	11.60	26.94	58.62
4.8 W/m² 36-70 SD	54	10.96	29.27	63.40
	64	11.50	28.40	55.50
12 W/m² 47-60 SD	54	13.27	34.44	65.56
	64	11.58	30.23	53.60
Significance		**	**	***
SED (5 d.f.)		*0.442*	*1.132*	*2.198*
LSD (5%)		*0.95*	*2.45*	*4.75*

As with the year 1 results, there was no consistent evidence from mean data that percentage dry matter was affected by supplementary lighting or spacing (figures 17 and 18, pages 50 and 51).

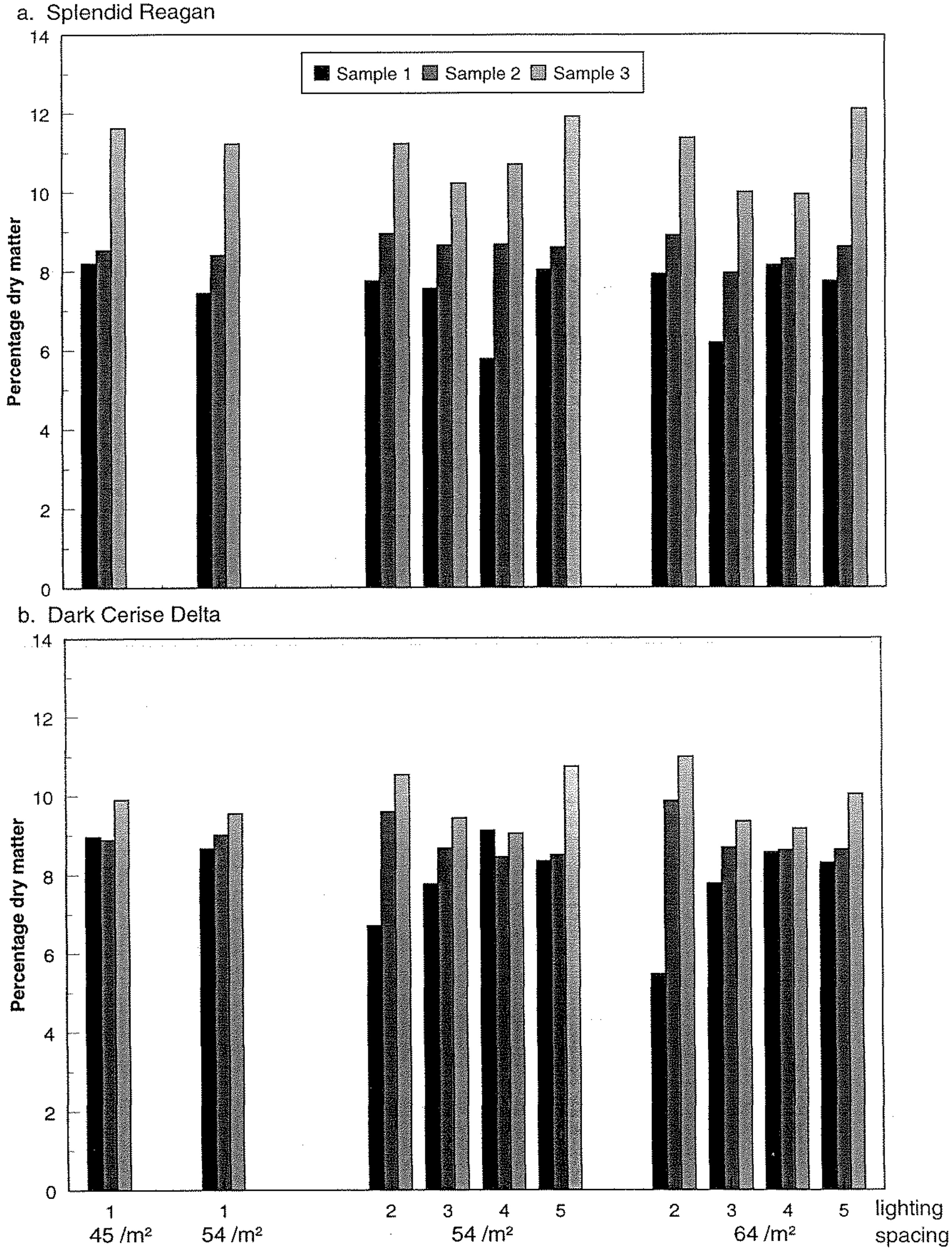
Figure 17. The Influence of Supplementary Lighting and Spacing on Percentage Dry Matter Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Figure 18. The Influence of Supplementary Lighting and Spacing on Percentage Dry Matter Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

2.1.3. Flower Number and Fresh Weight

The total number of flowers per stem and their combined fresh weight per stem (flowers with petals just expanding were removed from the stem by cutting immediately below the sepals) were closely aligned in their responses to the supplementary lighting treatments (figures 19-21, pages 53-56). Overall the trend in results from individual treatments indicates that the number and total fresh weight of flowers per stem increased in response to the supplementary lighting regimes investigated.

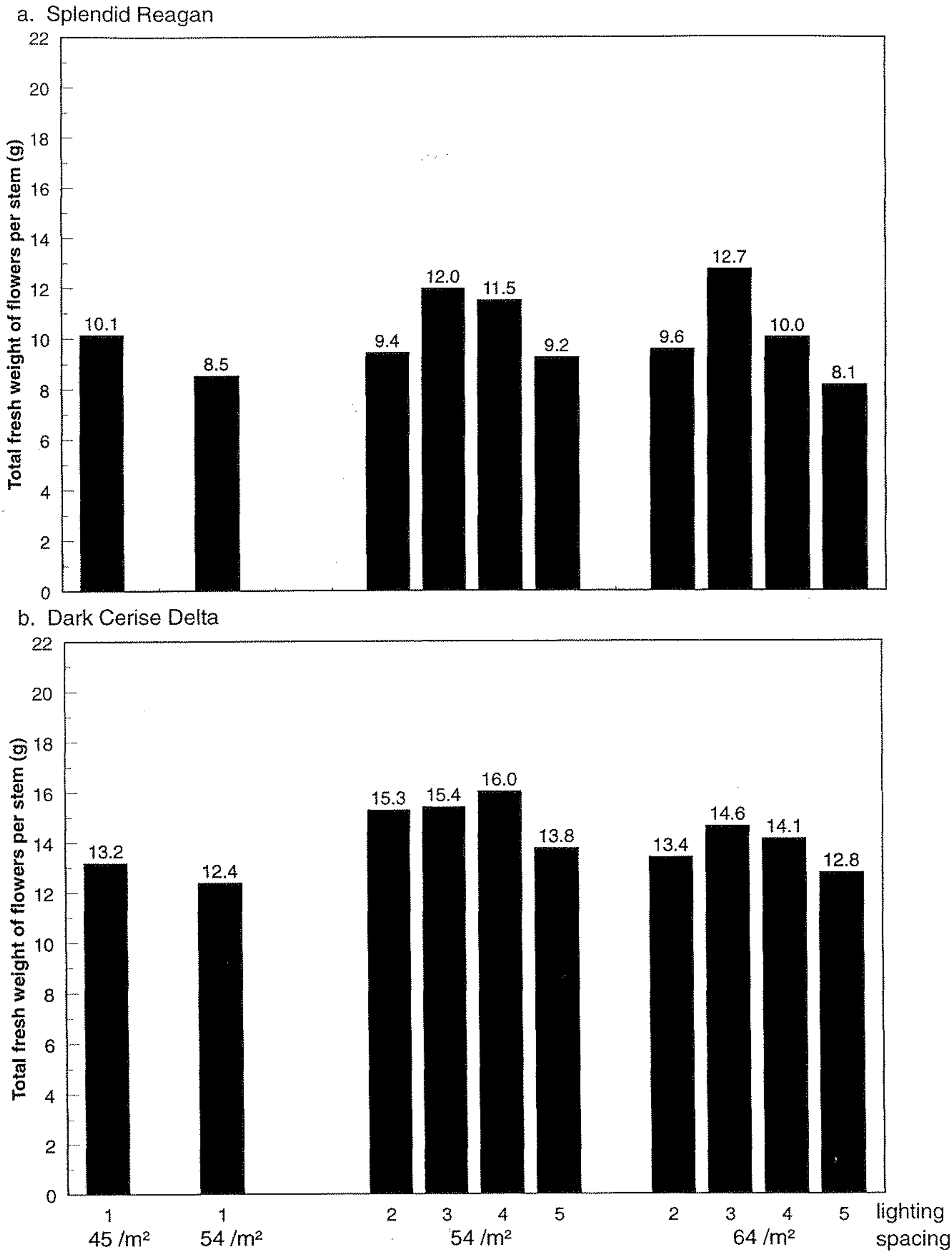
Furthermore, flower number from the week 45 planting (meaned across varieties and spacings) was significantly increased through the use of supplementary lighting (Table 6). Whilst not significantly different according to the analysis the remaining mean values in this table follow the same trend (i.e. increased through the use of supplementary lighting).

Table 6: Effect of supplementary lighting on number and fresh weight of flowers produced per stem

Treatment	Week 40 Planting		Week 45 Planting	
	Number	Fresh weight (g)	Number	Fresh weight (g)
No Supplementary Lighting	8.15	11.05	6.98	14.28
With Supplementary Lighting	8.33	12.36	8.28	14.82
Significance	*NS*	*NS*	*	*NS*
SED (5 d.f.)	-	-	*0.428*	-
LSD (5%)	-	-	1.1	-

Small differences were also apparent between individual lighting treatments (figures 19-21, pages 53-56). The treatments 12 W/m² 36-70 SD and 4.8 W/m² 36-70 SD generally produced the highest flower fresh weight and number per stem, particularly for the 54 plants/m² spacing treatment. This was also evident from the statistical comparisons of means across variety and spacings (Table 7). Lighting at 12 W/m² 36-70 SD and 4.8 W/m² 36-70 SD significantly increased flower number from the week 40 planting and the same trend can be seen in the remaining data.

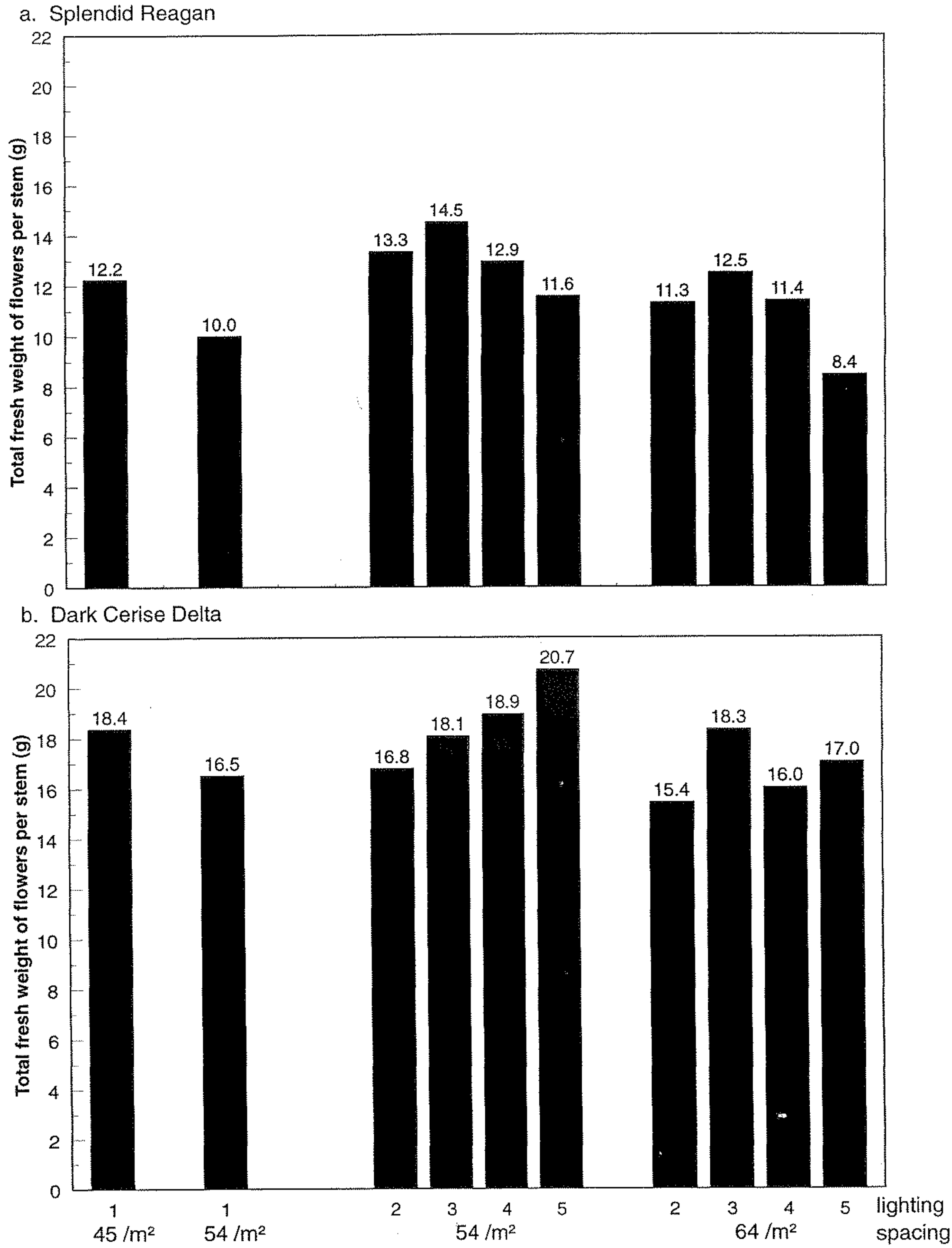
Figure 19. The Influence of Supplementary Lighting and Spacing on Flower Fresh Weight per stem - Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

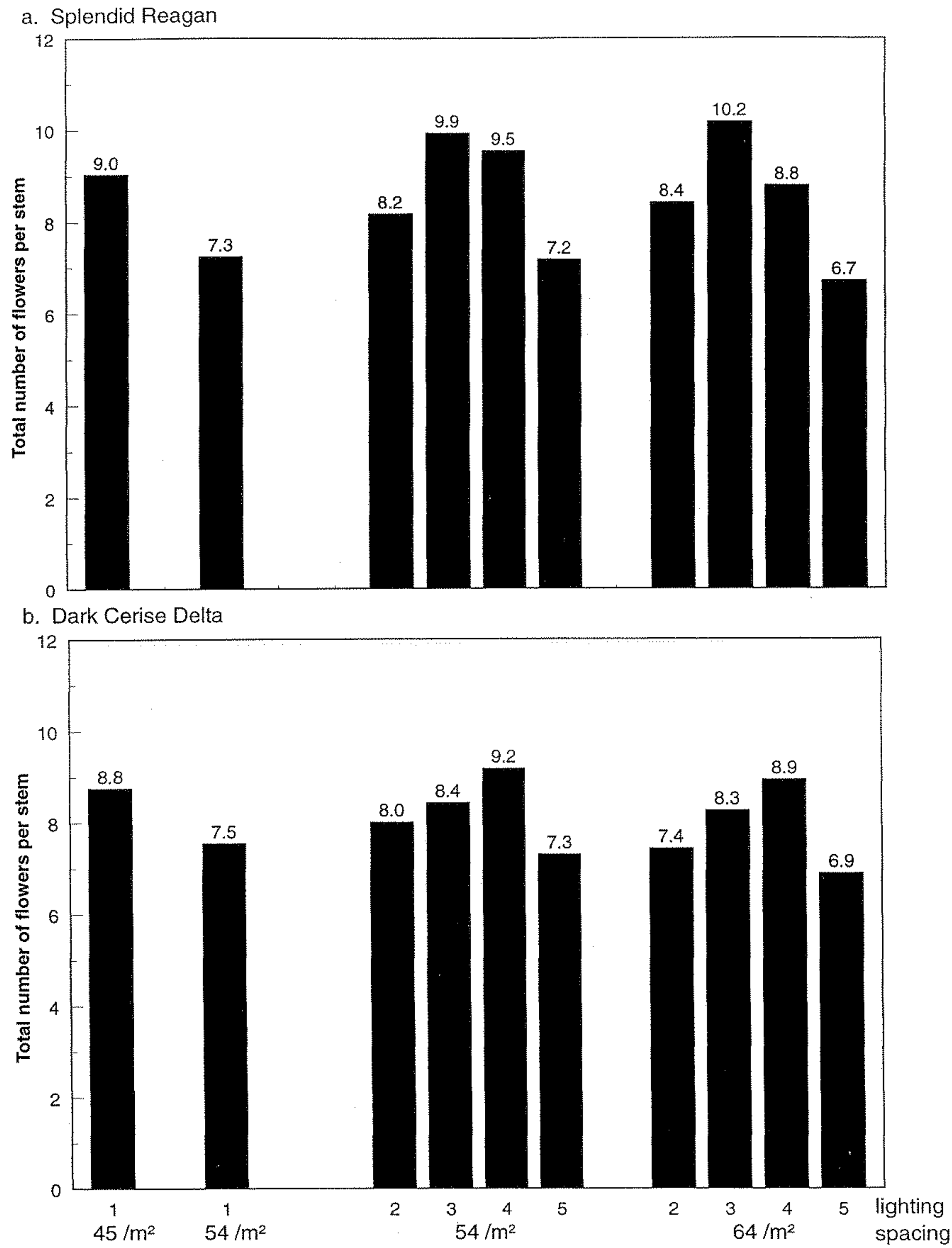
Figure 20. The Influence of Supplementary Lighting and Spacing on Flower Fresh Weight per stem - Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

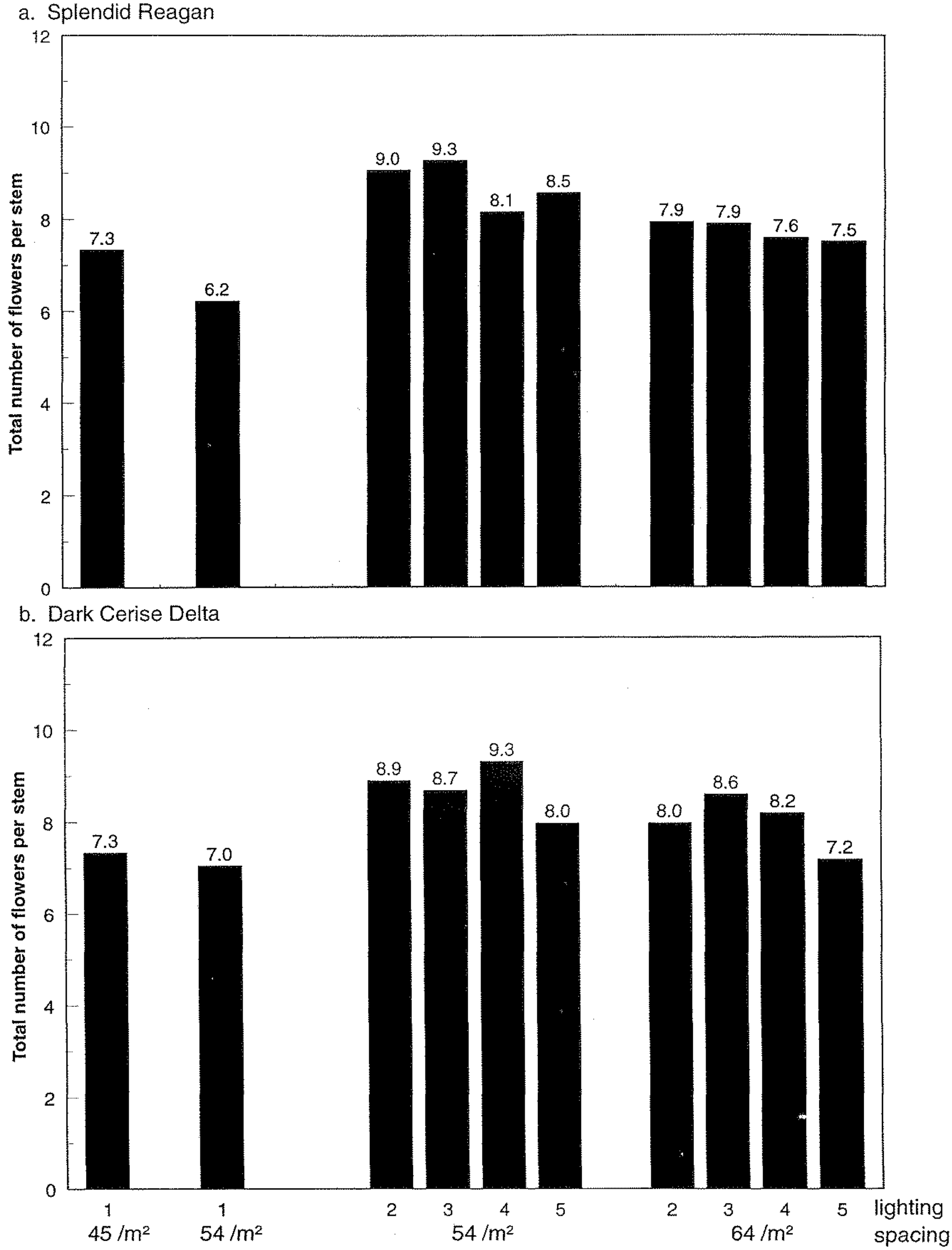
Figure 21. The Influence of Supplementary Lighting and Spacing on Flower number per stem - Week 40 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Figure 22. The Influence of Supplementary Lighting and Spacing on Flower number per stem - Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Table 7: **Effect of individual supplementary lighting treatments on number and fresh weight of flowers produced per stem**

Treatment	Week 40 Planting		Week 45 Planting	
	Number	Fresh weight (g)	Number	Fresh weight (g)
4.8 W/m² throughout	8.00	11.9	8.45	14.20
12 W/m² 36-70 SD	9.19	13.67	8.59	15.84
4.8 W/m² 36-70 SD	9.10	12.91	8.29	14.81
12 W/m² 47-60 SD	7.01	10.97	7.79	14.43
Significance	**	*NS*	*NS*	*NS*
SED (5 d.f.)	*0.528*	-	-	-
LSD (5%)	*1.36*	-	-	-

2.2 The Influence of Supplementary Lighting on Final Product

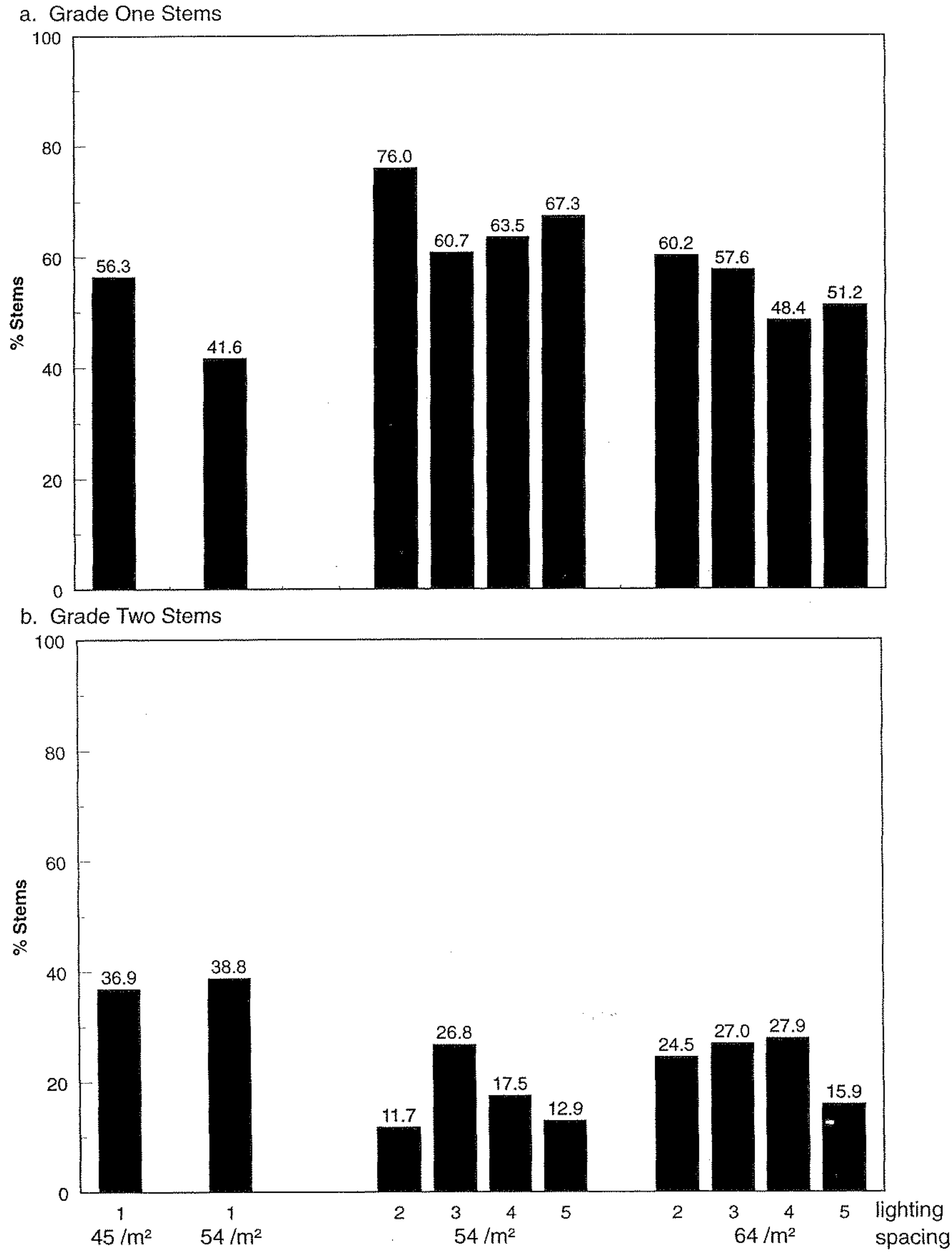
2.2.1 Speed of Production

The supplementary lighting treatments had a small impact on speed of production. Lighting at 12 W/m² 36-70 SD and 4.8 W/m² 36-70 SD were the fastest treatments in the week 40 planting reaching the stage of first harvesting 2-3 days faster than the remaining treatments. Lighting at 4.8 W/m² throughout production was no faster than no supplementary lighting for this first planting. For the week 45 planting however the treatments 4.8 W/m² throughout production, 12 W/m² 36-70 SD and 4.8 W/m² 36-70 SD were equal in speed of production and were 5 days faster than the no supplementary lighting and lighting at 12 W/m² 47-60 SD treatments.

