Project title: **Chrysanthemum: investigation of reduced night-length treatments to improve final stem weight and quality under winter and summer environments**

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CONTENTS Page

PRACTICAL SECTION FOR GROWERS

1.1 Background and Introduction

Production of high quality AYR chrysanthemum during the winter is extremely challenging. Light limits plant productivity, but installation and use of assimilation lighting is expensive, and growers have sought cost-effective alternatives to maintaining winter quality. As light levels fall during the autumn and into winter, assimilation rates are reduced, with stem weight declining as a result. This not only impacts on stem quality, but can reduce saleability in a market place, where multiple retailers are now demanding a minimum stem weight in their specifications.

Currently, for growers without supplementary lighting, production of high quality, uniform crops of AYR chrysanthemum during the winter period relies on careful "interruption" of the inductive short day phase with a period of long days to promote vegetative development post bud initiation. The period of interruption is viewed as a cost in that it extends crop duration, but the increased quality (in terms of added bulk) that result from interruption is worth the added crop time. This technique was developed in the 1950's as an easy way of improving bulk and stem strength during the winter. Early in its use, the timing and length of interruption was not clearly defined, and although very effective in manipulating plant bulk in the winter, each variety required different management to gain maximum benefit from the technique. Mis-timing of the interruption in realtion to bud initiation resulted in undesirable spray forms such as double-deckering, and there was a greater risk of high numbers of waste stems. More recently, HDC-funded work by Allen Langton (see HDC Project PC 12 & Langton ,1992) has further refined the technique to enable better scheduling of the interruption in relation to the light integral received by the crop after the start of short days. The technique was developed for "Pink Gin", "Snowdon", "Daymark", "Delta" and "Snapper", and since the work was conducted, many new varieties have been developed that have replaced the original 'model varieties' in the market place. On many nurseries, there is increasing pressure from the market to diversify and produce a larger range of varieties together. When growing mixed variety bays or beds, it would be desirable to avoid interruption altogether, and use alternative methods for increasing bulk without compromising plant form or crop duration.

Work in Holland on spray chrysanthemums has demonstrated that use of longer day and shorter night periods during short days may be effective in giving some delay in production and hence increasing the vegetative bulk of the plant, as well as its final quality. This work focused on the use of supplementary lighting to increase the length of the day and therefore reduce the length of the night.

During the winter seasons of 1997-98 and 98-99, HDC funded work at HRI Efford examined the use of tungsten lighting to reduce the length of night given to pot chrysanthemums during the winter (PC 92b), and these treatments had a significant impact on the vegetative growth. Applying night-lengths of 11 hours 40 minutes or 11 hours 20 minutes with assimilation lighting also demonstrated the potential for this technique in increasing bulk during the winter. Varietal differences were

apparent, with further work required to refine detail, but trials to date have demonstrated the potential of this technique.
This current work studied the potential for using reduced night-length, as an alternative to interruption, as a means of increasing vegetative growth.

Work examined the response of a number of spray chrysanthemum varieties to a shorter night period through the use of tungsten lighting to extend the length of the day during the winter period, and investigated whether this technique also had any benefits during the summer period. During the naturally long days of summer, AYR spray chrysanthemums are blacked out during daylight hours to initiate flowers, thus restricting the potential assimilation that might be achieved during the full day length of summer. Providing extended days during the summer could, therefore, also improve quality, and the interaction between reduced night-length and potential crop delays was investigated at this time of year.

Objectives

a) The primary aim was to investigate the use of reduced night-length rather than interruption as a tool for controlling crop duration and quality in a range of spray chrysanthemum varieties.

b) Improve plant bulk without the use of the interruption to ease management of a range of varieties grown in the same unit and also reduce potential wastage from varieties such as Reagan.

c) Establish the critical night length required for a range of response types to significantly impact on rate of flower development.

d) Comparison of a range of night-length treatments in winter and summer to examine how pre-dawn tungsten lighting might affect both winter and summer plantings.

Brief description of the work

Varieties used:
Splendid Reagan, Kent, Snowdon*, Delta*, Sheena$ and White Fresco$
* = winter plantings only
$ = summer plantings only

Planting weeks:
40, 45*, 6, 16 and 25
* Factors other than applied treatments confounded data from the week 45 planting, and an extra planting was made in week 6. However, main effects of night-length treatment on response could be determined, and week 45 data is included, though the information on stem and wrap quality needs treating with caution, due to bed-to-bed variability caused by factors other than the applied treatments.

Treatments:

Five treatments were imposed over each variety from the start of short days (SDs):

1) 13 hours 30 minute night (summer) or Natural night-length (Winter when NL was longer than 13 ½ hours) plus interruption (NL + I)

2) 13 hours 30 minute night (summer) or Natural night-length (Winter when NL was longer than 13 ½ hours) minus interruption (NL - I)

3) 12 hour night minus interruption (12 – I)

4) 11 hour 40 minute night minus interruption (11:40 – I)

5) 11 hour 20 minute night minus interruption (11:20 – I)

On each occasion, the varieties were given the same number of initial long days prior to the start of the short day regimes. This would favour certain varieties over others. For all varieties, the main effects of reduced night-length was assessed in relation to the control NL + I treatment (treatment 1 above).

1.2 Summary of results

- The potential for replacing interruption with an un-interrupted reduced night-length regime varied with season and variety.

- The standard interrupted natural night length produced the best results overall, allowing programming of crops with good quality and bulk, without compromising flowering, albeit with a delay in flowering.

- Increasing night length without interruption increased speed of cropping, but at the expense of stem strength (bulk), particularly over the winter period when ambient light levels were low.

- Unacceptable delays occurred over winter under the un-interrupted 11:20 regime, though 11:40 gave satisfactory results for the week 40 and 45 plantings, without loss of stem bulk. Delays subsequent to these planting dates became progressively greater. However, these shorter night length treatments resulted in fewer open flowers per spray at harvest.

- The 12-I regime produced faster crops in the winter plantings, between week 45-06, but these plants had less bulk and consequently weaker stems.

- In practice, night-lengths of between 11:40 and 12 hours may be the best option for maintaining crop speed and flower quality in the winter, without compromising bulk, but this needs further work.

- Reduced night-lengths did increase plant bulk during the spring and summer, when light levels were high, but this was at the expense of extended crop duration.

- There was an interaction between light integral and temperature which affected crop response to photo-period. When background light levels and temperature were high, there was evidence that the "critical" night-length for flowering was extended. These interactions preclude the use of reduced night-length during the spring and summer as a means of increasing plant quality.

- Reduced night-length affected varieties differently, and was inappropriate for Delta during the winter. The technique worked better for Reagan and Kent and this would indicate that its use should concentrate on the more vigorous varieties with short-to-medium response times.

The table below summarises the main effects of each treatment on crop duration, plant bulk, flower numbers and overall quality together with an indication of when each treatment might be used most successfully. However, it is important to note that many treatments do have drawbacks and these must be considered before adopting one treatment over another.

	Measured variable				**Time to use?**
	Crop duration	**Plant bulk**	**Flower number**	**Quality**	
NL + I (control)	Longest in winter when interruption = 10 days. Shortest in summer... interruption not needed at that time of year.	GOOD in winter when maintained by interruption. No added benefits in summer against high light background	GOOD: consistently producing 5 open flowers per stem and with only very small reductions due to the use of an interruption.	Consistently high proportion of grade I stems.	**Winter: weeks 40 to 06**
NL – I	Shorter than NL + I, but reduced time for assimilation precludes its use during winter. Good in summer when growth is not light limited.	Reduced compared to NL + I during winter due to restricted duration, but OK in spring and summer.	Consistently high numbers of open flowers produced in continuous positive short days (highest flower numbers across all treatments).	Poor in winter due to lack of bulk, but good in summer.	**After week 6**
12 – I	To week 6, shorter than NL + I but slower than NL – I. Compared to NL + I, duration was extended after week 6.	Suffered from reduced bulk in winter associated with shorter duration. Small increases in summer at the expense of short crop delays.	Small reduction in open flower number due to slower initiation under slightly less inductive conditions.	POOR in week 40, but otherwise GOOD	**Week 45, but not beyond week 6**
11:40 - I	OK for week 40 – 45 plantings. May replace interruption in winter for vigorous varieties, but no added quality benefits. Delays in summer	OK: no reduction in bulk in winter. More bulky stems in summer, but associated with crop delays.	As for 12 – I above, but slightly nore marked reductions in open flower number (3- 5 / stem).	Slightly better than 12 – I and NL – I due to added bulk in winter. N/A in summer.	**40 – 45 only.**
11:20 - I	No delay for vigorous varieties in week 40, but delays thereafter. Delayed crops in weaker varieties across ALL plantings.	No benefits in week 40, even for vigorous varieties. Increased bulk in summer associated with extreme delays and reduced quality.	Bed development slow leading to reduced flower numbers per stem (2 – 4 / stem).	Generally OK in winter, but very poor in summer.	**40 only, (but not recommended).**

1.3 Action points for growers

- From the current data, use of reduced night-lengths could be an option during the winter and early spring plantings, but their use in the high-light summer would result in unacceptable crop delays, and be unlikely to yield any improvements in quality.

- Of the reduced night-length treatments tested, the 11:20 – I should not be used at any time of year, and the 11:40 – I would only be useful for winter plantings with vigorous varieties which have good flowering response (i.e. those which characteristically produce many flowers per spray).

- When considering the use of reduced night-length regimes during the winter, they should only be regarded as a replacement of interruption at this time of year to ease crop management, rather than as a means of improving plant quality. All reduced night-length treatments slowed flower development and resulted in fewer open flowers per spray at harvest, which is the reason why these techniques are suggested only for vigorous and free-flowering varieties.

- An interruption still offers the best technique for maintaining stem bulk and flower quality during the winter when light levels are low. If reduced night-length is considered as a replacement for interruption, then a night-length between 12 hours and 11 hours 40 minutes appears reasonable, though further work is needed to identify the optimum.

- On the basis of current the data, production of crops during the summer period was best when using an un-interrupted 13½ hour night-length throughout short days.

- Further development of reduced night-length techniques for improved quality needs to include work on producing crops under different night-lengths for specific times during the short day phase, rather than throughout short days.

1.4 Practical and anticipated financial benefits

The current trials data provide a comprehensive study of the interactions between photo-period and aspects of plant quality throughout the year at the commercial level. This information can be used when planning production, or when anticipating or understanding the interactions between localised environmental variables within the nursery environment throughout the seasons.

Although it is unlikely that reduced night-length techniques will be adopted in their current form on a large scale, understanding the effects of these treatments under a range of lighting and temperature conditions may lead to specific niche-market applications. Their application would not require additional investment when using tungsten lighting. Whether there would be an advantage in using the more expensive option of assimilation lighting for reducing night length requires further work, but the Dutch industry have already started to use 4 klx assimilation lights with a 12 hour night in winter.

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. Although supplementary lighting can be used to offset these difficulties, it does require significant capital investment. Production of high quality AYR chrysanthemums during the winter is light-limited. As light levels fall during the autumn and into winter, assimilation rates are reduced, with stem weight declining as a result. This impacts on saleability in a market place where multiple retailers are now demanding a minimum stem weight in their specifications. In cases where assimilation lighting is not an option, growers have sought cost-effective alternatives to maintaining winter quality.

Currently, for growers without supplementary lighting, production of high quality, uniform crops of AYR chrysanthemum during the winter period relies on careful "interruption" of the inductive short day phase with a period of long days to promote vegetative development post bud initiation. The period of interruption is viewed as a cost in that it extends crop duration, but the increased quality (in terms of added bulk) that result from interruption are worth the added crop time. This technique was refined for the industry by Allen Langton (Langton ,1992) and provides a cost-effective way of increasing the vegetative bulk and strength of flower stems in the spray when ambient light levels are at their lowest. The technique was developed for "Pink Gin", "Snowdon", "Daymark", "Delta" and "Snapper".

Relationships between the number of short days required for total floral commitment and the average light integral were determined for six chrysanthemum varieties. Although the speed of commitment to flowering varied between varieties, there was a conservative asymptotic relationship when light integrals were above 1.0 - 1.5 $MJ/m^2/day$ photosynthetically active radiation, and an exponential relationship at lower light integrals. Low light slowed the commitment of the terminal meristem. This meant that if plants received an average of 1.95 $MJ/m^2/day$, interruption could begin after 15 short days, whereas if they were only receiving 0.3 $MJ/m^2/day$ they may need up to 29 short days before interruption. The sensitivity of the response varied considerably between varieties so that whereas "Daymark" would require 18 short days at 0.3 $MJ/m^2/day$, and "Delta" required 29 short days for full commitment to flowering.

Since the work was conducted, many new varieties have been developed that have replaced the original 'model varieties' in the market place. For example, Reagan is now widely grown and is also a variety that is difficult to interrupt to a consistently high standard. On many nurseries, there is increasing pressure from the market to diversify and produce a larger range of varieties together. Although interruption is effective in manipulating plant bulk in the winter, each variety requires slightly different management to gain maximum benefit from the technique, and mis-timing of the interruption can result in poor spray form (e.g. 'double-decker' or layered sprays). When growing mixed variety bays or beds, it would be desirable to avoid interruption altogether, and use alternative methods for increasing bulk without compromising plant form or crop duration.

Work in Holland on spray chrysanthemums has focused on the use of supplementary lighting to increase the length of the day and therefore reduce the length of the night. It demonstrated that the use of longer day and shorter night periods during short days may be effective in giving some delay in production and hence increasing the vegetative bulk of the plant as well as its final quality.

During the winter seasons of 1997-98 and 98-99, HDC funded work at HRI Efford examined the use of tungsten lighting to reduce the length of night given to pot chrysanthemums during the winter (PC 92b). The work investigated the effects of using night-lengths of between 11 and 13 hours, compared against normal seasonal variation in night-length (when longer than 13 hours 30 mins). Reducing the night-length to 11 hours had a significant impact on the vegetative growth, but delayed flowering to such an extent that is was not commercially viable. However, using night-lengths of 11 hours 20, 30 or 40 minutes all resulted in increased vegetative bulk, with flowering, but with a crop delay associated with each treatment. Delays increased as night-length was reduced. This work also indicated that, as with interruption on sprays, each variety responded differently, and so further refinements would be needed for new untested varieties before it could be fully implemented commercially.

The current work studied the potential for using reduced night-length as an alternative to interruption as a means of increasing vegetative growth.

The work examined the response of a number of spray chrysanthemum varieties to a shorter night period, through the use of tungsten lighting to extend the length of the day during the winter period, and investigated whether this technique had any benefits during the summer period. During the naturally long days of summer, AYR spray chrysanthemums are blacked out during daylight hours to initiate flowers. This technique therefore restricts the potential assimilation that might be hieved during the full day length of summer. Reducing the length of time of blacking out each day would allow plants to accumulate more assimilates and therefore improve quality.

2.2 Objectives

a) The primary aim was to investigate the use of reduced night-length rather than interruption as a tool for controlling crop duration and quality in a range of spray chrysanthemum varieties.

b) Improve plant bulk without the use of the interruption to ease management of a range of varieties grown in the same unit and also reduce potential wastage from varieties such as Reagan.

c) Establish the critical night length required for a range of response types to significantly impact on rate of flower development.

d) Comparison of a range of night-length treatments in winter and summer examined how pre-dawn tungsten lighting affected both winter and summer plantings.

2.3 Material and Methods

2.3.1 Glasshouse site

The trial was conducted in C Block, a traditional aluminium construction wide-span house with the ridge running east - west. The glasshouse contained 24 production beds. The trial was planted in the eastern 12 beds with the bed nearest the eastern glass wall used as a guard. Black polythene curtains ran between each bed, with tungsten lights linked to timers to allow independent night-length control over each bed.

2.3.2 Trial description

Planting dates:	Sticking Dates:	Weeks 38, 43, 4*, 14 & 23
	Planting Dates:	Weeks 40, 45, 6*, 16, & 25
	Harvesting Dates	Weeks 2, 7, 18*, 27 & 36 (approx.)

* Factors other than applied treatments confounded data from the week 45 planting, and an extra planting was made in week 6. However, the main effects of night-length treatment on response could be determined, but the effects of treatment on stem and wrap quality may be confounded with bed-to bed variability caused by factors other than the applied treatments.

Plant material: Appropriate varieties were used for the summer and winter plantings as follows:

Winter plantings:	Splendid Reagan (Dk pink single, 8.5 week), Delta (pink single, 9.5 week), Snowdon (white decorative, 9.5 week), Kent (White/cream decorative, 8.5)
Summer plantings:	Splendid Reagan, Sheena (white spider, 9 week), White Fresco (white decorative, 10 week), Kent.

Cuttings were supplied ex Kenya by Yoder Toddington Ltd. All cuttings were rooted on-site in peat blocks conforming to winter specification size (5 x 5 x 3 cm) from week 37, and summer size (3.5 x 3.5 x 3 cm) from week 8, with etridiazole incorporated as Aaterra.

