Project title	Optimising the propagation environment for endive, escarole, celery and Chinese cabbage
Project number:	FVPC 311
Project leader:	Dr Debbie Fuller, Warwick HRI
Report:	Annual report, November 2007
Previous report	
Key staff:	Mrs Jayne Akehurst Mrs Angela Hambidge Mr Geoff Clarke Miss Leanne Cozens
Location of project:	Warwick HRI J.E. Piccaver & Co., Lincolnshire. G S Shropshires, Cambridgeshire
Project coordinator:	Mr David Norman
Date project commenced:	01 January 2007
Date project completed (or expected completion date):	December 2009
Key words:	Endive, escarole, celery, Chinese cabbage, propagation, temperature, energy saving, mechanical transplanting

Signed on behalf of: WarwickHRI

Simon Bright

Signature: ………………………………………………………………………………………

Name: Professor Simon Bright
(Director and Head of Department)

Date: …………………………29 January 2008………………………………………

The results and conclusions in this report are based on an investigation conducted over a one-year period. 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.

CONTENTS

Grower Summary

Headline

- Transplanting date and hence temperature in the field had the greatest influence on plant size and bolting at harvest.
- Of the propagation treatments tested, size of plant at transplanting had a greater influence over incidence of bolting than propagation temperature for early season crops of Chinese cabbage, endive and escarole at harvest.
- Celery (cv Victoria) was the least susceptible to bolting of the species assessed.

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 18°C. To delay bolting in the field it is desirable to initiate as many leaves as possible during propagation to maximise vegetative growth prior to the start of bolting when crops have to be harvested in order to meet quality standards.

In conflict with the requirement to maximise leaf number during propagation as outlined above, there is increasing demand for propagators to produce smaller plants which are more compatible with mechanical transplanting. Reducing the production time may increase the risk of bolting as plants will 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 goes against current strategies to reduce bolting. Information is needed so that growers can make informed decisions concerning the trade-off.

Year one of this project aimed to:

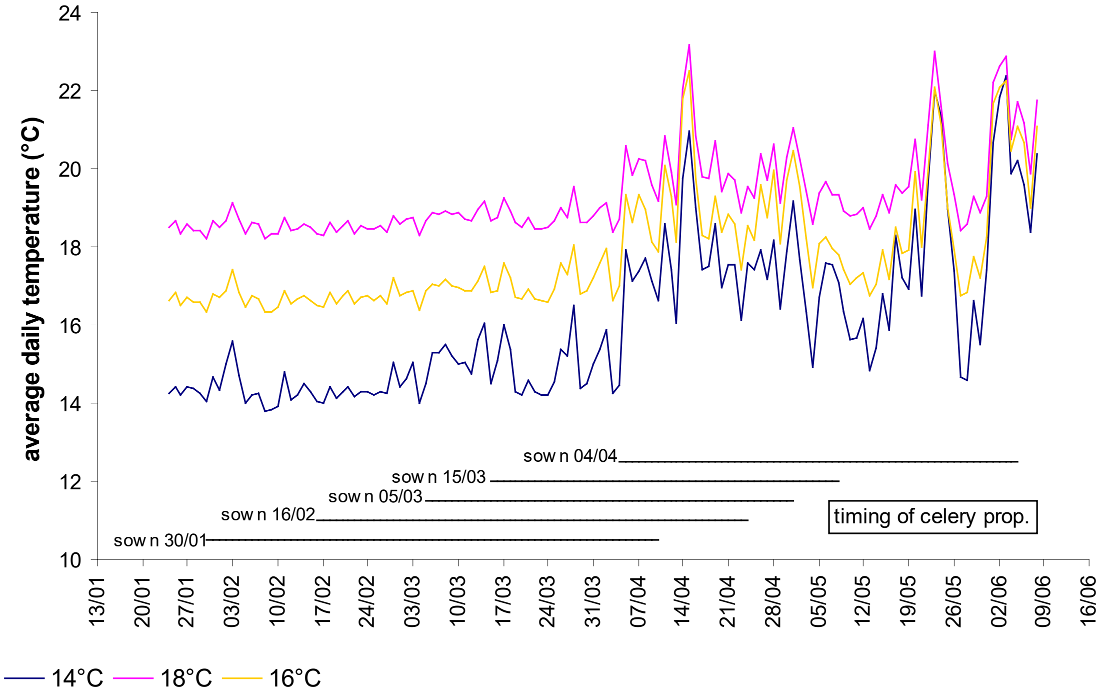
- Determine how incidence of bolting in the field at maturity is affected by lower temperature propagation in order to determine the safe limits for energy saving propagation regimes.

and

- Examine if reducing the size of transplant influences incidence of bolting in the field at maturity and how this interacts with propagation temperature.

Summary of the project and main conclusions

Four species, celery (cv Victoria), endive (cv Barundi), escarole (cv Nuance) and Chinese cabbage (cv 1 Kilo SB) were propagated using heating set-points of 14, 16 or 18°C to assess if reducing glasshouse temperature would increase bolting of plants grown on in the field. Venting was set at 1°C above the heating set point in order to test for the worst case scenario with each of these temperatures. Achieved temperatures are illustrated below along with an indication of how this aligned with batches of celery plants produced for the experiment.



Achieved temperatures in propagation.