2.2.2 Qualitative Grade Out

In accordance with results from year 1 of the trial, grade out was improved by supplementary lighting. In particular, trends in the treatment mean data indicate improvements in the number of grade one stems produced from both planting dates (figures 23 and 24, pages 58-61); with the best treatments (4.8 W/m² throughout production and 12 W/m² day 36-70SD) producing over 50% more grade one stems than the standard treatment (i.e. no supplementary lighting and 54 plants/m²).

Figure 23. The Influence of Supplementary Lighting and Spacing on Grade Out of Splendid Reagan - Week 40 Planting - 1995/96

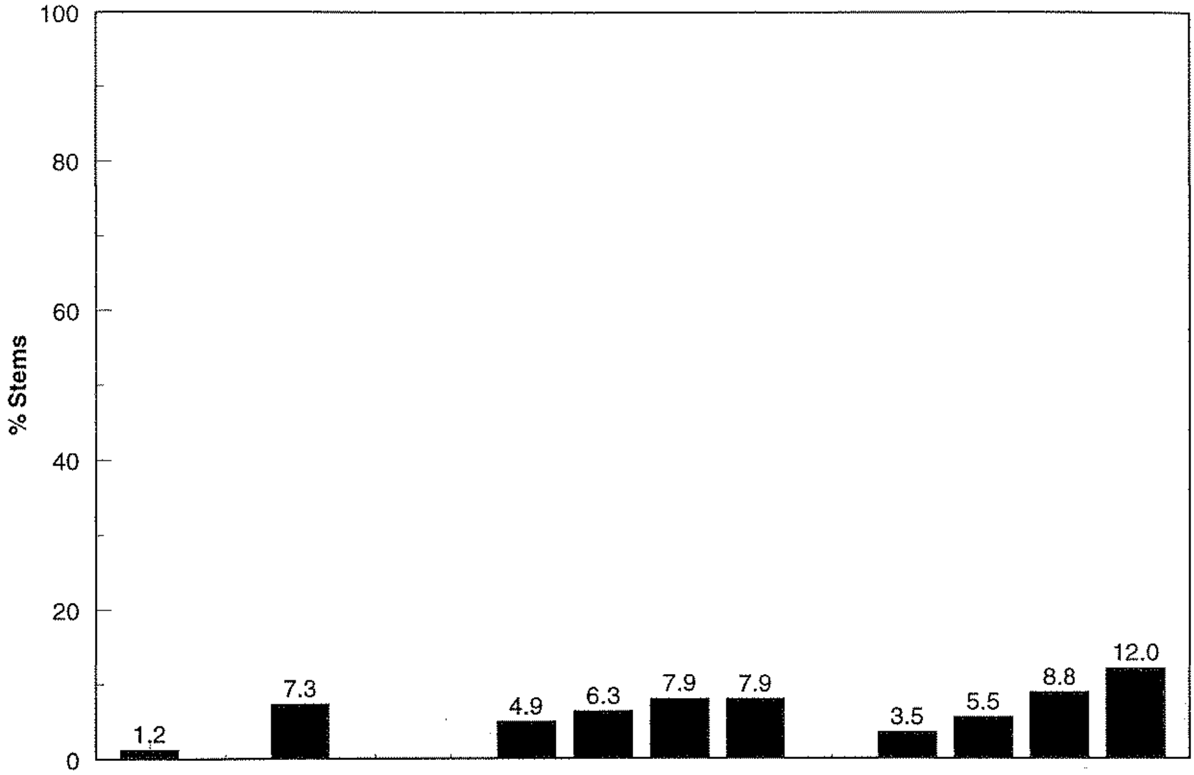


Lighting Treatments:

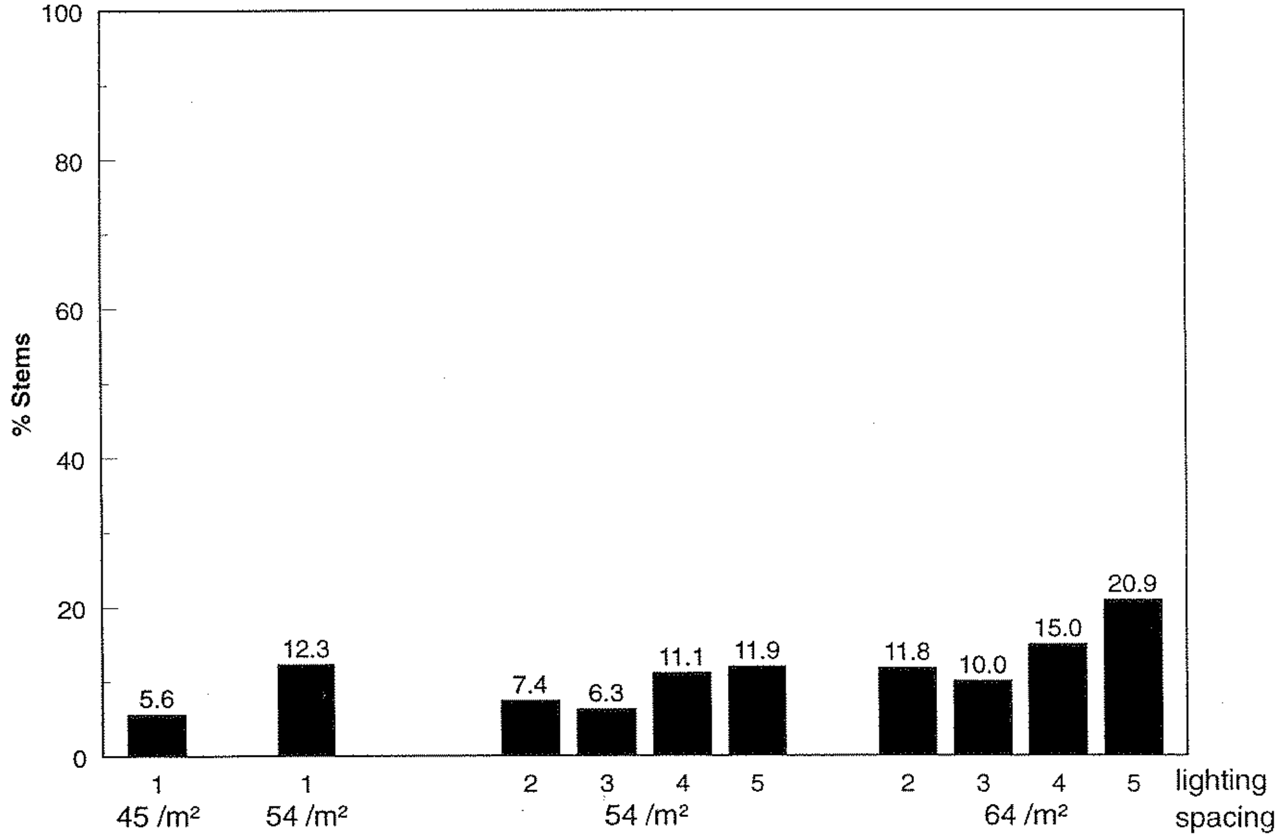
1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Figure 23. The Influence of Supplementary Lighting and Spacing on Grade Out of Splendid Reagan - Week 40 Planting - 1995/96

c. Grade Three Stems



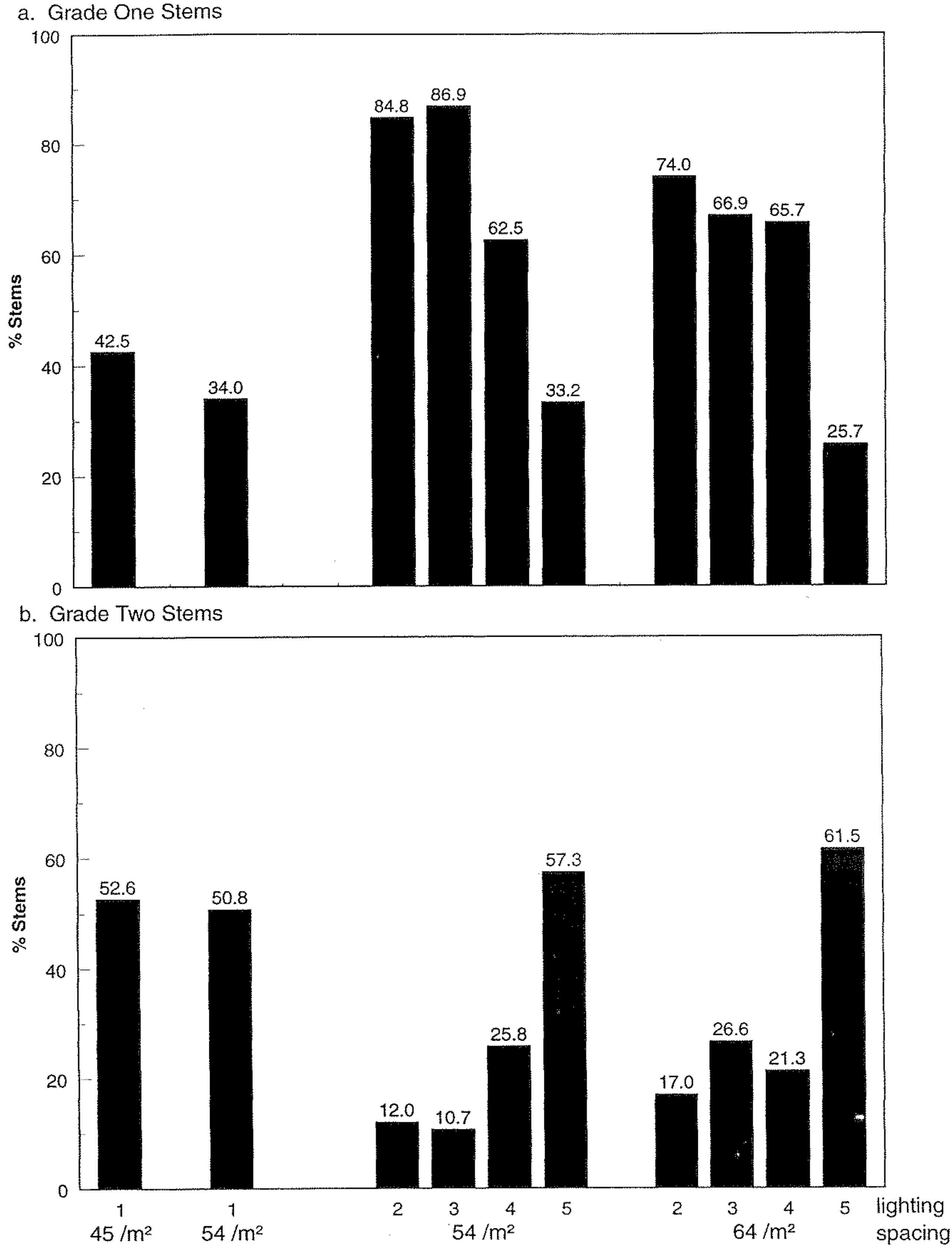
d. Waste Stems



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

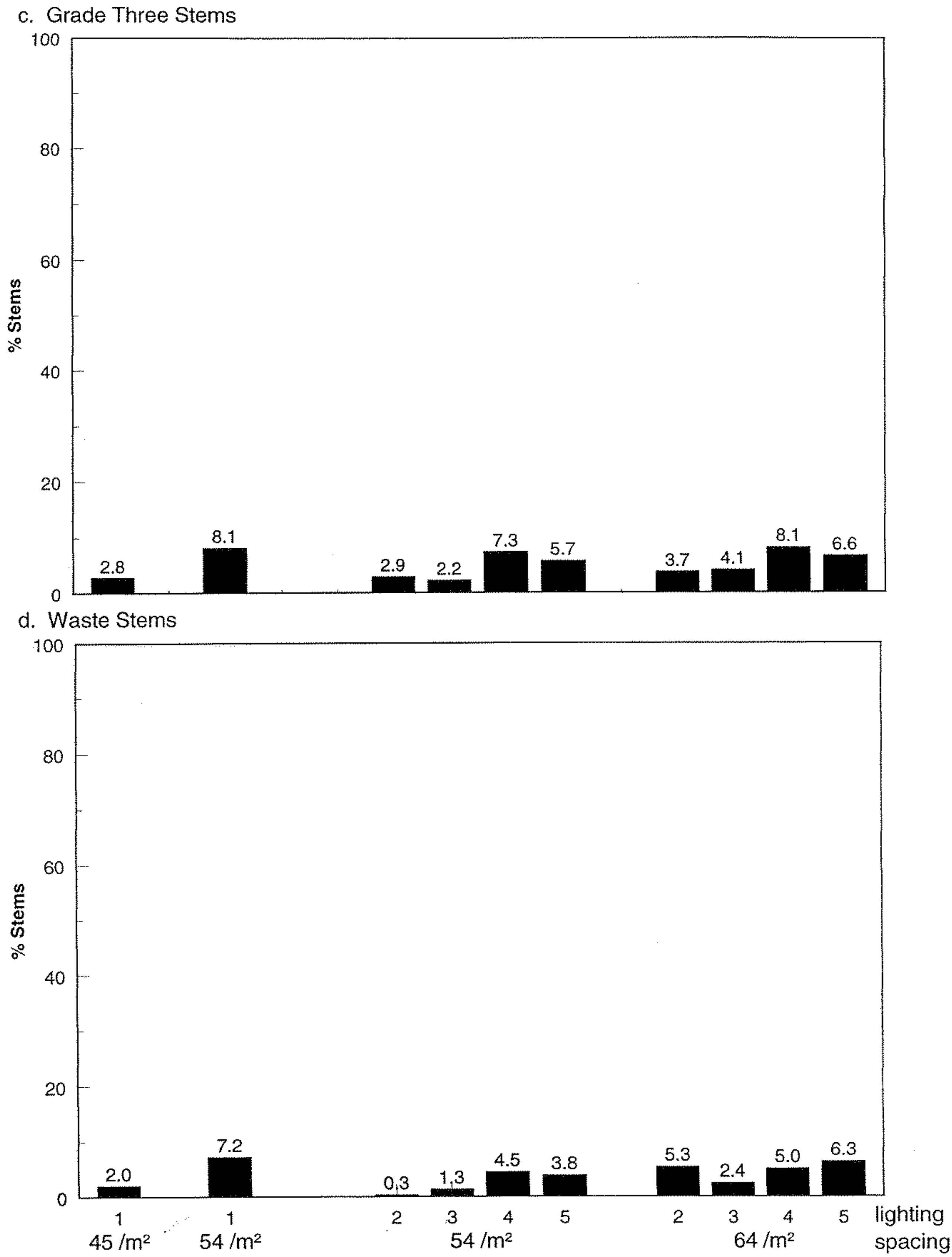
Figure 24. The Influence of Supplementary Lighting and Spacing on Grade Out of Splendid Reagan - Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m² throughout production
3 = 12 W/m² 36-70 SD
4 = 4.8 W/m² 36-70 SD
5 = 12 W/m² 47-60 SD

Figure 24. The Influence of Supplementary Lighting and Spacing on Grade Out of Splendid Reagan - Week 45 Planting - 1995/96



Lighting Treatments:

1 = No Supplementary Lighting
2 = 4.8 W/m^2 throughout production
3 = 12 W/m^2 36-70 SD
4 = 4.8 W/m^2 36-70 SD
5 = 12 W/m^2 47-60 SD

Statistical analysis indicates a significant increase in percentage grade one stems from the week 45 planting, and a similar trend from the week 40 planting (Table 8). This table also indicates that these improvements in grade one stems for the mean of the supplementary lighting treatments generally lead to a significant decrease in grade two stems and no significant difference in grade three or waste stems (Table 8).

Table 8: Effect of supplementary lighting on proportion of stems per grade category

Treatment	Grade 1 % stems	Grade 2 % stems	Grade 3 % stems	Waste % stems
Week 40 planting				
No Supplementary Lighting	49.0	37.8	4.2	9.0
With Supplementary Lighting	60.5	20.6	7.1	11.8
Significance	*NS*	**	*NS*	*NS*
SED (5 d.f.)	-	*4.28*	-	-
LSD (5%)	-	*11.0*	-	-
Week 45 planting				
No Supplementary Lighting	38.3	51.7	5.4	4.6
With Supplementary Lighting	62.5	29.0	5.0	3.5
Significance	*	*	*NS*	*NS*
SED (5 d.f.)	*10.1*	*7.5*	-	-
LSD (5%)	*26.0*	*19.2*	-	-

The pattern in changes in grade out for the individual lighting treatments (Table 9) were however different to the data meaned across these treatments described above (Table 8). The treatments 4.8 W/m² throughout SD, 12 W/m² day 36-70 SD and 4.8 W/m² day 36-70 SD produced the highest proportion of grade one stems, with figures ranging from 63 to 87% grade one stems from the 54 plants/m² spacing and 48 to 74% grade one stems from the 64 plants/m² spacing. Furthermore the treatments 4.8 W/m² throughout production and 12 W/m² day 36-70 SD had lower percentage grade three and waste stems than the remaining lighting treatments. This may be observed in the trends of individual treatment means (figures 23 and 24, pages 58-61) and in the statistical comparisons meaned across spacing treatments (Table 9) although there were few statistically significant effects.

Lighting at 12 W/m² day 47-60 SD was less effective at improving quality, particularly for the week 45 planting, with 33% grade one stems at 54 plants/m² spacing and 26% grade one stems at 64 plants/m² spacing.

Table 9: **Effect of individual supplementary lighting treatments on proportion of stems per grade category**

Treatment	Grade 1 % stems	Grade 2 % stems	Grade 3 % stems	Waste % stems
Week 40 planting				
4.8 W/m² throughout	68.2	18.1	4.2	9.5
12 W/m² 36-70	59.1	26.9	5.9	8.1
4.8 W/m² 36-70	55.6	23.0	8.3	13.1
12 W/m² 47-60	59.2	14.4	10.0	16.4
Significance	*NS*	*NS*	*NS*	*NS*
SED (5 d.f.)	-	-	-	-
LSD (5%)	-	-	-	-
Week 45 planting				
4.8 W/m² throughout	79.4	14.5	3.3	2.8
12 W/m² 36-70	76.9	18.6	3.1	1.4
4.8 W/m² 36-70	64.1	23.5	7.7	4.7
12 W/m² 47-60	29.4	59.4	6.1	5.1
Significance	*	*	*NS*	*NS*
SED (5 d.f.)	*12.8*	*9.5*	-	-
LSD (5%)	*32.9*	*24.3*	-	-

Closer spacing at 64 plants/m^2 for plants receiving supplementary lighting rather than the standard winter spacing of 54 plants/m^2 did not produce any statistically significant effects on grade out. Trends in individual treatment means (figures 23 and 24, pages 58-61) indicate that closer spacing reduced the percentage of grade one stems and increased the percentage of grade three and waste stems produced. There are few significant differences between means across varieties used for statistical comparison (Table 10), but a similar pattern is evident in these data. Despite this apparent decline in grade out as a result of closer spacing, lit treatments at the closest plant spacing were generally better than standard spacing without supplementary lighting both in terms of higher percentages of grade one stems and lower percentages of grade three and waste stems.

Table 10: **Effect of spacing on percentage stems produced per grade category by individual supplementary lighting treatments**

Treatment	Spacing (stems/m²)	Grade 1 % stems	Grade 2 % stems	Grade 3 % stems	Waste % stems
Week 40 planting					
4.8 W/m² throughout	**54**	76.0	11.7	4.9	7.4
	64	60.3	24.5	3.5	11.7
12 W/m² 36-70 SD	**54**	60.5	26.9	6.3	6.3
	64	57.6	26.9	5.5	10.0
4.8 W/m² 36-70 SD	**54**	59.7	16.5	7.4	16.4
	64	51.5	29.4	9.2	9.9
12 W/m² 36-70 SD	**54**	67.3	12.9	7.9	11.9
	64	51.2	15.9	12.0	20.9
Significance		*NS*	*NS*	*NS*	*NS*
SED (5 d.f.)		-	-	-	-
LSD (5 %)		-	-	-	-
Week 45 planting					
4.8 W/m² throughout	**54**	84.8	12.0	2.9	0.3
	64	74.0	16.9	3.7	5.4
12 W/m² 36-70 SD	**54**	86.9	10.7	2.1	0.3
	64	66.9	26.6	4.1	2.4
4.8 W/m² 36-70 SD	**54**	62.5	25.8	7.3	4.4
	64	65.7	21.2	8.0	5.1
12 W/m² 36-70 SD	**54**	33.2	57.4	5.7	3.7
	64	25.7	61.5	6.6	6.2
Significance		*NS*	*NS*	*NS*	*NS*
SED (5 d.f.)		-	-	-	-
LSD (5 %)		-	-	-	-

Where plants were grown without supplementary lighting, trends in treatment mean data (figures 23 and 24, pages 58-61) indicated that wider spacing improved grade out. The proportion of grade one stems produced increased by 9-15% through decreasing spacing from 54 plants/m^2 to 45 plants/m^2, whilst the proportion of waste stems decreased by 5-7% as a result of this wider spacing. Statistical analyses found a significant decrease in grade three stems from wider spacing for stems planted in week 40 and also a significant decrease in waste stems resulting from wider spacing for stems planted in week 45 (Table 11).

