Project title	Optimising the propagation environment for endive, escarole, celery and chinese cabbage
Project number:	FVPC 311
Project leader:	Dr Debbie Fuller, Warwick HRI
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Location of project:	Warwick HRI J.E. Piccaver & Co., Lincolnshire. G S Shropshires, Cambridgeshire
Project coordinator:	Mr David Norman
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The results and conclusions in this report are based on an investigation conducted over three years. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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Grower Summary

Headline

- Temperature integration strategies may be adopted for the production of endive, escarole, chinese cabbage and celery

- Smaller transplants can be used without increasing the risk of bolting

Background and expected deliverables

Low temperature can cause bolting (premature flower initiation) in endive, escarole, celery and chinese cabbage. To reduce the risk of bolting, plants are normally propagated at around 17°C and, to delay bolting, propagators aim to initiate as many leaves as possible to maximise vegetative growth before low temperatures are experienced in the field. In conflict with the requirement to maximise leaf number during propagation, there is increasing demand by growers for smaller plants which are more compatible with mechanical transplanting, as well as to reduce energy use during propagation. Commercial pressures to reduce energy inputs and produce smaller plants therefore conflict with current strategies to reduce bolting. Information is needed to enable growers to make informed decisions concerning the trade-off.

In the first year of this project, time of planting and hence external temperatures had the greatest impact on levels of bolting, although lower temperature propagation (down to 14°C) also increased bolting. Size of transplant had little impact when external conditions stimulated bolting, but where differences were found; larger transplants generally had more bolting. However there was a loss of crops for intermediate planting dates and a change in the strategy for imposing transplant size treatments, therefore, further work was required. In year two, a variable temperature regime in propagation (including a night temperature set point of 10°C) did not increase the risk of bolting providing a suitable day temperature was achieved to raise average temperature to around 17°C. However the low night combined with high day temperature treatment used may not be the most energy efficient method of achieving a suitable average temperature during the winter period and was found to create quality issues as a result of plant stretching. Initial trends suggesting higher risk of bolting as a result of increasing transplant size were repeated in year 2 although there were concerns that the method of assessment may have influenced the results. In the final year of the project, temperature integration treatments were investigated where temperature was allowed to vary during the 24 hour period whilst maintaining a suitable (17°C) average and vent temperatures were raised in order to maximise solar gain. This was combined with experiments to examine transplant size with an extra method of assessment introduced in order to remove uncertainties regarding the use of data from plots harvested on one occasion.

Year three of this project therefore aimed to:

- Determine how incidence of bolting in the field at maturity is affected by temperature integration during propagation with a view to optimizing energy efficiency.
- Continue to examine how reducing the size of transplant influences incidence of bolting in the field at maturity and how this interacts with temperature integration regimes.

Summary of the project and main conclusions

Four batches of the species, celery (cv Victoria), endive (cv Barundi), escarole (cv Nuance) and chinese cabbage (cv 1 Kilo SB) were propagated for early season planting in repeat batches planted between week 11 and week 17 using treatments designed to examine the impact of temperature integration strategies on risk of bolting and final quality. These included:

1. Conventional 17˚C heat set point day and night with venting at 21˚C, as a control (17/17).

2. Standard temperature integration (Ti-std) with venting at 25˚C, minimum temperature at 10˚C during the night and target average temperature set to match the control.

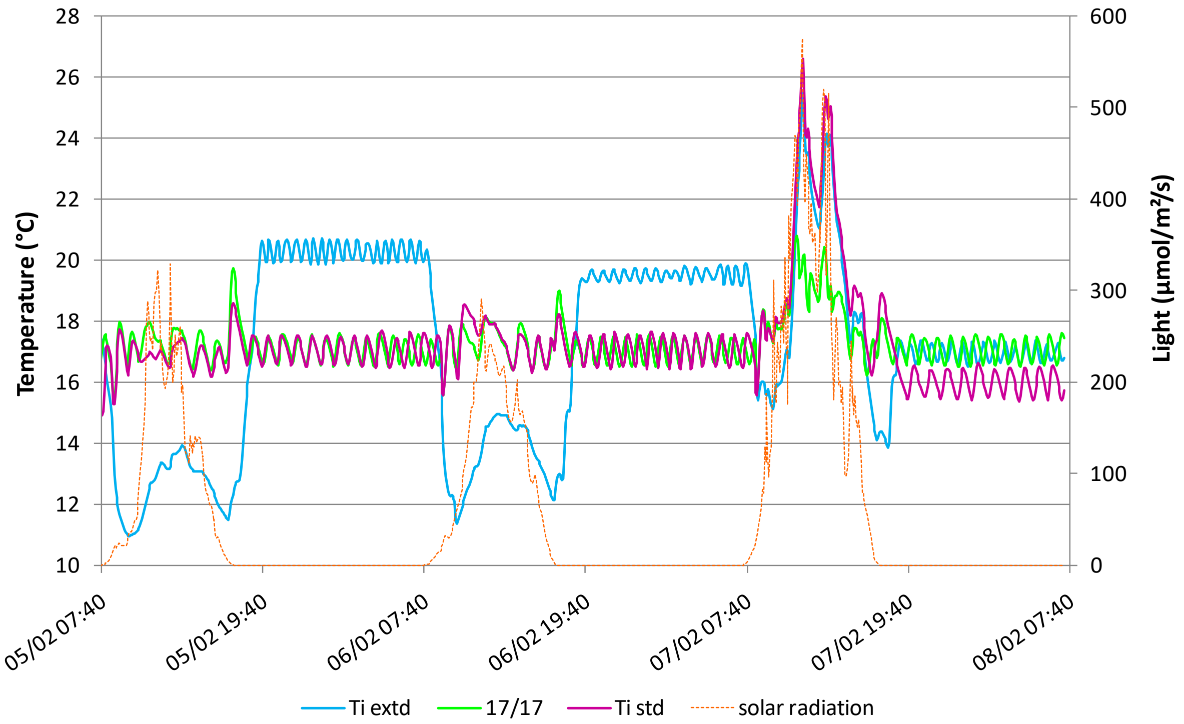
3. Extended temperature integration (Ti-extd) with venting at 25˚C, day heat set point at 10˚C and target average temperature set to match the control.

4. Commercially raised transplants (comm) were planted amongst all trial plots as a bench mark for production. These plants were raised according to standard commercial practise which would be close to the 17/17 treatment above but no attempt was made to reproduce either the temperatures or schedule of that in the experimental compartments.

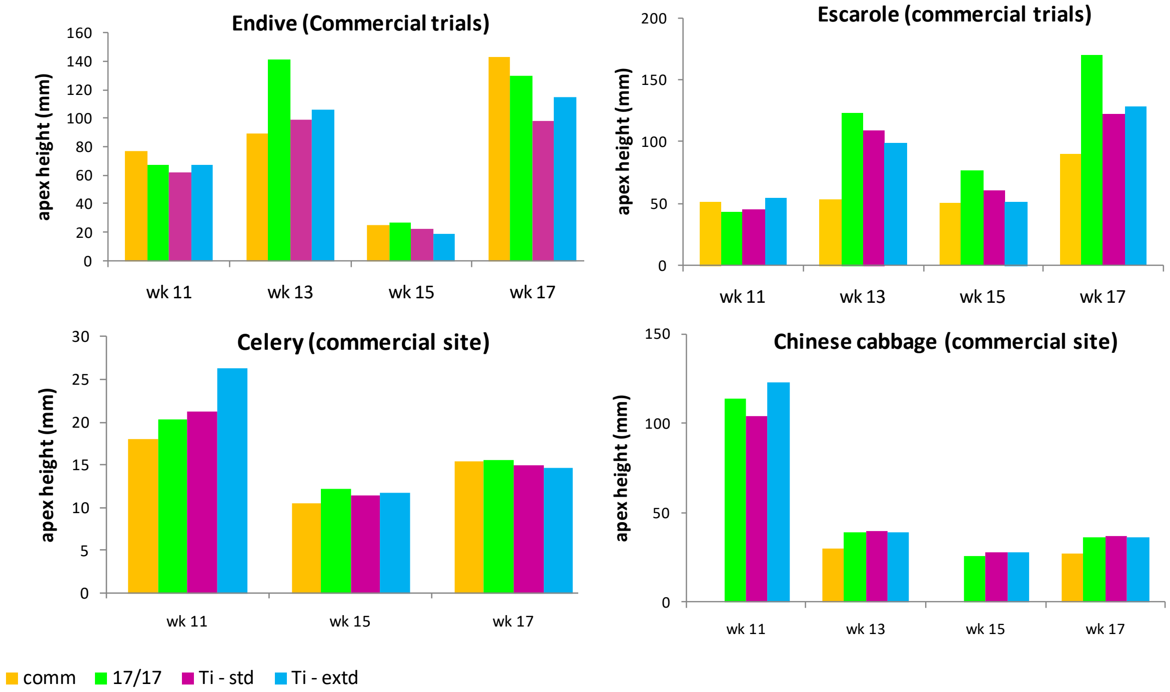
All compartments used a thermal screen at night with day and night set to change at dawn and dusk. Achieved average temperatures per batch of plants compared well between these three treatments throughout the season as summarised for celery in the table below, with an increase in achieved temperature occurring as the season progressed and amount of solar gain increased.

Average 24 hr Temperature (°C)				
	Planting week:			
	11	**13**	**15**	**17**
Celery				
17/17	17.6	17.7	18.0	18.4
Ti std	17.6	17.8	18.2	18.6
Ti extd	17.6	17.9	18.2	18.6

Instantaneous temperatures varied between the three treatments as demonstrated for data logged between 05/02/09 and 08/02/09 (below). Day temperature increased more in Ti treatments (venting at 25°C) than the control (venting at 21°C) on the sunny day (07/02), although temperature dropped at the start and end of the day in the Ti-extd treatment reflecting the lower temperature set point and lack of heating from the sun at these times. As a consequence of achieved average day temperature the Ti std treatment needed lower night temperature to achieve the target average 24 hour temperature. The differences between the two Ti treatments were greatest on overcast days (05/02 and 06/02) with heating used more during the day in the Ti std treatment (where temperature would only fall to the minimum set point if sufficient temperature credits had been accumulated) than the Ti extd treatment. As a consequence, the Ti extd treatment required a higher temperature at night which would be achieved more efficiently than during the day where a suitable thermal screen is in place.



The two Ti treatments produced at least equivalent final head weight to the conventional 17/17 treatment for transplanted crops grown on in the field. Furthermore there was no evidence of the Ti std regime increasing risk of bolting, measured as apex height at harvest, % bolting (when seen) or as bolting date. The more extreme Ti extd treatment also generally did not significantly increase the risk of bolting which reflects data collected in 2008 (year 2), where achieved temperatures during the night often fell to the 10°C set point used. Some of the 2009 data indicates an increase in apex height (suggesting greater progression towards bolting) for crops planted in week 11. For example celery grown on the commercial site in the figure below, however the risk appears slight with some contradictory trends in individual treatment means. Furthermore the absolute apex heights for celery at final assessment from the week 11 planting at the commercial site are below commercial specifications for maximum apex height (<40mm) suggesting all treatments are capable of delivering a commercially acceptable crop. Overall, the Ti extd treatment may require greater caution than the Ti std treatment for the earliest batch of transplants produced. Interestingly, when a 10°C set point was used during the night in the year 2 experiments there was no suggestion of increased bolting, and yet achieved temperatures during the night in year 2 were lower than those achieved in year 3 when the 10°C set point was in place (i.e. during the day). Further work would be required to assess if these differences are due to different responses to low temperature during the day and night.



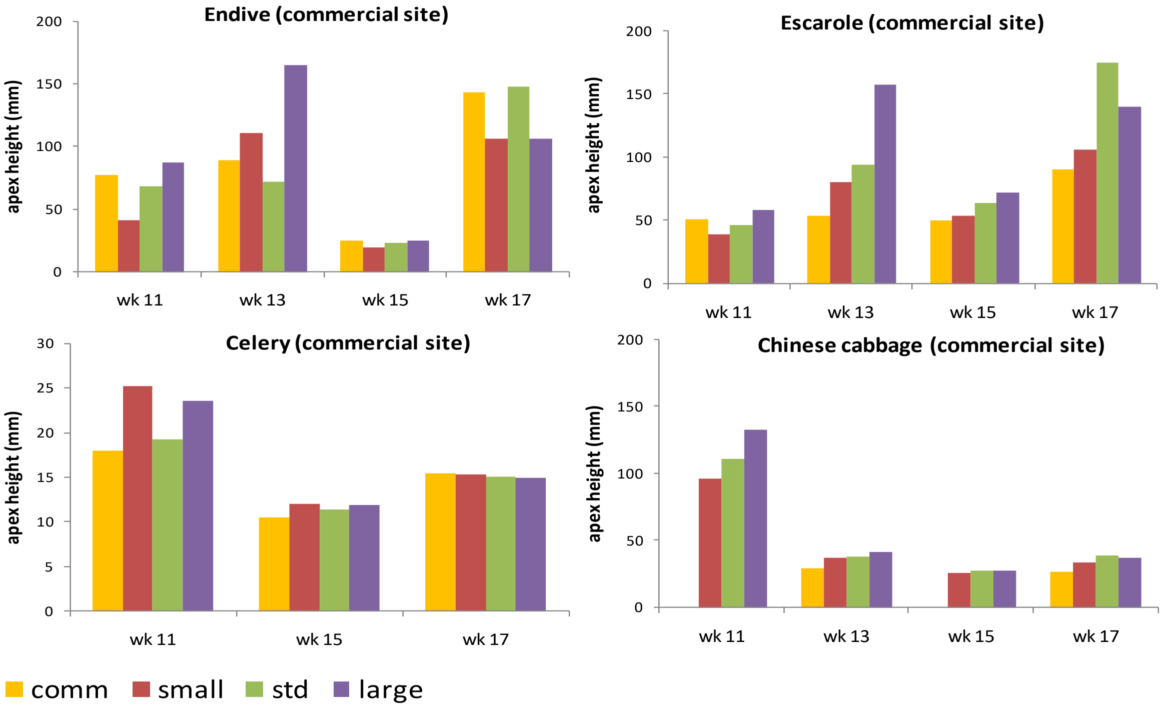
Sowings were staggered for each planting date in order to produce;

- ‘standard’ size plants - designed to represent the size of plants produced by commercial propagation,
- ‘large’ plants - sown approx 5 days earlier than the standard,
- ‘small’ plants - sown approx 5 days later than the standard.

A typical propagation schedule to achieve these treatments is given below for batches of plants grown on at the commercial site (Com) and at WHRI.

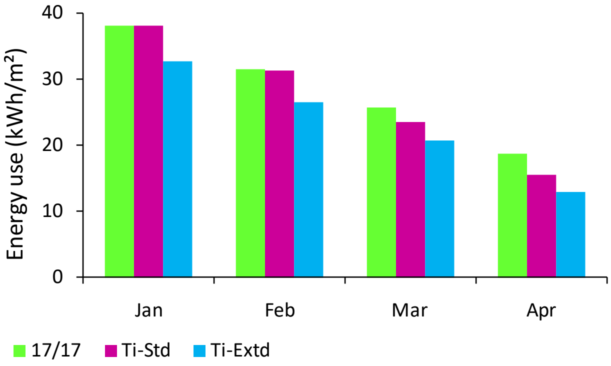
Batch/Week no.	**No. days in heat**			**Planting date**	**Harvest date**
	Small	**Standard**	**Large**		
Endive and Escarole					
11 WHRI	26	21	16	09/03	11-15/05
11 Com	26	21	16	10/03	19/05
13 Com	22	18	14	23/03	02/06
15 WHRI	20	16	12	07/04	01-05/06
15 Com	20	16	12	06/04	17/06
17 Com	17	14	11	21/04	02/07

Whilst results from the first two years of the project suggested that larger transplants may increase risk of bolting, there was a risk that harvesting the commercial plots on one date may have biased the data, with larger transplants possibly being left in the field longer than would be expected for a commercial crop harvested by head weight and therefore be more likely to bolt. In 2009 plots were therefore split with four batches planted at the commercial sites and harvested as normal (on one date per batch) and two batches planted at WHRI where treatments were harvested when they reached a target head weight. Where transplant size had a significant effect however it was the larger transplants that were apparently at greater risk of premature bolting as demonstrated below for trials planted at the commercial sites.



Financial benefits

Data from 2008 and 2009 indicate that the species studied may be propagated with variable temperature regimes providing a suitable average temperature is achieved. A standard approach to temperature integration including a vent set point of 25˚C, a minimum temperature of 10˚C and a target average temperature of 17˚C created no more risk of premature bolting than a conventional regime (17˚C heat set point day and night with venting at 21˚C), and would be expected to reduce energy inputs. Savings of around 4.8% are predicted for the settings used in these experiments compared with a conventional regime over the January to April period assuming



a thermal screen is used at night. The extended Ti regime was predicted to save 18.5% on energy use over the January to April period (again assuming the use of a thermal screen at night).

Savings from changes in transplant size would be related to reduction in speed of throughput and hence energy input per batch as well as improved efficiency during transplanting and potential to reduce losses resulting from damage suffered in mechanical transplanters. Smaller transplants should separate more readily when being fed into the transplanting equipment and therefore speed up rate of planting. Reduction in losses has potential to increase yield since damaged plants are likely to be slower to establish and therefore may compete less well with neighbouring plants as well as reduce the need for fungicide sprays by reducing sites of entry for pathogens. Trial plots were hand transplanted as they were relatively small compared with commercial areas and also complicated by the randomisation necessary for statistical analysis and hence these benefits of using smaller transplants have not been quantified. Given the increased risk of bolting these results also suggest that where transplanting produced for early season production is significantly delayed, it may be detrimental to final production via increased incidence of bolting. It may therefore be more cost effective to discard such transplants than to continue with production which will require further labour inputs to clear in the event of excessive bolting.

Action points for growers

- Where feasible propagators should move towards using temperature integration for the production of transplants of celery, chinese cabbage, escarole and endive. It is suggested that settings are adjusted towards the Ti std treatment initially whilst experience is gained with the technique.
- Growers may prefer to initially make small adjustments to minimum heat set points and vent set points as recommended in the HDC fact sheet 06/09*; with gradual progression towards the settings tested in this project i.e.:-
    - venting at 25°C (which may be reduced as the season progresses and excess temperature credits accumulate)
    - minimum heat set point of 10°C
    - average achieved temperature should reflect current achieved temperatures since lower achieved temperatures have been found to increase risk of bolting in this project using current commercial varieties.
- There is scope to further energy savings if screens are installed by progressing further towards the Ti extd settings, at least for planting weeks other than the earliest

of the season. To extend temperature integration, settings used in the experiment described in this report include those outlined for standard Ti above but with a 10°C heat set point during the day.

- Propagators and growers may move towards the use of smaller transplants in order to assist with mechanical transplanting. There has been no increased risk of bolting as a result of using transplants propagated for up to one less week than a typical standard commercial schedule. Furthermore it may be detrimental in terms of risk to bolting as well as to the mechanical transplanting process to plant larger transplants and it may make more economic sense to discard overgrown transplants than to continue with planting and growing on in the field.

* Steve Adams and Allen Langton, Warwick HRI, and Chris Plackett, FEC Services Ltd (2009). HDC fact sheet 06/09. Energy management in protected cropping: Manipulation of glasshouse temperature.

Science Section

Introduction

Low temperatures can cause bolting (premature flower initiation) in endive, escarole, celery and chinese cabbage. To reduce the risk of bolting, plants are normally propagated at around 17-18°C and to delay bolting in the field, propagators aim to initiate as many leaves as possible to maximise vegetative growth prior to the start of planting.

With the rapid increase in gas and oil prices there has been increasing pressure to reduce energy use. Options for reducing energy consumption in glasshouse production include reducing heat set points but there has been a fear that reducing propagation temperatures may increase the risk of bolting, however, little information was available prior to starting this project. Temperature integration (Ti), which allows fluctuation in instantaneous temperatures providing longer term averages are met, has successfully been adopted for various protected crops. In Ti, achieved temperatures above conventional set-point levels resulting from solar gain are offset against lower temperatures in overcast weather or at night, reducing heat required from the boiler. In crops tested previously, the risks of using temperature integration were related to yield, timing and quality. However crops susceptible to bolting had not been considered and so it was unclear whether allowing greater temperature fluctuations and, therefore, periods of low temperature would increase the risk of bolting.

In conflict with the requirement to maximise leaf number during propagation as outlined above, there has been increasing demand by growers for smaller transplants which are more compatible with mechanical transplanting. However there was concern that reducing transplant size would increase the risk of bolting as plants would be exposed to 'chilling' earlier (i.e. at a lower leaf number) in the field. The need to reduce energy use and produce smaller plants therefore contradicted strategies used to reduce bolting and information was needed to enable growers to make informed decisions concerning the trade-off.

Whilst studies relating to temperature integration and bolting were lacking, there was information from the literature regarding flower initiation of the species included in this project. Wurr (1996) has shown how conditions in propagation will have a carry over effect into the field in terms of progression towards flowering. The aim of commercial propagators is to ensure young transplants have not been triggered to flower before leaving the nursery, although once in the field, flowering may be rapidly initiated by low temperature early in the season and by increasing daylength. Hence with smaller transplants that have fewer leaves initiated prior to transplanting it has been considered particularly important that transplants are either juvenile or vegetative with minimum progression towards flowering when planted out. Crop management would then be used in the field to ensure that plants are harvested before signs of bolting become visible.

All species covered by this project are triggered to flower by either low temperature or long days (Friend, 1985; Paulet, 1985; Pressman and Sachs, 1985) although the relative importance of these factors varies with species and variety. Low temperature is the predominant factor influencing flowering in chinese cabbage with effective temperatures and duration of chilling depending on cultivar and also daylength. Once induced, flowering is then hastened by long days (LD). High temperature may also reverse induction suggesting that allowing wide fluctuations in temperatures in propagation may work well for both energy saving and minimizing bolting. Elers and Wiebe (1984) demonstrated how high day temperature combined with low night temperature delayed bolting in comparison with low temperature both day and night. However in these studies, average 24 hour temperature varied which also affected parameters such as head dry weight.

Low temperature (5-10°C) is also reported to be the predominant factor influencing flowering in celery with temperatures above 14°C required to prevent induction and with potential to use high temperature to delay the effects of previous low temperature induction (Pressman and Sachs, 1985). LDs during induction of celery prevent bolting but then after induction, LDs promote bolting. Since propagation temperatures are designed to prevent induction, introducing LD lighting is unlikely to be useful in celery propagation. For endive and escarole most of the work from the Handbook of Flowering was carried out on plants in vitro. These studies again point to low temperature hastening flowering (although not an absolute requirement particularly in early varieties), but unlike the other species covered previously, varieties of *Cichorium intybus* and *C. endivia* also required LD to flower (Paulet, 1985; Gianquinto, 1997).

If species need to be propagated in common conditions, then temperature would need to be above that of the highest requirement to prevent induction, and variable temperature regimes to save energy may be acceptable given that the higher temperatures accumulated for part of the day may be effective in delaying/reversing induction in plants exposed to lower temperature at other times of the day or if plants integrate and respond to the average. Daylength control however may be less suited to compromise, whilst LD lighting may be suitable for celery (at least until it is induced to flower), for *C.intybus* flowering may be promoted.

In order to respond to triggers for flowering, plants must have completed their juvenile phase and data to support this information can be less reliable. For *C.intybus*, plants were capable of responding to daylength 2-3 weeks from germination (Paulet, 1985) which suggests that the juvenile phase may end before the end of the commercial propagation period and hence temperature and daylength during propagation may be expected to have an impact on subsequent bolting as well as environmental conditions that the young plants are exposed to following transplanting. For celery, imbibed seeds were capable of being vernalized (Ramin & Atherton, 1991a) but a juvenile period has also been reported (Ramin & Atherton, 1991b) if imbibed seeds are not exposed to low temperature (which is likely to be the case for commercial propagators). For *C.intybus* anti-vernalization was achieved through exposing imbibed seed to higher temperature, which is effective in pre-empting the later effects of low temperature, although high temperatures during germination may reduce emergence rates (Gianquinto and Pimpini, 1989). For chinese cabbage, sensitivity to inductive conditions from germination has also been reported (Friend, 1985; Elers and Wiebe, 1984). Overall it appears that the species covered by this project may be expected to be receptive to inductive conditions for at least part of the propagation period (3 to 7 weeks depending on species and sowing date) highlighting the requirement for work to determine the safe limits in order to benefit from energy saving strategies during propagation.

In the first year of this project, propagation at 14 or 16 °C rather than 18°C increased levels of bolting in endive and escarole in particular and also in chinese cabbage very early in the season. No bolting was recorded for celery which may in part be due to the relatively mild early season conditions in 2007. Apical dissections indicated that transplants from all temperature regimes were vegetative at transplanting stage but that endive and escarole plants at least may have progressed further towards flowering following propagation at lower temperature than at higher temperature, which agreed with the data collected at harvest stage. Hence reducing propagation temperature to save energy is expected to increase bolting of at least two of the species studied. In the most extreme conditions however, where there were high levels of bolting; propagation temperature had relatively little impact on levels of bolting. Experiments in year 2 were designed to see if moving towards variable temperature regimes would be a more suitable strategy for these crops, with extra treatments included to give some plants an extra low temperature ‘challenge’ prior to planting out in order to maximize the chances of creating bolting. The variable temperature treatments consisted of a 10°C heat set point at night combined with either a high day set point in order to raise average temperature to that of a control treatment set at 17°C day and night or combined with a more conventional 17°C day heat set point. The treatments therefore compared fixed and variable temperature regimes designed to achieve comparable average temperature and also variable regimes at two different achieved average temperatures. In order to fully assess the risk of the low (10°C) set points used, venting was set at +1°C. Results in year 2 suggested that reducing average achieved temperature was detrimental in terms of risk of bolting whether given as a variable regime (i.e. as in year 2) or as a constant regimes (as in year 1). However the variable temperature regime achieving a comparable average temperature to the 17°C/17°C control, did not increase the risk of bolting, despite the prolonged period at 10°C (which was generally the achieved temperature given the low vent set point). Quality of transplants suffered in the variable regime (where night was around 10°C average temperature and day at around 24°C average temperature) with transplants appearing stretched. It is well known in ornamentals production that low night and high day will produce a more stretched plant habit and this response also appears to apply to the species studied here. Overall, year two indicated that there is potential for using temperature integration to reduce energy inputs for the propagation of early season salad crops. Year 3 (2009) treatments were designed to consolidate this work and examine variable temperature regimes that are more commercially realistic. Specifically vent set points were raised which would reduce the extreme differences in temperature achieved in the first two years when a low vent set point was used. The low night combined with high day approach tested in 2008 was reversed in 2009 via the Ti extended treatment which aims to encourage more heating during the night under a thermal screen. Hence the plant stretching as a result of high achieved day temperature in 2008 should at least be avoided by this approach and in fact low day combined with high night would be expected to produce a more compact plant habit. An extended Ti approach would also be expected to give greater energy savings than standard Ti in the winter when there is less solar gain.

Results for transplant size in 2007 and 2008 were less clear cut. There was a suggestion that larger transplants may increase bolting for plants harvested on a set date. However in practice these larger transplants may have been harvested artificially late given the design of assessments which involved harvesting all treatments in a batch on one date; thus increasing the likelihood of bolting for the larger transplants. In 2009 therefore an extra trial area at WHRI was introduced. The aim of this third site was to repeat some of the batches planted at the commercial sites in order to facilitate assessment of individual treatments according to achieved head weight. This design then allowed for earlier harvesting of larger transplants relative to smaller transplants if this was justified on the basis of achieved head weight.