Treatments (see Appendix 1 for plot layouts):

The following 5 treatments were imposed on each of 4 varieties from the start of SDs using pre dawn tungsten day-length extension

1) **NL + I**: 13 hours 30 minutes night with interruption (or natural night when winter night lengths were longer than 13 ½ hours)

2) **NL - I**: 13 hours 30 minutes without interruption (or natural night when winter night lengths were longer than 13 ½ hours)

3) **12H**: 12 hours - without interruption

4) **11:40**: 11 hours and 40 minutes - without interruption

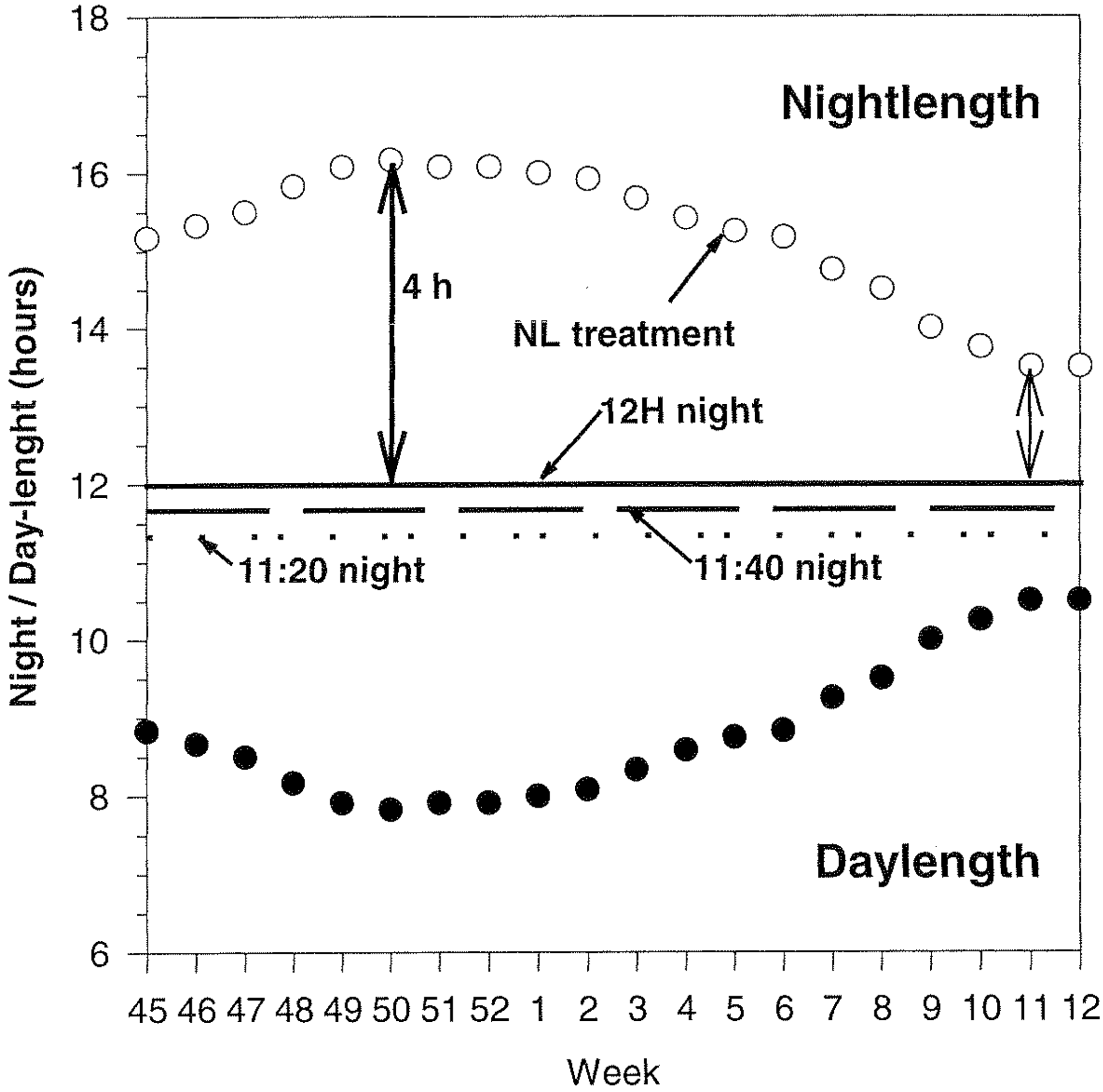
5) **11:20:** 11 hours and 20 minutes - without interruption

For treatments blackouts and timers were be set weekly (Monday of each week) as follows:

Week number	Blackout screen Closed	Open	Timer settings: ON 12	11:40	11:20	Timer OFF	
45	16:20	07:30	04:20	04:00	03:40	07:35	
46	16:10	07:30	04:10	03:50	03:30	07:35	
47	16:00	07:30	04:00	03:40	03:20	07:35	
48	15:55	08:30	03:55	03:35	03:15	08:35	
49	15:50	08:30	03:50	03:30	03:10	08:35	
50	15:45	08:30	03:45	03:25	03:05	08:35	
51	15:50	08:30	03:50	03:30	03:10	08:35	
52	15:50	08:30	03:50	03:30	03:10	08:35	
01	15:55	08:30	03:55	03:35	03:15	08:35	
02	16:00	08:30	04:00	03:40	03:20	08:35	
3	16:15	08:15	04:15	03:55	03:35	08:20	
4	16:30	08:15	04:30	04:10	03:50	08:20	
5	16:45	08:00	04:45	04:25	04:05	08:05	
6	16:50	08:00	04:50	04:30	04:10	08:05	
7	17:00	07:45	05:00	04:40	04:20	07:50	
8	17:15	07:45	05:15	04:55	04:35	07:50	
9	17:30	07:30	05:30	05:10	04:50	07:35	
10	17:45	07:30	05:45	05:25	05:05	07:35	
11	18:00	07:30	06:00	05:40	05:20	07:35	
Summer	18:00	07:30	06:00	05:40	05:20	07:35	(BST)

All beds were screened and de-screened in line with the NL. This means that the NL treatment received a variable night-length, with a peak in the height of winter when day-length was only 8 hours. To reduce night-length in the remaining treatments, pre-dawn tungsten lighting was given. The effect of naturally changing night-length on each treatment can be seen in Figure 1:

Figure 1: Diagrammatic representation of changing night- and day-length at HRI Efford during the winter period, and how the natural night-length treatment (NL) varied from the other imposed night-length treatments.



Experimental design and analysis :

The trial had a winter phase and a summer phase, with two plantings during the winter phase and three plantings during the summer phase. Each phase used a single set of four varieties, with two common to both phases. This meant that comparisons for varieties across all 5 plantings could only be made for Kent and Splendid Reagan. There were five night-length treatments within each planting and each treatment was applied to a single bed of plants. The four varieties were applied to sub-plots within each bed.

Five beds were available for each planting so no replication of night-length treatments was possible within plantings. However, because the experiment was done over several planting dates, the repeatability of the observed effects could be assessed by analysing the relative magnitude of planting effects, night-length effects and planting by night-length interaction effects within each phase of the experiment.

The varieties were not randomised individually within beds, but were arranged as a criss-cross design with respect to the applied treatments. Each variety comprised a set of plots with the same relative position in each bed, so that any interactions between variety main effects and north-south positional effects were consistent both within and between plantings. This provided maximum precision for the comparison of the effects of night-length treatment within variety.

	4	varieties
x	5	night-length treatments
x	1	replicate
x	5	planting dates
=		100 plots (20 plots / planting)

Plot size = 340 / 396 (winter / summer), with 200/230 grade-out sample (winter/summer).

Data were analysed using analysis of variance (ANOVA; Genstat 5.1), but due to the lack of replication within plantings, no S.E.D values could be generated for the main effects of treatments. Where appropriate, data are presented graphically, with within-treatment standard error bars included on the mean values. The magnitude of the error bars can be used to assess the variability within a treatment and to gauge the importance of each treatment on the variable being presented.

2.3.3 Cultural techniques

***Propagation*:** Cuttings were stuck in trays of peat blocks in the weeks specified above and propagated according to SOP GTCF/002. Plants received 12 long days in propagation, with LDs provided by tungsten night break lighting from 21:30 to 02:30 (cycle of 50%, 15 minutes on and 15 off). Temperature set points were 18/19°C day/night with venting at 23°C. Clear polythene sheets were removed after 6 long days in propagation.

Planting: Planting onto steam-sterilised beds was carried out according to SOP GTCF/004 in the week numbers specified earlier. Planting density was at $55/m^2$ in the winter, with summer $64/m^2$ (expressed in terms of plants per unit bed area, not including pathways)

Schedule: A common schedule for all beds was maintained as follows.

Short days were started when the shortest variety (Delta in winter and Sheena* in summer) had reached 28 - 30 cm in height, with a 10 day interruption given in winter and a 4 day interruption in summer, timed according to cumulative light integral on the control treatment only.

* In the summer plantings, Sheena took far longer than the other trial varieties to reach 30 cm. In these cases, to avoid severely compromising the more vigorous varieties in the trial, SDs were started when Splendid Reagan had reached 30 cm.

Environment/Nutrition: 18°C day 19°C night with venting at 23°C. CO_2 set to 1000 vpm with vents up to 5% open or 500 vpm with vents more than 5% open. Standard ADAS winter and summer feeds applied to soil beds, with irrigation scheduled according to light levels (SOP GTCF/013).

Plant Growth Regulation: Daminozide was applied as B - Nine at the following rates (in g/litre and the times shown:

Variety	2 weeks before short days	Start of short days	14 d after start short days	10 days later
Week 40/45				
Reagan	-	0.75	0.75	0.75
Snowdon	0.75	0.75	1.00	0.75
Kent	0.75	-	-	-
Week 6/16/25				
Reagan	-	0.75	0.75	0.75
Snowdon	N/A			
Kent	-	0.75	-	-

In varieties that required growth regulant during interruption, all treatments (including non-interrupted) received growth regulant as outlined above at the appropriate times.

Pest and Disease Control: Routine spray programme for preventative WFT control plus spot treatments were applied as required through daily crop monitoring (SOP GTCF/007; see Appendix 2 for crop diary).

2.3.4 Experimental Records

Plant development was assessed on a destructive sample of 24 plants (two complete rows) on two occasions:

1. At the end of long days (sample 1).

2. At harvest (sample 2).

The remaining plants in each plot were used for the grade-out sample.

On each of the above occasions records of the following measurements were made according to the procedures detailed in SOPs RTCF/002, 007 & 008.

i) Stem length from top of peat block to stem apex (cm).

ii) Fresh weight of material above peat block (g/plant).

iii) Leaf number (leaflets arising from the same node were counted as one and nodes where leaves had been lost through damage/decay were also counted).

iv) Foliar mineral element analysis (50 expanded leaves per variety, across treatments, data in Appendix 7).

Additional records at maturity on all plots included:

1) Date of first bud colour on each plot.

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

3) Bulk dry weight of all stems in destructive sample (g).

4) Grade out of harvested stems from each plot, with number and weight of all the wraps produced in marketing grades 1, 2 and 3 as defined below, with a record of bulk fresh weight and number of waster (i.e. below grade 3 stems.

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

   Grade 2 = At least three open flowers with an additional three buds with potential to open post-harvest.

   Grade 3 = At least two open flowers and a further two buds with potential to open post-harvest.

5) Photographic records (including a key to qualitative scores) were taken as appropriate.

2.3.5 Environmental data:

1) Solar radiation levels ($MJ/m^2/day$).

2) Mean day and night air temperatures (°C).

3) Mean day and night relative humidity (%RH).

2.4 RESULTS AND DISCUSSION

The trial was designed to identify whether reduced night-lengths could be used as a technique for increasing plant bulk during the winter period, without the need for an interruption.

The emphasis of the results and discussion is on comparison between the standard night-length treatment with an interruption (NL + I), and the various reduced night-length treatments without interruption. Trade-offs between stem quality and the implications of effects of reduced night-length on crop duration are discussed.

2.4.1 Environmental data (graphs relating to environmental data can be seen in Appendix 3)

Light: (Appendix 3.1a): The earliest planting in week 40 represented a crop which started in poor light, and finished at the time when light levels were at the seasonal low of approximately 2 $MJ/m^2/day$ at Christmas time. The week 45 planting started in low light and finished in increasing light with average levels of 5 – 7 $MJ/m^2/day$. The week 6 planting went through steadily increasing light from 6 to 12 $MJ/m^2/day$. The week 16 planting represented high summer, with the highest light levels at about 20 $MJ/m^2/day$ throughout production, and with peaks of 25 $MJ/m^2/day$, which were associated with the highest external and compartment temperatures (Appendix 3.1b and 3.2a). The final planting in week 25 started in full summer irradiance and ran into autumn, with light decreasing to about 12 $MJ/m^2/day$ by harvest.

Temperature: External temperatures fell from 15°C at the start of the week 40 planting, to a minimum weekly average of 2°C in week 5, increasing to 17°C by week 24. There was one particularly prominent increase in mean daytime temperature during week 20 – 21, with average external temperatures of 20°C (Appendix 3.1b), and this pushed the compartment daytime temperatures up to an average of 26 – 29°C during this period. The significance of this in relation to the week 16 planting will be discussed.

Humidity: Data in Appendix 3.2b show that daytime relative humidity averaged 65 – 70%, with a minimum of 50% during the warmest spell in weeks 20 – 21. The 24 hourly averages showed means of 70% RH throughout the trial.

2.4.2 Schedule

The schedules below relate to the NL + I treatment for Splendid Reagan as a benchmark in each planting (start of SDs and interruption common for all varieties). The effects of each night-length treatment on time to first cut and the harvest window (time from first cut to bed clearance) can be seen in Appendix 4, Figures 4.1 – 4.5.

	Plant date	LDs	SDs	Interruption	SDs	Total
Week 40	29/09/97	21	15	13*	52	101
Week 45	03/11/97	32	19	10	45	106
Week 06	02/02/98	21	14	4	43	82
Week 16	13/04/98	21	11	4	35	71
Week 25	15/6/98	17	10	4	41	72

* Timer failure over the interrupted bed resulted in a longer interruption being applied, and ultimately, this fed through to a 4 day increase in crop duration

The schedules show how natural seasonal variation in light level and the use of longer interruptions in the winter affected crop duration in the NL + I treatment when applied to Splendid Reagan. The other varieties showed similar responses in line with their natural response time. The effects of specific night-length treatments on crop duration are presented in section 2.4.4.

2.4.3 Assessments at the end of long days

Destructive samples were taken from each treatment bed at the end of long days to check that the plants in each variety were similar across beds at the time treatments were due to start. In cases where large differences were apparent between treatment beds at this time, this would have been borne in mind when considering any additional treatment effects due to reduced night-length imposed from the start of SDs.

Graphs in Appendix 4.1 – 4.4 present stem length, leaf number and fresh and dry weights averaged across varieties on each of the treatment beds, pre-treatment. At this time, there was no evidence that any of the treatment beds varied markedly from any of the others in the trial, so that it can be assumed that plants within each variety were equivalent at the time treatments were imposed. As was mentioned earlier, differences in the plants during LDs in the week 45 planting resulted in an additional week 6 crop being produced. For this reason, no destructive samples were collected from the week 45 planting at the end of LDs, but the crop was grown to maturity to provide some information on the impact of reduced night-length on crop response.

2.4.4 Harvest data

In addition to stem quality, the other two most important factors to consider when assessing the commercial economic viability of a growing technique are crop duration and the variability in that crop, measured as the time taken to harvest a bed.

Previous HDC funded research carried out at HRI Efford demonstrated the clear impact that reduced night-length could have on pot chrysanthemums (PC 92b), with significant increases in plant dry weight observed in crops produced under 2 klx assimilation lighting using an 11 hour 20 minute night during short days. However, extended crop duration was associated with this increase in bulk, making production using such a short night commercially unattractive. Further research is studying the use of less extreme night-length reductions to achieve an acceptable compromise between crop duration and increased bulk / quality during the winter period (PC 92c). This current trial aimed to apply the same technique, but against an ambient light background, and controlling the night-length using pre-dawn tungsten day extension.

2.4.4.1 Crop duration

Bar charts in Appendix 5.1-5.4 clearly show how each night-length treatment affected crop duration and the harvest window (time for plot clearance at harvest) in each variety across plantings.

Winter plantings: During the winter period, when a 10 day interruption was being used, there was the greatest scope for using reduced night-length as a direct replacement for interruption in all varieties except Delta, in which neither the 11:40 nor 11:20 night-length treatments were as quick to respond as the control interrupted treatment (NL + I).

This suggests that the slower-growing, less vigorous varieties may require the positive night-length signal in the standard culture regime in order to perform at their best, whereas the more vigorous varieties such as Kent and Reagan may be produced under reduced night-lengths more easily.

In both the week 40 and 45 plantings, the 11 hour 40 night-length treatment was either quicker than, or overlapped with the harvest of the interrupted control (NL + I), but the 11:20 treatment was consistently slower to respond, adding up to a week to production in the week 45 planting. This, combined with an extended harvest window, made the use of an 11 hour 20 night commercially unattractive.

Although an un-interrupted crop grown under natural night-length conditions responded most quickly, and crop duration was reduced, this was at the expense of stem quality, with smaller, lighter wraps being produced at a time of year when increased bulk is required to sell the product.

During the winter plantings, both the 12 hour and 11 hour 40 minute night-length treatments without interruption produced crops of Reagan, Kent and Snowdon as quickly as the interrupted controls. However, the 12 hour treatment also suffered from reduced wrap weight bulk in the same way as crops produced using natural night-lengths without interruption.

Spring and summer plantings: In the week 6 planting, although the response time was quicker for all the reduced night-length treatments compared to the control, the shorter interruption used at this time of year outstripped the benefits of a sharpened flowering response using reduced night-length. In the spring planting, only the 12 hour night could be used with any certainty as a replacement for an interruption if one was to avoid the 3 – 4 day delays incurred due an 11 hour

40 night. In the spring planting, the 11 hour 20 treatment was significantly faster to respond than in any of the other plantings, but it still lagged behind the other night-length treatments sufficiently to preclude its use commercially at this time of year.

During the week 16 and 25 plantings, there was a marked decline in the efficacy of the reduced night-length treatments as a means of increasing quality without compromising duration. This was demonstrated by the fact that, at this time of year, there were only small differences in crop duration between plants produced under ambient night lengths either with or without an interruption, but marked delays occurred in even the 12 hour night treatment.

The 11 hour 20 treatment is not presented on the week 16 graph, as this treatment was so dramatically delayed that it never reached a commercial marketing stage. In the week 16 planting, the flower buds were abnormal and vegetative, with enlarged leafy bracts in the flower rather than petals. This occurred during the period of highest light and temperatures recorded during the trial in weeks 20-21, and would have coincided with the time of bud initiation in the shortest night-length treatment. The fact that the natural night-length treatment (either with or without interruption) continued to develop buds and flowers normally at that time would indicate that there may be a strong interaction between the effects of light integral, photo-period and temperature. Similar abnormalities to those described here have been reported in response to high temperatures (> 32 °C) in several varieties of *Dendranthema grandiflora* (Lawson and Dienelt, 1992; Cockshull and Kofranec, 1993)

The data indicate that AYR production using reduced night-lengths is only worth considering in plantings when ambient light levels are either low, or increasing during the spring period. There was clearly an interaction between response to photo-period and light integral, and perhaps temperature, with higher light levels and temperatures resulting in increased sensitivity to photo-period. As light integral increased, so the "critical" night-length below which the flowering response was inhibited may be longer than in crops produced in lower-light environments (as in winter / spring).

2.4.4.2 Plant bulk and quality: destructive samples at harvest.

At harvest, the treatment plots were sampled destructively (two complete rows per plot) to assess how treatment affected plant development (stem length, fresh and dry weights and leaf numbers). The remaining stems (from an allocated guarded area of the plot) were graded according to commercial quality criteria (spray form and numbers of open flowers). Weights of wraps in each quality grade were recorded. Graphs showing treatment effects for each variety and mean treatment effects within planting are presented in full in Appendix 6.1 – 6.10. The trends of how each measured variable was affected by night-length across plantings can be seen in Figures 2 and 3.

Main effects of each night-length treatment compared to the interrupted control (NL + I) across plantings (see graphs and tables of means in Appendix 6).

Natural night-length without interruption (NL – I): The speed of crops given a natural night without interruption reduced the potential for dry matter accumulation in the early winter plantings, where some stem elongation occurred under the low light ambient levels at that time of year. Stems were shorter (Figure 2a), fresh and dry weights lower (fresh weights reduced by up to 18%, Figure 2c & Appendix 6), with fewest grade I stems in the week 45 planting when light levels were lowest (Figure 3a). In the spring and summer plantings, as light levels increased, the un-interrupted crop given a natural night (or 13½ hour night in the height of summer) provided a product that was at least as good as the interrupted control. At this time of year, the NL - I treatment resulted in the highest proportion of grade I stems per plot of any of the night-length treatments. Production during the spring and summer, using a natural night without interruption, had the added advantages of reduced crop duration and higher flower numbers. The NL – I treatment highlighted the interaction between light integral and flower development under continuous positive short-day conditions, with markedly more open flowers per stem in the week 6, 16 and 25 plantings, compared to the winter plantings when the light integrals were low.

12 hour night without interruption (12 – I): The un-interrupted night-length treatment was also quicker than the control interrupted crop, but slower than the NL – I treatment. However, reduced duration in the 12 - I treatment in the winter plantings was also associated with reduced fresh and dry weights as observed for the NL – I treatment. The un-interrupted 12 hour night treatment suffered from lower grade I wrap weight than the control, with a higher proportion of grade II stems in the week 40 planting when ambient light levels were low and declining (Figure 3b).

Although the 12 hour night without interruption was not suitable for either a week 40 or 45 planting for the reasons outlined above, it did have potential for use in the spring (week 6 planting). At that time of year, it was the only reduced night-length (of those tested) that could be applied without compromising crop duration compared to the interrupted control (see Appendix 5). Although the un-interrupted 12 hour night could be used as a direct replacement for the interruption in week 6, giving a slightly faster crop than the NL + I treatment, there were no additional benefits in terms of bulk, and the poorer flowering response resulted in fewer open flowers per stem. This observation was interesting and highlighted a difference between the effect of reduced night-length when used for spray as compared to pot chrysanthemum varieties. Work in PC 92b indicated that there was little or no effect of using a 12 hour night on the flowering response in several pot chrysanthemum varieties.