Table 11: Effect of wider spacing on percentage stems per grade category for plants grown without supplementary lighting

Treatment	Grade 1 % stems	Grade 2 % stems	Grade 3 % stems	Waste % stems
Week 40 planting				
45 plants/m²	56.3	36.9	1.2	5.6
54 plants/m²	41.6	38.8	7.3	12.3
Significance	*NS*	*NS*	*	*NS*
SED (5 d.f.)	-	-	*1.791*	-
LSD (5%)	-	-	*4.60*	-
Week 45 planting:				
45 plants/m²	42.5	52.6	2.8	2.1
54 plants/m²	34.0	50.7	8.1	7.2
Significance	*NS*	*NS*	*NS*	*
SED (5 d.f.)	-	-	-	*2.092*
LSD (5%)	-	-	-	*5.38*

2.2.3 Grade Out By Wrap Weight

Improvements in final grade out through the use of supplementary lighting may be further illustrated by assessment of the weight of wraps grouped into key categories. As described previously, current specifications from multiple outlets require wraps in the region of 275g or above. Wraps over 375g represents the top specification on the Dutch Auctions although the category of 325-375g is also distinguished above the 275g+ class.

Supplementary lighting treatments clearly improved the proportion of wraps weighing 275g and over (representing stems likely to be acceptable through the multiples), in comparison with standard spacing and no supplementary lighting (i.e. the current 'standard' for UK winter production, figures 25 and 26, pages 71 and 72). The impact of lighting on the proportion of wraps weighing more than 275g depended on treatment and planting date. The standard treatment of no supplementary lighting and 54 plants/m^2 produced 73% wraps of 275g or over from planting in week 40, but only 50% wraps from planting in week 45. Fewer treatments therefore improved on this standard production planted in week 40. Lighting at 4.8 W/m^2 and spacing at 54 plants/m^2 produced an extra 34% wraps in this weight grade compared with standard production. This was reduced to 20% extra wraps at the closer spacing of 64 plants/m^2, but this treatment had the further advantage of increasing productivity by 10% (i.e. through producing a higher number of stems/m^2) on top of the improvements in wrap weight described. Lighting at 12 W/m^2 day 36-70 SD at 54 plants/m^2 produced 31% more wraps than the standard treatment for the week 40 planting date but there was no improvement at the closer spacing of 64 plants/m^2.

In contrast, all lighting treatments at 54 plants/m^2 spacing planted in week 45 increased the percentage of stems above 275g in weight above that from the standard treatment receiving no supplementary lighting. Increases ranged from 14 to 34% across the four lighting treatments at 54 plants/m^2 spacing, with the highest proportions resulting from lighting at 4.8 W/m^2 throughout production and 12 W/m^2 day 36-70 SD. Furthermore, at 64 plants/m^2 spacing, these two treatments were the only ones to improve the percentage of stems of 275g+ in weight, with an increase of 20% over standard production by lighting at 4.8 W/m^2 throughout production and 5% at 12W/m^2 day 36-70 SD.

There is therefore potential to improve qualitative grade out results and the percentage of stems of a suitable weight to sell to multiple outlets through the use of supplementary lighting. It is also possible with some lighting treatments to offset some of the costs of lighting by increasing the throughput of stems using closer spacings without reducing quality below that currently produced in the winter by 'standard' UK practice. The improvements in visual quality through darker leaf and flower colour would also be expected to improve market prices realised.

Improvements were also achieved without supplementary lighting through wider spacing (45 plants/m^2) than the current standard in winter (54 plants/m^2). Again the impact of wider spacing was greater from the week 45 planting when solar radiation levels began to decline with for example 24% more stems weighing 275g or above, than from the week 40 planting with only a 17% increase in the percentage of stems of this weight.

2.3 The Influence of Supplementary Lighting and Spacing on Leaf Mineral Status

In accordance with year one results, there were no obvious treatment effects on leaf mineral status (Tables 2 and 3, Appendix I, pages 89-92). Mineral levels were generally within the satisfactory ranges required. Percentage nitrogen levels overall were at the bottom end or even below the range expected (i.e. 4.1-5.5% in winter) and potassium levels by comparison were high.

2.4 The Impact of Supplementary Lighting on Total Light Receipt

The daily PAR light levels received by each treatment were most strongly influenced by solar radiation levels, even where the highest intensity treatments were being given (figures 27 and 28, pages 73 and 74). Daily MJ/m^2 levels steadily declined during the long day and initial short day period following planting in week 40 and remained below 2 MJ/m^2 from the end of interruption until final harvest.

Light levels remained low for the majority of the production period following planting in week 45 and only began to improve towards the end of production.

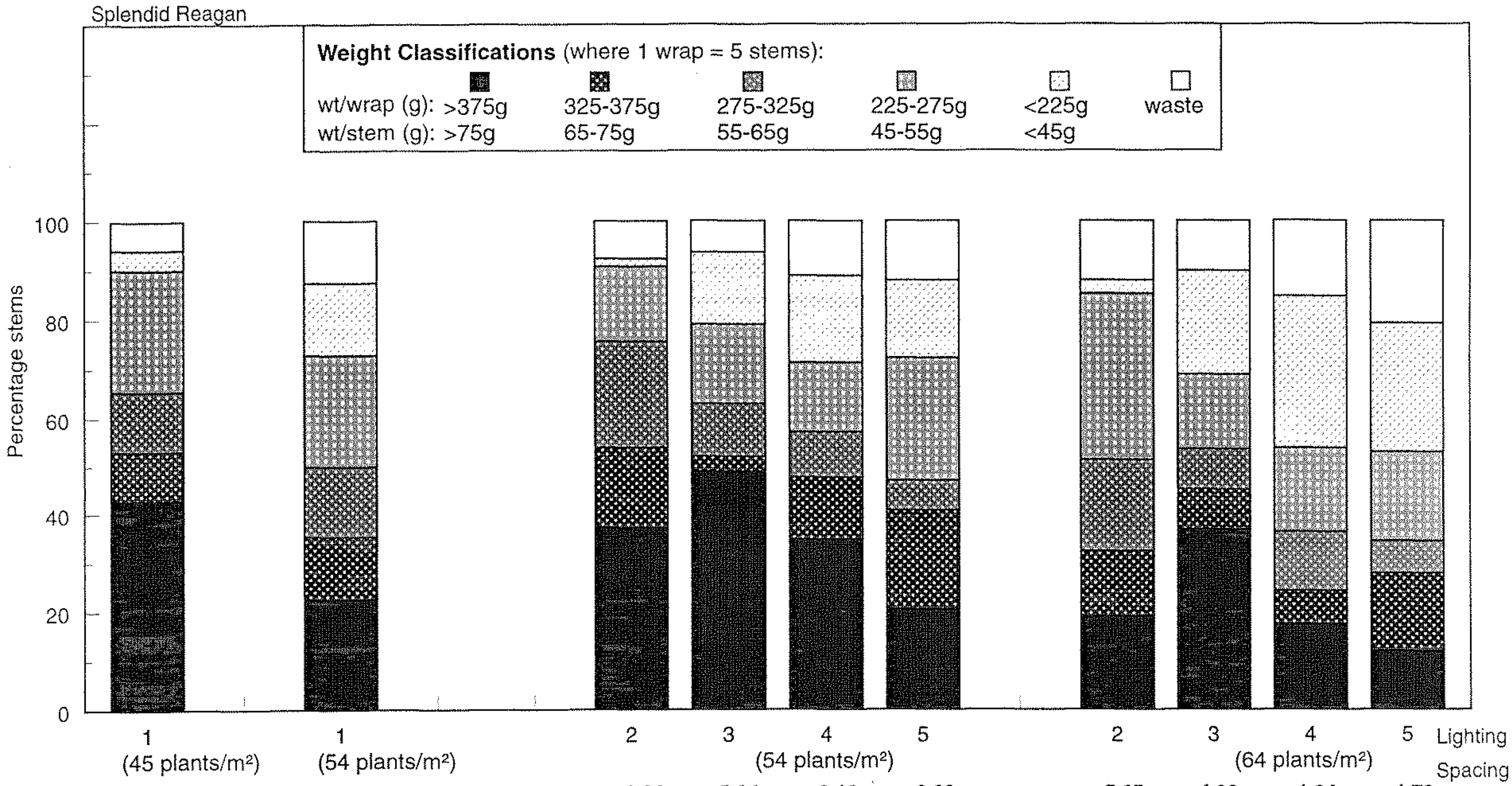
2.5 The Influence of Supplementary Lighting and Spacing on Post-harvest Longevity

There were no statistically significant differences between treatments in terms of vase life of stems. There was also no evidence of trends in the mean data (Table 12) to suggest lighting or spacing effected post-harvest longevity.

Table 12: **The effect of supplementary lighting and spacing on post-harvest longevity**

Lighting	Spacing (plants/m²)	Length of time to deterioration Spendid Reagan (days)	 Dark Cerise Delta (days)
a. Week 40 planting			
No Supplementary Lighting	45	18.9	18.3
	54	21.7	13.7
4.8 W/m² throughout SD	54	16.8	14.0
	64	17.9	15.4
12 W/m² 36-70 SD	54	14.1	10.0
	64	23.6	17.1
4.8 W/m² 36-70 SD	54	19.6	12.0
	64	19.4	10.0
12 W/m² 47-60 SD	54	19.6	13.8
	64	22.7	15.6
b. Week 45 planting			
No Supplementary Lighting	45	22.1	10.4
	54	23.9	13.9
4.8 W/m² throughout SD	54	25.6	9.8
	64	23.4	11.6
12 W/m² 36-70 SD	54	22.0	9.9
	64	27.6	16.3
4.8 W/m² 36-70 SD	54	28.6	11.0
	64	29.1	11.5
12 W/m² 47-60 SD	54	23.7	9.9
	64	20.3	10.9

Figure 25. Summary of the Influence of Supplementary Lighting and Spacing on Weight Grading - Week 40 Planting - 1995/96 (stems cut to 70 cm length for sleeving)

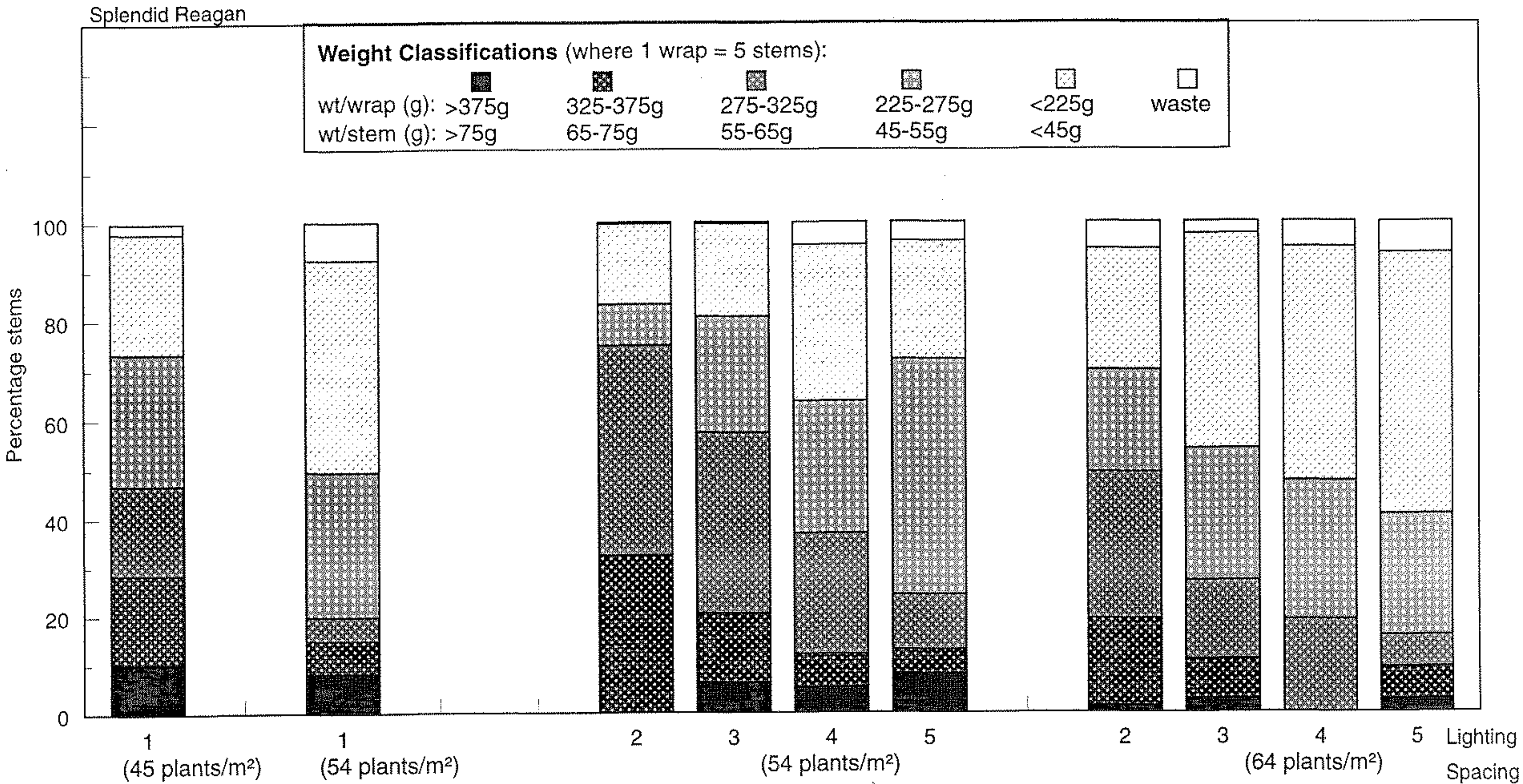


*Lighting cost per stem planted:	6.64	5.04	2.16	2.02	5.65	4.29	1.84	1.72
Lighting cost per stem marketed:	7.18	5.38	2.43	2.29	6.42	4.77	2.17	2.17

KEY TO LIGHTING TREATMENTS:
1 = No supplementary lighting 2 = 4.8 W/m² throughout SD
3 = 12 W/m² day 36-70 SD only 4 = 4.8 W/m² day 36-70 SD only
5 = 12 W/m² day 47-60 SD only

Refer to page 75 for further details of costings calculated

Figure 26. Summary of the Influence of Supplementary Lighting and Spacing on Weight Grading - Week 45 Planting - 1995/96 (stems cut to 70 cm length for sleeving)



*Lighting cost per stem planted:	6.64	5.04	2.16	2.02	5.65	4.29	1.84	1.72
Lighting cost per stem marketed:	6.66	5.06	2.26	2.10	5.98	4.40	1.94	1.84

KEY TO LIGHTING TREATMENTS:
1 = No supplementary lighting 2 = 4.8 W/m² throughout SD
3 = 12 W/m² day 36-70 SD only 4 = 4.8 W/m² day 36-70 SD only
5 = 12 W/m² day 47-60 SD only

Refer to page 75 for further details of costings calculated

Figure 27. PAR light levels received per treatment corrected for transmission and additional light supplied by luminaires
Week 40 Planting - 1995/96

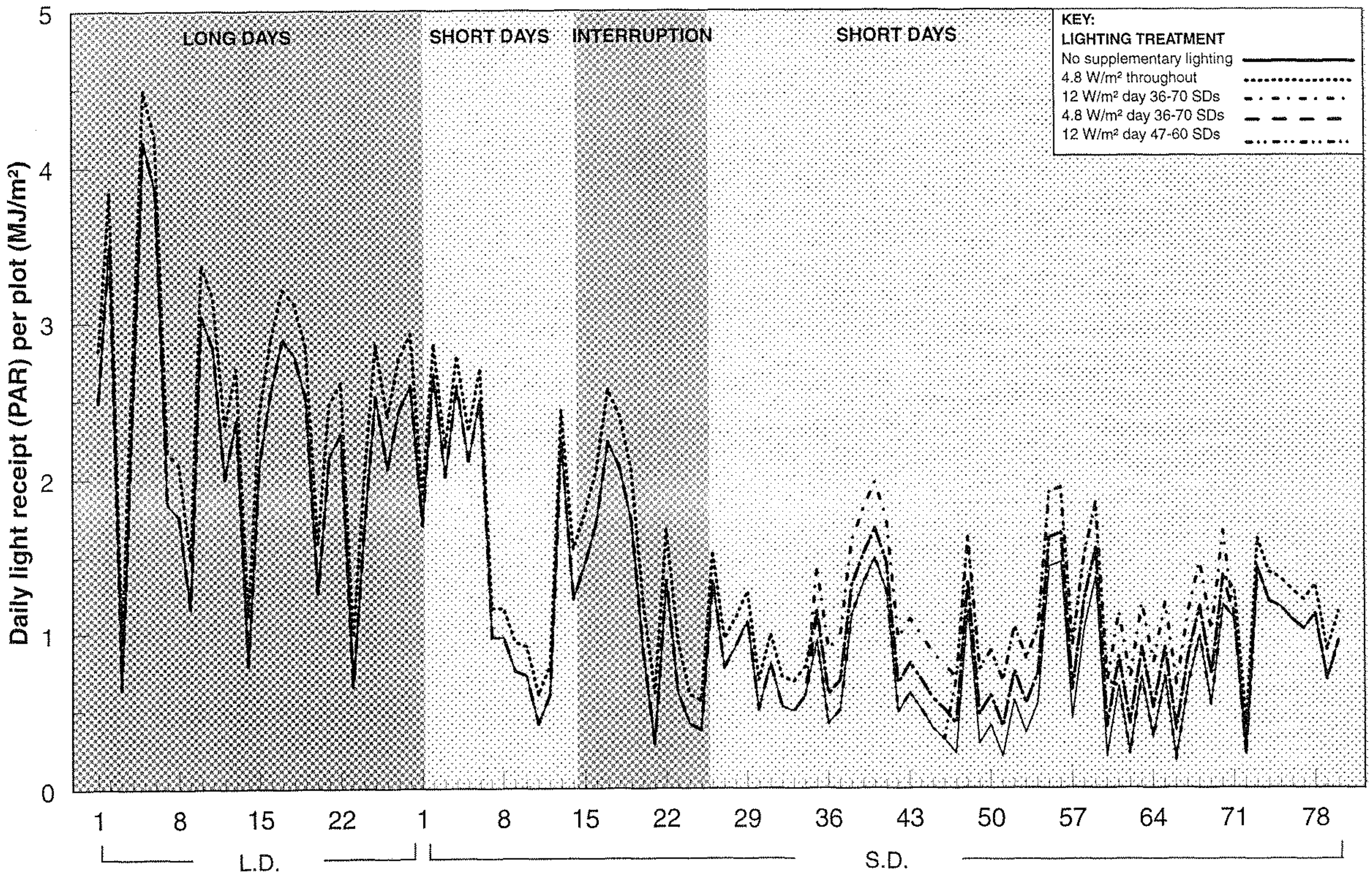
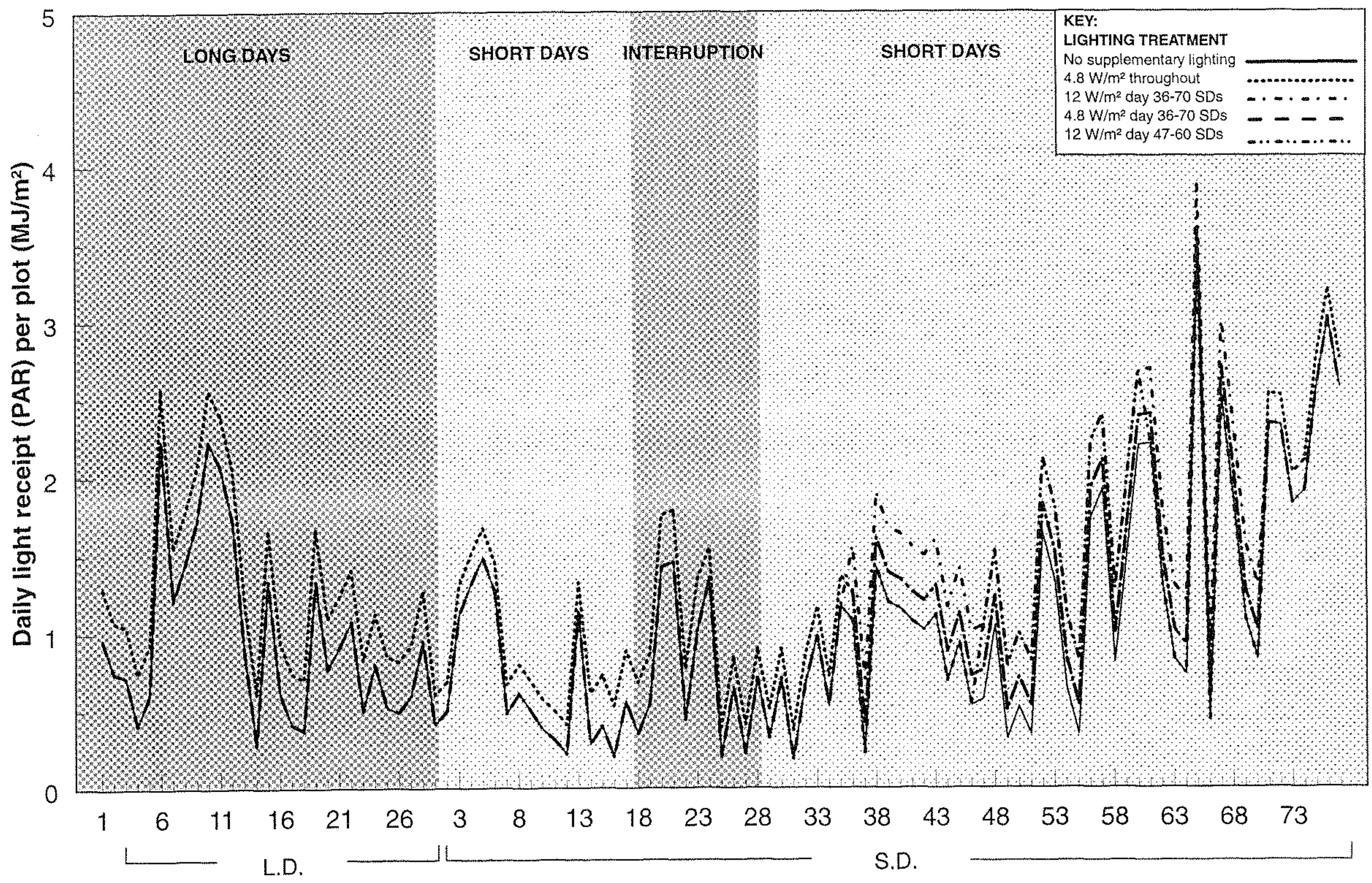


Figure 28. PAR light levels received per treatment corrected for transmission and additional light supplied by luminaires Week 45 Planting - 1995/96



COSTINGS

To assist in assessing the practicality of using the supplementary lighting regimes assessed in the trial, figures were calculated to assess the cost of supplying the treatments (both in terms of the capital required for the lamp units themselves, and the electricity required to run them). The method used to calculate the cost of lighting was drawn from that previously used in work on pot chrysanthemums (e.g. Finlay, 1993). The full calculations used are given in Appendix II (page 94). These figures are based on average figures estimated for electricity supply etc. which will vary according to individual nurseries. It is therefore recommended that individual growers put their own figures (e.g. electricity charges relevant to their own nursery, prices quoted for the supply of lamps etc) into these calculations to arrive at a more accurate figure for their own circumstances. The figures calculated within this report however can be used to compare the benefits of individual treatments with each other since they are all based on the same set of assumptions.

The costs for supplying the lighting only for each of the individual lighting treatments assessed are summarised in Table 13. These figures represent the extra cost required to produce each stem under the different supplementary lighting regimes assessed. Since there is generally a proportion of stems at final harvest which are not marketable, a set of figures have also been calculated to represent the cost required per stem harvested to recover the price of the treatment supplied (since it is obviously not possible to recover such costs on waste stems).