Six batches of plants were sown to give a range of planting dates and to test how early to main season production would be affected by lower temperature propagation. The schedule produced material for planting in the field from week 12 to week 34 as detailed below:

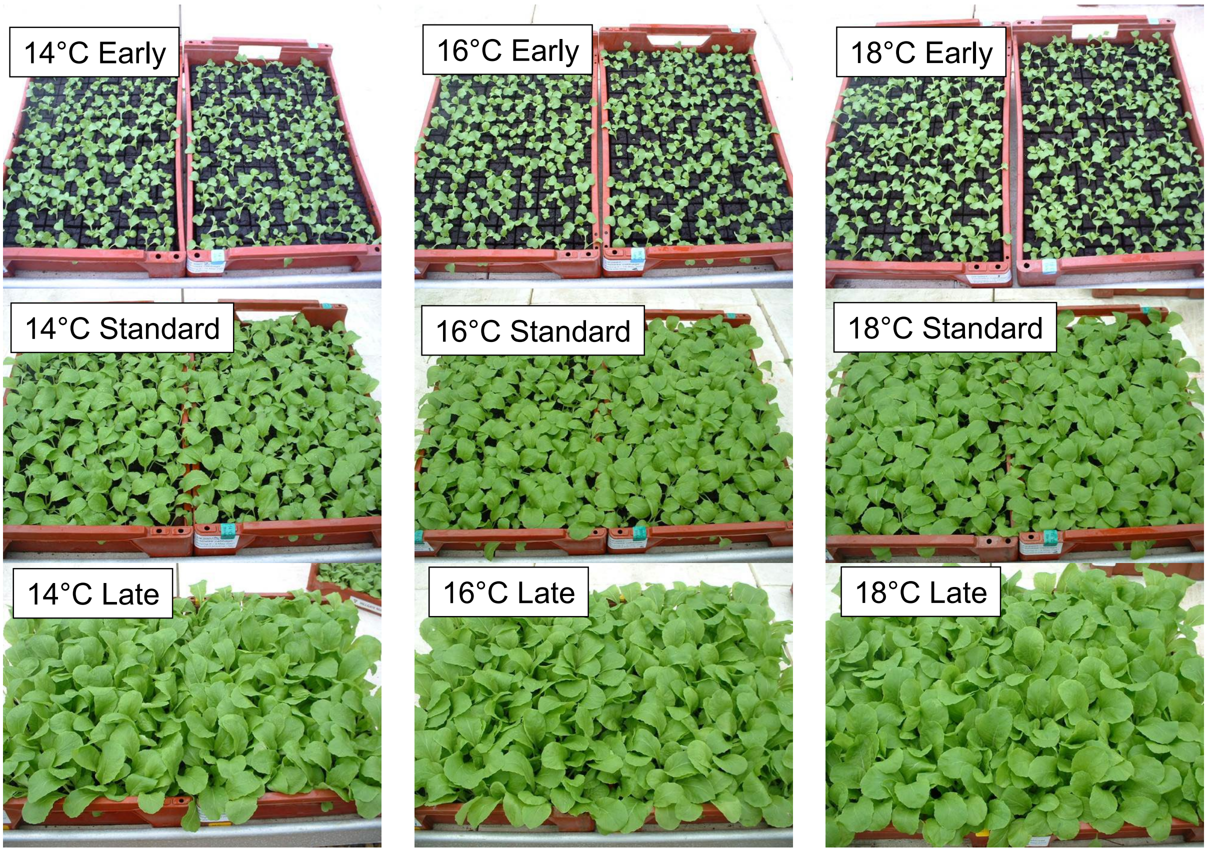
Batch	Sowing date	No. days in heat	Planting date	Harvest date
Celery				
1	30-Jan	50	10-Apr	29-Jun
2	16-Feb	48	24-Apr	23-Jul
3	02-Mar	37	24-Apr	23-Jul
4	12-Mar	33	01-May	30-Jul
5	23-Mar	33	08-May	06-Aug
6	11-Apr	35	05-Jun	21-Aug
Endive and Escarole				
1	06-Feb	31	27-Mar	29-May
2	02-Mar	27	10-Apr	26-Jun
3	14-Mar	24	17-Apr	-
4	29-Mar	18	01-May	-
5	13-Apr	17	08-May	16-Jul
6	01-May	19	05-Jun	02-Aug
Chinese cabbage				
1	06-Feb	24	23-Mar	17-May
2	06-Mar	20	05-Apr	05-Jun
3	22-Mar	17	17-Apr	-
4	05-Apr	12	01-May	-
5	23-Apr	13	17-May	05-Jul
6	09-May	13	05-Jun	26-Jul

For each scheduled planting date, sowings were staggered in order to produce plants at three stages as follows:

1. ‘standard’ size plants - designed to represent the size of plants produced by commercial propagation,
2. ‘late’ plants - sown 1 week earlier to produce larger plants,
3. ‘early’ plants - sown 1 week later than the standard to produce smaller plants.

The temperature and plant stage treatments therefore produced a range of plant sizes at the transplanting stage. As illustrated in the example below for Chinese cabbage, plant stage had the greatest impact on plant size at transplanting. The late stage plants were taller (34%), heavier (120%) and had more leaves (34%) than the standard plants and the early stage plants were shorter (47%), lighter (72%) and had fewer leaves (37%) that the standard stage plants. These trends were reflected in all species grown.

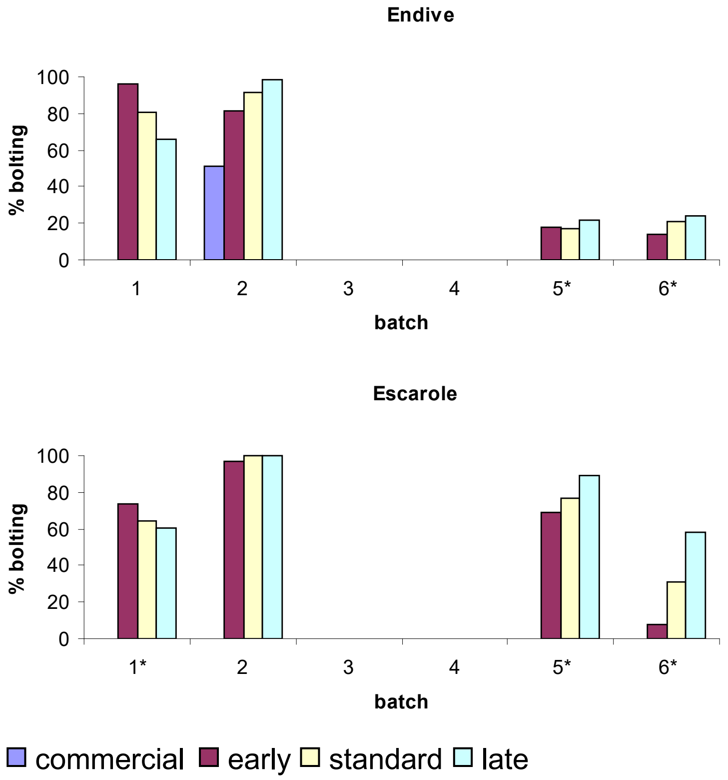
Chinese cabbage planted 05/06



Following propagation in glasshouses at WHRI Wellesbourne, plants were planted out on commercial farms for growing on. Chinese cabbage and celery were grown on at G.S. Shropshires and endive and escarole at J.E. Piccaver & Co. Harvest and therefore final assessment date was determined by the commercial harvesting date for each batch of plants.