The use of a 12 hour night also tended to extend the harvest window (time to clear a plot) by between 1 and 3 days compared to the interrupted control (Appendix 5). At this time of year, the NL – I treatment performed at least as well as the 12 – I without compromising wrap weight, number of open flowers per stem or harvest window, and for this reason should be used in preference to any reduced night-length from week 6 onwards.

11 hour 40 minute night without interruption (11:40 – I): During the winter plantings, using an 11:40 – I treatment stimulated marked increases in stem length and fresh and dry weights, without compromising crop duration relative to the interrupted control. During the week 40 and 45 plantings, the 11:40 – I treatment was the closest achieved in the current trial to a viable replacement for interruption during the winter. This treatment was best used with the more vigorous varieties (Reagan and Kent), with a poorer result for Snowdon. From the current data, it would not be advisable to use nights as short as 11:40 for Delta or varieties with similar characteristics.

In the week 6 planting, response time was much quicker in all the reduced night-length treatments than in the week 40 – 45 plantings, but the crop was still slower than the interrupted control and offered no advantages in terms of improved plant bulk or quality (Figure 2). Because the interruption in the week 6 planting was only 4 days rather than the 10 days, as had been used during winter, even small delays incurred due to reduced night-length made these treatments commercially un-viable.

As with the 12 – I treatment above, the 11:40 – I treatment was delayed more in the week 16 planting when light integral combined with periods of high temperature had large effects on the flowering response in this treatment. From the available data, it was clear that crop delays resulted from an interaction between photo-period, light integral and temperature, rather than purely a delay in flowering due to high temperatures. The evidence for this came from plants growing in the same ambient light and temperature environment (in the NL + I & NL – I treatments), which, given more positive short days, did not suffer from delayed flowering.

11 hour 20 minute night-length without interruption (11:20 – I): Of the reduced night-length treatments tested, 11:20 – I produced the most marked effects on plant bulk and quality. In the week 40 planting, there was no benefit of using an 11:20 – I treatment as a replacement for interruption. There were no increases in plant fresh or dry weights (Figure 2 and Appendix 6), and production at a time of year when light integral was falling was not compensated for by enhanced vegetative growth. Across all plantings, the 11:20 – I treatment resulted in increased stem length of between 7 and 30% relative to the control (NL + I; Figure 2a). The observed increases were due to a combination of two factors: extended duration and assimilation over this period, plus the passive effects of stem extension under day-length control using tungsten lamps. The proportion of stem extension due to each of the above factors cannot be separated using the available data. Having said this, the observed increases in stem length in the week 40 planting probably reflected the effects of tungsten day-extension on inter-node extension rather than increased assimilate availability or enhanced vegetative growth, as no increase in bulk was recorded. At this time of year, the flowering response was also poor (worse than in the other reduced night-length treatments), and the number of open flowers was reduced by an average of 37% compared to the interrupted control.

As light integral increased in the week 45 and 6 plantings, there were small increases in plant bulk due to an 11:20 night, with a 43% increase in fresh weight observed in the week 16 planting. Unfortunately, this increase in bulk was associated with a loss in stem quality associated with abnormal flower development, a reduction in leaf number, and extreme crop delays resulting from the interactions already discussed for the other reduced night-length treatments at this time of year.

Contrary to expectations, data for leaf number at harvest indicated that leaf number in the 11:40 and 11:20 – I treatments were reduced in the week 16 planting (Figure 2b). From the data collected at the end of long days (pre-treatment), there were no differences in leaf numbers for each treatment bed at that time (Appendix 4.3). Assuming that all leaves had been laid down in the NL treatments within a few days of the start of short days, one would expect to see increased leaf numbers in any treatments which slowed initiation rate (in the same way as for chrysanthemums grown continuously in long days). The apparent anomaly in week 16 planting leaf number data was due to some leaves being omitted from the count, as there were both abnormal leafy bracts and stunted leaves produced in the shortest night-length treatment, which, although present, were not included in the data. Had leaf and bract numbers been included, there would have been increases in leaf numbers in the 11:20 night treatment, which was the most "marginal" with respect to the flowering response at tat time of year.

Figure 2: Mean effects of each night-length treatment on a) stem length b) leaf number, c) fresh weight, d) total bud and e) flower numbers

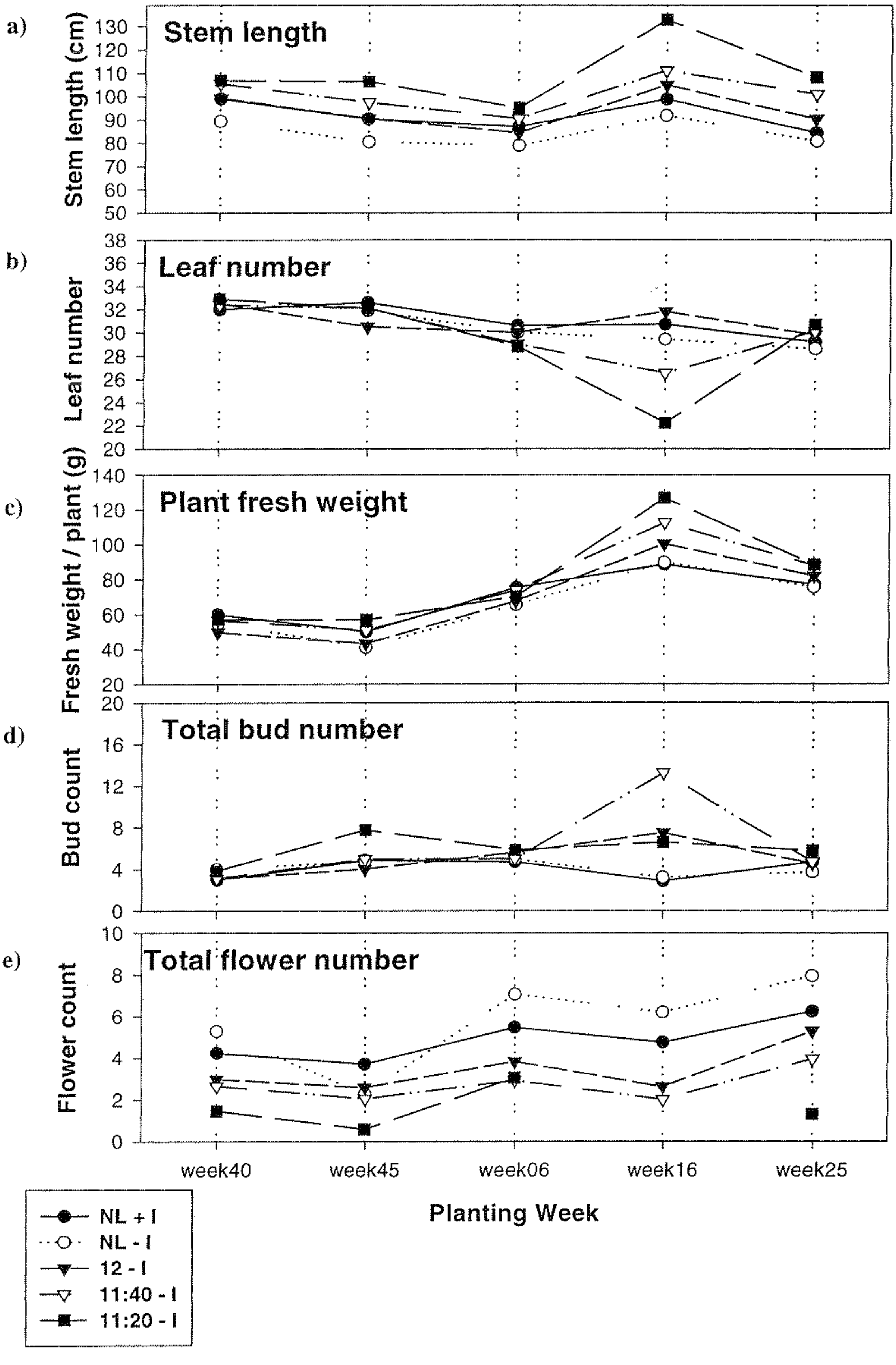
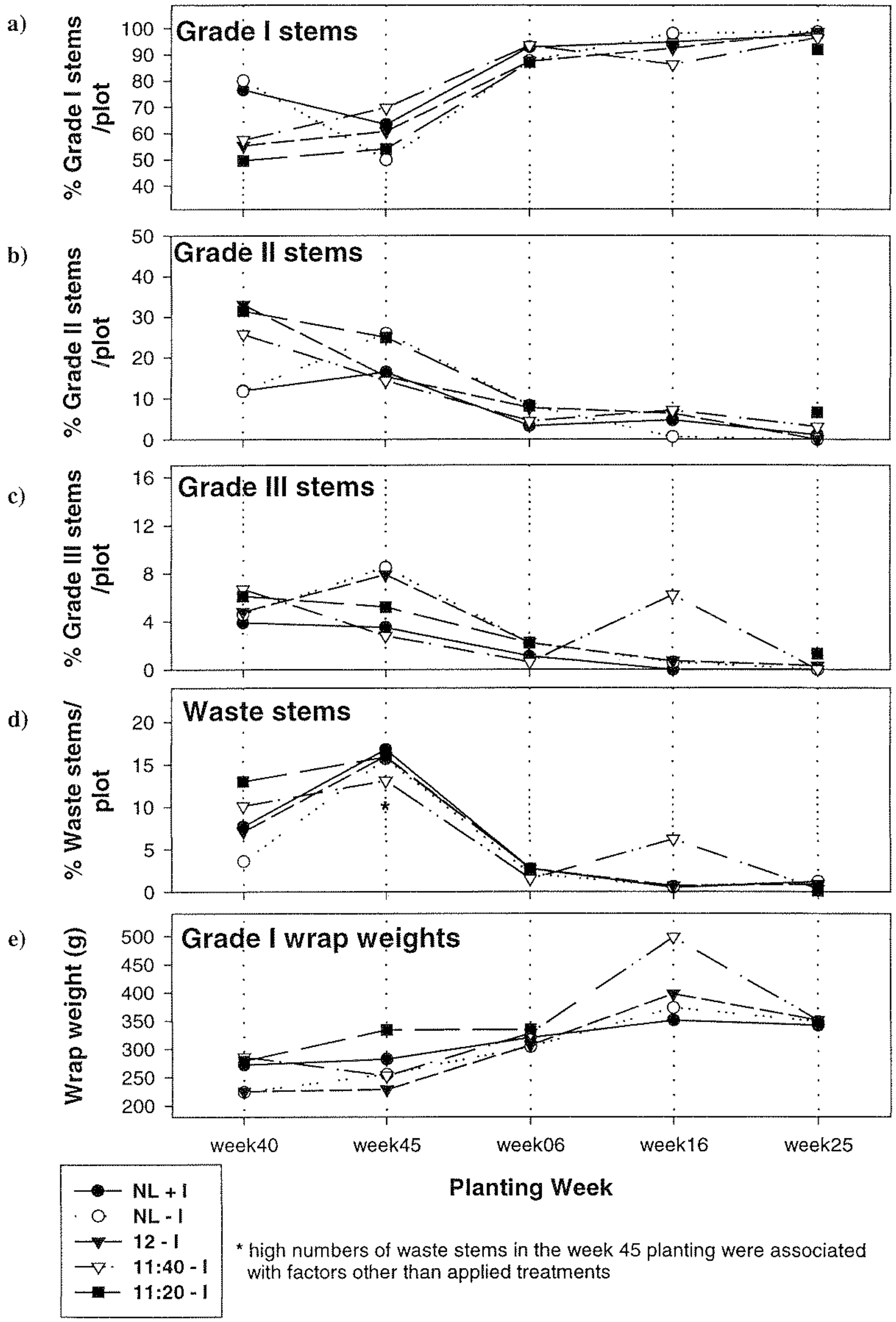


Figure 3: Mean effects of each night-length treatment on percentage of a) grade I b) grade II, c) grade III & d) waste stems, together with e) grade I wrap weights



2.5 CONCLUSIONS

- There were strong interactions between plant responses to photo-period throughout the year as production light integral and temperature changed. The sensitivity of the flowering response was altered against high light and temperature backgrounds, with extreme delays observed in the shortest night-length treatment. This suggests that the "critical" night-length, i.e. that below which floral induction would not occur, lengthened with increasing light integral and temperature.

- By the time reduced night-length treatments had marked effects on plant bulk, the interaction with light integral / temperature precluded their commercial viability due to vastly extended crop duration compared to the interrupted control.

- The potential of reduced night-length treatments as a replacement for interruption was greatest in the winter plantings when light integrals were lowest. The 'best' reduced night-length treatment to replace the interruption was the 11: 40 – I treatment which did not compromise crop duration. However, there were no benefits in terms of increased bulk or quality associated with using a reduced night over an interruption. 11 hour 20 night-lengths were not commercially useful at any time of year.

- Shorter crop duration in the un-interrupted NL and 12 hour night treatments, and light-limitation during the winter, resulted in reduced wrap weights at a time when growers need to maximise stem strength and bulk.

- After week 45, in the absence of benefits from improved quality, night-lengths below 12 hours should be avoided in the spring and summer plantings, due to crop delays, and extended harvest times due to increased variability in time to flowering within the bed.

- There was no evidence to indicate that either reduced night-length or use of an interruption resulted in improved quality or bulk during the summer plantings, and at this time of year*, culture using the standard night without interruption was the quickest way to produce a high quality crop.

- At any time of year, reduced night-length treatments slowed bud and flower development so that, although there were as many buds per spray, fewer flowers were open at harvest. This will be an important factor when considering which varieties may be appropriate to use with reduced night-length techniques.

- Reduced night-lengths in the winter should only be used with the more vigorous varieties (e.g. Reagan/Kent). In weaker varieties (e.g. Delta), more positive flower initiation conditions were needed if crop delays and high variability in time to flowering were to be avoided.

* Only tested under the conditions described in the current trial and with a limited number of varieties. The appropriateness of an un-interrupted crop may vary from grower–to– grower depending on the nursery location and light environment.

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Appendix 1

Plot layouts

Appendix 1: Plot layouts for plantings in weeks 40 and 45

Guard	12H - I	NL - I	NL + I	11:20 - I	11:40 - I	11:20 - I	11:40 - I	NL - I	12H - I	NL + I	Guard
	Delta	Delta	Delta	Delta	Delta	Delta	Delta	Delta	Delta	Delta	
	SR	SR	SR	SR	SR	SR	SR	SR	SR	SR	
	Snow	Snow	Snow	Snow	Snow	Snow	Snow	Snow	Snow	Snow	
	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Kent	
BED NO: 4	5	6	7	8	9	10	11	12	13	14	15

SIDEWALL

Beds 5–9: Week 40 planting

Beds 10–14: Week 45 planting

N

+/- I = with / without interruption
SR = Splendid Reagan
Snow = Snowdon

Appendix 1: Plot layouts for plantings in weeks 6, 16 and 25

	Guard	12H - I	NL - I	NL + I	11:20 - I	11:40 - I	11:20 - I	11:40 - I	NL - I	12H - I	NL + I	Guard
↑ SIDEWALL ↓	Orange Reagan	Fresco	Fresco	Fresco	Fresco	Fresco	Fresco	Fresco	Fresco	Fresco	Fresco	Orange Reagan
	Orange Reagan	SR	SR	SR	SR	SR	SR	SR	SR	SR	SR	Orange Reagan
	Orange Reagan	Sheena	Sheena	Sheena	Sheena	Sheena	Sheena	Sheena	Sheena	Sheena	Sheena	Orange Reagan
	Orange Reagan	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Kent	Orange Reagan
BED NO:	4	5	6	7	8	9	10	11	12	13	14	15
		← Week 06 & 25 plantings				→	← Week 16 planting				→	

↓ N

+/- I = with / without interruption
SR = Splendid Reagan

Appendix 2

Crop diary

Planting week 40

Date	Activity
17.09.1997	Stuck
19.09.1997	Mycotal (1g/l) Vertalec (2g/l)
22.09.1997	Rovral (5g/l) (yellowing on lower leaves S.Reagan and Snowdon)
23.09.1997	Removed polythene
28.09.1997	Rovral (5g/l)
29.09.1997	Planted (Lights on)
05.10.1997	Thiodan (2mls/l)
11.10.1997	B-Nine .75g/l Kent and Snowdon
12.10.1997	Malathion (1.8ml/l)
19.10.1997	Dichlorvos (1ml/l)
20.10.1997	Start S.D. Lights off Start of night length on beds 5,8 & 9
21.10.1997	B-Nine (.75g/l) SW & SR only
26.10.1997	Thiodan (2ml/l)
02.11.1997	Malathion (1.8ml)
04.11.1997	Start Interruption Bed 4 & 7
07.11.1997	B-Nine .75 S.R & S.W. (1g/l)
09.11.1997	Dichlorvos (1ml/l)
16.11.1997	Thiodan (2g/l)
17.11.1997	End of Interruption Beds 4 & 7
23.11.1997	Malathion (1.5ml/l)
26.11.1997	Disbudded Bed 6 all varieties
30.11.1997	Disbudded Bed 5 Kent, Snowdon, Splendid Reagan & Delta Disbudded Kent on Bed 8-9 Dichlorvos (1ml/l)
01.12.1997	Disbudded Bed 4 K and SW, Bed 7 K, SW Bed 8 SW & SR, Bed 9 SW & SR
04.12.1997	Disbudded Bed 7 Splendid Reagan/Delta
07.12.1997	Malathion (1.5 g/l)
11.12.1997	Disbudded Bed 8 Delta, Bed 9 Delta
14.12.1997	Thiodan (2ml/l)
15.12.1997	Delta 12H-1 Bud Colour Kent 11:20-1 Bud Colour Kent 11:40-1 Bud Colour
17.12.1997	Kent NL + I Bud Colour Snowdon 11:40-1 Bud Colour
19.12.1997	Snowdon NL + I Bud Colour Snowdon11:20-1 Bud Colour
22.12.1997	Splendid Reagan 11:40-1 Bud Colour
25.12.1997	Delta NL + I Bud Colour Splendid Reagan NL + I Bud Colour
26.12.1997	Splendid Reagan 11:20-1 Bud Colour
02.01.1998	Delta 11:40-1 Bud Colour
04.01.1998	Delta 11:20-1 Bud Colour