Please note that where lighting is given for only part of the production period, two figures have been calculated. The first assumes luminaires are fixed so only running costs are saved where lighting is not given for the whole production period. The second assumes luminaires are mounted on mobile systems and hence capital costs may be spread over more stems on an annual basis. The calculations do not however include a figure for setting up lamps on a mobile system since this is not currently common practice and hence estimating a figure for these costs may be misleading.

Table 13a: Summary of the costs of providing lighting for each of the treatments assessed

Year One Treatments		Cost of Providing Lighting (p/stem)		
		p/stem planted	p/stem harvested Splendid Reagan	p/stem harvested Dark Cerise Delta
4.8 W/m² throughout production:				
54 plants/m²	fixed	6.64	7.11	6.79
64 plants/m²	fixed	5.65	6.72	6.21
12 W/m² day 1-28 LD:				
54 plants/m²	fixed	9.31	12.75	4.92
	mobile	5.36	7.34	8.59
64 plants/m²	fixed	7.91	11.48	12.90
	mobile	4.56	6.62	7.44
12 W/m² day 1-35:				
54 plants/m²	fixed	8.55	9.84	10.89
	mobile	5.04	5.80	6.42
64 plants/m²	fixed	7.67	9.49	10.93
	mobile	4.69	5.80	6.68
12 W/m² day 36-70 SD:				
54 plants/m²	fixed	8.55	8.86	18.84
	mobile	5.04	5.22	5.21
64 plants/m²	fixed	7.27	8.11	7.98
	mobile	4.29	4.76	4.71

Table 13b: Summary of the costs of providing lighting for each of the treatments assessed

Year Two Treatments		Cost of Providing Lighting (p/stem)		
		p/stem planted	p/stem harvested planting 1	p/stem harvested planting 2
4.8 W/m² throughout production:				
54 plants/m²	fixed	6.64	7.18	6.66
64 plants/m²	fixed	5.65	6.42	5.98
12 W/m² day 36-70 SD:				
54 plants/m²	fixed	8.55	9.13	8.58
	mobile	5.04	5.38	5.06
64 plants/m²	fixed	7.27	8.09	7.45
	mobile	4.29	4.77	4.40
4.8 W/m² day 36-70 SD:				
54 plants/m²	fixed	3.66	4.12	3.84
	mobile	2.16	2.43	2.26
64 plants/m²	fixed	3.12	3.68	3.29
	mobile	1.84	2.17	1.94
12 W/m² day 47-60 SD:				
54 plants/m²	fixed	6.84	7.77	7.11
	mobile	2.02	2.29	2.10
64 plants/m²	fixed	5.81	7.32	6.20
	mobile	1.72	2.17	1.84

To further analyse costings, a 'cost-benefit' analysis was carried out on the year two treatments (i.e. the treatments which showed the greatest potential for improving quality). This analysis calculated the returns on the treatment representing current standard winter production (i.e. no supplementary lighting and 54 plants/m^2 spacing) as a baseline figure (with a standard set of figures for a block rooted plant and returns per stem within each grade category).

The returns of all treatments were calculated after subtracting the cost of supplying lighting as appropriate and measured against this baseline to indicate the increase in returns required above that of standard production to break even on supplying the supplementary lighting (or using wider spacing and hence reducing productivity). The summary of these calculations is presented in Table 14 which includes a ranking of treatments from lowest (ranked as 1) to highest (ranked as 10) cost; full calculations are presented in Appendix II (page 117).

The increase in cost per wrap of 5 stems over standard commercial production varied with planting date. Due to the higher quality achieved with the standard treatment planted in week 40 (when solar radiation levels were more favourable), the increase in returns required to offset the cost of supplying supplementary lighting were generally greater. This may be demonstrated by the treatment 4.8 W/m^2 day 36-70 SD for which an increase in 2.99 - 6.57 p per wrap (assuming mobile lighting) would be necessary to cover the lighting costs for planting in week 40. For planting in week 45 however, this treatment actually produced an improved return in comparison with standard lighting (despite the need to cover the cost of supplying the lighting) for the 64 plants/m^2 spacing. For a year round programme it may be expected therefore that the returns required per wrap would be more accurately calculated from an average of successive sticking dates throughout the period over which lighting would be utilised (i.e. October - March).

The assumption that mobile lighting may be used also had a large impact on the increase in returns necessary to offset lighting costs (due to the larger capital outlay required). One lighting treatment which is low in the ranking of all comparisons made in Table 14 is lighting at 4.8 W/m^2 day 36-70 SD. The ranking of the standard Dutch treatment of 4.8 W/m^2 throughout production is clearly affected by whether or not a mobile lighting system is assumed for those treatments lit for short periods of production. That is, it is the most expensive treatment if mobile lighting can be assumed but more favourable if mobile lighting cannot be assumed.

It should be noted that these cost benefit figures are based on the 'qualitative' grade out results (i.e. grading on number of open flowers plus buds with potential to open). These figures therefore do not take into account the benefits demonstrated such as improved wrap weights, improvements in visual quality (namely improved petal and foliage colour), and increases in flower numbers per stem above the number required to meet the grade one standard. These improvements in quality should assist in obtaining premium prices for stems treated with supplementary lighting. It is also not possible to put a value on the ability to continue to compete in the winter market with product grown under naturally high light levels in southern climates.

Table 14a: Summary of cost-benefit analysis of treatments

Assuming lighting is mobile where appropriate

Planting 1 (Flower week 2)			Increased price, pence per stem all grades to match £5.58/m²	Increased price per wrap	Rank	Increased price, pence per stem gr.1 only to match £5.58/m²	Increased price per wrap gr.1 only	Rank
Treatment								
1	45/m²	no supplementary lighting	0.12	0.59	2	0.20	0.99	2
1	54/m²	no supplementary lighting	0.00	0.00	1	0.00	0.00	1
2	54/m²	4.8 W/m² throughout	4.70	23.48	10	5.72	28.60	10
3	54/m²	12 W/m² days 36-70 SD	3.47	17.34	8	5.36	26.78	9
4	54/m²	4.8 W/m² 36-70 SD	1.28	6.40	5	1.79	8.96	5
5	54/m²	12 W/m² 47-60 SD	1.09	5.47	4	1.43	7.17	4
2	64/m²	4.8 W/m² throughout	3.48	17.39	9	5.10	25.48	8
3	64/m²	12 W/m² days 36-70 SD	1.80	9.01	6	2.82	14.10	6
4	64/m²	4.8 W/m² 36-70 SD	0.65	3.25	3	1.14	5.72	3
5	64/m²	12 W/m² 47-60 SD	1.84	9.21	7	2.84	14.22	7

Table 14a (cont.): Summary of cost-benefit analysis of treatments

Assuming lighting is mobile where appropriate

Planting 2 (Flower week 8)			Increased price, pence per stem all grades to match £5.84/m²	Increased price per wrap	Rank	Increased price, pence per stem gr.1 only to match £5.84/m²	Increased price per wrap gr.1 only	Rank
Treatment								
1	45/m²	no supplementary lighting	0.25	1.25	3	0.57	2.87	4
1	54/m²	no supplementary lighting	0.00	0.00	2	0.00	0.00	2
2	54/m²	4.8 W/m² throughout	3.23	16.13	10	3.79	18.95	9
3	54/m²	12 W/m² days 36-70 SD	1.48	7.41	8	1.70	8.51	7
4	54/m²	4.8 W/m² 36-70 SD	0.58	2.91	6	0.89	4.45	6
5	54/m²	12 W/m² 47-60 SD	1.43	7.14	7	4.14	20.72	10
2	64/m²	4.8 W/m² throughout	2.01	10.03	9	2.57	12.83	8
3	64/m²	12 W/m² days 36-70 SD	0.36	1.82	5	0.53	2.66	3
4	64/m²	4.8 W/m² 36-70 SD	-1.43	-7.16	1	-2.07	-10.37	1
5	64/m²	12 W/m² 47-60 SD	0.23	1.15	4	0.84	4.20	5

Table 14b: **Summary of cost-benefit analysis of treatments**

Assuming fixed lighting throughout

Planting 1 (Flower week 2)			Increased price, pence per stem all grades to match £5.58/m^2	Increased price per wrap	Rank	Increased price, pence per stem gr.1 only to match £5.58/m^2	Increased price per wrap gr.1 only	Rank
Treatment								
1	45/m^2	no supplementary lighting	0.12	0.59	2	0.20	0.99	2
1	54/m^2	no supplementary lighting	0.00	0.00	1	0.00	0.00	1
2	54/m^2	4.8 W/m^2 throughout	4.70	23.48	6	5.72	28.60	6
3	54/m^2	12 W/m^2 days 36-70 SD	7.21	36.05	10	11.14	55.69	10
4	54/m^2	4.8 W/m^2 36-70 SD	2.97	14.87	4	4.16	20.82	4
5	54/m^2	12 W/m^2 47-60 SD	6.56	32.80	8	8.59	42.95	8
2	64/m^2	4.8 W/m^2 throughout	3.48	17.38	5	5.10	25.48	5
3	64/m^2	12 W/m^2 days 36-70 SD	5.12	25.60	7	8.01	40.03	7
4	64/m^2	4.8 W/m^2 36-70 SD	2.16	10.78	3	3.79	18.96	3
5	64/m^2	12 W/m^2 47-60 SD	7.02	35.10	9	10.83	54.17	9

Table 14b (cont.): **Summary of cost-benefit analysis of treatments**

Assuming fixed lighting throughout

Planting 2 (Flower week 8)			Increased price, pence per stem all grades to match £5.84/m²	Increased price per wrap	Rank	Increased price, pence per stem gr.1 only to match £5.84/m²	Increased price per wrap gr.1 only	Rank
Treatment								
1	45/m²	no supplementary lighting	0.25	1.25	3	0.57	2.87	3
1	54/m²	no supplementary lighting	0.00	0.00	2	0.00	0.00	2
2	54/m²	4.8 W/m² throughout	3.23	16.13	6	3.79	18.95	6
3	54/m²	12 W/m² days 36-70 SD	5.00	25.01	9	5.74	28.70	8
4	54/m²	4.8 W/m² 36-70 SD	2.16	10.80	5	3.30	16.50	5
5	54/m²	12 W/m² 47-60 SD	6.43	32.17	10	18.66	93.31	10
2	64/m²	4.8 W/m² throughout	2.01	10.03	4	2.57	12.83	4
3	64/m²	12 W/m² days 36-70 SD	3.42	17.12	7	4.99	24.96	7
4	64/m²	4.8 W/m² 36-70 SD	-0.08	-0.42	1	-0.12	-0.61	1
5	64/m²	12 W/m² 47-60 SD	4.60	22.99	8	16.80	83.99	9

CONCLUSIONS

The studies completed in 1994/95 illustrated the type of effects which may be achieved through providing assimilation lighting for only selected periods of the total production period.

That is, to obtain maximum increases in plant height, lighting should be targeted at the long day phase of production. Such a treatment alone would not be expected to improve quality. Furthermore from observations made, changing from high light intensity during vegetative growth to low intensity during bud initiation may slow response time and delay harvest.

Speed of production may also be increased by providing assimilation lighting during the initial period of short days when flower initiation occurs. Again this treatment would not be expected to give significant improvements in final quality.

Fresh weight may be increased by providing supplementary lighting for any of the phases of production studied. To gain maximum benefit however, it is clearly better to target the final stages of short days (i.e. the last five weeks) since improvements in visual quality will then accompany these gains in fresh weight.

Studies completed in 1995/96 confirmed the observations made in 1994/95. Furthermore the importance of light intensity and total light energy supplied was demonstrated. As expected, the higher light intensity (i.e. 12 W/m^2) gave superior results to the lower light intensity (i.e. 4.8 $/m^2$) over the last 5 weeks of short days. In cost benefit terms however, the lower intensity treatment was more favourable (particularly in the case of fixed lighting systems).

Giving the same total additional light energy (i.e. 6.65 MJ/m^2) for different lengths of time (and therefore at different intensities) did not produce the same result. The treatment 4.8 W/m^2 day 36-70 SD produced better quality and stem weight than 12 W/m^2 day 46-60 SD (which provided the same total light energy). It is, however, possible that such a treatment may be improved by targeting a different period. For example, lighting at 12 W/m^2 for the last 14 days of short days (i.e. day 57-70) may improve the effectiveness of such a treatment.

Spacing may also be used to manipulate winter quality. Wider spacing with no supplementary lighting produced significant improvements in stem weight but did not reproduce the visual improvements in foliage and flower colour found with supplementary lighting. Closer spacing reduced the improvements achieved with supplementary lighting. It is, however, possible to use closer spacing to offset the costs of supplying lighting and still achieve superior quality to that produced under current standard practice in the winter.

RECOMMENDATIONS FOR FURTHER WORK

Results from this trial have demonstrated the impact that lighting may have at different stages of production and the particular benefits from using lighting during the period when buds are developing and maturing into flowers. To date however studies of lighting during the last five weeks of short days have been limited to only two intensities (4.8 W/m^2 and 12 W/m^2) and two periods (day 36-70 SD and day 47-60 SD). Manipulation of both of these factors may identify more efficient lighting regimes than those studied to date.

The full economic potential of the treatments identified in this work would be fully exploited if mobile lighting rigs were available. To date these rigs are not commonplace and the practicalities of their use for the UK industry has not been investigated. Such work would greatly add to the value of the above work and assist commercial growers in fully exploiting the benefits which may be achieved using supplementary lighting.

Finally, difficulties were experienced in this trial with the temperature sensitivity of the variety Reagan which can impact on the timing of the interruption. Work previously conducted on timing the interruption according to light integrals has been successfully used on the varieties on which the work was carried out. Reagan is now the UK industry standard variety but growers continue to face this difficulty with timing the interruption throughout the winter period. This problem should therefore be addressed through the type of studies carried out on varieties which are now less commonly produced.

APPENDIX I

FOLIAGE MINERAL ANALYSIS - TABLES OF RESULTS

Table 1a: **The influence of supplementary lighting and spacing on foliage mineral status Planting 2 - 1994/95 - Splendid Reagan**

Sample	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m²	8.83	7.11	7.84	4.51	6.08	3.98	0.65	0.67	0.47	7.74	7.44	7.83	1.55	1.90	1.92	0.56	0.47	0.42	296.44	394.23	516.54
1-54/m²	8.50	7.46	7.89	4.50	5.99	4.30	0.65	0.64	0.48	7.22	7.24	7.55	1.60	1.88	1.88	0.61	0.51	0.42	301.16	519.27	390.85
2-54/m²	8.87	8.92	9.22	5.10	5.38	4.19	0.77	0.58	0.50	6.95	7.04	7.66	1.36	1.63	1.88	0.46	0.39	0.40	349.53	352.79	426.07
3-54/m²	9.72	8.61	8.97	4.89	5.74	4.02	0.77	1.39	0.50	6.48	6.01	7.60	1.50	3.25	1.96	0.51	0.70	0.42	491.44	587.68	803.21
4-54/m²	9.49	8.28	8.47	4.82	6.11	3.99	0.82	1.41	0.52	7.69	6.99	7.31	1.57	3.09	1.97	0.59	0.67	0.37	361.40	431.69	599.44
5-54/m²	8.07	7.62	8.68	4.76	6.78	4.24	0.81	1.49	0.51	8.63	7.43	7.86	1.45	3.72	1.96	0.54	0.75	0.37	370.78	599.11	553.59
2-64/m²	8.65	7.92	9.90	4.74	5.13	4.23	0.80	0.55	0.48	7.51	6.90	7.45	1.41	1.79	1.98	0.49	0.39	0.41	261.09	284.21	459.72
3-64/m²	9.12	7.88	8.71	4.83	5.96	4.13	0.80	1.50	0.47	6.71	6.68	7.39	1.44	3.66	2.19	0.49	0.69	0.47	451.77	576.56	746.41
4-64/m²	9.75	7.96	8.26	4.75	5.78	3.93	0.82	1.56	0.53	8.34	7.21	7.44	1.50	3.23	1.82	0.60	0.67	0.42	327.19	368.19	454.34
5-64/m²	8.94	7.12	8.88	4.27	5.70	4.34	0.77	1.19	0.49	7.56	7.85	7.99	1.46	3.09	1.89	0.52	0.65	0.34	337.92	613.46	576.13

Table 1b: **The influence of supplementary lighting and spacing on foliage mineral status Planting 2 - 1994/95 - Dark Cerise Delta**

Sample	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m²	8.72	7.02	7.18	4.44	5.69	3.98	0.69	0.77	0.62	6.36	7.39	8.02	1.60	2.04	2.41	0.62	0.58	0.52	186.62	280.72	387.00
1-54/m²	9.06	7.38	7.56	3.96	5.75	4.34	0.67	0.75	0.54	5.92	7.04	6.75	1.66	2.14	2.21	0.62	0.65	0.55	193.20	310.73	263.24
2-54/m²	9.23	8.53	8.82	4.37	5.03	3.96	0.89	0.68	0.45	6.68	6.62	7.13	1.67	2.01	2.27	0.65	0.57	0.45	227.28	231.99	251.44
3-54/m²	10.42	8.81	9.61	4.40	5.43	3.70	0.85	1.49	0.46	5.45	6.17	6.83	1.71	2.78	2.50	0.63	0.75	0.52	294.45	384.69	434.63
4-54/m²	9.25	7.63	7.61	4.13	5.85	3.94	0.81	1.71	0.51	6.92	7.04	8.05	1.67	3.80	2.31	0.67	0.69	0.46	200.87	265.80	312.88
5-54/m²	8.31	7.08	8.48	4.38	5.90	4.42	0.88	1.66	0.63	7.53	7.63	7.57	1.77	3.85	2.45	0.68	0.82	0.49	255.69	358.98	440.05
2-64/m²	9.70	8.29	8.65	4.48	4.98	4.16	0.88	0.65	0.47	6.01	6.69	7.80	1.63	1.85	2.30	0.61	0.49	0.45	227.74	259.03	355.11
3-64/m²	10.37	8.55	8.67	4.54	5.49	3.98	0.85	1.59	0.50	5.39	5.33	7.02	1.80	3.30	2.80	0.66	0.77	0.55	300.40	487.81	708.36
4-64/m²	9.76	8.51	8.07	3.98	5.42	3.73	0.78	1.57	0.52	6.87	6.05	6.67	1.65	3.46	2.55	0.66	0.75	0.66	201.58	282.62	487.21
5-64/m²	8.38	7.18	9.16	4.10	5.60	4.13	0.95	1.09	0.61	7.74	7.30	7.50	1.63	2.65	2.49	0.65	0.59	0.53	241.22	571.65	440.41

Key to treatments:

1 - no supplementary lighting 2 - 4.8 W/m² throughout production 3 - 12 W/m² during LD 4 - 12 W/m² day 1 - 35 SD 5 - 12 W/m² day 36 - 70 SD

Table 1c: The influence of supplementary lighting and spacing on foliage mineral status Planting 2 - 1994/95 - Mean Values

	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
Sample	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m²	8.77	7.06	7.51	4.47	5.88	3.98	0.67	0.72	0.54	7.05	7.42	7.92	1.58	1.97	2.16	0.59	0.52	0.47	241.53	337.47	451.77
1-54/m²	8.78	7.42	7.72	4.23	5.87	4.32	0.66	0.69	0.51	6.57	7.14	7.15	1.63	2.01	2.05	0.61	0.58	0.48	247.18	415.00	327.05
2-54/m²	9.05	8.73	9.02	4.73	5.20	4.07	0.83	0.63	0.47	6.82	6.83	7.39	1.52	1.82	2.07	0.55	0.48	0.43	288.40	292.39	338.75
3-54/m²	10.07	8.71	9.29	4.65	5.58	3.86	0.81	1.44	0.48	5.96	6.09	7.22	1.61	3.02	2.23	0.57	0.72	0.47	392.94	486.18	618.92
4-54/m²	9.37	7.95	8.04	4.47	5.98	3.96	0.82	1.56	0.51	7.31	7.01	7.68	1.62	3.45	2.14	0.63	0.68	0.41	281.13	348.74	456.16
5-54/m²	8.19	7.35	8.58	4.57	6.34	4.33	0.84	1.58	0.57	8.08	7.53	7.71	1.61	3.78	2.20	0.61	0.79	0.43	313.23	479.04	496.82
2-64/m²	9.17	8.10	9.28	4.61	5.05	4.19	0.84	0.60	0.47	6.76	6.80	7.62	1.52	1.82	2.14	0.55	0.44	0.43	244.42	271.62	407.42
3-64/m²	9.74	8.22	8.69	4.69	5.72	4.05	0.82	1.54	0.48	6.05	6.00	7.20	1.62	3.48	2.49	0.57	0.73	0.51	376.08	532.19	727.39
4-64/m²	9.76	8.23	8.17	4.36	5.60	3.83	0.80	1.56	0.52	7.61	6.63	7.06	1.58	3.34	2.18	0.63	0.71	0.54	264.38	325.40	470.78
5-64/m²	8.66	7.15	9.02	4.18	5.65	4.23	0.86	1.14	0.55	7.65	7.57	7.75	1.55	2.87	2.19	0.58	0.62	0.44	289.57	592.55	508.27

Key to treatments:

1 - no supplementary lighting   2 - 4.8 W/m² throughout production   3 - 12 W/m² during LD   4 - 12 W/m² day 1 - 35 SD   5 - 12 W/m² day 36 - 70 SD

Table 2a: **The influence of supplementary lighting and spacing on foliage mineral status Planting 1 - 1995/96 - Splendid Reagan**

Sample	Organic Dry Matter 1	Organic Dry Matter 2	Organic Dry Matter 3	Nitrogen % 1	Nitrogen % 2	Nitrogen % 3	Phosphorus % 1	Phosphorus % 2	Phosphorus % 3	Potassium % 1	Potassium % 2	Potassium % 3	Calcium % 1	Calcium % 2	Calcium % 3	Magnesium % 1	Magnesium % 2	Magnesium % 3	Manganese mg/kg 1	Manganese mg/kg 2	Manganese mg/kg 3
1-45/m²	8.83	7.55	7.50	4.83	4.40	3.37	0.60	0.54	0.41	7.11	8.00	8.26	1.24	1.45	1.89	0.37	0.31	0.33	360.94	371.67	467.33
1-54/m²	8.54	7.95	7.08	5.25	4.27	3.45	0.59	0.51	0.42	7.37	7.53	8.86	1.16	1.57	1.66	0.33	0.35	0.37	368.50	360.56	432.83
2-54/m²	8.95	8.34	7.66	4.61	4.11	3.92	0.56	0.49	0.39	6.66	7.55	8.48	1.18	1.50	1.65	0.39	0.32	0.32	334.50	318.03	413.68
3-54/m²	8.62	8.14	7.67	4.46	4.43	3.88	0.60	0.52	0.40	7.01	3.96	7.70	1.18	1.54	1.83	0.36	0.37	0.31	414.14	522.60	470.24
4-54/m²	9.32	8.33	7.94	4.03	4.06	3.99	0.55	0.48	0.42	7.09	3.98	8.19	1.13	1.46	1.65	0.34	0.34	0.34	359.14	462.63	588.19
5-54/m²	8.70	7.99	7.89	5.11	4.53	3.97	0.60	0.56	0.47	7.07	7.56	8.50	1.14	1.53	1.61	0.37	0.37	0.32	354.88	424.60	441.63
2-64/m²	8.62	8.39	7.90	4.71	4.62	3.73	0.60	0.48	0.37	7.08	7.15	8.18	1.18	1.50	1.53	0.38	0.36	0.33	303.57	326.69	331.33
3-64/m²	9.37	8.16	7.60	4.38	4.34	3.67	0.48	0.50	0.45	6.86	7.49	8.80	1.20	1.44	1.72	0.38	0.31	0.38	361.43	489.83	456.18
4-64/m²	8.92	7.96	7.81	3.90	4.06	3.80	0.49	0.48	0.38	6.86	7.93	7.98	1.11	1.44	1.66	0.35	0.36	0.34	401.30	506.27	597.94
5-64/m²	8.52	7.59	7.49	4.58	4.27	4.21	0.59	0.56	0.49	7.37	7.85	8.06	1.07	1.45	1.75	0.37	0.34	0.45	315.46	420.30	381.78