Materials and methods

Temperature treatments

Plants from commercial production (comm) were compared with plants raised in experimental compartments set either to 17°C day and night (17/17) with venting at 21°C, to represent a commercial regime, or with compartments with higher vent set points (25°C) as part of two different temperature integration (Ti) strategies where temperature was allowed to fluctuate more widely than for conventional heating strategies. In both Ti treatments, the target average temperature was the same as the achieved average temperature from the 17/17 treatment. In the Ti-std treatment, temperature during the day would be expected to be higher than the 17/17 treatment whenever there was solar gain because of the higher vent set point. This 'extra' accumulation of temperature during a sunny day would be expected to be offset during overcast conditions when a lower heating set point would be sufficient to achieve the 24 hour target average of around 17°C. In the Ti–extended treatment, solar gain would also be possible during the day due to the higher vent set point, but there would be less active heating as the day time target temperature was set at 10°C in order to encourage heating to occur more frequently at night when thermal screens would be closed and therefore heating would be more efficient. Figure 1 aims to illustrate how these three treatments vary on sunny and overcast days (where day is daylight hours, in this case 07:00 to 17:30).

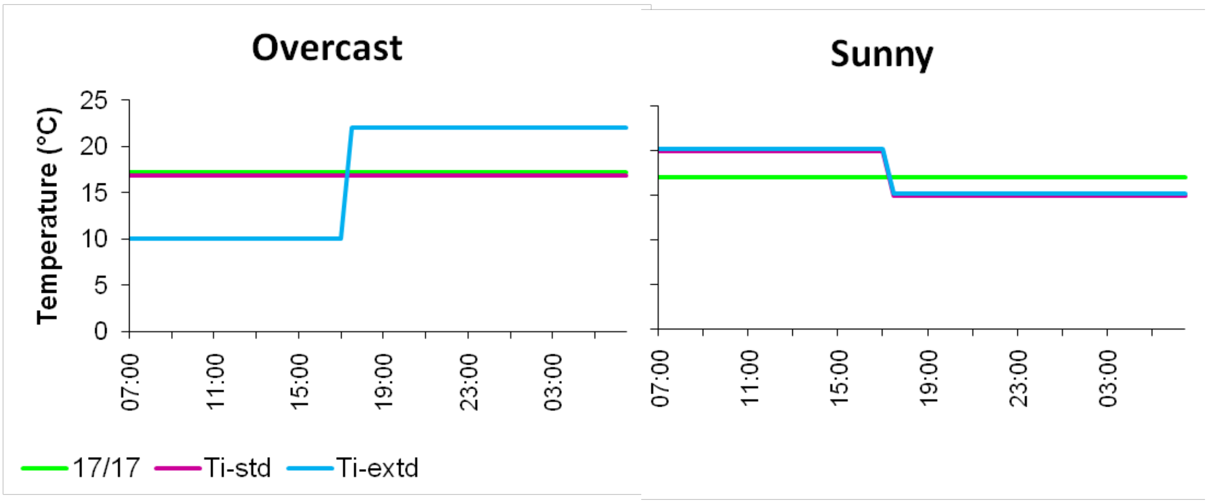


Figure 1. Schematic diagram of temperature treatments

The treatments described above are summarised below and were imposed in one each of three internal 43m² glasshouse compartments of a linear array:

- 17°C heat set point night and day (17/17) with venting at 21°C; as a control,
- Standard temperature integration (Ti-std) with average achieved 24 hour temperature set to match the control compartment, minimum temperature at 10°C during the night and venting set at 25°C,
- Extended temperature integration (Ti-extd) with day heat set point of 10°C and average achieved 24 hour temperature set to match control and venting set at 25°C.

Day and night were adjusted according to daylight hours.

Transplant size treatments

As in the first two years of the project, the propagation schedule was designed to produce three sizes of transplants which were smaller than, comparable to or larger than commercial transplants. In 2009, the schedule was initially staggered by 5 days for each size, and the total length of propagation was scheduled according to commercial schedules and prior experience with this project from 2007 and 2008. Since the aim of the propagation schedule was to have all treatments moving out of the heat at the same time, there was no flexibility to vary the schedule according to progress as would happen commercially for any one batch of plants. The propagation schedule is summarised below. As the total time in propagation reduced for later sowing dates, the interval between sowing dates was also reduced with the aim of keeping the difference between the three transplant sizes constant.

The following propagation schedule was applied to provide 6 batches of plants:

Batch/Week no.	**No. days in heat**			**Planting date**	**Harvest date**
	Small	**Standard**	**Large**		
Celery					
11 WHRI	45	40	35	09/03	6-10/07
11 Com	45	40	35	10/03	16/06
13 Com	42	37	32	25/03	n/a
15 WHRI	35	31	27	07/04	13-17/07
15 Com	35	31	27	06/04	08/07
17 Com	30	27	24	21/04	22/07
Chinese cabbage					
11 WHRI	27	20	13	11/03	26-28/05
11 Com	27	20	13	20/03	26/05
13 Com	26	19	12	26/03	26/05
15 WHRI	23	16	9	06/04	15-16/06
15 Com	23	16	9	07/04	09/06
17 Com	23	16	9	22/04	24/06
Endive and escarole					
11 WHRI	26	21	16	09/03	11-15/05
11 Com	26	21	16	10/03	19/05
13 Com	22	18	14	23/03	02/06
15 WHRI	20	16	12	07/04	01-05/06
15 Com	20	16	12	06/04	17/06
17 Com	17	14	11	21/04	02/07

Germination times were 5 days for celery, 4 days for endive and escarole and 3 days for chinese cabbage. Plants were given 5 days for weaning with frost prevention.

The effects of the three propagation temperatures and the three plant stage treatments were compared on four species grown for early season production i.e. celery (cv Victoria), chinese cabbage (cv 1 Kilo SB), escarole (cv Nuance) and endive (cv Barundi).

In summary, treatments compared:

3 propagation temperatures
x
3 stages of plant development at transplanting
x
4 species
x
6 batches of plants

- giving 36 treatment combinations which were each replicated over two block trays during propagation and over four plots when planted into the field for each of the 6 batches.

Details of agronomy and environmental control

Seed sourced from commercial suppliers (and primed in the case of celery) were sown in standard peat blocks produced by Hillgate Nursery, Terrington St Clement, Norfolk and transported to Wellesbourne for the experiments. Seed of all species were sown one per peat block by hand.

Trays were stacked in piles for germination in an air conditioned glasshouse compartment set to 18°C day and night. An empty tray was used at the top of each stack in order to achieve comparable levels of lighting to all trays when arranged in these stacks. Stacks were wrapped with clear polythene to prevent drying out during germination.

Trays were moved to compartments to receive temperature treatments once seed had chitted and signs of emergence were just visible.

The first 2 batches of trays were not watered until 10 days after sowing. Care was needed not to over-water early on, although water requirements increased once the cotyledons had expanded. Later batches of trays needed a very light watering after transferring to compartments using a fine rose. Subsequent watering was by hand overhead as needed with borehole water.

Routine sprays for prevention of fungal or insect infections were as follows:

> Chinese cabbage – Chlorpyrifos to prevent cabbage root fly for any batches planted out after 1st March (and therefore without fleece covers)
>
> Endive and escarole - Rovral WP spray for botrytis control in the week before planting
>
> Celery - Amistar and Bravo, for Septoria control applied a week apart starting two weeks from weaning.

After weaning, plants were either transported to the commercial sites for planting out or to the field plots at WHRI. Celery and chinese cabbage were planted at Shropshires, on organic soils near Feltwell, Norfolk, and endive and escarole were planted at Piccavers on silty soils near Holbeach, Lincolnshire. Blocks were planted into field plots using pre-dibbed holes at Piccavers, or by creating space to plant blocks manually at Shropshires and WHRI. In all cases blocks were planted so that the surface of the peat block was approximately level with the surface of the soil. Field plots varied in location at each commercial site to ensure plants from experiments would be grown alongside those raised for commercial production at the same time which ensured experimental plots would receive identical management to commercial crops (i.e. irrigation, fleecing and pesticide treatment). This meant that a fully randomised design to account for batch effects could not be used for field plots from different planting dates. Plots of commercially produced plants were therefore planted alongside plants raised in experimental treatments to provide some benchmark information within each batch. All batches of plants were covered with fleece after planting out.

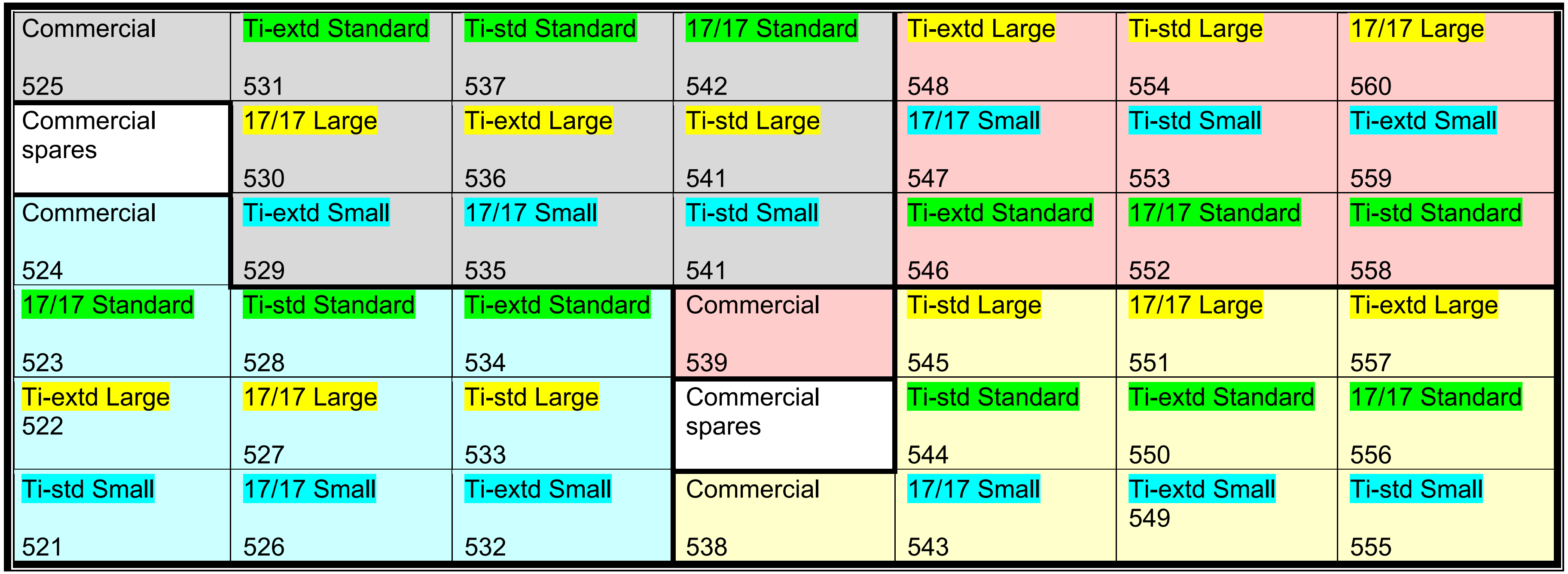
Experimental layout

Propagation treatments were given in three 43 m² glasshouse compartments in a linear array. The benches in each of the glasshouse compartments were divided in half lengthways with each half bench dedicated to a species. Trays were placed on the south end of the bench initially and moved down towards the north end of the bench as each new batch moved into a compartment. There were 2 replicate trays of 150 plants per tray for each combination of species/sowing date/ transplanting date and site/propagation temperature.

The bed layout in the field was different on each site due to differences in bed preparation. At Piccavers a triple bed former, had been used which produced 6 beds with 4 staggered rows per bed. At Shropshires prepared beds were in rows of 12 plants wide. An example of the plan for each site is given in Figures 2a and 2b. Beds of 1.83m width were prepared at WHRI with plants spacings marked out with strings.

All plantings were laid out using a split plot design where each of four blocks had a complete set of treatments as well as a plot of commercially raised plants with plots grouped by transplant size. Individual commercial plots consisted of 12 rows of plants with four plants per row. Edge plants in each plot served as guard plants with 20 fully guarded plants in the centre of each plot for experimental records. Each batch of plants was further guarded by commercial material on all sides. Individual plots of the main four replicate blocks at WHRI consisted of 5 rows of plants with 4 plants per row, edge plants were treated as guards and centre plants harvested for final assessment. A fifth replicate of plots at WHRI consisted of 6 rows of plants which were dedicated to the interim destructive sampling necessary to determine timing of harvests of the main 4 replicate plots according to achieved head weight (Figure 2c). Example layout for one batch of plants at each site is given below (Figure 2).

Rep 3 **Rep 4**

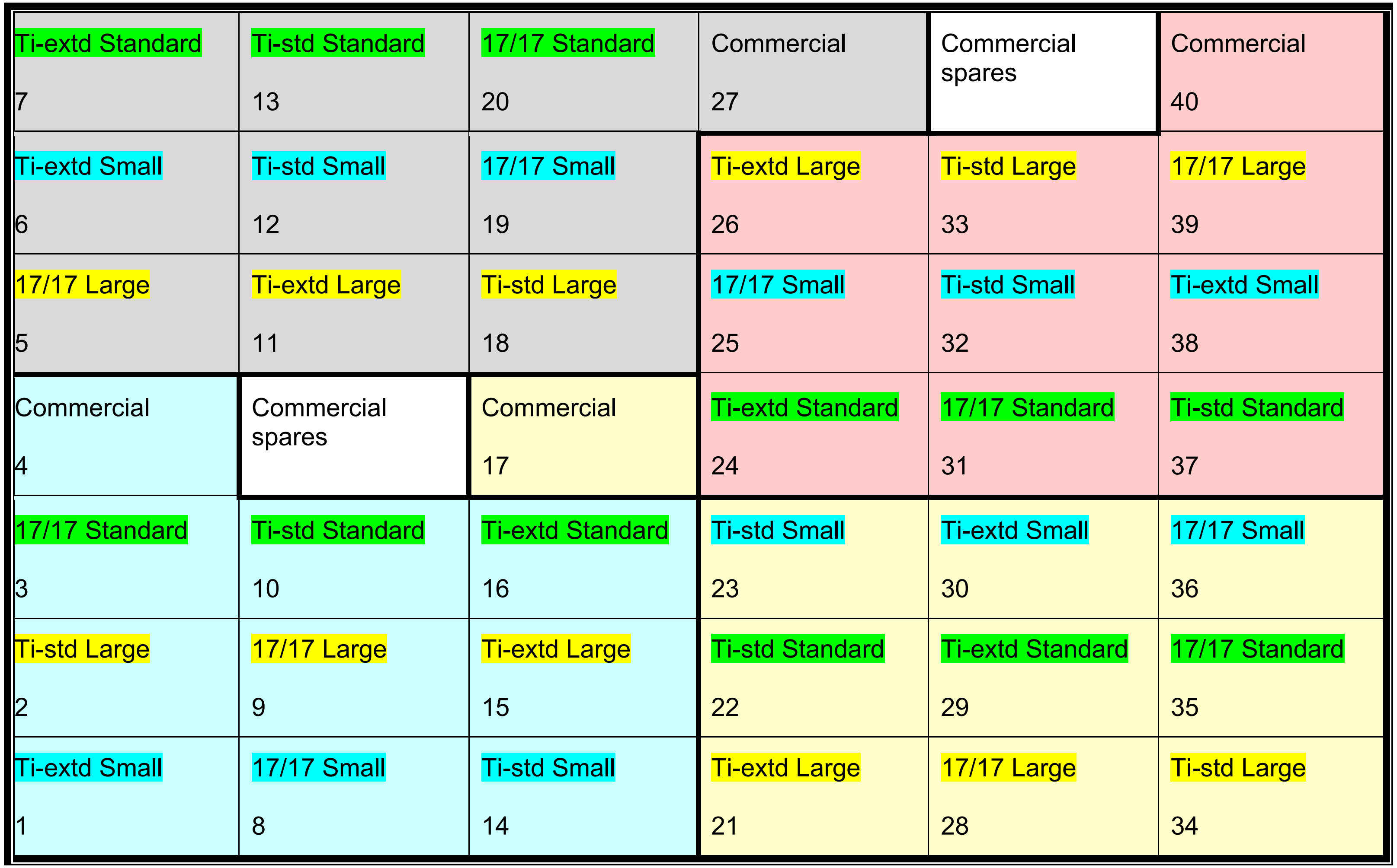


Commercial 525	Ti-extd Standard 531	Ti-std Standard 537	17/17 Standard 542	Ti-extd Large 548	Ti-std Large 554	17/17 Large 560
Commercial spares	17/17 Large 530	Ti-extd Large 536	Ti-std Large 541	17/17 Small 547	Ti-std Small 553	Ti-extd Small 559
Commercial 524	Ti-extd Small 529	17/17 Small 535	Ti-std Small 541	Ti-extd Standard 546	17/17 Standard 552	Ti-std Standard 558
17/17 Standard 523	Ti-std Standard 528	Ti-extd Standard 534	Commercial 539	Ti-std Large 545	17/17 Large 551	Ti-extd Large 557
Ti-extd Large 522	17/17 Large 527	Ti-std Large 533	Commercial spares	Ti-std Standard 544	Ti-extd Standard 550	17/17 Standard 556
Ti-std Small 521	17/17 Small 526	Ti-extd Small 532	Commercial 538	17/17 Small 543	Ti-extd Small 549	Ti-std Small 555

Rep 1 **Rep 2**

Figure 2a. Field plan for Shropshires – Celery Week 11 planting

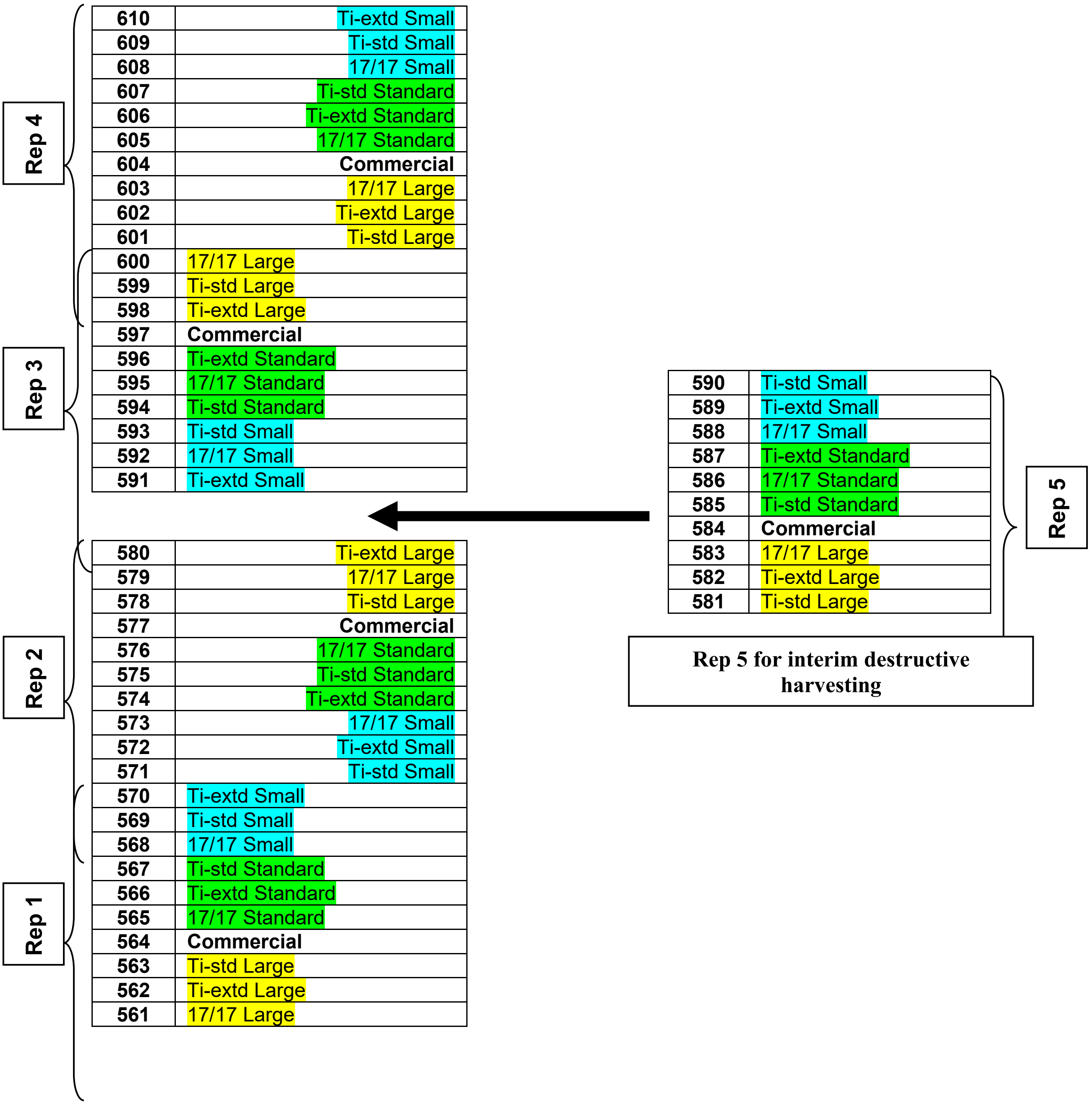
Rep 3 **Rep 4**



Ti-extd Standard 7	Ti-std Standard 13	17/17 Standard 20	Commercial 27	Commercial spares	Commercial 40
Ti-extd Small 6	Ti-std Small 12	17/17 Small 19	Ti-extd Large 26	Ti-std Large 33	17/17 Large 39
17/17 Large 5	Ti-extd Large 11	Ti-std Large 18	17/17 Small 25	Ti-std Small 32	Ti-extd Small 38
Commercial 4	Commercial spares	Commercial 17	Ti-extd Standard 24	17/17 Standard 31	Ti-std Standard 37
17/17 Standard 3	Ti-std Standard 10	Ti-extd Standard 16	Ti-std Small 23	Ti-extd Small 30	17/17 Small 36
Ti-std Large 2	17/17 Large 9	Ti-extd Large 15	Ti-std Standard 22	Ti-extd Standard 29	17/17 Standard 35
Ti-extd Small 1	17/17 Small 8	Ti-std Small 14	Ti-extd Large 21	17/17 Large 28	Ti-std Large 34

Rep 1 **Rep 2**

Figure 2b. Field plan for Piccavers 2009 – ENDIVE week 11 planting



610	Ti-extd Small
609	Ti-std Small
608	17/17 Small
607	Ti-std Standard
606	Ti-extd Standard
605	17/17 Standard
604	**Commercial**
603	17/17 Large
602	Ti-extd Large
601	Ti-std Large
600	17/17 Large
599	Ti-std Large
598	Ti-extd Large
597	**Commercial**
596	Ti-extd Standard
595	17/17 Standard
594	Ti-std Standard
593	Ti-std Small
592	17/17 Small
591	Ti-extd Small

590	Ti-std Small
589	Ti-extd Small
588	17/17 Small
587	Ti-extd Standard
586	17/17 Standard
585	Ti-std Standard
584	**Commercial**
583	17/17 Large
582	Ti-extd Large
581	Ti-std Large

580	Ti-extd Large
579	17/17 Large
578	Ti-std Large
577	**Commercial**
576	17/17 Standard
575	Ti-std Standard
574	Ti-extd Standard
573	17/17 Small
572	Ti-extd Small
571	Ti-std Small
570	Ti-extd Small
569	Ti-std Small
568	17/17 Small
567	Ti-std Standard
566	Ti-extd Standard
565	17/17 Standard
564	**Commercial**
563	Ti-std Large
562	Ti-extd Large
561	17/17 Large

Figure 2c. Field plan for WHRI – Celery week 11 planting

Monitoring and assessment

Achieved temperatures in germination, experimental compartments and weaning areas were logged throughout the experiment. Data loggers were placed in selected field plots at planting.

Growth assessments were made prior to transplanting, recording the following parameters on five plants per replicate:

- Shoot fresh weight.
- Shoot height (as length of longest leaf).
- Visible leaf number (all leaves above 2mm length).

A photographic record was kept of all treatments in trays prior to transplanting.

Final assessments in the commercial plots were made after commercial plants surrounding each plot had been harvested, recording the following parameters:

- Number of plants per plot bolted (out of the 24 guarded plants per plot).
- Head weight (on 5 or 6 heads for commercial and WHRI plots respectively).
- Apex length of plants dissected longitudinally (on 5 or 6 heads for commercial and WHRI plots respectively). All reps of celery and chinese cabbage measured at both sites, one rep of endive and escarole measured in commercial plots and all reps in WHRI plots).

At WHRI one dedicated replicate set of plots was sampled prior to the expected harvesting date and then regularly in order to monitor increase in head weight with a target minimum weight of 500g for the week 11 batch and 700g for the week 15 batch. One row of plants was harvested for each interim assessment and the remaining four plots of the relevant treatment was harvested as part of the next sample once average head weight exceeded the target minimum weight. Where achieved head weight on the first interim sample exceeded the target, it was necessary to adjust the target head weight for all treatments of that batch. As a routine, samples for interim assessments were taken three times a week although treatments were only sampled when weight was sufficiently close to the target in order to ensure sufficient supply of plants for subsequent sampling.

Final assessments of the four main replicate WHRI plots consisted of the same parameters as the commercial plots namely:

- Number of plants per plot bolted
- Head weight

- Apex length of plants dissected longitudinally (all reps of all species)

In addition, a record was taken of date of bolting of intact rows within the plots dedicated to interim destructive sampling.

Results

Achieved temperatures in propagation

Achieved temperatures varied according to prevailing conditions, particularly solar radiation. The graph below (Figure 3) illustrates how treatments influenced achieved temperatures on days with low (5-6/02) and higher (7/02) solar gain.

Where solar gain was lower; achieved day temperature in the Ti extd treatment was between 11 and 15°C. Consequently the compartment was heated to 19.5 to 20.5°C at night under the thermal screen in order to raise average 24 hour temperature to the equivalent of the achieved average temperature in the 17/17 treatment. Where solar gain was higher, both of the Ti treatments achieved higher day temperature (peaking at around 26°C) than the 17/17 treatment (peaking at around 21°C). Since the Ti extd treatment had a minimum temperature set point of 10°C during the day, achieved temperatures dipped at the start of the day (when screens opened and cool air from above the screen dropped down) and at the end of the day as the benefits of solar gain diminished; giving a lower average temperature during the day than the Ti standard treatment. Consequently, the night temperature set point in the Ti standard treatment was lower for the Ti extd treatment. Despite these variations within the day and night, the three treatments had comparable 24 hour temperature (see Table 1 below the graph).

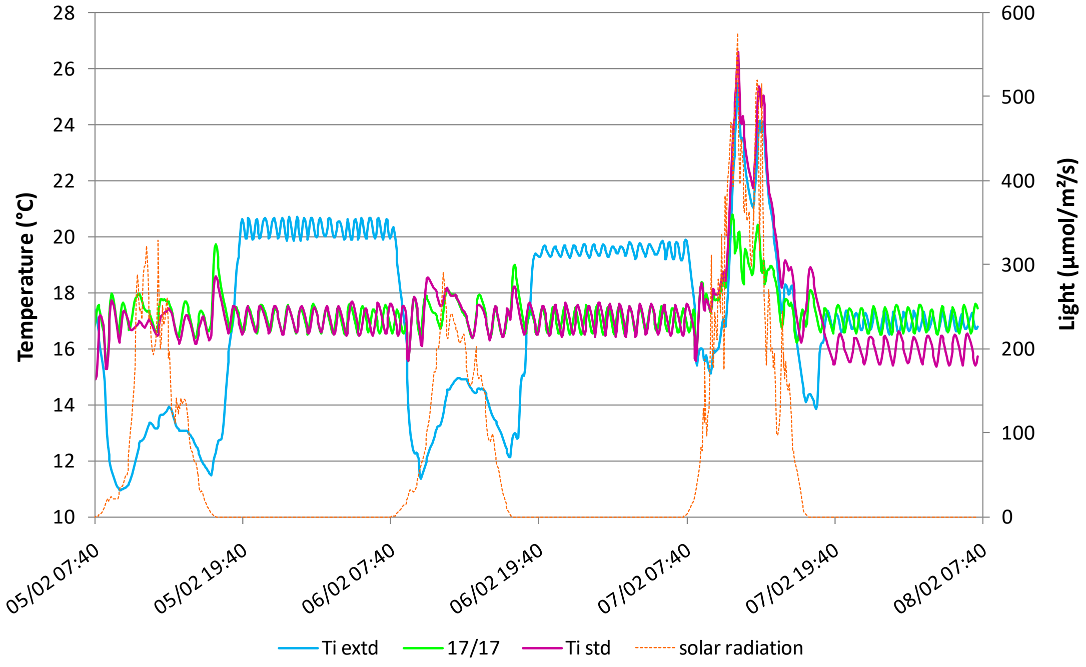


Figure 3. Achieved instantaneous temperatures in the three experimental compartments from 05/02/09 to 08/02/09

Table 1. 24 hour achieved average temperatures from 05/02/09 to 07/02/09

	17/17	Ti std	Ti extd
05-Feb	17.17	16.98	16.90
06-Feb	17.14	17.18	17.11
07-Feb	17.53	17.69	17.66
3 day avg	***17.28***	***17.28***	***17.22***

Achieved temperatures per batch of plants sown varied according to levels of solar gain and hence differences between treatments may be expected to vary according to batch. This is summarised in Table 2 for the four batches produced in 2009. Hence average 24 hour achieved temperature was 0.8 to 1.0 °C higher for batches of celery plants programmed for a week 17 planting than for a week 11 planting. Whilst the average 24 hour temperature achieved compared well between the three treatments throughout the experiment, it tended to be slightly higher (by up to 0.3C) in the two Ti treatments than in the standard 17/17 treatment.