Planting week 45

Date	Activity
22.10.1997	Stuck
23.10.1997	Mycotal (1g/l) Vertalec (2g/l)
29.10.1997	Removed polythene
02.11.1997	Rovral (5g/l)
03.11.1997	Planted (Lights on)
09.11.1997	Malathion (2g/l)
16.11.1997	Thiodan (2g/l)
18.11.1997	B-Nine (.75g/l) Kent & SW
23.11.1997	Malathion (1.8ml/l)
30.11.1997	Dichlorvos (1ml/l)
05.12.1997	Start S.D. (Lights off)
07.12.1997	Malathion (1.8ml/l)
14.12.1997	Thiodan (2ml/l)
21.12.1997	Malathion (1.8ml/l)
24.12.1997	Start Interruption Beds 14 & 15 Pirimor (.5g/l)
28.12.1997	Dichlorvos (1ml/l)
31.12.1997	B-Nine Snowdon & S.Reagan (.75g/l)
03.01.1998	End of Interruption
04.01.1998	Thiodan (2ml/l)
11.01.1998	Malathion (1.8ml/l)
12.01.1998	Disbudded Kent 11:40-1, NL - I, 12H-1
18.01.1998	Thiodan (2ml/l)
19.01.1998	Disbudded Kent NL + I Guard Kent 11:20-1 Snowdon 11:40-1, NL - I, 12H-1, Splendid Reagan 11:40-1, NL - I, 12H-1 Delta 11:40-1, NL - I, 12H-1
22.01.1998	Disbudded Snowdon 11:40 – I, 11:20 - I Reagan 23, 39, Delta 40
23.01.1998	Kent 12H-1 & NL - I Bud Colour
25.01.1998	Dichlorvos (1ml/l)
26.01.1998	Bud Colour Snowdon NL – I
29.01.1998	Pirimor (.5g/l) Splendid Reagan NL - I and Delta NL - I Bud Colour
31.01.1998	Snowdon 12H-1 & Splendid Reagan 12H-1 Bud Colour Kent 11:40-1 Bud Colour
02.02.1998	Delta 12H-1 Bud Colour Splendid Reagan 11:40-1 Bud Colour Snowdon 11:40-1 Bud Colour
04.02.1998	Kent NL + I & Snowdon NL + I Bud Colour
06.02.1998	Snowdon 11:40-1, Kent 11:20-1 & Delta 11:40-1 Bud Colour
09.02.1998	Splendid Reagan NL + I & DeltaNL + I Bud Colour
14.02.1998	Splendid Reagan 11:20-1 Bud Colour
17.02.1998	Snowdon 11:20-1 Bud Colour
22.02.1998	Delta 11:20-1 Bud Colour

Planting week 6

Date	Activity
21.01.1998	Stuck Mycotal (1g/l) Vertalec (2g/l)
27.01.1998	Removed polythene Rovral (5g/l)
02.02.1998	Planted (lights on)
08.02.1998	Thiodan (2ml/l)
15.02.1998	Malathion (1.8ml/l)
16.02.1998	B-Nine (0.75g/l)
22.02.1998	Malathion (1.8ml/l)
23.02.1998	Start off short days B-Nine (0.75g/l) Reagans only
01.03.1998	Thiodan (2ml/l)
08.03.1998	Dichlorvos
09.03.1998	Start off interruption
10.03.1998	Pirimor (.5g/l)
11.03.1998	B-Nine 0.75g/l) Reagans only
13.03.1998	End of interruption
15.03.1998	Malathion (1.8ml/l)
22.03.1998	Thiodan (1ml/l)
27.03.1998	Pirimor (.5g/l)
29.03.1998	Dichlorvos (1ml/l)
31.03.1998	Disbudded all Kent 11:40-1, 11:20-1, NL + I, NL - I, 12H-1 Splendid NL - I, 12H-1, 11:40-1
02.04.1998	Splendid 11:20-1, NL + I, W Fresco NL - I
03.04.1998	Disbudded Sheena 12H-1, NL - I, 11:40-1, W Fresco 12H-1, NL + I, plus guard
05.04.1998	Malathion 1.8ml/l
06.04.1998	Disbudded 11:20-1, 11:40-1, NL + I
07.04.1998	Kent NL - I Bud Colour
09.04.1998	Pirimor (.5g/l)
10.04.1998	Kent 11:40-1
12.04.1998	Thiodan (2ml/l)
13.04.1998	Bud Colour Reagan 12H-1 W Fresco NL + I
14.04.1998	W Fresco 12H-1, S Reagan NL + I, 11:40-1 Sheena NL + I, 11:40-1 Bud Colour
15.04.1998	Bed 4 Guard Bud Colour
17.04.1998	Bed 8 Kent 11:20-1 Bud Colour
20.04.1998	Bed 8 S Reagan plus Y.Sheena Bud Colour
23.04.1998	W Fresco 11:20-1 Bud Colour
24.04.1998	Tilt (40ml/100l)
1.05.1998	Tilt (40ml/100l)
08.05.1998	Tilt (40ml/100l)

Planting week 16

Date	Activity
01.04.1998	Stuck
13.04.1998	Planted
04.05.1998	Start SDs
15.05.1998	Start of interruption
19.05.1998	End of interruption
05.06.1998	Disbudded 11:20-1, 11:40-1, 11:40-1, 11:40-1, NL - I, NL - I, NL - I, 12H-1, NL + I, NL + I, NL + I plus guard
08.06.1998	Disbudded 12H-1 & 12H-1
07.06.1998	Hostaquick (.75ml/l)
13.06.1998	Thiodan (2mg/l)
14.06.1998	Pirimor (.5g/l)
16.06.1998	Bud Colour showing Bed 12 Kent NL - I, Sheena NL - I
19.06.1998	Bud Colour showing Bed 12 SR NL - I
20.06.1998	Bud Colour showing Bed 12 WF NL - I Bud Colour showing Bed 14 Kent NL + I, Sheena NL + I
21.06.1998	Dichlorvos (1ml/l)
22.06.1998	Bud Colour Bed 14 WF NL + I, SR NL + I
24.06.1998	Bud Colour Bed 13 Kent 12H-1, SR 12H-1 Malathion (1.8ml/l)
26.06.1998	Bud Colour Bed 13 Sheena 12H-1
28.06.1998	Thiodan (12ml/l)
30.06.1998	Bud Colour WF 12H-1, Kent 11:40-1
01.07.1998	Dichlorvos (1ml/l)
03.07.1998	Bud Colour SR11:40-1
05.07.1998	Malathion (1.8ml/l)
06.07.,1998	Bud Colour Sheena 11:40-1
13.07.1998	Bud Colour WF 11:40-1
29.07.1998	Bud Colour Kent 11:20-1
02.08.1998	Dichlorvos (1ml/l)

Planting week 25

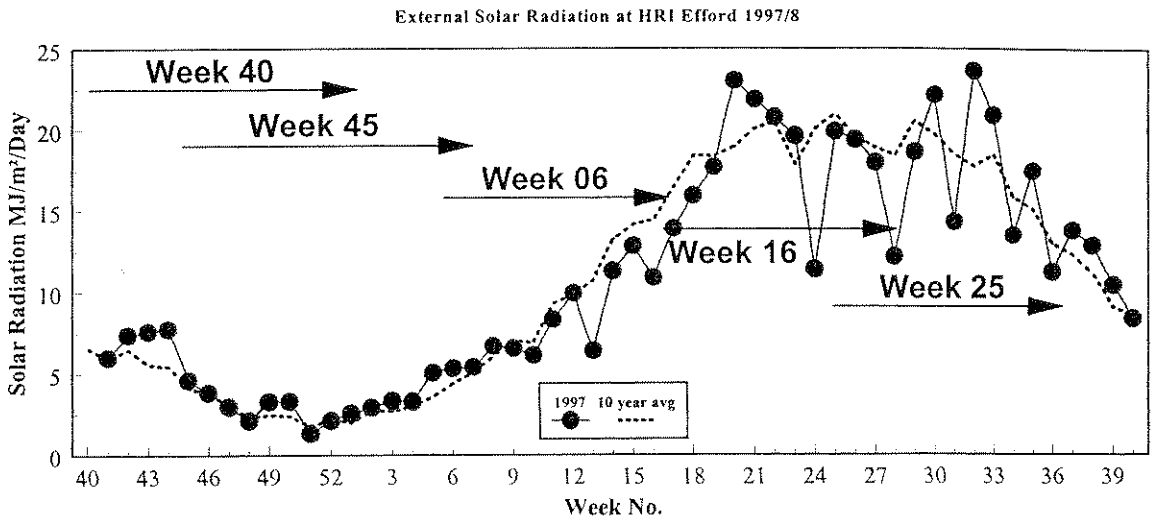
Date	Activity
03.06.1998	Stuck
15.06.1998	Planted
02.07.1998	Start of SDS
21.06.1998	Malathion (1.8ml/l)
24.06.1998	Malathion (1.8ml/l)
28.06.1998	Thiodan (2ml/l)
29.06.1998	B-Nine (.75g/l) Kent & S Reagan
01.07.1998	Dichlorvos (1ml/l)
03.07.1998	Long daylight off Treatment lights on
05.07.1998	Malathion (1.8ml/l)
12.07.1998	Start off interruption Dynamec (.5ml/l)
15.07.1998	Dynamec (.5ml/l)
16.07.1998	End off interruption
18.07.1998	Malathion (1.8ml/l)
21.07.1998	Dichlorvos (1ml/l)
26.07.1998	Thiodan (2ml/l)
29.07.1998	Malathion (1.8m./l)
31.07.1998	Disbudded Kent 12H-1, Kent NL - I, Kent NL + I, Kent 11:40-1
01.08.1998	Bud Colour Kent 11:20-1, SR 11:20-1, WF 11:40-1
02.08.1998	Dichlorvos (1ml/l)
03.08.1998	Disbudded Kent 11:20-1, SR 12H-1, Sheena 12H-1, WF NL - I, SR NL - I, Sheena NL - I, WF NL + I, SR NL + I, Sheena NL + I, SR 11:40-1
06.08.1998	Disbudded WF 12H-1,
09.08.1998	Thiodan (2ml/l)
11.08.1998	Kent NL - I Bud Colour Disbudded SR 11:20-1, WF 11:40-1, Sheena 11:40-1
14.08.1998	Disbudded WF 11:20-1 Bud Colour Kent 12H-1, WF NL - I, SR NL - I, Sheena NL - I, Kent NL + I, SR NL + I, Sheena NL + I
16.08.1998	Hostaquick (.75m./l)
17.08.1998	Disbudded Sheena 11:20-1 Bud Colour SR 12H-1, Sheena 12H-1, WF NL + I
23.08.1998	Dichlorvos (1ml/l) Bud Colour WF 12H-1, Kent 11:40-1, SR 11:40-1, Sheena 11:40-1
30.08.1998	Malathion (1.8ml/l)

Appendix 3

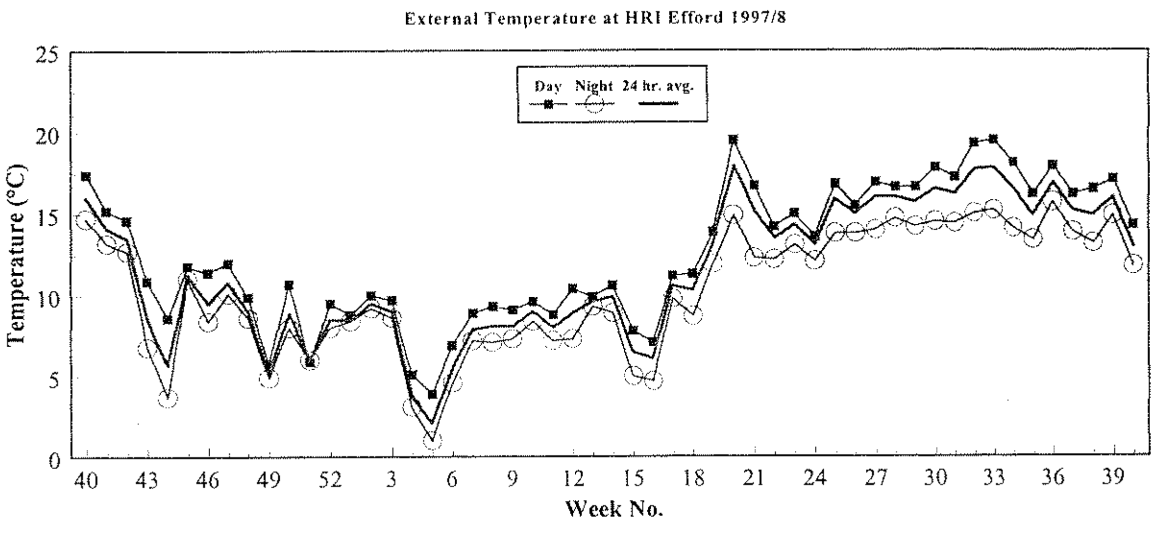
Environmental data

Appendix 3.1: External light (a) and temperatures (b) at HRI Efford from week 40 1997 to week 40 1998

a

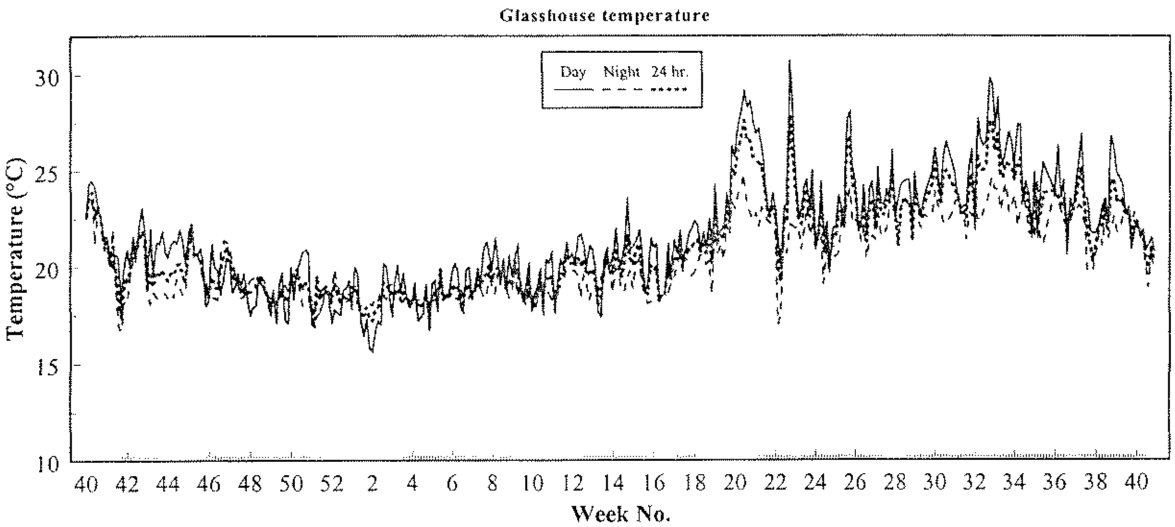


b

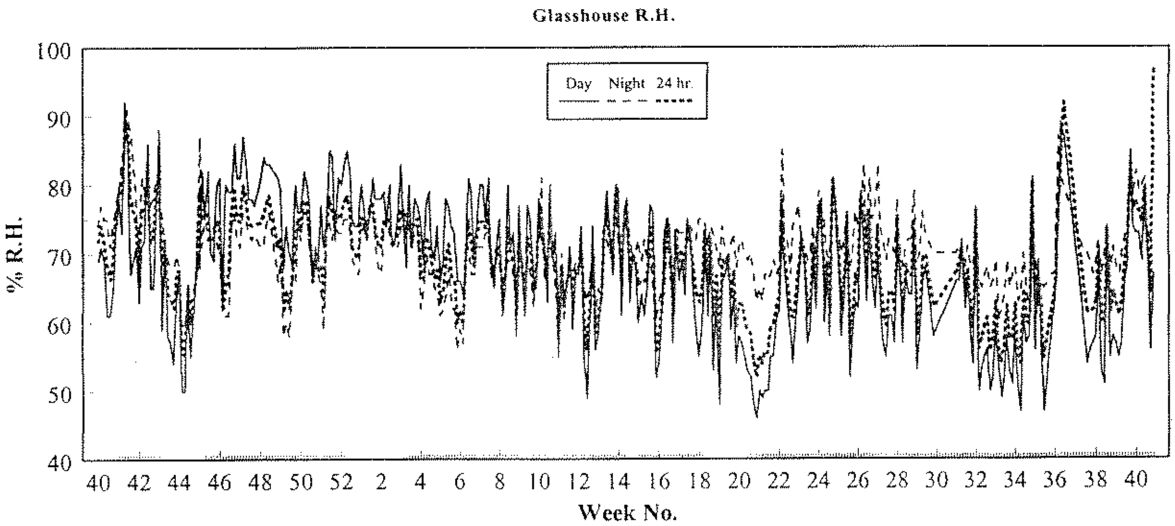


Appendix 3.2: Compartment day, night and 24 hour average temperature (a) and relative humidity (b)

