CONTRACT REPORT

Supplementary lighting techniques to improve the quality of early-season Begonia elatior.

HDC PC 146

Final Report 1997-98

Begonia elatior var. Annebell produced using 12 W/m^2 during the first and last 5 weeks of production, with 2 weeks ambient lighting during the 1/2 spacing phase.

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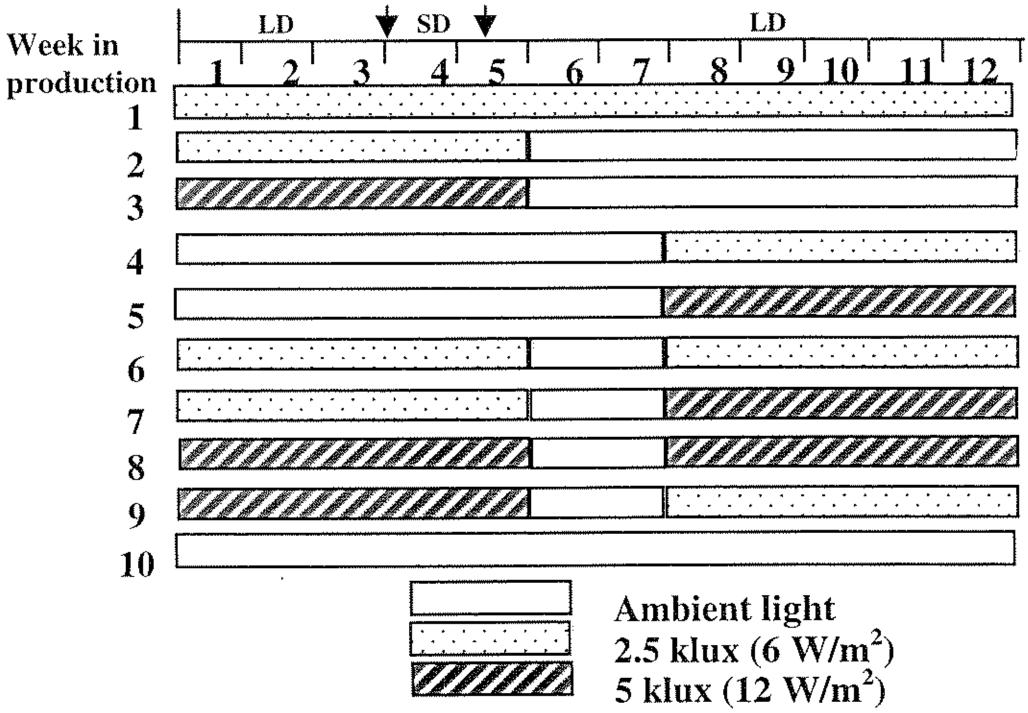
1 PRACTICAL SECTION FOR GROWERS

1.1 Background and Introduction

Previous HDC-funded research has identified optimal supplementary lighting regimes for winter pot mum production. Judicious use of supplementary lighting has resulted in increased plant bulk, improved flowering and flower colour during a period when ambient light levels are lowest. Growers on the continent routinely use supplementary lighting throughout production in the winter period out of necessity, as their ambient light levels are often worse than in the UK. This produces better quality plants than unlit in the UK, prompting growers to consider use of supplementary light for their winter Begonia crops. This project considers use of supplementary lighting in the most cost effective way while still maintaining quality.

The trial during the winter and spring of 1997 – '98 studied the impact of a range of supplementary lighting treatments on the growth and quality in two varieties of Begonia elatior with contrasting characteristics: Annebell (yellow) and Dark Netja (Pink). The treatment combinations provided lighting at 3 levels (ambient background, ambient + 6 or +12 W/m^{-2}) either at the beginning of production, at the end, or at both times. These regimes were compared with crops either lit throughout at 6 W/m^{-2} (commercial standard), or grown using ambient light only.

The above light levels were combined to produce the following 10 production lighting regimes:



In order to determine the effects of lighting treatment alone, time of pinching, growth regulation and nutrition were applied to all treatments according to the requirements of the commercial standard.

Plants were potted in weeks 47 and 51 for Mother's Day and Easter marketing (respectively). All plots were given 3 weeks of long days (18 h/d) followed by 10 short days before being returned into long days. Compartment temperatures were controlled to 20°C D/N.

At marketing, a sub-set of pots from each plot was transferred into a controlled shelf-life environment for assessment of post-harvest performance.

In addition to the crop data, a costing was generated to compare the lamp running costs in each lighting treatment.

Objectives

- To examine the potential for manipulating the intensity and timing of supplementary lighting to make efficient use of this technique to improve winter quality.

- To identify how lighting regimes may influence post-harvest performance.

1.2 Summary of results

Effects of lighting treatments during production:

- At pinching, plants started in the highest lighting regime (12 W/m^{-2}) were significantly bulkier, with more new leaves and thicker stems, than in the other treatments.

- The level of supplementary lighting had very little impact on crop duration, but duration was significantly reduced in all lit crops compared to those produced in ambient light.

- In addition to increased duration, there was a general reduction in plant bulk, number of breaks and vigor of rooting in ambient-grown crops.

- Production at 12 W/m^{-2} either at the start and end, or at the end only resulted in a 10% increase in dry matter at marketing.

- Plants produced under 12 W/m^{-2} were more compact than in the 6 W/m^{-2} or ambient treatments indicating that there may be potential for reductions in the use of plant growth regulators in the highest light treatments.

- Supplying high light during production stimulated a marked increase in the proportion of double flowers produced at marketing. Correlated with this, was an increase in single flower production in the ambient crop, particularly in the week 47 potting, when light levels were lowest during flower initiation.

- The most cost-effective time to apply high levels of assimilation lighting was during the first five weeks of production when pots were at close spacing. Even supplying 12 W/m^2 for the first and then 6 W/m^2 for the last 5 weeks was not any more expensive than the commercial standard (lamp running costs only).

- Lighting at the end of production was not only costly at final spacing, but also did not produce the benefits in plant quality or form compared to plants lit at the start of production only.

- During the final 3 weeks of production, there were fluctuations in nutrition, with increasing pH and decreasing calcium and magnesium contents in the compost observed across all lighting treatments. Plants under the high light regimes appeared to be sensitive to these fluctuations, producing excessively large leaves at the top of the canopy, chlorotic foliage and clumped flowers, none of which were observed in plants grown throughout or finished in ambient light. Further work will address the interactions between lighting, nutrition and plant form / quality during the winter.

Effects of lighting treatments on post-harvest performance:

- Plants produced or finished in ambient light benefited from continued flower opening during shelf-life, with much higher rates of flower opening during the sleeved phase (in the retail outlet) than in any of the lit treatments.

- This trend resulted in ambient grown plants retaining more flowers during shelf-life than in the lit treatments.

- Buds produced in the supplementary lighting treatments did not continue to open during shelf-life in the same way as in ambient-grown plants, indicating that pre-adaptation to low light levels during production may favour continued flower development in ambient-finished pots post-harvest.

Effect of light levels at the end of production on net flower gain / loss during shelf-life.

Lighting Treatment	6 W/m^{-2} throughout	6 W/m^{-2} finished	12 W/m^{-2} finished	Ambient finished
Net gain / loss of flowers	-5.64	-3.84	-5.07	+4.02

5% LSD: 5.66 when comparing 6 W/m^{-2} throughout with other treatments
4.00 when comparing means of treatments finished at 6, 12 W/m^{-2}

- Post-harvest performance could not be related directly to production lighting regime as the data were, to some extent, confounded with the differential effects of fluctuating nutrition. This is an important area for further research.

1.3 Action points for growers

- Good quality crops were produced under the standard 6 W/m^2 lighting regime throughout production.

- Given that the initial capital investment had been made, estimates of the lamp running costs showed that it was cost-effective to light crops using 12 W/m^2 early in production, but probably prohibitively expensive to run lighting at this level when pots were at final spacing. By running at 12 W/m^2 for 5 weeks, then with ambient light for the ½ space phase and finishing at 6 W/m^2 for 5 weeks at final spacing, it proved possible to use this lighting regime without adding to the cost of the commercial standard treatment (6 W/m^2 throughout).

- Lighting at 12 W/m^2 was most cost-effective early in production when pots were close together, producing significant increases in bulk early on. Lighting at the start of production was most important if any benefits of supplementary lighting later on were to be obtained (by creating a balanced plant).

- It was not cost-effective to light at the end of production only, and there was no evidence to suggest that plant quality or form was enhanced by lighting during this phase.

- There was some evidence that finishing the crop under lower light levels (ambient) may be beneficial for improving post-harvest performance of flower buds (particularly in the week 47 potting). This may be mediated by pre-adaptation of plants to the lower light levels characteristic of home environments.

- Finishing crops under high levels of supplementary light (12 W/m^2) resulted in higher incidence of "elephant ear" and leaf chlorosis, both of which may be associated with nutrient imbalance.

- Future trials should address the interactions between lighting and nutrition and their effects on post-harvest performance.

1.4 Practical and anticipated financial benefits

- From the current trial data, growers can clearly benefit from high levels of supplementary lighting early in production to generate bulkier plants at marketing, but there were some quality defects that should be addressed with further work.

- The use of high levels of assimilation lighting resulted in more compact plants. This highlights potential savings in the numbers of applications of plant growth regulators needed to produce the crop under high light conditions (together with associated savings in labour and chemical costs).

- From the current trial, the full implications of using high supplementary light levels during production for improved product quality and post harvest performance cannot be fully assessed until the interactions between lighting and nutrition have been addressed.

- Overall, the use of any supplementary lighting reduced crop duration and gave more reliable scheduling than in crops produced under ambient light conditions.

2 SCIENCE SECTION

2.1 Introduction

Low light levels over the winter period in the UK restrict the quality of production of a range of ornamental plants grown in protected environments. Supplementary lighting can be used to offset these difficulties, but does require significant capital investment. Growers therefore need to be sure of the most efficient method of using supplementary lighting to optimise the returns for their product. The significant differences resulting from manipulating both the intensity and timing of the application of supplementary lighting within a commercial situation has been shown with recent HDC funded studies on pot- as well as spray chrysanthemums (PC 92 / 13b / 104). Lighting for relatively short phases during the production period can save on the investment required and is particularly well suited to production of pot plants, where movement of benches of plants between lit and unlit blocks within the glasshouse is possible. The benefits that have been achieved with this approach for chrysanthemums include reduced total production time by lighting early in the short day period, whilst lighting during the period of bud development can significantly improve flower and foliage quality as well as stimulating increases in plant bulk. All of these factors contribute to potential cost-benefits to the grower together with increased and more reliable markets for a superior product.

In the same way as supplementary lighting has been successfully implemented for chrysanthemum, there is considerable scope for its use with Begonia elatior, particularly for improving early season production. Improving the quality of products reaching the market place in early March for Mothers Day could provide added incentive to growers to invest in lighting for production at this time of year with the potential of increased returns offseting the costs of supplying lighting.

In addition to the potential benefits in marketing a product with greater consumer appeal through brighter flowers, greener leaves and bulkier plants, the use of supplementary lighting may have significant implications for post-harvest performance of the plants. In a marketing environment which is making more demands on the producer to ensure customer satisfaction, the home-life performance of pot plants is becoming an increasingly important factor, with multiples expecting to offer guarantees on pot plants to the consumer. If supplementary lighting were to provide a more reliable post-harvest performance, it would be another factor in helping to offset the costs of the lighting.

2.2 Objectives

i. Examine the potential for manipulating the intensity and timing of supplementary lighting to make efficient use of this technique to improve winter quality.

ii. Identify how lighting regimes may influence post-harvest performance.

iii. Provide an estimate of lighting treatment running costs in the form of a simple versatile spreadsheet.

2.3 Material and Methods

2.3.1 Glasshouse site

K Block: compartments 3, 4 ,7 & 8

2.3.2 Trial description

Treatments (see appendix 1 for treatment allocation within K Block)

- **2 potting dates**: weeks 47 and 51 (for the Mother's Day and Easter markets respectively)

- **2 varieties** : Dark Netja and Annebel

- **3 light levels**: - Ambient
  - Ambient plus 2.5 klux (6 W/m^2)*
  - Ambient plus 5 klux (12 W/m^2)*

* supplementary lighting supplied using SON-T 400W plus bulbs in POOT-9 E medium luminaires.

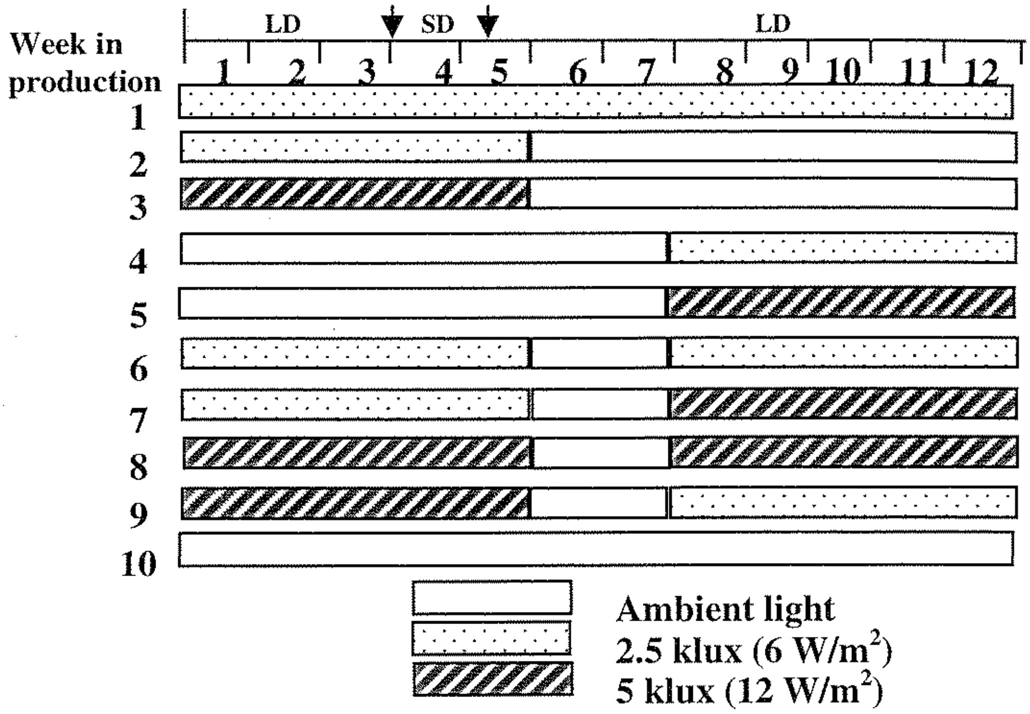
Three key periods for lighting were examined:

i. Lighting throughout production (at 2.5 klx; = commercial standard)).

ii. Lighting during the pot thick phase of production (i.e. when maximum number of plants could be lit per lamp).

iii. Lighting for the last 5 weeks of production only (i.e. aiming to commence lighting from the point when buds were just visible in the growing point but had not developed colour).

The above light levels were applied during production in the following 10 combinations:



Treatment 1 was used as the industry commercial standard. In order to determine the effects of lighting treatment alone, the time of pinching, growth regulation and nutrition were applied to all treatments according to the requirements of the commercial standard. Although the concentration of nutrients in the irrigation was the same for all treatments, the fact that more watering was required under the high light regimes meant that these treatments received more feed in total than lower light levels. All plots were given 3 weeks of long days (for 18 hours / day) followed by 10 short days to give positive flower initiation, and then back into long days (in the ambient treatment, tungsten bulbs were used to maintain long days).

Experimental design and analysis

Design: The trial was set out as a two-replicate split plot design, with potting date applied as a main plot treatment, and variety and lighting as sub-plot treatments. Different lighting levels were applied within separate compartments, with plots for different lighting treatments moved between compartments. Plants were randomly allocated to lighting regime at the start of the trial, so lighting regime was applied at the sub-plot level. For plot layouts, see appendix 2.

	2	varieties
x	10	lighting treatments
x	2	replicates
x	2	pot dates (week 47 & 51)
	=	80 plots (40 plots / potting date)

Plot size = 32 ((4 rows of 8 pots) with 15 recorded pots / plot).

2.3.3 Cultural Techniques

- **Propagation:** Rooted cuttings were sourced from Frede Larsen (Denmark) and potted in 13C pots using SHL Begonia compost prior to moving into treatments.

- **Schedule:** Plants were pot thick (59/m^2) for up to five weeks, spaced through ½ space (30 pots/m²; pot-pot spacing 18.2 cm; row-row 12.9 cm) for approximately two weeks, with final spacing at 23 pots/m² (pot-pot spacing 20.9 cm; row-row 14.7 cm). Timing of spacing was managed as required to maintain plant form in each treatment (within the limits defined above). In order to avoid stress to the young plants, in K Block, where humidity was generally lower than in commercial blocks (due to concrete floors and small compartment area with high roof), spacing had to go through more gradual steps than generally practised in the industry. Plants were pinched approximately one week after potting (when the plants had three mature leaves) by removal of the tip (soft pinch), according to plant vigour in each treatment.

  Long days were given for the first three weeks after potting, achieved with 18 hours of assimilation lighting from midnight (taking advantage of the low tariff) where plants received supplementary lighting treatments. In the ambient lighting treatment, continuous night break lighting was applied from 22:00 to 04:00 each night (with tungsten lamps set to give a minimum of 0.5 W/m² at plant height). After the initial long day phase, plants received an inductive short day (SD) period for two weeks (SD's were applied on week days only and not weekends i.e. for 10 working days). During the SD phase assimilation lighting was either: applied for 11 hours per day (when a whole compartment could be treated as a unit), or blacked out from 16:00 in the evening until 07:30 the next morning in the ambient compartments. After 2 weeks of SDs, pots were returned to LD conditions as described above.

  When week 47 plants in the second LD phase overlapped with week 51 pots in the SD phase, the week 51 pots were blacked out with black polythene from 16:00 to 07:30 for 10 working days (not including weekends). Following the two weeks of short day treatments, plants were returned to long day conditions as described above.

  SD's always started on the same day in week as the original day of potting (i.e. if potted on a Thursday, they started SD's on the Thursday three weeks later).

  All compartments were screened from dusk until dawn throughout the trial to conserve energy and prevent light spill between compartments receiving different lighting treatments.

  Compartment temperatures were set to 20°C day and night with venting 2°C above set point.

  Pure CO_2 was applied to all treatments to achieve a concentration of 750ppm with vents closed, and 350ppm with vents up to 3% open.

Shading was set to come across when external light levels exceeded 300 W/m^2 during plant establishment.

- **Environment/Nutrition:** Three weeks after potting, liquid feed was started with each irrigation. Feed recipe was according to the recommendations of the grower co-ordinator, in line with current commercial practice: 200 ppm N : 50 ppm P : 225 ppm K with 30 ppm Mg to give a final EC of 1.9 mS (including background) and a pH of 6.2.

- **Pest and Disease Control:** Plants were grown using biological control as appropriate for thrips (*Amblyseius* applied), aphids (*Aphidoletes* applied), sciarid (*Hypoaspis* applied) and white fly (*Encarsia* applied).

- **Plant Growth Regulation:** Plant growth regulation was applied to all treatments in line with the commercial standard. Height control was achieved using Cycocel sprays (chlormequat; 46%) applied at 460 ppm. The first application was made immediately after pinching in each variety.

For full details of schedules see crop diary in appendix 3.

2.3.4 Experimental Records

During production:

Initial cutting quality was recorded, with treatment effects also assessed at the time of pinching and at marketing. The conventional marketing stage was defined as:

Plant height	= 30-33 cm (from the bench)
Plant spread	= 25-30 cm
Number of open flowers	= 8 (90% reflexed)

a) At potting

1. Cutting height (cm)
2. Cutting stem diameter at base (mm)

b) At pinching

1. Cutting height (cm)
2. Leaf number left after the pinch point
3. Score of stage of maturity of top leaf at the pinch (Plate 1: = immature unexpanded, 2 = expanding, 3 = expanded)

Records at times a) and b) were made on a sub-sample of 5 pots / plot.

c) At marketing

1. Duration from potting to conventional marketing stage.
2. Plant height from bench to apex (cm).
3. Average plant spread (cm).
4. Number of double flowers produced per pot.
5. Number of single flowers produced per pot.
6. Number of main shoots (from the pinch)
7. Number of coloured buds per pot.
8. Qualitative score of foliage (Plate 1; 1-5, 5 = best) and flower colour score (1 – 5, 5 = best).
9. Wastage / plot
10. Number of harvests required to clear each plot.
11. Plant dry weight (sub-sample 3 pots / replicate plot)

In addition to the above samples of compost were taken in each lighting treatment for each variety at potting and at three weekly intervals thereafter to monitor the nutritional status of the crop overall. A foliage sample was also taken from each lighting treatment at marketing.

Photographic records were taken to demonstrate the effects of supplementary lighting treatments on plant quality at marketing.

During shelf-life:

A sub sample of 5 plants per replicate plot was taken for assessment in a simulated shelf life environment to examine the effects of each lighting treatment on post harvest longevity. Plants were assessed at de-sleeving and then weekly for four weeks through the following records:

1. Number of open flowers per pot.
2. Number of coloured buds per pot.
3. Number of open flowers dropped per pot.
4. Number of coloured buds dropped per pot.
5. Foliage quality score (1-5, 5 = best) and note of leaf drop.
6. Incidence of *Botrytis*.