Despite the significant variation found in plants at the end of transplanting, Chinese cabbage and celery at the final harvest stage had no significant differences in head weight relating to either propagation temperature or stage of growth at transplanting. The length of apex in plants dissected in half at final harvest, which indicates progression towards bolting, was significantly greater for Chinese cabbage from the first batch planted with propagation at 14°C producing taller apices (22cm) than 16°C or 18°C (16-17cm). Stage of plant growth had a greater influence on this first batch of plants with early stage plants producing taller apices (29cm) than standard (18cm) or late (9cm) stage plants. However early stage plants in this first batch were also transferred out of propagation to weaning earlier than the standard or late stage plants and hence were also exposed to temperatures expected to induce flowering for longer. Schedules planned for 2008 will allow for comparison of different dates of transfer out of the heat from a common sowing date with staggered sowing dates, giving a common date of transfer out of the heat. Neither propagation temperature nor stage of growth at transplanting had a significant influence on later batches planted.

Endive and escarole appeared to be more susceptible to bolting; both propagation temperature and stage of plant growth at transplanting significantly influenced head weight and incidence of bolting at harvest. Propagation at 14°C and 16°C resulted in more bolting (94%+) than propagation at 18°C (45-77%) for the first two batches of endive. For the first batch of endive, an early stage of growth at transplanting resulted in more bolting (96%) than a standard (81%) or late (66%) stage of growth. However for the second batch of endive (planted 10/04/07), there was less bolting from transplanting at an earlier stage of growth than from later stages. Response of escarole to propagation temperature and plant stage followed the same trends as described for endive but with a higher incidence of bolting overall, and particularly for the later batches (planted 08/05/07 and 05/06/07).



** no commercial controls available*

Samples of plants grown constantly in the propagation compartments were also assessed by apical dissection to determine if plants had been initiated. Dissected plants of celery remained vegetative throughout these assessments and few Chinese cabbage plants were found to initiate flowers before the end of May. Endive and escarole eventually initiated flowers in all three propagation temperatures and initiation occurred earlier at 14°C propagation than at 18°C propagation as detailed below.

	Propagation heating set point		
	14°C	**16°C**	**18°C**
Endive	79	93	113
Escarole	79	93	100

Time (days from sowing) to flower initiation from plants sown 06/02/07 and grown in one of three propagation temperatures.

By comparison, transplanting from this sowing date was at 35 days from sowing. Therefore all plants were vegetative prior to transplanting. It is clear from the above table however, that plants grown at 14°C had progressed further towards flowering than those grown at higher temperatures and hence could be expected to bolt in the field earlier if exposed to the same average temperatures after transplanting.

A good linear relationship was found between rate of initiation (i.e. the reciprocal of days to initiation) and average temperature for endive. The model generated from this data can therefore be used to predict rate of initiation for other temperatures within the range used in experiments (i.e. achieved average temperatures of 14 to 19°C).

Similar analyses were also carried out for total leaf number (i.e. number of visible leaves plus number of microscopic leaf primordia) of endive against average temperature which also produced a good linear relationship for data collected from 30 to 79 days from sowing. Whilst further work is needed to extend the range of this model, there is potential to use this approach to predict leaf number in propagation at different temperatures.

Taking the two models together a grower could evaluate how propagation temperature will influence progression towards flowering (i.e. by predicting expected time of initiation) and evaluate if this is likely to result in bolting before the normal length of time for production in the field. Furthermore they could predict how many leaves a plant will have initiated by the end of propagation or at final harvest to evaluate impact on plant size (this data could be referenced against expected leaf number for a mature head of acceptable size for marketing). This approach could be used to decide on suitable temperature strategies for optimising energy inputs without compromising quality.

The modelling approach described above has been used to illustrate approaches that might be taken in order to help with future propagation planning. At present, data collected from apical dissection was limited by the incidence of flower initiation, which only occurred in all three temperature treatments for the first batch of endive and escarole. The relationships for endive produced better fits than for escarole and the data range is limited to the temperature range and age of plants used in experiments. If there is sufficient grower interest in this approach, further development including expanding the range of the models and validating them could be explored.

Financial benefits

It is too early to make predictions of figures at this stage of the project; however there appears to be potential for energy savings for lower propagation temperatures for celery and Chinese cabbage propagation at least from year 1 data. Furthermore if provisional models generated can be effectively used for prediction of initiation in the field there may be potential to improve the timing of harvests to minimise bolting whilst maximising plant size and hence head weight.

Lower temperature propagation produced less bolting than originally expected for celery and Chinese cabbage in particular in year 1 of this project. The potential for further energy savings through the use if fluctuating temperatures will be explored in year two with minimum night temperatures as low as 10°C. This work will also focus more on early season production with planting week 10 to 17 planned.

Action points for growers

- Whilst propagation at lower temperatures (down to 14°C heat set point) did not initiate flowers before the time that plants would be transplanted, the risk of bolting in the field was increased in endive and escarole in particular. Chinese cabbage and celery appear to have a lower temperature range for flower induction.

- Provisional models produced from apical dissections in year one show potential for assisting with propagation management. Further data collection and validation would be required if this approach is of interest to growers.

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 18°C and to delay bolting in the field it is desirable to initiate as many leaves as possible during propagation to maximise vegetative growth prior to the start of bolting when crops have to be harvested in order to meet quality standards.

With the rapid increase in gas and oil prices there is increasing pressure to reduce energy use but there is a fear that reducing production temperatures may increase the risk of bolting, however, little information is available. Temperature integration (TI) which allows fluctuation in instantaneous temperatures providing longer term averages are met, has successfully been adopted for various protected crops. Temperatures which rise above conventional set-point levels due to solar gain are offset against lower temperatures in overcast weather or at night when heat would have been required, which reduces the amount of heating required from the boiler. In crops tested so far, the risks of using temperature integration have been related to yield, timing and quality. However crops susceptible to bolting have not been considered and so it is unclear whether allowing greater temperature fluctuations and, therefore, short periods of low temperature will increase the risk of bolting.