Table 2. Average 24 hour temperature (°C) achieved during propagation for three temperature regimes and four batches of plants

Average 24 hr Temperature (°C):				
	Planting week:			
	11	**13**	**15**	**17**
Celery				
17/17	17.6	17.7	18.0	18.4
Ti std	17.6	17.8	18.2	18.6
Ti extd	17.6	17.9	18.2	18.6
Chinese cabbage				
17/17	17.6	17.9	18.2	18.5
Ti std	17.7	18.0	18.5	18.7
Ti extd	17.8	18.1	18.5	18.8
Endive and Escarole				
17/17	17.5	17.9	18.2	18.5
Ti std	17.6	17.9	18.4	18.7
Ti extd	17.7	18.1	18.4	18.8

Whilst 24 hour average temperature remained comparable between treatments during the experiment, treatments did vary in terms of average achieved day temperature (Table 3). Hence average day temperature was 1.2 to 1.6°C lower in the Ti extd treatment than the Ti std treatment for the plants programmed for planting in week 11. Later in the season (e.g. week 17 batch) the difference between these treatments was reduced to 0.3 to 0.5°C due to increasing contribution of solar gain to achieved day time temperature. It is interesting to note despite the low day time heating set point, average day temperatures of 17.7 to 20.8°C were achieved in the Ti extd treatment between January and April.

Table 3. Average day temperature (°C) achieved during propagation for three temperature regimes and four batches of plants

Average day Temperature (°C):				
	Planting week:			
	11	**13**	**15**	**17**
Celery				
17/17	18.2	18.4	18.9	19.4
Ti std	19.3	20.0	20.9	21.2
Ti extd	17.7	18.9	20.3	20.7
Chinese cabbage				
17/17	18.2	18.8	19.3	19.6
Ti std	19.7	20.9	21.4	21.1
Ti extd	18.5	20.2	20.8	20.8
Endive and Escarole				
17/17	18.1	18.7	19.2	19.6
Ti std	19.4	20.5	21.2	21.1
Ti extd	18.1	19.9	20.6	20.8

In summary, the three treatments compared well for achieved 24 hour average temperatures throughout the period of the experiment (i.e. propagation between January and April). As would be expected, the Ti extd treatment had lower achieved day time temperature than the Ti std treatment and these differences were greater earlier on in the experiment when there was less contribution from solar gain to day time temperature. The higher vent set point in the two Ti treatments meant that in general, the conventional 17/17 treatment had the lowest achieved day time temperature.

The use of higher vent set points to maximise solar gain in the Ti regimes tested would be expected to reduce heat (and therefore energy) input required. Energy inputs were not measured during this experiment but predictions of energy use for these treatments

(Figure 4) have been made using a model developed for recent Defra funded studies on energy optimisation in protected crops (HH3611SPC). This model assumes a commercial scale (6,000 m²) glasshouse equipped with thermal screens used for energy saving at night. On this basis, the standard Ti regime is predicted to save 4.8% of the energy inputs predicted for the conventional 17/17 regime between January and April and the extended Ti would increase this saving to around 18.5%.

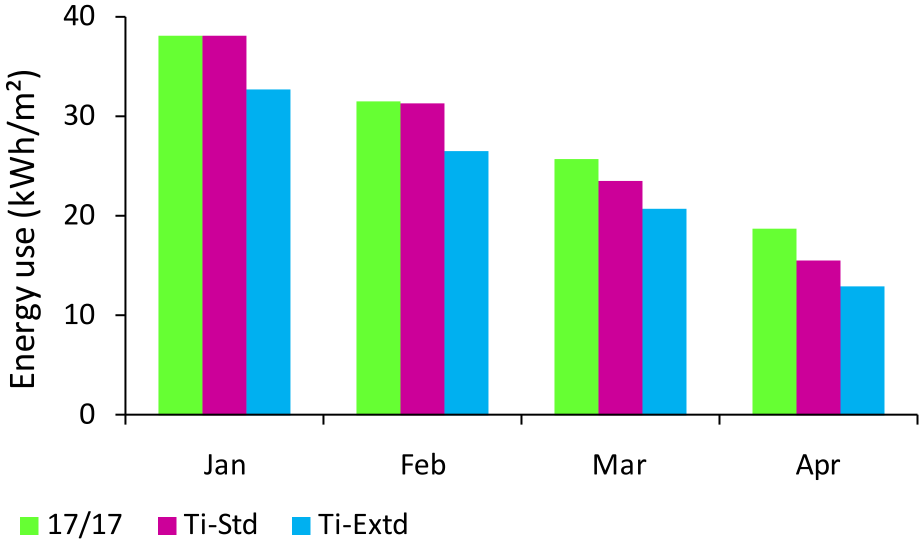


Figure 4. Predicted monthly heating energy inputs for three temperature regimes

Assessments at weaning stage

Statistical analysis of plant growth analysis data recorded at weaning stage was carried out as an analysis of variance. Data presented from this analysis are mainly as means across treatments e.g. values given for each temperature treatment will be the means of all transplant size treatments within each temperature regime. Interactions relating to individual treatment means will be described where relevant. Where treatments were found to have a significant influence over a parameter, values of the least significant difference at the P<0.05 level are given in order to indicate where treatments differ from each other.

Propagation temperature effects at transplanting

Transplants propagated using the two Ti regimes had at least equivalent and often higher shoot fresh weight compared with the standard 17/17 treatment when assessed prior to transfer to weaning (Figure 5). Plants raised in Ti treatments for planting out in weeks 13, 15 or 17 were generally significantly heavier than those from the 17/17 standard regime. This may relate to the slightly higher average temperature achieved in the Ti treatments as noted previously. Where differences in transplant fresh weight were smaller (week 11 batch), differences in achieved propagation temperature were also smaller. Chinese cabbage transplants had a slightly different response to the other three species tested in that the Ti-std treatment was comparable with the standard 17/17 treatment rather than the Ti- extd treatment for the week 15 and 17 batches. This cannot be explained by differences in achieved propagation temperature which followed similar trends for all four species.

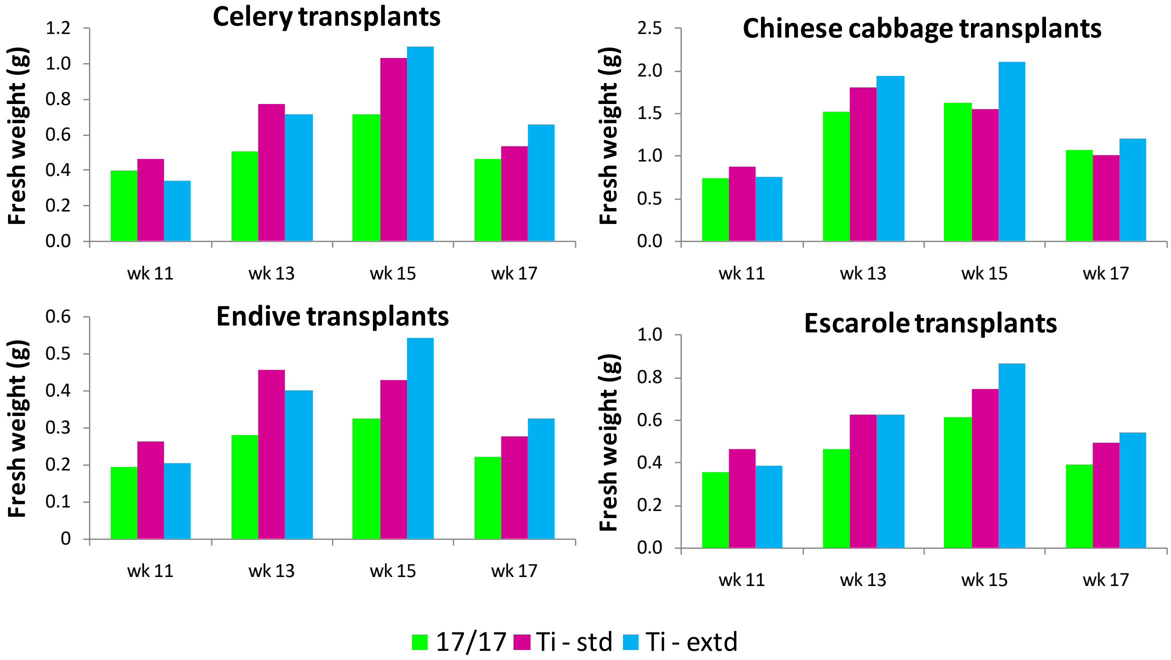


Figure 5. The influence of temperature regime on shoot fresh weight at transplanting stage (L.S.D. (P<0.05) = 0.07 celery; 0.20 chinese cabbage; 0.04 endive; 0.07 escarole)

Differences in transplant height reflect those discussed above for plant fresh weight (Figure 6). That is plants raised in the Ti treatments for planting out in weeks 13, 15 and 17 were significantly taller than those raised in the 17/17 treatment. In these experiments the differences appear to reflect an overall increase in plant size rather than any plant stretch as was seen in the high day / low night experiments in 2008. Low day temperature would normally be expected to result in more compact plant habit but the high vent temperature combined with the low day temperature set point in the Ti-low day treatment resulted in higher achieved day temperatures than would be expected to generate this type of benefit.

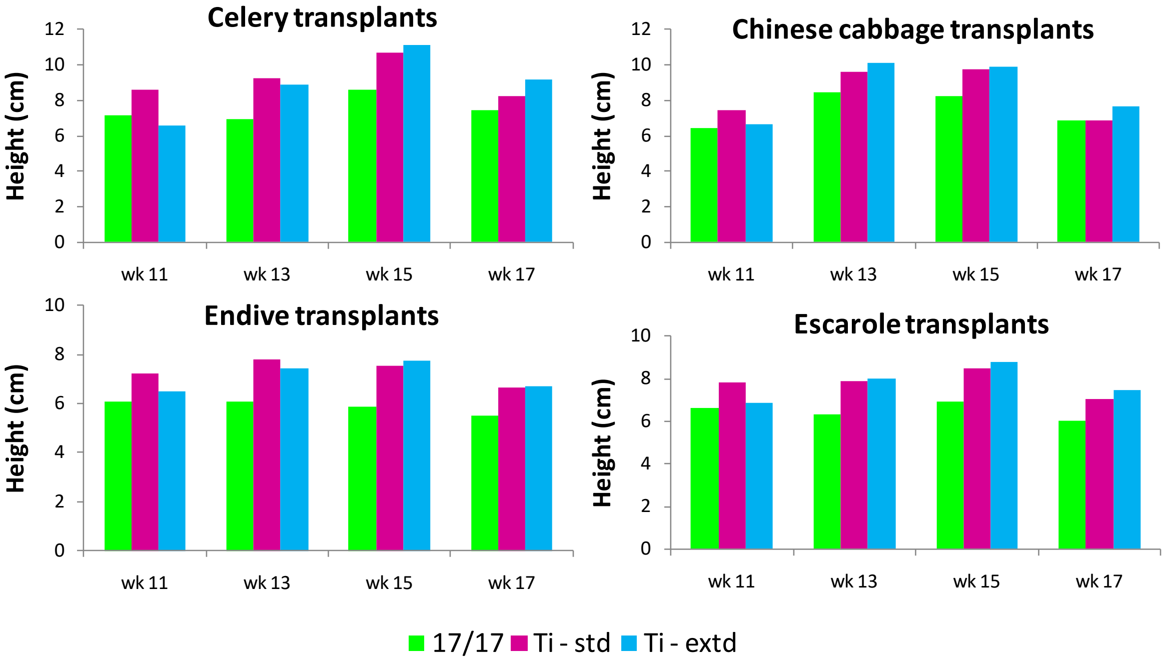
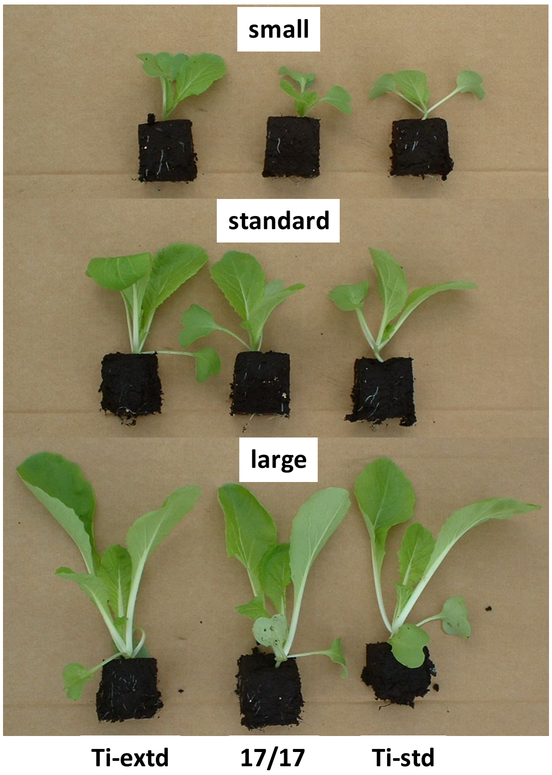
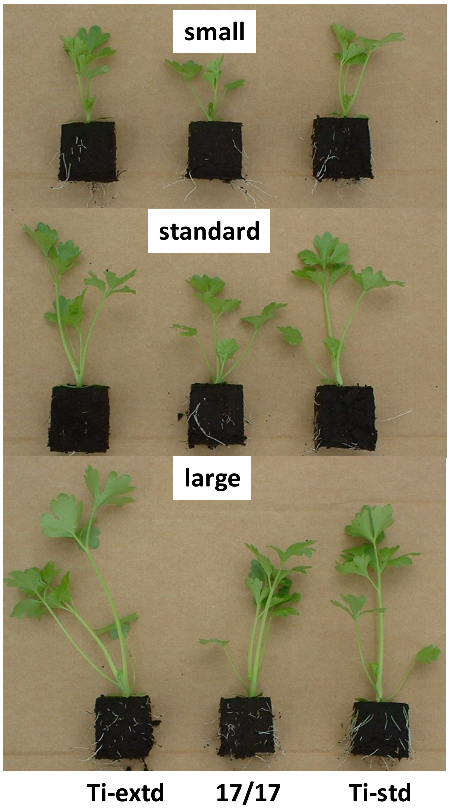


Figure 6. The influence of temperature regime on shoot height at transplanting stage (L.S.D. ($P<0.05$) = 0.46 celery; 0.43 chinese cabbage; 0.51 endive; 0.44 escarole)

The photographs of individual plants at weaning stage from the week 15 batch (Figure 7) and also of the trays of plants at weaning stage (Appendix 1) demonstrate the differences between temperature treatments highlighted in the fresh weight and plant height data discussed above. That is slightly larger plants from the two Ti based treatments and no consistent differences relating to plant habit.

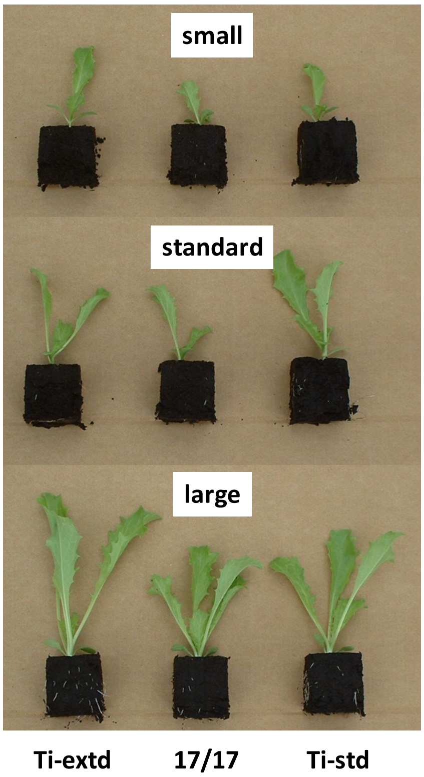


Week 15 Chinese cabbage

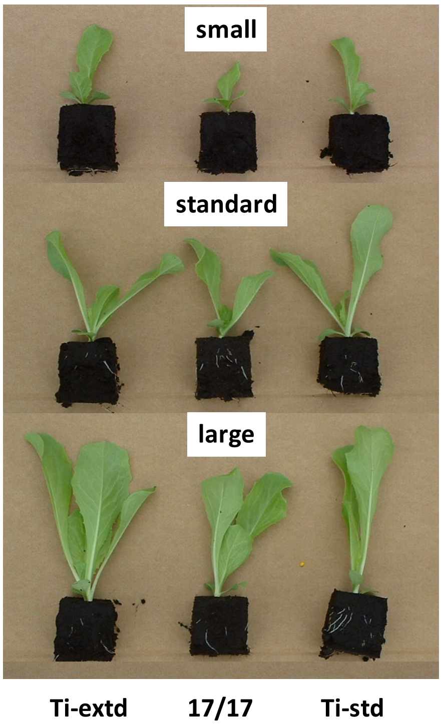


Week 15 Celery

Figure 7. Transplants at weaning stage



Week 15 Endive



Week 15 Escarole

Figure 7 (contd.). Transplants at weaning stage

Transplant size effects at transplanting

As indicated by assessments carried out at the stage of moving plants from the heat to weaning (Figures 8 and 9), three clearly different sizes of transplants were produced for each planting date. Overall, small endive, escarole and chinese cabbage transplants were between 30 and 50% smaller than standard sized transplants in terms of fresh weight across the four batches assessed and larger sized transplants of these species were between 39 and 74% heavier than the respective standard sized transplants. There was greater variation for the slower growing small celery transplants which had 47-70% less fresh weight across the four batches assessed than the standard transplants, with the large transplants being 53-81% heavier than the standard sized transplants. Differences in shoot height reflected those in fresh weight.

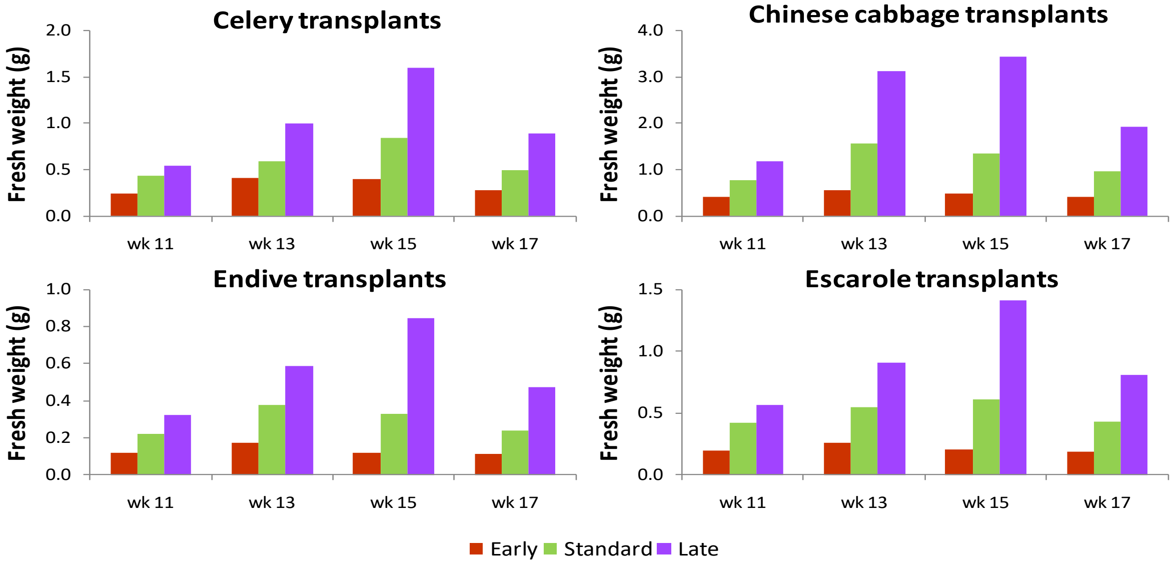


Figure 8. Transplant size treatments assessed for shoot weight at the weaning stage. L.S.D. (P<0.05) = 0.07 celery; 0.20 chinese cabbage; 0.04 endive; 0.07 escarole

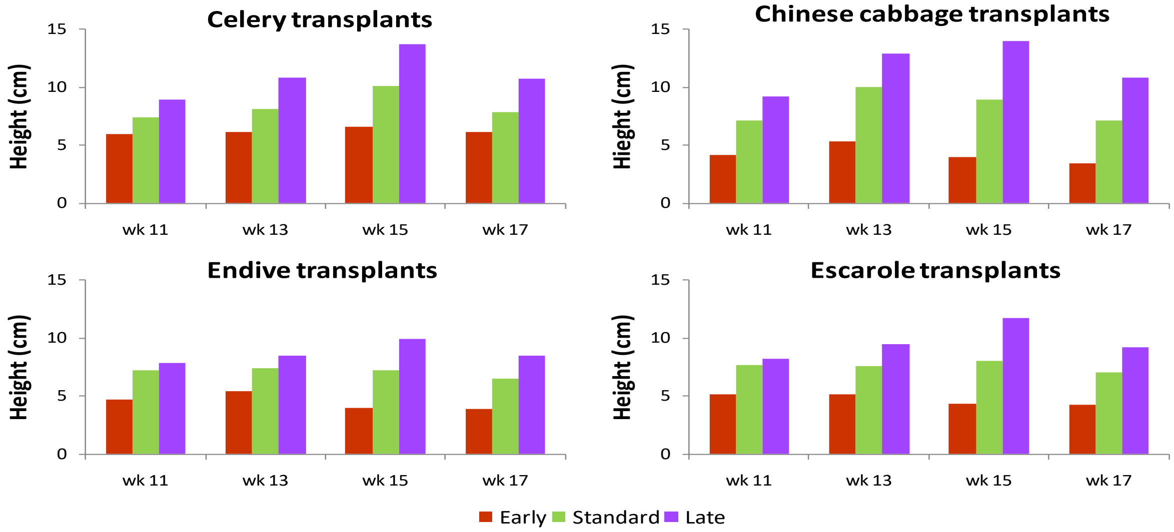


Figure 9. Transplant size treatments assessed for shoot height at the weaning stage. L.S.D. (P<0.05) = 0.46 celery; 0.43 chinese cabbage; 0.51 endive; 0.44 escarole

Assessments at harvest stage

As with the data recorded at weaning, most of the statistical analysis of data recorded at harvesting stage has taken the form of analysis of variance. Data presented from these analyses are mainly as means across treatments e.g. data presented for a temperature treatment will be the mean of all transplant size treatments from each temperature regime. Relevant interactions (e.g. between propagation temperature and transplant size) will be described as appropriate. Where treatments were found to have a significant influence over a parameter, values of the least significant difference at the $P<0.05$ level are given in order to indicate where treatments differ from each other.

Given the gaps in data due to lack of bolting / missing plants, bolting data was analysed as a regression with individual treatment means evaluated only and hence will be presented in a different format with standard error for each mean used to indicate variability within data.

Throughout the text, data are considered to be significantly different if the relevant probability factor is 0.05 or less (i.e. significant at the 95% + level).

All treatments in each batch of plants in the commercial trials were harvested and assessed together on one day which was timed to follow the commercial harvest from the same planting week in order to give time for bolting to be expressed. In practice a grower would harvest a field when plants have reached a suitable head weight. Hence where treatments may have needed more or less time until harvest this would be expected to be indicated by lower or higher than average head weight respectively in the final assessment data. Commercial plants (labeled comm in Figures) within each batch planted provide a benchmark of what might be expected from conventional production. All treatments in each batch of plants in the trials at WHRI were harvested according to head weight as described in the materials and methods section previously.

Propagation temperature effects at harvesting

Temperature treatments effects will be reviewed for each species separately in the following.

Endive

Head weight of endive averaged across transplant size treatments varied between 378 and 507g for the temperature treatments in the wk 11, 13 and 17 batches of plants and between 399 and 539g for the commercially raised transplants (Figure 10). Head weights for the wk 15 batch of plants raised in the experiments were higher (862-879g) than the commercial plants from the same planting week and also than heads harvested from other planting weeks. This was apparently due to differences in the vigor of commercial and experimental plants in the week 15 batch which was evident in plots grown at WHRI (see later).

Commercial trials from each of the four batches tested were harvested either 71 or 72 days from planting. There were no significant effects of propagation temperature on average trimmed head weight in any of the plants grown in the commercial trials.

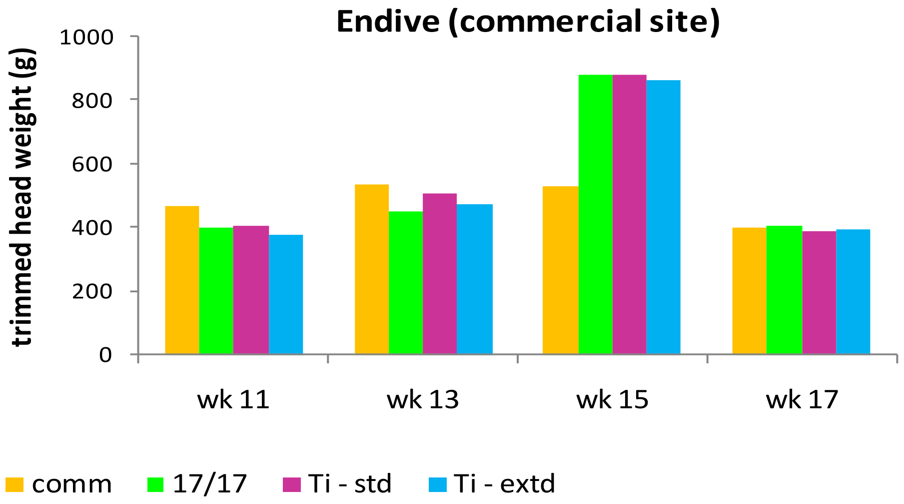


Figure 10. Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within any of the batches of plants grown)

Plants in WHRI trials were harvested according to development with the aim of harvesting treatments at a target head weight. This approach worked well for the wk 11 plots (trimmed head weights 512-545g) and also for the wk 15 plots (trimmed head weights 570-617g), but the commercially raised plants in the week 15 batch were less vigorous and were less well timed for final harvest (i.e. extra time was allowed before harvest but the heads then grew beyond the target weight). This is reflected in the commercial trials for the same batch of plants (above) where the commercial plants were smaller than the treatment plants and in fact the treatment plants were heavier than those from other batches indicating that how the commercial schedule was timed to the progress of commercial (rather than experimental) plants.