2.3.5 Environmental Records

1. Compartment temperature (average day / night / 24 hour; °C)
2. Compartment relative humidity (% RH)
3. Compartment CO_2 concentration (vpm)
4. External light level (MJ / m^2 / day)
5. Shelf – life environment temperature (average day / night / 24 hour)
6. Shelf-life relative humidity (%RH)

2.3.6 Statistical Analysis

Analysis: Effects of variety and potting date, and interactions involving these varieties were analysed using the standard analysis of variance (ANOVA). For the lighting regimes, the analysis has been approached by analysing each lighting phase in relation to the commercial standard as follows:

- Control = Comparison of the commercial standard (6 W/m^2) throughout with the mean value of the other lighting treatments.

- Phase 1 = Comparison of the three different lighting levels at the start of production.

- Phase 2 = Comparison of the three different lighting levels applied during the final 5 weeks of production

This structure enables analysis of the effects of lighting at the start and end of production compared to the commercial standard, and also allows the interactions between different light levels applied at each stage during production.

Statistical terms used include:

L.S.D.	Least squares difference of the means
P = 0.05 or 5%	The probability of this result occurring purely by chance is equal to 1 in 20.

2.4 RESULTS AND DISCUSSION

2.4.1 Environmental data

Average weekly light, temperature and relative humidity are presented in appendix 4. Ambient light levels between week 48 and 51 fluctuated between 1.5 and 3 MJ/m^2/day. From week 51 ambient light gradually increased to 6 MJ/m^2/day in week 10, with rapid increases in light during week 11 and 12 to 10 MJ/m^2/day. Compartment temperatures were approximately 1°C higher in the lit compartments for the first 2 weeks as set points were altered to bring temperatures in line (this could only be satisfactorily achieved with plants in the compartments). From week 51, temperatures in all compartments were always within 0.5°C of each other, but increasing across all treatments as external light levels rose during the second half of production.

2.4.2 Assessments of the cutting material

Height and stem thickness of the cutting material was assessed on receipt. The material supplied in week 47 was significantly less bulky than the week 51 intake (table 1). On both occasions, the Annebell cuttings were, on average, slightly taller, but with thinner stems than in Dark Netja (not statistically significant; data not presented).

Commercially, differences in the bulk of cutting material are often seen when material is obtained from more than one supplier. In these cases, cuttings from each supplier may require specific management early in production. The differences in cutting size in the current trial were relatively small and so independent management for each variety was not necessary.

Table 1: Mean cutting height and stem diameter on arrival (data averaged across varieties).

	Potting week		5% LSD (d.f.)
Potting week	**47**	**51**	
Cutting height (mm)	37.47	44.07	5.72 (1)
Stem diameter (mm)	5.28	6.22	0.87 (1)

2.4.3 Assessments at the time of pinching

Time of pinch: Week 47 = 15 days after potting
Week 51 = 14 days after potting

Providing supplementary light early in production appeared to give significant advantages in terms of more rapid plant establishment and enhanced rates of development. By the time of the pinch, there was a 7% increase in plant height in plants lit from potting at 12 W/m^2, whereas plants grown in ambient light were 12.5% shorter than in the commercial standard regime (table 2; both significant at the 5% probability level). It is generally accepted that when plants are young, all leaves are able to intercept all the light falling on the canopy to produce assimilates for growth. Under normal conditions, it is only when the leaves start to overlap and mutually shade one another, that the effect of competition between leaves starts to reduce productivity. From the current data, the use of 12 W/m^2 lighting early in production markedly increased the rate of new leaf development. The development of extra leaves at this stage would only be beneficial if subsequent growth regulation was managed to allow internode extension and avoid clumping of the foliage within the canopy. The top leaf was significantly less developed in the ambient lighting treatment, again indicating the advantages in terms of rapid plant establishment and rapid canopy development through providing supplementary lighting at this stage. There was no effect of lighting treatment on the number of mature leaves which was largely determined by the size of cutting at potting. It is possible that leaf temperatures were slightly elevated in the lit compartments, and this could contribute to the advanced development. From the current trial, no data are available for canopy temperatures, but the compartment temperatures were within 0.5°C.

Table 2: Effects of light levels at the start of production on plant height (cm) at the time of pinching (measured from compost to top leaf; data averaged across varieties and potting dates).

	Light level				
	Commercial Standard (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**	**5% LSD** (32 d.f.)
Plant height (cm)	4.15	3.96	4.45	3.63	0.37$ 0.26*
No. of mature leaves	3.53	3.40	3.47	3.37	0.13$ 0.09*
No. of immature leaves	1.18	1.33	1.62	0.26	0.43$ 0.31*
Top leaf expansion score (1 – 3, 3 = largest)	2.38	2.51	2.56	2.13	0.22$ 0.15*

$: 5% LSD when comparing Commercial Std. treatment with other light levels
* : 5% LSD for comparison between other light levels (& not the standard)

2.4.4 Marketing data

2.4.4.1 Crop duration

Crop duration was reduced by an average of 6 days in the week 51- compared to the week 47 potting. This was probably due to the rising ambient light levels in the second potting which increased the rate of plant development. There was no significant difference in crop duration for either variety in week 47, but in week 51, Dark Netja took 3 days longer to reach marketing than Annebell (table 3).

Table 3: Crop duration: effects of variety and potting date (data averaged across lighting treatments).

Variety	Potting Wk 47	Potting Wk 51
Annebell	91.0	83.4
Dark Netja	90.9	86.4

5% LSD (38 d.f.) comparing varieties within potting date: 1.31
5% LSD (1 d.f.) comparing between potting dates: 19.9

The data in table 4 clearly shows that applying assimilation lighting treatments at either 6 or 12 W/m^2 significantly reduced the time from potting to marketing compared to plants grown with ambient lighting during production (by an average of 4.7 and 4.1 days in week 47 and 51 pottings respectively). Although there was a small reduction in crop duration (1-2 days) in the highest lighting regimes compared to the commercial standard, this was not statistically significant. In the week 47 potting, crop duration in plants grown in ambient light during the first five weeks of production was reduced by 4.9 days compared to pots finished in ambient light, an observation suggesting that overall duration may be most sensitive to light levels during the second half of production, perhaps due to the effect of light levels on bud and flower development. The graphs in appendix 5 also show a strong trend for increased crop duration in pots finished in ambient light. This was supported by the data from the week 51 potting in which there were no significant differences in duration between plants produced with ambient lighting either at the start- or the end of production. Light levels in the week 51 crop increased steadily from potting to market, and the data indicated that crop duration may be less sensitive to irradiance when plant establishment occurred during a period of increasing ambient light. Previous work by Mortensen and Ulsaker (1985) also indicated that flowering was advanced in higher light levels, and also by elevated CO_2, when supplied under light-limited conditions.

Table 4: Effects of light levels at the start and end of production on crop duration (data averaged across varieties).

Potting Week	Time during production	Light level: Commercial Standard (6 W/m^2 throughout)	6 W/m^2 (2.5 klx)	12 W/m^2 (5 klx)	Ambient
Week 47 potting	**First 5 weeks**	88.7	90.8	91.0	91.7
	Last 5 weeks	88.7	88.7	88.4	96.6
Week 51 potting	**First 5 weeks**	84.5	84.5	82.0	88.4
	Last 5 weeks	84.5	84.2	83.3	87.4

5% LSD (38 d.f.) comparing Commercial Std within potting : 2.91
5% LSD (38 d.f.) comparing Commercial Std. With other light levels within potting : 2.38
5% LSD (38 d.f.) for comparison between other light levels (& not the standard) within potting : 1.68

Although supplying assimilation lighting during the final weeks of production in the week 47 crop appeared to increase the rate of crop development, it would be inadvisable to adopt this regime for the following reasons: (i) this was the most expensive time to apply lighting (see table 16 on page 27), and (ii) plant form and quality tended to be poorer than in plants which had been lit at the start of production only.

2.4.4.2 Plant height, spread and dry weight at marketing

Plant height was greatest in the commercial standard treatment (6 W/m^2 throughout production), and reduced in plants either lit using high light levels at the end of production, or in plants grown in ambient light early in production (table 5). In the highest light treatment (starting and finishing in 12 W/m^2), competition for light between plants would be reduced, resulting in shorter internodes and thicker stems (no data available for stem thickness at marketing). However, shorter plants in the ambient light treatment probably resulted from reduced canopy development and plant vigour, leading to less bulky plants (tables 5 & 6). Plants in the treatment starting and finishing in 6 W/m^2 were also slightly shorter than in the commercial standard, and this may result from reduced growth during the two-week period of ambient light in the middle of production.

In order to identify the effects of lighting treatment alone, all plant growth regulation was applied to all treatments according to the requirements of the commercial standard treatment. The fact that plants grown in with the highest levels of assimilation lighting were shorter than the control (and not short due to reduced dry mater production), would suggest that growers may benefit from savings due to reduced chemical and labour requirements associated with growth regulation in the highest light treatments.

Table 5: Effects of light levels at the start and end of production on plant height at marketing (cm from pot rim; data averaged across varieties and potting dates).

	Light level			
Time during production	**Commercial Standard** (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**
First 5 weeks	34.4	33.1	33.0	29.9
Last 5 weeks	34.4	32.2	30.7	33.1

5% LSD (38 d.f.) comparing Commercial Std. treatment with other light levels : 0.91
5% LSD (38 d.f.) for comparison between other light levels (& not the standard) : 0.64

Spread was reduced in plants either started in ambient light, or grown with ambient light throughout production, and there was no significant effect of lighting during the latter half of production (table 6). This correlated with the observation that ambient-grown plants were also shorter, and highlighted the importance of investing in the plants' framework early on in production. Plants that were started in ambient light and then lit later in production never recovered the lost bulk compared to those which had been lit early in production.

Table 6: Effects of light levels at the start and end of production on plant spread at marketing (cm ; average across widest point and at right angles; data averaged across varieties and potting dates)

	Light level			
Time during production	**Commercial Standard** (6 W/m² throughout)	**6 W/m²** (2.5 klx)	**12 W/m²** (5 klx)	**Ambient**
First 5 weeks	30.8	30.3	30.5	27.5
Last 5 weeks	30.8	29.3	29.3	29.7

5% LSD (38 d.f.) comparing Commercial Std. treatment with other light levels : 0.79
5% LSD (38 d.f.) for comparison between other light levels (& not the standard) : 0.56

The most marked effect of lighting on plant dry weight was achieved by lighting the crop at the end of production, with all plants grown at either 6 or 12 W/m² producing significantly more leaf material than ambient-finished plants (table 7). The largest increases in dry weight were in the stem and petiole tissues, particularly in the 12 W/m² treatment, where increases of 18 and 28% were observed compared to the commercial standard and ambient treatments (respectively).

Table 7: Effects of light levels at the end of production on plant dry weight at marketing (data averaged across varieties and potting dates).

	Light level				
	Commercial Standard (6 W/m² throughout)	**6 W/m²** (2.5 klx)	**12 W/m²** (5 klx)	**Ambient**	**5% LSD** (19 d.f.)
Leaf dry weight (g)	12.79	11.97	13.03	11.38	0.52$ 0.36*
Stem / petiole dry wt (g)	14.00	13.29	16.48	12.89	3.09$ 2.19*
Total dry weight (g)	26.79	25.25	29.51	24.27	3.31$ 2.34*

$: 5% LSD when comparing Commercial Std. treatment with other light levels
* : 5% LSD for comparison between other light levels (& not the standard)

Although significant increases in bulk could be obtained by lighting at the end of production, this often resulted in unbalanced canopy development in plants which had been started in ambient light. These plants generally failed to develop sufficient strength in the stems and the architecture early on to support the increased bulk due to lighting later in production. This means that the greatest benefits in lighting at high levels towards the end of production could only be achieved if the plants had also been lit at the start of production to invest in the plants' structural framework. As was mentioned earlier on, the cost of lighting was highest at the end of production, and would not be beneficial unless considered together with lighting earlier in the crop.

2.4.4.3 Flower numbers and flower quality at marketing

From the current data, there was no significant effect of lighting treatment during production on total flower number per pot. Marginally fewer flowers on pots grown under ambient conditions did not prove to be significant.

The two varieties in the trial had contrasting flowering characteristics, with Annebell not only producing on average more flowers per pot than Dark Netja, but also a significantly higher proportion of single flowers (table 8).

Table 8: Characteristic flower types in each variety (data averaged across lighting treatments and potting dates).

	Variety		
Flower type	**Annebell**	**Dark Netja**	**5% LSD (38 d.f.)**
Double	4.90	9.35	0.51
Single	5.81	0.39	0.43
Total	10.72	9.74	0.25

Light levels during the last 5 weeks of production had the most marked effects on flowering. There were fundamental differences between varieties in the effects of lighting regime on the proportion of single to double flowers produced at marketing. This trend was particularly marked in Annebell, which as stated above, produced more singles. For Annebell, higher light levels at the end of production promoted a larger proportion of double flowers to be produced per pot (tables 9 & 10), with 46% double flowers produced in the commercial standard treatment, compared to 51% and 57% in those finished at 6 and 12 W/m^2 (respectively), but with only 29% in ambient light. In Dark Netja, flower form was less sensitive to production lighting regime than in Annebell, with 99% double flowers in the commercial standard treatment, declining to 91% in the ambient-finished crop (not significantly different at the 5% probability level).

Table 9: Effects of light levels during the final 5 weeks of production on the number of double flowers at marketing (data averaged across potting dates).

Variety	Light level			
	Commercial Standard (6 W/m² throughout)	**6 W/m²** (2.5 klx)	**12 W/m²** (5 klx)	**Ambient**
Annebell	4.91	5.49	6.08	3.14
Dark Netja	9.61	9.52	9.54	8.91

5% LSD (38 d.f.) comparing Commercial Std. Treatment between varieties : 1.62
5% LSD (38 d.f.) comparing Commercial Std. Treatment with other light levels : 1.32
5% LSD (38 d.f.) for comparison between other light levels (& not the standard) : 0.93

Table 10: Effects of light levels during the final 5 weeks of production on the number of single flowers at marketing (data averaged across potting dates).

Variety	Light level			
	Commercial Standard (6 W/m² throughout)	**6 W/m²** (2.5 klx)	**12 W/m²** (5 klx)	**Ambient**
Annebell	5.68	5.03	4.55	7.91
Dark Netja	0.13	0.23	0.15	0.90

5% LSD (38 d.f.) comparing Commercial Std. Treatment between varieties : 1.37
5% LSD (38 d.f.) comparing Commercial Std. Treatment with other light levels : 1.12
5% LSD (38 d.f.) for comparison between other light levels (& not the standard) : 0.79

2.4.4.4 Flower colour score at marketing

Flowers were scored using an objective shade scoring system with 5 representing the best flower colour. This type of system was used for two reasons: (i) the differences between flower colour, particularly in the paler yellow variety (Annebell), were too subtle to be differentiated using RHS colour cards; (ii) the degree of variability in shade of colour was high even within a flower, making single point assessments of colour to represent a pot impossible. In the event, no significant effects of lighting during production or post harvest on flower colour were observed. These data highlight the need to develop new objective techniques for quantifying colour for quantification of treatment effects on flower and foliage quality.

2.4.4.5 Number of breaks

The number of breaks tended to be promoted by higher light levels supplied early in production (see appendix 5, figure 6), with the most freely breaking plants started and finished in the 12 W/m^2 lighting regime. Increased breaking was important if plants were to develop sufficient framework to continue to support increased growth in treatments receiving supplementary lighting later in production. These data were consistent with the observation that, in some poinsettia varieties, additional breaks often developed from otherwise dormant nodes when plants were spaced too early and when light levels were high.

2.4.4.6 Foliage quality

Foliage quality was assessed on a scale of 1 to 5, with a score of 5 indicating high quality, uniformly green foliage with good lustre (plate 1). Data in table 11 show that foliage quality was better in plants grown under ambient light throughout, or in those finished in ambient light than in those supplied with assimilation lighting. The poorest leaf quality was observed in plants given the highest light levels. This result was contrary to expectations in the light of experience gained from other crops provided with supplementary lighting during production. Generally, high light levels have been associated with enhanced photosynthesis, chlorophyll content, and added growth giving potential benefits to the grower in the market place, where a bulkier product may often secure a sale. Although previous work in Denmark, Holland and Norway has shown that it is beneficial to light Begonia crops in the winter (Mortensen & Ulsaker, 1985), their trials investigated lighting continuously throughout production, rather than the effects of lighting only during specific periods (as in the current trial). The absolute amounts of light provided using assimilation lights were not sufficiently high to damage photosystem II:
6 W/m^2 = 30µmol / m^2 / sec = 1.95 mol / m^2 / 18 h day,
12 W/m^2 = 60µmol / m^2 / sec = 3.9 mol / m^2 / day,
Sunny winter day = 150 W/m^2 = 750µmol / m^2 / sec = 24.3 mol / m^2 / 9 h day, so a probable cause of reduced leaf quality would be some form of nutrient deficiency.

Graphs in appendix 6 show data from nutrient analysis of the potting media during production, with foliar analysis of each treatment at marketing. Although the balance between macro-nutrients remained stable during the first 7 – 8 weeks of production, in the final phase, pH increased from an average of 6.3 to 7 across both potting dates. From these data, there was no evidence to suggest that nutrition in the lit treatments diverged markedly from the ambient light treatments in a way that might affect them differently. This means that under the standard nutrient regime applied in the trial, plants in the higher supplementary lighting treatments appeared to be more sensitive to fluctuating nutrition towards the end of production than those grown using ambient light for all or only part of production. It is well known that increasing pH is detrimental to plants growing in hydroponic culture through restricting the availability of phosphorus, manganese, iron and boron. Begonias are prone to nutrient deficiency with increasing media pH, and are particularly susceptible to calcium and iron deficiency. Data were only available for macro-nutrient foliar analysis, so the effects of increased pH on iron content could not be obtained. From these data on nitrogen, potassium, phosphorus and magnesium content of the foliage in each treatment (see appendix 6), there was no consistent evidence to suggest that plants from the highest light regimes had lower concentrations of these elements than those grown in ambient light conditions. There were however, slight reductions in the calcium content of leaves in plants which had been grown with 12 W/m^2 during the last 5 weeks of production. If this pattern was repeated for iron, this would certainly account for the observation of increased levels of leaf chlorosis in the highest lighting treatments, and this needs investigating.

Interactions between nutrition during the final phase of production in lit versus unlit crops needs to be fully understood if growers are to optimise their investment in assimilation lighting during the winter period. Use of extended daily lighting period may impose significant stresses on plants during the winter period if nutritional status becomes marginal for any reason. Current trials with early season new guinea impatiens have also seen similar interactions between the use of supplementary lighting for 16 hours/day and marked reductions in compost nutrition.

Table 11: Effects of light levels at the start and end of production on foliage quality score at marketing (averaged across potting dates).

		Light level during the last 5 weeks			
	Light level during first 5 weeks	**Commercial Standard** (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**
Annebell	**Comm Std**	3.61	-	-	-
	6 W/m^2	-	4.00	3.56	4.63
	12 W/m^2	-	4.00	4.07	4.29
	Ambient	-	4.29	3.77	4.61
Dark Netja	**Comm Std**	3.84	-	-	-
	6 W/m^2	-	4.05	3.71	4.57
	12 W/m^2	-	4.12	3.14	4.46
	Ambient	-	4.21	3.98	4.55

5% LSD (38 d.f.) for all comparisons : 0.21

Further trials are required that investigate these interactions between lighting and nutrition during the final phase of production and how this may affect post-harvest performance.

2.4.4.7 Large leaf occurrence (or "elephant ear leaves")

In some varieties and at particular times of year (especially during early-season production), a condition known as "elephant ear" leaves is observed. The affected plants produce excessively large leaves relative to the normally accepted leaf form, resulting in unbalanced non-uniform plants (plate 2). This condition was most commonly observed in Annebell and with the highest levels in the week 47 potting. Data in table 12 show that the development of large leaves was predominantly in treatments which received lighting above the control 6 W/m^2 throughout production. There was a 4.7-fold increase in "elephant ear" in pots given 12 W/m^2 both at the start and end of production, with reductions when plants only had 12 W/m^2 for half of production (increase based on transformed data). In the ambient-grown plants, no elephant ear leaves were observed. This problem has been traditionally been related to low potassium in the feed, and several growers, who use high potassium in the feed report that they no longer see elephant ear leaves at any time during the year. The media analysis data showed that the lowest potassium concentration were recorded in the week 51 potting, and there was no evidence of low foliar K in the highest light treatment in either potting. These data indicate that the elephant ear condition is unlikely to be wholly attributed to compost or foliar K content, but there could be an interaction with other factors such as high pH or the ratio of K:N. which needs further investigation.

Table 12: Effects of light levels at the start and end of production on the occurrence of excessively large leaves at marketing (data angle-transformed; numbers in brackets are back-transformed % values; data averaged across varieties).

	Light level during the last 5 weeks			
Light level during first 5 weeks	**Commercial Standard** (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**
Comm Std	7.3 (1.60)	-	-	-
6 W/m^2	-	12.7 (4.80)	21.9 (13.9)	7.5 (1.70)
12 W/m^2	-	24.9 (17.7)	34.6 (32.2)	11.0 (3.64)
Ambient	-	5.4 (0.89)	1.9 (0.11)	0.0 (0.00)

5% LSD (38 d.f.) for all comparisons : 9.68

2.4.4.8 Flower clumping

Another undesirable attribute observed was clumping of the flowers. Certain treatments were prone to production of a tight head of flowers at the top of the canopy rather than an even covering of flowers over the canopy. Flower clumping was significantly increased in plants receiving the high light treatment either throughout- or at the end of production only (table 13). In the highest light level regimes, less growth regulation was required than in the standard treatment, and excessive growth regulation in the latter half of production may have been the main factor contributing to flower clumping.