a



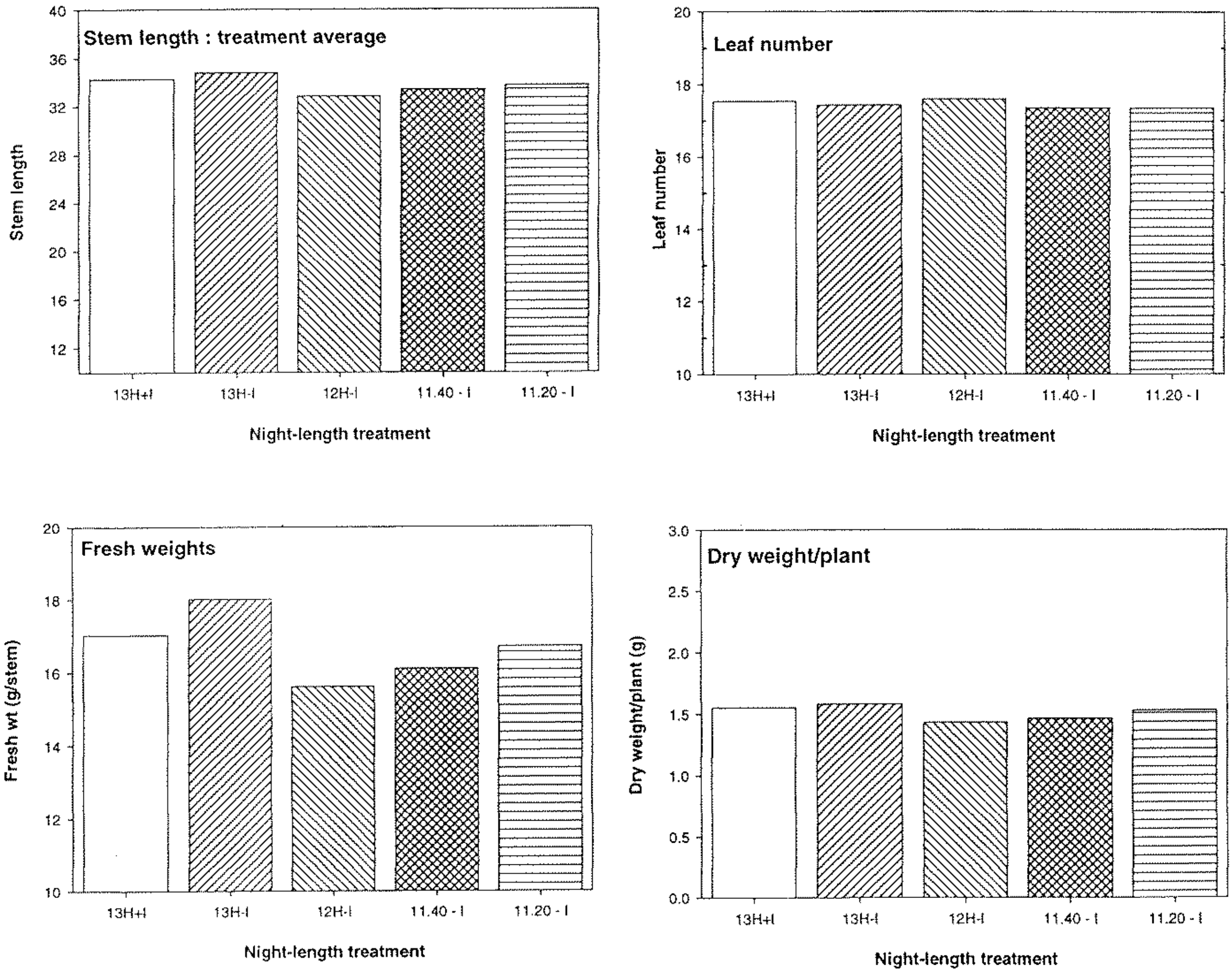
b



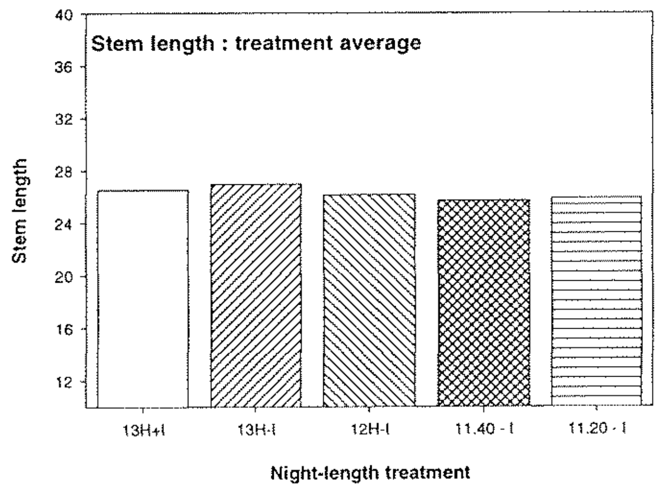
Appendix 4

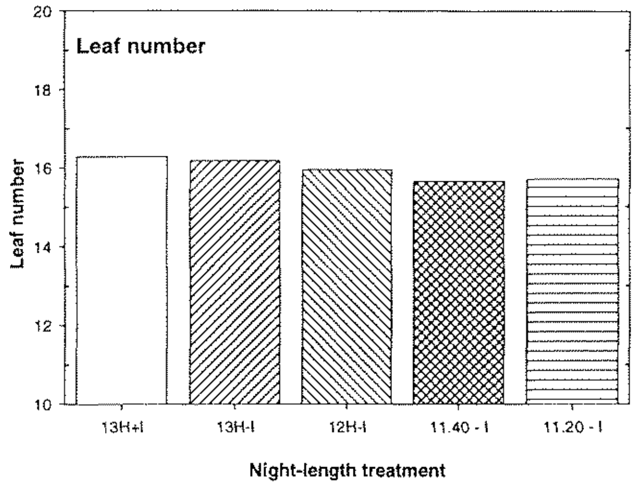
Data at the end of long-days

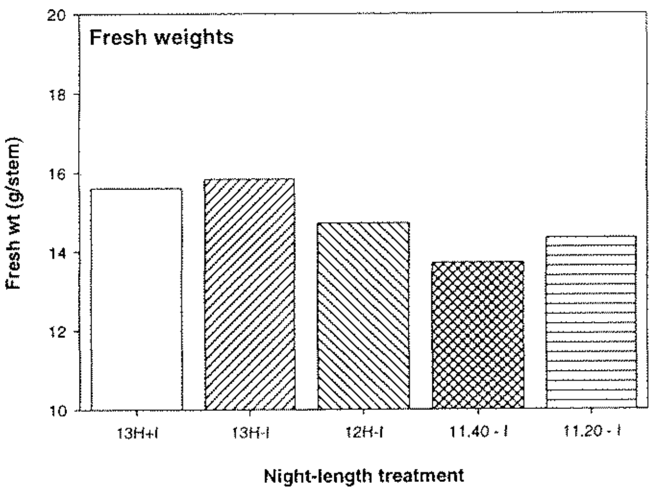
Appendix 4.1: Samples at the end of long days (pre-treatment): stem length, leaf number, fresh and dry weights (mean across varieties) for the week 40 planting

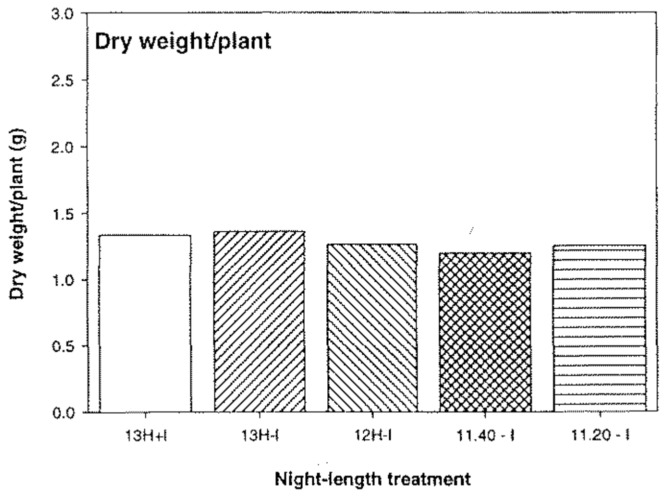


Appendix 4.2: Samples at the end of long days (pre-treatment): stem length, leaf number, fresh and dry weights (mean across varieties) for the week 06 planting

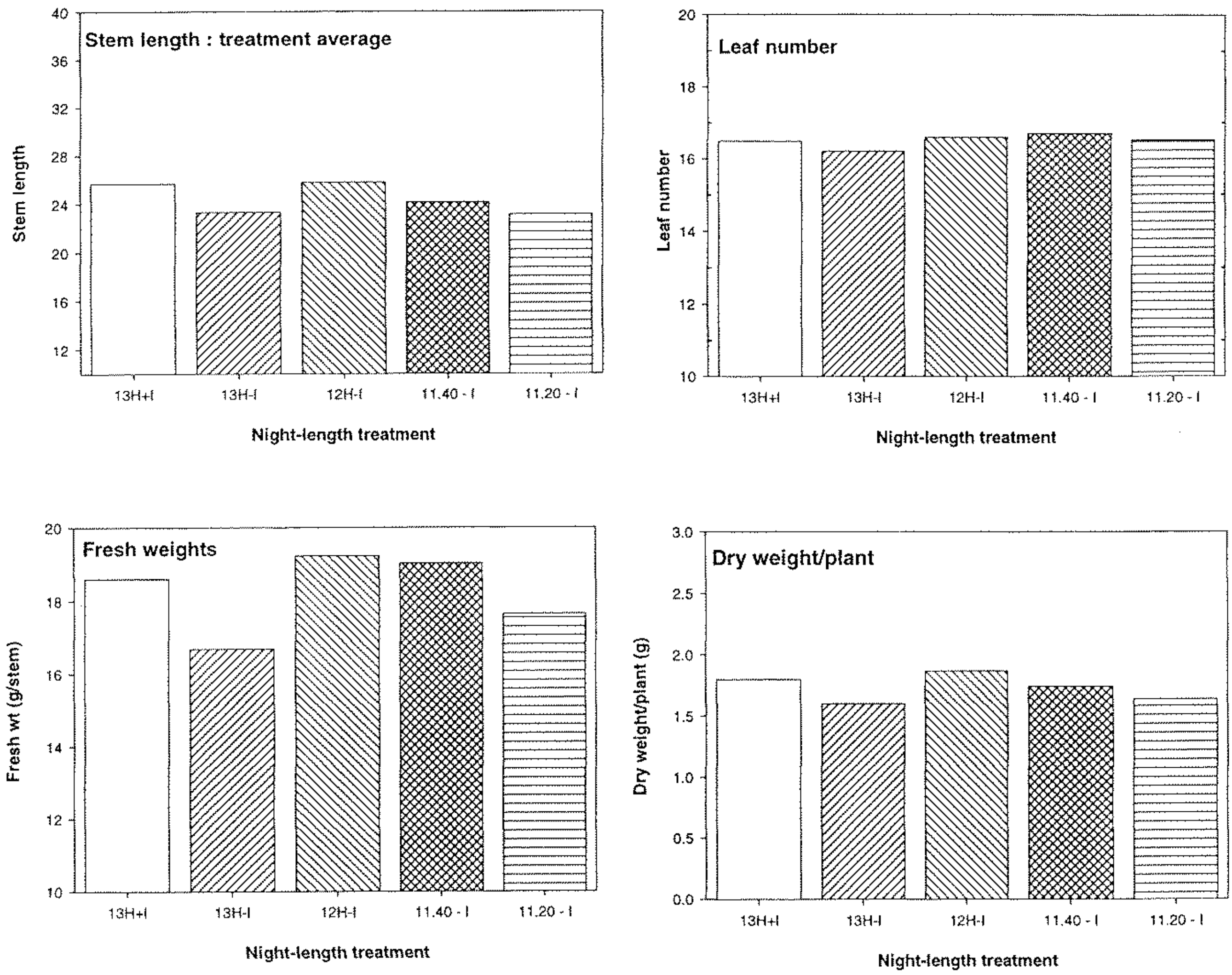




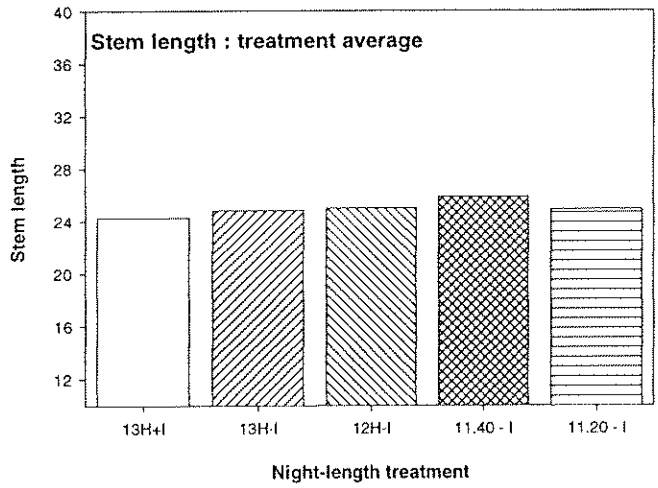


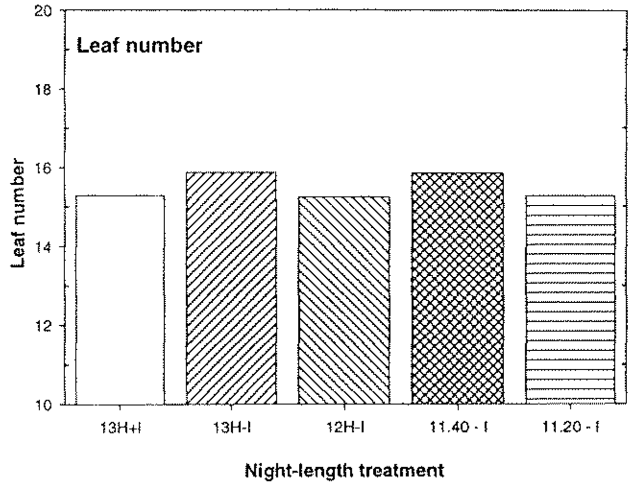


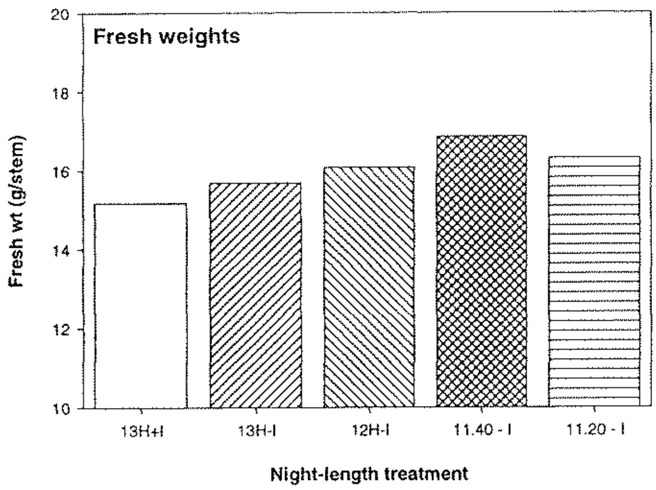
Appendix 4.3: Samples at the end of long days (pre-treatment): stem length, leaf number, fresh and dry weights (mean across varieties) for the week 16 planting

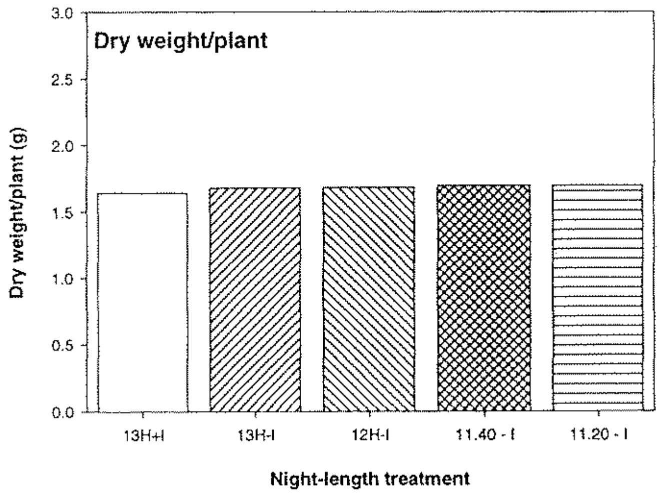


Appendix 4.4: Samples at the end of long days (pre-treatment): stem length, leaf number, fresh and dry weights (mean across varieties) for the week 25 planting





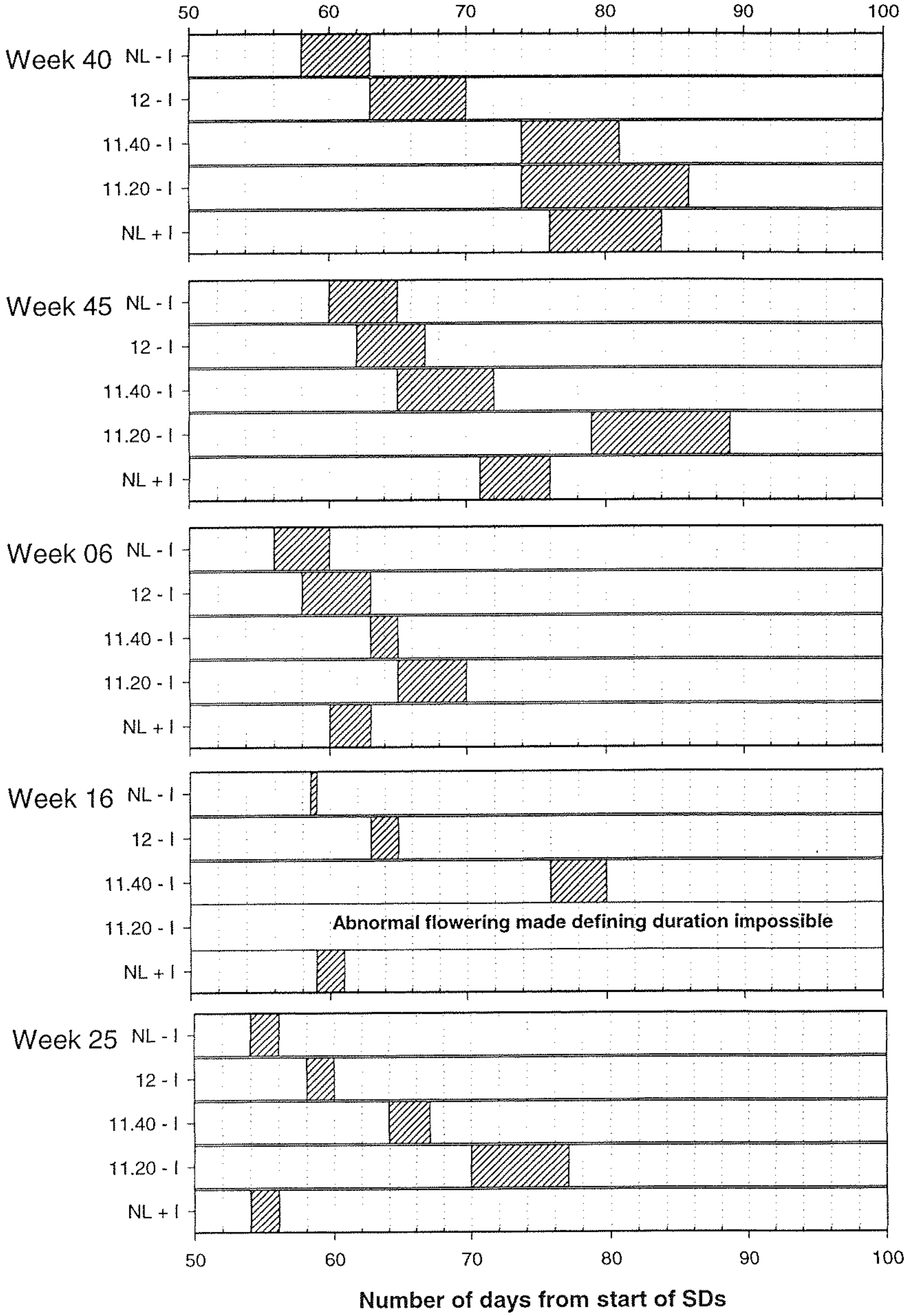




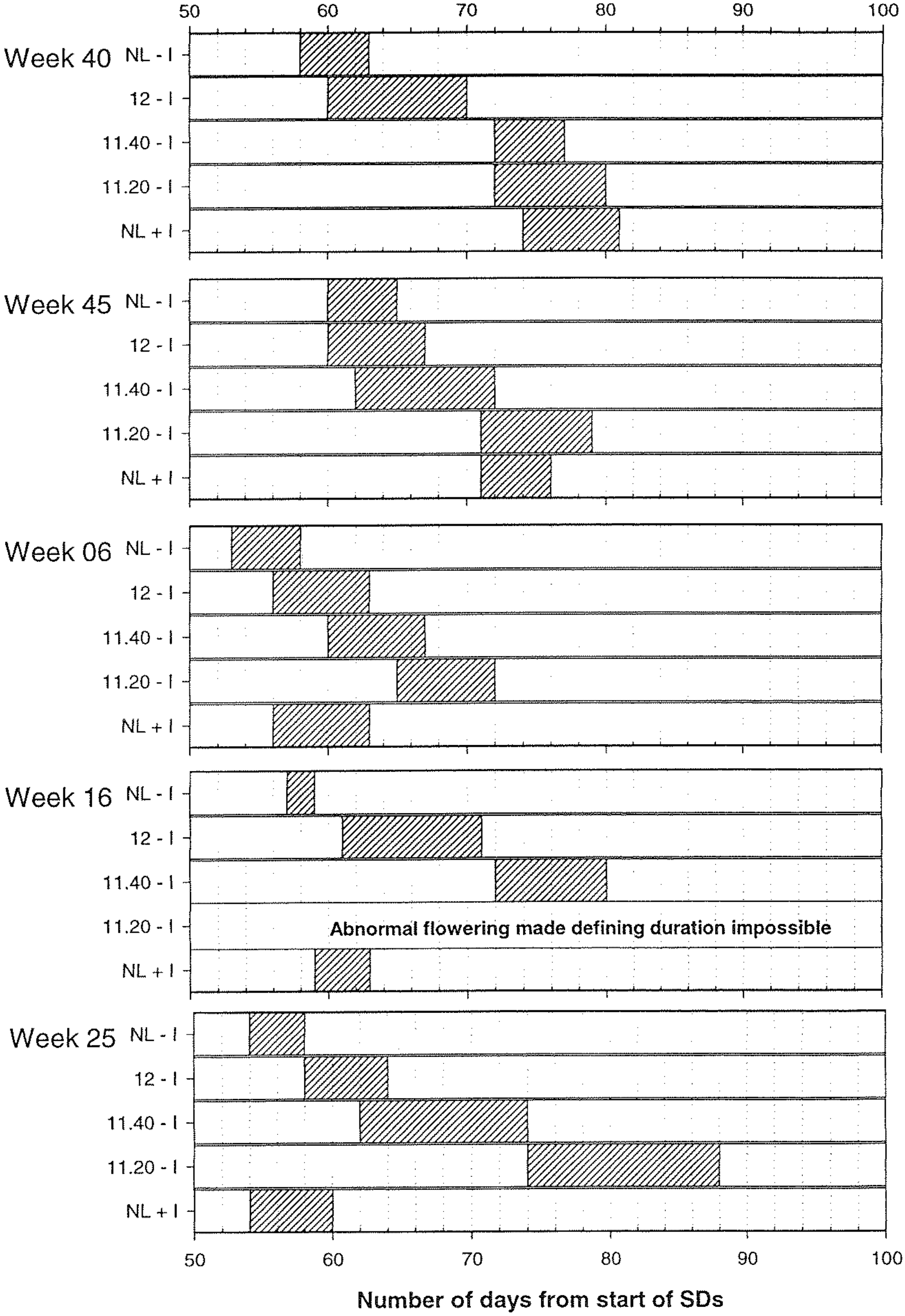
Appendix 5

Effects of night-length treatment on crop duration and harvest window in each variety