Table 2b: **The influence of supplementary lighting and spacing on foliage mineral status Planting 1 - 1995/96 - Dark Cerise Delta**

Sample	Organic Dry Matter 1	Organic Dry Matter 2	Organic Dry Matter 3	Nitrogen % 1	Nitrogen % 2	Nitrogen % 3	Phosphorus % 1	Phosphorus % 2	Phosphorus % 3	Potassium % 1	Potassium % 2	Potassium % 3	Calcium % 1	Calcium % 2	Calcium % 3	Magnesium % 1	Magnesium % 2	Magnesium % 3	Manganese mg/kg 1	Manganese mg/kg 2	Manganese mg/kg 3
1-45/m²	11.01	8.20	7.75	4.53	4.26	3.57	0.51	0.52	0.40	5.49	3.52	7.68	1.38	1.94	2.36	0.46	0.47	0.50	268.71	332.79	351.66
1-54/m²	10.53	8.24	7.91	4.98	4.05	3.32	0.48	0.52	0.32	5.85	3.56	7.67	1.32	1.92	2.00	0.44	0.45	0.40	271.22	309.55	366.86
2-54/m²	11.13	9.00	7.92	4.30	4.27	3.61	0.47	0.49	0.36	5.51	6.81	7.57	1.38	1.74	1.86	0.45	0.40	0.36	239.76	261.39	288.22
3-54/m²	10.66	8.93	8.34	4.22	4.14	3.60	0.45	0.49	0.36	6.11	7.16	7.38	1.33	1.72	2.04	0.36	0.40	0.37	246.30	301.55	327.08
4-54/m²	11.01	8.35	8.12	3.77	4.26	3.58	0.45	0.47	0.34	5.55	7.15	6.96	1.30	1.64	2.00	0.47	0.40	0.41	432.67	273.12	288.57
5-54/m²	9.85	7.86	7.87	4.87	4.17	3.61	0.56	0.59	0.45	6.56	3.78	8.30	1.23	1.68	1.71	0.41	0.39	0.39	279.69	367.55	278.34
2-64/m²	10.83	8.65	8.01	4.39	4.25	3.59	0.50	0.49	0.36	5.44	6.81	7.12	1.39	1.74	1.76	0.45	0.37	0.36	236.17	201.16	236.62
3-64/m²	11.27	8.75	8.12	4.64	4.23	3.38	0.47	0.48	0.33	5.97	7.21	6.81	1.24	1.70	1.88	0.41	0.42	0.37	229.59	266.53	245.15
4-64/m²	11.70	9.51	8.74	3.77	4.15	3.80	0.43	0.48	0.32	5.69	7.43	6.94	1.27	1.65	2.04	0.44	0.43	0.43	215.36	348.28	353.51
5-64/m²	9.83	7.68	7.83	4.24	3.95	3.79	0.56	0.56	0.43	6.42	7.61	7.63	1.27	1.69	2.09	0.47	0.40	0.46	271.30	326.36	408.45

Key to treatments:

1 - no supplementary lighting 2 - 4.8 W/m² throughout production 3 - 12 W/m² day 36 - 70 SD 4 - 4.8 W/m² day 36 - 70 SD 5 - 12 W/m² day 47 -60 SD

Table 2c: The influence of supplementary lighting and spacing on foliage mineral status Planting 1 - 1995/96 - Mean Values

	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
Sample	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m^2	9.92	7.87	7.62	4.68	4.33	3.47	0.55	0.53	0.41	6.30	5.76	7.97	1.31	1.69	2.13	0.42	0.39	0.41	314.82	352.23	409.50
1-54/m^2	9.54	8.09	7.50	5.11	4.16	3.38	0.53	0.52	0.37	6.61	5.54	8.27	1.24	1.74	1.83	0.38	0.40	0.38	319.86	335.05	399.84
2-54/m^2	10.04	8.67	7.79	4.45	4.19	3.77	0.52	0.49	0.37	6.08	7.18	8.02	1.28	1.62	1.75	0.42	0.36	0.34	287.13	289.71	350.95
3-54/m^2	9.64	8.54	8.00	4.34	4.28	3.74	0.52	0.50	0.38	6.56	5.56	7.54	1.26	1.63	1.94	0.36	0.39	0.34	330.22	412.07	398.66
4-54/m^2	10.17	8.34	8.03	3.90	4.16	3.78	0.50	0.47	0.38	6.32	5.56	7.58	1.21	1.55	1.82	0.41	0.37	0.38	395.90	367.87	438.38
5-54/m^2	9.27	7.92	7.88	4.99	4.35	3.79	0.58	0.58	0.46	6.82	5.67	8.40	1.19	1.61	1.66	0.39	0.38	0.36	317.28	396.08	359.99
2-64/m^2	9.72	8.52	7.95	4.55	4.43	3.66	0.55	0.48	0.37	6.26	6.98	7.65	1.28	1.62	1.65	0.41	0.36	0.35	269.87	263.92	283.97
3-64/m^2	10.32	8.45	7.86	4.51	4.29	3.53	0.48	0.49	0.39	6.41	7.35	7.81	1.22	1.57	1.80	0.40	0.36	0.38	295.51	378.18	350.66
4-64/m^2	10.31	8.74	8.27	3.83	4.10	3.80	0.46	0.48	0.35	6.27	7.68	7.46	1.19	1.55	1.85	0.39	0.39	0.39	308.33	427.28	475.72
5-64/m^2	9.17	7.63	7.66	4.41	4.11	4.00	0.57	0.56	0.46	6.89	7.73	7.85	1.17	1.57	1.92	0.42	0.37	0.45	293.38	373.33	395.12

Key to treatments:

1 - no supplementary lighting 2 - 4.8 W/m^2 throughout production 3 - 12 W/m^2 day 36 - 70 SD 4 - 4.8 W/m^2 day 36 - 70 SD 5 - 12 W/m^2 day 47 -60 SD

Table 3a: The influence of supplementary lighting and spacing on leaf mineral status Planting 2 - 1995/96 - Splendid Reagan

Sample	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m²	7.63	7.38	9.17	4.84	5.06	4.27	0.69	0.60	0.37	7.45	7.70	8.48	1.24	1.67	2.25	0.45	0.39	0.34	321.49	340.42	280.00
1-54/m²	7.78	7.61	7.59	4.47	4.46	4.41	0.70	0.59	0.42	7.94	7.82	8.64	1.20	1.66	2.14	0.46	0.38	0.32	316.81	312.28	325.28
2-54/m²	8.10	7.81	8.46	4.61	4.26	4.05	0.57	0.52	0.39	6.78	7.56	7.66	1.09	1.60	1.88	0.37	0.33	0.33	356.00	301.96	373.34
3-54/m²	6.98	6.99	7.56	4.43	4.26	4.47	0.77	0.65	0.43	7.94	8.99	8.52	1.29	1.68	2.19	0.44	0.37	0.35	376.78	448.33	705.51
4-54/m²	7.71	7.04	7.62	4.81	4.41	4.03	0.71	0.65	0.44	7.45	8.06	8.29	1.23	1.62	2.13	0.45	0.38	0.39	339.68	374.05	468.53
5-54/m²	7.73	7.42	7.65	4.63	4.38	3.97	0.73	0.62	0.42	7.47	8.16	8.27	1.20	1.55	2.00	0.45	0.39	0.39	356.16	447.91	509.29
2-64/m²	7.91	7.91	8.23	4.67	4.45	4.34	0.58	0.55	0.41	6.89	8.04	8.38	1.15	1.52	1.97	0.36	0.31	0.36	327.81	346.13	382.28
3-64/m²	7.13	6.89	7.16	4.68	4.19	3.90	0.81	0.69	0.48	4.06	8.66	8.56	1.26	1.59	2.02	0.42	0.40	0.35	388.18	566.94	715.52
4-64/m²	7.69	7.16	6.98	4.60	4.10	3.86	0.70	0.66	0.48	3.61	8.45	7.99	1.29	1.62	2.05	0.46	0.40	0.43	376.81	383.07	514.92
5-64/m²	7.54	7.50	6.84	4.57	4.57	3.96	0.75	0.64	0.44	7.60	7.49	8.42	1.19	1.61	1.83	0.45	0.42	0.39	375.86	435.82	523.49

Table 3b: The influence of supplementary lighting and spacing on leaf mineral status Planting 2 - 1995/96 - Dark Cerise Delta

Sample	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m²	8.24	7.56	9.45	4.48	4.59	4.05	0.62	0.62	0.35	6.60	7.82	7.19	1.29	1.68	2.54	0.49	0.40	0.43	234.71	258.82	261.99
1-54/m²	8.22	7.37	8.14	4.39	4.55	4.04	0.69	0.62	0.36	7.05	7.69	8.23	1.34	1.85	2.59	0.49	0.47	0.46	212.70	276.69	261.53
2-54/m²	8.42	8.42	8.72	4.68	4.39	4.23	0.54	0.49	0.33	6.05	7.55	6.86	1.36	1.84	2.59	0.46	0.43	0.45	222.36	208.49	262.03
3-54/m²	7.46	6.80	7.81	4.33	4.34	4.36	0.66	0.66	0.42	6.50	8.47	7.79	1.58	1.79	2.62	0.56	0.45	0.47	298.96	365.41	475.99
4-54/m²	7.57	7.08	7.73	4.53	4.12	4.02	0.66	0.58	0.41	6.65	8.32	7.82	1.67	1.91	2.76	0.61	0.55	0.58	300.72	279.17	360.03
5-54/m²	7.06	6.82	7.46	4.42	4.19	3.70	0.70	0.70	0.46	7.05	7.81	8.31	1.51	1.87	2.51	0.61	0.52	0.51	304.03	317.08	427.55
2-64/m²	8.06	8.06	8.77	4.60	4.09	4.37	0.59	0.51	0.35	6.08	7.23	7.82	1.41	1.76	2.57	0.52	0.43	0.45	266.92	284.92	255.96
3-64/m²	7.36	6.62	7.93	4.43	4.17	4.18	0.73	0.66	0.42	6.83	8.24	7.89	1.58	2.04	2.81	0.61	0.61	0.57	292.56	379.78	522.13
4-64/m²	7.80	7.05	7.73	4.66	3.82	3.78	0.66	0.64	0.41	6.47	8.28	7.67	1.63	1.90	2.56	0.65	0.49	0.56	269.51	255.48	320.57
5-64/m²	7.59	6.64	7.54	4.32	4.09	3.69	0.67	0.65	0.42	6.85	8.41	8.16	1.49	1.90	2.57	0.61	0.51	0.49	281.66	305.05	408.24

Key to treatments:

1 - no supplementary lighting 2 - 4.8 W/m² throughout production 3 - 12 W/m² day 36 - 70 SD 4 - 4.8 W/m² day 36 - 70 SD 5 - 12 W/m² day 47 -60 SD

Table 3c: The influence of supplementary lighting and spacing on leaf mineral status Planting 2 - 1995/96 - Mean Values

Sample	Organic Dry Matter			Nitrogen %			Phosphorus %			Potassium %			Calcium %			Magnesium %			Manganese mg/kg		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1-45/m²	7.93	7.47	9.31	4.66	4.82	4.16	0.66	0.61	0.36	7.02	7.76	7.83	1.26	1.67	2.40	0.47	0.40	0.39	278.10	299.62	270.99
1-54/m²	8.00	7.49	7.86	4.43	4.51	4.22	0.69	0.60	0.39	7.50	7.75	8.43	1.27	1.75	2.37	0.48	0.43	0.39	264.75	294.49	293.41
2-54/m²	8.26	8.12	8.59	4.64	4.32	4.14	0.55	0.51	0.36	6.42	7.55	7.26	1.22	1.72	2.23	0.41	0.38	0.39	289.18	255.22	317.68
3-54/m²	7.22	6.89	7.68	4.38	4.30	4.41	0.72	0.66	0.42	7.22	8.73	8.16	1.43	1.73	2.41	0.50	0.41	0.41	337.87	406.87	590.75
4-54/m²	7.64	7.06	7.67	4.67	4.27	4.03	0.69	0.61	0.43	7.05	8.19	8.06	1.45	1.77	2.45	0.53	0.46	0.49	320.20	326.61	414.28
5-54/m²	7.39	7.12	7.55	4.52	4.29	3.83	0.71	0.66	0.44	7.26	7.99	8.29	1.36	1.71	2.25	0.53	0.45	0.45	330.09	382.49	468.42
2-64/m²	7.99	7.98	8.50	4.63	4.27	4.35	0.58	0.53	0.38	6.49	7.63	8.10	1.28	1.64	2.27	0.44	0.37	0.40	297.37	315.52	319.12
3-64/m²	7.24	6.76	7.54	4.55	4.18	4.04	0.77	0.68	0.45	5.44	8.45	8.22	1.42	1.81	2.41	0.51	0.51	0.46	340.37	473.36	618.82
4-64/m²	7.74	7.10	7.36	4.63	3.96	3.82	0.68	0.65	0.44	5.04	8.37	7.83	1.46	1.76	2.30	0.56	0.44	0.49	323.16	319.27	417.74
5-64/m²	7.56	7.07	7.19	4.44	4.33	3.83	0.71	0.65	0.43	7.23	7.95	8.29	1.34	1.75	2.20	0.53	0.46	0.44	328.76	370.43	465.87

Key to treatments:

1 - no supplementary lighting   2 - 4.8 W/m² throughout production   3 - 12 W/m² day 36 - 70 SD   4 - 4.8 W/m² day 36 - 70 SD   5 - 12 W/m² day 47 -60 SD

APPENDIX II

ECONOMIC APPRAISAL OF LIGHTING TREATMENTS

1. COST OF SUPPLEMENTARY LIGHTING FOR SPRAY CHRYSANTHEMUMS

The following presents calculations for the costs of lighting treatments assessed in this trial. There are a number of variables which will affect final costing. These include the lighting regime itself as well as the spacing density of plants in the bed.

Costs 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, the following calculations have been based on two separate set of assumptions which originate from costing exercises carried out for trials on pot chrysanthemums (e.g. PC92a - Wilson 1995).

Costings - AYR treatments

Assumptions

1. Capital cost of 400 SON/T lamp & installation = £160* *(£150)°*

2. Illuminance

12 W/m²	1 lamp covers	6 m²
4.8 W/m²	1 lamp covers	14 m²

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

$$\frac{£160}{5\text{ yrs}} + \left(\frac{80}{100} \times 14\%\right) = £43.20 \quad \textit{or} \quad \frac{150}{5\text{ yrs}} + \left(\frac{80}{100} \times 9\%\right) = £37.20$$

4. Annual capital cost per m²

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

$$\text{at } 4.8\text{ W/m}^2 = \frac{43.2}{14} = £3.09/\text{m}^2/\text{year}^* \qquad \frac{37.2}{14} = £2.66/\text{m}^2/\text{year}^\circ$$

5. L.D. lighting for 19 hours/day (03.30 - 22.30)

6. S.D. lighting for 11 hours/day (07.00 - 18.00)

7. Spacings

   85% spacing = 54.4 plants/m²
   100% spacing = 64 plants/m²

8. Pathways - lighting on pathways is not included and the calculations assume 100% space utilisation. Percentage space occupied by pathways should be estimated according to individual circumstances and costs adjusted accordingly.

9. 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.

10. Electricity running costs

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

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

* Assumed cost in original costings calculated in the 1991/92 HDC funded project PC13b (Finlay, 1993)

° Assumed cost according to average figures in the 1994 HDC funded project PC92a (Wilson, 1995)

1. Calculation for treatments assessed in year 1 of PC104 (i.e. Winter 1994/95)

Costing for 54 plants/m^2 (85%) spacing

A. Capital Cost

a. L.D. 12 W/m^2 (assuming 28 days*)

1m^2 will service 2 crops if fixed at 54.4 plants/m^2 = 108.8 stems

Capital cost = $\frac{720}{108.8}$ = 6.62p/stem *or* $\frac{620}{108.8}$ = *5.70p/stem*

or 1m^2 will service 6.5 crops if mobile at 54.4 plants/m^2 = 353.6 stems

Capital cost = $\frac{720}{353.6}$ = 2.04p/stem *or* $\frac{620}{353.6}$ = *1.75p/stem*

* It is possible that under supplementary lighting, this period may be reduced and hence improve the economics. This needs to be addressed in future trials.

b. S.D. 12 W/m^2 (either weeks 1-5 of S.D. or weeks 6-10 of S.D.)

1m^2 will service 2 crops if fixed at 54.4 plants/m^2 = 108.8 stems

Capital cost = $\frac{720}{108.8}$ = 6.62p/stem *or* $\frac{620}{108.8}$ = *5.70p/stem*

or 1m^2 will service 5.2 crops if mobile at 54.4 plants/m^2 = 282.9 stems

Capital cost = $\frac{720}{282.9}$ = 2.55p/stem *or* $\frac{620}{282.9}$ = *2.19p/stem*

c. 4.8 W/m^2 throughout production

$1m^2$ will service 2 crops at 54.4 plants/m^2 = 108.8 stems

Capital cost = $\frac{309}{108.8}$ = 2.84p/stem *or* $\frac{266}{108.8}$ = *2.44p/stem*

B. Running Cost

a. L.D. at 12 W/m^2 for 28 days

15.5 hrs Standard	7.78p/kWhr	<u>*or*</u>	*5.50p/kWhr*
3.5 hrs Off-Peak	2.61p/kWhr	<u>*or*</u>	*3.00p/kWhr*

$$\frac{0.44 \text{ kW} \times 15.5 \text{ hrs} \times 28 \text{ days} \times 7.78 \text{ p/kWhr}}{6m^2} = 247.6p/m^2$$

$$\frac{0.44 \text{ kW} \times 3.5 \text{ hrs} \times 28 \text{ days} \times 2.61 \text{ p/kWhr}}{6m^2} = 18.8p/m^2$$

$$= 247.6 + 18.8 = 266.4p/m^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{266.4}{54.4} = 4.89\text{p/stem}$$

<u>*or*</u>

$$\frac{0.44 \text{ kW} \times 15.5 \text{ hrs} \times 28 \text{ days} \times 5.50 \text{ p/kWhr}}{6m^2} = 175.0p/m^2$$

$$\frac{0.44 \text{ kW} \times 3.5 \text{ hrs} \times 28 \text{ days} \times 3.00 \text{ p/kWhr}}{6m^2} = 21.6p/m^2$$

$$= 175.0 + 21.6 = 196.6p/m^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{196.6}{54.4} = 3.61\text{p/stem}$$

b. Weeks 1-5 of S.D. at 12 W/m^2 (including interruption lighting)

25 days at	11 hrs Standard	7.78p/kWhr	<u>*or*</u>	*5.50p/kWhr*
10 days at	15.5 hrs Standard	7.78p/kWhr	<u>*or*</u>	*5.50p/kWhr*
+	3.5 hrs Off-Peak	2.61p/kWhr	<u>*or*</u>	*3.00p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 25 \text{ days} \times 7.78 \text{ p/kWhr}}{6m^2} = 156.90 \text{ p/m}^2$$

$$\frac{0.44 \text{ kW} \times 15.5 \text{ hrs} \times 10 \text{ days} \times 7.78 \text{ p/kWhr}}{6m^2} = 88.43 \text{ p/m}^2$$

$$\frac{0.44\text{ kW x }3.5\text{ hrs x }10\text{ days x }2.61\text{ p/kWhr}}{6m^2} = 6.70p/m^2$$

$= \quad 156.90 + 88.43 + 6.70 = 252.03p/m^2$

at 54.4 plants/m^2 $= \dfrac{252.03}{54.4} = 4.63$p/stem

or

$$\frac{0.44\text{ kW x }11\text{ hrs x }25\text{ days x }5.50\text{ p/kWhr}}{6m^2} = 110.92p/m^2$$

$$\frac{0.44\text{ kW x }15.5\text{ hrs x }10\text{ days x }5.50\text{ p/kWhr}}{6m^2} = 62.52p/m^2$$

$$\frac{0.44\text{ kW x }3.5\text{ hrs x }10\text{ days x }3.00\text{ p/kWhr}}{6m^2} = 7.70p/m^2$$

$= \quad 110.92 + 62.52 + 7.70 = 181.14p/m^2$

at 54.4 plants/m^2 $= \dfrac{181.14}{54.4} = 3.33$p/stem

c. Weeks 6-10 of S.D. at 12 W/m^2

35 days at 11 hrs Standard 7.78p/kWhr *or* *5.50p/kWhr*

$$\frac{0.44\text{ kW x }11\text{ hrs x }35\text{ days x }7.78\text{ p/kWhr}}{6m^2} = 219.66p/m^2$$

at 54.4 plants/m^2 $= \dfrac{219.66}{54.4} = 4.04$p/stem

or

$$\frac{0.44\text{ kW x }11\text{ hrs x }35\text{ days x }5.50\text{ p/kWhr}}{6m^2} = 155.28p/m^2$$

at 54.4 plants/m^2 $= \dfrac{155.28}{54.4} = 2.85$p/stem

d. 4.8 W/m^2 throughout production

38 days at	15.5 hrs Standard	7.78p/kWhr	<u>*or*</u>	*5.50p/kWhr*
+	3.5 hrs Off-Peak	2.61p/kWhr	<u>*or*</u>	*3.00p/kWhr*
60 days at	11 hrs Standard	7.78p/kWhr	<u>*or*</u>	*5.50p/kWhr*

$$\frac{0.44\text{ kW} \times 15.5\text{ hrs} \times 38\text{ days} \times 7.78\text{ p/kWhr}}{14\text{m}^2} = 144.02\text{p/m}^2$$

$$\frac{0.44\text{ kW} \times 3.5\text{ hrs} \times 38\text{ days} \times 2.61\text{ p/kWhr}}{14\text{m}^2} = 10.91\text{p/m}^2$$

$$\frac{0.44\text{ kW} \times 11\text{ hrs} \times 60\text{ days} \times 7.78\text{ p/kWhr}}{14\text{m}^2} = 161.38\text{p/m}^2$$

$$= 144.02 + 10.91 + 161.38 = 316.31\text{p/m}^2$$

$$\text{at } 54.4\text{ plants/m}^2 = \frac{316.31}{54.4} = 5.81\text{p/stem}$$

<u>*or*</u>

$$\frac{0.44\text{ kW} \times 15.5\text{ hrs} \times 38\text{ days} \times 5.50\text{ p/kWhr}}{14\text{m}^2} = 101.81\text{p/m}^2$$

$$\frac{0.44\text{ kW} \times 3.5\text{ hrs} \times 38\text{ days} \times 3.00\text{ p/kWhr}}{14\text{m}^2} = 12.54\text{p/m}^2$$

$$\frac{0.44\text{ kW} \times 11\text{ hrs} \times 60\text{ days} \times 5.50\text{ p/kWhr}}{14\text{m}^2} = 114.09\text{p/m}^2$$

$$= 101.81 + 12.54 + 114.09 = 228.44\text{p/m}^2$$

$$\text{at } 54.4\text{ plants/m}^2 = \frac{228.44}{54.4} = 4.20\text{p/stem}$$

Costing for 64 plants/m² (100%) spacing

A. Capital Cost

a. L.D. 12 W/m² (assuming 28 days)

1m² will service 2 crops if fixed at 64 plants/m² = 128 stems

Capital cost = $\frac{720}{128}$ = 5.63p/stem *or* $\frac{620}{128}$ = *4.84p/stem*

or 1m² will service 6.5 crops if mobile at 64 plants/m² = 416 stems

Capital cost = $\frac{720}{416}$ = 1.73p/stem *or* $\frac{620}{416}$ = *1.49p/stem*

b. S.D. 12 W/m² (either weeks 1-5 of S.D. or weeks 6-10 of S.D.)