2.4.4.9 Root score

There were no varietal effects on rooting, and so varieties were bulked and the effects of lighting and potting date were analysed. From the data presented in table 14, the plants in the first potting date had significantly better root systems than in the second potting. The most significant factor appeared to be light level at the end of production, with roots in ambient-finished plants far poorer than in any of the other treatments.

Table 13: Effects of light levels at the start and end of production on the flower clumping at marketing (data angle-transformed; numbers in brackets are back-transformed % data).

	Light level during first 5 weeks	Light level during the last 5 weeks			
		Commercial Standard (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**
Annebell	**Comm Std**	14.2 (6.0)	-	-	-
	6 W/m^2	-	15.0 (6.7)	29.0 (23.4)	12.0 (4.3)
	12 W/m^2	-	20.9 (12.7)	26.2 (19.5)	0.0 (0.0)
	Ambient	-	3.9 (0.46)	20.4 (12.1)	3.9 (0.46)
Dark Netja	**Comm Std**		-	-	-
	6 W/m^2	-	4.0 (0.49)	25.7 (18.8)	3.9 (0.46)
	12 W/m^2	-	3.9 (0.46)	23.2 (15.5)	7.9 (1.9)
	Ambient	-	3.9 (0.46)	0.0 (0.0)	0.0 (0.0)

5% LSD (38 d.f.) for all comparisons : 11.68

Table 14: Effects of light levels during the final 5 weeks of production on root score at marketing (data averaged across varieties).

	Light level			
Potting week	**Commercial Standard** (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**
Week 47	4.90	4.52	4.70	2.87
Week 51	3.80	3.48	3.71	2.89

5% LSD comparing Commercial Std. Treatment between varieties: 0.77 between pottings (26 d.f.) & 0.75 within potting (38 d.f.)
5% LSD comparing Commercial Std. Treatment with other light levels: 0.65 between pottings (17 d.f.) & 0.61 within potting (38 d.f.)
5% LSD for comparison between other light levels (& not the standard): 0.55 between pottings (6 (d.f.) and 0.43 within potting (38 d.f.)

2.4.4.10 Summary of the effects of production lighting treatment on plant bulk and quality at marketing

From the marketing data, each lighting treatment was assessed in terms of a ranking system. Equal weighting was assigned to each measurement and an overall rank was given based on the sum of all ranked data sets. The treatment judged as having performed best was ranked 1, with the worst 10. Table 15 shows a summary of the strengths and apparent weaknesses of each lighting regime under the conditions of the current trial. Because each variable was weighted equally, the picture presented below may assign too much importance to some variables over others, and this needs bearing in mind when drawing conclusions.

Plants in the commercial standard treatment were judged as being of the highest quality at marketing, with the ambient-grown plants ranked worst. Of the treatments, where lighting was only given for the first- or last five weeks of production, those lit at the start and finished in ambient light were, on average, better than those which had only been lit at the end of production. The reasons for the highest lighting treatments not attaining higher scores related to reduced quality due to production of elephant ear leaves and leaf chlorosis already discussed, with clumping of flowers related to over regulation with PGRs (applied according to the standard treatment across all treatments).

- Providing assimilation lighting at 6 W/m^2 throughout production (commercial standard) produced significantly higher quality plants than those grown using ambient lighting throughout which were also significantly delayed.

- Supplying higher levels of assimilation lighting above the commercial standard promoted:
  - Rapid plant establishment and development when applied during the first 5 weeks.
  - Gave a good plant framework essential for quality & form later on.
  - Good breaking habit.
  - Increased dry weight.
  - Increased proportion of double flowers, especially in Annebell in which flower form was sensitive to light level.
  - Potential for reduced plant growth regulator use.

- Data suggest that the greatest impact of lighting during production on quality and flower form was achieved by lighting at the end of production.

- However, if no supplementary lighting was given early on, plants were unlikely to develop the framework necessary to support any potential benefit through assimilation light supplied subsequently. To gain the best by lighting at the end of production, crops needed to be lit early on to develop a good framework.

Table 15: Summary of strengths and weaknesses of each lighting regime tested: based on plant assessments at marketing.

Treatment	Strengths	Weaknesses
6 throughout Rank 1	• Balanced habit • Good roots • + buds • Few singles • + breaks	• Moderate-poor foliage • + some clumped flowers
6-A Rank 7	• Balanced plant • + buds • Good foliage • No large leaves	• Crop delays • - dry matter • + single flowers (fewer flowers in general) • - shoots • – roots • + waste
12-A Rank 5	• large • + buds • Good foliage • No clumping • + flowers	• Crop delays • - dry matter • - roots • + single flowers
A-6 Rank 8		• - dry matter • Compact habit • Variable rooting • - breaks
A-12 Rank 6	• + dry matter • Few single flowers • No large leaf / clumpy flowers	• Compact habit • Poor foliage
6-6 Rank 3	• Good habit • V few single flowers • No flower clumping / large leaf	• Moderate - poor foliage
6-12 Rank 9	• + dry matter • + flowers • Good roots	• Poor foliage • Clumpy flowers • Large leaf • Compact habit • + waste
12-12 Rank 4	• + dry matter • + flowers • + shoots • Good roots	• + large leaf • + clumpy flowers • Poor foliage (chlorotic)
12-6 Rank 2	• + dry matter • No delay • Good roots	• + large leaf • + clumpy flowers
Ambient throughout Rank 10	• No large leaf • No clumpy flowers	• Large crop delays • - dry matter • - flowers (+ singles) • - root • - breaks

But there were problems associated with higher assimilation light levels:

- Running the lamps in the highest lighting treatment was expensive (12 W/m^2 during the first and last 5 weeks of production; see table 16 below). It was more cost-effective to light early when pots were closer together, and this made high light levels at the start of production more feasible, and also produced a better plant framework for any lighting applied later in production. If such high light levels are to be used, further studies would need to be done to optimise production factors such as the number of initial long days, timing of the pinch and subsequent plant growth regulation required.

- In order to assess the effects of lighting during production, background nutrition was kept constant for all treatments. High light treatments received irrigation more frequently as required, with the assumption that they would also receive sufficient nutrients.

- Plants grown using high levels of supplementary lighting, particularly at the end of production, had an increased number of quality defects, including a higher proportion of elephant ear leaves, foliage chlorosis and flower clumping, which led to this treatment having a higher proportion of waste pots.

- Any reduction in plant nutrient status at marketing would have affected subsequent shelf-life performance and so these factors were confounded during the second phase of the trial.

- These negative factors could all be associated with nutritional imbalances (elephant ear, chlorosis) and PGR regimes (flower clumping), and this needs to be an important component of future trials.

2.4.5 Lighting treatment running costs

One objective of the current trial is to provide an estimate of the lamp running costs for each of the treatments. The installation of the lighting system would vary greatly between nurseries, so these would need to be assessed independently of the running costs. However, the calculation of running costs presented here should provide valuable information on how cost-effective investment in different lighting regimes may be. Running costs for each lighting treatment are presented in table 16 and have been calculated based on the following:

Bench area per luminaire (data supplied by Farm Energy Centre):
12 W/m^2 (5 klx) with each lamp covering 6.5 m^2
6 W/m^2 (2.5 klx) with each lamp covering 12 m^2

Electricity tariff:
Off-peak rate = 2.6 p/kW
Standard rate = 7.6 p/kW

Production Regime (based on an 85 day crop):
21 long days (18 h/day; 11 h off-peak + 7 h standard)
10 short days (3 h off-peak + 7 h standard)
4 long days

Pot spacing:
35 days at $58/m^2$ (Pot thick)
14 days at $30/m^2$ (½ space)
36 days at $23/m^2$ (Final)

14 days at ambient
36 long days to market

Table 16: Calculated running costs / pot

Lighting regime	Long day costs (p / pot)			Short day costs (p / pot)			Total running cost (p / pot)
	Pot thick	½ space	Final	Pot thick	½ space	Final	
6 W/m² throughout (Comm std)	1.61	1.74	5.84	0.38	-	-	9.58
6 W/m² → ambient	1.61	-	-	0.38	-	-	1.99
12 W/m² → ambient	2.97	-	-	0.71	-	-	3.68
Ambient → 6 W/m²	-	-	5.84	0.38	-	-	6.23
Ambient → 12 W/m²	-	-	10.79	0.71	-	-	11.50
6 W/m²→ 6 W/m²	1.61	-	5.84	0.38	-	-	7.84
6 W/m²→ 12 W/m²	1.61	-	10.78	0.71	-	-	13.10
12 W/m²→ 12W/m²	2.97	-	10.78	0.71	-	-	14.47
12W/m²→ 6W/m²	2.97	-	5.84	0.38	-	-	9.20
Ambient throughout	Minimal costs associated with running either tungsten bulbs or fluorescent strip lights during the long day periods.						

Note improved cost-effectiveness of lighting early in production during the pot-thick phase.

Lighting at 12 W/m^2 at the start and end of production increased the lighting running costs by 50% compared to the commercial standard. This increase in running cost has to be offset against the increases in plant bulk during the winter, but in the current trial, was also associated with some reduced plant quality bought about by unforeseen interactions between light levels and a possible imbalance of nutrients.

There were no benefits observed in providing crops with high light levels at the end of production only, as plants tended to be unbalanced, with insufficient framework generated early in production to support added growth later on in high light. Also, the application of high light levels when pots were at final spacing was very costly relative to lighting early in production only.

Savings were made by not lighting during the ½ space phase. Data suggest that starting and finishing production in 6 W/m^2 did not reduce quality, so there is scope to make an 18% saving in running costs by using ambient light for 2 weeks after the initial pot-thick phase (based on the comparison between the commercial standard and the treatment starting and ending in 6 W/m^2). Growers who have the flexibility in their system could take advantage of this.

Purely from a running costs perspective, it was equally cost-effective to give 12 W/m^2 during the pot thick phase and the 6 W/m^2 during final spacing, as to supply 6 W/m^2 throughout production (commercial standard). The plant data suggest that the investment in a sturdy framework together with rapid development and breaking may be enhanced by lighting at 12 W/m^2 early on, but further work would be required to determine optimal nutrition and growth regulation to ensure that the product is of sufficiently high quality at marketing.

2.4.6 The effects of production lighting regime on post-harvest performance

For analysis of post-harvest data, each measured variable was analysed at sleeving, de-sleeving and 4 weeks after de-sleeving. These points were identified as being the most useful times to give a good indication of how plants performed both during the retail phase and then with the consumer.

For some of the variables, the effects of variety and potting dominated any lighting treatment effects. There was also the problem of poorer quality from the high lighting treatment (nutrition/PGR interactions) confounding the effects of supplementary lighting ion the post harvest phase.

The shelf-life assessment data are presented in full in appendix 7.

2.4.6.1 Effects of production lighting regime on post-harvest flower and bud numbers per pot.

In line with the marketing data, there was no significant effect of lighting treatment during production on total flower number at sleeving (table 17). In all treatments (lit and ambient), there were increases in the number of open flowers between marketing and de-sleeving, and this factor in itself may represent increased visual impact to the consumer in the retail environment.

The most significant result was the marked increase in flower opening during the sleeved phase in plants grown in or finished under ambient light conditions compared to those given supplementary lighting at the end of production. Open flower numbers in the lit treatments increased by, on average, 29% during the retail phase, whilst in ambient-grown plants this increased to 78%. Work currently being conducted on the OPKOT programme of research in Denmark is investigating the influence of "acclimation" during production to post-production factors. This work has indicated that pre-stressing plants to mild water stress may facilitate better post-harvest performance as the plants become pre-adapted to potential water deficits which may occur during the transport, retail and consumer phases. The Danish work will also address whether acclimation to lower light levels during the final phase of production may be beneficial to pot plants which subsequently go into a low-light home environment. If this is indeed the case, then the buds on plants grown in ambient light or finished under low light conditions may be able to continue to open and flourish better when put in a low light environment, than buds which have developed under relatively high light conditions.

The increased number of open flowers at de-sleeving in the ambient-grown pots gave them an advantage at the start of shelf-life which was maintained through the rest of the study, with these pots having consistently higher flower counts at the end of the post-harvest phase than the plants finished in higher light conditions.

Table 17: Effect of production light regime on flower numbers per pot during shelf-life (averaged across varieties and potting dates).

		Light level				
Period of lighting during production	**Time in shelf-life**	**Commercial Standard** (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**	**5% LSD** (37 d.f.)
1st 5 weeks	**Sleeving**	12.1	12.0	12.3	10.8	1.37$ 0.97*
2nd 5 weeks	**Sleeving**	12.1	11.9	11.9	11.4	1.37$ 0.97*
2nd 5 weeks	**De-sleeve**	15.2	15.3	15.5	19.6	2.28$ 1.61*
2nd 5 weeks	**4 weeks after de-sleeve**	6.4	8.0	6.8	13.4	5.52$ 3.90*

$: 5% LSD when comparing Commercial Std. Treatment with other light levels
* : 5% LSD for comparison between other light levels (& not the standard)

Data presented in table 18 show how the ratio of open flowers at the end : sleeve, end : de-sleeve and de-sleeve : sleeve varied. This analysis provides a picture of how buds converted to flowers in each lighting treatment. Ratios > 1 indicated increased flower number at the second assessment than the first (i.e. net increase in flower number). A high ratio of flowers at the end relative to at sleeving indicated that there was a net increase in flower number during shelf-life. The ratio of flowers at de-sleeving compared to sleeving showed the degree of flower opening during the transport and retail phases, with the ratio of the flower number at end ÷ de-sleeving giving the net gain / loss of flowers from de-sleeving to the end of shelf-life. All treatments had a ratio > 1 from sleeving to de-sleeving indicating a net flower opening, but in all comparisons, the crop finished in ambient light had significantly higher flower ratios than in plants produced in any of the supplementary lighting regimes.

Table 18: Effect of production light regime during the final 5 weeks of production on flower numbers per pot expressed as ratios between measurement points during shelf-life (averaged across varieties and potting dates).

Ratio flowers t_2/t_1	Light level				
	Commercial Standard (6 W/m² throughout)	**6 W/m²** (2.5 klx)	**12 W/m²** (5 klx)	**Ambient**	**5% LSD** (37 d.f.)
End / de-sleeve	0.54	0.72	0.58	1.45	0.53$ 0.37*
End / sleeve	0.43	0.57	0.46	0.85	0.33$ 0.24*
De-sleeve / sleeve	1.26	1.30	1.31	1.73	0.18$ 0.13*

$: 5% LSD when comparing Commercial Std. Treatment with other light levels
* : 5% LSD for comparison between other light levels (& not the standard)

The graphs in appendix 7 also show that, generally, there were increases in the numbers of buds during shelf-life in plants which had been produced in the higher light regimes, with reductions in bud numbers in pots either grown in ambient light throughout- or at the end of production. These data support the idea that acclimation to lower light levels during production may be important for continued bud development and flower opening in low-light post-harvest environments.

The flowering data are re-enforced by the bud ratio data (table 19). In the week 47 potting, plants finished in ambient light showed a net decline in bud ratio. This indicated a reduction in total bud number during shelf-life. As seen from the previous data, this was not due to bud drop, but rather to continued flower opening. In the week 51 potting, however, plants finished in ambient light showed a net gain in bud numbers relative to the other lit treatments, suggesting that the acclimation of ambient-grown plants to home-life light levels (as imposed in the current trial) may have been less significant as external light levels were higher at the end of the week 51 crop.

Table 19: Effect of production light regime during the final 5 weeks of production on the ratio of buds at the end of shelf-life : number at sleeving at each potting date (averaged across varieties).

Ratio buds: end / sleeve	Light level			
	Commercial Standard (6 W/m² throughout)	**6 W/m²** (2.5 klx)	**12 W/m²** (5 klx)	**Ambient**
Week 47	1.00	0.94	1.08	0.71
Week 51	0.84	1.31	1.17	1.45

5% LSD for comparison between Commercial standard & other light levels within potting date : 0.480 (37 d.f.)
5% LSD for comparison between other light levels (not the Comm. Std.) within potting date : 0.339 (37 d.f.)
5% LSD when comparing Commercial Std. Treatments between potting dates : 0.853 (6 d.f.)
5% LSD for comparison between Commercial standard & other light levels between pottings : 0.975 (3 d.f.)
5% LSD for comparison between other light levels (not the Comm. Std.) between pottings : 3.26 (1 d.f.)

In addition to the reduction in ratio of flowers at de-sleeving / sleeving, there was an increased incidence of flower loss at de-sleeving in plants which had been produced using the highest lighting regimes (table 20). There were no consistent significant effects of lighting regime on flower or bud losses at 2 or 4 weeks after de-sleeving (data not presented), but ambient-grown plants tended to lose fewer buds towards the end of shelf-life than lit crops. Again, this may be due to the impact of nutrition, rather than lighting regime on post-harvest flowering. Previous research (Hell & Hendriks, 1995; Nell & Barrett, 1995) has shown that post-harvest performance in impatiens, poinsettia and potted roses was strongly correlated with nitrogen supply and the ratio of K : N at marketing. They highlighted that high levels of N (> 200 ppm) or an excess of ammonium N, resulted in increased rates of quality loss post-harvest. Culture notes for begonia (Larsen; Denmark) highlight that this species is sensitive to high pH and calcium deficiency, both of which may impact on plant quality at marketing and post-harvest performance.

Table 20: Effects of light levels at the start and end of production on flower loss at de-sleeving (averaged across varieties and potting dates)

	Light level			
Time during production	**Commercial Standard** (6 W/m^2 throughout)	**6 W/m^2** (2.5 klx)	**12 W/m^2** (5 klx)	**Ambient**
First 5 weeks	0.71	1.05	1.57	0.82
Last 5 weeks	0.71	0.96	1.74	0.74

5% LSD (37 d.f.) comparing Commercial Std. treatment with other light levels : 0.78
5% LSD (37 d.f.) for comparison between other light levels (& not the standard) : 0.55

There were no significant differences in flower colour score due to lighting regime at sleeving, and no evidence to suggest that providing high levels of supplementary lighting during production facilitated the maintenance of improved flower colour post-harvest. The data did indicate that flower colour was better in the week 51 crop, suggesting that ambient light levels rather than assimilation lighting may be the most important factor in improving flower colour.

The main effects of lighting treatment during production on post-harvest performance have been summarised in a table of strengths and weaknesses in the same way as for the marketing data (table 21).

2.4.6.2 Effects of production lighting regime on post-harvest performance: overall summary.

- During shelf-life, the plants grown in ambient light or finished with ambient light showed the best performance in terms of flower development throughout shelf-life (mediated by a large increase in the number of open flowers during the retail phase, especially in the week 47 potting).

Table 21: Summary of strengths and weaknesses of each production lighting regime tested: based on post-harvest assessments.

Treatment	Strengths	Weaknesses
6 throughout **Rank 8**	• + leaf retention (wk 47) • + buds (but not opening!)	• flowers opening • + bud drop • + flower drop • + leaf loss (wk 51)
6-A **Rank 1**	• ++ flower opening during retail (in sleeves); esp wk 47 • + flowers during shelf-life • + buds (new buds developing) • Few leaves lost	
12-A **Rank 2**	• ++ flower opening during retail (in sleeves); esp wk 47 • + flowers during shelf-life • + buds (new buds developing)	• + leaf loss
A-6 **Rank 9**		• + bud drop • + flower loss (esp Annebel) • + leaf loss (esp Annebel)
A-12 **Rank 10**		• + flower drop • + bud drop • + leaf loss
6-6 **Rank 5**	• Good leaf retention • + flowers (Dark Netja)	• - flower opening • - bud development
6-12 **Rank 5**		• + flower drop
12-12 **Rank 4**	• + buds	• - flower opening • + flower drop • variable leaf loss
12-6 **Rank 7**		• + flower drop • + bud drop • variable leaf loss
Ambient throughout **Rank 3**	• ++ flower opening during retail (in sleeves); esp wk 47 • + flower number throughout	• + leaf loss

- In plants finished in the ambient lighting treatments, buds continued to develop and open in shelf-life to replace those flowers which were lost

- Bud development in the ambient-grown plants may have become adapted to low light levels by marketing. In both the 6 an 12 W/m^2 light treatments, plants leaving the bench went into a lower light environment than the one (in which they were produced) and this may have influenced how the buds performed later.

- Although the high light treatments (12-12, 6-12, 12-6 W/m^2) produced plants with more dry matter at marketing than those in the commercial standard or ambient light regimes, the flower retention and replenishment by new buds opening was relatively poor.

- The fact that plants given the highest light levels during production exhibited symptoms thought to be associated with nutrient deficiency means that the effects of lighting treatment on post-harvest performance may have been confounded in this trial.

2.5 CONCLUSIONS

- During the winter period, providing supplementary assimilation lighting at any stage during production resulted in crops with shorter duration than ambient-grown crops.

- There were no further reductions in duration achieved by lighting at 12 W/m^2 compared to the commercial standard treatment (6 W/m^2 throughout).

- The most cost-effective time to apply high levels of assimilation lighting was during the first five weeks of production when pots were at close spacing. Even supplying 12 W/m^2 for the first- and then 6 W/m^2 for the last 5 weeks was not more expensive than the commercial standard (lamp running costs only).

- High light at the start of production gave benefits in terms of rapid plant establishment and development.

- The development of strong, bulky plants at the early stages was essential if one was to gain any benefits of giving supplementary lighting later in production.

- Lighting at the end of production was not only costly, but also did not produce any benefits in plant quality or form compared to plants lit at the start of production only.

- Although high light levels stimulated increased bulk and the potential for reduced PGR inputs early in production, the crops produced under the highest light regimes showed some quality defects which a thought to be associated with nutrient imbalance late in production.

- The use of high levels of supplementary lighting during production also resulted in more compact plants than in the standard treatment. Further work would need to quantify potential PGR savings together with the effects on plant quality.