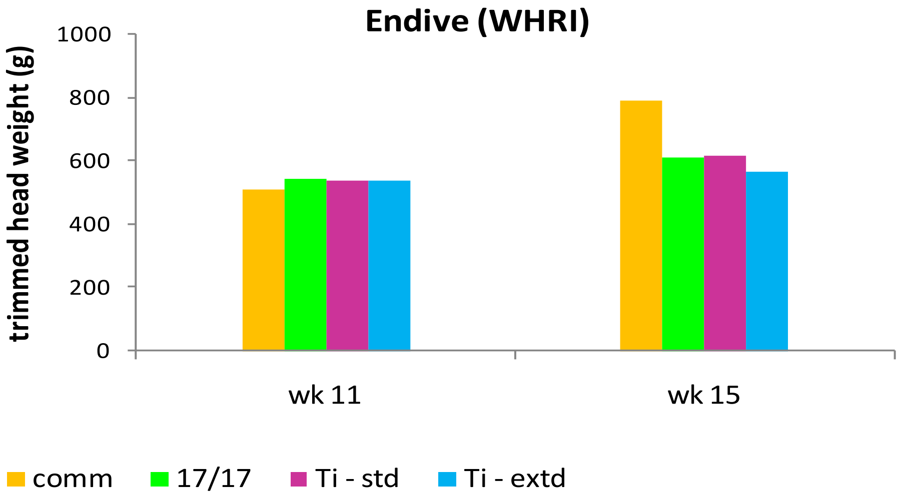


Figure 11. Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within either of the batches grown)

Overall, propagation temperature treatments had little influence over time to harvest (Figure 12). In the week 11 batch of plants, commercially raised transplants were harvested first (at 69 days from planting) but the slowest treatment (17/17) only required an extra 3 days before harvesting. To put this into context, commercial harvest of one batch of plants may be expected to span a week and may also run over to the following week. As all replicates of one treatment were harvested at the same time, the time to harvest data has not been analysed formally although clearly there will be a limit to the accuracy of timing individual plots by the interim destructive sample method used. Similarly the treatment plots of the week 15 batch of plants were harvested within 1 day of each other at 59-60 days with only the commercial transplants taking notably more time to reach the target weight (harvested 74 days after planting).

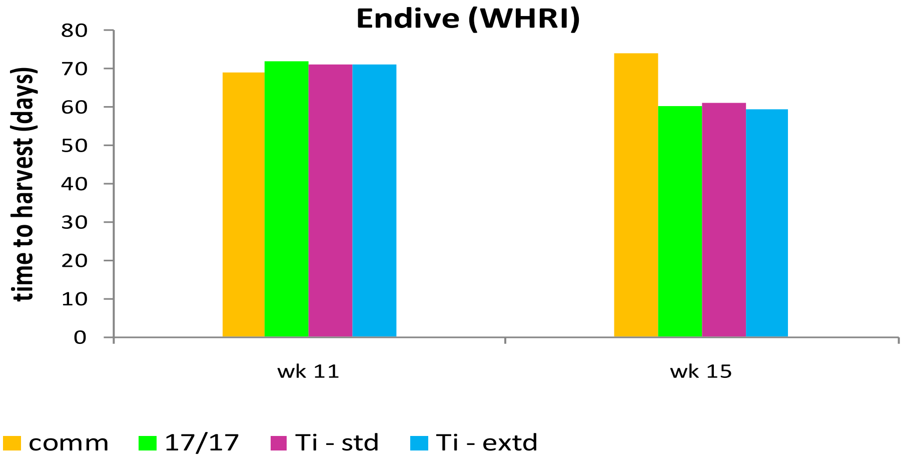


Figure 12. Time to harvest plants grown in the field following propagation in different temperature regimes

There were no significant interactions between plant size and propagation temperature and hence the results described above for average trimmed head weight (where the average was taken across the three sizes of transplant within each temperature treatment) are suitable for describing the trends in individual treatment means.

Since there was little evidence of bolting at harvest, Endive plots at WHRI were assessed for apex height at harvest using dissected plants (Figure 13). These data suggest less progress towards bolting due to significantly ($P<0.001$) shorter apex height for the Ti std treatment and the commercially raised plants (apex heights of 68-75 mm) than the 17/17 or Ti extended treatments (at 90-94 mm) from the week 11 planting. There were no significant propagation temperature treatment effects on apex height of the week 15 planted batch of plants, although commercially raised transplants had taller average apex height than propagation temperature treatments which was probably due to the later harvest of these commercial plants as described previously.

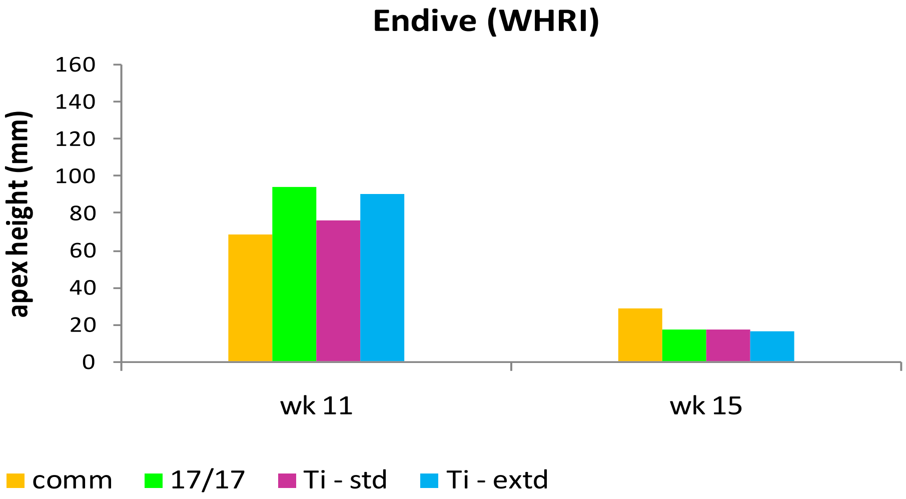


Figure 13. Apex height as an indication of progress towards bolting in the field following propagation in different temperature regimes (L.S.D. ($P<0.05$) = 12.7 and 1.5 between propagation temperature treatments (wk11 and wk 15 respectively); = 17.8 and 2.1 between commercial plants and propagation temperature treatments (wk11 and wk 15 respectively)

Apex height was also measured for one of the four replicate plots planted at commercial sites which provides an indication of progress towards bolting but cannot be analysed formally (Figure 14). Apex heights for the week 11 and 15 planted batches of plants at the commercial sites (62-77mm and 20-27mm respectively) were comparable with those from the same batches planted at WHRI. The week 13 and 17 batches of commercially raised plants had taller apex heights overall. In both batches, apex height was taller for the 17/17 treatment than for the Ti std and Ti extd treatments. Hence there is no evidence from these data to suggest that the Ti treatments increased progression towards bolting. This trend is also supported by the data from the WHRI trials (above) where formal analysis was possible.

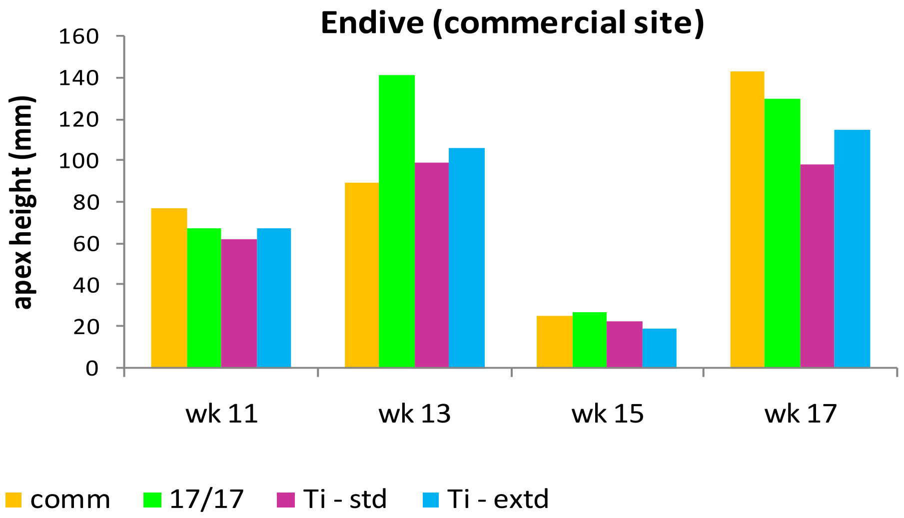


Figure 14. Apex height as an indication of progress towards bolting in the field following propagation in different temperature regimes (measured on 1 replicate only)

There were no significant interactions between plant size and propagation temperature and hence the results described above for average apex height (where the average was taken across the three sizes of transplant within each temperature treatment) are suitable for describing the trends in individual treatment means.

Bolting of endive only occurred in the commercial batches in weeks 11, 13 and 17 (Table 4). There were no significant effects of propagation temperature on bolting in the week 11 batch of plants. The effects of temperature in the week 13 and 17 batches of plants varied with transplant size. That is in the week 13 batch, the small transplants from the 17/17 treatment had significantly more bolting than either of the Ti treatments. The 17/17 treatment also produced significantly more bolting than Ti std for the large transplants in the week 13 batch; however there were no significant effects of temperature on the standard sized transplants. The 17/17 regime produced more bolting for the large and standard transplants in the week 17 batch compared with Ti extd. These data therefore agree with the apex height data reviewed previously that indicates no increased risk of bolting as a result of the two Ti regimes to propagate endive, and in fact the Ti regimes were more favorable than the 17/17 treatment in terms of incidence of bolting. There was no bolting in endive plots at WHRI at the harvest assessment stage.

Table 4. Percentage of endive plants bolting in the field after propagation in different temperature regimes and to different transplant sizes

Transplant size	**Temperature treatment**			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Endive wk 11 commercial				
Small	0.0	0.0	0.0	
(s.e.)	*(0.0)*	*(0.0)*	*(0.0)*	
Standard	0.0	0.0	0.5	
(s.e.)	*(0.0)*	*(0.0)*	*(0.7)*	
Large	1.6	0.5	0.5	
(s.e.)	*(1.2)*	*(0.7)*	*(0.7)*	
Comm				1.1
(s.e.)				*(1.0)*
Endive wk 13 commercial				
Small	7.6	1.0	0.0	
(s.e.)	*(3.4)*	*(1.3)*	*(0.0)*	
Standard	0.6	0.0	0.0	
(s.e.)	*(1.0)*	*(0.0)*	*(0.0)*	
Large	31.4	14.4	24.5	
(s.e.)	*(5.9)*	*(4.5)*	*(5.5)*	
Comm				1.9
(s.e.)				*(1.9)*
Endive wk 17 commercial				
Small	0.0	1.0	0.0	
(s.e.)	*(0.0)*	*(1.0)*	*(0.0)*	
Standard	8.3	5.3	0.0	
(s.e.)	*(3.0)*	*(2.4)*	*(0.0)*	
Large	10.4	2.1	1.0	
(s.e.)	*(3.3)*	*(1.5)*	*(1.0)*	
Comm				2.1
(s.e.)				*(1.5)*

Escarole

Experimental plants grown in different propagation temperature treatments produced comparable trimmed head weight (between 464 and 536 for week 11 planting, 602 to 631 for week 13 and 765 to 770 for week 17) at harvest to commercial transplants planted at the same time for all commercial batches of escarole except for those planted in week 15 (Figure 15). Trimmed head weight in week 15 escarole was higher overall reflecting the week 15 data for endive where harvest was later than may normally expected due to the slow rate production for the commercial endive plants in this batch (since endive and escarole were routinely harvested on the same day).

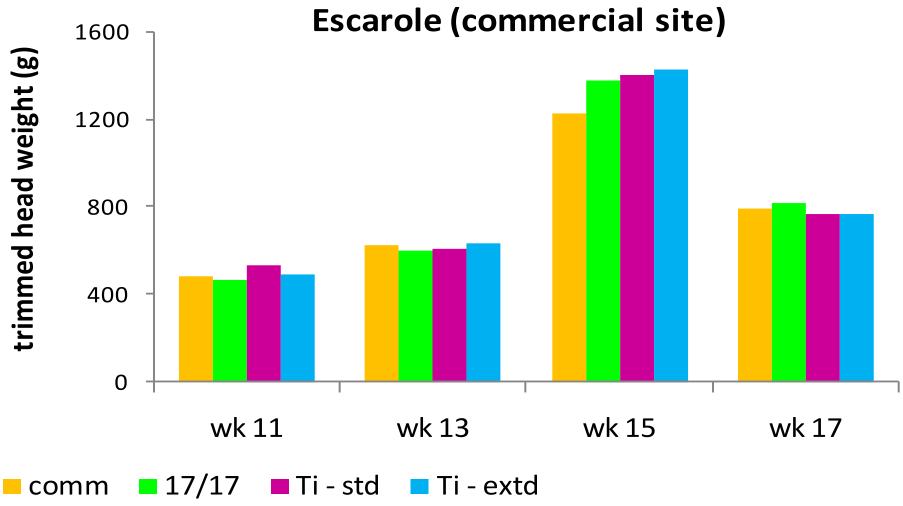


Figure 15. Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within any of the batches of plants grown)

There were also no significant effects of propagation temperature on head weight at harvest of escarole grown in plots at WHRI (Figure 16).

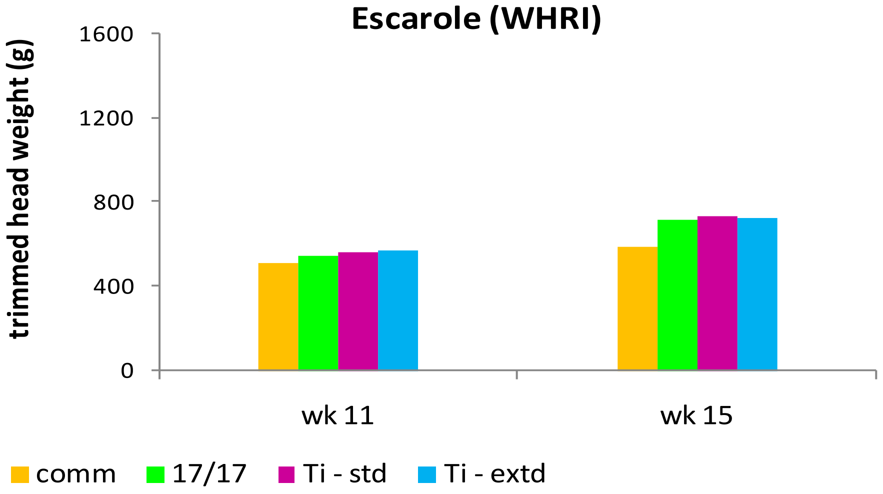


Figure 16: Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within any of the batches of plants grown)

As with endive, where plants in plots at WHRI were harvested according to achieved head weight, temperature treatment did not appear to influence time required for the crop to achieve a harvested weight after transplanting (Figure 17).

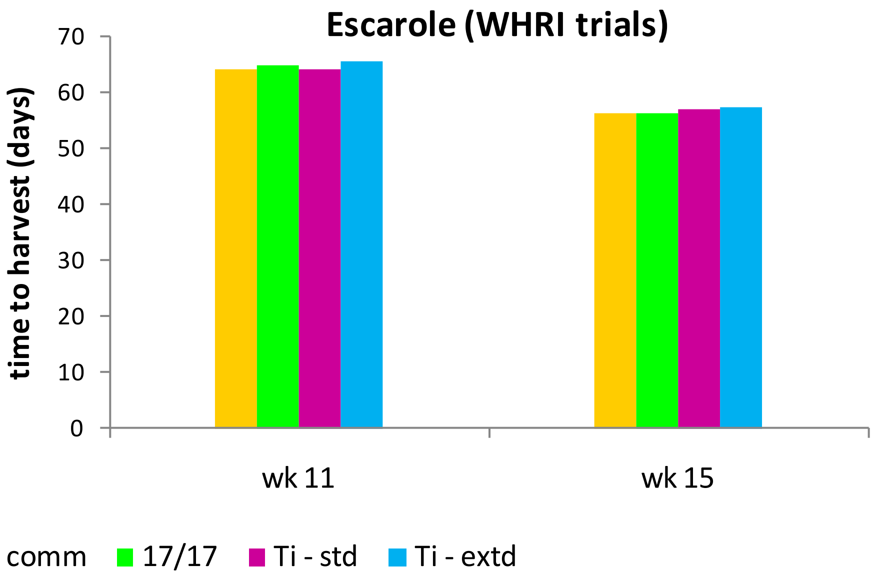


Figure 17: Time taken to achieve harvestable head weight for plants grown in the field following propagation in different temperature regimes

There were no significant interactions between plant size and propagation temperature and hence the results described above for average trimmed head weight (where the average was taken across the three sizes of transplant within each temperature treatment) are suitable for describing the trends in individual treatment means.

Overall apex height both from the unreplicated data collected from commercial trials (Figure 18) and from the trials at WHRI (Figure 19) indicated that the two Ti treatments had not increased the risk of bolting through increasing apex height at harvest stage. For the week 11 batch at WHRI, the Ti extd treatment had significantly taller apex height than the 17/17 regime, although this difference was small (at 4mm) whilst the Ti std regime had shorter apex height than both the Ti extd and 17/17 treatments in this batch of plants.

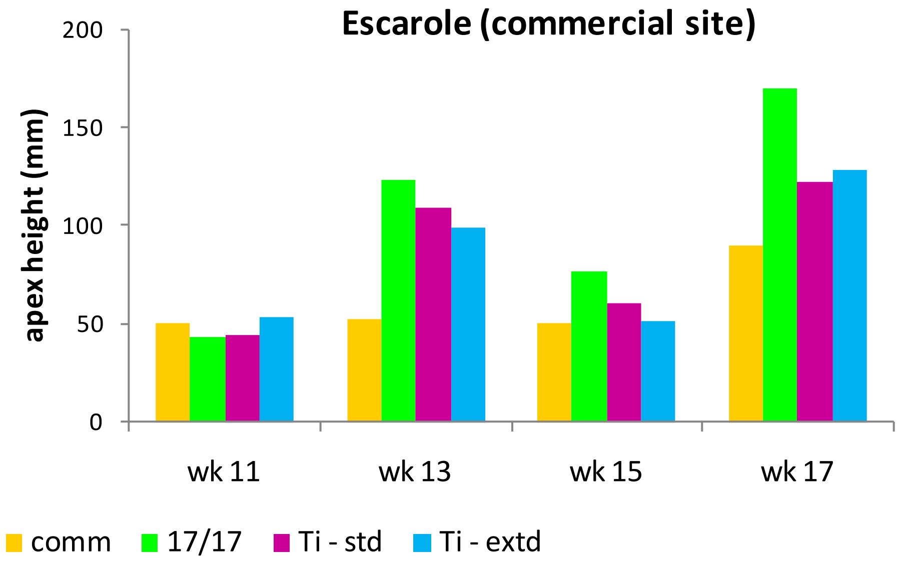


Figure 18: Apex height of plants grown in the field following propagation in different temperature regimes (Based on measurements from one replicate only)

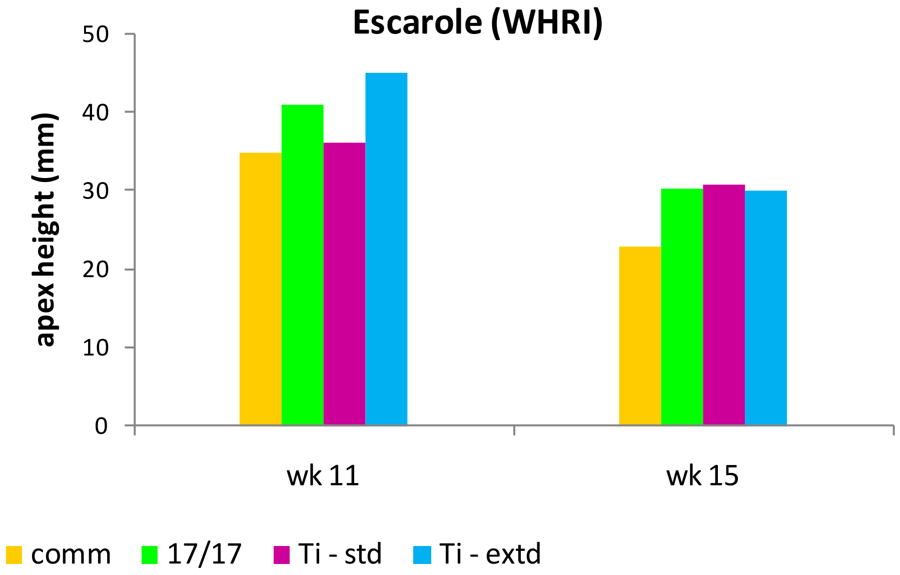


Figure 19: Apex height of plants grown in the field following propagation in different temperature regimes (L.S.D. $(P<0.05) = 2.8$ between propagation temperature treatments wk 11 and 4.0 between commercial plants and propagation temperature treatments; NS for wk 15 batch)

There were no significant interactions between plant size and propagation temperature and hence the results described above for average apex height (where the average was taken across the three sizes of transplant within each temperature treatment) is suitable for describing the trends in individual treatment means.

Bolting was only visible in the week 13 and week 17 batches of plants from the commercial plots. There were significant propagation temperature treatment effects on the large transplants of the week 13 batch of plants (Table 5), where the Ti extd treatment had significantly more bolting than the Ti std treatment. However there was no significant difference between the 17/17 treatment and either of the Ti treatments. A similar trend was found for the standard sized transplants from the week 17 batch with Ti extd having more bolting than Ti std but no different to 17/17. However differences between achieved temperatures in the Ti extd and Ti std regimes were at their lowest for this final batch of plants (Tables 2 and 3). There was no bolting in escarole plots at WHRI at the harvest assessment stage.

Table 5: Percentage of escarole plants bolting in the field after propagation in different temperature regimes and to different transplant sizes

Transplant size	**Temperature treatment**			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Escarole wk 13 commercial				
Small	1.1	0.5	0.0	
(s.e.)	*(0.8)*	*(0.6)*	*(0.0)*	
Standard	0.5	0.0	0.0	
(s.e.)	*(0.6)*	*(0.0)*	*(0.0)*	
Large	7.9	5.1	13.0	
(s.e.)	*(2.2)*	*(1.9)*	*(2.7)*	
Comm				0.0
(s.e.)				*(0.0)*
Escarole wk 17 commercial				
Small	7.3	2.1	7.4	
(s.e.)	*(3.4)*	*(1.9)*	*(3.0)*	
Standard	4.3	1.1	11.5	
(s.e.)	*(2.6)*	*(1.3)*	*(4.1)*	
Large	3.1	0.0	3.1	
(s.e.)	*(2.3)*	*(0.0)*	*(2.3)*	
Comm				3.0
(s.e.)				*(2.0)*

Celery

The week 13 batch of celery planted on the commercial site was harvested before assessments had taken place and hence there is no final harvest data for this batch.

Propagation temperature had no significant influence over trimmed head weight at harvest either in the commercial plots (Figure 20) where all plots were harvested on the same day; or in the WHRI plots which were harvested according to head weight (Figure 21). Comparison of achieved head weight at final harvest between commercial (519-559g) and WHRI (429-445g) plots planted in week 11 suggests that crop performance was limited at WHRI.

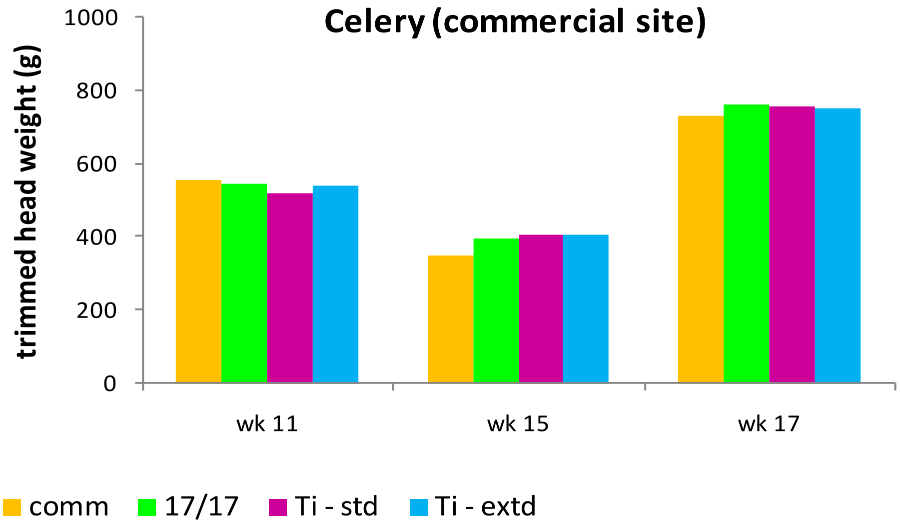


Figure 20: Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within any of the batches of plants grown)

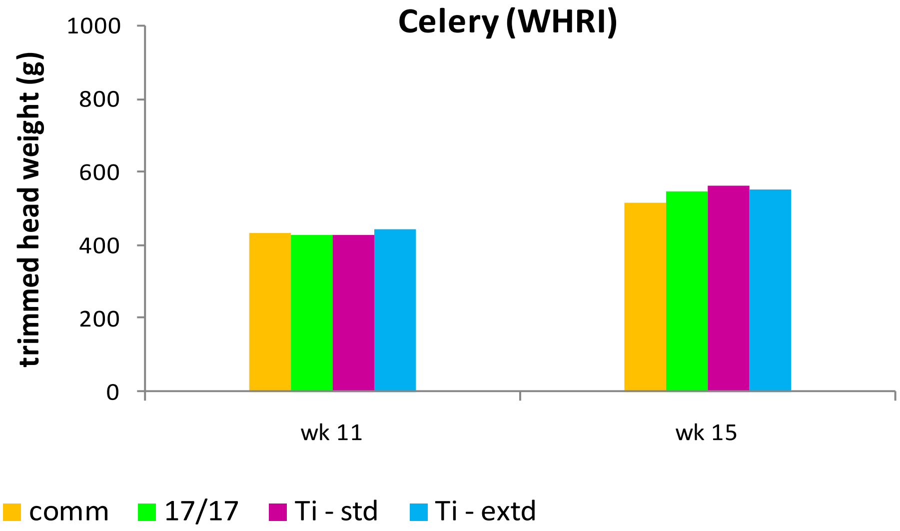


Figure 21: Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within any of the batches of plants grown)

As with endive and escarole, where plants in plots at WHRI were harvested according to achieved head weight, temperature treatment did not appear to influence time required for the crop to achieve a harvestable weight after transplanting (Figure 22).

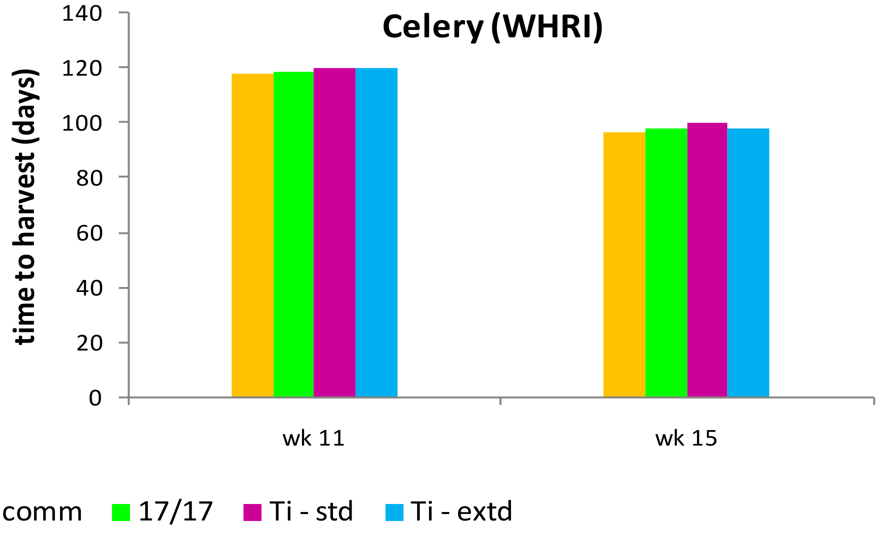


Figure 22: Time taken to achieve harvestable head weight for plants grown in the field following propagation in different temperature regimes

There were no significant interactions between plant size and propagation temperature and hence the results described above for average trimmed head weight (where the average was taken across the three sizes of transplant within each temperature treatment) are suitable for describing the trends in individual treatment means.