1m² will service 2 crops if fixed at 64 plants/m² = 128 stems

Capital cost = $\frac{720}{128}$ = 5.63p/stem *or* $\frac{620}{128}$ = *4.84p/stem*

or 1m² will service 5.2 crops if mobile at 64 plants/m² = 332.8 stems

Capital cost = $\frac{720}{332.8}$ = 2.16p/stem *or* $\frac{620}{332.8}$ = *1.86p/stem*

c. 4.8 W/m² throughout production

1m² will service 2 crops at 64 plants/m² = 128 stems

Capital cost = $\frac{309}{128}$ = 2.41p/stem *or* $\frac{266}{128}$ = *2.08p/stem*

B. Running Cost

a. L.D. at 12 W/m^2 for 28 days

15.5 hrs Standard	7.78p/kWhr	*or*	*5.50p/kWhr*
3.5 hrs Off-Peak	2.61p/kWhr	*or*	*3.00p/kWhr*

$$\frac{0.44\ kW \times 15.5\ hrs \times 28\ days \times 7.78\ p/kWhr}{6m^2} = 247.61p/m^2$$

$$\frac{0.44\ kW \times 3.5\ hrs \times 28\ days \times 2.61\ p/kWhr}{6m^2} = 18.76p/m^2$$

$$= 247.61 + 18.76 = 266.37p/m^2$$

$$\text{at 64 plants}/m^2 = \frac{266.37}{64} = 4.16p/stem$$

or

$$\frac{0.44\ kW \times 15.5\ hrs \times 28\ days \times 5.50\ p/kWhr}{6m^2} = 175.05p/m^2$$

$$\frac{0.44\ kW \times 3.5\ hrs \times 28\ days \times 3.00\ p/kWhr}{6m^2} = 21.56p/m^2$$

$$= 175.05 + 21.56 = 196.61p/m^2$$

$$\text{at 64 plants}/m^2 = \frac{196.61}{64} = 3.07p/stem$$

b. Weeks 1-5 of S.D. at 12 W/m^2 (including interruption lighting)

25 days at	11 hrs Standard	7.78p/kWhr	*or*	*5.50p/kWhr*
10 days at	15.5 hrs Standard	7.78p/kWhr	*or*	*5.50p/kWhr*
+	3.5 hrs Off-Peak	2.61p/kWhr	*or*	*3.00p/kWhr*

$$\frac{0.44\ kW \times 11\ hrs \times 25\ days \times 7.78\ p/kWhr}{6m^2} = 156.90\ p/m^2$$

$$\frac{0.44\ kW \times 15.5\ hrs \times 10\ days \times 7.78\ p/kWhr}{6m^2} = 88.43\ p/m^2$$

$$\frac{0.44 \text{ kW x } 3.5 \text{ hrs x } 10 \text{ days x } 2.61 \text{ p/kWhr}}{6\text{m}^2} = 6.70\text{p/m}^2$$

= 156.90 + 88.43 + 6.70 = 252.03p/m^2

at 64 plants/m^2 = $\frac{252.03}{64}$ = 3.94p/stem

or $$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 25 \text{ days x } 5.50 \text{ p/kWhr}}{6\text{m}^2} = 110.92\text{p/m}^2$$

$$\frac{0.44 \text{ kW x } 15.5 \text{ hrs x } 10 \text{ days x } 5.50 \text{ p/kWhr}}{6\text{m}^2} = 62.52\text{p/m}^2$$

$$\frac{0.44 \text{ kW x } 3.5 \text{ hrs x } 10 \text{ days x } 3.00 \text{ p/kWhr}}{6\text{m}^2} = 7.70\text{p/m}^2$$

= 110.92 + 62.52 + 7.70 = 181.14p/m^2

at 64 plants/m^2 = $\frac{181.14}{64}$ = 2.83p/stem

c. Weeks 6-10 of S.D. at 12 W/m^2

35 days at 11 hrs Standard 7.78p/kWhr *or* *5.50p/kWhr*

$$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 35 \text{ days x } 7.78 \text{ p/kWhr}}{6\text{m}^2} = 219.66\text{p/m}^2$$

at 64 plants/m^2 = $\frac{219.66}{64}$ = 3.43p/stem

or $$\frac{0.44 \text{ kW x } 11 \text{ hrs x } 35 \text{ days x } 5.50 \text{ p/kWhr}}{6\text{m}^2} = 155.28\text{p/m}^2$$

at 64 plants/m^2 = $\frac{155.28}{64}$ = 2.43p/stem

d. 4.8 W/m² throughout production

38 days at	15.5 hrs Standard	7.78p/kWhr	<u>or</u>	*5.50p/kWhr*
+	3.5 hrs Off-Peak	2.61p/kWhr	<u>or</u>	*3.00p/kWhr*
60 days at	11 hrs Standard	7.78p/kWhr	<u>or</u>	*5.50p/kWhr*

$$\frac{0.44\ kW \times 15.5\ hrs \times 38\ days \times 7.78\ p/kWhr}{14m^2} = 144.02p/m^2$$

$$\frac{0.44\ kW \times 3.5\ hrs \times 38\ days \times 2.61\ p/kWhr}{14m^2} = 10.91p/m^2$$

$$\frac{0.44\ kW \times 11\ hrs \times 60\ days \times 7.78\ p/kWhr}{14m^2} = 161.38p/m^2$$

$$= 144.02 + 10.91 + 161.38 = 316.31p/m^2$$

at 64 plants/m² $= \frac{316.31}{64} =$ 4.94p/stem

<u>or</u>

$$\frac{0.44\ kW \times 15.5\ hrs \times 38\ days \times 5.50\ p/kWhr}{14m^2} = 101.81p/m^2$$

$$\frac{0.44\ kW \times 3.5\ hrs \times 38\ days \times 3.00\ p/kWhr}{14m^2} = 12.54p/m^2$$

$$\frac{0.44\ kW \times 11\ hrs \times 60\ days \times 5.50\ p/kWhr}{14m^2} = 114.09p/m^2$$

$$= 101.81 + 12.54 + 114.09 = 228.44p/m^2$$

at 64 plants/m² $= \frac{228.44}{64} =$ *3.57p/stem*

Table 1: Overall cost of treatments (1994/95)

	Capital p/stem		Running p/stem		Total p/stem	
54 plants/m^2						
a. 12 W/m^2 L.D.						
fixed	6.62	*(5.70)*	4.89	*(3.61)*	11.51	*(9.31)*
mobile	2.04	*(1.75)*	4.89	*(3.61)*	6.93	*(5.36)*
b. 12 W/m^2 weeks 1 - 5 S.D.						
fixed	6.62	*(5.70)*	4.63	*(3.33)*	11.25	*(9.03)*
mobile	2.55	*(2.19)*	4.63	*(3.33)*	7.18	*(5.52)*
c. 12 W/m^2 weeks 6-10 S.D.						
fixed	6.62	*(5.70)*	4.04	*(2.85)*	10.66	*(8.55)*
mobile	2.55	*(2.19)*	4.04	*(2.85)*	6.59	*(5.04)*
d. 4.8 W/m^2 throughout production	2.84	*(2.44)*	5.81	*(4.20)*	8.65	*(6.64)*
64 plants/m^2						
a. 12 W/m^2 L.D.						
fixed	5.63	*(4.84)*	4.16	*(3.07)*	9.79	*(7.91)*
mobile	1.73	*(1.49)*	4.16	*(3.07)*	5.89	*(4.56)*
b. 12 W/m^2 weeks 1-5 S.D.						
fixed	5.63	*(4.84)*	3.94	*(2.83)*	9.57	*(7.67)*
mobile	2.16	*(1.86)*	3.94	*(2.83)*	6.10	*(4.69)*
c. 12 W/m^2 weeks 6-10 S.D.						
fixed	5.63	*(4.84)*	3.43	*(2.43)*	9.06	*(7.27)*
mobile	2.16	*(1.86)*	3.43	*(2.43)*	5.59	*(4.29)*
d. 4.8 W/m^2 throughout production	2.41	*(2.08)*	4.94	*(3.57)*	7.35	*(5.65)*

2. Calculation for treatments assessed in year 2 of PC104 (i.e. Winter 1995/96)

Costing for 54 plants/m²

A. Capital Cost

a. 12 W/m² day 36-70 of S.D.

1m² will service 2 crops if fixed at 54.4 plants/m² = 108.8 stems

Capital cost = $\frac{720}{108.8}$ = 6.62p/stem <u>or</u> *$\frac{620}{108.8}$ = 5.70p/stem*

<u>or</u> 1m² will service 5.2 crops if mobile at 54.4 plants/m² = 282.9 stems

Capital cost = $\frac{720}{282.9}$ = 2.55p/stem <u>or</u> *$\frac{620}{282.9}$ = 2.19p/stem*

b. 4.8 W/m² day 36-50 of S.D.

1m² will service 2 crops if fixed at 54.4 plants/m² = 108.8 stems

Capital cost = $\frac{309}{108.8}$ = 2.84p/stem <u>or</u> *$\frac{266}{108.8}$ = 2.44p/stem*

<u>or</u> 1m² will service 5.2 crops if mobile at 54.4 plants/m² = 282.9 stems

Capital cost = $\frac{309}{282.9}$ = 1.09p/stem <u>or</u> *$\frac{266}{282.9}$ = 0.94p/stem*

c. 12 W/m² day 47-60 of S.D.

1m² will service 2 crops if fixed at 54.4 plants/m² = 108.8 stems

Capital cost = $\frac{720}{108.8}$ = 6.62p/stem <u>or</u> *$\frac{620}{108.8}$ = 5.70p/stem* *or* $1m^2$ will service 13 crops if mobile at 54.4 plants/m^2 = 707.2 stems

Capital cost = $\frac{720}{707.2}$ = 1.02p/stem *or* *$\frac{620}{707.2}$* = *0.88p/stem*

d. 4.8 W/m^2 throughout production

$1m^2$ will service 2 crops if fixed at 54.4 plants/m^2 = 108.8 stems

Capital cost = $\frac{309}{108.8}$ = 2.84p/stem *or* *$\frac{266}{108.8}$* = *2.44p/stem*

B. Running Cost

a. 12 W/m² day 36-70 of S.D.

35 days at 11 hrs Standard 7.78p/kWhr *or* *5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 7.78 \text{ p/kWhr}}{6\text{m}^2} = 219.66\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{219.66}{54.4} = 4.04\text{p/stem}$$

or

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 5.50 \text{ p/kWhr}}{6\text{m}^2} = 155.28\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{155.28}{54.4} = 2.85\text{p/stem}$$

b. 4.8 W/m² day 36-70 of S.D.

35 days at 11 hrs Standard 7.78p/kWhr *or* *5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 7.78 \text{ p/kWhr}}{14\text{m}^2} = 94.14\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{94.14}{54.4} = 1.73\text{p/stem}$$

or

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 5.50 \text{ p/kWhr}}{14\text{m}^2} = 66.55\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{66.55}{54.4} = 1.22\text{p/stem}$$

c. 12 W/m² day 47-60 of S.D.

14 days at 11 hrs Standard	7.78p/kWhr	or	*5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 14 \text{ days} \times 7.78 \text{ p/kWhr}}{6\text{m}^2} = 87.86\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{87.86}{54.4} = 1.62\text{p/stem}$$

or

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 14 \text{ days} \times 5.50 \text{ p/kWhr}}{6\text{m}^2} = 62.11\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{62.11}{54.4} = 1.14\text{p/stem}$$

d. 4.8 W/m² throughout production

38 days at	15.5 hrs Standard	7.78p/kWhr	or	*5.50p/kWhr*
+	3.5 hrs Off-Peak	2.61p/kWhr	or	*3.00p/kWhr*
60 days at	11 hrs Standard	7.78p/kWhr	or	*5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 15.5 \text{ hrs} \times 38 \text{ days} \times 7.78 \text{ p/kWhr}}{14\text{m}^2} = 144.02\text{p/m}^2$$

$$\frac{0.44 \text{ kW} \times 3.5 \text{ hrs} \times 38 \text{ days} \times 2.61 \text{ p/kWhr}}{14\text{m}^2} = 10.91\text{p/m}^2$$

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 60 \text{ days} \times 7.78 \text{ p/kWhr}}{14\text{m}^2} = 161.38\text{p/m}^2$$

$$= 144.02 + 10.91 + 161.38 = 316.31\text{p/m}^2$$

$$\text{at } 54.4 \text{ plants/m}^2 = \frac{316.31}{54.4} = 5.81\text{p/stem}$$

$$\text{or} \quad \frac{0.44\ kW \times 15.5\ hrs \times 38\ days \times 5.50\ p/kWhr}{14m^2} = 101.81p/m^2$$

$$\frac{0.44\ kW \times 3.5\ hrs \times 38\ days \times 3.00\ p/kWhr}{14m^2} = 12.54p/m^2$$

$$\frac{0.44\ kW \times 11\ hrs \times 60\ days \times 5.50\ p/kWhr}{14m^2} = 114.09p/m^2$$

$$= 101.81 + 12.54 + 114.09 = 228.44p/m^2$$

$$\text{at } 54.4\ plants/m^2 = \frac{228.44}{54.4} = 4.20p/stem$$

Costing for 64 plants/m² spacing

a. 12 W/m² day 36-70 of S.D.

1m² will service 2 crops if fixed at 64 plants/m² = 128 stems

Capital cost = $\frac{720}{128}$ = 5.63p/stem *or* $\frac{620}{128}$ = *4.84p/stem*

or 1m² will service 5.2 crops if mobile at 64 plants/m² = 332.8 stems

Capital cost = $\frac{720}{332.8}$ = 2.16p/stem *or* $\frac{620}{332.8}$ = *1.86p/stem*

b. 4.8 W/m² 36-70 of S.D.

1m² will service 2 crops if fixed at 64 plants/m² = 128 stems

Capital cost = $\frac{309}{128}$ = 2.41p/stem *or* $\frac{266}{128}$ = *2.08p/stem*

or 1m² will service 5.2 crops if mobile at 64 plants/m² = 332.8 stems

Capital cost = $\frac{309}{332.8}$ = 0.93p/stem *or* $\frac{266}{332.8}$ = *0.80p/stem*

c 12 W/m² day 47-60 of S.D.

1m² will service 2 crops if fixed at 64 plants/m² = 128 stems

Capital cost = $\frac{720}{128}$ = 5.63p/stem *or* $\frac{620}{128}$ = *4.84p/stem*

or 1m² will service 13 crops if mobile at 64 plants/m² = 832 stems

Capital cost = $\frac{720}{832}$ = 0.87p/stem *or* $\frac{620}{832}$ = *0.75p/stem*

d. 4.8 W/m^2 throughout production

$1m^2$ will service 2 crops at 64 plants/m^2 = 128 stems

Capital cost = $\frac{309}{128}$ = 2.41p/stem *or* $\frac{266}{128}$ = *2.08p/stem*

B. Running Cost

a. 12 W/m^2 day 36-70 of S.D.

35 days at 11 hrs Standard 7.78p/kWhr <u>*or*</u> *5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 7.78 \text{ p/kWhr}}{6\text{m}^2} = 219.66\text{p/m}^2$$

$$\text{at 64 plants/m}^2 = \frac{219.66}{64} = 3.43\text{p/stem}$$

<u>*or*</u>

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 5.50 \text{ p/kWhr}}{6\text{m}^2} = 155.28\text{p/m}^2$$

$$\text{at 64 plants/m}^2 = \frac{155.28}{64} = 2.43\text{p/stem}$$

b. 4.8 W/m^2 day 36-70 of S.D.

35 days at 11 hrs Standard 7.78p/kWhr <u>*or*</u> *5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 7.78 \text{ p/kWhr}}{14\text{m}^2} = 94.14 \text{ p/m}^2$$

$$\text{at 64 plants/m}^2 = \frac{94.14}{64} = 1.47\text{p/stem}$$

<u>*or*</u>

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 35 \text{ days} \times 5.50 \text{ p/kWhr}}{14\text{m}^2} = 66.55\text{p/m}^2$$

$$\text{at 64 plants/m}^2 = \frac{66.55}{64} = 1.04\text{p/stem}$$

c. 12 W/m^2 day 47-60 of S.D.

14 days at 11 hrs Standard 7.78p/kWhr <u>*or*</u> *5.50p/kWhr*

$$\frac{0.44 \text{ kW} \times 11 \text{ hrs} \times 14 \text{ days} \times 7.78 \text{ p/kWhr}}{6\text{m}^2} = 87.86\text{p/m}^2$$

at 64 plants/m² = $\frac{87.86}{64}$ = 1.37p/stem

or *0.44 kW x 11 hrs x 14 days x 5.50 p/kWhr / 6m²* = *62.11p/m²*

at 64 plants/m² = $\frac{62.11}{64}$ = *0.97p/stem*

d. 4.8 W/m² throughout production

38 days at	15.5 hrs Standard	7.78p/kWhr	*or*	*5.50p/kWhr*
+	3.5 hrs Off-Peak	2.61p/kWhr	*or*	*3.00p/kWhr*
60 days at	11 hrs Standard	7.78p/kWhr	*or*	*5.50p/kWhr*

0.44 kW x 15.5 hrs x 38 days x 7.78 p/kWhr / 14m² = 144.02p/m²

0.44 kW x 3.5 hrs x 38 days x 2.61 p/kWhr / 14m² = 10.91p/m²

0.44 kW x 11 hrs x 60 days x 7.78 p/kWhr / 14m² = 161.38p/m²

= 144.02 + 10.91 + 161.38 = 316.31p/m²

at 64 plants/m² = $\frac{316.31}{64}$ = 4.94p/stem

or *0.44 kW x 15.5 hrs x 38 days x 5.50 p/kWhr / 14m²* = *101.81p/m²*

0.44 kW x 3.5 hrs x 38 days x 3.00 p/kWhr / 14m² = *12.54p/m²*

0.44 kW x 11 hrs x 60 days x 5.50 p/kWhr / 14m² = *114.09p/m²*

= *101.81 + 12.54 + 114.09 = 228.44p/m²*

at 64 plants/m² = $\frac{228.44}{64}$ = *3.57p/stem*

Table 2: Overall cost of treatments (1995/96)

	Capital p/stem		Running p/stem		Total p/stem	
54 plants/m² spacing						
a. 12 W/m² day 35-70 S.D:						
fixed	6.62	*(5.70)*	4.04	*(2.85)*	10.66	*(8.55)*
mobile	2.55	*(2.19)*	4.04	*(2.85)*	6.59	*(5.04)*
b. 4.8 W/m² day 35-70 S.D:						
fixed	2.84	*(2.44)*	1.73	*(1.22)*	4.57	*(3.66)*
mobile	1.09	*(0.94)*	1.73	*(1.22)*	2.82	*(2.16)*
c. 12 W/m² day 47-60 S.D:						
fixed	6.62	*(5.70)*	1.62	*(1.14)*	8.24	*(6.84)*
mobile	1.02	*(0.88)*	1.62	*(1.14)*	2.64	*(2.02)*
d. 4.8 W/m² throughout	2.84	*(2.44)*	5.81	*(4.20)*	8.65	*(6.64)*
64 plants/m² spacing						
a. 12 W/m² day 35-70 S.D:						
fixed	5.63	*(4.84)*	3.43	*(2.43)*	9.06	*(7.27)*
mobile	2.16	*(1.86)*	3.43	*(2.43)*	5.59	*(4.29)*
b. 4.8 W/m² day 35-70 S.D:						
fixed	2.41	*(2.08)*	1.47	*(1.04)*	3.88	*(3.12)*
mobile	0.93	*(0.80)*	1.47	*(1.04)*	2.40	*(1.84)*
c. 12 W/m² day 47-60 S.D:						
fixed	5.63	*(4.84)*	1.37	*(0.97)*	7.00	*(5.81)*
mobile	0.87	*(0.75)*	1.37	*(0.97)*	2.24	*(1.72)*
d. 4.8 W/m² throughout	2.41	*(2.08)*	4.94	*(3.57)*	7.35	*(5.65)*

2. COST - BENEFIT ANALYSIS FOR THE SUPPLEMENTARY LIGHTING AND SPACING TREATMENTS ASSESSED

Taking the grade-out results from the supplementary lighting treatments most effective at improving quality (i.e. 1995/96 treatments); an analysis of the cost recovery per stem required to break even against standard winter production has been outlined in the following tables.