- There is some evidence that winter-grown crops which become pre-adapted to low light levels during production may continue to flower better post-harvest than pots finished in high light and then subsequently placed in a low-light home environment.

- Further trial work on early-season begonia is required to investigate the interactions between light, nutrition and post-harvest performance.

Acknowledgements

The author would like to acknowledge Mr Mike Holmes for all his time and effort and always being willing to help whenever a question is asked, and also the Pot Plant Committee for their help, guidance and input throughout the current trial.

References

Hell, B., & Hendriks, L. 1995. The influence of nitrogen nutrition on keeping quality of pot plants. *ACTA Horticulturae*, **405**, 138 – 147.

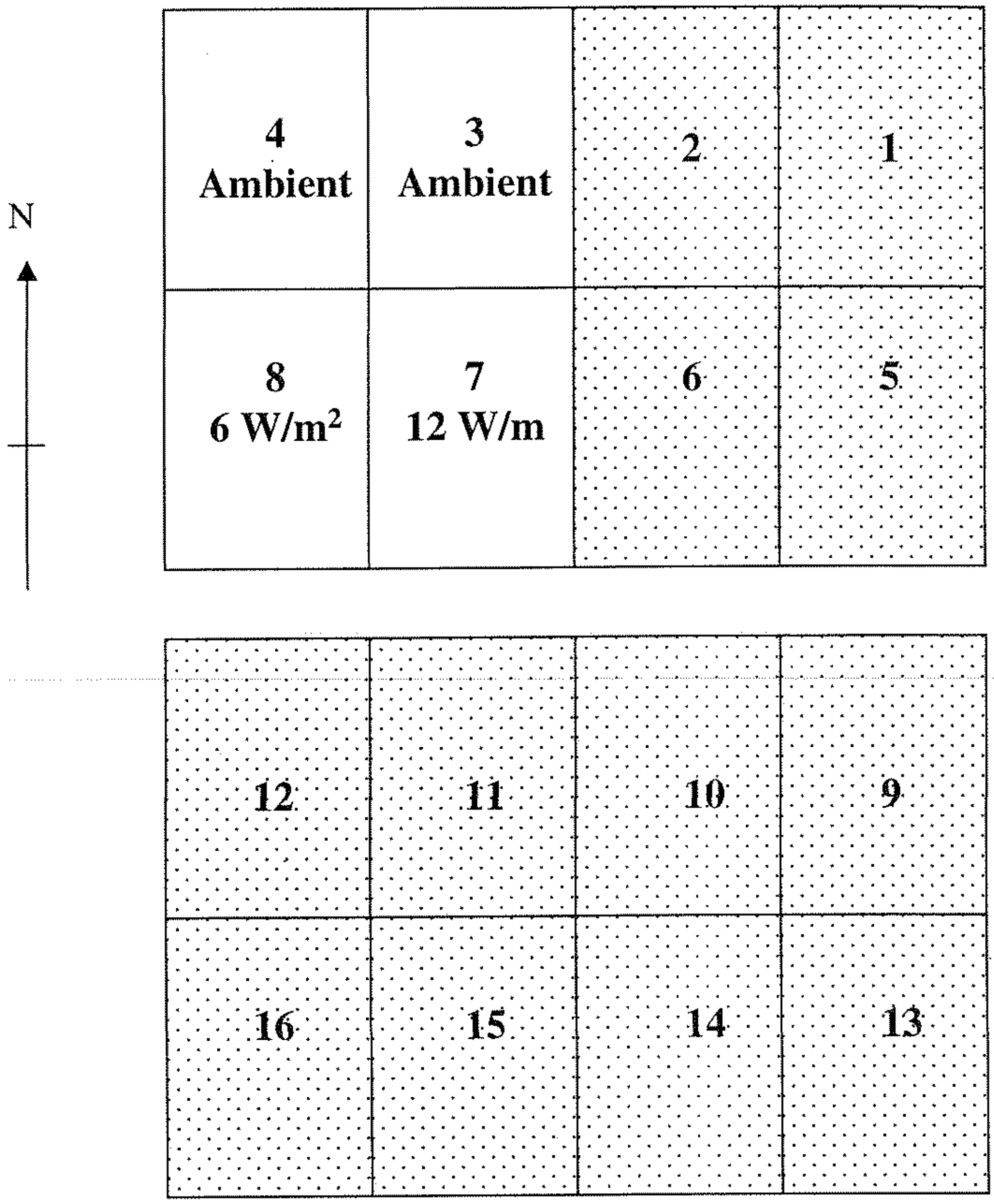
Mortensen, L.M., & Ulsaker, R. 1985. Effect of CO_2 concentration and light levels on growth, flowering and photosynthesis of *begonia x hiemalis* Fotsch. ***Scientia Horticulturae*, 27,** 133 – 141.

Nell, T.A., & Barrett, J.E. 1995. Production factors affect the postproduction performance of poinsettia – a review. *ACTA Horticulturae*, **405**, 132 - 137.

Appendix 1

Treatment allocation within K Block

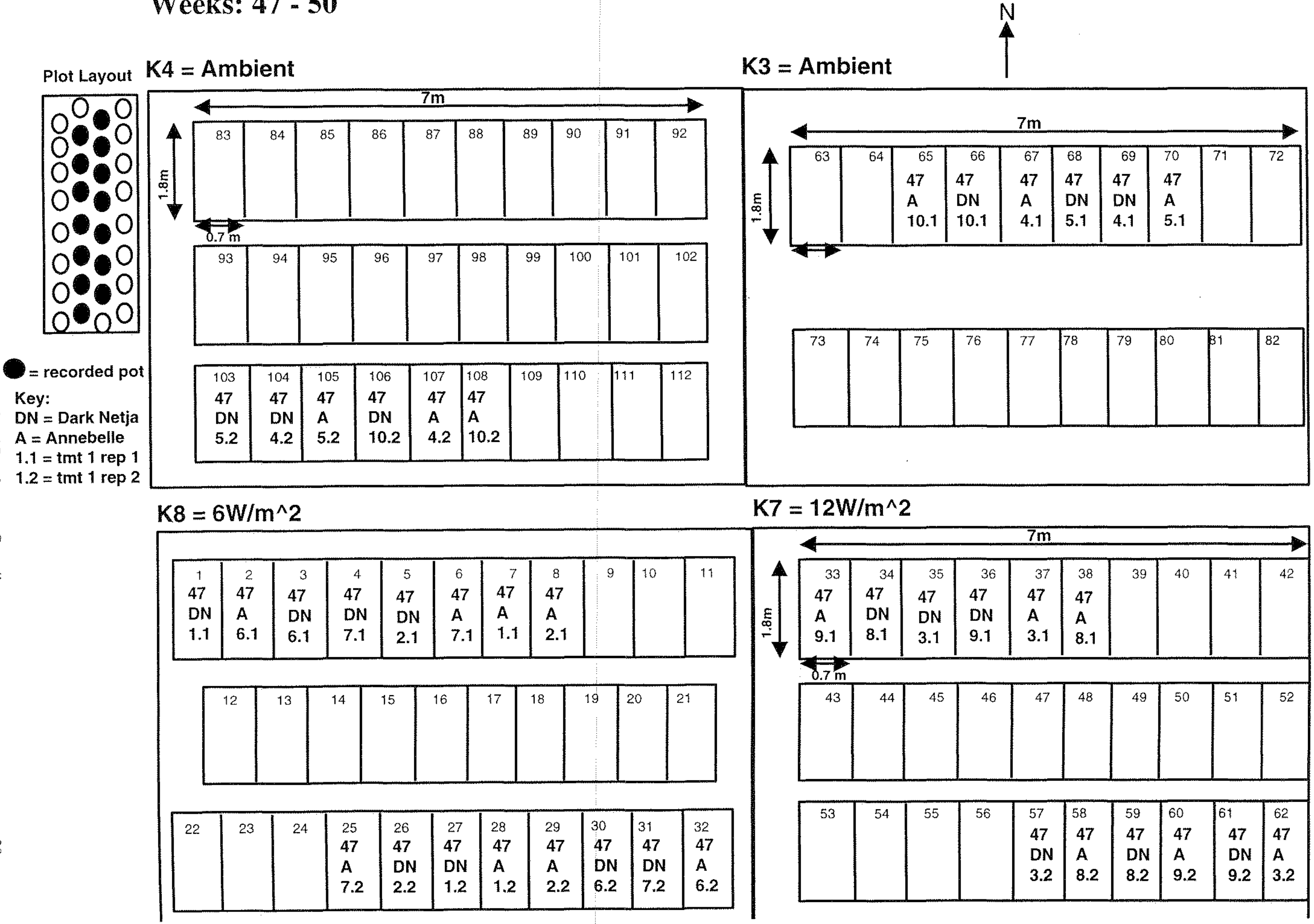
K BLOCK



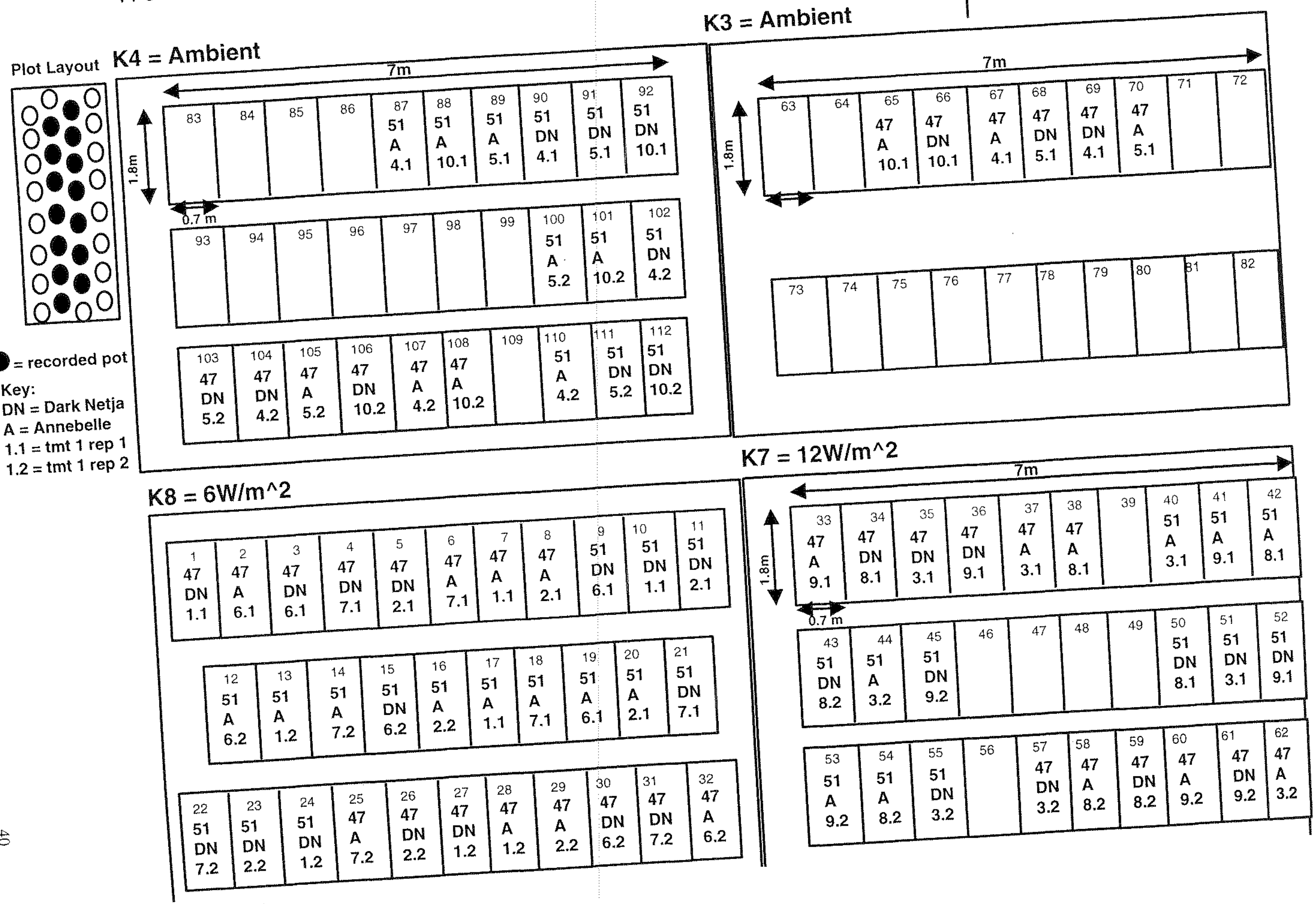
Appendix 2

Plot layouts

Weeks: 47 - 50


N
Plot Layout
= recorded pot
Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2
K4 = Ambient
7m
1.8m
0.7 m
83 84 85 86 87 88 89 90 91 92
93 94 95 96 97 98 99 100 101 102
103 47 DN 5.2
104 47 DN 4.2
105 47 A 5.2
106 47 DN 10.2
107 47 A 4.2
108 47 A 10.2
109 110 111 112
K3 = Ambient
7m
1.8m
63 64
65 47 A 10.1
66 47 DN 10.1
67 47 A 4.1
68 47 DN 5.1
69 47 DN 4.1
70 47 A 5.1
71 72
73 74 75 76 77 78 79 80 81 82
K8 = 6W/m^2
1 47 DN 1.1
2 47 A 6.1
3 47 DN 6.1
4 47 DN 7.1
5 47 DN 2.1
6 47 A 7.1
7 47 A 1.1
8 47 A 2.1
9 10 11
12 13 14 15 16 17 18 19 20 21
22 23 24
25 47 A 7.2
26 47 DN 2.2
27 47 DN 1.2
28 47 A 1.2
29 47 A 2.2
30 47 DN 6.2
31 47 DN 7.2
32 47 A 6.2
K7 = 12W/m^2
7m
1.8m
0.7 m
33 47 A 9.1
34 47 DN 8.1
35 47 DN 3.1
36 47 DN 9.1
37 47 A 3.1
38 47 A 8.1
39 40 41 42
43 44 45 46 47 48 49 50 51 52
53 54 55 56
57 47 DN 3.2
58 47 A 8.2
59 47 DN 8.2
60 47 A 9.2
61 47 DN 9.2
62 47 A 3.2

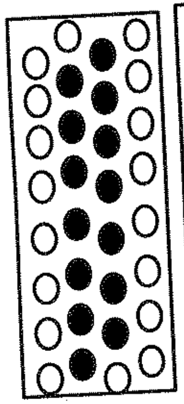
Week: 51


Plot Layout
= recorded pot
Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2
K4 = Ambient
7m
1.8m
0.7 m
83
84
85
86
87 51 A 4.1
88 51 A 10.1
89 51 A 5.1
90 51 DN 4.1
91 51 DN 5.1
92 51 DN 10.1
93
94
95
96
97
98
99
100 51 A 5.2
101 51 A 10.2
102 51 DN 4.2
103 47 DN 5.2
104 47 DN 4.2
105 47 A 5.2
106 47 DN 10.2
107 47 A 4.2
108 47 A 10.2
109
110 51 A 4.2
111 51 DN 5.2
112 51 DN 10.2
K3 = Ambient
7m
1.8m
63
64
65 47 A 10.1
66 47 DN 10.1
67 47 A 4.1
68 47 DN 5.1
69 47 DN 4.1
70 47 A 5.1
71
72
73
74
75
76
77
78
79
80
81
82
K8 = 6W/m^2
1 47 DN 1.1
2 47 A 6.1
3 47 DN 6.1
4 47 DN 7.1
5 47 DN 2.1
6 47 A 7.1
7 47 A 1.1
8 47 A 2.1
9 51 DN 6.1
10 51 DN 1.1
11 51 DN 2.1
12 51 A 6.2
13 51 A 1.2
14 51 A 7.2
15 51 DN 6.2
16 51 A 2.2
17 51 A 1.1
18 51 A 7.1
19 51 A 6.1
20 51 A 2.1
21 51 DN 7.1
22 51 DN 7.2
23 51 DN 2.2
24 51 DN 1.2
25 47 A 7.2
26 47 DN 2.2
27 47 DN 1.2
28 47 A 1.2
29 47 A 2.2
30 47 DN 6.2
31 47 DN 7.2
32 47 A 6.2
K7 = 12W/m^2
7m
1.8m
0.7 m
33 47 A 9.1
34 47 DN 8.1
35 47 DN 3.1
36 47 DN 9.1
37 47 A 3.1
38 47 A 8.1
39
40 51 A 3.1
41 51 A 9.1
42 51 A 8.1
43 51 DN 8.2
44 51 A 3.2
45 51 DN 9.2
46
47
48
49
50 51 DN 8.1
51 51 DN 3.1
52 51 DN 9.1
53 51 A 9.2
54 51 A 8.2
55 51 DN 3.2
56
57 47 DN 3.2
58 47 A 8.2
59 47 DN 8.2
60 47 A 9.2
61 47 DN 9.2
62 47 A 3.2

Weeks: 52 - 02

N ↑

Plot Layout



● = recorded pot

Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2

K4 = Ambient

(7m × 1.8m; 0.7 m)

83	84	85	86	87	88	89	90	91	92
47	47	47	47	51	51	51	51	51	51
DN	A	DN	DN	A	A	A	DN	DN	DN
7.2	5.2	8.2	2.2	4.1	10.1	5.1	4.1	5.1	10.1

93	94	95	96	97	98	99	100	101	102
47	47	47	47	47	47	47	51	51	51
A	A	A	DN	DN	DN	A	A	A	DN
7.2	10.2	4.2	3.2	4.2	10.2	8.2	5.2	10.2	4.2

103	104	105	106	107	108	109	110	111	112
47	47	47	47	47	47	47	51	51	51
DN	A	DN	A	DN	A	A	A	DN	DN
6.2	6.2	5.2	9.2	9.2	3.2	2.2	4.2	5.2	10.2

K3 = Ambient

(7m × 1.8m)

63	64	65	66	67	68	69	70	71	72
	47	47	47	47	47	47	47	47	47
	A	A	DN	DN	A	A	A	DN	DN
	2.1	5.1	3.1	4.1	10.1	4.1	8.1	7.1	5.1

73	74	75	76	77	78	79	80	81	82
47	47	47	47	47	47	47	47	47	
A	A	DN	DN	DN	DN	A	A	DN	
7.1	3.1	2.1	10.1	8.1	6.1	9.1	6.1	9.1	

K8 = 6W/m^2

1	2	3	4	5	6	7	8	9	10	11
47	47							51	51	51
DN	A							DN	DN	DN
1.1	1.1							6.1	1.1	2.1

12	13	14	15	16	17	18	19	20	21
51	51	51	51	51	51	51	51	51	51
A	A	A	DN	A	A	A	A	A	DN
6.2	1.2	7.2	6.2	2.2	1.1	7.1	6.1	2.1	7.1

22	23	24	25	26	27	28	29	30	31	32
51	51	51			47	47				
DN	DN	DN			DN	A				
7.2	2.2	1.2			1.2	1.2				

K7 = 12W/m^2

(7m × 1.8m; 0.7 m)

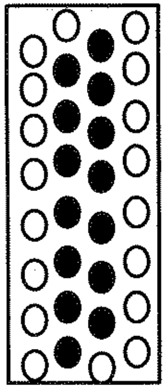
33	34	35	36	37	38	39	40	41	42
							51	51	51
							A	A	A
							3.1	9.1	8.1

43	44	45	46	47	48	49	50	51	52
51	51	51					51	51	51
DN	A	DN					DN	DN	DN
8.2	3.2	9.2					8.1	3.1	9.1

53	54	55	56	57	58	59	60	61	62
51	51	51							
A	A	DN							
9.2	8.2	3.2							

Week: 03

Plot Layout



● = recorded pot

Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2

K4 = Ambient

(7m × 1.8m beds; 0.7 m plots)

83	84	85	86	87	88	89	90	91	92
				51 A 4.1	51 A 10.1	51 A 5.1	51 DN 4.1	51 DN 5.1	51 DN 10.1

93	94	95	96	97	98	99	100	101	102
							51 A 5.2	51 A 10.2	51 DN 4.2

103	104	105	106	107	108	109	110	111	112
47 DN 10.2	47 A 2.2	47 A 10.2	47 DN 3.2	47 DN 2.2	47 A 3.2		51 A 4.2	51 DN 5.2	51 DN 10.2

K3 = Ambient

N ↑

(7m × 1.8m beds)

63	64	65	66	67	68	69	70	71	72
		47 DN 10.1	47 A 2.1	47 DN 3.1	47 DN 2.1	47 A 10.1	47 A 3.1		

73	74	75	76	77	78	79	80	81	82

K8 = 6W/m^2

1	2	3	4	5	6	7	8	9	10	11
47 DN 6.1	47 DN 9.1	47 A 4.1	47 A 1.1	47 DN 1.1	47 DN 4.1	47 A 9.1	47 A 6.1	51 DN 6.1	51 DN 1.1	51 DN 2.1

12	13	14	15	16	17	18	19	20	21
51 A 6.2	51 A 1.2	51 A 7.2	51 DN 6.2	51 A 2.2	51 A 1.1	51 A 7.1	51 A 6.1	51 A 2.1	51 DN 7.1

22	23	24	25	26	27	28	29	30	31	32
51 DN 7.2	51 DN 2.2	51 DN 1.2	47 DN 1.2	47 A 4.2	47 DN 4.2	47 A 9.2	47 DN 6.2	47 A 1.2	47 A 6.2	47 DN 9.2