In conflict with the requirement to maximise leaf number during propagation as outlined above, there is increasing demand for propagators to produce smaller plants which are more compatible with mechanical transplanting. Reducing the production time may increase the risk of bolting as plants will 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 goes against current strategies to reduce bolting. Information is needed so that growers can make informed decisions concerning the trade-off.

Whilst studies relating to temperature integration and bolting are lacking, there is information from the literature regarding flower initiation of in 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 since differences in apex height after propagation were maintained under a range of environmental conditions after transplanting. The aim of commercial propagators is therefore 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 is particularly important that transplants are either juvenile or vegetative with minimum progression towards flowering when planted out. Crop management may 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 although effective temperatures and duration of vernalization varies with cultivar and also daylength. Once vernalized, flowering is then hastened by long days (LD). Devernalization can also occur however which suggests the high-day / low-night temperature regimes 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 the predominant factor influencing flowering in celery with temperatures above 14°C required to prevent vernalization and with devernalization possible at high temperature. LDs during vernalization of celery prevent bolting but then after vernalization, LDs promote bolting; since propagation temperatures are designed to prevent vernalization 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 vernalization 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 vernalization, 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 devernalizing 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 vernalized), 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 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.

Experiments in year 1 of the project were therefore designed to examine how propagation temperature using conventional set-points and planting stage (i.e. size of plant at transplanting) would influence incidence of bolting in transplanted material of four bolting susceptible species.

Materials and methods

Treatments:

Three internal 43m² glasshouse compartments of a linear array were set to one of the propagation temperature treatments (14, 16 or 18°C heating set-point).

Sowing dates were scheduled (based on 2006 data from a commercial nursery) to produce plants suitable for planting out on six occasions over the early to main season production period.

To produce different sizes at transplanting, plants within each batch sown were grown to three different stages, trays were sown either on the predicted date from commercial scheduling data to produce plants of a standard stage of development at planting out; a week earlier than the predicted date producing larger plants at a late stage of development when planted out and a week later than the predicted date, producing smaller plants at an early stage of development.

It was necessary to adjust schedules as the season progressed in order to account for differences in plant vigour under changing environmental conditions; hence the actual schedule for sowing and planting is given in table 1. Germination times were 5 days for celery, 4 days for endive and escarole and 3 days for Chinese cabbage. A weaning period of 5 days was given at the start of the season and this was reduced to 3 days for the later batches planted.

Table 1. Overview of key scheduling dates for 2007 experiments; No. days in heat refers to time spent in each temperature treatment excluding time for germination and weaning.

	Sowing date			**No. days in ‘heat’**			**Planting date**		
batch	**early**	**std**	**late**	**early**	**std**	**late**	**early**	**std**	**late**
Celery									
1	30-Jan	30-Jan	30-Jan	43	50	57	10-Apr	10-Apr	10-Apr
2	16-Feb	16-Feb	16-Feb	40	48	51	24-Apr	24-Apr	24-Apr
3	09-Mar	02-Mar	16-Feb	29	37	51	24-Apr	24-Apr	24-Apr
4	19-Mar	12-Mar	05-Mar	26	33	40	01-May	01-May	01-May
5	30-Mar	23-Mar	15-Mar	26	33	40	08-May	08-May	08-May
6	18-Apr	11-Apr	04-Apr	28	35	42	05-Jun	05-Jun	05-Jun
Endive and Escarole									
1	06-Feb	06-Feb	06-Feb	24	31	38	27-Mar	27-Mar	27-Mar
2	09-Mar	02-Mar	23-Feb	20	27	34	10-Apr	10-Apr	10-Apr
3	21-Mar	14-Mar	07-Mar	17	24	31	17-Apr	17-Apr	17-Apr
4	05-Apr	29-Mar	22-Mar	11	18	25	01-May	01-May	01-May
5	20-Apr	13-Apr	05-Apr	10	17	25	08-May	08-May	08-May
6	08-May	01-May	24-Apr	12	19	26	05-Jun	05-Jun	05-Jun
Chinese cabbage									
1	06-Feb	06-Feb	06-Feb	17	24	31	23-Mar	23-Mar	23-Mar
2	13-Mar	06-Mar	23-Feb	13	20	28	05-Apr	05-Apr	05-Apr
3	29-Mar	22-Mar	15-Mar	10	17	24	17-Apr	17-Apr	17-Apr
4	13-Apr	05-Apr	30-Mar	7	12	18	01-May	01-May	01-May
5	30-Apr	23-Apr	16-Apr	8	13	20	17-May	17-May	17-May
6	15-May	09-May	02-May	7	13	20	05-Jun	05-Jun	05-Jun

Initial plans were to sow seed on a common date and then stagger their movements to weaning and planting out to give differences in planting stage. Hence trays for the first batch of plants were sown on the same day and were moved to the weaning area until all trays from the batch were ready for planting out. This approach was changed for subsequent plantings by staggering sowing date so that plants were moved out of the heat of propagation at the same time and hence received comparable external environmental conditions.

The effects of the three propagation temperature 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

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

An extra set of trays for each species and temperature combination were sown alongside the first, third and fifth batch of plants to provide material for routine apical dissection in order to assess when plants initiated. These plants were held in each temperature treatment for as long as possible, or until 100% of plants sampled were found to be floral.

Details of agronomy and environmental control

Seed sourced from commercial suppliers (and pre-germinated in the case of celery) were sown in standard peat blocks produced by Hillgate Nursery, Terrington St Clement 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. In practise this gave germination times of 5, 4, 4 and 3 days for celery, endive, escarole and Chinese cabbage respectively.

Glasshouse heat set-points were 14°C, 16°C or 18°C. Venting was +1°C above heating temperature in all compartments to ensure that the low temperature treatments dropped as low as possible to test worst case scenarios for low heating set point. Thermal screens were set to close at dusk and open at dawn each day to reduce energy consumed in night time heating.