Table 1: Comparative returns for varied spacing and lighting treatments - Efford 1995/96
Flower week 2 - (Planting week 40)

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m^2	Increased price per wrap gr. 1 only
Treatment 1a - 45/m^2, no supplementary lighting									
% Grade 1	25.37	0.15	3.81	0.00					
% Grade 2	16.59	0.11	1.82	0.00					
% Grade 3	0.53	0.05	0.03	0.00					
% Waste	2.51	-0.05	-0.13	0.00					
Total	**45.00**		**5.53**	**0.00**	5.53	**0.12**	**0.59**	**0.20**	0.99
Treatment 1b - 54/m^2, no supplementary lighting									
% Grade 1	22.63	0.15	3.39	0.00					
% Grade 2	21.11	0.11	2.32	0.00					
% Grade 3	3.97	0.05	0.20	0.00					
% Waste	6.69	-0.05	-0.33	0.00					
Total	**54.40**		**5.58**	**0.00**	5.58	**0.00**	**0.00**	**0.00**	0.00

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 1 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96**
Flower week 2 - (Planting week 40)

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m²	Increased price per wrap gr. 1 only
Treatment 2a - 54/m², 4.8 W/m² throughout production									
% Grade 1	41.34	0.15	6.20	2.75	3.45				
% Grade 2	6.36	0.11	0.70	0.42	0.28				
% Grade 3	2.67	0.05	0.13	0.18	-0.04				
% Waste	4.03	-0.05	-0.20	0.27	-0.47				
Total	54.40		6.83	3.62	3.22	4.70	23.48	5.72	28.60
Treatment 2b - 64/m², 4.8 W/m² throughout production									
% Grade 1	38.53	0.15	5.78	2.18	3.60				
% Grade 2	15.68	0.11	1.72	0.89	0.84				
% Grade 3	2.24	0.05	0.11	0.13	-0.01				
% Waste	7.55	-0.05	-0.38	0.43	-0.80				
Total	64.00		7.24	3.62	3.62	3.48	17.39	5.10	25.48

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 1 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 2 - (Planting week 40)**

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m²	Increased price per wrap gr. 1 only
Treatment 3a - 54/m², 12 W/m² days 36-70 SD									
% Grade 1	33.01	0.15	4.95	1.66	3.29				
% Grade 2	14.56	0.11	1.60	0.73	0.87				
% Grade 3	3.42	0.05	0.17	0.17	-0.00				
% Waste	3.41	-0.05	-0.17	0.17	-0.34				
Total	54.40		6.55	2.74	3.81	3.47	17.34	5.36	26.78
Treatment 3b - 64/m², 12 W/m² days 36-70 SD									
% Grade 1	36.84	0.15	5.53	1.58	3.95				
% Grade 2	17.26	0.11	1.90	0.74	1.16				
% Grade 3	3.51	0.05	0.18	0.15	0.03				
% Waste	6.39	-0.05	-0.32	0.27	-0.59				
Total	64.00		7.28	2.74	4.54	1.80	9.01	2.82	14.10

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 1 (cont.): Comparative returns for varied spacing and lighting treatments - Efford 1995/96
Flower week 2 - (Planting week 40)

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m²	Increased price per wrap gr. 1 only
Treatment 4a - 54/m², 4.8 W/m² days 36-70 SD									
% Grade 1	34.54	0.15	5.18	0.75	4.43				
% Grade 2	9.52	0.11	1.05	0.21	0.84				
% Grade 3	4.30	0.05	0.22	0.09	0.12				
% Waste	6.04	-0.05	-0.30	0.13	-0.43				
Total	54.40		6.14	1.18	4.96	1.28	6.40	1.79	8.96
Treatment 4b - 64/m², 4.8 W/m² days 36-70 SD									
% Grade 1	30.95	0.15	4.64	0.57	4.07				
% Grade 2	17.84	0.11	1.96	0.33	1.63				
% Grade 3	5.62	0.05	0.28	0.10	0.18				
% Waste	9.59	-0.05	-0.48	0.18	-0.66				
Total	64.00		6.41	1.18	5.23	0.65	3.25	1.14	5.72

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 1 (cont.): Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 2 - (Planting week 40)

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m^2	Increased price per wrap gr. 1 only
Treatment 5a - 54/m^2, 12 W/m^2 days 47-60 SD									
% Grade 1	36.61	0.15	5.49	0.74	4.75				
% Grade 2	7.02	0.11	0.77	0.14	0.63				
% Grade 3	4.30	0.05	0.22	0.09	0.13				
% Waste	6.47	-0.05	-0.32	0.13	-0.45				
Total	**54.40**		**6.16**	**1.10**	**5.06**	**1.09**	**5.47**	**1.43**	**7.17**
Treatment 5b - 64/m^2, 12 W/m^2 days 47-60 SD									
% Grade 1	32.79	0.15	4.92	0.56	4.35				
% Grade 2	10.13	0.11	1.11	0.17	0.94				
% Grade 3	7.69	0.05	0.38	0.13	0.25				
% Waste	13.39	-0.05	-0.67	0.23	-0.90				
Total	**64.00**		**5.75**	**1.10**	**4.65**	**1.84**	**9.21**	**2.84**	**14.22**

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 2: Comparative returns for varied spacing and lighting treatments - Efford 1995/96
Flower week 2 - (Planting week 40)

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m²	Increased price per wrap gr. 1 only
Treatment 1a - 45/m², no supplementary lighting									
% Grade 1	25.37	0.15	3.81	0.00					
% Grade 2	16.59	0.11	1.82	0.00					
% Grade 3	0.53	0.05	0.03	0.00					
% Waste	2.51	-0.05	-0.13	0.00					
Total	**45.00**		**5.53**	**0.00**	**5.53**	**0.12**	**0.59**	**0.20**	**0.99**
Treatment 1b - 54/m², no supplementary lighting									
% Grade 1	22.63	0.15	3.39	0.00					
% Grade 2	21.11	0.11	2.32	0.00					
% Grade 3	3.97	0.05	0.20	0.00					
% Waste	6.69	-0.05	-0.33	0.00					
Total	**54.40**		**5.58**	**0.00**	**5.58**	**0.00**	**0.00**	**0.00**	**0.00**

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 2 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 2 - (Planting week 40)**

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m^2	Increased price per wrap gr. 1 only
Treatment 2a - 54/m^2, 4.8 W/m^2 throughout production									
% Grade 1	41.34	0.15	6.20	2.75	3.45				
% Grade 2	6.36	0.11	0.70	0.42	0.28				
% Grade 3	2.67	0.05	0.13	0.18	-0.04				
% Waste	4.03	-0.05	-0.20	0.27	-0.47				
Total	54.40		6.83	3.62	3.22	4.70	23.48	5.72	28.60
Treatment 2b - 64/m^2, 4.8 W/m^2 throughout production									
% Grade 1	38.53	0.15	5.78	2.18	3.60				
% Grade 2	15.68	0.11	1.72	0.89	0.84				
% Grade 3	2.24	0.05	0.11	0.13	-0.01				
% Waste	7.55	-0.05	-0.38	0.43	-0.80				
Total	64.00		7.24	3.62	3.62	3.48	17.39	5.10	25.48

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 2 (cont.): Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 2 - (Planting week 40)

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m^2	Increased price per wrap gr. 1 only
Treatment 3a - 54/m^2, 12 W/m^2 days 36-70 SD									
% Grade 1	33.01	0.15	4.95	2.82	2.13				
% Grade 2	14.56	0.11	1.60	1.24	0.36				
% Grade 3	3.42	0.05	0.17	0.29	-0.02				
% Waste	3.41	-0.05	-0.17	0.29	-0.46				
Total	54.40		6.55	4.65	1.90	7.21	36.05	11.14	55.69
Treatment 3b - 64/m^2, 12 W/m^2 days 36-70 SD									
% Grade 1	36.84	0.15	5.53	2.68	2.85				
% Grade 2	17.26	0.11	1.90	1.25	0.64				
% Grade 3	3.51	0.05	0.18	0.26	-0.08				
% Waste	6.39	-0.05	-0.32	0.46	-0.78				
Total	64.00		7.28	4.65	2.63	5.12	25.60	8.01	40.03

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 2 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 2 - (Planting week 40)**

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m^2	Increased price per wrap gr. 1 only
Treatment 4a - 54/m^2, 4.8 W/m^2 days 36-70 SD									
% Grade 1	34.54	0.15	5.18	1.27	3.91				
% Grade 2	9.52	0.11	1.05	0.35	0.70				
% Grade 3	4.30	0.05	0.22	0.16	0.06				
% Waste	6.04	-0.05	-0.30	0.22	-0.52				
Total	**54.40**		**6.14**	**2.00**	**4.14**	**2.97**	**14.87**	**4.16**	**20.82**
Treatment 4b - 64/m^2, 4.8 W/m^2 days 36-70 SD									
% Grade 1	30.95	0.15	4.64	0.97	3.68				
% Grade 2	17.84	0.11	1.96	0.56	1.40				
% Grade 3	5.62	0.05	0.28	0.18	0.11				
% Waste	9.59	-0.05	-0.48	0.30	-0.78				
Total	**64.00**		**6.41**	**2.00**	**4.41**	**2.16**	**10.78**	**3.79**	**18.96**

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 2 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 2 - (Planting week 40)**

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.58/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.58/m^2	Increased price per wrap gr. 1 only
Treatment 5a - 54/m^2, 12 W/m^2 days 47-60 SD									
% Grade 1	36.61	0.15	5.49	2.50	2.99				
% Grade 2	7.02	0.11	0.77	0.48	0.29				
% Grade 3	4.30	0.05	0.22	0.29	-0.08				
% Waste	6.47	-0.05	-0.32	0.44	-0.77				
Total	54.40		6.16	3.72	2.44	6.56	32.80	8.59	42.95
Treatment 5b - 64/m^2, 12 W/m^2 days 47-60 SD									
% Grade 1	32.79	0.15	4.92	1.91	3.01				
% Grade 2	10.13	0.11	1.11	0.59	0.53				
% Grade 3	7.69	0.05	0.38	0.45	-0.06				
% Waste	13.39	-0.05	-0.67	0.78	-1.45				
Total	64.00		5.75	3.72	2.03	7.02	35.10	10.83	54.17

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 3: **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m^2	Increased price per wrap gr. 1 only
Treatment 1a - 45/m^2, no supplementary lighting									
% Grade 1	19.14	0.15	2.87	0.00					
% Grade 2	23.68	0.11	2.60	0.00					
% Grade 3	1.27	0.05	0.06	0.00					
% Waste	0.91	-0.05	-0.05	0.00					
Total	**45.00**		**5.49**	**0.00**	5.73	**0.25**	**1.25**	**0.57**	**2.87**
Treatment 1b - 54/m^2, no supplementary lighting									
% Grade 1	18.50	0.15	2.78	0.00					
% Grade 2	27.61	0.11	3.04	0.00					
% Grade 3	4.41	0.05	0.22	0.00					
% Waste	3.90	-0.05	-0.20	0.00					
Total	**54.42**		**5.84**	**0.00**	**5.84**	**0.00**	**0.00**	**0.00**	**0.00**

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 3 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96**
Flower week 8 - (Planting week 45)

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m^2	Increased price per wrap gr. 1 only
Treatment 2a - 54/m^2, 4.8 W/m^2 throughout production									
% Grade 1	46.14	0.15	6.92	3.07	3.85				
% Grade 2	6.53	0.11	0.72	0.43	0.28				
% Grade 3	1.55	0.05	0.08	0.10	-0.03				
% Waste	0.17	-0.05	-0.01	0.01	-0.02				
Total	54.39		7.71	3.62	4.09	3.23	16.13	3.79	18.95
Treatment 2b - 64/m^2, 4.8 W/m^2 throughout production									
% Grade 1	47.36	0.15	7.10	2.68	4.42				
% Grade 2	10.85	0.11	1.19	0.61	0.58				
% Grade 3	2.39	0.05	0.12	0.14	-0.02				
% Waste	3.40	-0.05	-0.17	0.19	-0.36				
Total	64.00		8.25	3.62	4.62	2.01	10.03	2.57	12.83

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 3 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m²	Increased price per wrap gr. 1 only
Treatment 3a - 54/m², 12 W/m² days 36-70 SD									
% Grade 1	47.26	0.15	7.09	2.38	4.71				
% Grade 2	5.81	0.11	0.64	0.29	0.35				
% Grade 3	1.16	0.05	0.06	0.06	-0.00				
% Waste	0.17	-0.05	-0.01	0.01	-0.02				
Total	54.40		7.78	2.74	5.04	1.48	7.41	1.70	8.51
Treatment 3b - 64/m², 12 W/m² days 36-70 SD									
% Grade 1	42.84	0.15	6.43	1.83	4.59				
% Grade 2	17.04	0.11	1.87	0.73	1.15				
% Grade 3	2.57	0.05	0.13	0.11	0.02				
% Waste	1.55	-0.05	-0.08	0.07	-0.14				
Total	64.00		8.35	2.74	5.61	0.36	1.82	0.53	2.66

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 3 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m^2	Increased price per wrap gr. 1 only
Treatment 4a - 54/m^2, 4.8 W/m^2 days 36-70 SD									
% Grade 1	34.00	0.15	5.10	0.74	4.36				
% Grade 2	14.00	0.11	1.54	0.30	1.24				
% Grade 3	3.95	0.05	0.20	0.09	0.11				
% Waste	2.42	-0.05	-0.02	0.05	-0.17				
Total	54.37		6.72	1.18	5.54	0.58	2.91	0.89	4.45
Treatment 4b - 64/m^2, 4.8 W/m^2 days 36-70 SD									
% Grade 1	41.96	0.15	6.29	0.77	5.52				
% Grade 2	13.59	0.11	1.49	0.25	1.24				
% Grade 3	5.19	0.05	0.26	0.10	0.16				
% Waste	3.19	-0.05	-0.06	0.06	-0.22				
Total	63.93		7.89	1.18	6.71	-1.43	-7.16	-2.07	-10.37

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 3 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming mobile lighting where appropriate

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m²	Increased price per wrap gr. 1 only
Treatment 5a - 54/m², 12 W/m² days 47-60 SD									
% Grade 1	18.05	0.15	2.71	0.36	2.34				
% Grade 2	31.21	0.11	3.43	0.63	2.80				
% Grade 3	3.09	0.05	0.15	0.06	0.09				
% Waste	2.06	-0.05	-0.10	0.04	-0.14				
Total	54.41		6.19	1.10	5.09	1.43	7.14	4.14	20.72
Treatment 5b - 64/m², 12 W/m² days 47-60 SD									
% Grade 1	16.42	0.15	2.46	0.28	2.18				
% Grade 2	39.37	0.11	4.33	0.68	3.65				
% Grade 3	4.19	0.05	0.21	0.07	0.14				
% Waste	4.02	-0.05	-0.20	0.07	-0.27				
Total	64.00		6.80	1.10	5.70	0.23	1.15	0.84	4.20

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 4: Comparative returns for varied spacing and lighting treatments - Efford 1995/96
Flower week 8 - (Planting week 45)

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m²	Increased price per wrap gr. 1 only
Treatment 1a - 45/m², no supplementary lighting									
% Grade 1	19.14	0.15	2.87	0.00					
% Grade 2	23.68	0.11	2.60	0.00					
% Grade 3	1.27	0.05	0.06	0.00					
% Waste	0.91	-0.05	-0.05	0.00					
Total	45.00		5.49	0.00	5.73	0.25	1.25	0.57	2.87
Treatment 1b - 54/m², no supplementary lighting									
% Grade 1	18.50	0.15	2.78	0.00					
% Grade 2	27.61	0.11	3.04	0.00					
% Grade 3	4.41	0.05	0.22	0.00					
% Waste	3.90	-0.05	-0.20	0.00					
Total	54.42		5.84	0.00	5.84	0.00	0.00	0.00	0.00

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 4 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m^2	Increased price per wrap gr. 1 only
Treatment 2a - 54/m^2, 4.8 W/m^2 throughout production									
% Grade 1	46.14	0.15	6.92	3.07	3.85				
% Grade 2	6.53	0.11	0.72	0.43	0.28				
% Grade 3	1.55	0.05	0.08	0.10	-0.03				
% Waste	0.17	-0.05	-0.01	0.01	-0.02				
Total	54.39		7.71	3.62	4.09	3.23	16.13	3.79	18.95
Treatment 2b - 64/m^2, 4.8 W/m^2 throughout production									
% Grade 1	47.36	0.15	7.10	2.68	4.42				
% Grade 2	10.85	0.11	1.19	0.61	0.58				
% Grade 3	2.39	0.05	0.12	0.14	-0.02				
% Waste	3.40	-0.05	-0.17	0.19	-0.36				
Total	64.00		8.25	3.62	4.62	2.01	10.03	2.57	12.83

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 4 (cont.): Comparative returns for varied spacing and lighting treatments - Efford 1995/96
Flower week 8 - (Planting week 45)

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m²	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m²	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m²	Increased price per wrap gr. 1 only
Treatment 3a - 54/m², 12 W/m² days 36-70 SD									
% Grade 1	47.26	0.15	7.09	4.04	3.05				
% Grade 2	5.81	0.11	0.64	0.50	0.14				
% Grade 3	1.16	0.05	0.06	0.10	-0.04				
% Waste	0.17	-0.05	-0.01	0.01	-0.02				
Total	54.40		7.78	4.65	3.13	5.00	25.01	5.74	28.70
Treatment 3b - 64/m², 12 W/m² days 36-70 SD									
% Grade 1	42.84	0.15	6.43	3.11	3.31				
% Grade 2	17.04	0.11	1.87	1.24	0.64				
% Grade 3	2.57	0.05	0.13	0.19	-0.06				
% Waste	1.55	-0.05	-0.08	0.11	-0.19				
Total	64.00		8.35	4.65	3.70	3.42	17.12	4.99	24.96

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 4 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m^2	Increased price per wrap gr. 1 only
Treatment 4a - 54/m^2, 4.8 W/m^2 days 36-70 SD									
% Grade 1	34.00	0.15	5.10	1.25	3.85				
% Grade 2	14.00	0.11	1.54	0.51	1.03				
% Grade 3	3.95	0.05	0.20	0.15	0.05				
% Waste	2.42	-0.05	-0.12	0.09	-0.21				
Total	**54.37**		**6.72**	**2.00**	**4.72**	**2.16**	**10.80**	**3.30**	**16.50**
Treatment 4b - 64/m^2, 4.8 W/m^2 days 36-70 SD									
% Grade 1	41.96	0.15	6.29	1.31	4.98				
% Grade 2	13.59	0.11	1.49	0.42	1.07				
% Grade 3	5.19	0.05	0.26	0.16	0.10				
% Waste	3.19	-0.05	-0.16	0.10	-0.26				
Total	**63.93**		**7.89**	**2.00**	**5.89**	**-0.08**	**-0.42**	**-0.12**	**-0.61**

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

Table 4 (cont.): **Comparative returns for varied spacing and lighting treatments - Efford 1995/96 Flower week 8 - (Planting week 45)**

Assuming fixed lighting throughout

	No. stems per grade	* Pence per grade - 5p	Income (£)	Cost of Elec./m^2	Margin (£)	Increased price, pence per stem, all grades to match £5.84/m^2	Increased price per wrap	Increased price, pence per stem, gr.1 only to match £5.84/m^2	Increased price per wrap gr. 1 only
Treatment 5a - 54/m^2, 12 W/m^2 days 47-60 SD									
% Grade 1	18.05	0.15	2.71	1.23	1.47				
% Grade 2	31.21	0.11	3.43	2.13	1.30				
% Grade 3	3.09	0.05	0.15	0.21	-0.06				
% Waste	2.06	-0.05	-0.10	0.14	-0.24				
Total	54.41		6.19	3.72	2.47	6.43	32.17	18.66	93.31
Treatment 5b - 64/m^2, 12 W/m^2 days 47-60 SD									
% Grade 1	16.42	0.15	2.46	0.95	1.51				
% Grade 2	39.37	0.11	4.33	2.29	2.04				
% Grade 3	4.19	0.05	0.21	0.24	-0.03				
% Waste	4.02	-0.05	-0.20	0.23	-0.43				
Total	64.00		6.80	3.72	3.08	4.60	22.99	16.80	83.99

* Calculated from market net price per stem minus cost of planting each stem (i.e. 5p)

APPENDIX III

CROP DIARIES

CROP DIARY

Week 40 Planting

20/09/95	Cuttings stuck and plastic covers placed over
20/09/95	Night break lighting on
20/09/95	Mycotal (1 g/l) and Vertalec (2 g/l)
30/09/95	Cuttings uncovered
04/10/95	Rovral (5 g/l)
04/10/95	Trial planted, night break lighting on
08/10/95	Thiodan (2 ml/l)
13/10/95	Feeding commenced
15/10/95	Malathion (1.8 ml/l)
22/10/95	Malathion (1.8 ml/l)
23/10/95	B-Nine (1 g/l) - Splendid Reagan only
29/10/95	Thiodan (2 ml/l)
01/11/95	Start of short days (night break lighting off)
05/11/95	Malathion (1.8 ml/l)
10/11/95	Pirimor (0.5 g/l)
12/11/95	Dichlorvos (1 ml/l)
14/11/95	Start of interruption treatment 2
15/11/95	Start of interruption treatments 1, 3-5
19/11/95	Thiodan (2 ml/l)
21/11/95	Draza pellets
21/11/95	Decis (0.7 ml/l)
24/11/95	End of interruption treatment 2
25/11/95	End of interruption treatments 1, 3-5
26/11/95	Malathion (1.8 ml/l)
03/12/95	Dichlorvos (1 ml/l)
10/12/95	Thiodan (2 ml/l)
12/12/95	Disbudding commenced
17/12/95	Malathion (1.8 ml/l)
24/12/95	Dichlorvos (1 ml/l)
31/12/95	Thiodan (2 ml/l)

CROP DIARY

Week 45 Planting

25/10/95	Cuttings stuck and plastic covers placed over
25/10/95	Night break lighting on
25/10/95	Mycotal (1 g/l) and Vertalec (2 g/l)
03/11/95	Cuttings uncovered
07/11/95	Rovral (0.5 g/l)
08/11/95	Trial planted, night break lighting on
12/11/95	Malthion (1.8 ml/l)
19/11/95	Thiodan (2 ml/l)
21/11/95	Draza pellets
21/11/95	Decis (0.7 ml/l)
26/11/95	Malathion (1.8 ml/l)
27/11/95	B-Nine (1 g/l) - Splendid Reagan only
03/12/95	Dichlorvos (1 ml/l)
06/12/95	Start of short days (night break lighting off)
10/12/95	Thiodan (2 ml/l)
17/10/95	Malathion (1.8 ml/l)
22/12/95	Pirimor (0.5 g/l)
23/12/95	Start of interruption - treatment 2
24/12/95	Start of interruption - treatments 1, 3-5
31/12/95	Thiodan (2 ml/l)
02/01/96	End of interruption - treatment 2
03/01/96	End of interruption - treatments 1, 3-5
03/01/96	B-Nine (1.5 g/l) - Splendid Reagan only
07/01/96	Malathion (1.8 ml/l)
14/01/96	Dichlorvas (1 ml/l)
21/01/96	Thiodan (2 ml/l)
19/01/96	Disbudding commenced
28/01/96	Malathion (1.8 ml/l)
04/02/96	Dichlorvos (1 ml/l)
11/02/96	Thiodan (2 ml/l)

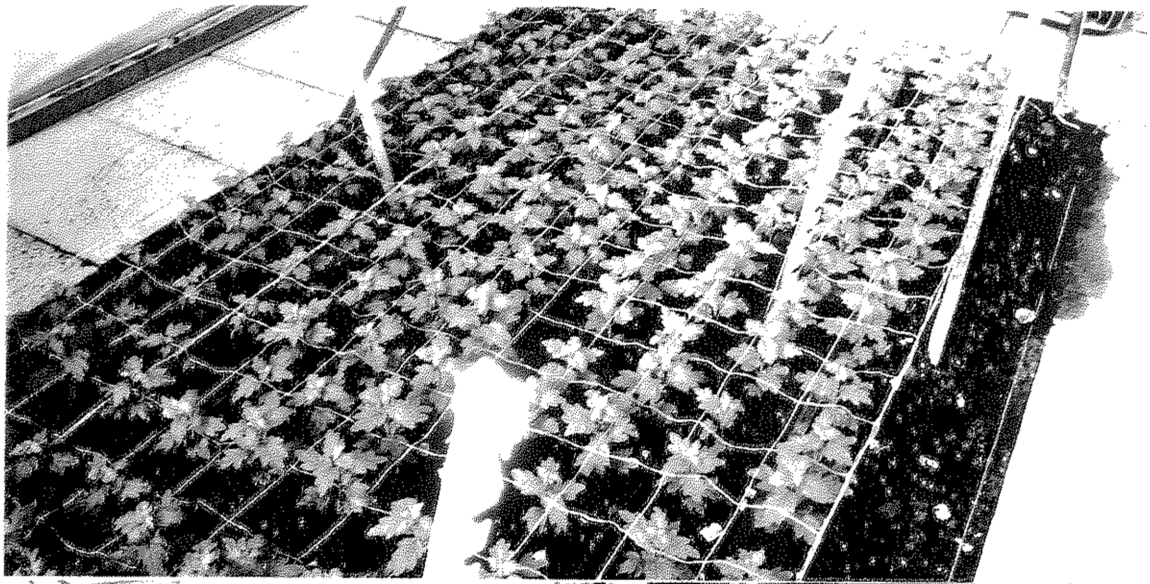
APPENDIX IV

PHOTOGRAPHIC RECORDS

APPENDIX IV

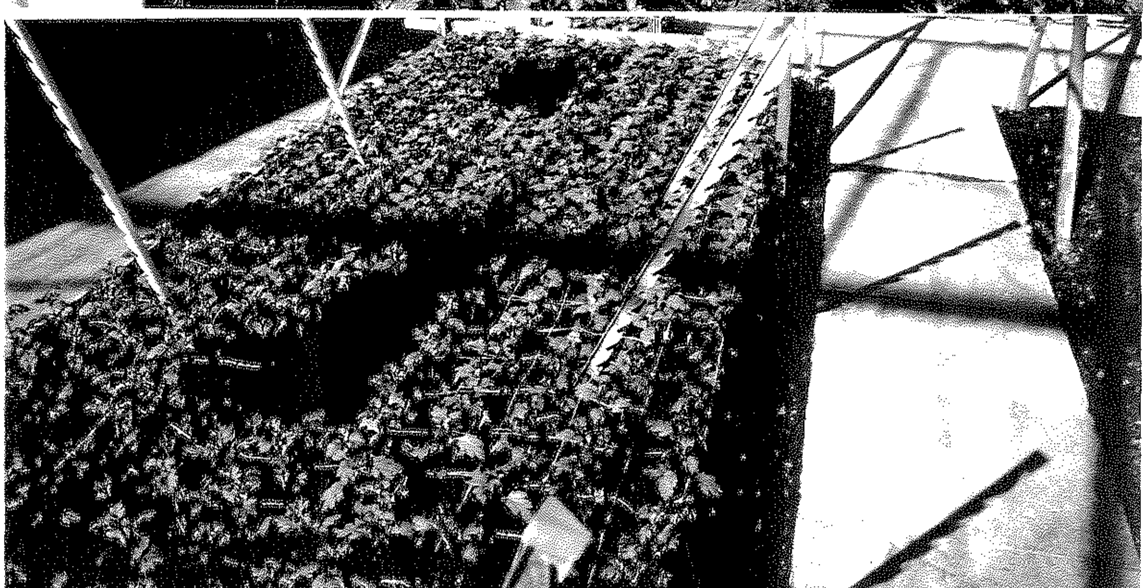
Plate 1. Layout of the three spacing treatments 45, 54 and 64 plants/m^2 planted using an even spacing arrangement (1994/95)