K7 = 12W/m^2

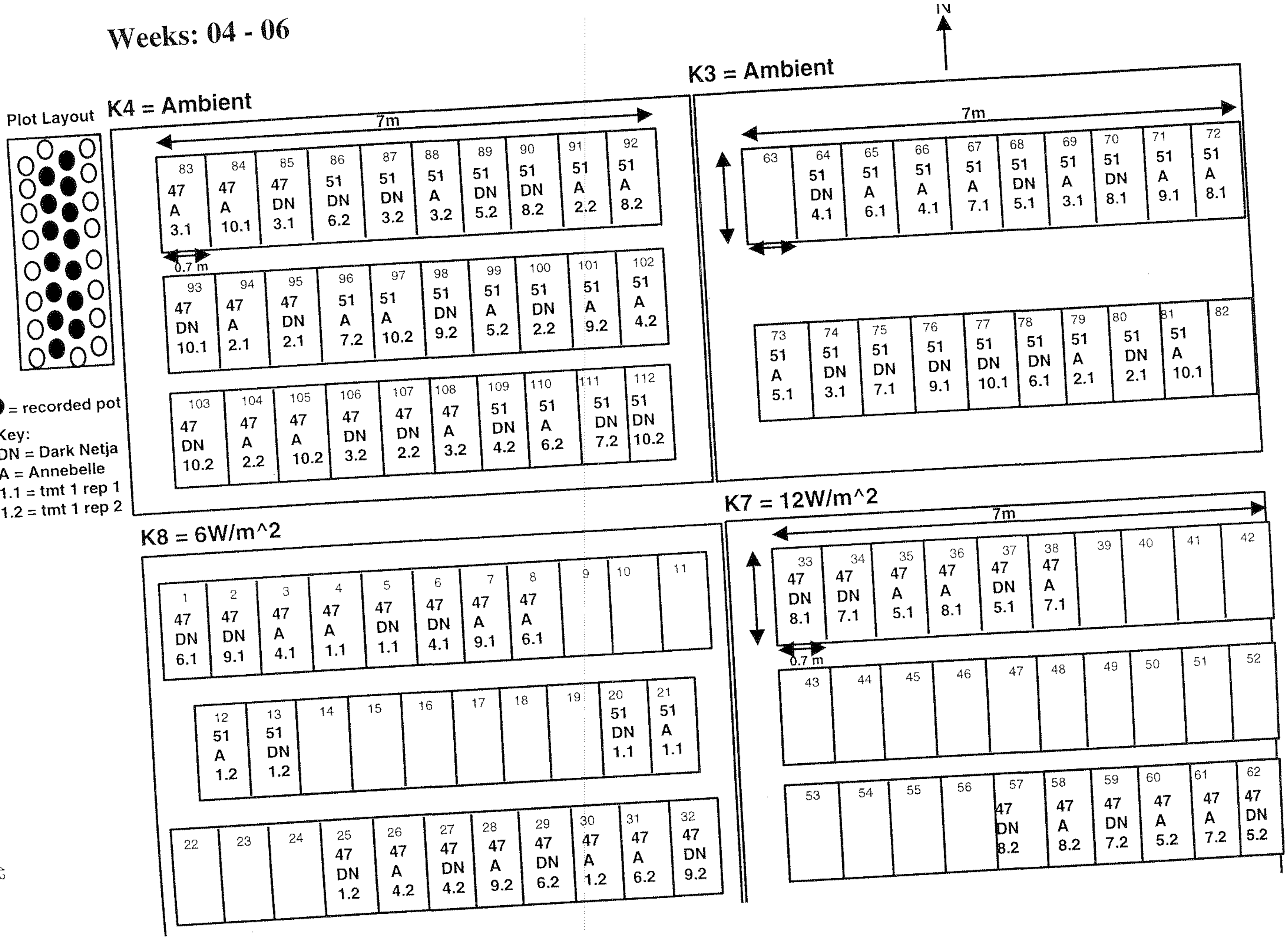
(7m × 1.8m beds; 0.7 m plots)

33	34	35	36	37	38	39	40	41	42
47 DN 8.1	47 DN 7.1	47 A 5.1	47 A 8.1	47 DN 5.1	47 A 7.1		51 A 3.1	51 A 9.1	51 A 8.1

43	44	45	46	47	48	49	50	51	52
51 DN 8.2	51 A 3.2	51 DN 9.2					51 DN 8.1	51 DN 3.1	51 DN 9.1

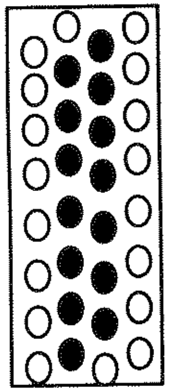
53	54	55	56	57	58	59	60	61	62
51 A 9.2	51 A 8.2	51 DN 3.2		47 DN 8.2	47 A 8.2	47 DN 7.2	47 A 5.2	47 A 7.2	47 DN 5.2

Weeks: 04 - 06


N
Plot Layout
= recorded pot
Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2
K4 = Ambient
7m
0.7 m
83 47 A 3.1
84 47 A 10.1
85 47 DN 3.1
86 51 DN 6.2
87 51 DN 3.2
88 51 A 3.2
89 51 DN 5.2
90 51 DN 8.2
91 51 A 2.2
92 51 A 8.2
93 47 DN 10.1
94 47 A 2.1
95 47 DN 2.1
96 51 A 7.2
97 51 A 10.2
98 51 DN 9.2
99 51 A 5.2
100 51 DN 2.2
101 51 A 9.2
102 51 A 4.2
103 47 DN 10.2
104 47 A 2.2
105 47 A 10.2
106 47 DN 3.2
107 47 DN 2.2
108 47 A 3.2
109 51 DN 4.2
110 51 A 6.2
111 51 DN 7.2
112 51 DN 10.2
K3 = Ambient
7m
63
64 51 DN 4.1
65 51 A 6.1
66 51 A 4.1
67 51 A 7.1
68 51 DN 5.1
69 51 A 3.1
70 51 DN 8.1
71 51 A 9.1
72 51 A 8.1
73 51 A 5.1
74 51 DN 3.1
75 51 DN 7.1
76 51 DN 9.1
77 51 DN 10.1
78 51 DN 6.1
79 51 A 2.1
80 51 DN 2.1
81 51 A 10.1
82
K8 = 6W/m^2
1 47 DN 6.1
2 47 DN 9.1
3 47 A 4.1
4 47 A 1.1
5 47 DN 1.1
6 47 DN 4.1
7 47 A 9.1
8 47 A 6.1
9
10
11
12 51 A 1.2
13 51 DN 1.2
14
15
16
17
18
19
20 51 DN 1.1
21 51 A 1.1
22
23
24
25 47 DN 1.2
26 47 A 4.2
27 47 DN 4.2
28 47 A 9.2
29 47 DN 6.2
30 47 A 1.2
31 47 A 6.2
32 47 DN 9.2
K7 = 12W/m^2
7m
0.7 m
33 47 DN 8.1
34 47 DN 7.1
35 47 A 5.1
36 47 A 8.1
37 47 DN 5.1
38 47 A 7.1
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57 47 DN 8.2
58 47 A 8.2
59 47 DN 7.2
60 47 A 5.2
61 47 A 7.2
62 47 DN 5.2

Week: 07

Plot Layout



● = recorded pot

Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2

N ↑

K4 = Ambient

7m (row length); 0.7 m (plot width)

83 47 A 3.1	84 47 A 10.1	85 47 DN 3.1	86	87 51 A 3.2	88 51 DN 10.2	89 51 DN 3.2	90 51 A 10.2	91 51 A 2.2	92 51 DN 2.2
93 47 DN 10.1	94 47 A 2.1	95 47 DN 2.1	96	97	98	99	100	101	102
103 47 DN 10.2	104 47 A 2.2	105 47 A 10.2	106 47 DN 3.2	107 47 DN 2.2	108 47 A 3.2	109	110	111	112

K3 = Ambient

7m

63	64	65	66	67	68	69	70	71	72
73	74	75 51 DN 2.1	76 51 A 3.1	77 51 A 2.1	78 51 A 10.1	79 51 DN 10.1	80 51 DN 3.1	81	82

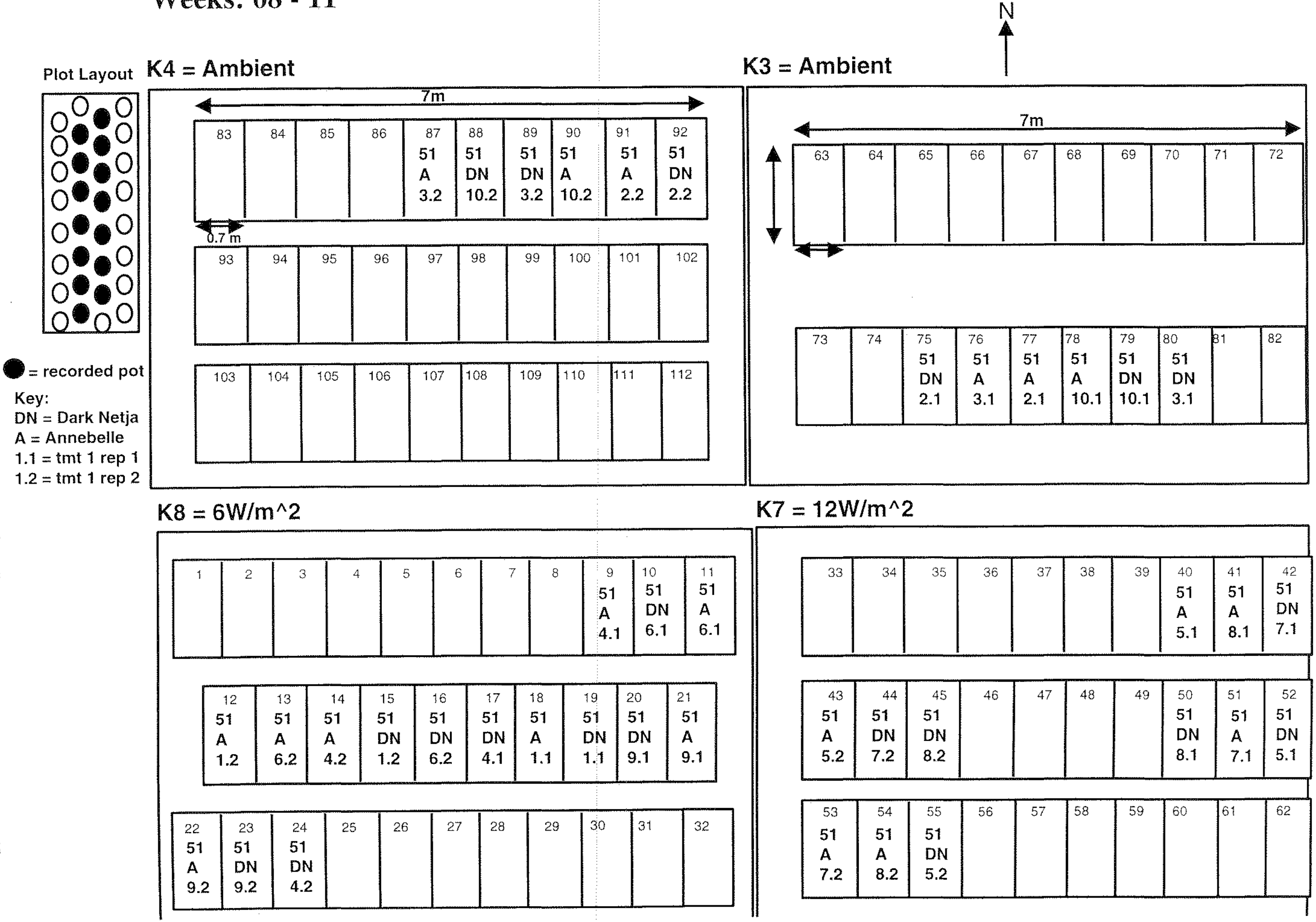
K8 = 6W/m^2

1 47 DN 6.1	2 47 DN 9.1	3 47 A 4.1	4 47 A 1.1	5 47 DN 1.1	6 47 DN 4.1	7 47 A 9.1	8 47 A 6.1	9 51 A 4.1	10 51 DN 6.1	11 51 A 6.1
12 51 A 1.2	13 51 A 6.2	14 51 A 4.2	15 51 DN 1.2	16 51 DN 6.2	17 51 DN 4.1	18 51 A 1.1	19 51 DN 1.1	20 51 DN 9.1	21 51 A 9.1	
22 51 A 9.2	23 51 DN 9.2	24 51 DN 4.2	25 47 DN 1.2	26 47 A 4.2	27 47 DN 4.2	28 47 A 9.2	29 47 DN 6.2	30 47 A 1.2	31 47 A 6.2	32 47 DN 9.2

K7 = 12W/m^2

33 47 DN 8.1	34 47 DN 7.1	35 47 A 5.1	36 47 A 8.1	37 47 DN 5.1	38 47 A 7.1	39	40 51 A 5.1	41 51 A 8.1	42 51 DN 7.1
43 51 A 5.2	44 51 DN 7.2	45 51 DN 8.2	46	47	48	49	50 51 DN 8.1	51 51 A 7.1	52 51 DN 5.1
53 51 A 7.2	54 51 A 8.2	55 51 DN 5.2	56	57 47 DN 8.2	58 47 A 8.2	59 47 DN 7.2	60 47 A 5.2	61 47 A 7.2	62 47 DN 5.2

Weeks: 08 - 11


Plot Layout
= recorded pot
Key:
DN = Dark Netja
A = Annebelle
1.1 = tmt 1 rep 1
1.2 = tmt 1 rep 2
N
K4 = Ambient
7m
0.7 m
83
84
85
86
87 51 A 3.2
88 51 DN 10.2
89 51 DN 3.2
90 51 A 10.2
91 51 A 2.2
92 51 DN 2.2
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
K3 = Ambient
7m
63
64
65
66
67
68
69
70
71
72
73
74
75 51 DN 2.1
76 51 A 3.1
77 51 A 2.1
78 51 A 10.1
79 51 DN 10.1
80 51 DN 3.1
81
82
K8 = 6W/m^2
1
2
3
4
5
6
7
8
9 51 A 4.1
10 51 DN 6.1
11 51 A 6.1
12 51 A 1.2
13 51 A 6.2
14 51 A 4.2
15 51 DN 1.2
16 51 DN 6.2
17 51 DN 4.1
18 51 A 1.1
19 51 DN 1.1
20 51 DN 9.1
21 51 A 9.1
22 51 A 9.2
23 51 DN 9.2
24 51 DN 4.2
25
26
27
28
29
30
31
32
K7 = 12W/m^2
33
34
35
36
37
38
39
40 51 A 5.1
41 51 A 8.1
42 51 DN 7.1
43 51 A 5.2
44 51 DN 7.2
45 51 DN 8.2
46
47
48
49
50 51 DN 8.1
51 51 A 7.1
52 51 DN 5.1
53 51 A 7.2
54 51 A 8.2
55 51 DN 5.2
56
57
58
59
60
61
62

Appendix 3

Crop diary

Crop Diary : Week 47 potting

WK 47

20.11.1997 Potted - SHL begonia compost; 13 cm pots spacing 59 pots m^{-2}; temperature 20°C D/N vent 22°C D/N; ambient lighting treatment long days given using tungsten lights 22.00 - 04.00 & assimilation lighting treatments long days given with SON-T 18 hr/ day 00.00 - 18.00 (K3 & K4 ambient, K7 12 W/m^{-2}, K8 6 W/m^{-2})

WK 49

5.12.1997 Pinched cvs Annebell, Dark Netja 3/4 leaves; assimilation lighting times changed 22.30 - 16.30 duration still 18 hours.

WK 50

8.12.1997 Cycocel (chlormequat 46.5%) 0.5 ml l^{-1}

11.12.1997 Started short days (10 days continuous) K3 & K4 tungsten lights off until 18.12.1997; K7 & K8 assimilation lighting until 18.12.1997 8 hrs. 07.30 - 15.30

12.12.1997 Started feed : 200 ppm N, 50 ppm P, 225 ppm K, 30 ppm Mg, EC 1.9mS, pH 6.2

WK 51

18.12.1997 Blackout covers on 15.30 - 0.7.30 K7 & K8, assimilation lighting 18 hrs. 22.30 - 16.30 (long days for wk 51 potting); blackout covers on 16.30 - 07.30; K4 tungsten lights on 22.00 - 04.00 (long days for wk 51 potting only).

20.12.1997 Finished short days.

WK 52

23.12.1997 Transfers (rep. 1 to K3 & rep, 2 to K4)
Transferred from 6 W/m^{-2} lighting to ambient
Tr. 2 for rest of production, tr. 6 until last 5 weeks, tr. 7 until last 5 weeks
Transferred from 12 W/m^{-2} lighting to ambient
Tr. 3 for rest of production, tr. 8 until last 5 weeks, tr. 9 until last 5 weeks

Spacing - all treatments - 30 pots m^{-2}

27.12.1997 Cycocel (chlormequat 46.5%) 0.5 ml l^{-1} (Annebell) all cycocel application timings based on treatment 1 (6 W/m^{-2} throughout production - current industry standard)

WK 2

8.1.1998 Transfers (from K3 rep. 1 & K4 rep. 2)
Transferred from ambient to 12 W/m^{-2} lighting
Tr. 5 for last 5 weeks, tr. 7 for last 5 weeks, tr. 8 for last 5 weeks transferred from ambient to 6 W/m^{-2} lighting
Tr. 4 for last 5 weeks, tr. 6 for last 5 weeks, tr. 9 for last 5 weeks

Spacing - all treatments - 23 pots m^{-2}

10.1.1998 Cycocel (chlormequat 46.5%) 0.5 ml l^{-1}

WK 4

19.1.1998 Cycocel (chlormequat 46.5%) 1.0 ml l^{-1}

WK 6

2.2.1998 Cycocel (chlormequat 46.5%) 0.5 ml l^{-1}

Crop Diary : Week 51 potting

WK 51

15.12.1997 Potted - SHL begonia compost; 13 cm pots, spacing 59 pots m^{-2} ; temperatures 20^0C D/N vent 22^0C D/N; ambient lighting treatments long days applied using tungsten lights 22.00 - 04.00; assimilation lighting treatments for 18 hrs/day 22.30 - 16.30 using SON-T lamps.
(K3 & K4 ambient, K7 12 W/m^{-2}, K8 6 W/m^{-2})

WK 1

29.12.1997 Pinched cvs Annebell, Dark Netja 3/4 leaves

31.12.1997 Cycocel (chlormequat 46.5%) 05 ml $^{-1}$

WK 2

8.1.1998 Started short days (10 days continuous); K4 - covers on 16.30 off 07.30; K7 & K8 - covers on 15.30 off 07.30 assimilation lighting 18hrs. 22.30 - 16.30 (long days for wk 47 potting) K7 & K8 tungsten lights on 22.00 - 04.00 (long days for wk 47 potting) K3 & K4

9.1.1998 Started feed : 200 ppm N, 50 ppm P, 225 ppm K, 30 ppm Mg, EC 1.9 mS, pH 6.2

WK 3

17.1.1998 Finish short days

WK 4

20.1.1998 Transfers (rep. 1 to K3 & rep. 2 to K4)
Transferred fro 6 W/m^{-2} lighting to ambient
Tr. 2 for rest of production, tr. 6 until last 5 weeks, tr. 7 until last 5 weeks
Transferred from 12 W/m^{-2} lighting to ambient
Tr. 3 for rest of production, tr. 8 until last 5 weeks, tr. 9 until last 5 weeks

Spacing - all treatments - 30 pots m^2

19.1.1998 Cycocel (chlormequat 46.5%) 1.0 ml l^{-1} all cycocel application timings based on treatment 1 (6 W/m^{-2} throughout production - current industry standard)

WK 6

2.2.1998 Cycocel (chlormequat 46.5%) 0,5 ml l^{-1}

5.2.1998 Transfers (from K3 rep. 1 & K4 rep. 2)
transferred from ambient to 12 W/m^{-2} lighting
Tr. 5 for last 5 weeks, Tr. 7 for last 5 weeks, Tr. 8 for last 5 weeks

transferred from ambient to 6 W/m^{-2} lighting
Tr. 4 for last 5 weeks, Tr. 6 for last 5 weeks, Tr. 9 for last 5 weeks