Trays remained in treatments until plants were considered ready for transplanting based on size against reference photographs as well as the predicted scheduling data mentioned previously. In practise, actual schedules were slower than predicted schedules for early sowing dates but adjustments made to allow for slower production early on, over compensated for later batches under improving external conditions (light and temperature in particular).

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 root aphid for any batches planted out after 1st March (and therefore without fleece covers)
>
> Endive and escarole - Rovral WP spray in the week before planting
>
> Celery - Amistar and Bravo, applied a week apart starting two weeks from weaning.

Once removed from heated glasshouse compartments, trays were weaned in polythene tunnels with frost protection heating only. Length of weaning varied according to planting date and became progressively shorter as the season progressed (see table 1 for actual scheduling data).

After weaning, plants were transported to the commercial sites for planting out. Celery and Chinese cabbage were planted at Piccavers and endive and escarole were planted at Shropshires. Blocks were planted into field plots using pre-dibbed holes at one site, or by creating space to plant blocks manually at the other site. In both 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 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.

Batches of plants transplanted before the end of May were covered with fleece after planting out for frost protection; later batches had no fleece protection after planting out.

Experimental layout:

Propagation treatments were given in three 43 m² glasshouse compartments in a linear array. The compartment with highest temperature treatment was in the centre of the three with the lower temperatures on either side. The benches in each of the glasshouse compartments were divided in half lengthways with each half bench dedicated to a species (figure 1). 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/propagation temperature. Trays sown to provide material for apical dissection were grown on a narrow side bench in each compartment.

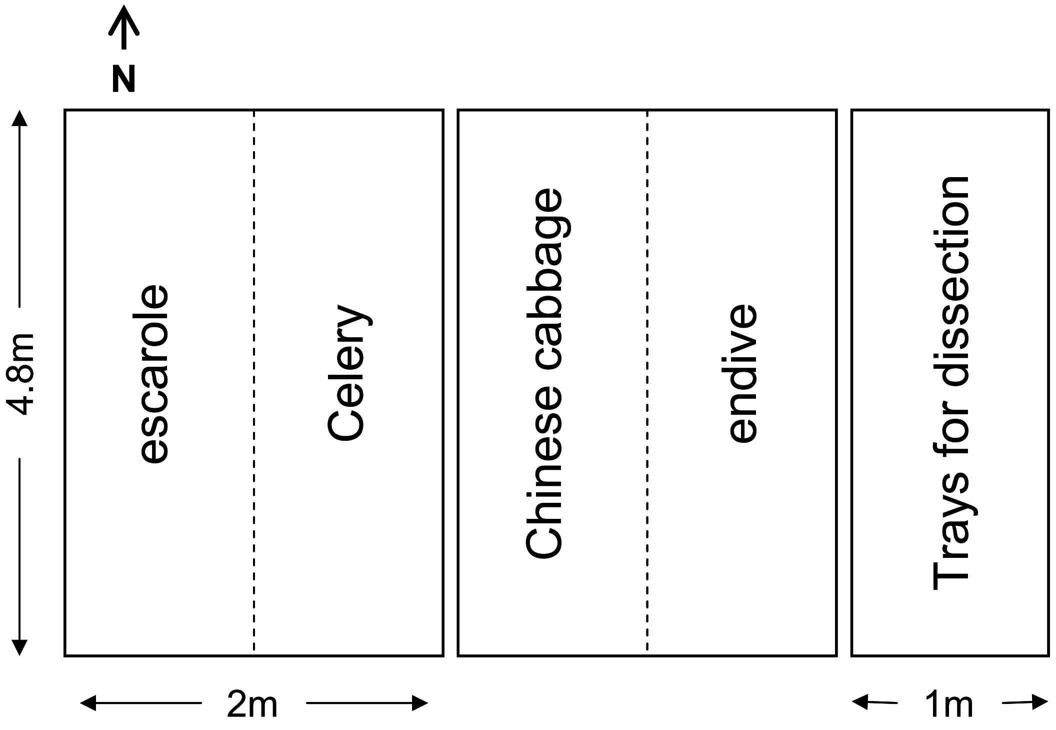
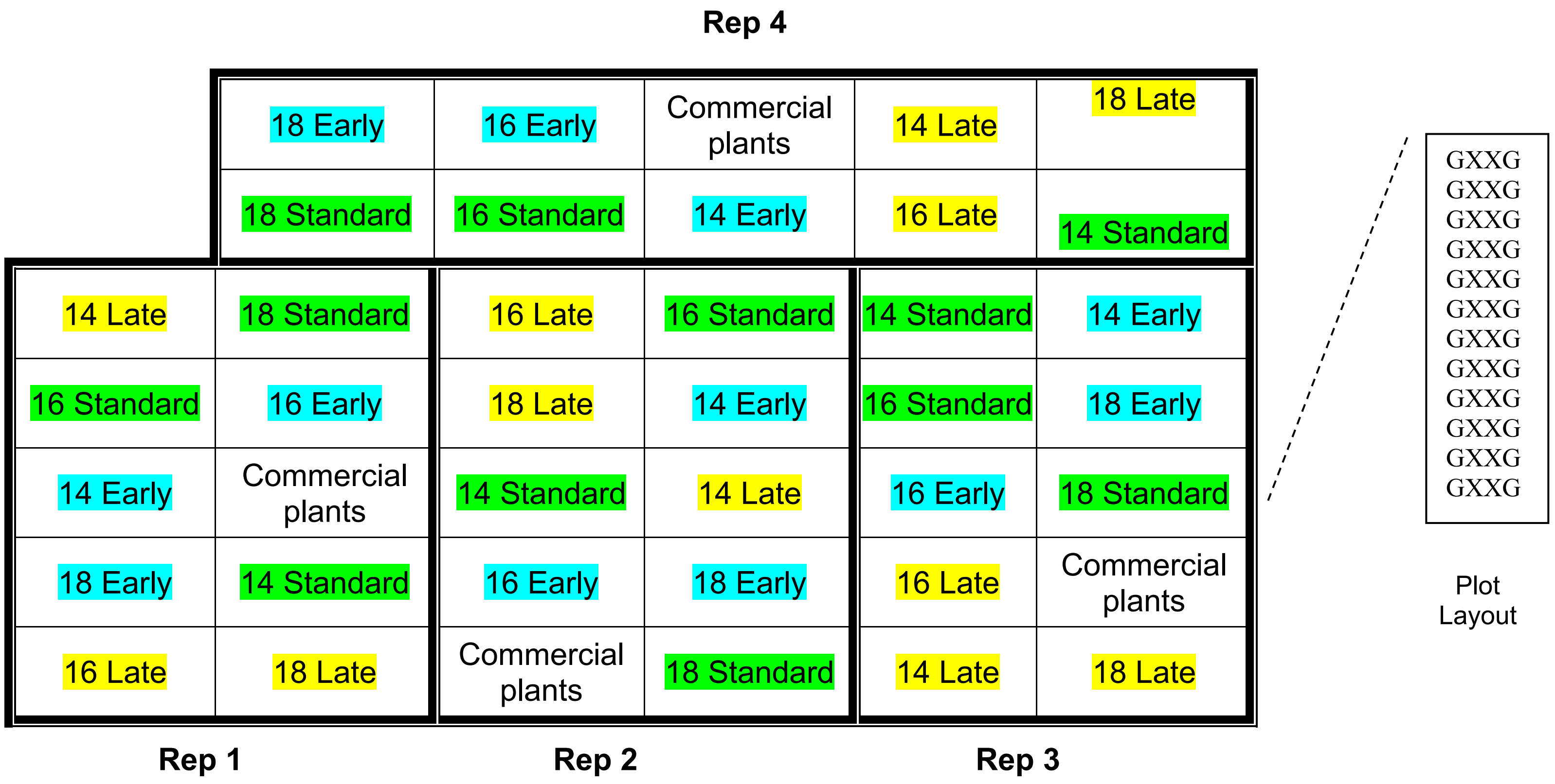