Apex height was significantly greater for the Ti extd treatment (at 26.4mm) of the week 11 batch of plants grown at the commercial site compared with the 17/17 treatment (18.0mm), although clearly the actual differences were small at 8mm (Figure 23). Examining individual treatment means (Figure 24) it is clear that this difference is largely due to the differences in apex height between small transplants with no significant differences due to propagation temperature for the large and standard transplants. There was no significant difference between the Ti std and 17/17 treatments in this batch of plants. There were no significant main effects of propagation temperature on apex height for plants from the week 15 or 17 batches.

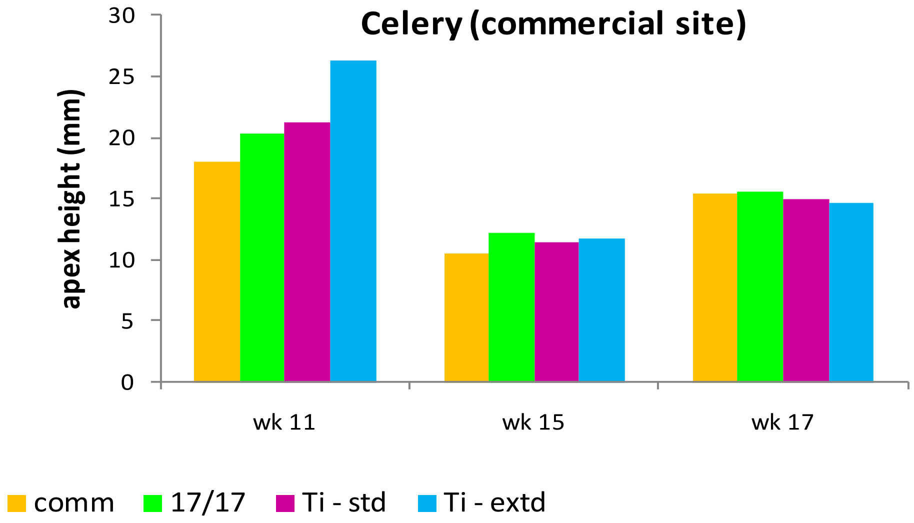


Figure 23: Apex height of plants grown in the field following propagation in different temperature regimes (L.S.D. (P<0.05) = 4.6 between propagation temperature treatments wk 11 and 6.5 between commercial plants and propagation temperature treatments wk 11; NS for wk 15 and wk 17 batches)

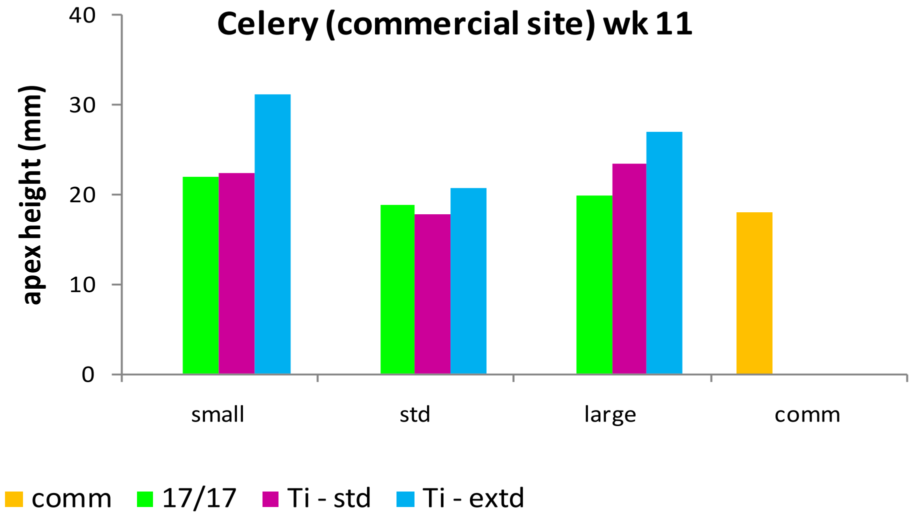


Figure 24: Interaction between transplant size and propagation temperature for celery plants grown in the field from week 11 (L.S.D. (P<0.05) = 8.0)

Celery grown in WHRI plots had taller apex height overall compared with the same batch at the commercial site, which coincides with the lower trimmed head weight from WHRI plots highlighted previously. However WHRI celery had a similar response to propagation temperature to that from the commercial plots. That is, for the week 11 batch of plants, Ti extd had significantly taller apex height (124 mm) than the standard Ti or 17/17 treatment (at 75-80mm) (Figure 25). As with the data from commercial sites, examining the data in more detail (Figure 26) indicates that whilst Ti extd produced taller apex height for the small and standard transplants there were no significant propagation temperature effects on the large sized transplants. There were however no differences between Ti std and 17/17 in the week 11 batch. Propagation temperature treatments had no significant influence over apex height of the week 15 batch of plants grown at WHRI.

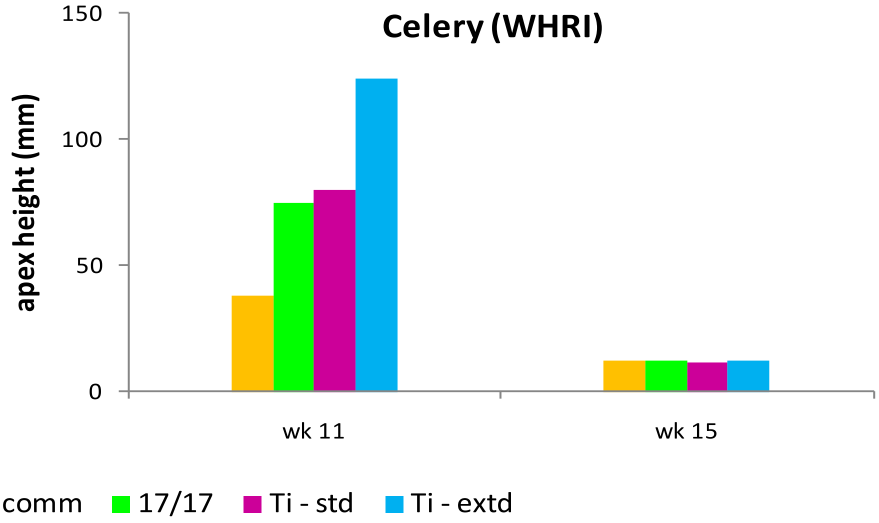


Figure 25: Apex height of plants grown in the field following propagation in different temperature regimes. (L.S.D. (P<0.05) = 35.5 between propagation temperature treatments wk 11 and 50.3 between commercial plants and propagation temperature treatments wk 11; NS for wk 15 batch)

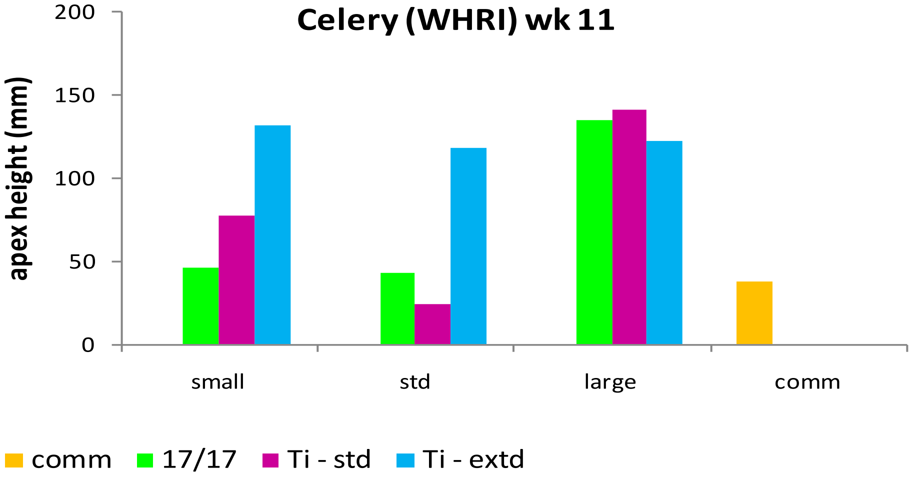


Figure 26: Interaction between transplant size and propagation temperature for celery plants grown at WHRI from week 11 (L.S.D. (P<0.05) = 61.6)

Only plants in the week 11 batch of celery grown in WHRI plots had visible bolting at the final harvest stage (Table 6). The Ti extd regime produced significantly more bolting than the 17/17 regime for both the small and standard sized transplants. There were no significant differences between the 17/17 and Ti std treatments. There were also no significant differences relating to propagation temperature treatments for the large transplants of this batch of celery. There was no bolting in celery plots at commercial sites at the harvest assessment stage.

Table 6. Percentage of celery plants bolting in the field after propagation in different temperature regimes and to different transplant sizes

Transplant size	**Temperature treatment**			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Celery wk 11 WHRI				
Small	3.1	8.4	16.7	
(s.e.)	*(2.0)*	*(3.2)*	*(4.2)*	
Standard	1.1	4.2	12.5	
(s.e.)	*(1.2)*	*(2.3)*	*(3.7)*	
Large	12.5	12.0	16.8	
(s.e.)	*(3.7)*	*(3.8)*	*(4.3)*	
Comm				3.1
(s.e.)				*(2.0)*

Chinese cabbage

Commercial planting of chinese cabbage started in week 12 rather than week 11 as originally planned, however as the experimental plants were scheduled for week 11, and for consistency with the summaries for the rest of the experiment this section will continue to describe the first commercial batch of chinese cabbage as week 11.

None of the commercial plots were intact at harvest stage and hence average data presented (Figure 27) represents incomplete replication. The week 11 batch represents only one replicate (with no commercially raised plants available for assessment). There was sufficient data for formal analysis in the remaining batches but no significant temperature effects were found on head weight in these data. These results need to be considered with care given that all batches suffered from some loss of replication, but given that a similar result had been found for the other species this would suggest that the propagation temperature treatments did not influence the head weight of chinese cabbage grown in commercial plots.

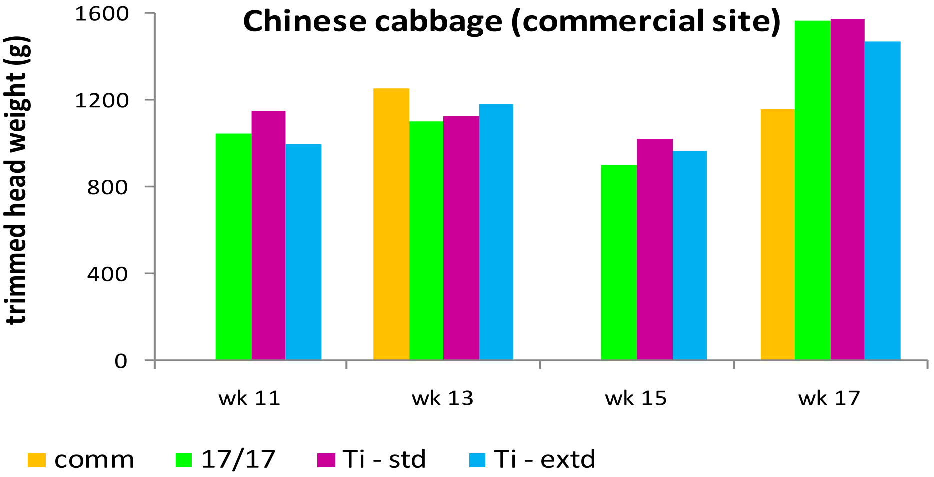


Figure 27: Trimmed head weight of plants grown in the field following propagation in different temperature regimes (no significant effects of propagation temperature within any of the batches of plants grown)

Since WHRI plots were harvested according to achieved head weight in one set of replicate plots, temperature treatments should not have influenced head weight at harvest and this is the case for the week 11 plots (Figure 28). For the week 15 plots, the Ti extd treatment may have been harvested slightly earlier than desirable since this treatment achieved significantly lower head weight than the 17/17 and Ti std treatments.

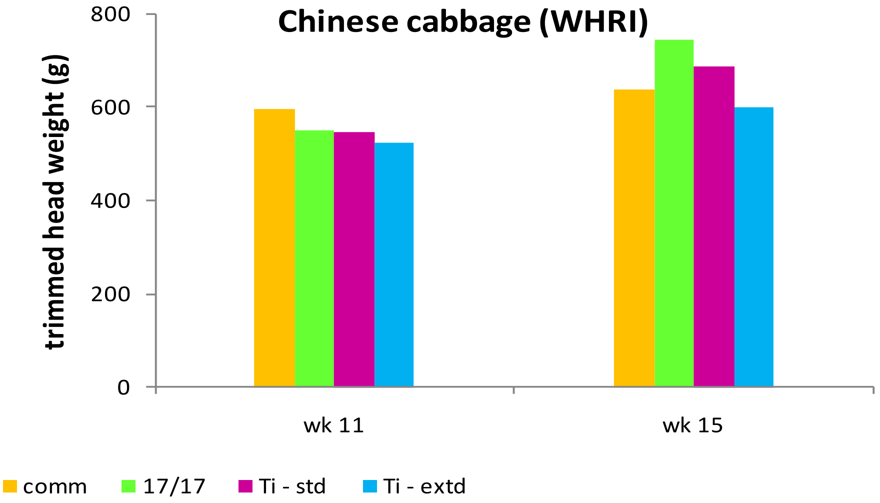


Figure 28: Trimmed head weight of plants grown in the field following propagation in different temperature regimes. (L.S.D. ($P<0.05$) = 100 between propagation temperature treatments wk 15 and 142 between commercial plants and propagation temperature treatments wk 15; NS for wk 11 batch)

There was also little difference between temperature treatments in terms of time to harvest (Figure 29). Plots planted in week 11 were harvested 76-78 days from planting and plots planted in week 15 were harvested 70-71 days from planting although given the head weight data presented above, the Ti extd treatment may have benefitted from a slightly longer growing period before harvest.

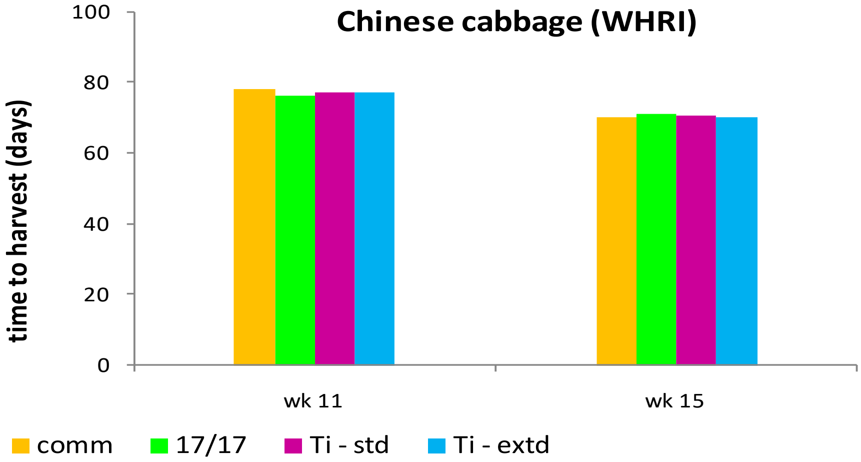


Figure 29: Time taken to achieve harvestable head weight for plants grown in the field following propagation in different temperature regimes

As with head weight for the commercial plots of chinese cabbage, limited availability of material at final harvest will restrict the sensitivity of the data analysis. Average apex height was below 40 mm in the week 13, 15 and 17 batches of plants with no significant differences relating to propagation temperature treatment (Figure 30). There was greater progression towards bolting in the week 11 batch of plants with apex heights between 104 and 123 mm, but there was insufficient replication for formal analysis of this batch.

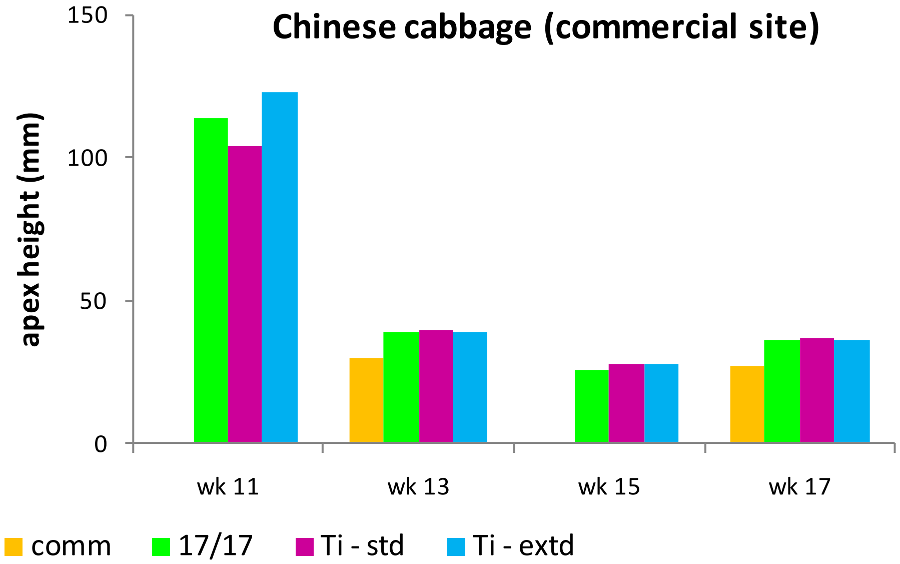


Figure 30: Apex height of plants grown in the field following propagation in different temperature regimes

The week 11 batch of chinese cabbage had taller apex height than the week 15 batch in the WHRI plots (Figure 31). Differences between the commercial and experimental plants in the week 11 batch will be at least partly due to the fact that there was no commercial material available for planting in week 11 and hence commercial plants were planted out one week later than experimental plants. Propagation temperature treatments created opposite trends for the two planting weeks. That is, plants raised in the 17/17 regime had significantly shorter apex height in the week 11 batch compared with the two Ti treatments but had significantly taller apex height in the week 15 batch. Interaction between propagation temperature and transplant size (Figure 32) indicates that for standard and large transplants from the week 11 batch, Ti extd and Ti std increased apex height compared with 17/17 while there were no differences relating to propagation temperature treatments between the small transplants in this batch. Conversely, there were no significant differences relating to propagation temperature regime in the larger transplants from the week 15 batch but in the small and standard transplants plants raised at 17/17 had taller apex height than those from the Ti extd treatment (Figure 33).

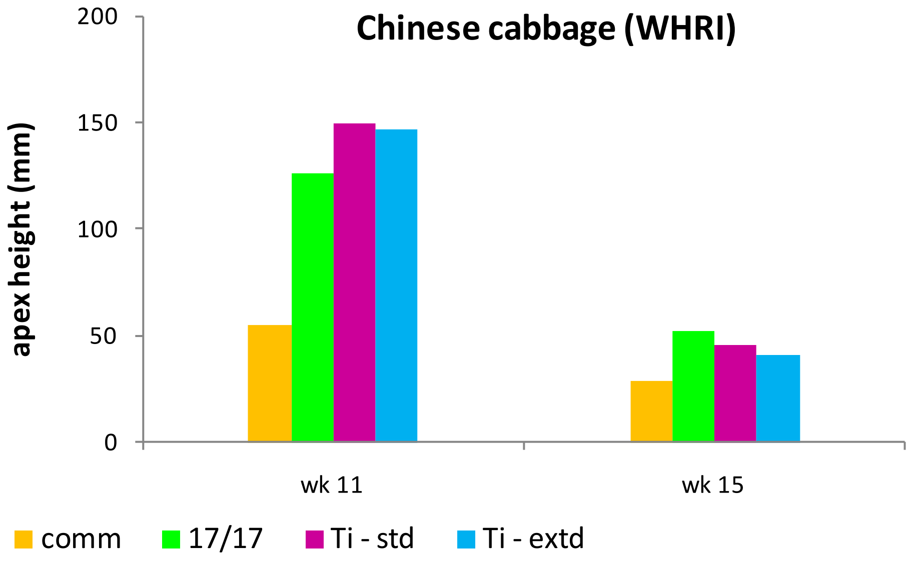


Figure 31: Apex height of plants grown in the field following propagation in different temperature regimes – main treatment effects. (L.S.D. (P<0.05) = 13.4 and 3.7 between propagation temperature treatments (wk 11 and wk 15 respectively) and 18.9 and 5.2 between commercial plants and propagation temperature treatments (wk 11 and wk 15 respectively)

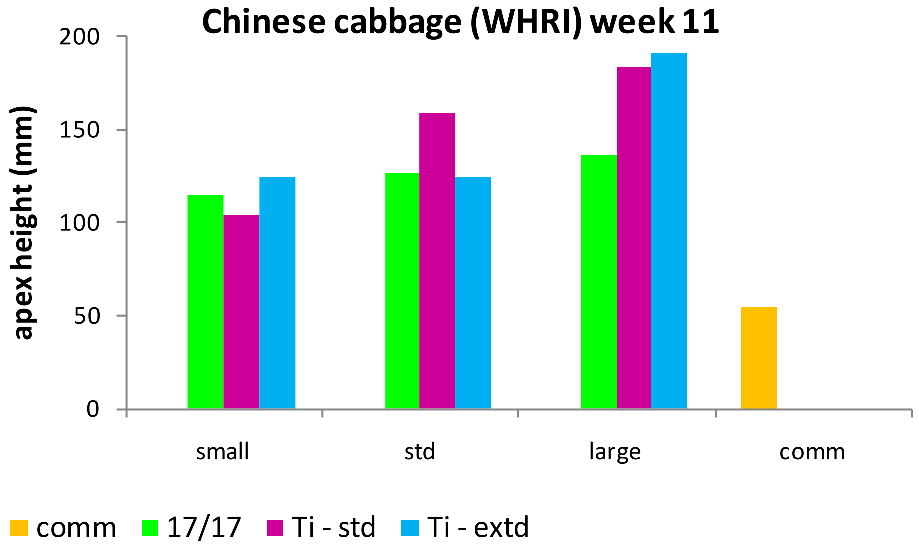


Figure 32: Interaction between transplant size and propagation temperature for chinese cabbage plants grown at WHRI from week 11 (L.S.D. (P<0.05) = 23.2)

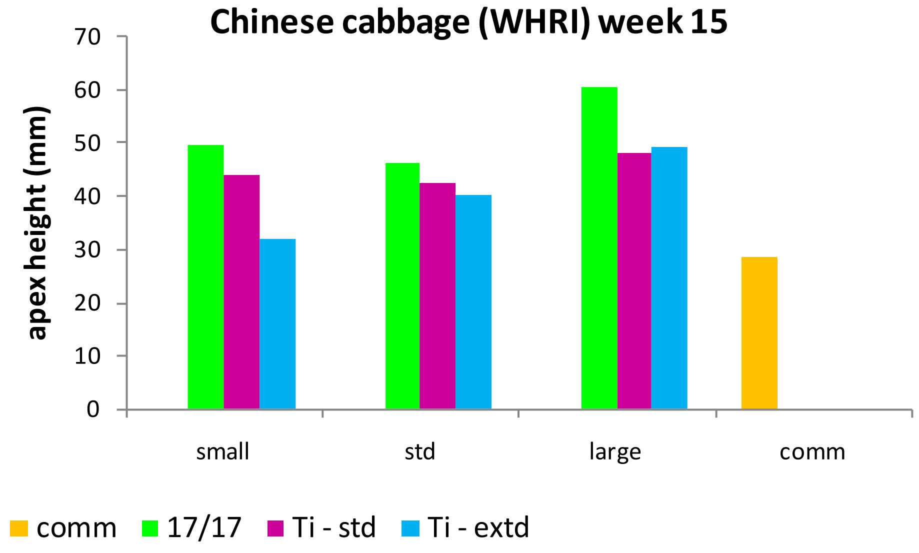


Figure 33: Interaction between transplant size and propagation temperature for chinese cabbage plants grown at WHRI from week 15 (L.S.D. (P<0.05) = 6.4)

Only plants in the week 11 batch grown at WHRI had visible bolting at the final harvest stage. The Ti extd and Ti std produced significantly more bolting than 17/17 for the large sized transplants (Table 7), and Ti extd also produced more bolting than 17/17 for the small transplants. There were no significant differences related to propagation temperature for the standard sized transplants of this batch. There was no bolting in chinese cabbage plots at the commercial site at the harvest assessment stage.

Table 7: Percentage of chinese cabbage plants bolting in the field after propagation in different temperature regimes and to different transplant sizes. (* commercial transplants were planted out later than experimental transplants)

Transplant size	Temperature treatment			
	17/17	Ti Std	Ti Extd	Comm
Chinese cabbage wk 11 WHRI				
Small	46.3	55.0	69.6	
(s.e.)	*(7.7)*	*(7.7)*	*(7.1)*	
Standard	61.3	77.5	60.0	
(s.e.)	*(7.5)*	*(6.4)*	*(7.5)*	
Large	59.0	95.0	92.5	
(s.e.)	*(7.7)*	*(3.4)*	*(4.1)*	
Comm				0.0*
(s.e.)				*(0.0)*

Date of bolting

It was possible to keep on growing treatment plots at WHRI to determine time to bolting. This was assessed in the replicate of plots dedicated to interim destructive sampling where spare rows of undisturbed plants remained available after final harvest at set head weight had been carried out on main plots. Hence it is not possible to formally analyse this data. For treatments to have increased the risk of bolting, time to bolting would be expected to shorten. As detailed in Table 8, neither of the Ti treatments resulted in fewer days to bolting compared with the 17/17 control treatment. Treatment plots of endive and escarole bolted at a similar time to the commercial reference plants whilst celery and chinese cabbage experimental plants bolted sooner than the commercial reference treatments.

Table 8: Time from planting to bolting for plants propagated in different temperature regimes (based on 1 set of plots only)

Planting week	Temperature treatment			
	comm	17/17	Ti std	Ti extd
Celery				
wk 11	150	135	139	135
wk 15	----no bolting----			
Chinese cabbage				
wk 11	-----no data-----			
wk 15	103	92	92	95
Endive				
wk 11	78	78	79	78
wk 15	84	85	86	87
Escarole				
wk 11	88	87	90	88
wk 15	85	83	83	83

Transplant size effects at harvesting

Smaller transplants from the wk11, 13 and 15 batches resulted in significantly lower head weight for endive at harvest in commercial trials where all treatments from a batch were harvested on the same day (Figure 34). Plants raised by a commercial propagator were heavier at harvest than experimental plants in the wks 11 and 13 batches but smaller than experimental plants in the wk 15 batch.

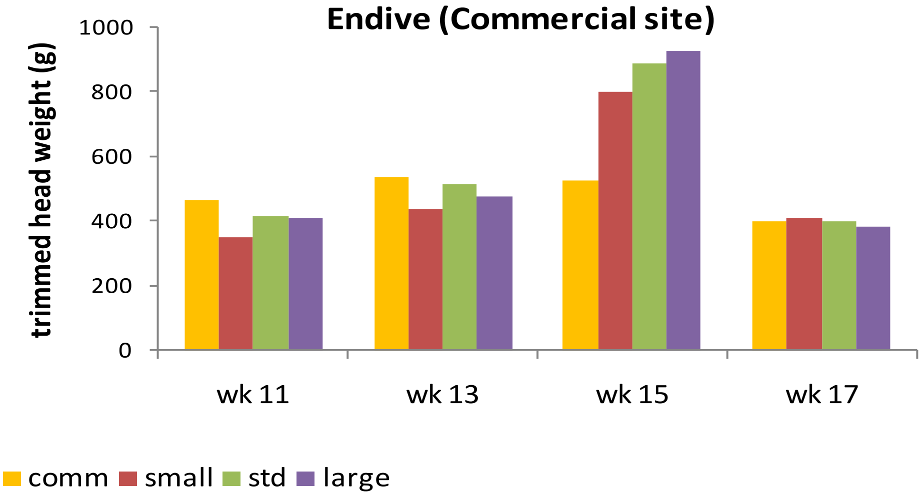


Figure 34: Head weight of plants grown in the field from different sizes of transplant (L.S.D.s ($P<0.05$): wk 11 = 34.8, wk13 = 54.6, wk15 = 79.7 between transplant size treatments, and wk11 = 49.2, wk13 =77.3, wk15 = 112.7, between commercial plants and transplant size treatments)

Where trials were harvested according to head weight (WHRI trials), no treatment effects would be expected on head weight at harvest. The small differences that were found (Figure 35) reflect the difficulty in using a small number of plants from one plot to represent plants in other plots, however overall head weight was similar between treatments. For plants at WHRI therefore time to harvest (Figure 36) needs to be considered. There is no formal analysis of this data since all replicates of one treatment were harvested on the same date according to progress in the replicate designated to interim destructive analysis. In the week 11 batch of plants, small transplants had lower head weight but both small and large transplants were harvested at the same time suggesting that the smaller transplants should have been harvested later to increase head weight. In the week 15 batch of plants, smaller transplants do appear to have increased time to harvest by around 3 days compared with the standard sized transplants. Commercial transplants were comparable with the standard sized transplants in the week 11 batch, but required the longest time to reach the desired head weight for the week 15 batch of plants. This is also reflected in differences between treatments in the week 15 plots planted at the commercial site (Figure 34 above), where head weight of experimental plants was notably higher than that of the commercially raised plants where plants were harvested on a set date. There were clearly larger than usual differences between the experimental plants and the commercially raised endive plants in this week 15 batch.