Spacing - all treatments - 23 pots m^{-2}

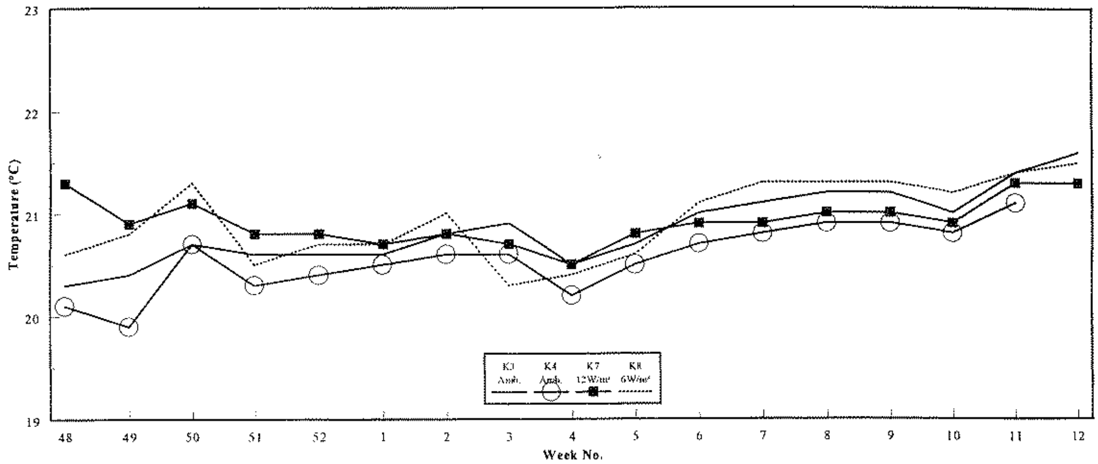
WK 9

25.2.1998 Cycocel (chlormequat 46.5%) 0,5 ml l^{-1}

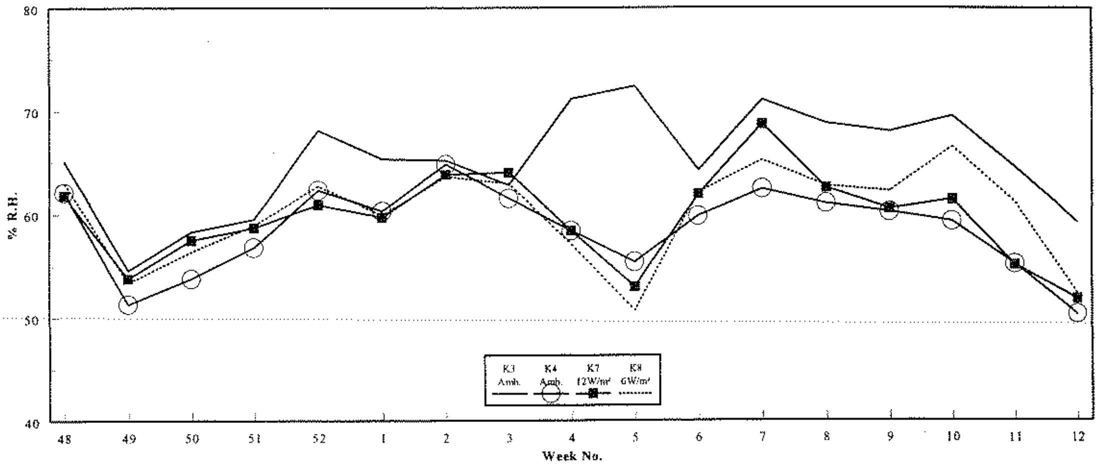
Appendix 4

Environmental data

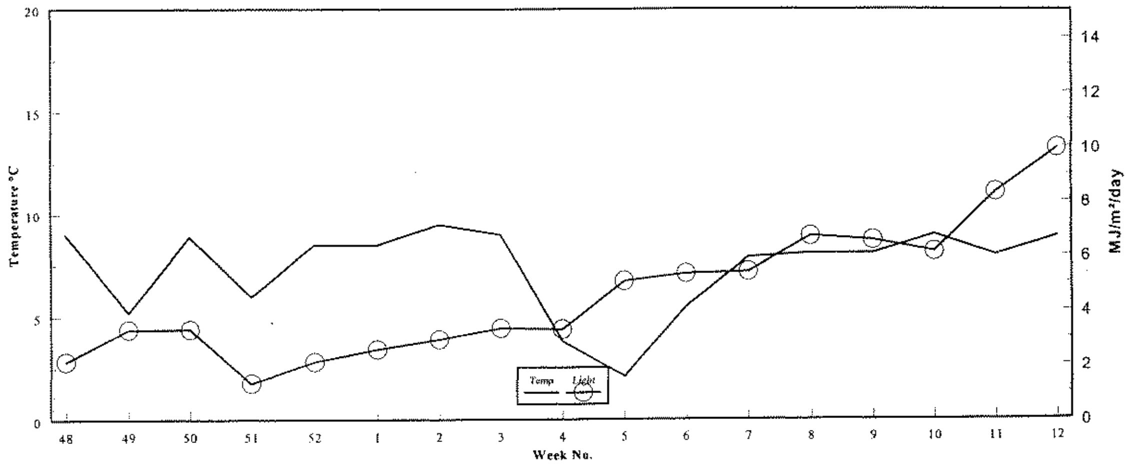
Temperature - 24hr. avg.



Relative Humidity - 24hr. avg.



External Temperature & light levels

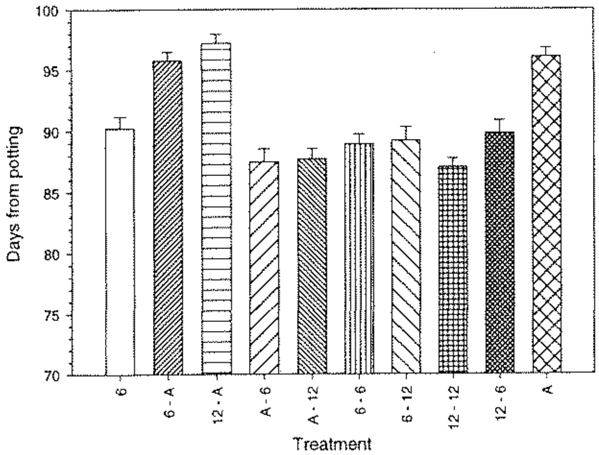


Appendix 5

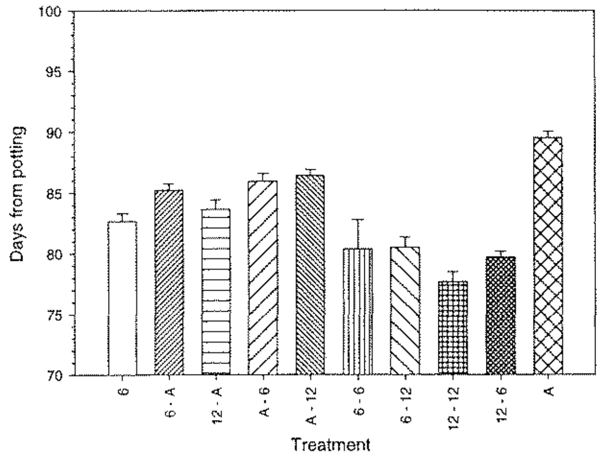
Graphs for marketing data

Appendix 5; figure 1: Effects of production lighting regime on crop duration

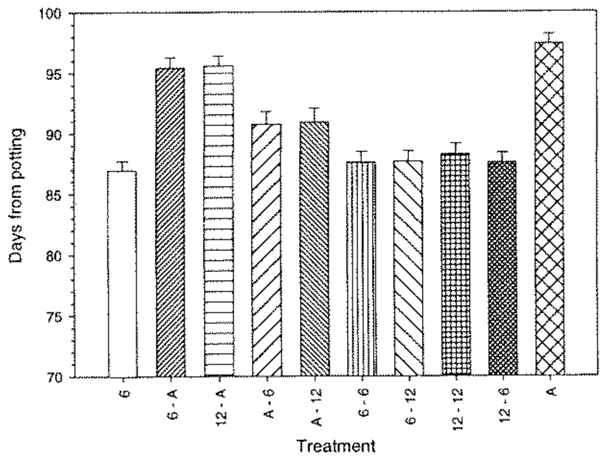
Annebell **Week 47**



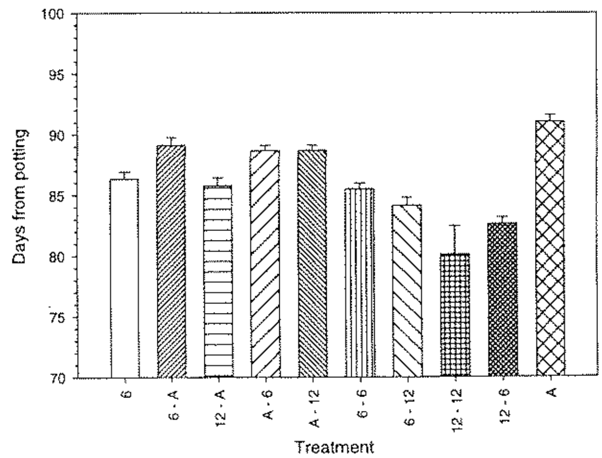
Week 51



Dark Netja **Week 47**

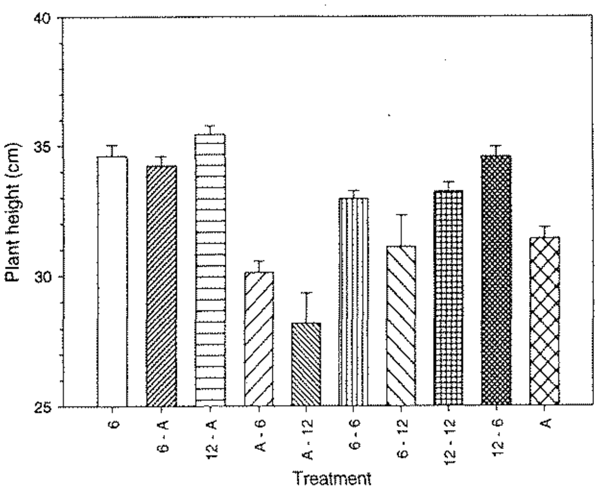


Week 51

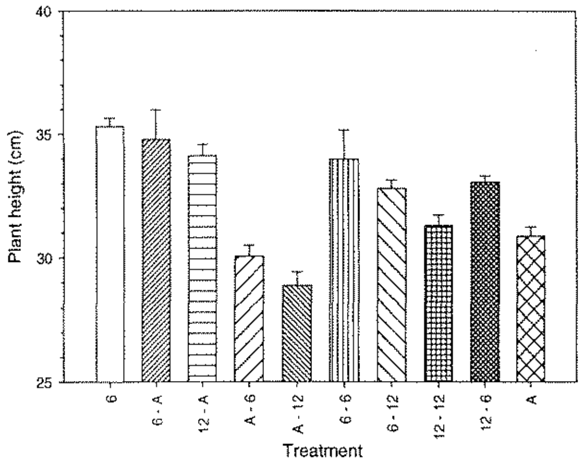


Appendix 5; figure 2: Effects of production lighting regime on plant height at marketing

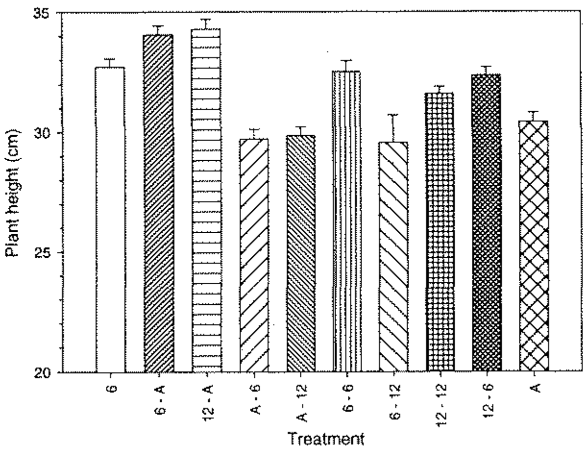
Annebell Week 47



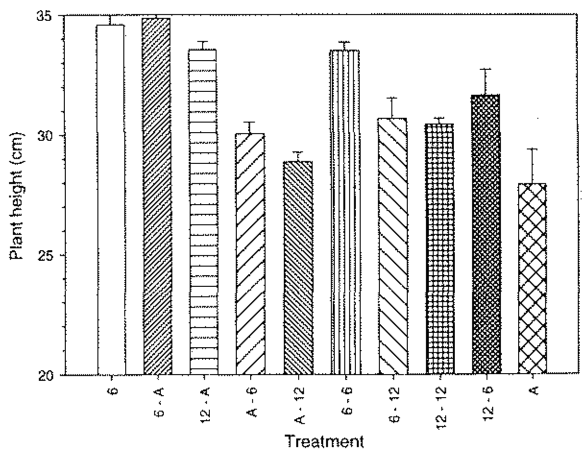
Week 51



Dark Netja Week 47

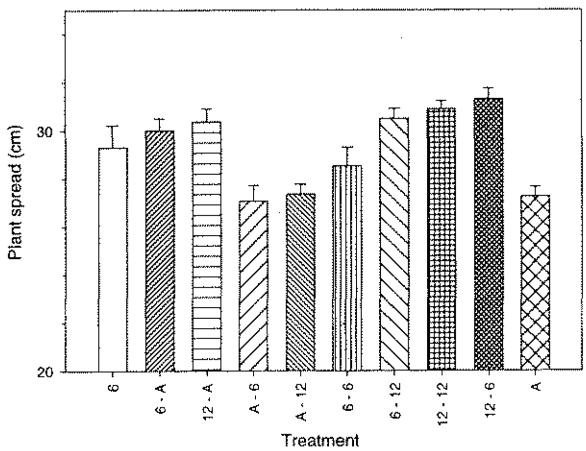


Week 51

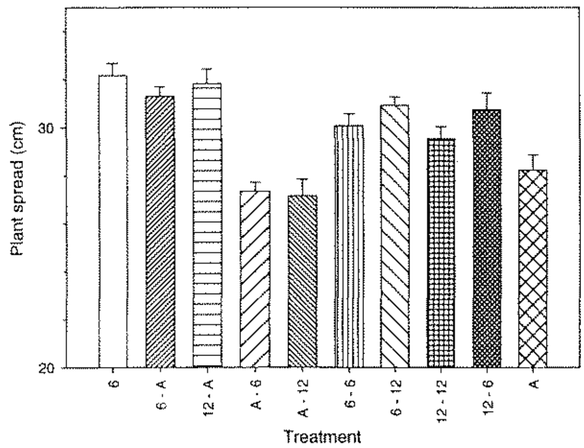


Appendix 5; figure 3: Effects of production lighting regime on average plant spread at marketing

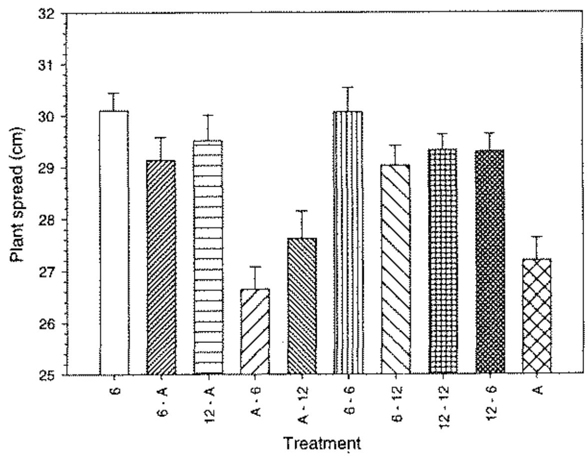
Annebell Week 47



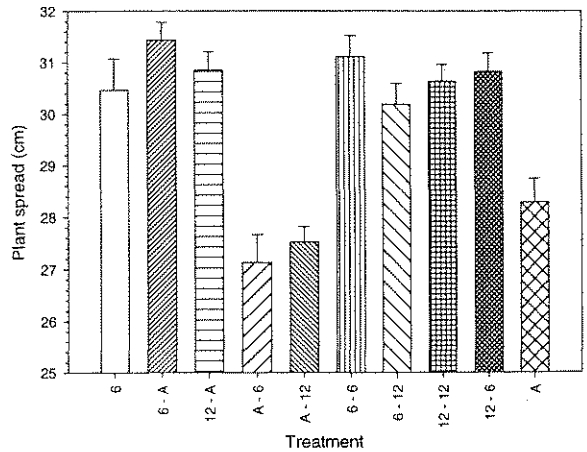
Week 51



Dark Netja Week 47

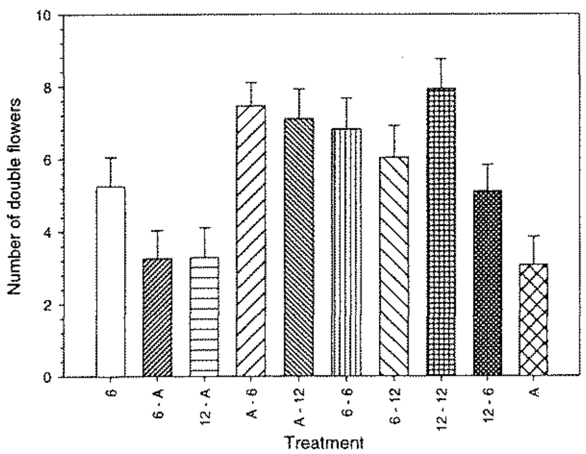


Week 51

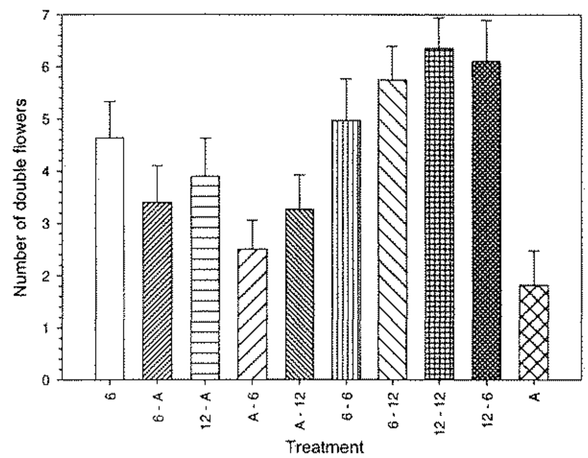


Appendix 5; figure 4: Effects of production lighting regime on number of double flowers at marketing

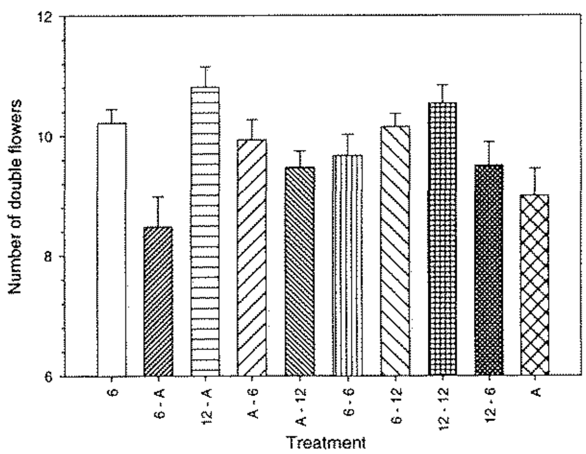
Annebell Week 47



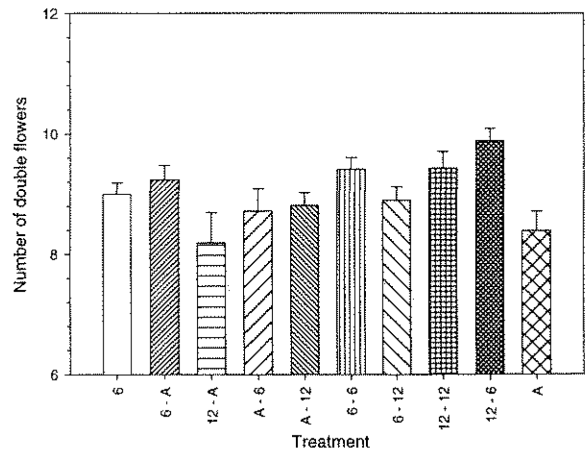
Week 51



Dark Netja Week 47

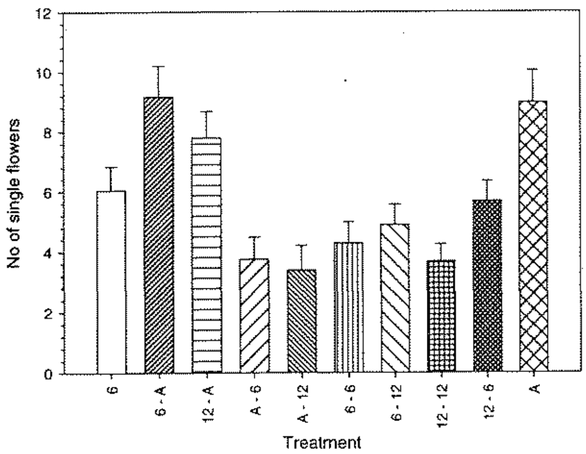


Week 51

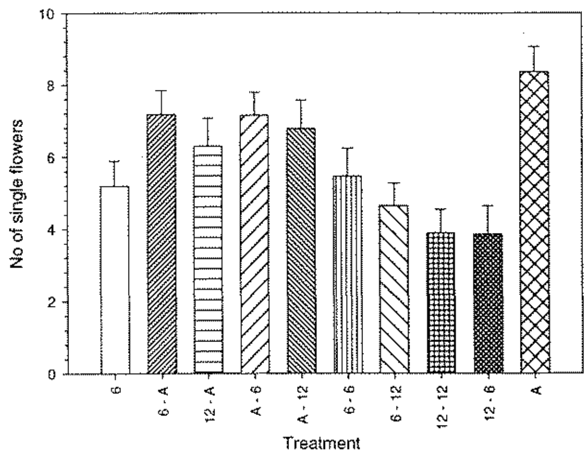


Appendix 5; figure 5: Effects of production lighting regime on number of single flowers per pot at marketing