Figure 1. Plan of propagation compartments

The bed layout in the field was different on each site due to differences in bed preparation. At Piccavers a triple bed former, which pre-dibbed holes for planting had been used which produced 6 beds with 4 staggered rows per bed. At Shropshires prepared beds were in rows of 12 rows wide and were not pre-dibbed. An example of the plan for each site is given in figures 2 and 3, but slight changes were necessary at each planting date.

All plantings were laid out using a randomised block design where each of the four blocks had a complete set of treatments as well as a plot of commercially raised plants. Individual 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.



Rep 4

18 Early	16 Early	Commercial plants	14 Late	18 Late
18 Standard	16 Standard	14 Early	16 Late	14 Standard

14 Late	18 Standard	16 Late	16 Standard	14 Standard	14 Early
16 Standard	16 Early	18 Late	14 Early	16 Standard	18 Early
14 Early	Commercial plants	14 Standard	14 Late	16 Early	18 Standard
18 Early	14 Standard	16 Early	18 Early	16 Late	Commercial plants
16 Late	18 Late	Commercial plants	18 Standard	14 Late	18 Late
Rep 1		Rep 2		Rep 3	

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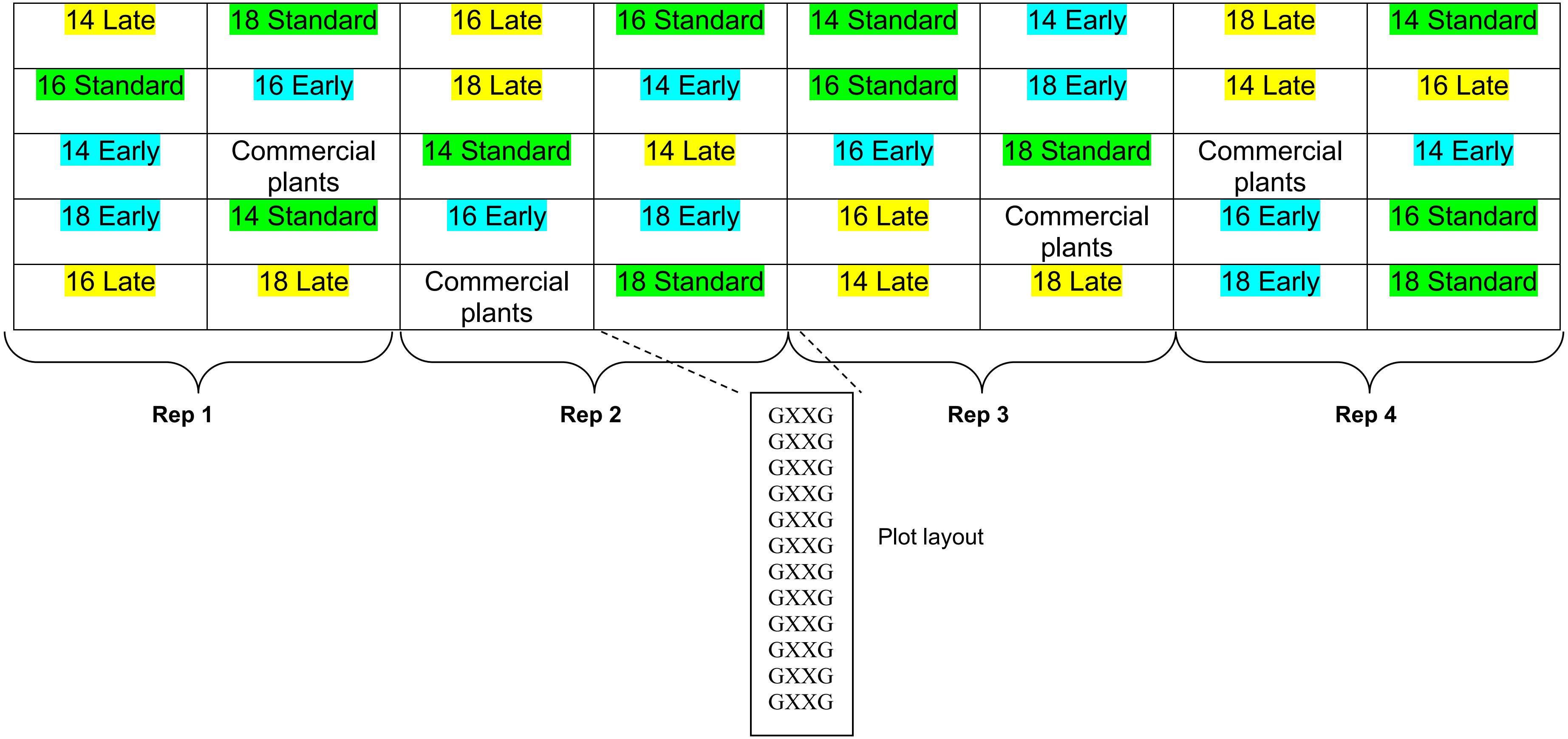
Plot Layout