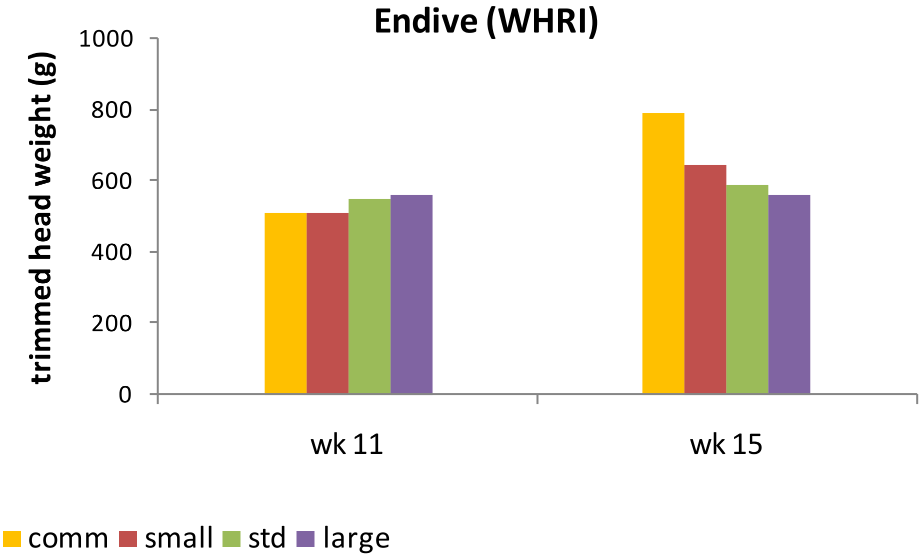


Figure 35: Trimmed head weight of plants grown in the field from different sizes of transplants. (L.S.D. (P<0.05) = 33.7 between size treatments and 47.7 between experimental treatments and commercial plants for wk 11 and 47.8 between size treatments and 66.1 between experimental treatments and commercial plants for wk 15)

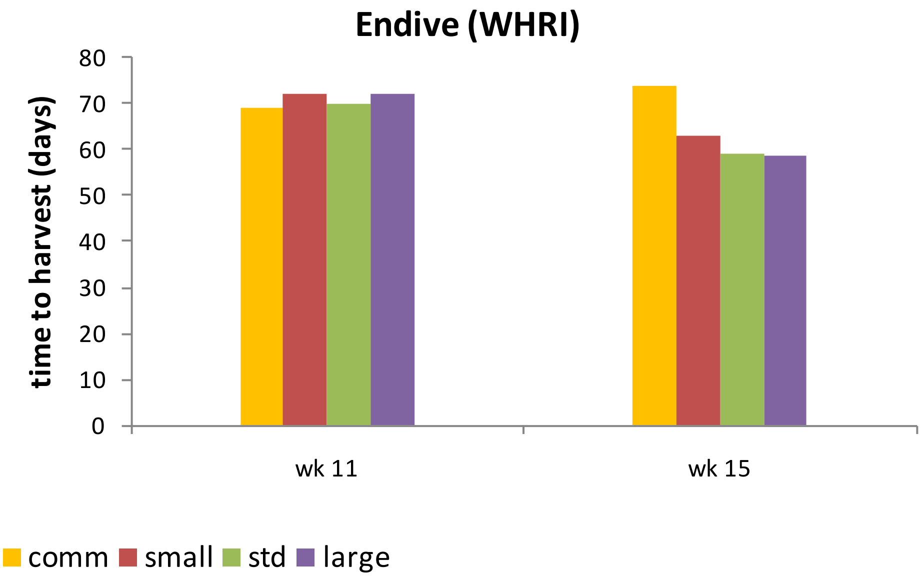


Figure 36: Time to harvest for plants grown in the field from different sizes of transplants

As suggested by data collected in 2007 and 2008, larger transplants appeared to increase apex height at harvest. This trend was apparent in the unreplicated data collected from endive grown in the week 11, 13 and 15 batches in commercial plots (Figure 37). Furthermore in the replicated assessments from the WHRI trials, large transplants planted in week 11 had significantly taller apex height than small transplants (Figure 38), although there were no significant differences due to transplant size in the week 15 batch of endive grown at WHRI when there was little apex extension in any treatments.

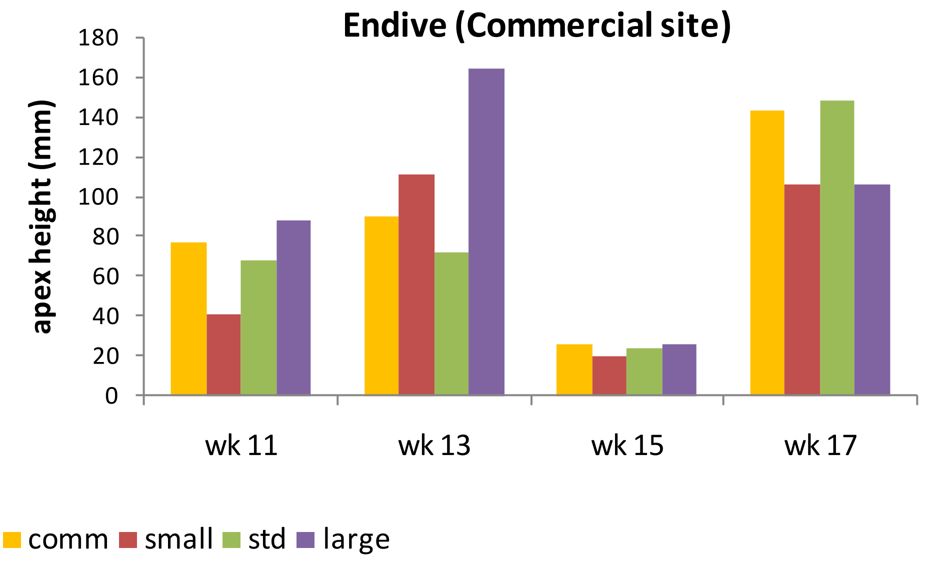


Figure 37: Apex height of plants grown in the field from different sizes of transplant. (based on 1 set of replicates only)

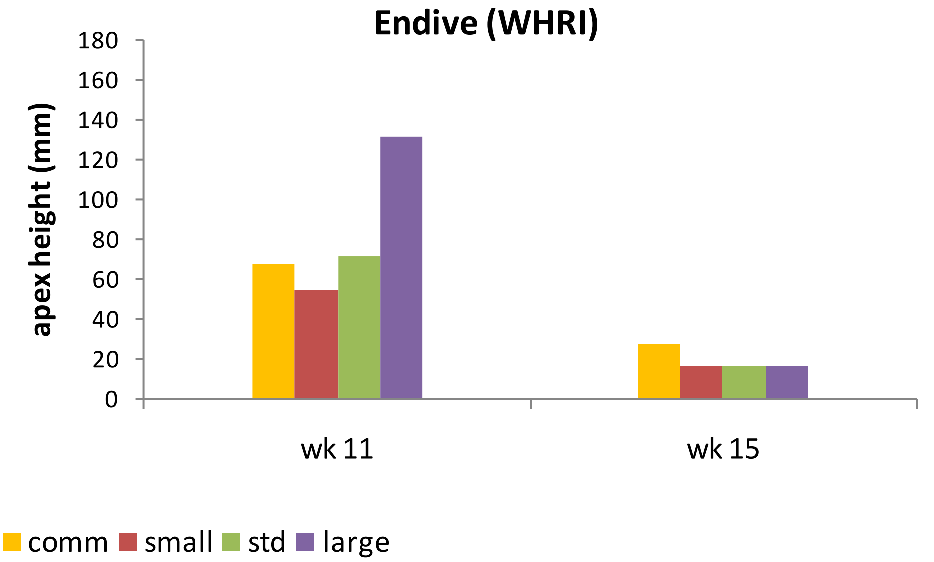


Figure 38: Apex height of plants grown in the field from different sizes of transplant. (L.S.D. (P<0.05) = 12.7 between size treatments & 17.9 between size treatments and commercial plants from wk 11)

Bolting of endive only occurred in the commercial batches in weeks 11, 13 and 17. There were no significant effects of transplant size on bolting in the week 11 batch of plants. Transplant size had a significant influence over incidence of bolting in batches planted in weeks 13 and 17 at the commercial site (Table 9 repeated from page 40). In the week 13 batch, large transplants had significantly more bolting than standard and small transplants within each temperature regime. There was less bolting overall in the week 17 batch of plants from commercial plots however, within this batch, large and standard transplants had significantly more bolting than small transplants propagated at 17/17 whilst transplant size did not influence bolting of plants propagated within the two Ti regimes. There was no visible bolting in plots at WHRI at the harvest assessment stage.

Table 9: Percentage of endive plants bolting in the field after propagation in different temperature regimes and to different transplant sizes

Transplant size	**Temperature treatment**			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Endive wk 11 commercial				
Small	0.0	0.0	0.0	
(s.e.)	*(0.0)*	*(0.0)*	*(0.0)*	
Standard	0.0	0.0	0.5	
(s.e.)	*(0.0)*	*(0.0)*	*(0.7)*	
Large	1.6	0.5	0.5	
(s.e.)	*(1.2)*	*(0.7)*	*(0.7)*	
Comm				1.1
(s.e.)				*(1.0)*
Endive wk 13 commercial				
Small	7.6	1.0	0.0	
(s.e.)	*(3.4)*	*(1.3)*	*(0.0)*	
Standard	0.6	0.0	0.0	
(s.e.)	*(1.0)*	*(0.0)*	*(0.0)*	
Large	31.4	14.4	24.5	
(s.e.)	*(5.9)*	*(4.5)*	*(5.5)*	
Comm				1.9
(s.e.)				*(1.9)*
Endive wk 17 commercial				
Small	0.0	1.0	0.0	
(s.e.)	*(0.0)*	*(1.0)*	*(0.0)*	
Standard	8.3	5.3	0.0	
(s.e.)	*(3.0)*	*(2.4)*	*(0.0)*	
Large	10.4	2.1	1.0	
(s.e.)	*(3.3)*	*(1.5)*	*(1.0)*	
Comm				2.1
(s.e.)				*(1.5)*

Escarole

There were no significant differences between transplant size treatments for average trimmed head weight at harvest in the week 11, 13 and 17 batches of plants (Figure 39). For the week 15 batch, standard transplants had significantly heavier heads than small and commercial transplants but there was no significant difference between the small and large sized transplants.

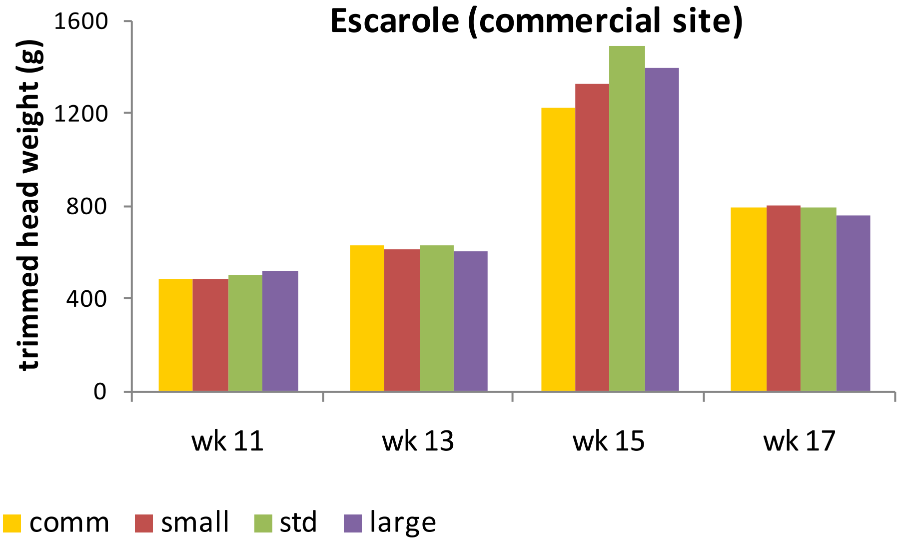


Figure 39: Head weight of plants grown in the field from different sizes of transplant (L.S.D. (P<0.05) = 104 between transplant size treatments from week 15 batch, = 147 between commercial plants and transplant size treatments from week 15 batch)

There were some differences between trimmed head weights for escarole grown at WHRI (Figure 40) but as these treatments were designed to be harvested at a common head weight these data must be considered in association with the data for time to harvest (Figure 41). Small transplants were harvested 2 days later than the standard and large transplants. Hence for the week 15 batch of plants the significant increase in head weight as transplant size increases does suggest a slight delay in harvesting will result from the use of smaller transplants when harvesting to a target head weight. The 2 day delay given in the WHRI trials was apparently too short to compensate for the lower head weight. For the week 11 batch of plants however the 2 day delay in harvest may have over compensated since the small transplants produced the heaviest trimmed heads.

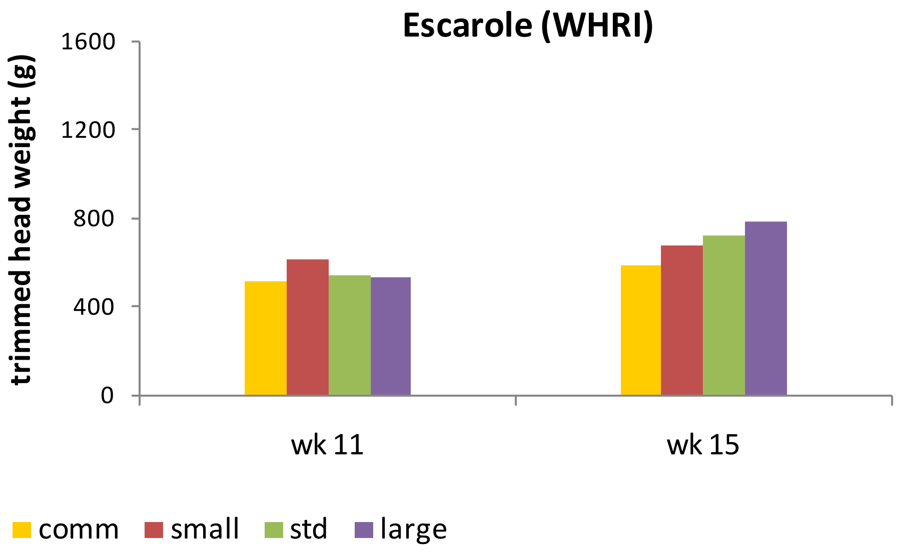


Figure 40: Head weight of plants grown in the field from different sizes of transplant (L.S.D. (P<0.05) = 38 and 32 between transplant size treatments from week 11 week 15 batches respectively, = 53 and 45 between commercial plants and transplant size treatments from week 11 and week 15 batches respectively)

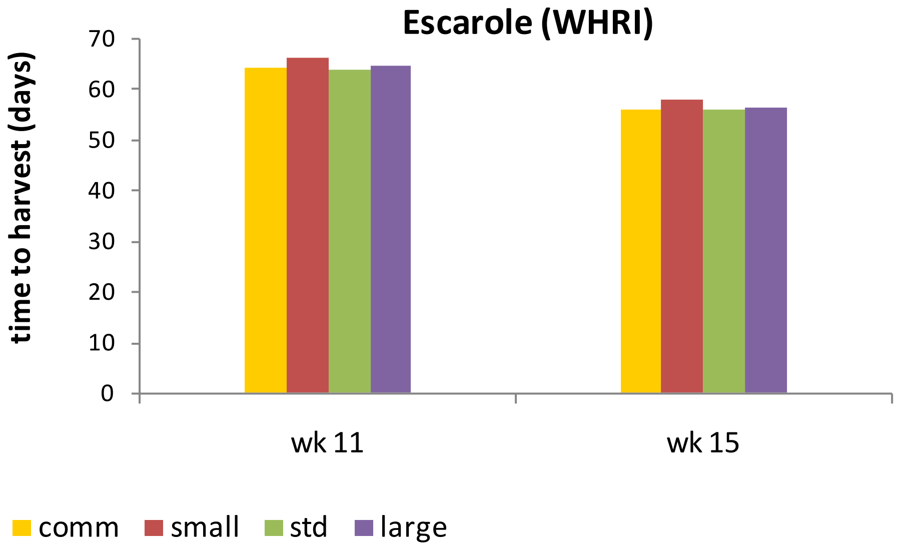


Figure 41: Time taken to achieve harvestable head weight for plants grown in the field following propagation in different temperature regimes

The data from the one replicate of endive assessed for apex height suggests a consistent trend of increasing apex height as initial transplant size increased (Figure 42). Larger transplants from WHRI plots (Figure 43) also produced significantly taller apex height than standard and smaller transplants planted in weeks 11 and 15.

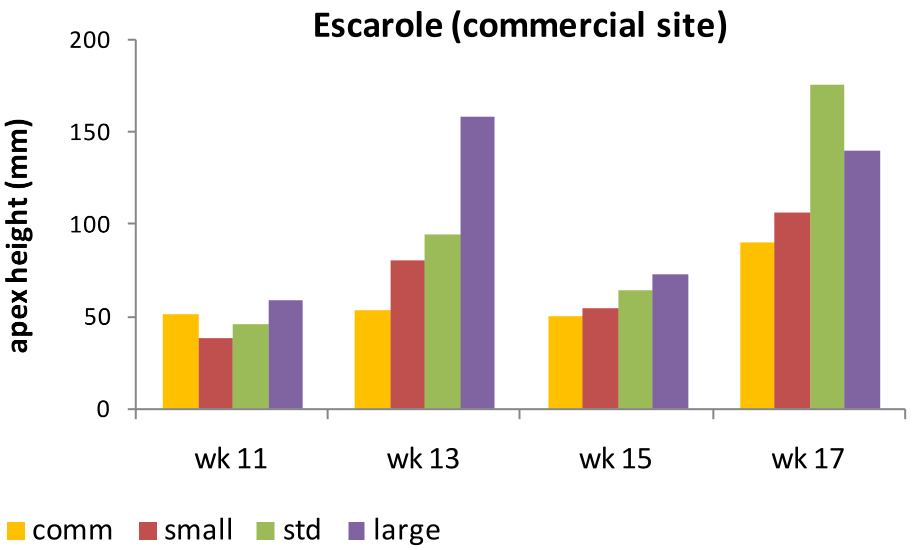


Figure 42: Apex height of plants grown in the field from different sizes of transplant. (based on 1 set of replicates only)

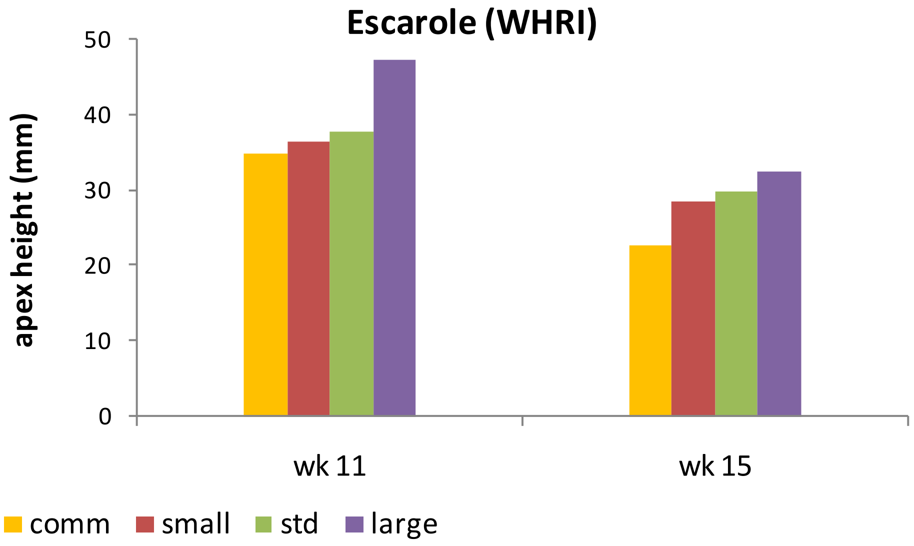


Figure 43: Apex height of plants grown in the field from different sizes of transplant. (L.S.D. ($P<0.05$) = 2.8 and 4.0 between size treatments for the wk 11 and wk 15 batches respectively = 2.0 and 4.0 between size treatments and commercial plants for the wk 11 and wk 15 batches respectively)

Bolting was only visible in the week 13 and week 17 batches of plants from the commercial plots (Table 10 repeated from page 45). Larger transplants produced significantly more bolting than small transplants in the week 13 batch of plants in all temperature treatments and also than the standard transplants in the 17/17 and Ti extd treatments. There were no significant differences resulting from transplant size for the week 17 plants propagated in the 17/17 or Ti std treatments. In the Ti extd treatment however the standard sized transplants produced the highest percentage bolting and the large transplants produced the lowest percentage bolting. There was no visible bolting in plots at WHRI at the harvest assessment stage.

Table 10: Percentage of escarole plants bolting in the field after propagation in different temperature regimes and to different transplant sizes

Transplant size	Temperature treatment			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Escarole wk 13 commercial				
Small	1.1	0.5	0.0	
(s.e.)	*(0.8)*	*(0.6)*	*(0.0)*	
Standard	0.5	0.0	0.0	
(s.e.)	*(0.6)*	*(0.0)*	*(0.0)*	
Large	7.9	5.1	13.0	
(s.e.)	*(2.2)*	*(1.9)*	*(2.7)*	
Comm				0.0
(s.e.)				*(0.0)*
Escarole wk 17 commercial				
Small	7.3	2.1	7.4	
(s.e.)	*(3.4)*	*(1.9)*	*(3.0)*	
Standard	4.3	1.1	11.5	
(s.e.)	*(2.6)*	*(1.3)*	*(4.1)*	
Large	3.1	0.0	3.1	
(s.e.)	*(2.3)*	*(0.0)*	*(2.3)*	
Comm				3.0
(s.e.)				*(2.0)*

Celery

There were no significant main effects of transplant size on trimmed head weight of celery at final harvest within the three batches assessed (Figure 44). Whilst there were some significant interactions between transplant size and temperature (data not shown), there were no consistent trends linking transplant size with either an increase or decrease in trimmed head weight of plants grown on at the commercial site. For the week 15 batch for example, small transplants raised at 17/17 had heavier head weight at harvest than large ones but conversely, large transplants raised in the Ti std treatment had heavier head weight at harvest than small transplants.

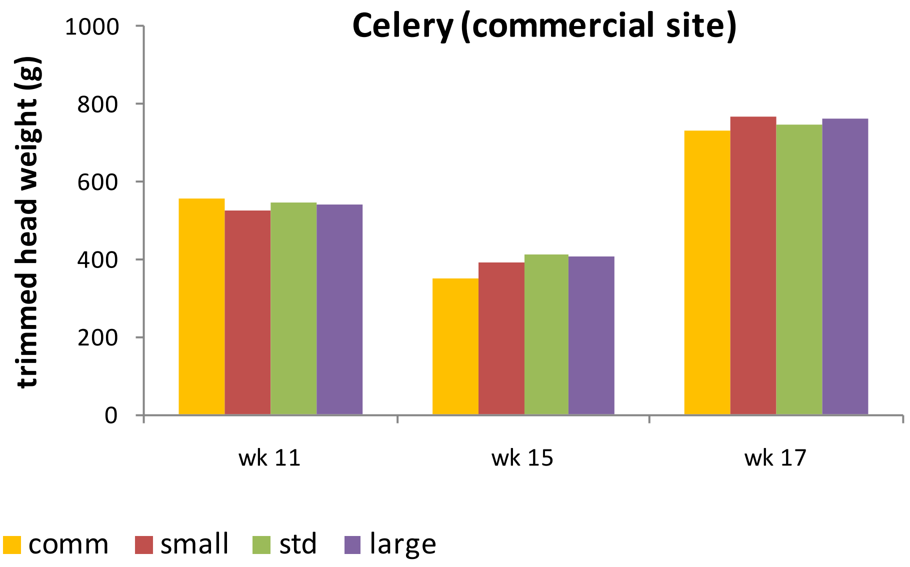


Figure 44: Head weight of plants grown in the field from different sizes of transplant.

As discussed previously, head weight at harvest for WHRI plots (Figure 45) must be considered in association with time to harvest data (Figure 46) given the sampling method used for this site. There was a maximum of 2 days difference in harvesting date for the week 11 batch of plants. Despite the extra time allowed for the small transplants to reach the target head weight, this treatment produced significantly smaller trimmed head weight than the large transplants. There were no significant differences in trimmed head weight for the week 15 batch of plants which were harvested at between 97 and 100 days from planting.

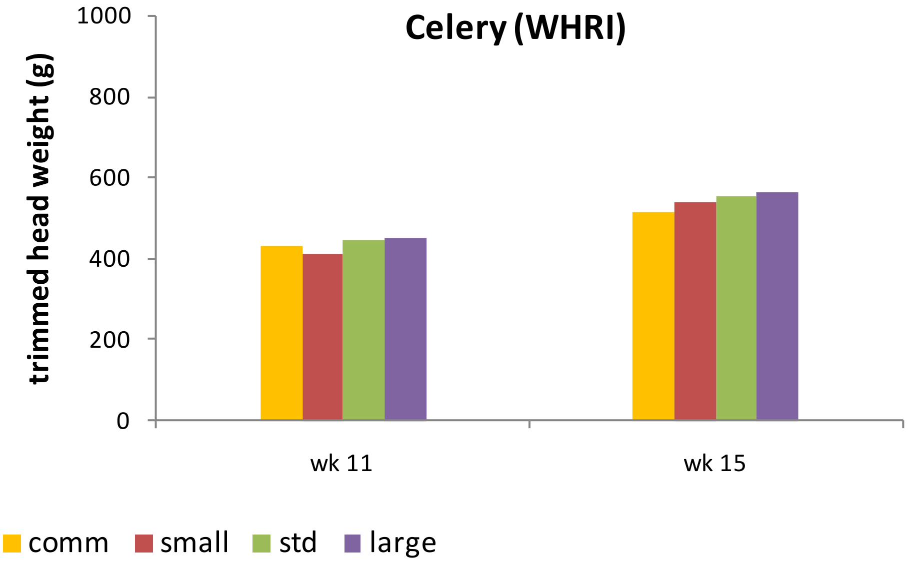


Figure 45: Head weight of plants grown in the field from different sizes of transplant (L.S.D. (P<0.05) = 32.1 between transplant size treatments from week 11 batch, = 45.5 between commercial plants and transplant size treatments from week 11 batch)

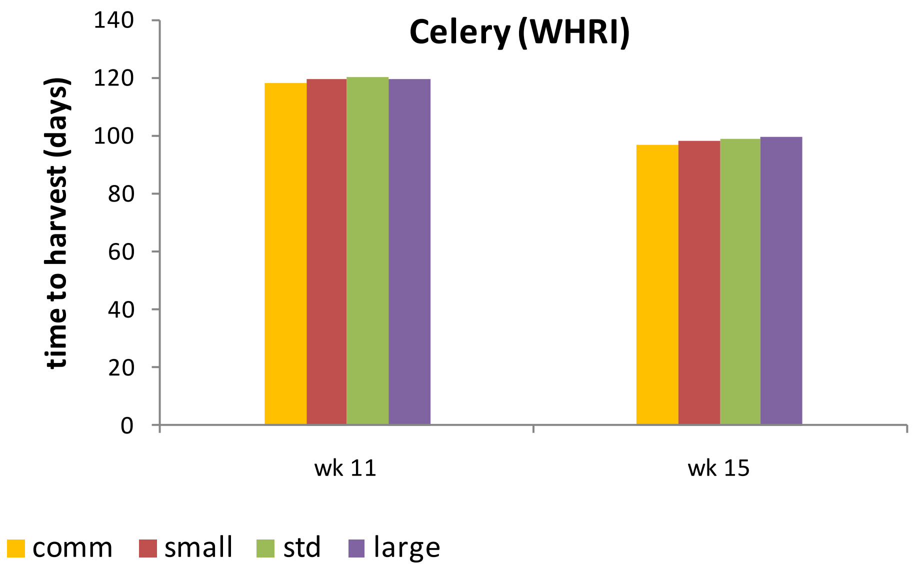


Figure 46: Time to harvest of plants grown in the field from different sizes of transplant

Response of apex height to transplant size was inconsistent for the plants grown at the commercial site. For the week 11 batch, standard sized transplants had smaller apex height than small transplants whilst there was no significant difference between the small and standard sized transplants (Figure 47). There were no significant differences due to transplant size within the week 15 or week 17 batches.