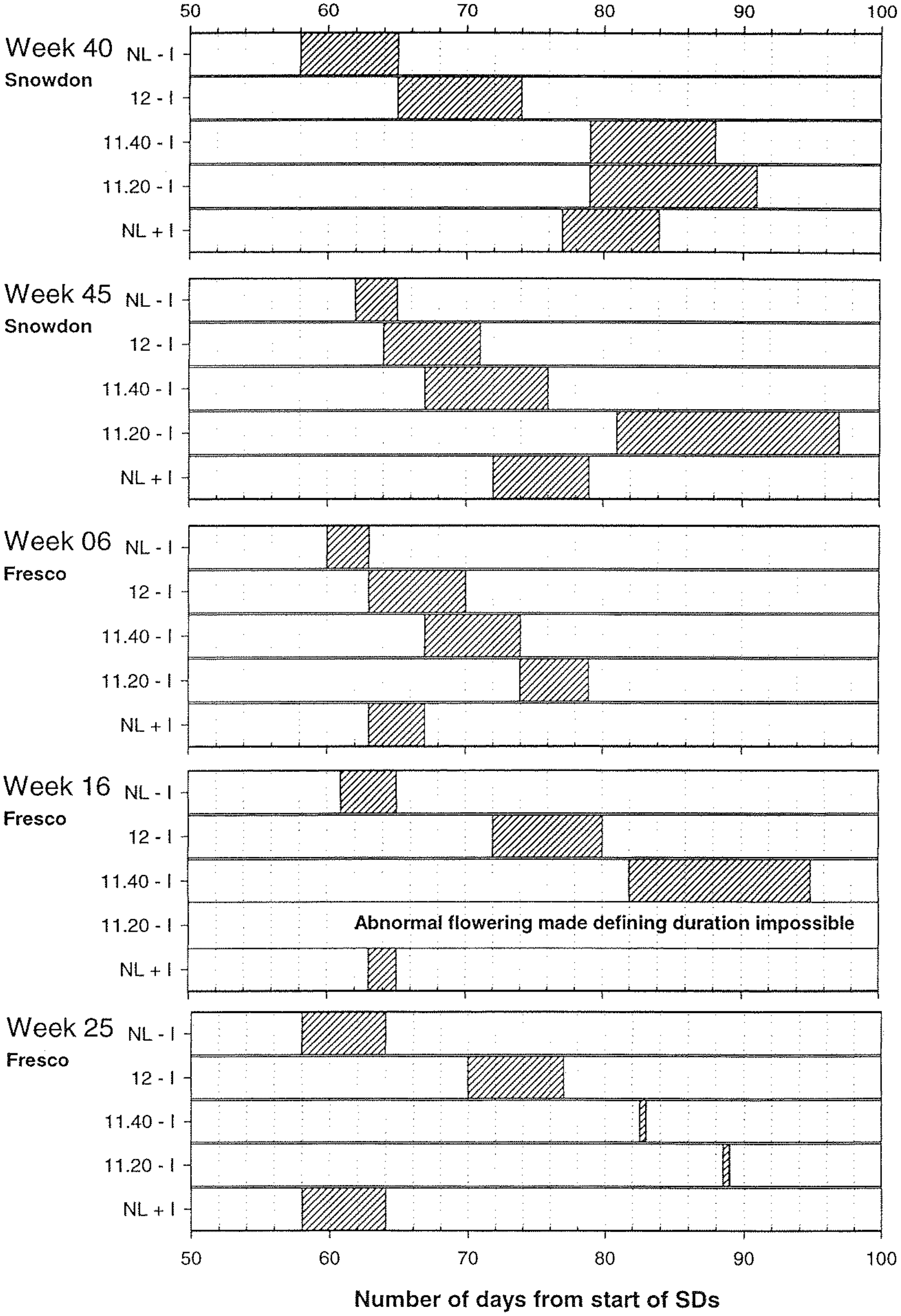
Appendix 5.1: Effect of nightlength treatments on time to harvest and harvest duration in Splendid Reagan in each planting week.



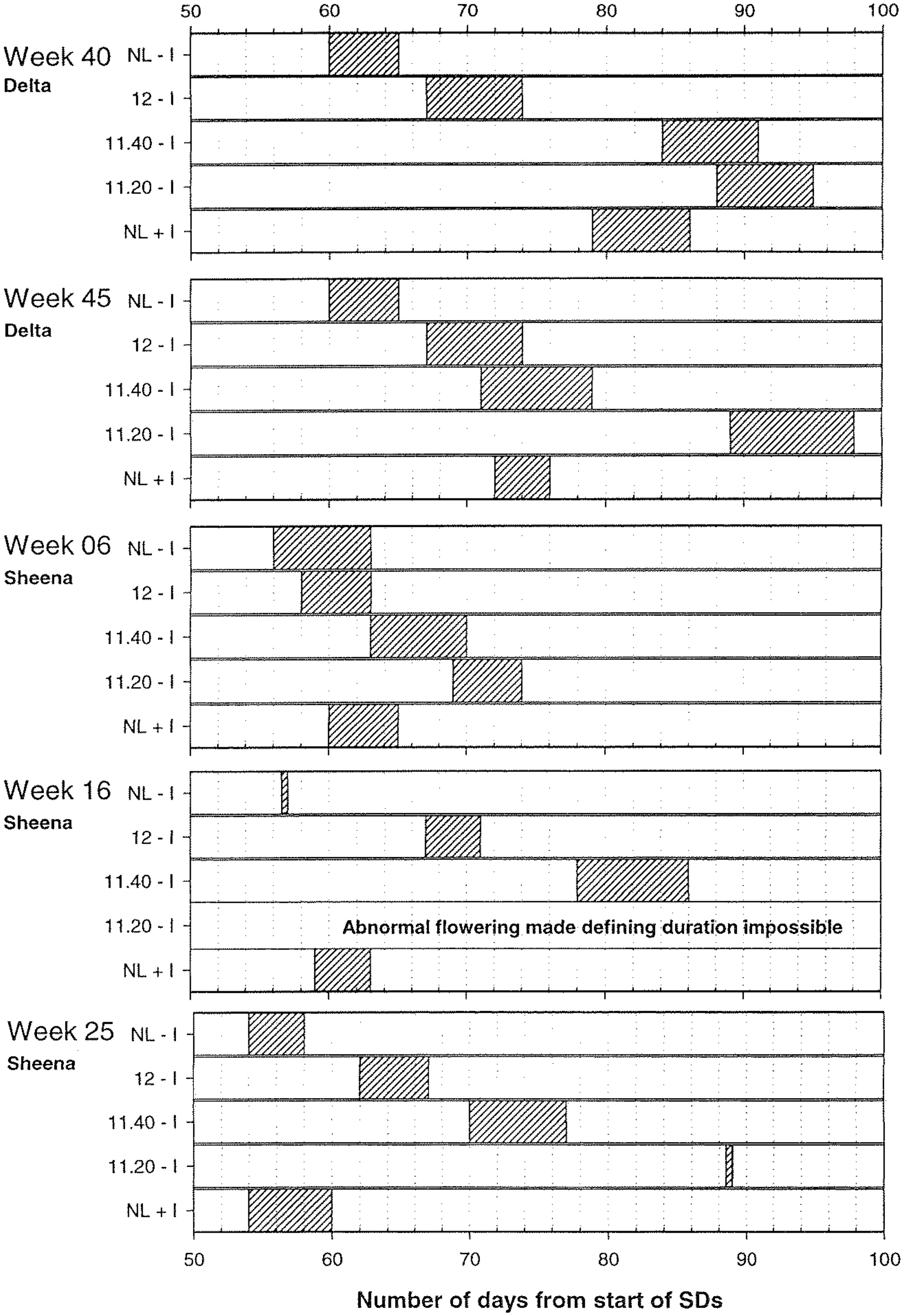
Appendix 5.2: Effect of nightlength treatments on time to harvest and harvest duration in Kent in each planting week.



Appendix 5.3: Effect of nightlength treatments on time to harvest and harvest duration in Snowdon (weeks 40 & 45) and White Fresco (weeks 6, 16 & 25).



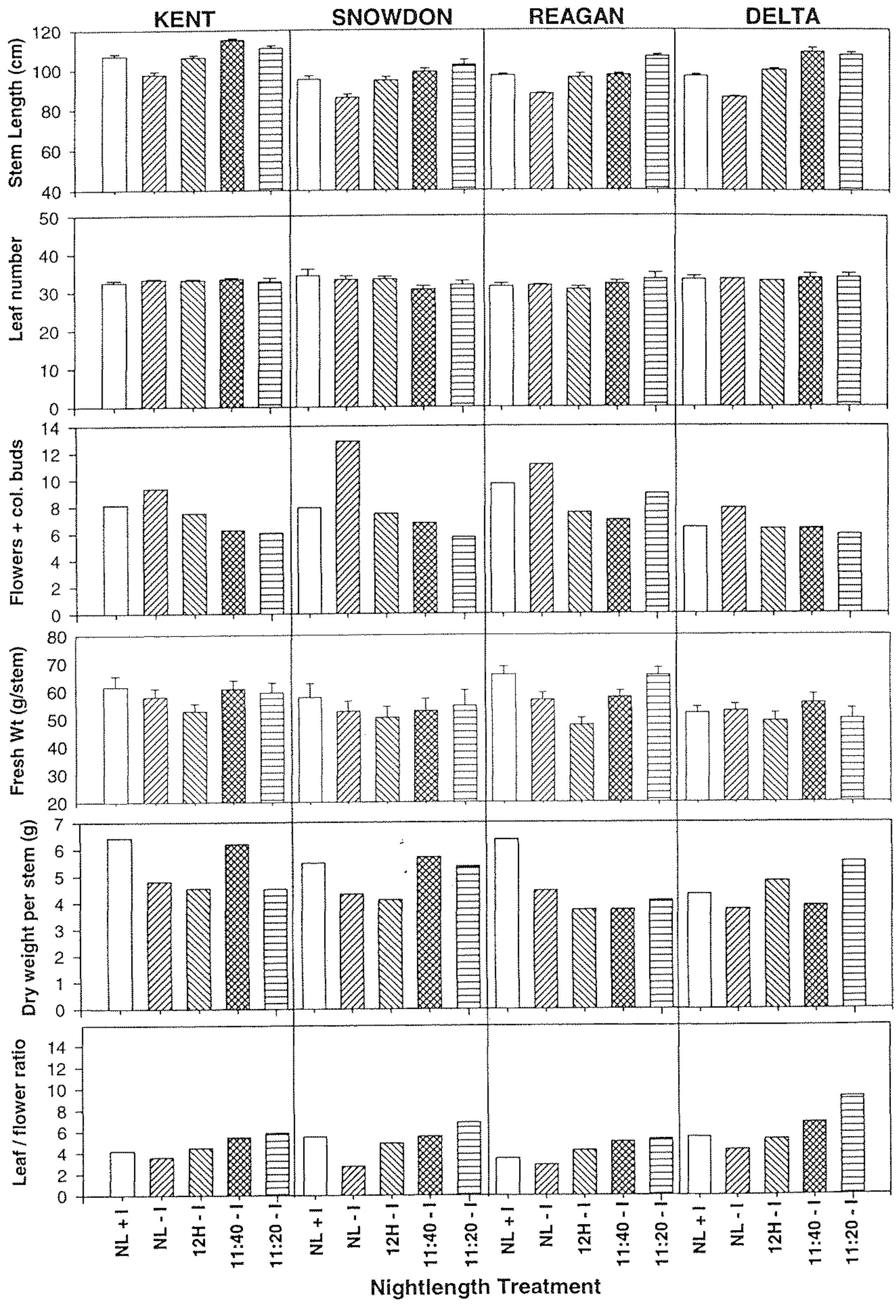
Appendix 5.4: Effect of nightlength treatments on time to harvest and harvest duration in Delta (weeks 40 & 45) and Sheena (weeks 6, 16 & 25).



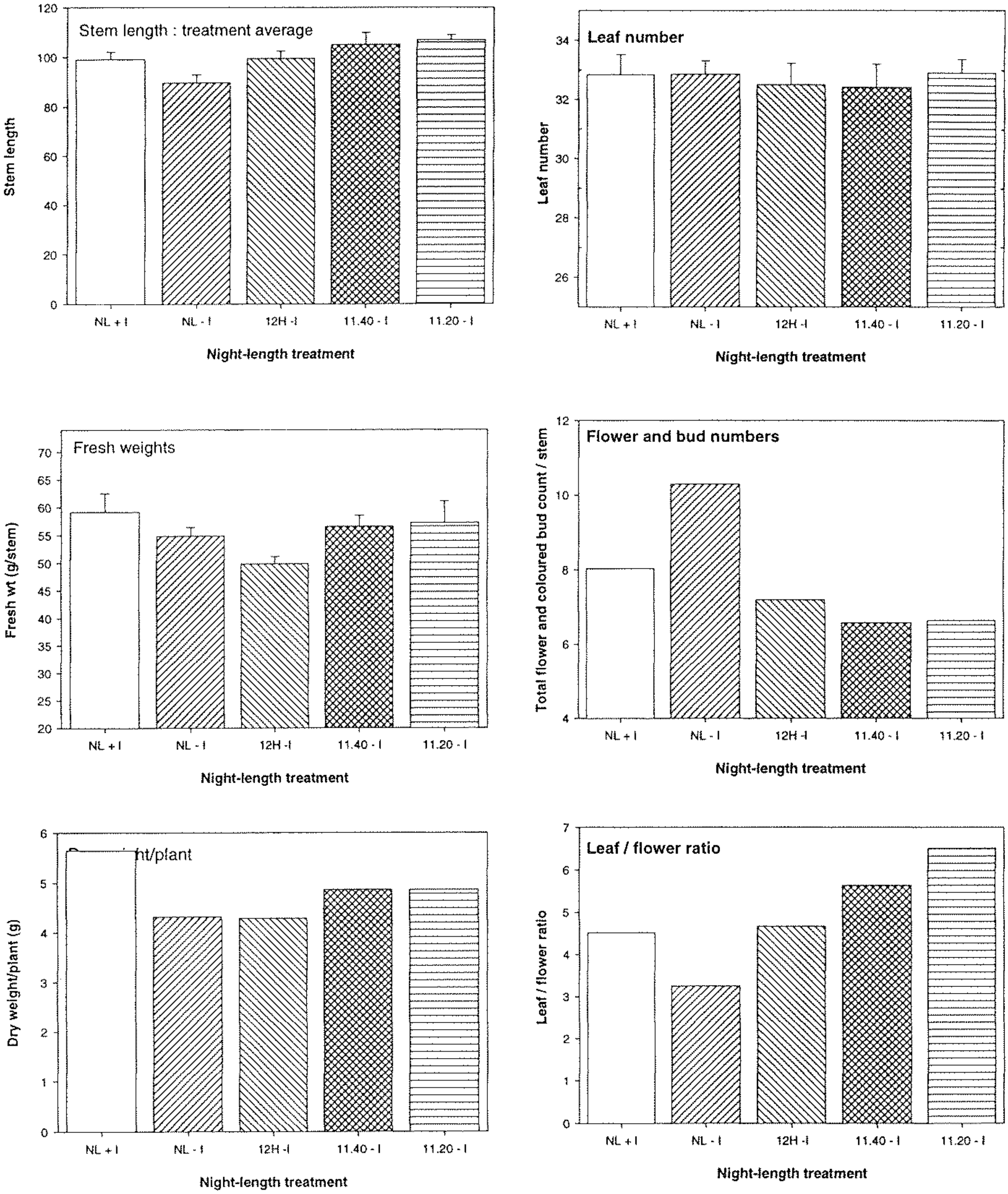
Appendix 6

Graphs and tables of means showing harvest data for each variety

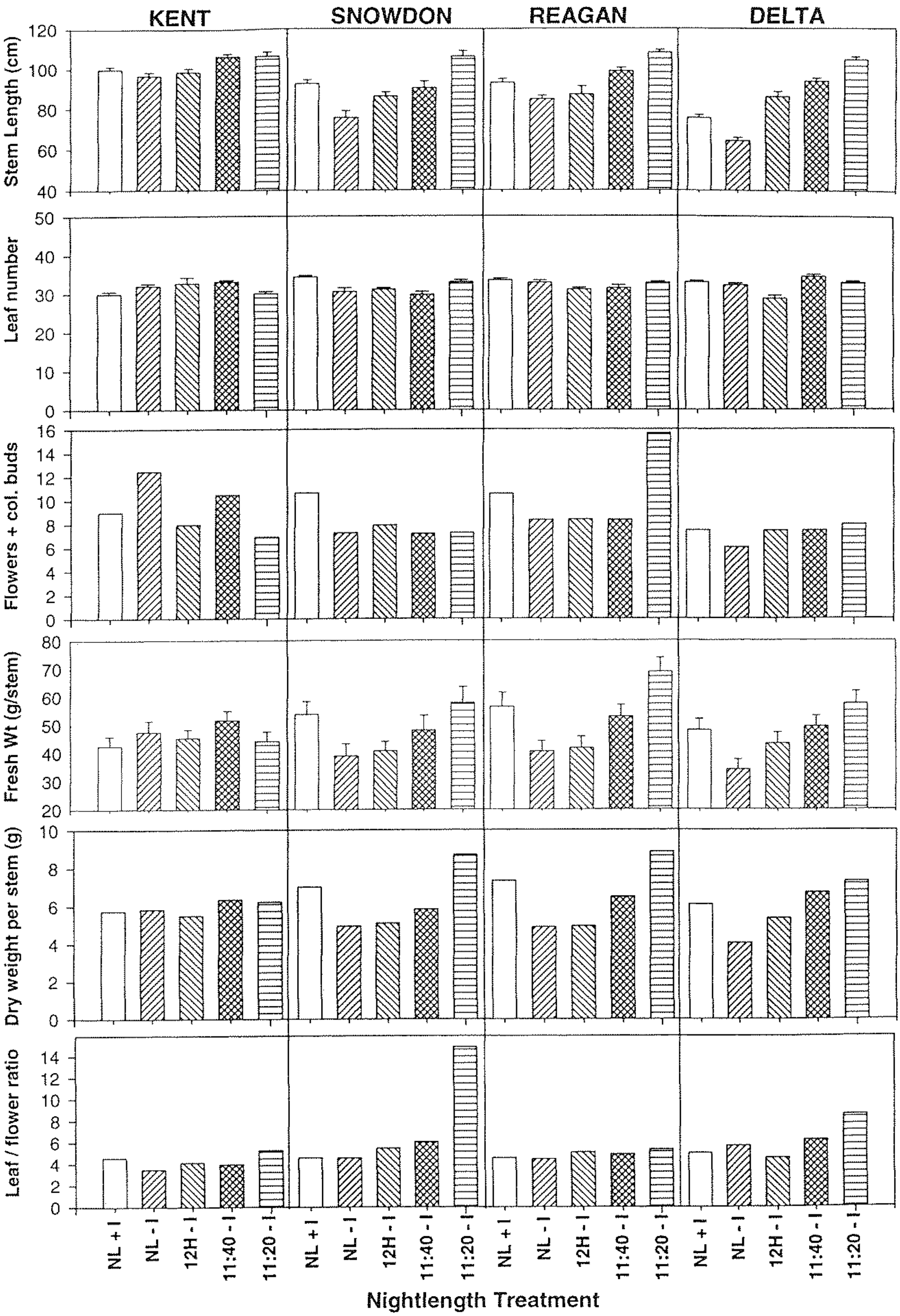
Appendix 6.1: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in each variety for the week 40 planting