Figure 2. Plan of plot design at Piccavers. 14, 16 and 18 represent propagation heating set-point; early, standard and late refer to stage of plant development at planting out. G represents guard plants and X represents plants sampled for assessment in the detailed plot layout plan.



14 Late	18 Standard	16 Late	16 Standard	14 Standard	14 Early	18 Late	14 Standard
16 Standard	16 Early	18 Late	14 Early	16 Standard	18 Early	14 Late	16 Late
14 Early	Commercial plants	14 Standard	14 Late	16 Early	18 Standard	Commercial plants	14 Early
18 Early	14 Standard	16 Early	18 Early	16 Late	Commercial plants	16 Early	16 Standard
16 Late	18 Late	Commercial plants	18 Standard	14 Late	18 Late	18 Early	18 Standard

Figure 3. Plan of plot design at Shropshires. 14, 16 and 18 represent propagation heating set-point; early, standard and late refer to stage of plant development at planting out. G represents guard plants and X represents plants sampled for assessment in the detailed plot layout plan.

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.

Plants were continuously monitored for development using reference photographs of commercial plants to assist in checking speed of development against the predicted schedule.

Plant assessments were made prior to transplanting, recording the following parameters:

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

A photographic record was kept of plant size for each of the three plant development stages (early, standard and late) and also of all treatments in trays prior to transplanting.

Plants from the first, third and fifth batches of plants sown were also dissected at regular intervals to check for floral initiation (minimum sample size of 5 plants). Dissections continued until a treatment was considered to have reached 100% initiation or the experiment had finished (i.e. glasshouse compartments were emptied when propagation of the main treatments had been completed). Measurements made during dissection included:

- State of the growing point (vegetative or floral)
- Shoot fresh weight
- Visible leaf number (leaves above 1cm)
- Microscopic number of leaf primordia.

Final assessments in the field were made approximately one week after commercial plants surrounding each plot were ready for harvest, recording the following parameters:

- Number of plants per plot bolted
- Head weight
- Apex length of plants dissected longitudinally (celery and Chinese cabbage)

Results

Scheduling data

The actual timings in propagation at each of the three temperatures varied according to transplanting date (i.e. batch). The first batch of plants required longer in treatments than was predicted from 2006 commercial schedules, the reasons for these differences are considered along with logged glasshouse temperatures in the following section. Additional time built into schedules to allow for the discrepancies with the first batch of plants was subsequently reduced as propagation times decreased at a greater rate than anticipated as the season progressed. Table 1 (repeated from materials and methods section) summarises key scheduling dates for the experiment.

Table 1. Overview of key scheduling dates for 2007 experiments; No. days in heat refers to time spent in each temperature treatment excluding time for germination and weaning.

	Sowing date			**No. days in 'heat'**			**Planting date**		
batch	**early**	**std**	**late**	**early**	**std**	**late**	**early**	**std**	**late**
Celery									
1	30-Jan	30-Jan	30-Jan	43	50	57	10-Apr	10-Apr	10-Apr
2	16-Feb	16-Feb	16-Feb	40	48	51	24-Apr	24-Apr	24-Apr
3	09-Mar	02-Mar	16-Feb	29	37	51	24-Apr	24-Apr	24-Apr
4	19-Mar	12-Mar	05-Mar	26	33	40	01-May	01-May	01-May
5	30-Mar	23-Mar	15-Mar	26	33	40	08-May	08-May	08-May
6	18-Apr	11-Apr	04-Apr	28	35	42	05-Jun	05-Jun	05-Jun
Endive and Escarole									
1	06-Feb	06-Feb	06-Feb	24	31	38	27-Mar	27-Mar	27-Mar
2	09-Mar	02-Mar	23-Feb	20	27	34	10-Apr	10-Apr	10-Apr
3	21-Mar	14-Mar	07-Mar	17	24	31	17-Apr	17-Apr	17-Apr
4	05-Apr	29-Mar	22-Mar	11	18	25	01-May	01-May	01-May
5	20-Apr	13-Apr	05-Apr	10	17	25	08-May	08-May	08-May
6	08-May	01-May	24-Apr	12	19	26	05-Jun	05-Jun	05-Jun
Chinese cabbage									
1	06-Feb	06-Feb	06-Feb	17	24	31	23-Mar	23-Mar	23-Mar
2	13-Mar	06-Mar	23-Feb	13	20	28	05-Apr	05-Apr	05-Apr
3	29-Mar	22-Mar	15-Mar	10	17	24	17-Apr	17-Apr	17-Apr
4	13-Apr	05-Apr	30-Mar	7	12	18	01-May	01-May	01-May
5	30-Apr	23-Apr	16-Apr	8	13	20	17-May	17-May	17-May
6	15-May	09-May	02-May	7	13	20	05-Jun	05-Jun	05-Jun

Environmental data

Early in the season (January to March), average temperatures in the three propagation treatments remained close to the desired set-points and good separation was maintained between treatments (figure 4). As external temperature and light levels increased from the beginning of April, achieved daily (24 hour) average temperature began to exceed set point temperature and differences between treatments decreased. Hence batches of plants sown early and finished before or close to the end of March (i.e. the first three batches of each species) received a greater difference in propagation temperature than those sown later. Figure 4 includes temperature data along with timelines showing how changes in temperature coincided with the production of each batch of celery plants sown, similar data for endive, escarole and Chinese cabbage are given in Appendix 1.