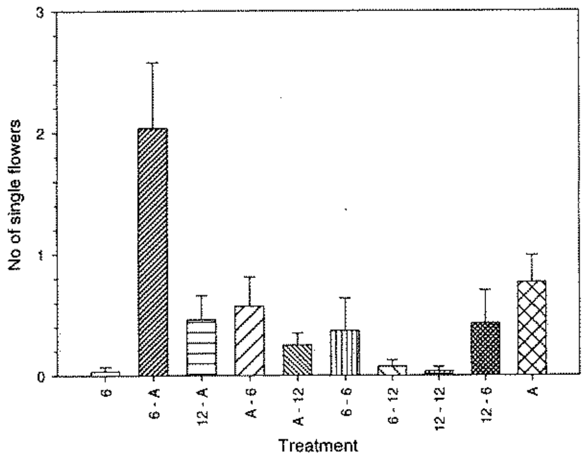
Annebell Week 47



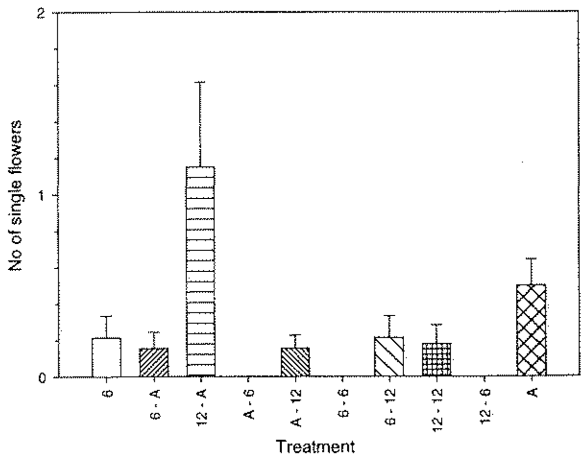
Week 51



Dark Netja Week 47

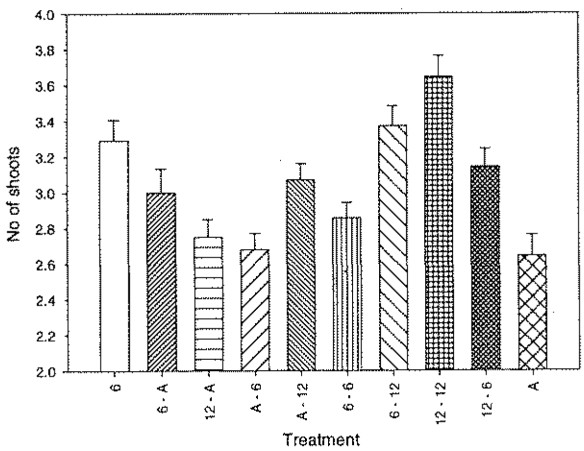


Week 51

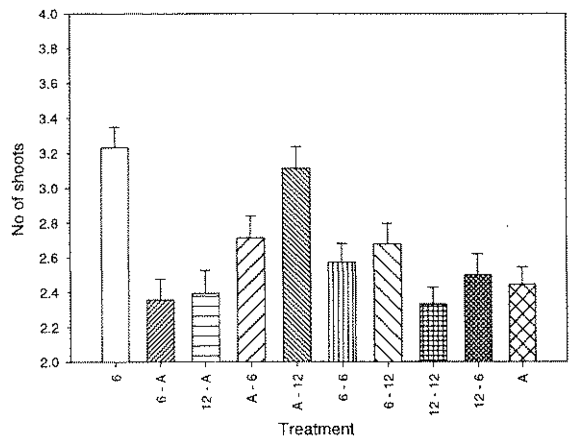


Appendix 5; figure 6: Effects of production lighting regime on number of breaks from the pinch at marketing

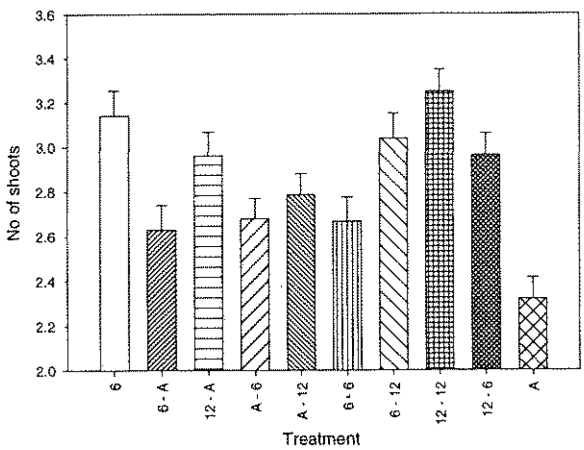
Annebell Week 47



Week 51



Dark Netja Week 47



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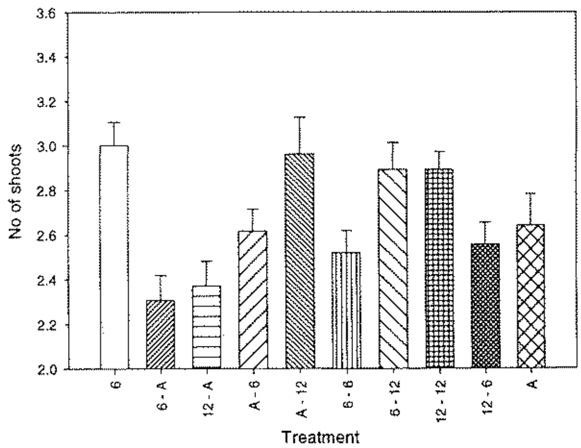
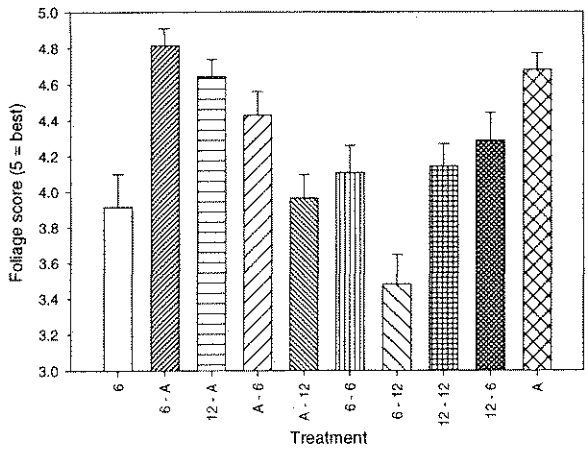
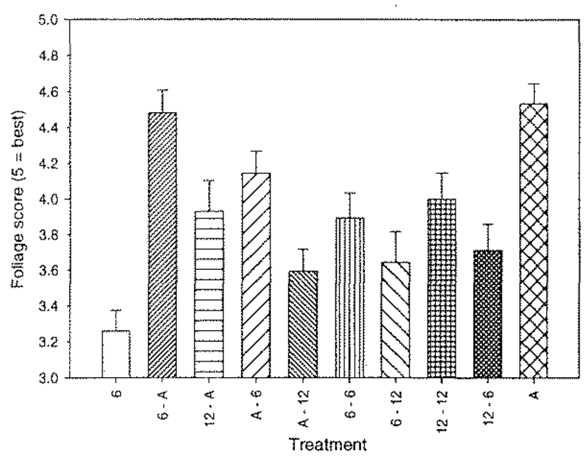


Appendix 5; figure 7: Effects of production lighting regime on foliage score at marketing

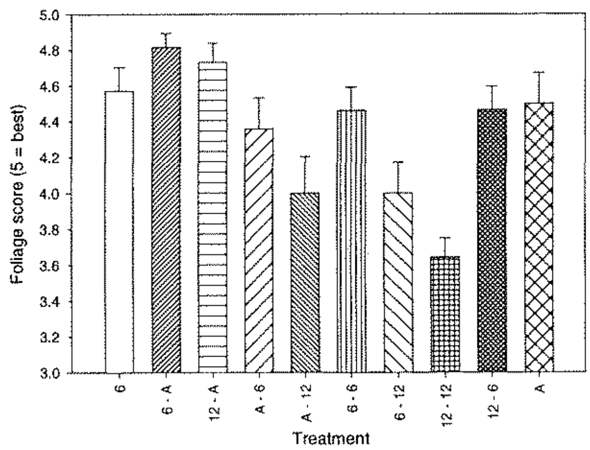
Annebell Week 47



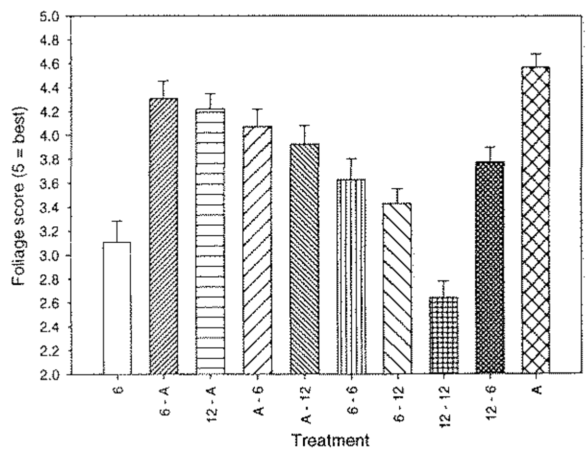
Week 51



Dark Netja Week 47

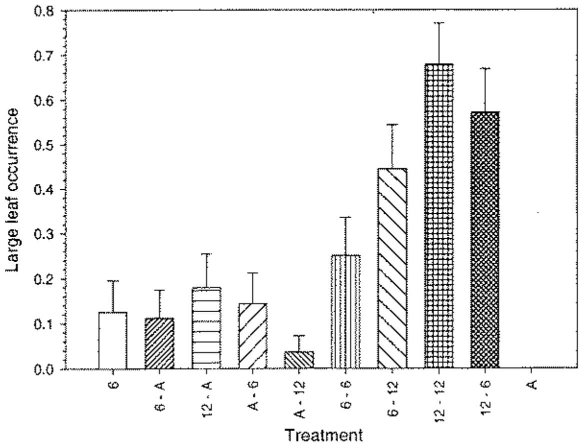


Week 51



Appendix 5; figure 8: Effects of production lighting regime on proportion of pots with "elephant ear" leaf at marketing

Annebell Week 47



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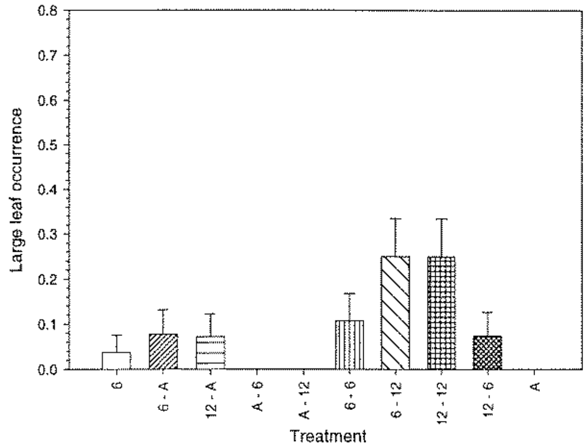
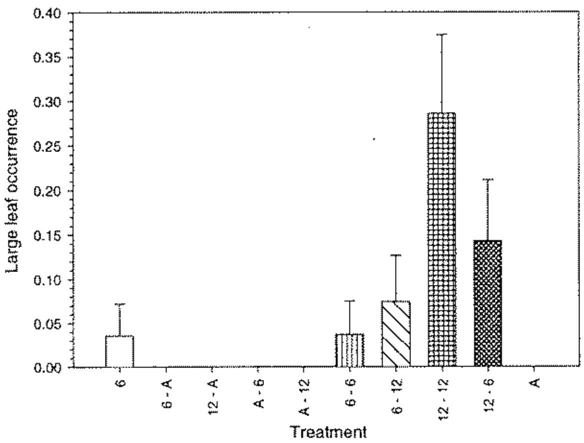


Dark Netja Week 47



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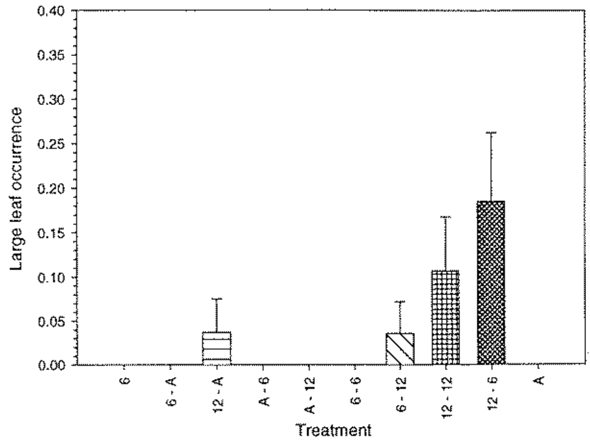
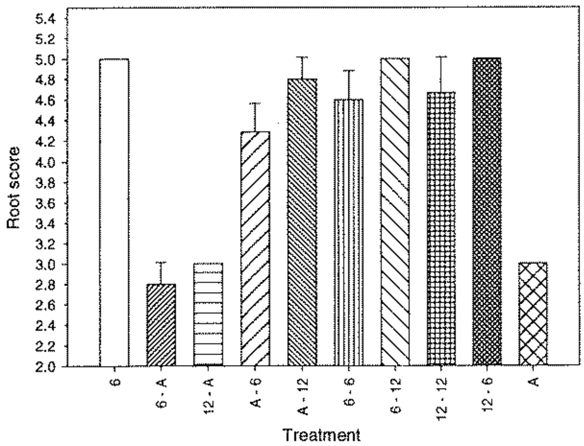
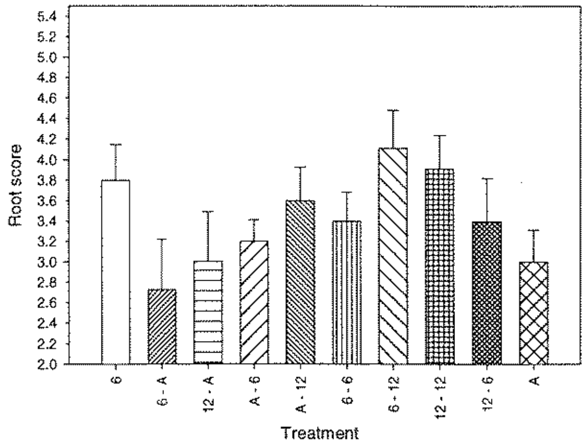


Appendix 5; figure 9: Effects of production lighting regime on root score at marketing.

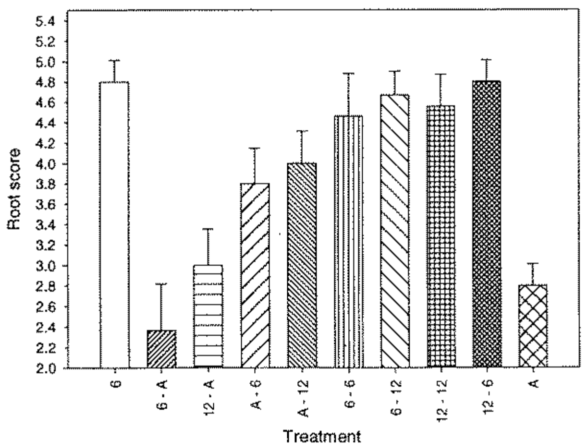
Annebell Week 47



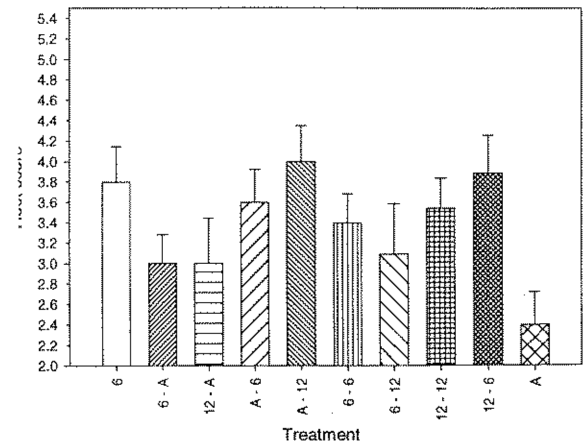
Week 51



Dark Netja Week 47

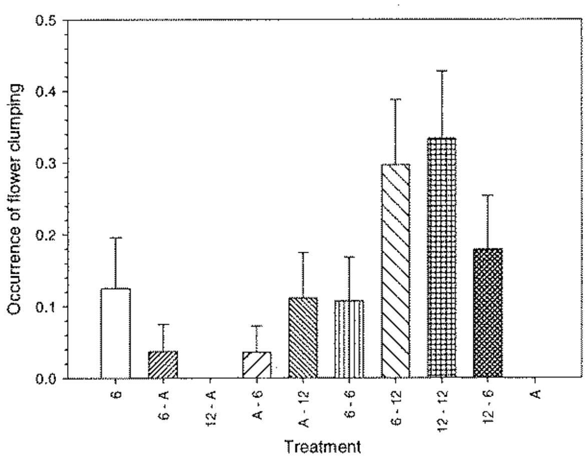


Week 51

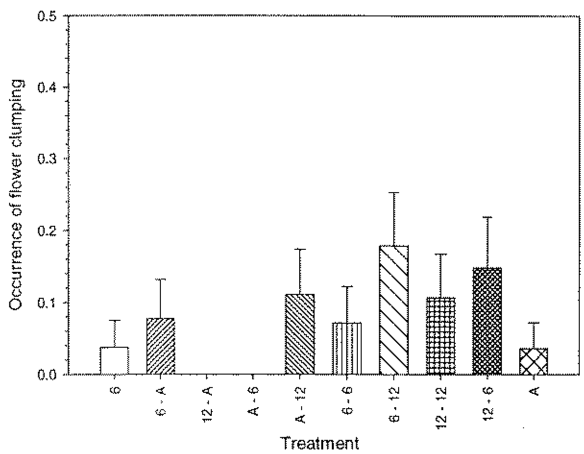


Appendix 5; figure 10: Effects of production lighting regime on proportion of pots with "clumpy" flowers at marketing.

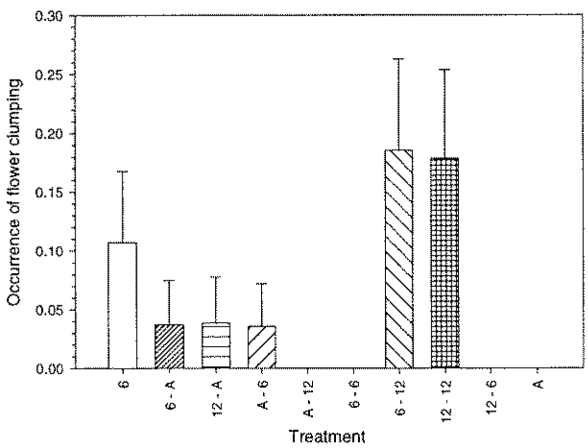
Annebell Week 47



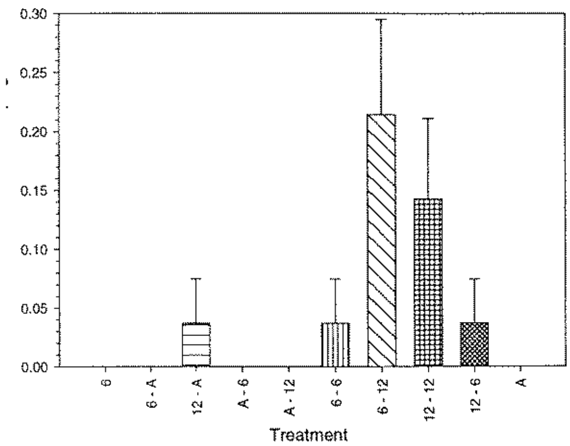
Week 51



Dark Netja Week 47

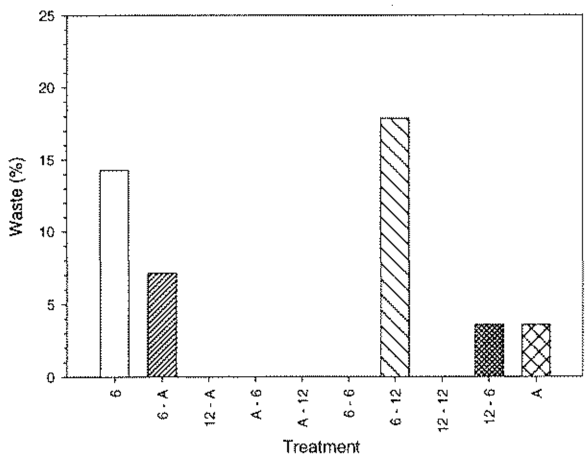


Week 51

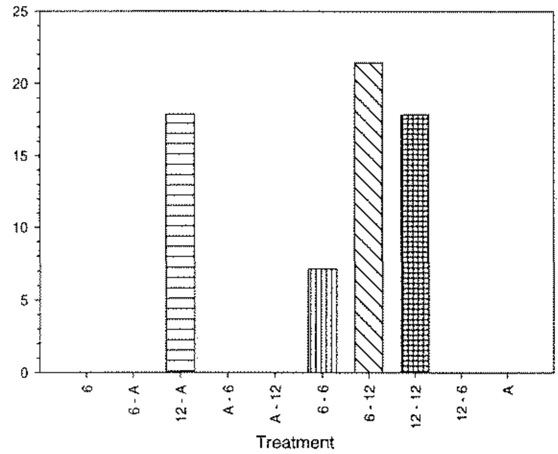


Appendix 5; figure 11: Effects of production lighting regime on percentage waste pots per treatment at marketing.