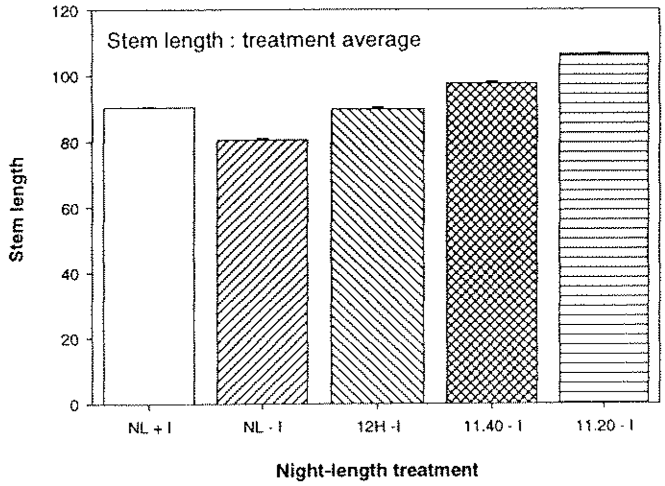
Appendix 6.2: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in the week 40 planting (average across varieties)

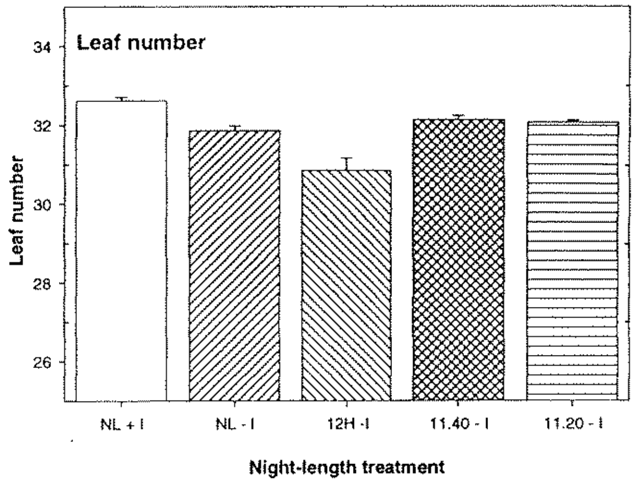


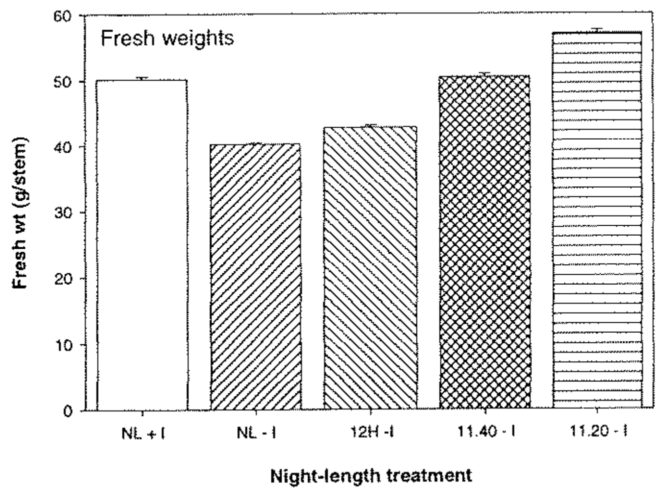
Appendix 6.3: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in each variety for the week 45 planting

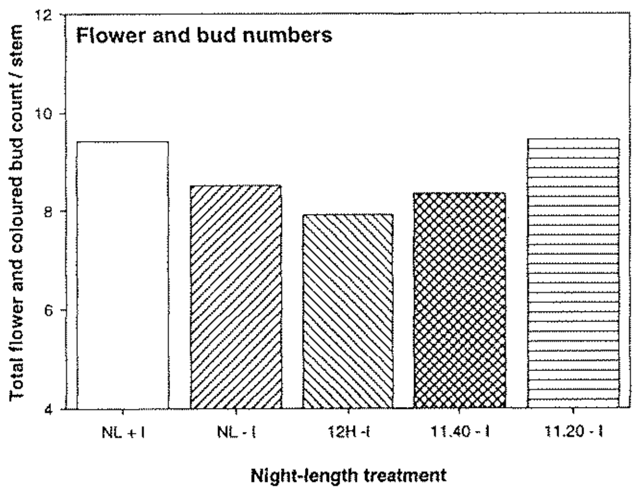


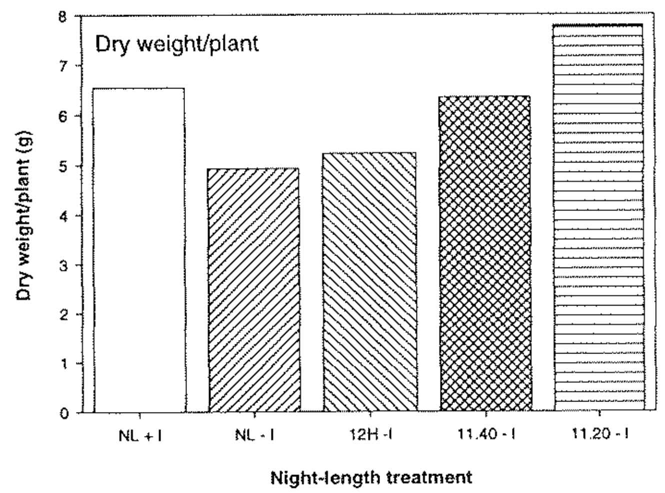
Appendix 6.4: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in the week 45 planting (average across varieties)

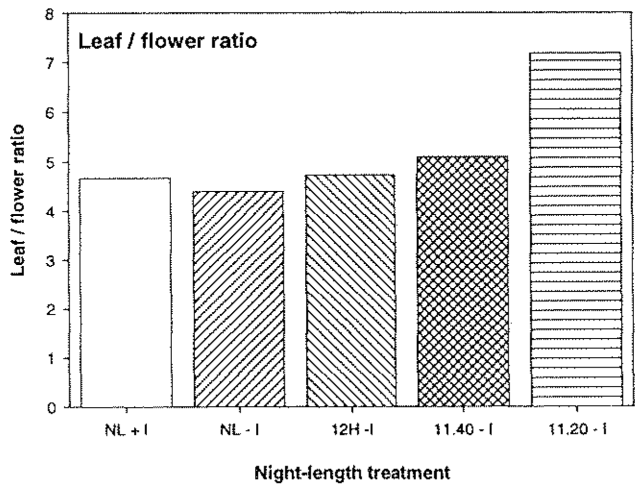




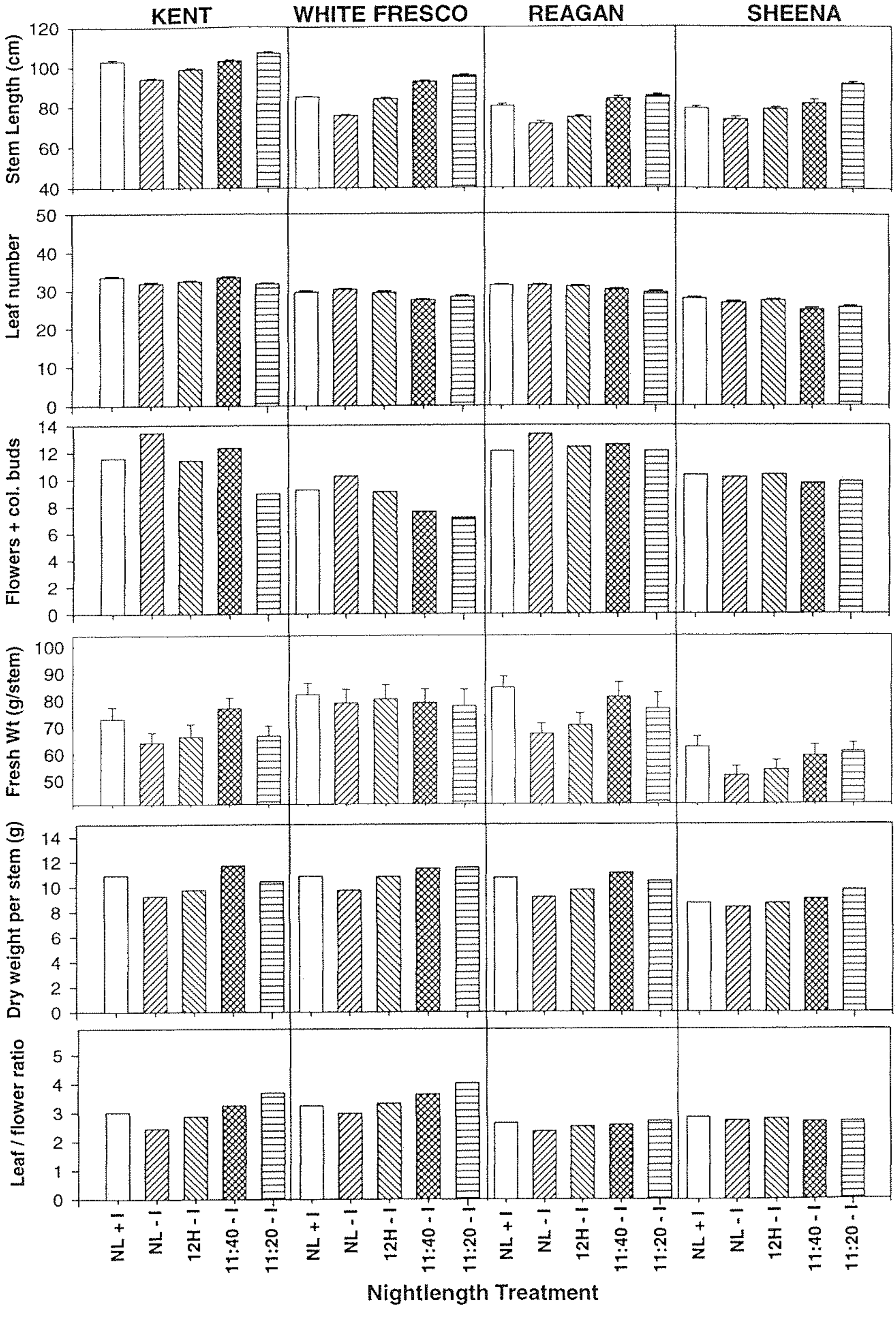




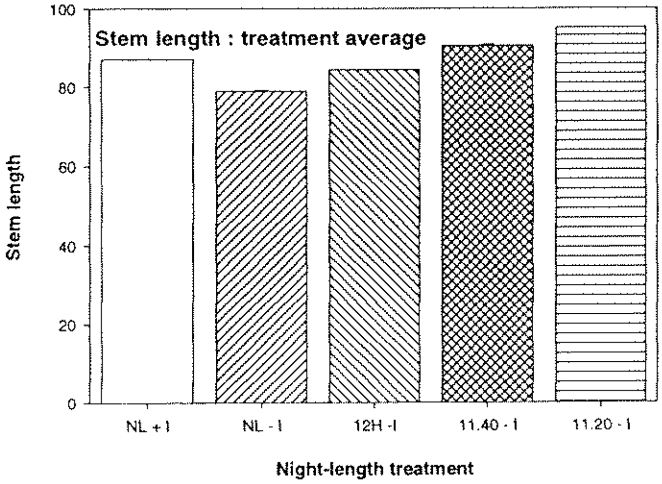


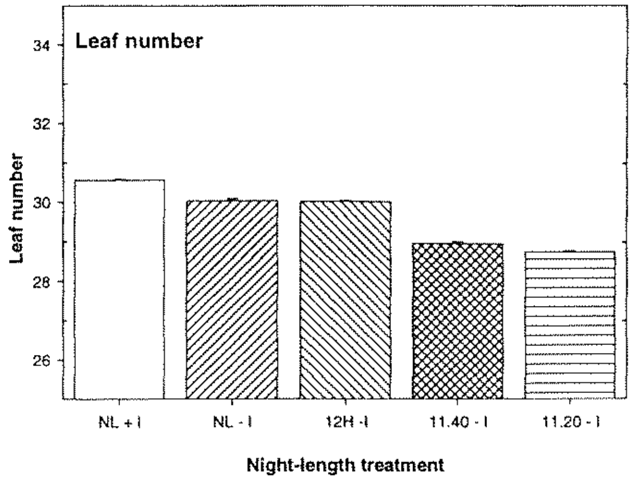


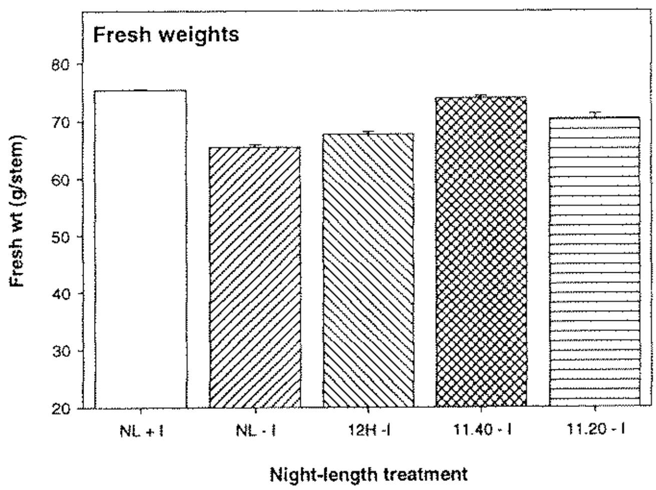
Appendix 6.5: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in each variety for the week 06 planting

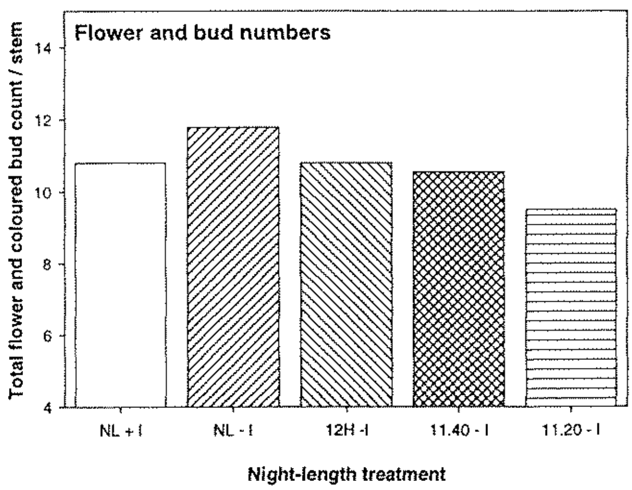


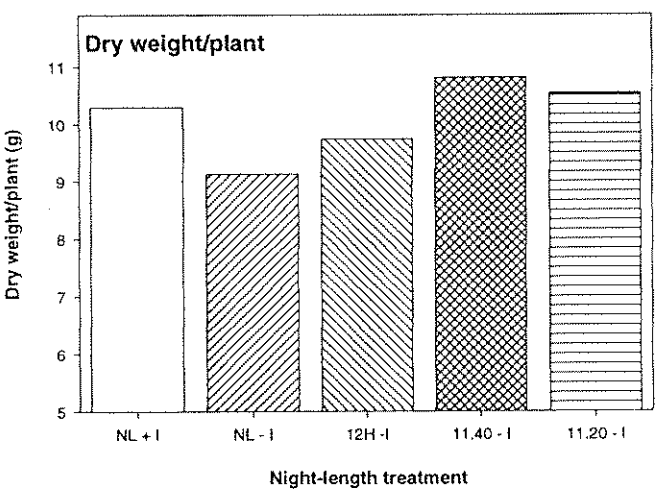
Appendix 6.6: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in the week 06 planting (average across varieties)