45 plants/m^2



54 plants/m^2

64 plants/m^2



APPENDIX IV

Plate 2. Illustration of differences in rates of bud initiation for 1994/95 treatments

Treatment 1 - No supplementary lighting

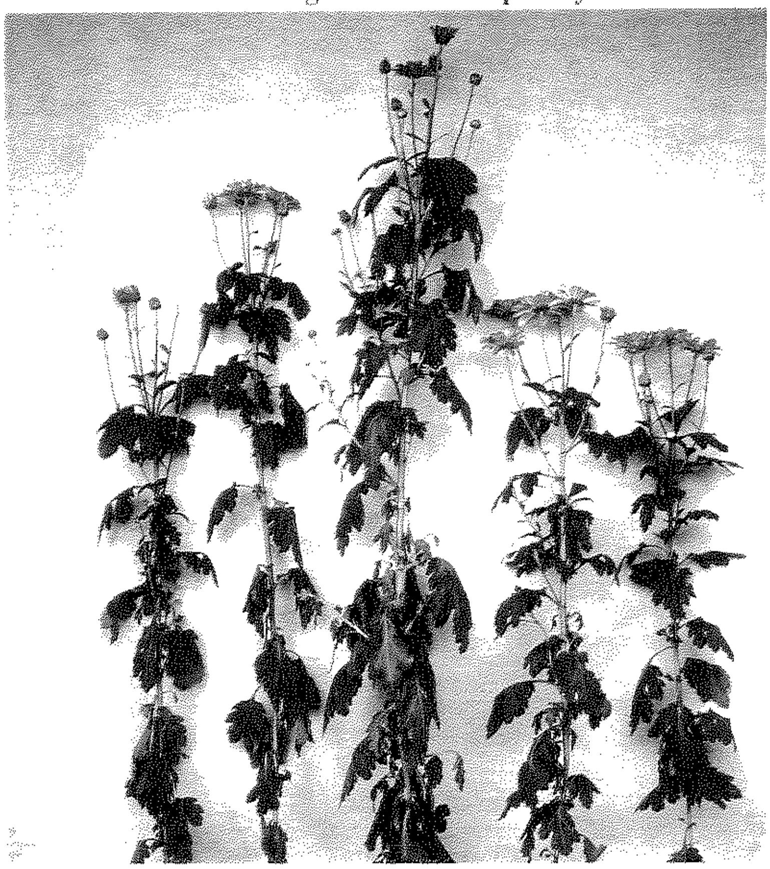
Treatment 2 - 4.8 W/m^2 throughout production

Treatment 3 - 12 W/m^2 during long days only

APPENDIX IV

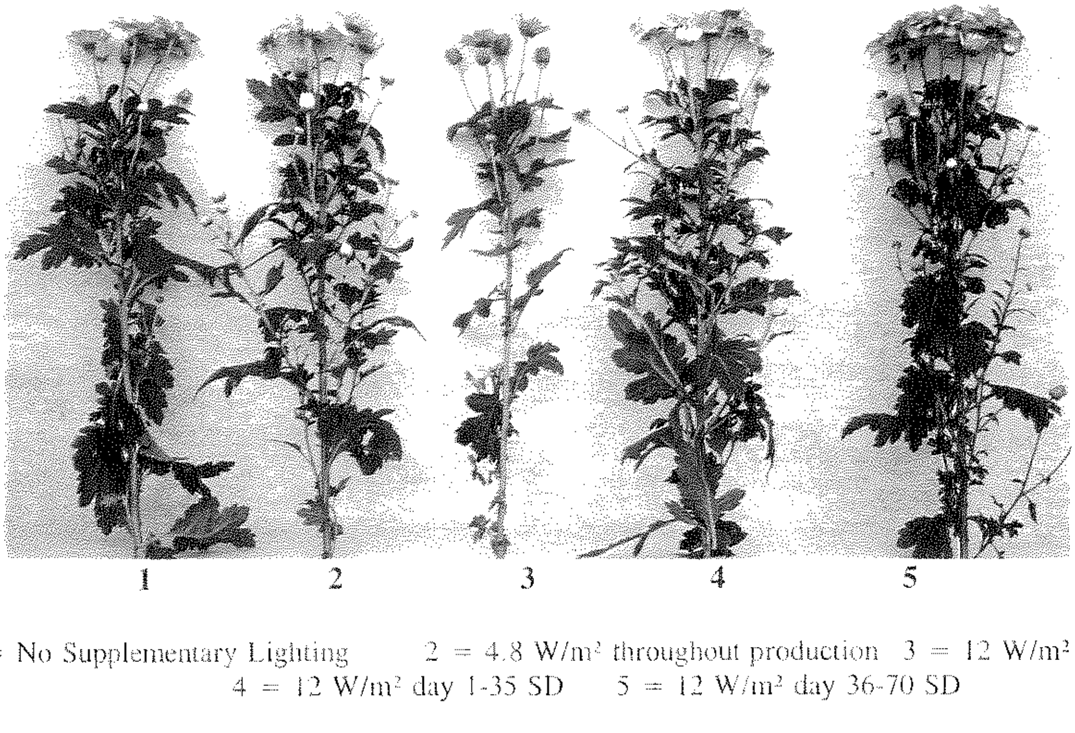
Plate 3. Lighting Treatment Effects on Final Product - Splendid Reagan (1994/95)

Whole plants to show effects on stem length and final quality:



1 2 3 4 5

Stems cut to sleeve length to focus on final quality:



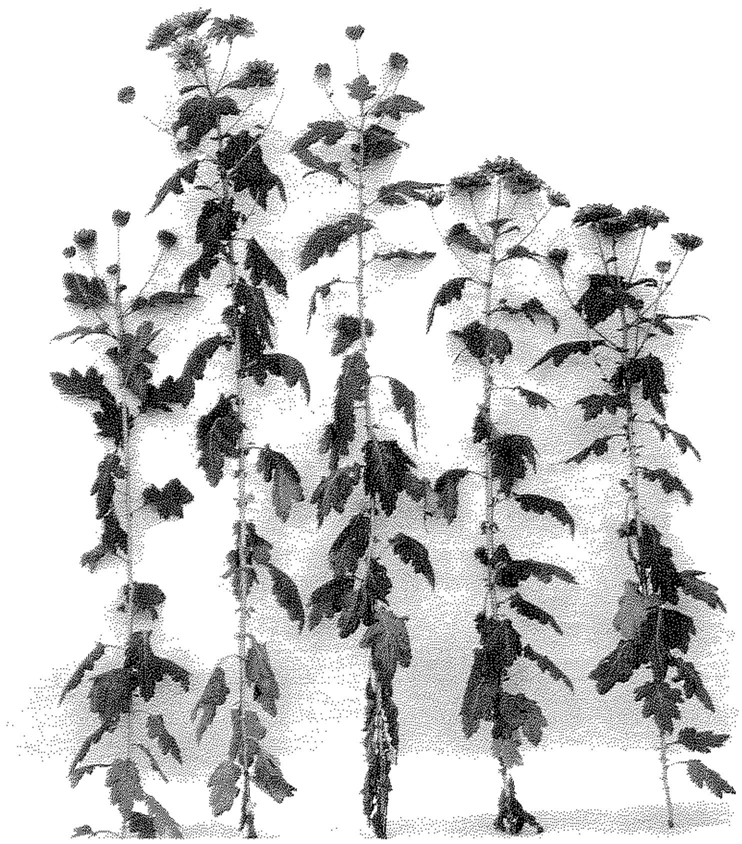
1 2 3 4 5

1 = No Supplementary Lighting 2 = 4.8 W/m^2 throughout production 3 = 12 W/m^2 LD
4 = 12 W/m^2 day 1-35 SD 5 = 12 W/m^2 day 36-70 SD

APPENDIX IV

Plate 4. Lighting Treatment Effects on Final Product - Dark Cerise Delta (1994/95)

Whole plants to show effects on stem length and final quality:



1 2 3 4 5

Stems cut to sleeve length to focus on final quality:

1 2 3 4 5

1 = No Supplementary Lighting 2 = 4.8 W/m^2 throughout production 3 = 12 W/m^2 LD
4 = 12 W/m^2 day 1-35 SD 5 = 12 W/m^2 day 36-70 SD

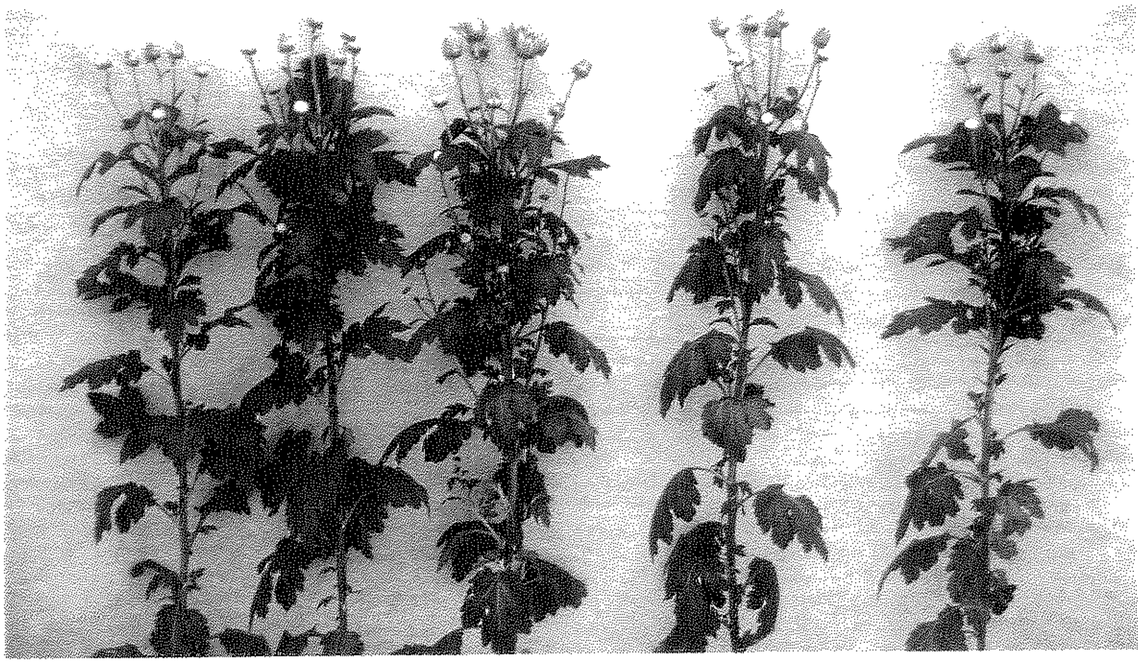
APPENDIX IV

Plate 5. Lighting Treatment Effects on Final Product - Splendid Reagan (1995/96)

Whole plants to show effects on stem length and final quality:

1 2 3 4 5

Stems cut to sleeve length to focus on final quality:



1 2 3 4 5

1 = No Supplementary Lighting 2 = 4.8 W/m^2 throughout production 3 = 12 W/m^2 day 1-35 SD
4 = 4.8 W/m^2 day 36-70 SD 5 = 12 W/m^2 day 47-60 SD

APPENDIX IV

Plate 6. Lighting Treatment Effects on Final Product - Dark Cerise Delta (1995/96)

Whole plants to show effects on stem length and final quality:

1 2 3 4 5

Stems cut to sleeve length to focus on final quality:

1 2 3 4 5

1 = No Supplementary Lighting 2 = 4.8 W/m² throughout production 3 = 12 W/m² day 1-35 SD
4 = 4.8 W/m² day 36-70 SD 5 = 12 W/m² day 47-60 SD

APPENDIX V

REFERENCES

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

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Langton, F.A. and Hammond S.L.J. 1994. Weighing the benefits of chrysanthemums. Grower 121 (12) 19, 20, 22.

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Wilson, D.P. 1994b. 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.

APPENDIX VII

COPY OF CONTRACT TERMS AND CONDITIONS

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

1. TITLE OF PROJECT

Contract No: PC104

CHRYSANTHEMUMS: AN ASSESSMENT OF THE INTERACTION BETWEEN SUPPLEMENTARY LIGHTING AND SPACING ON THE WINTER QUALITY OF AYR CHRYSANTHEMUMS

2. BACKGROUND AND COMMERCIAL OBJECTIVE

Even in the most favoured areas of the British Isles, there are three months of the winter when solar radiation levels are below the minimum required for satisfactory growth of chrysanthemums. Low light levels reduce the rate of growth and affect the rate of bud initiation, hence winter schedules are longer and quality is generally poorer compared with production in the summer. Timing the short day interruption in winter is also complicated by the low and variable solar radiation levels experienced.

Supplementary lighting has now become a recognised technique for the production of pot chrysanthemums during the winter period. Trial work initially at Lee Valley EHS and latterly at HRI Efford has clearly demonstrated that high intensity supplementary lighting can be effective on a commercial scale for both increasing the rate of bud initiation and hence reducing cropping time and improving pot quality. This work has also identified suitable lighting protocols for a range of commercial varieties with full economic evaluations.

The two most effective protocols emerging from these studies are:

i. Lighting at 4.8 W/m^2 (2000 lux) throughout the short day period.

ii. Lighting at 12 W/m^2 (5000 lux) for the first three weeks of short days.

The potential for improving winter quality of AYR Chrysanthemums through supplementary lighting is already well recognised in Holland and increasing numbers of growers are adopting this technique. It is therefore important to assess how the UK industry may best compete with imports grown under lighting.

If supplementary lighting is to be taken up by the UK industry for AYR production similar work is required for the production of commercial spray varieties. Principally work is required to quantify the potential benefits of lighting commercial varieties and to identify appropriate lighting protocols since intensity and timing have clearly been important in previous studies.

To reduce the impact of poor light levels on winter crops it is common practice for growers to plant at lower densities (typically around 85% compared with 100-110% in summer) to increase the light received by individual plants through reduced shading. Furthermore it has been demonstrated by work at HRI Littlehampton (Langton, 1993) that the weight of a stem produced is directly related to spacing of plants in a bed. The potential benefits achieved with reduced plant spacing therefore need to be assessed both economically and in terms of plant quality against those achieved with supplementary lighting.

Hence, the following studies are proposed:

i. To evaluate supplementary lighting intensity and timing of application on the rate of growth and quality of AYR chrysanthemum varieties produced over the winter period.

ii. To examine the interaction of spacing and lighting techniques on the rate of growth and quality of commercial AYR chrysanthemum varieties produced over the winter period.

iii. To evaluate supplementary lighting and spacing treatments economically.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

High intensity supplementary lighting for AYR chrysanthemums may be used to:

(a) improve the quality of product during the winter period.

(b) decrease the total production time and hence increase productivity.

(c) optimise spacing according to light conditions and hence number of plants produced per square metre.

(d) potentially substitute for imported product from Holland grown with the benefit of supplementary lighting.

These factors may be combined and balanced against production costs to maximise returns and a financial evaluation of the treatments will also be included.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

The quantitative and qualitative influence of supplementary lighting and spacing on the winter production of AYR chrysanthemums will be investigated. The effect of treatment on plant height, fresh and dry weight, rate of bud initiation and nutrient status will be examined at the final harvest stage. The influence of solar radiation will be monitored and compared over two winter grown crops establishing at different times in the winter period and hence in different natural light conditions. The effects on crop variability will be studied.

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

HDC funded work on supplementary lighting has provided an ongoing subject of investigation over the past few years at HRI Efford and Lee Valley EHS, and is likely to continue in 1994/95.

Studies on spacing in AYR chrysanthemums in natural light conditions have been funded by MAFF at HRI Littlehampton and have determined principles of response.

6. DESCRIPTION OF THE WORK

In assessing the effectiveness and economics of supplementary lighting, the following treatments will be compared:

i. No supplementary lighting.

ii. Supplementary lighting at 4.8 W/m^2 (2000 lux) from planting to harvesting.

iii. Supplementary lighting at 12 W/m^2 (5000 lux) during the long day period.

iv. Supplementary lighting at 12 W/m^2 (5000 lux) for the first five weeks following the start of initial short days.

v. Supplementary lighting at 12 W/m^2 (5000 lux) for weeks 6 to 10 following the start of initial short days.

Supplementary lighting will be provided by 400 W high pressure sodium (SONT) lamps for 19 hours per day during long days and for 11 hours from 0700 to 1800 during short days.

All treatments will receive 28 long days. Interruptions will be timed as necessary according to light received by length of interruption will be standard at 10 days for all treatments. The temperature regime for all treatments will be maintained as 18°C day and 19°C night.

The interaction of supplementary lighting with spacing will be assessed through comparisons of the following treatments:

a. Spacing at 45 plants per m^2 (70%) and 54.4 plants per m^2 (85%) for unlit crops.

b. Spacing at 54.4 plants per m^2 (85%) and 64 plants per m^2 (100%) for crops receiving supplementary lighting.

These treatments will be compared on two separate planting dates to evaluate the influence of different natural light conditions at different stages of crop development. The following sticking and planting dates will therefore be compared:

Planting I	Sticking in week 38 with planting in week 40
Planting II	Sticking in week 43 with planting in week 45.

Splendid Reagan and Cerise Delta will be grown to represent commercial varieties in current production.

The above treatments will be evaluated through assessments on the following occasions:

1. 2 days before the start of short days.

2. 5 weeks following the start of short days.

3. At maturity.

I. On each of these occasions, a destructive sample of plants will be assessed by recording the following measurements:

i) Stem length (cm)
ii) Fresh weight (g)
iii) Dry weight (g)
iv) Leaf number
v) Leaf mineral analysis.

II. A further non-destructive sample will also be recorded on each occasion for plant height in situ to assess extent of plant variability.

III. Additional records at maturity will include:

i) Number of harvests on each plot and date of each harvest.

ii) Grade out of harvested stems from each plot recording number and weight of the wraps produced in marketing grades 1, 2 and 3.

iii) Shelf-life.

IV. Daily monitoring of solar radiation levels.

V. Photographic record as appropriate.

7. COMMENCEMENT DATE, DURATION AND REPORTING

Start date 01.10.94; duration 10 months. The experimental work will be completed by early Spring, 1995 and the final report will be produced by 31 July 1995.

September 1995 in original but agreed new date by phone

8. STAFF RESPONSIBILITIES

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

9. LOCATION

HRI Efford (E-Block) (Bed dimensions approx. $15m^2$).

Contract No: PC104
Date: 21.9.94

TERMS AND CONDITIONS

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

Signed for the Contractor(s)

Signature..

Position..

Date..

Signed for the Contractor(s)

Signature..

Position..

Date..

Signed for the Council

Signature....J Murray....................
E.J. Kennedy

Position. PP CHIEF EXECUTIVE

Date......21-9-94..................

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

PC104
(extension for a second year)

1. TITLE OF PROJECT

CHRYSANTHEMUMS: AN ASSESSMENT OF THE INTERACTION OF SUPPLEMENTARY LIGHTING AND SPACING ON WINTER QUALITY

2. BACKGROUND AND COMMERCIAL OBJECTIVE

As for PC104

The potential for improving winter quality of AYR Chrysanthemums through supplementary lighting is already well recognised in Holland and increasing numbers of growers are adopting this technique. It is therefore important to assess how the UK industry may best compete with imports grown under lighting.

If supplementary lighting is to be taken up by the UK industry for AYR production similar work is required for the production of commercial spray varieties. Principally work is required to quantify the potential benefits of lighting commercial varieties and to identify appropriate lighting protocols since intensity and timing have clearly been important in previous studies.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

As for PC104

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

As for PC104

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

As for PC104

6. DESCRIPTION OF THE WORK

Year 1 - As for PC104, except that the first planting was abandoned because of difficulties with plant establishment.

Year 2

In assessing the effectiveness and economics of supplementary lighting, the following treatments will be compared:

i. No supplementary lighting.

ii. Supplementary lighting at 4.8 W/m^2 (2000 lux) from planting to harvesting.

iii. Supplementary lighting at 12 W/m^2 (5000 lux) from day 36 following the start of initial short days until day 70.

iv. Supplementary lighting at 4.8 W/m^2 (2000 lux) from day 36 following the start of initial short days until day 70.

v. Supplementary lighting at 12 W/m^2 (5000 lux) from day 47 following the start of initial short days until day 60.

Supplementary lighting will be provided by 400 W high pressure sodium (SONT) lamps for 19 hours per day during long days including the interruption, and for 11 hours from 0700 to 1800 during short days.

All treatments will receive 28 long days. Interruptions will be timed as necessary according to light received but length of interruption will be standard at 10 days for all treatments. The heating set points for all treatments will be 18^0C day and 19^0C night with ventilation at 24°C.

The interaction of supplementary lighting with spacing will be assessed through comparisons of the following treatments:

a. Spacing at 45 plants per m^2 (70%) and 54.4 plants per m^2 (85 %) for Unlit crops.

b. Spacing at 54.4 plants per m^2 (85%) and 64 plants per m^2 (100%) for crops receiving supplementary lighting.

These treatments will be compared on two separate planting dates to evaluate the influence of different natural light conditions at different stages of crop development. The following sticking and planting dates will therefore be compared:

Planting I Sticking in week 38 with planting in week 40

Planting II Sticking in week 43 with planting in week 45.

Splendid Reagan and Cerise Delta will be grown to represent commercial varieties in current production.

The above treatments will be evaluated through assessments on the following occasions:

1. 2 days before the start of short days.

2. 35 days following the start of initial short days.

3. At maturity.

I. On each of these occasions, a destructive sample of plants will be assessed by recording the following measurements:

   i) Stem length (cm)
   ii) Fresh weight (g)
   iii) Dry weight (g)
   iv) Leaf number

   A record will be kept of position in the bed for each plant assessed.

II. A further non-destructive sample will also be recorded on each occasion for plant height *in situ* to assess extent of plant variability.

III. Additional records at maturity will include:

   i) Number of harvests on each plot and date of each harvest.

   ii) Grade out of harvested stems from each plot recording number and weight of the wraps produced in marketing grades 1, 2 and 3.

   iii) Separate fresh and dry weight records on flowers and leaves plus stems for each plant destructively sampled.

   iv) Shelf-life.

IV. Daily monitoring of solar radiation levels.

V. Photographic record as appropriate.

7. Commencement date and duration:

Growing season October 1995 - February 1996.
Reporting: September 1997.

8. Staff Responsibilities:

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

9. Location:

HRI Efford (E-Block) (Bed dimensions approx. $15m^2$).

7. COMMENCEMENT DATE, DURATION AND REPORTING

Start date 01.10.94; duration 2 years (10 months pa.) The experimental work will be completed by early Spring in each year. The report for year 1 will be produced by 31 July 1995 and the trial report (including all the data presented in the first year report) will be produced by 31 July 1996.

8. STAFF RESPONSIBILITIES

As for PC104

9. LOCATION

As for PC104

Contract No: PC104
Extension for second year

TERMS AND CONDITIONS

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

Signed for the Contractor	Signature..
	Position....C&H Manager HR1....
	Date.........18/1/98.........
Signed for the Council	Signature..
	Position....CHIEF EXECUTIVE....
	Date.........1.6.99.........