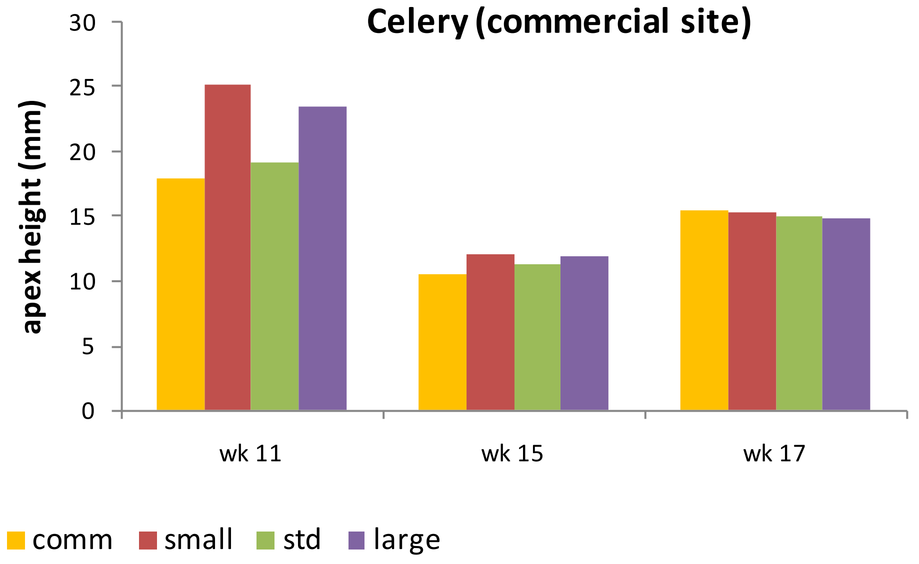


Figure 47: Apex height of plants grown in the field from different sizes of transplant. (L.S.D. (P<0.05) = 4.6 between size treatments for the week 11 batch; = 6.5 between size treatments and commercial plants for the week 11)

For plants grown on at WHRI, large transplants produced significantly taller apex height than standard transplants whilst there were no significant differences between large and small transplants or between standard and small transplants (Figure 48). In the week 15 batch at WHRI, small transplants produced significantly taller apex height than large transplants, although the absolute differences were small (<1mm).

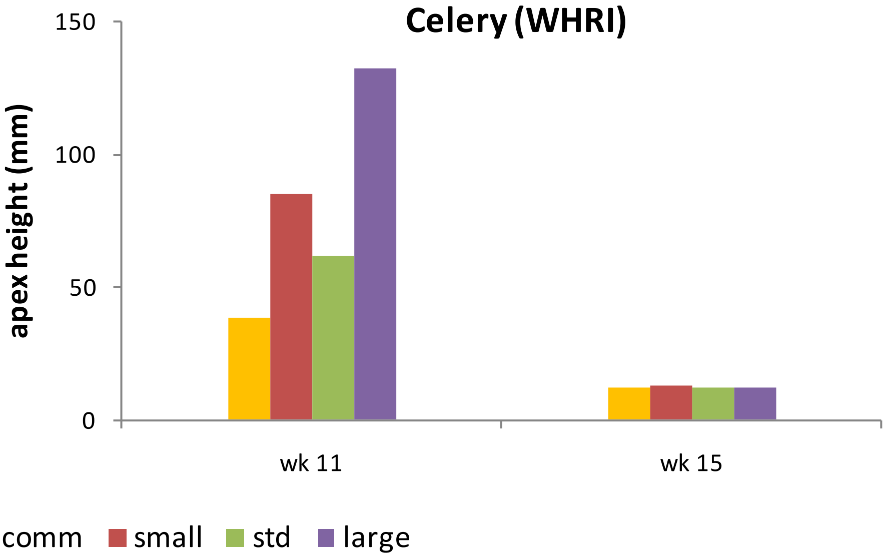


Figure 48: Apex height of plants grown in the field from different sizes of transplant. (L.S.D. ($P<0.05$) = 35.5 and 0.59 between size treatments for the wk 11 and wk 15 batches respectively; = 50.3 and 0.83 between size treatments and commercial plants for the wk 11 and wk 15 batches respectively

Only plants in the week 11 batch of celery grown in WHRI plots had visible bolting at the final harvest stage (Table 11 repeated from page 51). Within this batch of plants, large transplants produced significantly more bolting than standard and small transplants that had been raised in the 17/17 temperature treatment. However there were no significant differences relating to transplant size within the plants propagated in the Ti std or Ti extd treatments. There was no visible bolting in plots at the commercial site at the harvest assessment stage.

Table 11: Percentage of celery plants bolting in the field after propagation in different temperature regimes and to different transplant sizes

Transplant size	**Temperature treatment**			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Celery wk 11 WHRI				
Small	3.1	8.4	16.7	
(s.e.)	*(2.0)*	*(3.2)*	*(4.2)*	
Standard	1.1	4.2	12.5	
(s.e.)	*(1.2)*	*(2.3)*	*(3.7)*	
Large	12.5	12.0	16.8	
(s.e.)	*(3.7)*	*(3.8)*	*(4.3)*	
Comm				3.1
(s.e.)				*(2.0)*

Chinese cabbage

Transplant size had no significant influence over trimmed head weight at harvest for plants grown on at the commercial site (Figure 50).

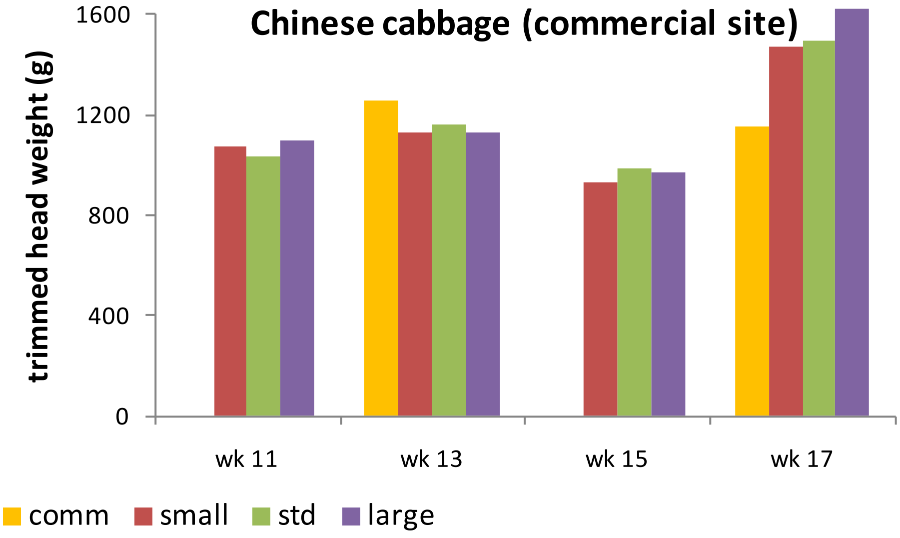


Figure 50: Head weight of plants grown in the field from different sizes of transplant

Plants grown on at WHRI should have had consistent head weight at harvest and whilst there were no significant differences between transplant size treatments at harvest stage, commercial transplants had significantly lower head weight than plants raised in propagation treatments at WHRI (Figure 51). If these data are considered along with the time to harvest data (Figure 52), it is clear that the commercial transplants should have been allowed more time to develop in the WHRI plots, although the head weights recorded from the plots reserved for interim assessments were comparable to the other treatments at the time of harvest.

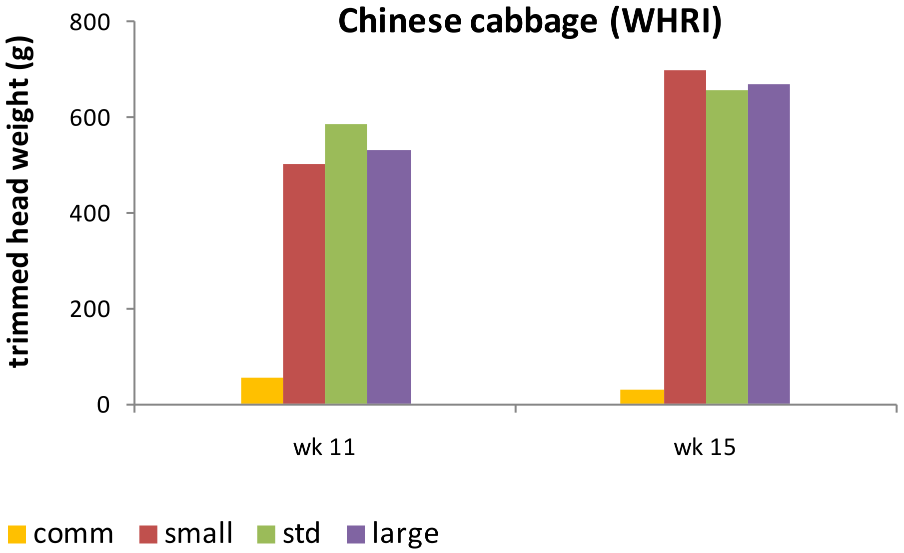


Figure 51: Head weight of plants grown in the field from different sizes of transplant

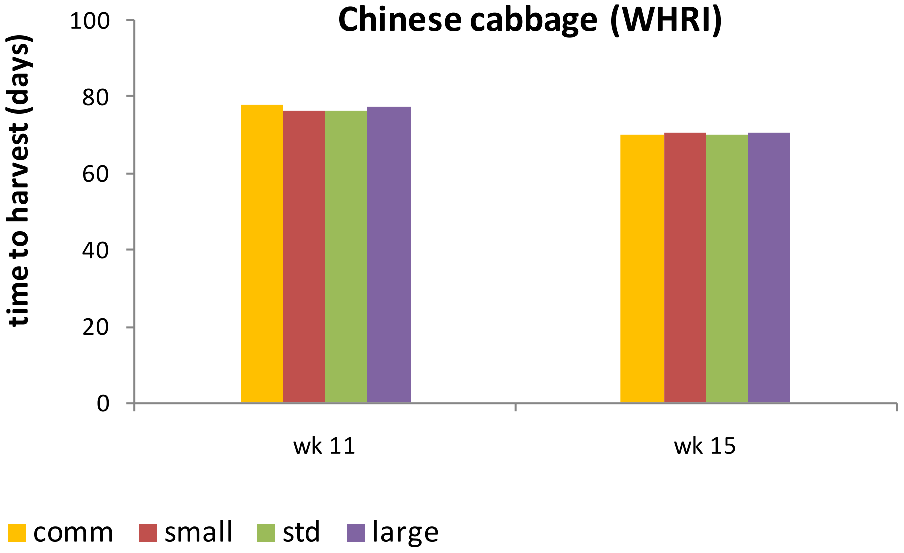


Figure 52: Time to harvest of plants grown in the field from different sizes of transplant

While large transplants appeared to produce the tallest apex height at harvest for the week 11 plants grown on at the commercial site, there was insufficient material for formal statistical analysis of this batch of plants (Figure 53). Large transplants had taller apex height than commercial transplants in the week 13 batch of plants but had comparable apex height to both the standard and small sized transplants in this batch. There were no significant differences relating to apex height within the week 15 or week 17 batches of plants at the commercial site.

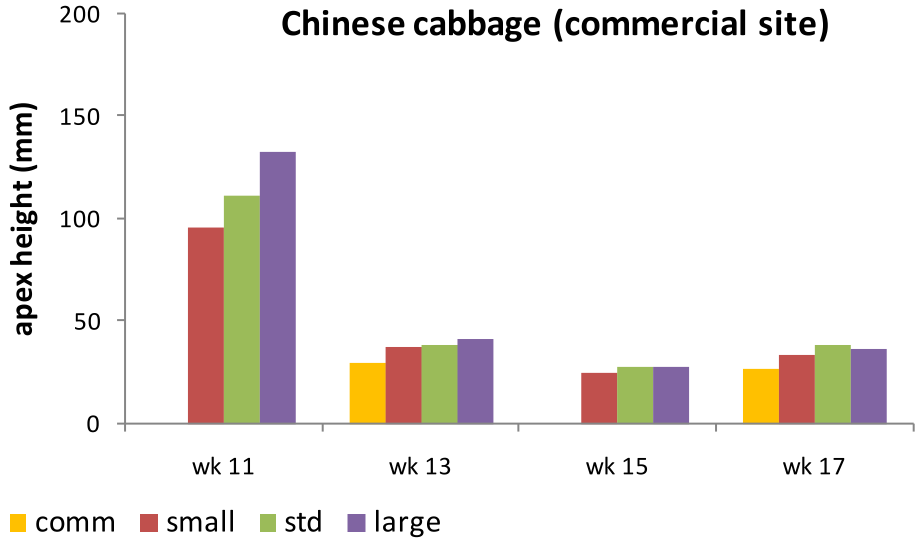


Figure 53: Apex height of plants grown in the field from different sizes of transplant. (L.S.D. (P<0.05) = 3.5 between size treatments for the wk 13 batch; = 4.9 between size treatments and commercial plants for the wk 13)

In terms of main treatment effects, large transplants of chinese cabbage produced the tallest apex height for transplants grown on at WHRI from both the week 11 and week 15 batches of plants (Figure 54). Large transplants also had taller apex height at harvest than standard transplants in the week 11 batch.

There was a significant interaction between transplant size and propagation temperature in both batches of transplants grown on at WHRI (data not shown). Hence for the week 11 batch, whilst plants grown in the Ti treatments followed the main trend already described, there were no differences relating to transplant size on apex height of transplants raised at 17/17. For the week 15 batch of plants there were no differences relating to transplant size for plants grown in the Ti std treatment with trends as main effects in the 17/17 and Ti extd treatments.

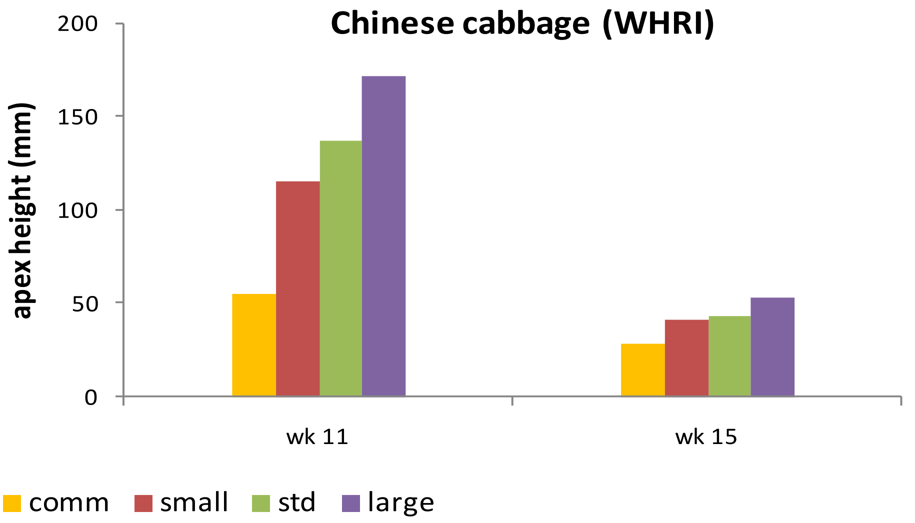


Figure 54: Apex height of plants grown in the field from different sizes of transplant. (L.S.D. ($P<0.05$) = 13.4 and 3.7 between size treatments for the wk 11 and wk 15 batches respectively; = 18.9 and 5.2 between size treatments and commercial plants for the wk 11 and wk 15 batches respectively)

Only plants in the week 11 batch of chinese cabbage grown in WHRI plots had visible bolting at the final harvest stage. Differences between transplant size treatments for bolting reflect the trends described previously for apex height (Table 12 repeated from page 57). That is, there were no significant differences in bolting for the three sizes of transplants propagated in the 17/17 treatment. However where plants were propagated in the two Ti treatments, larger transplants produced significantly more bolting than small transplants and also than standard transplants in the case of the Ti extd treatment. There was no visible bolting in plots at the commercial site at the harvest assessment stage.

Table 12: Percentage of chinese cabbage plants bolting in the field after propagation in different temperature regimes and to different transplant sizes. (* commercial transplants were not available until week 12 and so were planted out later than experimental transplants)

Transplant size	**Temperature treatment**			
	17/17	**Ti Std**	**Ti Extd**	**Comm**
Chinese cabbage wk 11 WHRI				
Small	46.3	55.0	69.6	
(s.e.)	*(7.7)*	*(7.7)*	*(7.1)*	
Standard	61.3	77.5	60.0	
(s.e.)	*(7.5)*	*(6.4)*	*(7.5)*	
Large	59.0	95.0	92.5	
(s.e.)	*(7.7)*	*(3.4)*	*(4.1)*	
Comm				0.0*
(s.e.)				*(0.0)*

Date of bolting

Time to bolting, measured on plots at WHRI that were allowed to grow on beyond the final assessment stage, followed the same trend as apex height and percentage bolting in response to transplant size treatments (Table 13). That is larger transplants generally bolted slightly earlier than smaller ones; however differences were small (up to 3 days on average data).

Table 13: Time from planting to bolting for plants propagated in different temperature regimes (based on 1 set of plots only)

Planting week	Transplant size treatment			
	comm	Small	std	large
Celery				
wk 11	150	137	138	134
wk 15	----no bolting----			
Chinese cabbage				
wk 11	-----no data-----			
wk 15	103	95	92	92
Endive				
wk 11	78	80	78	77
wk 15	84	87	85	86
Escarole				
wk 11	88	88	88	88
wk 15	85	84	82	83

Discussion

At the start of this three year project, propagation temperature was initially examined as fixed temperature treatments (14, 16 or 18°C) with vent set at +1°C in order to fully test the extremes of these temperature settings; particularly how plants would respond to the lowest of these treatments in a season where there is little solar gain. Reducing average temperature increased the risk of bolting although there was less bolting than may have been expected, especially in chinese cabbage and celery in these experiments. Having confirmed that lowering average temperature could not be used to save energy without increasing the risk of bolting, treatments in year 2 (2008) were designed to commence assessing how temperature integration might influence bolting of the final product. This was achieved by introducing variable propagation temperature regimes designed to achieve a similar average temperature to current commercial heat set points (i.e. 17°C). Since response to the lower temperatures in year 1 was less extreme than anticipated, treatments in year 2 allowed wide fluctuations in temperature with the whole of the night period set at 10°C in two treatments and day temperature designed to bring average achieved 24 hour temperature up to the same level as a more conventional 17°C / 17°C regime in one of these treatments. Results from these experiments indicated that temperature may be allowed to fluctuate within a 24 hour period without increasing the risk of bolting provided a suitable 24 hour average temperature was achieved. These experiments were however still carried out with low vent set points, again to make sure that the low temperatures set were achieved in order to assess worse case scenarios from the set points used. There were also issues regarding quality as a result of combining a low achieved average night temperature with a high average achieved day temperature.

Temperature treatments in the final year (2009) of the project built on the progress achieved in years 1 and 2 by assessing variable temperatures but in this case with higher vent set points (25°C for the Ti treatments) in order to maximize solar gain and minimize inputs from the heating system. Hence in 2009, achieved temperatures in the Ti extd treatment, which had a 10˚C day heat set point were generally above the minimum set point level and periods at low temperatures in this type of treatment were shorter than in 2008 where venting was set at +1°C.

Data from the three years of work combined indicate that reducing propagation temperature below the 17°C level used commercially may be expected to increase risk of bolting. Furthermore transplant size is reduced at lower propagation temperature which would increase production time and potentially mitigate any energy savings achieved from the reduction in heat set point. However, allowing temperature to fluctuate using temperature integration during propagation appears to be a sensible approach to saving energy in the propagation of the salad species tested. Higher day temperature than night temperature runs the risk of creating plant stretching although commercial regimes are unlikely to achieve the same extremes in temperature difference that were achieved experimentally. For glasshouses with screens, having a lower temperature set point during the day and encouraging heating more at night when screens are closed has the greatest potential to reduce energy inputs. In general the two Ti regimes tested in 2009 appeared to be at least equivalent to transplants raised in the standard 17/17 regime by the final harvest stage. In some cases, e.g. week 11 batch of all species, apex height was significantly taller for the Ti extd treatment and while differences were generally small, and in some cases inconsistent, this would suggest some caution is required when adopting extended Ti initially at least for the earliest batch of plants of the season and a standard Ti approach may be a sensible first step, moving towards a more extended approach as experience is gained. There are therefore some slight differences between results in 2008 when a 10°C night combined with a 24°C day resulted in no more bolting than a conventional 17°C fixed heat set point, and in 2009 when the Ti extd treatment gave a slight increase in bolting in the earliest planting of some species. Given that the temperatures achieved when the 10°C set point was in use were lower in 2008 (i.e. when given at night) than in 2009 (during the day) it might have been expected that the 2008 treatments posed the greater risk. Further work would be required to assess if these differences are due to different responses to low temperature during the day and night.

Experiments to examine the influence of transplant size on risk of bolting of final product have been included in all three years of the project. In 2007 lack of bolting and gaps resulting from crops lost in the field made interpretation of data difficult although data for endive and escarole later in the season suggested greater bolting as a result of planting larger transplants. These results contradicted expectations that smaller transplants were more likely to bolt prematurely as a result of having initiated fewer leaves prior to planting out into inductive conditions. Repeating treatments in 2008 confirmed these initial results but it was not clear if this was a result of the sampling process. That is, all treatments within one batch of plants were harvested on the same day with timing dictated by the harvest of the adjacent commercial crop. Since all sizes of transplants were also planted on the same day this meant that there was a risk smaller sized transplants had been harvested sooner than may be expected for a commercial harvest (which would be triggered by head weight) and that larger transplants may have been harvested later than might be expected commercially. Since the risk of bolting increases the longer the plants are left in the field, the larger transplants may have been disadvantaged by this method of assessment through being allowed to grow beyond commercial harvest stage and in doing so had more time for bolting to be expressed. Hence in 2009 a second assessment method was introduced with the aim of sampling treatments when they reached a set weight which potentially meant harvesting different treatments from within a batch on different dates. Given the need to visit these plots on a regular basis, it was necessary to grow them at WHRI but with replicate plots on commercial sites to provide a bench mark for overall crop production. The results from 2009 continue to support the overall view that larger transplants may be more likely to increase the risk of bolting than the smaller transplants used (that is transplants with 5 days less in heated propagation than given to a commercial crop). There has been some inconsistency in the data and hence not all combinations of transplant size and propagation temperature have conformed to the overall trend of larger transplants increasing the risk of bolting (indicated by apex height and/or incidence of bolting). In 2009, where larger transplants have not produced greater apex height or percentage bolting than smaller transplants, there have generally been no significant differences relating to transplant size. The exception to these overall trends are for bolting in one batch (week 17) of escarole in commercial plots where small transplants from the Ti extd treatment had significantly more bolting (at 7.4%)

than large transplants (at 4.1%) but standard sized transplants within this batch had the most bolting overall (11.5%). These overall trends are the same for both the data collected from commercial plots which were harvested on the same day and for the data from WHRI plots where harvesting was staggered to account for achieved head weight. The limitations of this latter approach are discussed below but in practice differences in time to harvest within a batch were small and within the period of time a commercial batch would normally be harvested (i.e. approx 1 week). Bolting date per treatment for plants left in WHRI plots beyond the main sampling dates further supports the overall trend for transplant size, with large transplants bolting after fewer days from planting than small transplants although differences were small (maximum 3 days). This suggests that the data for transplant size for 2007 and 2008 were a suitable representation of the treatment effects imposed. This is further supported by considering the data for head weight. In general, transplant size had no significant influence over trimmed head weight in 2009 (or on total head weight in 2007 and 2008). If the earlier bolting associated with the larger transplants had been due to delayed harvesting this should have been apparent as greater head weight. In some cases there is a slight reduction in head weight and/or time to harvest associated with smaller transplants but the differences are both small in commercial terms and also not consistently shown.

Overall then, the data suggest that the use of smaller transplants (with up to one week less in the heated phase of propagation after germination) does not increase the risk of premature bolting in early season production as was originally thought. In fact larger transplants may increase the risk of bolting, possibly because these plants have progressed further with development when planted out and are more capable of progressing towards bolting as a result.

Assessment of treatments on achieved head weight at harvest has generally shown little difference throughout the project. In the first two years this was on total head weight with trimmed head weights assessed in year three to represent the commercial product. Whilst trimming heads introduces a subjective variable into the assessment it is clear from the data in years 1 and 2 that head weight within a batch has generally shown few significant differences which may reflected the inherent variability in this type of data.

Assessment using counts of bolted heads at harvest has also been of limited use since in many batches there has been little bolting to record. Experience has suggested that leaving plants longer in commercial fields to allow bolting to express risks the loss of whole batches as commercial clearing operations commence. It is of course important to record any bolting that has occurred within a normal time period for a commercial crop but measurements of apex height at harvest have probably been the most useful in assessing the risk of bolting for any treatment. Unfortunately such data does not provide growers with figures of likely losses through bolting against any one regime which may be assessed in a risk / benefit type analysis of new regimes. Using apex height and bolting count data in conjunction appears to be a suitable compromise system for assessing the impact of treatments on bolting although future work would need to allow sufficient time for all replicates of species to be assessed through dissection and measurement of apex height for full statistical analysis to be possible.

Assessment of treatments in 2009 was also extended to the use of a third site for growing on plots in addition to the two commercial sites used in 2007 and 2008. New plots at WHRI were introduced in 2009 in order to allow assessment of treatments according to progress in head weight. Since the timing of harvest for commercial fields is dictated, at least in part, by achieved head weight, it was considered important to fully test treatments in this way in this final year. This then removed the uncertainty as to whether treatment effects have been constrained by assessment method. The data from 2009 however suggests that this was not a major constraint of the data from commercial plots since the time difference between harvesting of different treatments at WHRI was often just 1-2 days.

The difficulty of harvesting treatments according to progress towards a target head weight is finding a suitable representative sample that may be destructively harvested without creating gaps in the plot which will of course impact the future progress of adjacent plants. The system used was to allocate one set of replicates for interim destructive assessment and then harvesting the main plots of each treatment when the test plot had achieved the target weight. This approach does not account for the variability from one plot to the next and hence in some cases whilst the aim was to harvest all plants at a set weight, differences between treatments were seen. An alternative approach would be to extend all plots to including rows for interim destructive sampling so that each plot may be harvested by achieved head weight, but this would significantly increase the resources required and hence cost of work and would probably only be justifiable where accurate timing information is the primary aim of the work. The plots at WHRI did supplement the commercial data well and provided replicate data for apex height for endive and escarole as well as supplementary data for bolting date which was not possible on commercial sites that need to be cleared and prepare for future cropping. Although not desirable, there is always a risk that trial plots on commercial sites may be lost, particularly during very busy periods and having parallel experiments on commercial sites and experimental sites offers a suitable compromise to gaining grower confidence in the work whilst ensuring delivery of results.