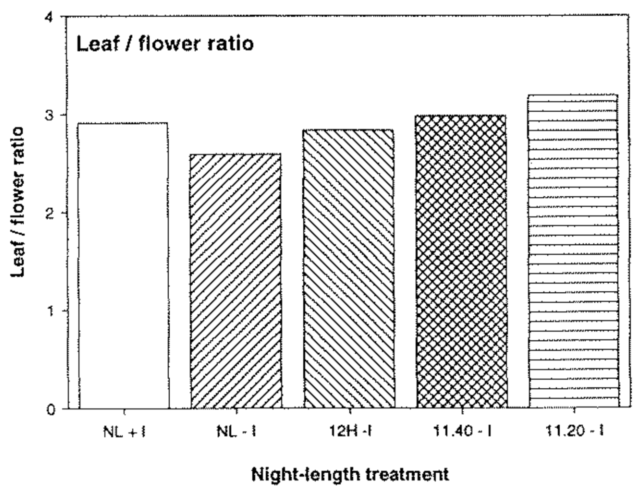




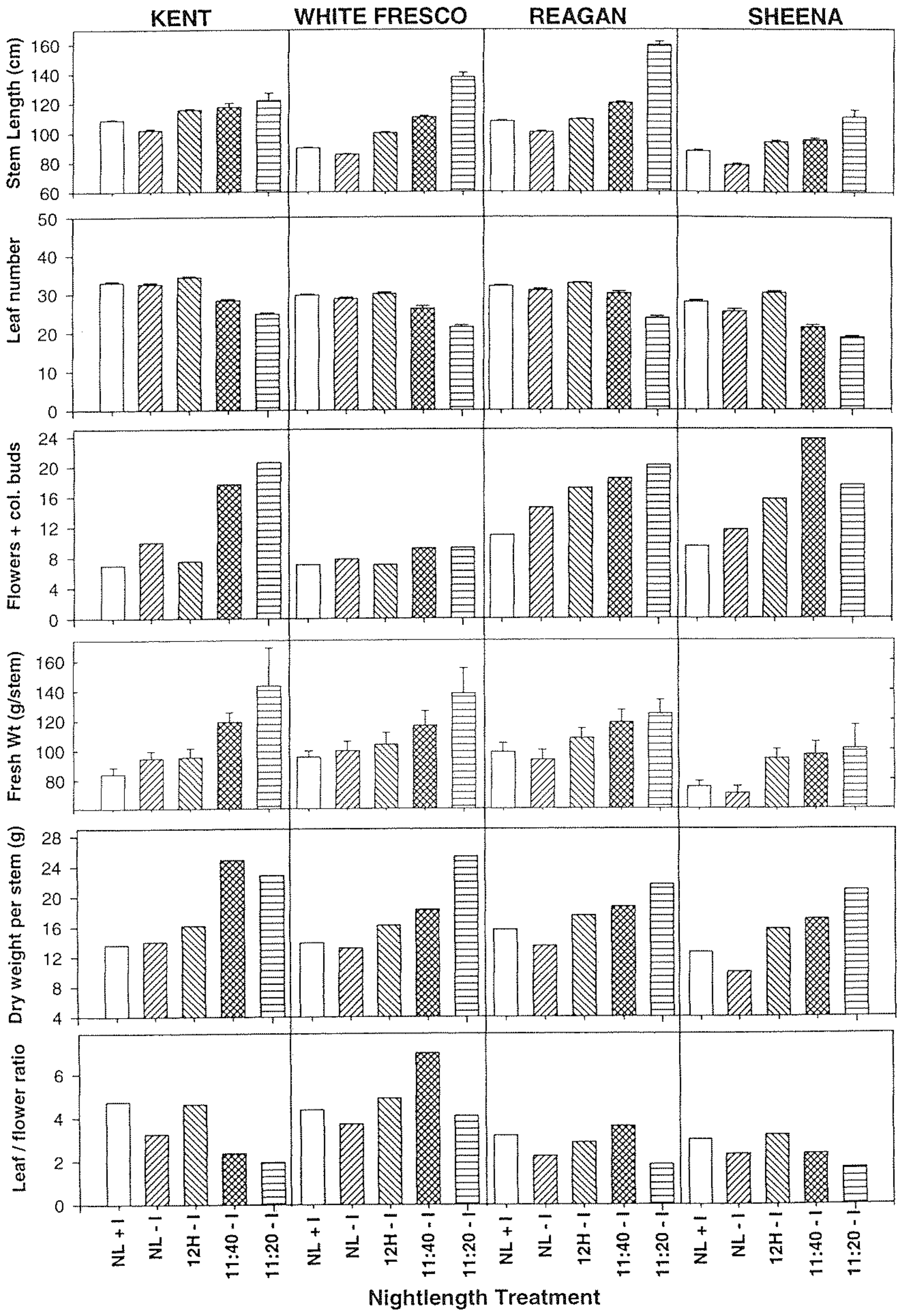




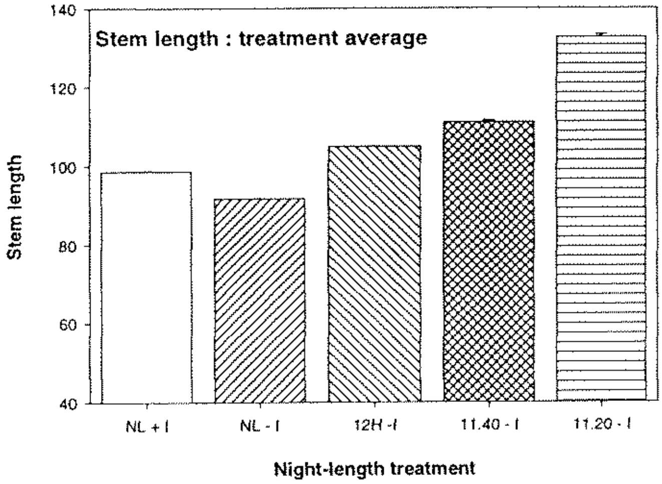


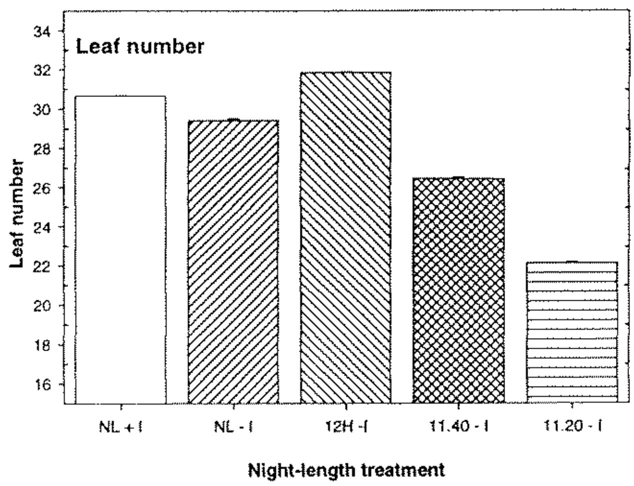


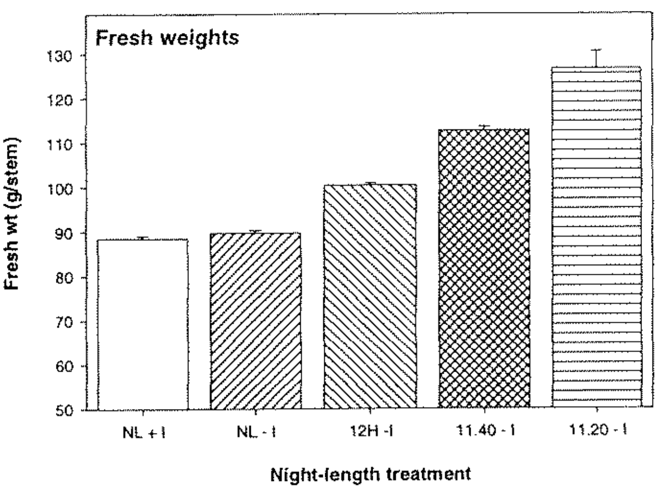
Appendix 6.7: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in each variety for the week 16 planting

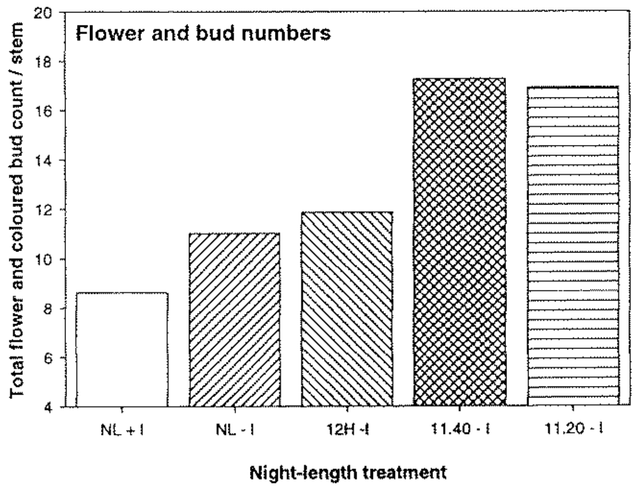


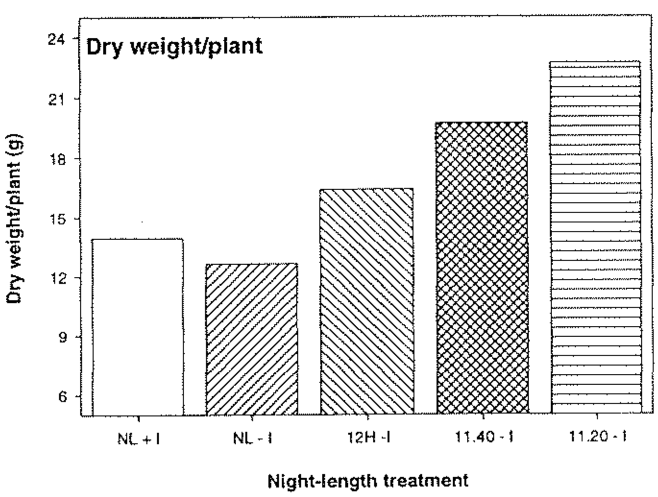
Appendix 6.8: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in the week 16 planting (average across varieties)

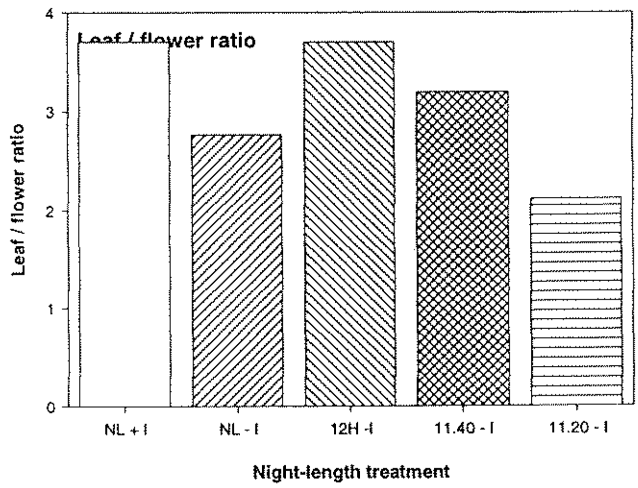




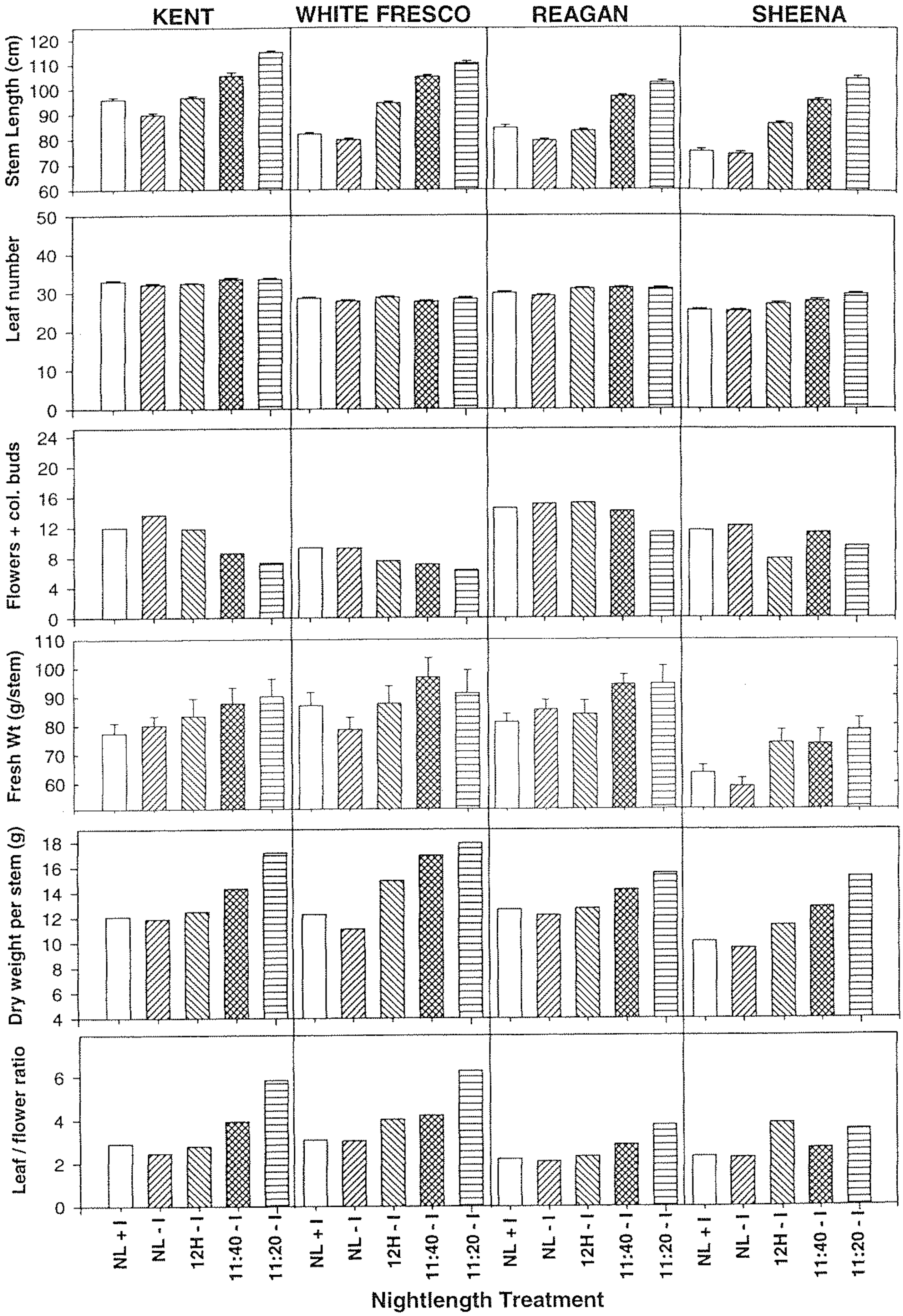




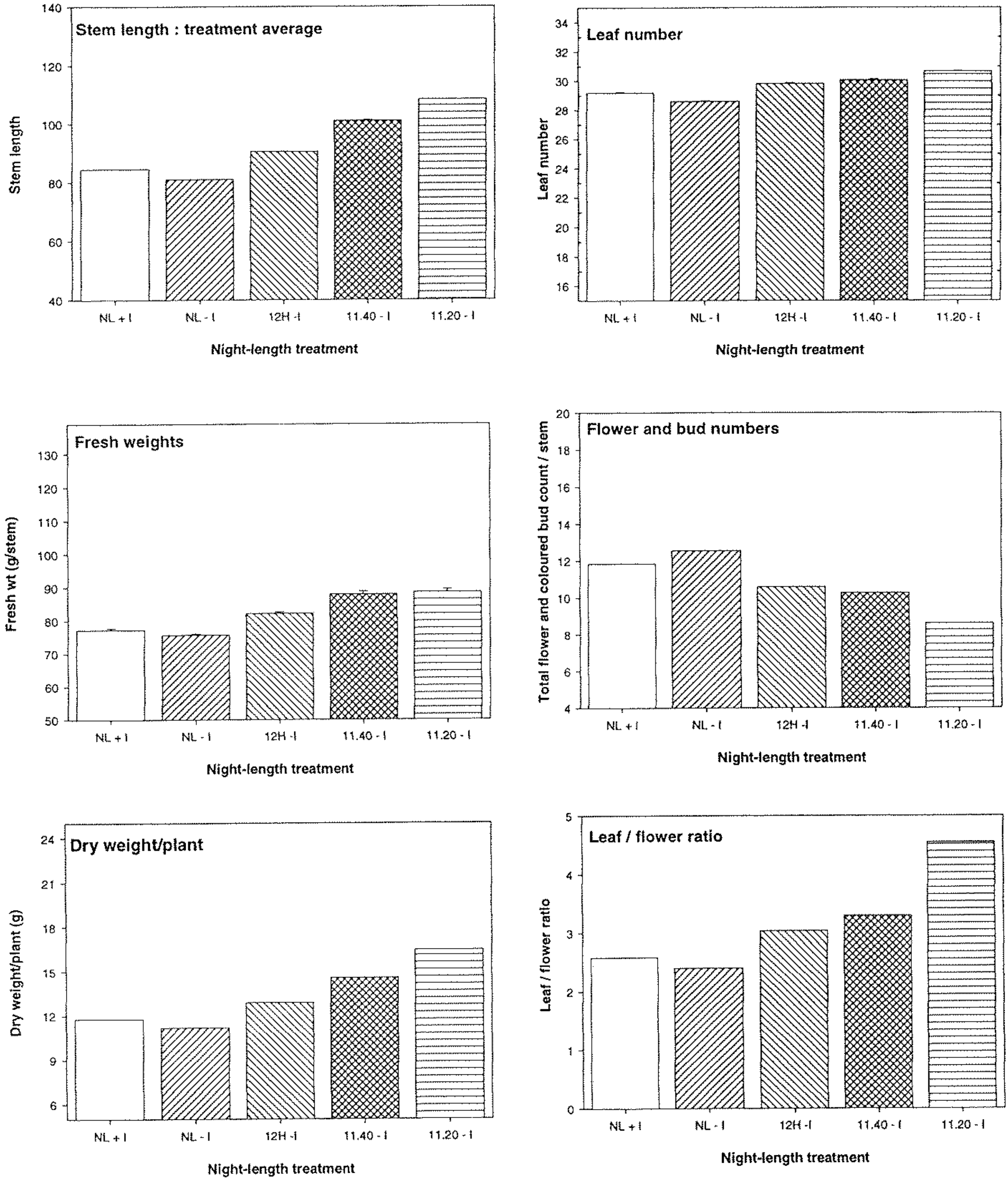




Appendix 6.9: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in each variety for the week 25 planting



Appendix 6.10: Effect of night-length treatments on stem length, leaf number, fresh and dry weights, and the leaf/flower ratio in the week 25 planting (average across varieties)



Tables of means for Figures 6.2, 6.4, 6.6, 6.8 & 6.10 (averaged across varieties)

Stem length (cm)

	Night-length treatment				
	NL + I	**NL - I**	**12 - I**	**11:40 - I**	**11:20 - I**
week 40	99.1	89.5	99.3	105.5	106.9
week 45	90.4	80.5	90.6	97.5	106.4
week 06	87.0	78.9	84.3	90.4	95.0
week 16	98.7	91.7	104.8	111.1	132.7
week 25	84.5	80.9	90.4	101.0	108.3

Fresh weight (g)

	Night-length treatment				
	NL + I	**NL - I**	**12 - I**	**11:40 - I**	**11:20 - I**
week 40	60.0	54.9	49.8	56.6	57.2
week 45	50.2	41.1	43.2	50.9	57.0
week 06	75.4	65.5	67.7	73.9	70.3
week 16	88.5	89.7	100.4	112.7	126.7
week 25	77.2	75.8	82.2	88.0	88.5

Leaf number

	Night-length treatment				
	NL + I	**NL - I**	**12 - I**	**11:40 - I**	**11:20 - I**
week 40	32.0	32.9	32.5	32.4	32.9
week 45	32.6	31.9	30.5	32.1	32.1
week 06	30.6	30.0	30.0	29.0	28.8
week 16	30.7	29.4	31.8	26.5	22.2
week 25	29.2	28.6	29.8	30.1	30.7

Total bud number per stem

	Night-length treatment				
	NL + I	**NL - I**	**12 - I**	**11:40 - I**	**11:20 - I**
week 40	2.99	4.00	3.10	3.13	3.84
week 45	4.88	4.75	4.04	4.97	7.78
week 06	4.71	4.97	5.62	5.02	5.86
week 16	2.89	3.24	7.51	13.25	6.60
week 25	4.71	3.76	4.58	4.75	5.81

Number of open flowers per stem

	Night-length treatment				
	NL + I	NL - I	12 - I	11:40 - I	11:20 - I
week 40	4.24	5.29	2.99	2.66	1.46
week 45	3.72	2.28	2.59	2.04	0.58
week 06	5.48	7.08	3.84	2.92	3.06
week 16	4.75	6.20	2.62	2.02	
week 25	6.25	7.95	5.29	3.96	1.30

% Grade I stems

	Night-length treatment				
	NL + I	NL - I	12 - I	11:40 - I	11:20 - I
week 40	76.5	80.1	55.2	57.4	49.6
week 45	63.3	49.8	60.7	69.7	54.0
week 06	92.9	87.6	87.4	93.5	87.0
week 16	94.8	98.2	92.5	86.2	
week 25	97.7	98.8	98.8	96.6	92.1

% Grade II stems

	Night-length treatment				
	NL + I	NL - I	12 - I	11:40 - I	11:20 - I
week 40	11.9	11.7	33.0	25.7	31.4
week 45	16.4	25.9	15.3	14.3	24.9
week 06	3.3	8.2	7.7	4.4	8.1
week 16	4.7	0.6	6.3	7.1	
week 25	1.1	0.0	0.0	3.1	6.6

% Grade III stems

	Night-length treatment				
	NL + I	NL - I	12 - I	11:40 - I	11:20 - I
week 40	3.9	4.6	4.8	6.7	6.1
week 45	3.5	8.5	7.9	2.8	5.2
week 06	1.1	2.2	2.2	0.6	2.2
week 16	0.0	0.6	0.7	6.2	
week 25	0.0	0.0	0.3	0.0	1.3

% Waste stems

	Night-length treatment				
	NL + I	NL - I	12 - I	11:40 - I	11:20 - I
week 40	7.7	3.6	7.1	10.1	13.0
week 45	16.8	15.7	16.0	13.1	15.9
week 06	2.7	2.1	2.7	1.5	2.7
week 16	0.5	0.6	0.7	6.2	
week 25	1.2	1.2	0.9	0.3	0.1

Grade I wrap weights (g)

	Night-length treatment				
	NL + I	NL - I	12 - I	11:40 - I	11:20 - I
week 40	271.9	223.9	225	285.3	278.2
week 45	281.7	255.1	228.4	252.3	333.6
week 06	319.9	303.8	306.6	327.9	334.4
week 16	350.7	372.9	397.8	498.1	
week 25	341.6	348.5	350.7	350.8	347.3