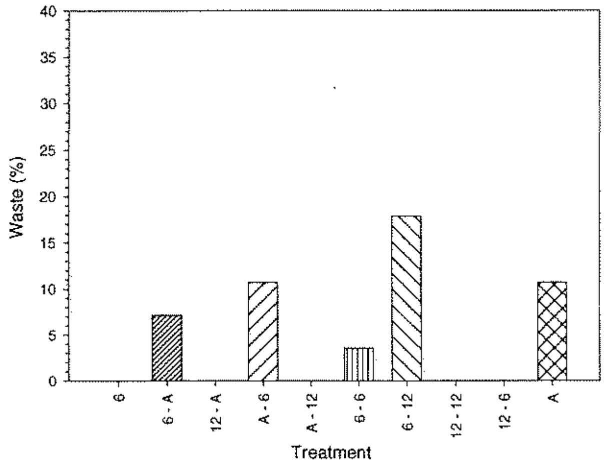
Annebell Week 47



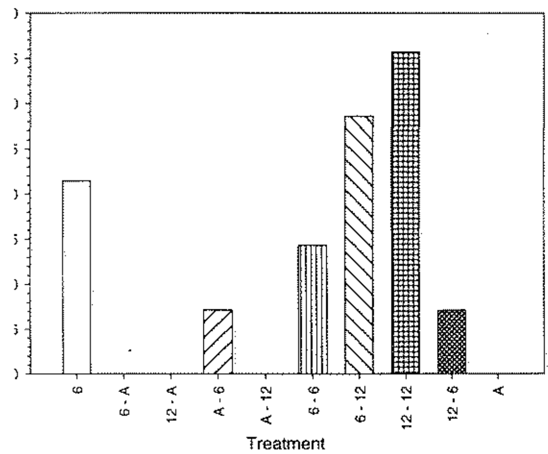
Week 51



Dark Netja Week 47



Week 51

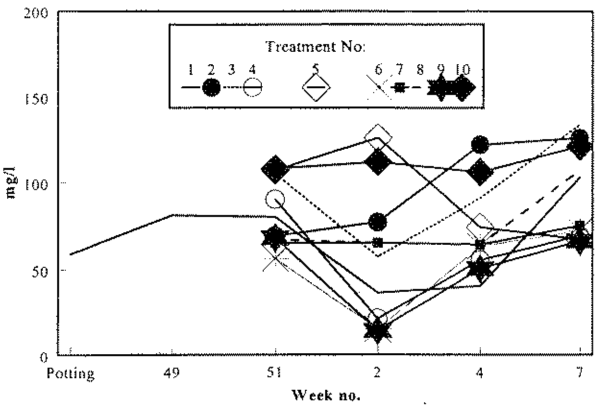


Appendix 6

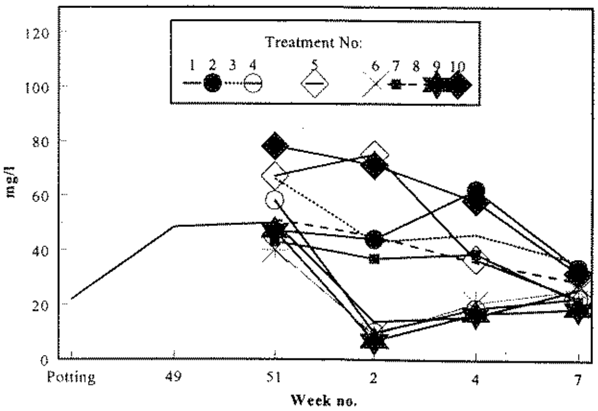
Media and foliar nutrient analyses

Media analysis - Week 47

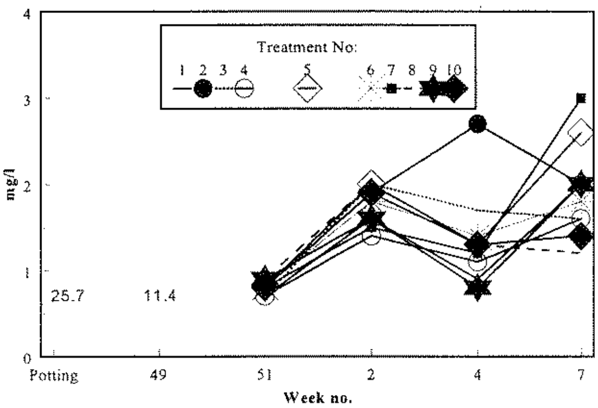
Nitrate N



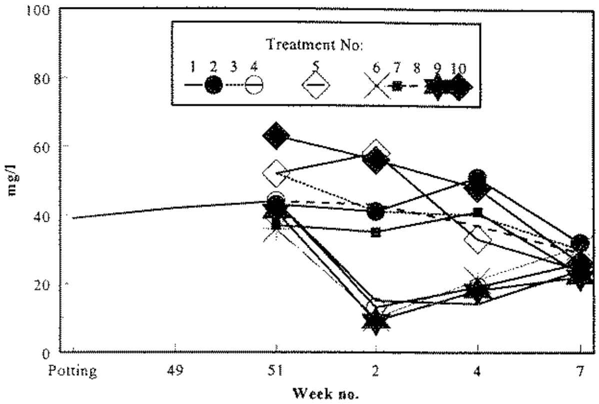
Magnesium



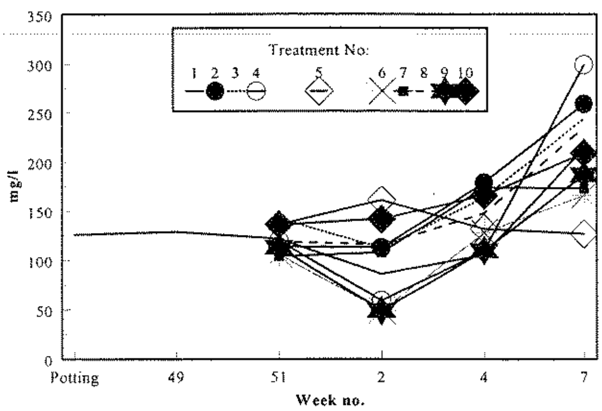
Ammonium N



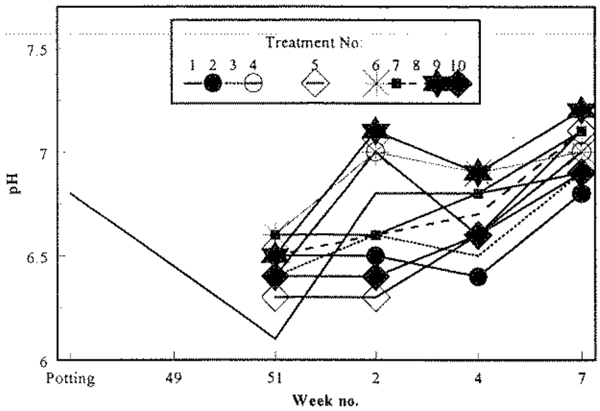
Phosphorus



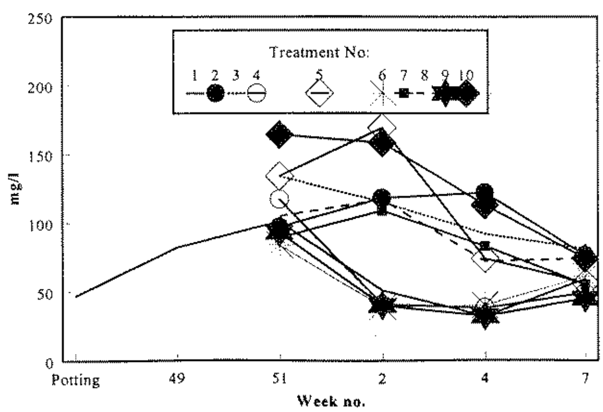
Potassium



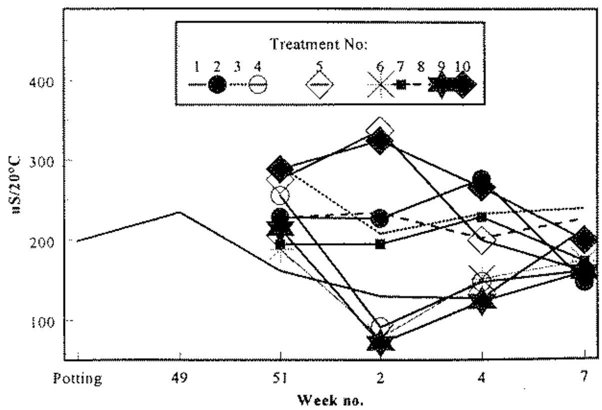
pH



Calcium



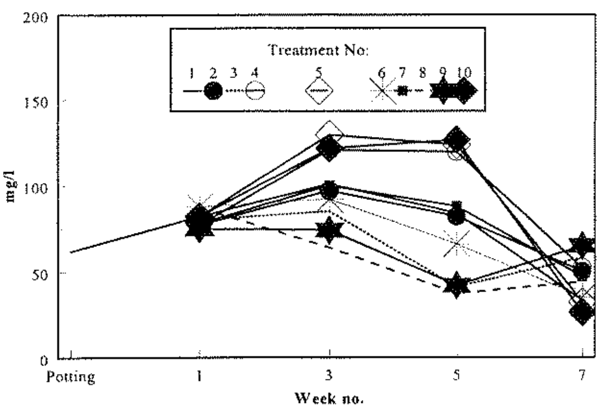
Conductivity



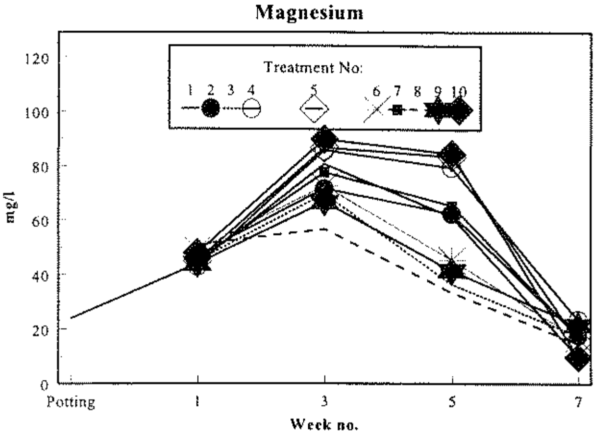
Note:At potting sample and sample 1 were across treatments/cultivars.

Media analysis - Week 51

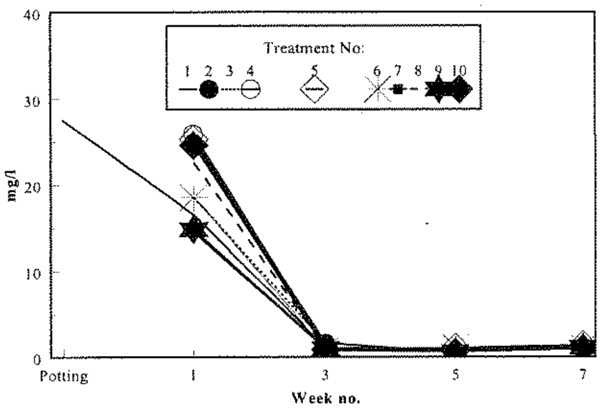
Nitrate N



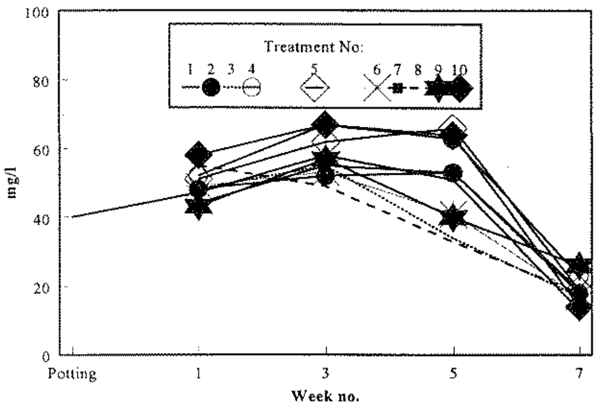
Magnesium



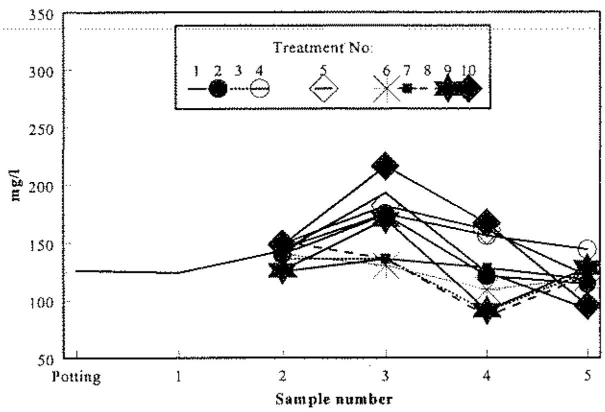
Ammonium N



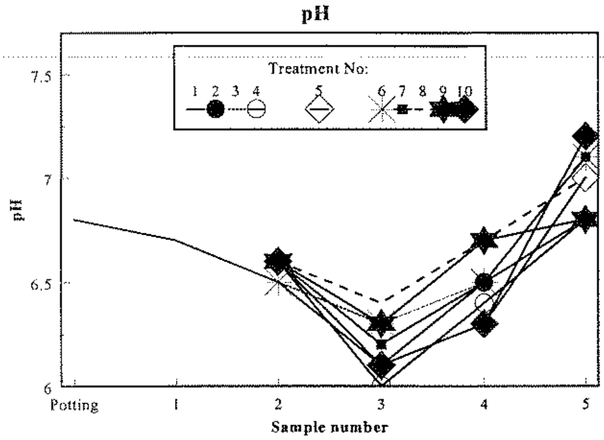
Phosphorus



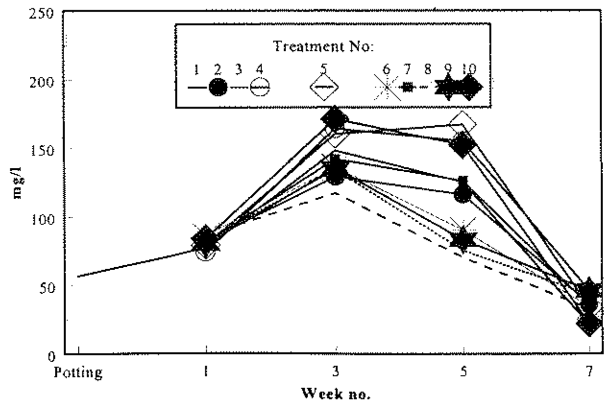
Potassium



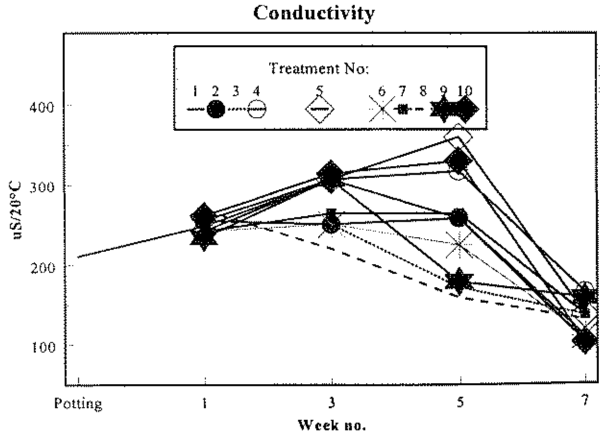
pH



Calcium



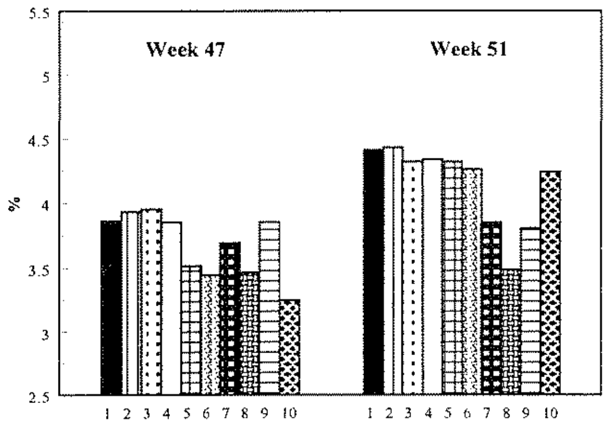
Conductivity



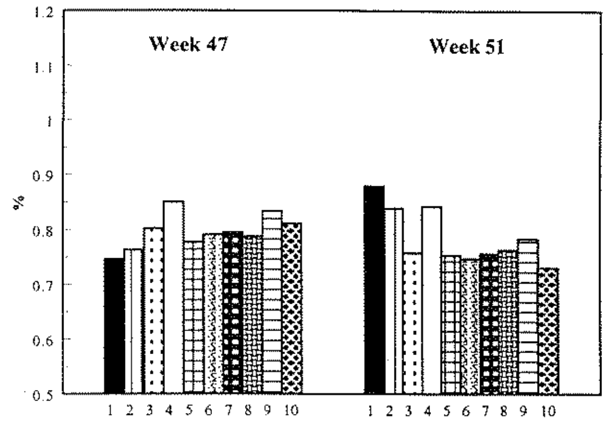
Note:At potting sample and sample 1 were across treatments/cultivars.

Foliage analysis at marketing

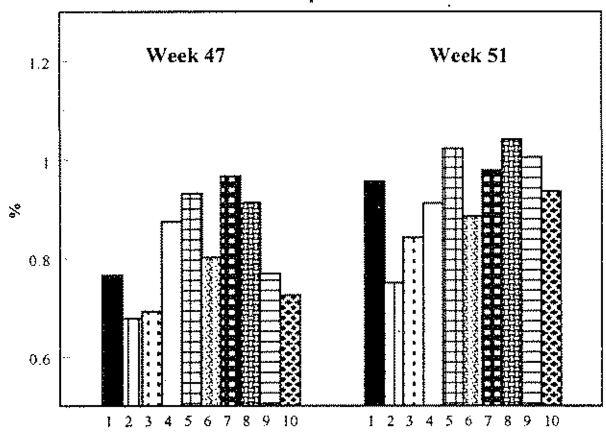
Nitrogen



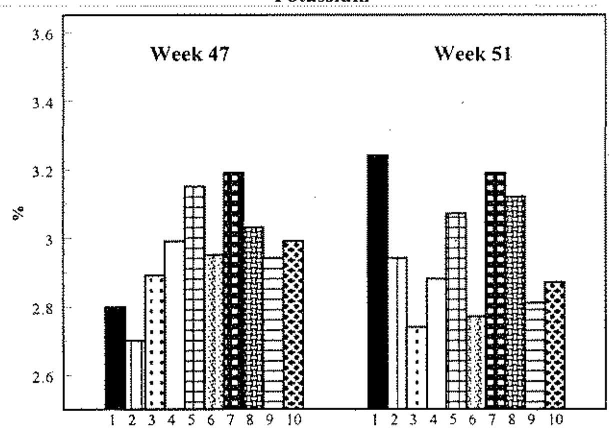
Magnesium



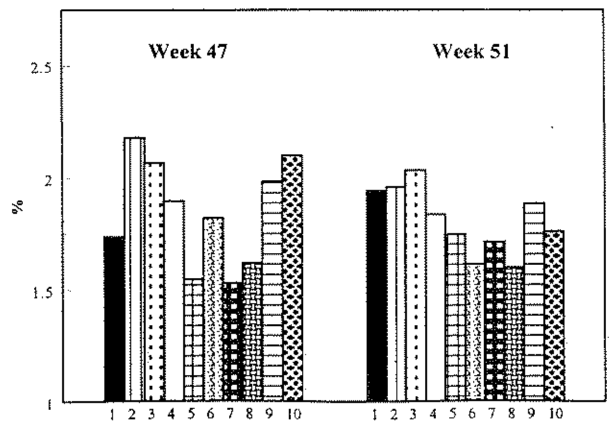
Phosphorus



Potassium



Calcium

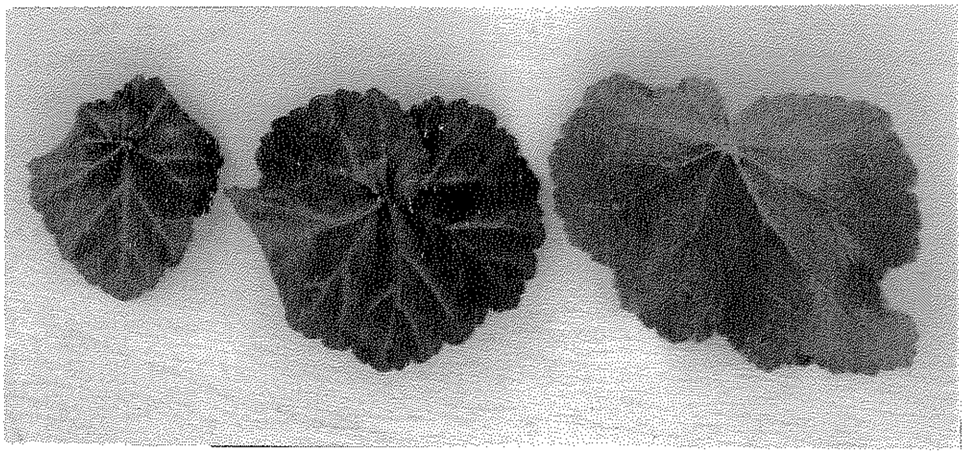


Treatment Key:

1. Lighting at 6 W/m² (2.5 klux) throughout production.
2. Lighting at 6 W/m² for the first 5 weeks after potting.
3. Lighting at 12 W/m² (5 klux) for the first 5 weeks after potting.
4. Lighting at 6 W/m² for the last 5 weeks of production (from first visible buds).
5. Lighting at 12 W/m² for the last 5 weeks of production (from first visible buds).
6. Lighting at 6 W/m² for first 5 weeks after potting, through ambient light and then followed by lighting at 6 W/m² for the last 5 weeks of production.
7. Lighting at 6 W/m² for the first 5 weeks after potting, through ambient light and then followed by lighting at 12 W/m² for the last 5 weeks of production.
8. Lighting at 12 W/m² for the first 5 weeks after potting followed by lighting at 12 W/m² for the last 5 weeks of production.
9. Lighting at 12 W/m² for the first 5 weeks after potting, through ambient light and then followed by lighting at 6 W/m² for the last 5 weeks of production.
10. Control, grown without any supplementary lighting.

Photographic plates

Plate 1



Leaf maturity score: score 1 = immature (left) and 3 = mature expanded (right)

Leaf quality score: score 1 = high quality (left) and 5 = low quality (right)

Root score: score 1 = poor root development (left) and 5 = good development (right)

Plate 2

The occurrence of "elephant ear" large leaf was often observed in plants finished in the highest light treatment (12 W/m^2)

Growing plants under high supplementary lighting regimes made them more susceptible to fluctuation in nutrition as indicated by the occurrence of necrotic leaves in the more recently expanded upper canopy foliage