Conclusions

Variable temperature regimes are suitable for propagating transplants of crops at risk of bolting through low temperature induction providing a suitable average temperature is achieved. These experiments have focused on four species including endive and escarole cultivars that appeared more susceptible to bolting as well as celery and chinese cabbage which tended to bolt prematurely only in the very early part of the season. Vent set points of up to 25°C have been tested with minimum temperature as low as 10°C for the whole of the day or the night period. Using the extended Ti approach and encouraging heating at night under thermal screens is likely to be the most energy efficient method of those assessed. Combining low night temperature with high day temperature increases the potential for having to actively heat the glasshouse at its maximum volume with the associated losses through glasshouse walls and roof (since screens will be open and there may not be sufficiently solar gain to achieve a suitable 24 hour average temperature is a low night temperature has been achieved) and also risks poor quality plants through stretching.

Despite modifications to experimental procedure to ensure fair testing, there has been no evidence from the three years of the project to support the view that smaller transplants are more prone to bolting. Any trends in incidence of bolting / increase in apex height, suggest that larger transplants are more likely to bolt early than smaller ones (where time from planting to bolting is considered). This suggests that it should be safe for propagators to gradually reduce transplant size in line with the requirements for mechanical transplanting.

It has also been clear from the project overall that whilst conditions in propagation do contribute to incidence of bolting, there is a limitation to how well suitable propagation can ensure the success of an early planted crop where external conditions are particularly extreme.

Technology Transfer

Presentations given to

- Plant Propagators Ltd meeting on 07/10/09 in Huntingdon
- The project steering group on 10/11/09 at Wellesbourne
- The British Leafy Salads Association (outdoor and protected R&D committee's) on 26/01/10 at PGRO, Peterborough

HDC News article

- Secrets of bolting unlocked, p18-20 issue 148, November 2008
- Propagation by integration, p 26-27 issue 160, February 2010

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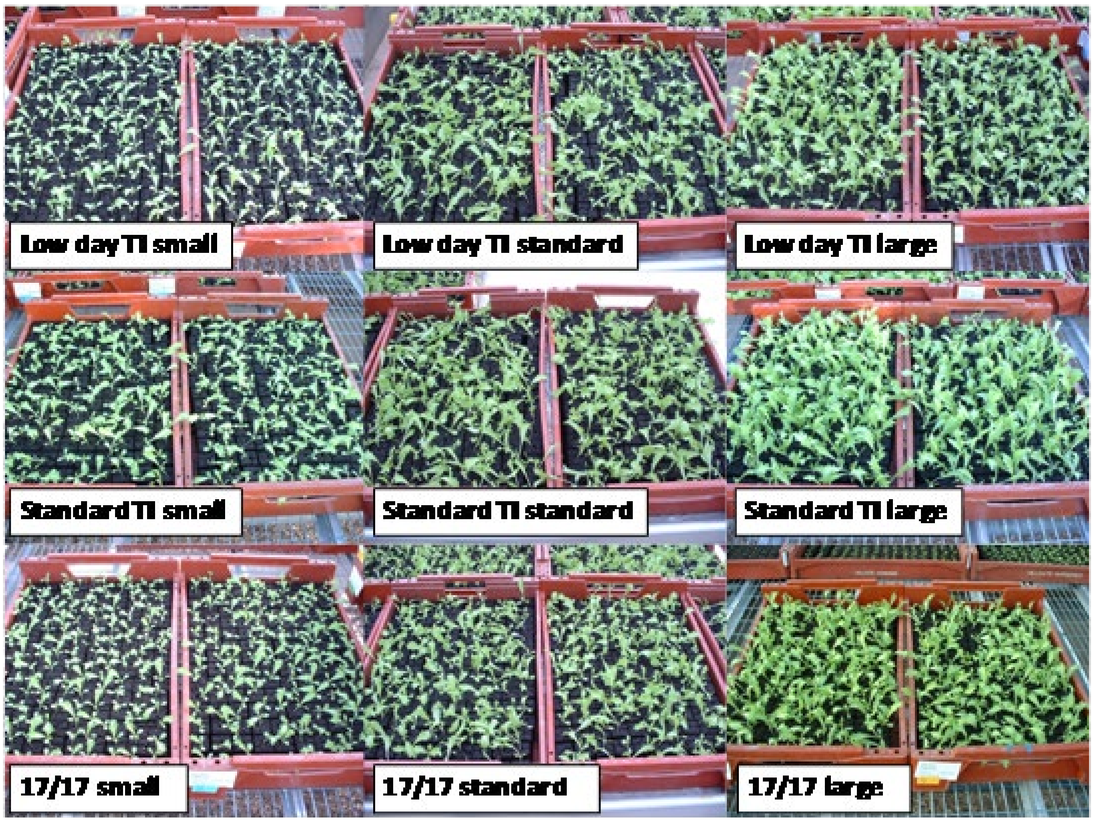
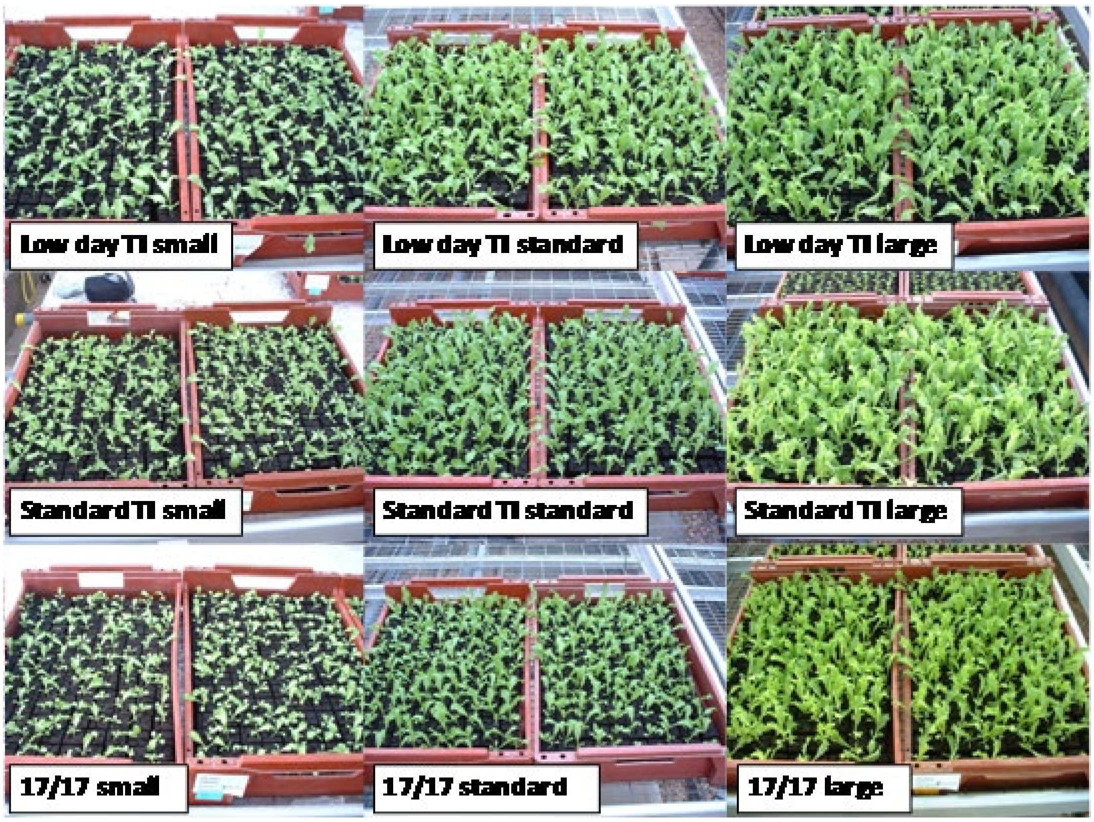
Appendix 1. Photographs of treatments at transplanting stage

Week 11 Endive (planted 9-10/3/09)

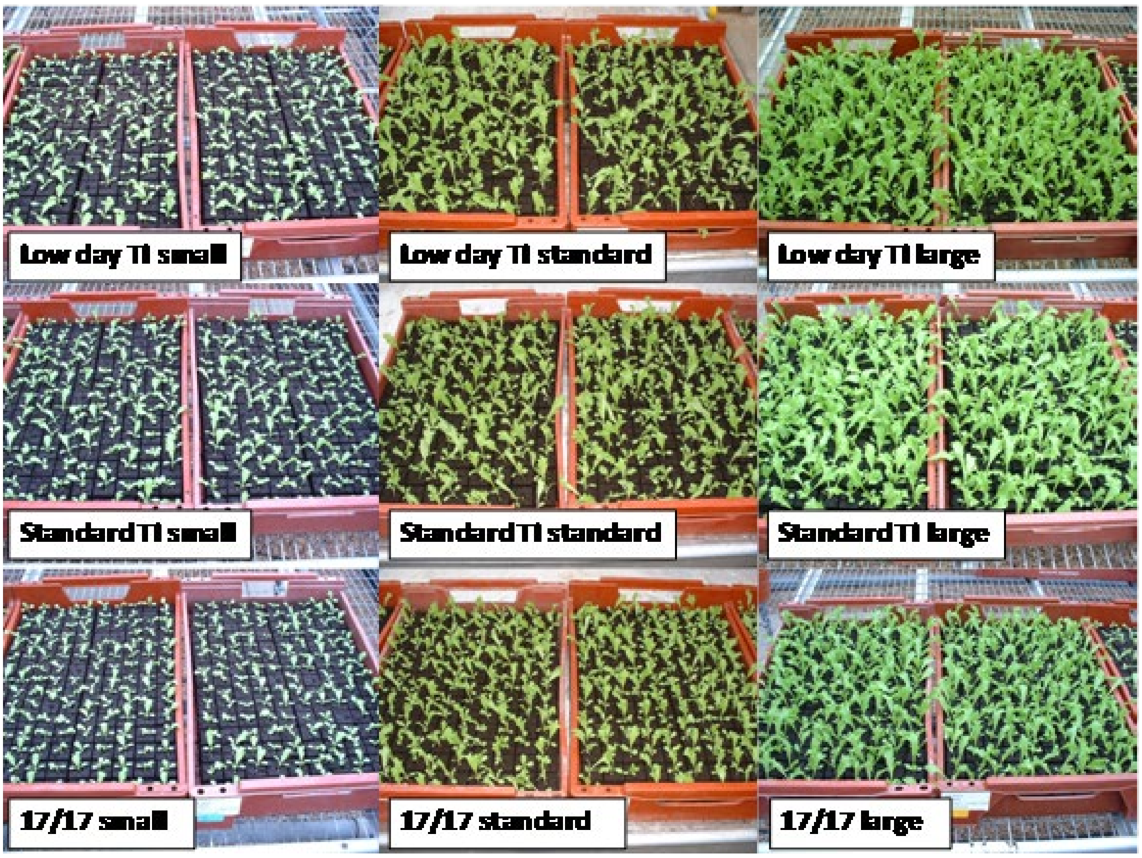


Week 13 Endive (planted 23/3/09)



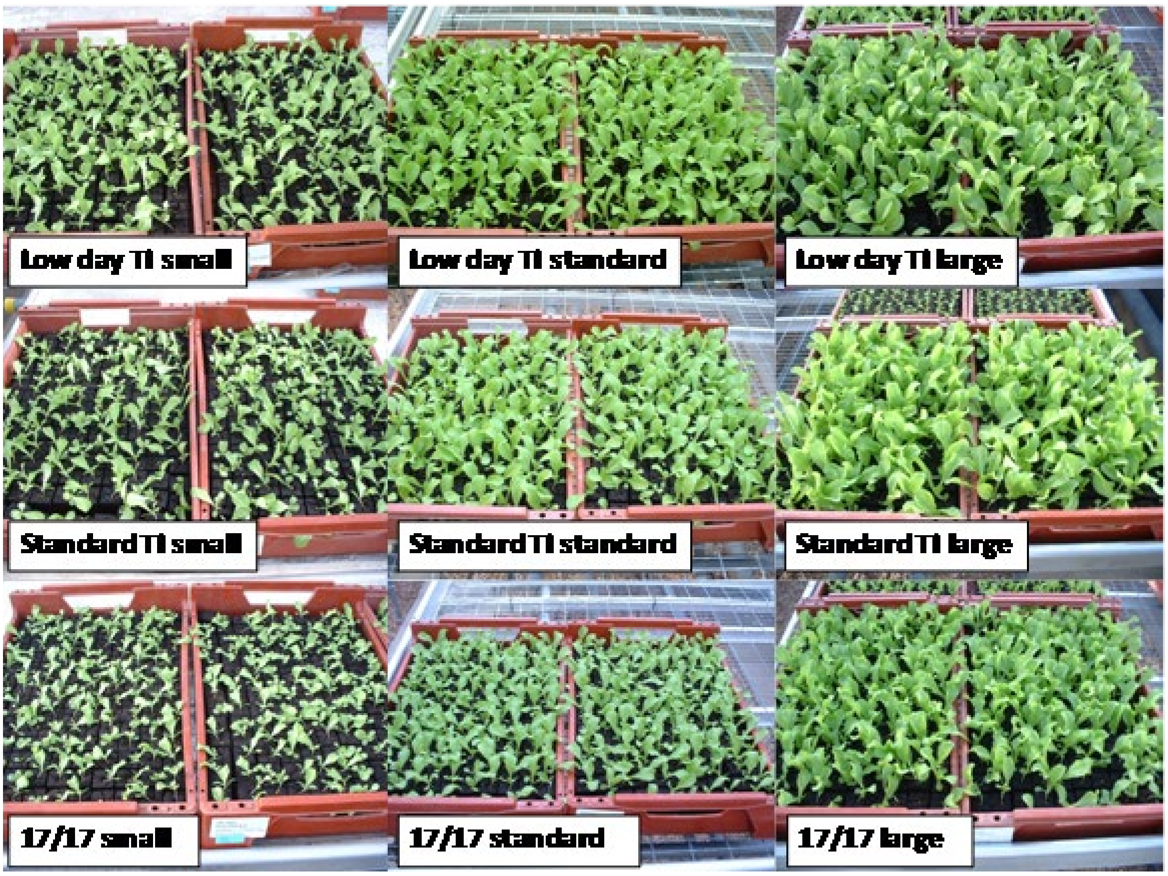
Week 15 Endive (planted 6/4/09)

Week 17 Endive (planted 21/4/09)



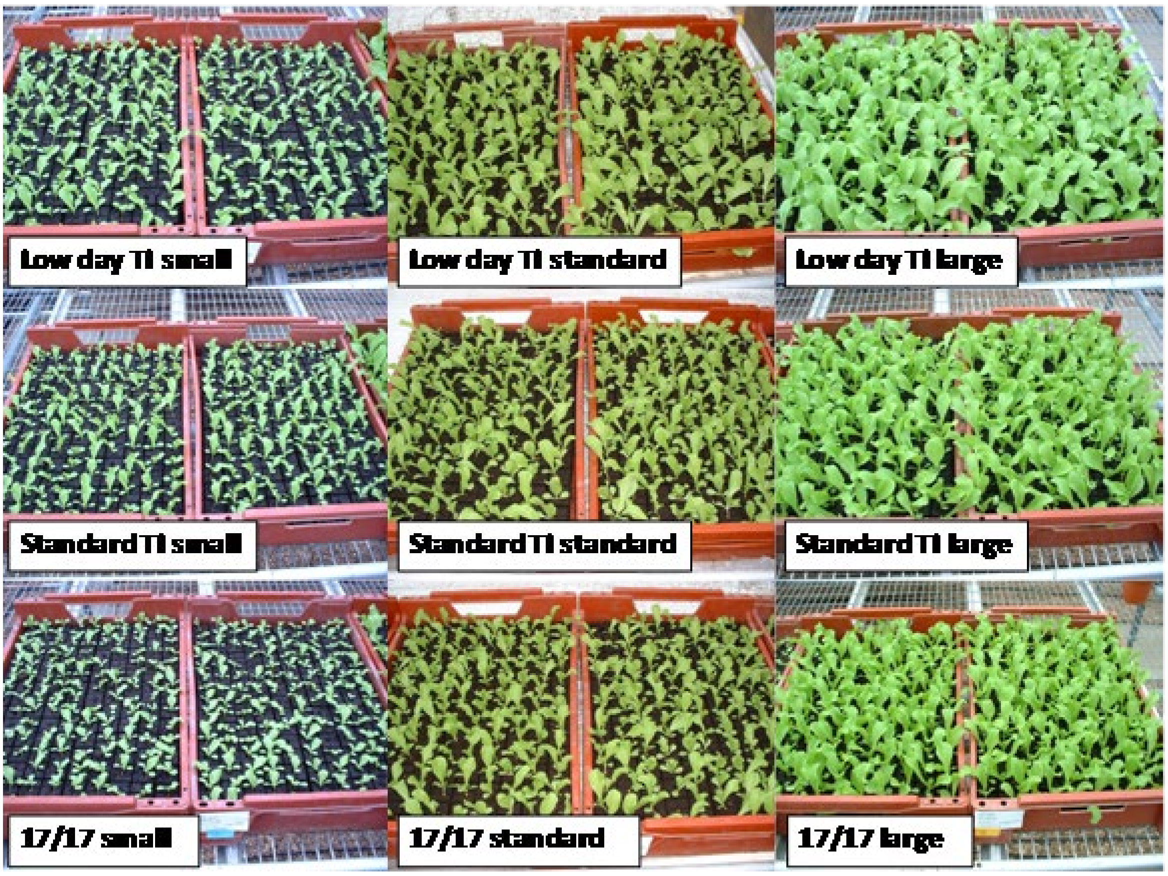
Week 11 Escarole (planted 9-10/3/09)

Week 13 Escarole (planted 23/3/09)

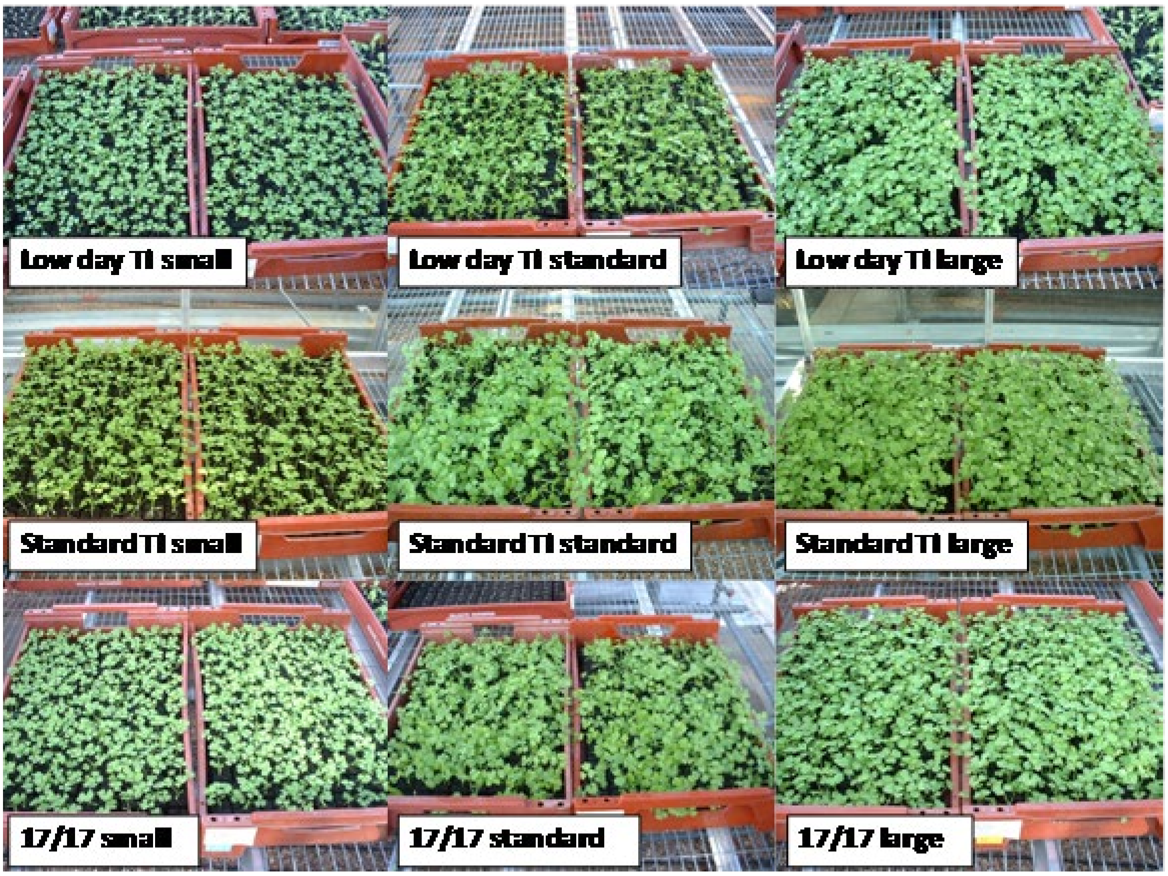


Week 15 Escarole (planted 6-7/4/09)

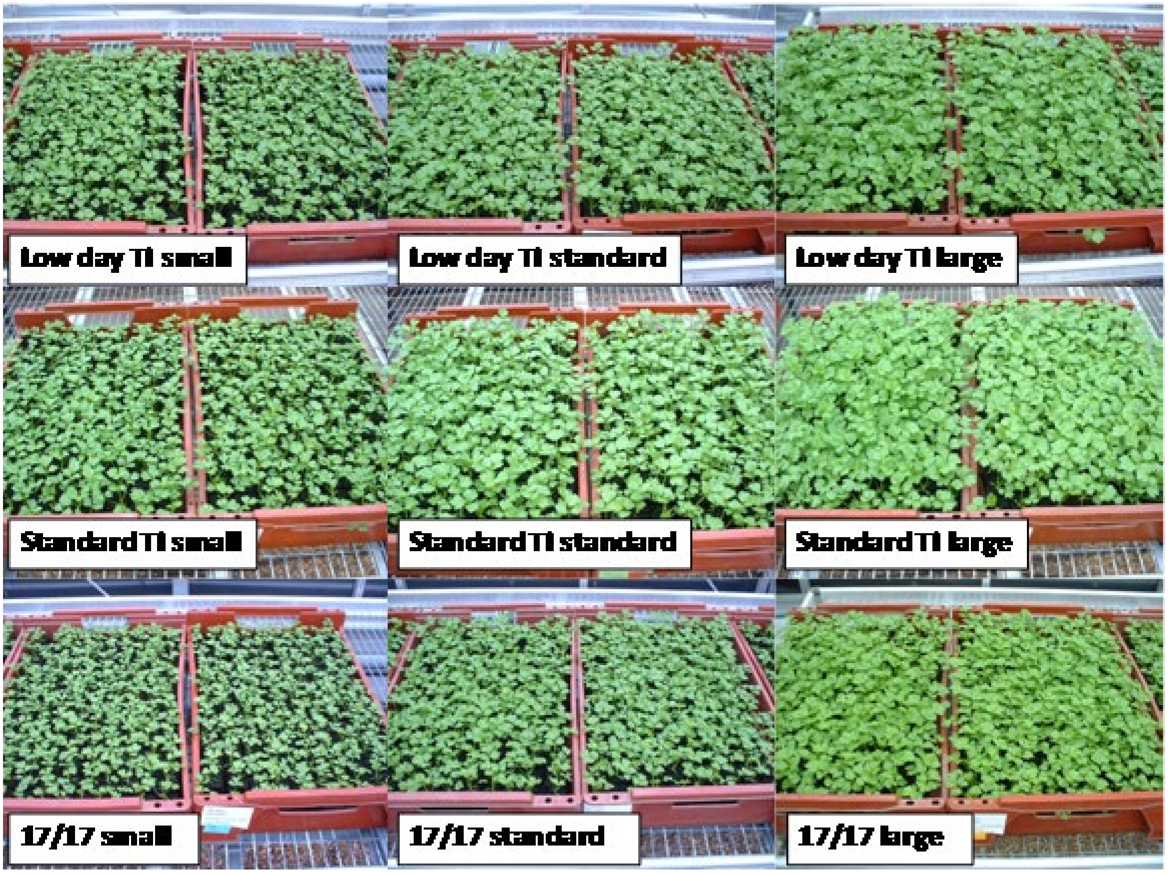
Week 17 Escarole (planted 21/4/09)



Week 11 Celery (planted 9-10/3/09)



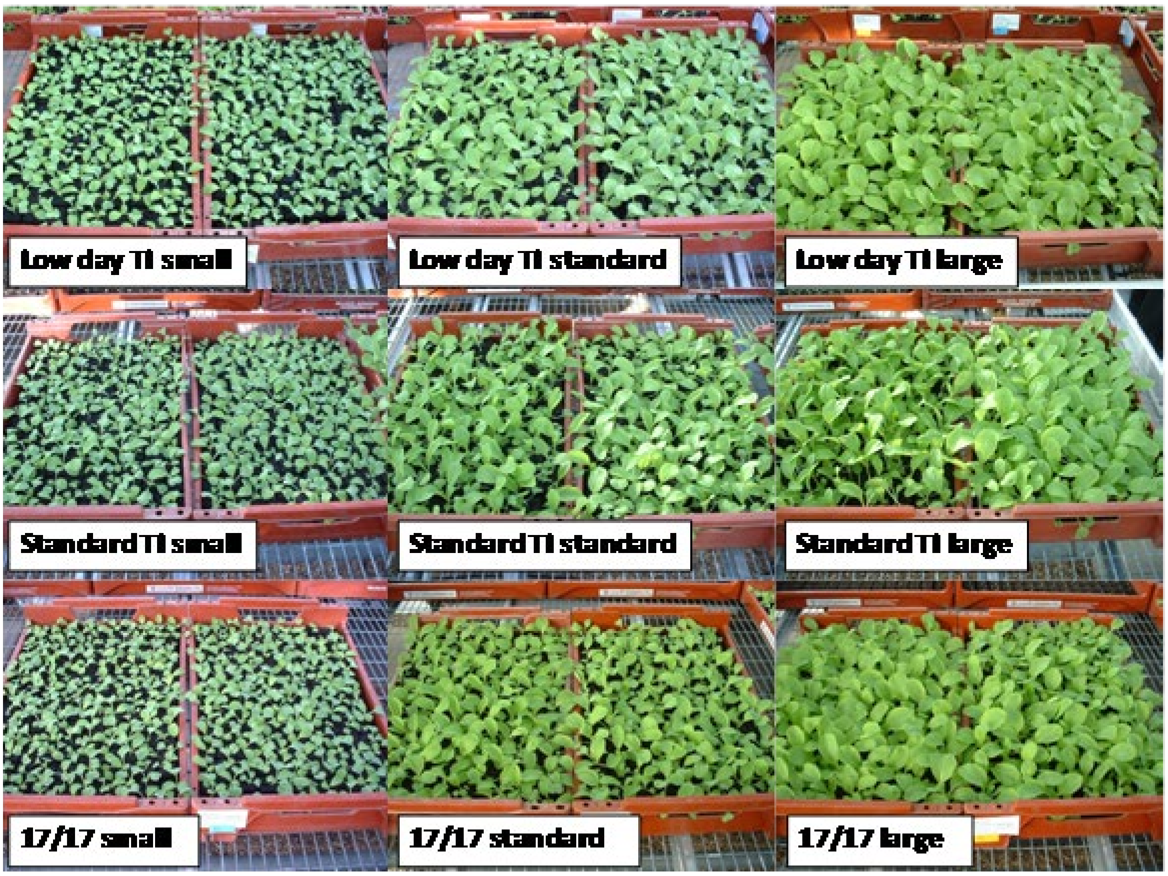
Week 13 Celery (planted 25/3/09)



Week 15 Celery (planted 6-7/4/09)

Week 17 Celery (planted 21/4/09)

Week 11 Chinese cabbage (planted 11-20/3/09)



Week 13 Chinese cabbage (planted 26/3/09)

Week 15 Chinese cabbage (planted 6-7/4/09)

Week 17 Chinese cabbage (planted 22/4/09)