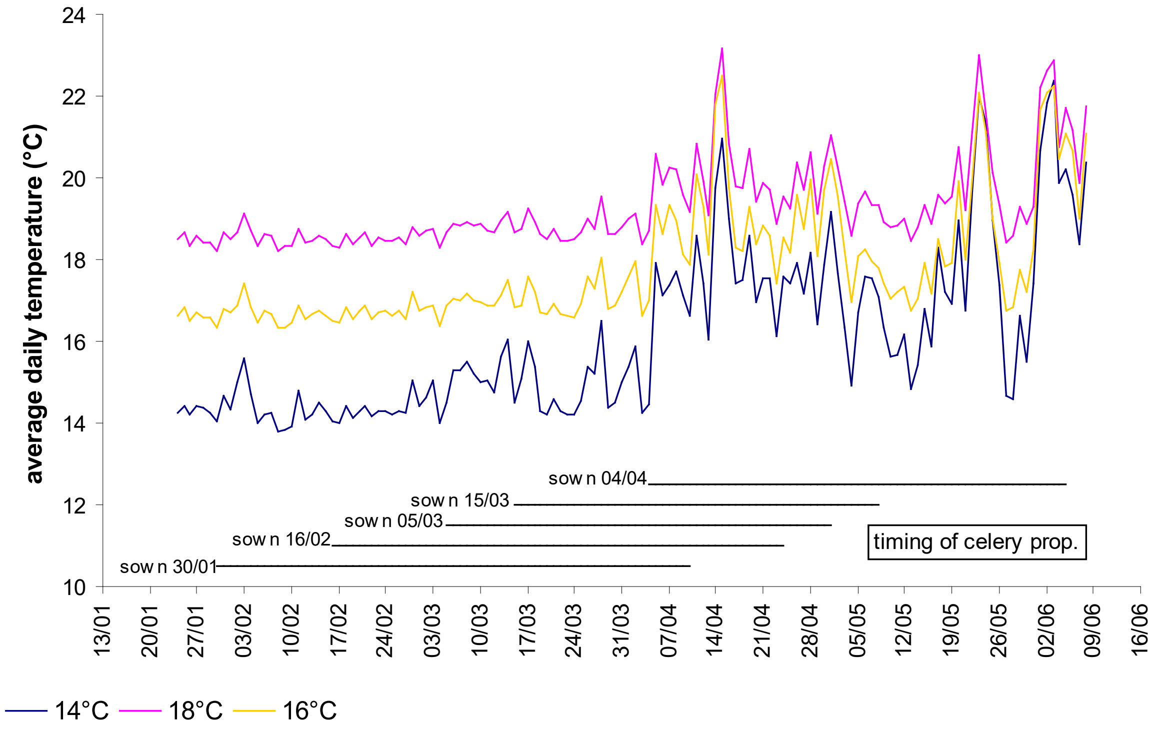


Figure 4. Achieved temperatures in propagation compared with the timing of propagation of batches of celery plants.

Temperatures logged in aspirated screens at a commercial propagating nursery were closest to the highest temperature treatment (18°C) in experiments at Wellesbourne (figure 5). In experiments, vents were set to start opening from 1°C above the heating threshold which would reduce average achieved temperature in comparison with a more typical set point of around 20-22°C for 17.5-18°C heat set point that would be used commercially.

Differences between actual schedules in the 2007 experiments and the predicted schedules based on commercial schedules from 2006 may be related to the lower achieved temperatures in two of the three treatments at Wellesbourne. Furthermore, to ensure plants received comparable climate after moving out of the heat and on to weaning and planting, plants from any one stage (early, standard or late) were transferred from all three temperature treatments to weaning on the same day. This inevitably meant there was some compromise on timing the move to ensure plants at the lowest temperature had sufficient growth to withstand the lower temperatures after transfer which added to the delays experienced with the schedule.

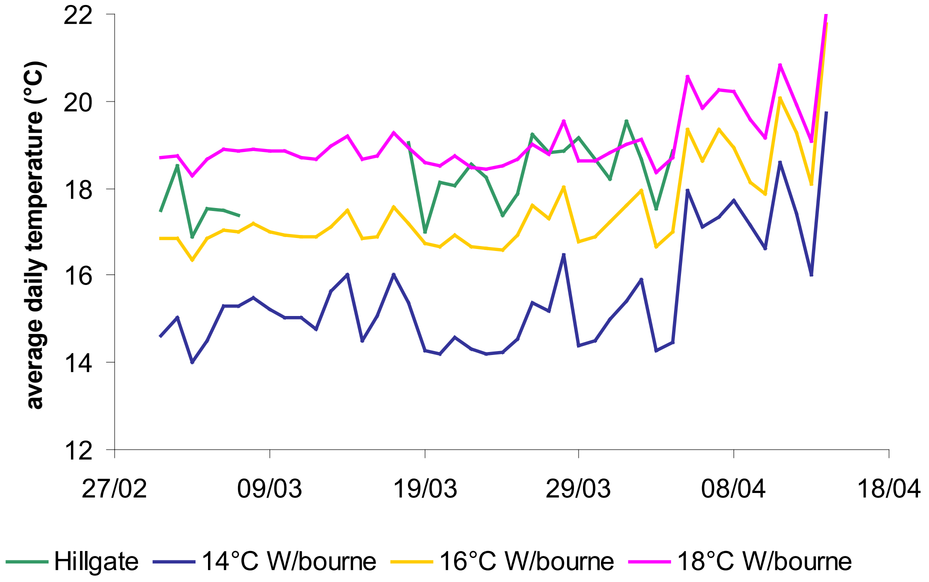


Figure 5. Comparison of temperatures achieved in experiments with a commercial nursery.

Average temperature correlating to the period of production in the field (i.e. from planting to harvesting) varied with planting date from 11.9°C for the earliest crop of endive and escarole (planting 27/03/07) to 15.3°C for the latest crop planted (figure 6). Minimum average daily (i.e. 24 hour) temperature was 7.1°C. Overall, early season temperatures were considered to be above average.

Average temperatures correlating to the later batches of Chinese cabbage and celery (figure 7) were comparable with those logged at the site producing the escarole and endive; unfortunately there is a gap in the early season data for this site resulting from a logger failure.

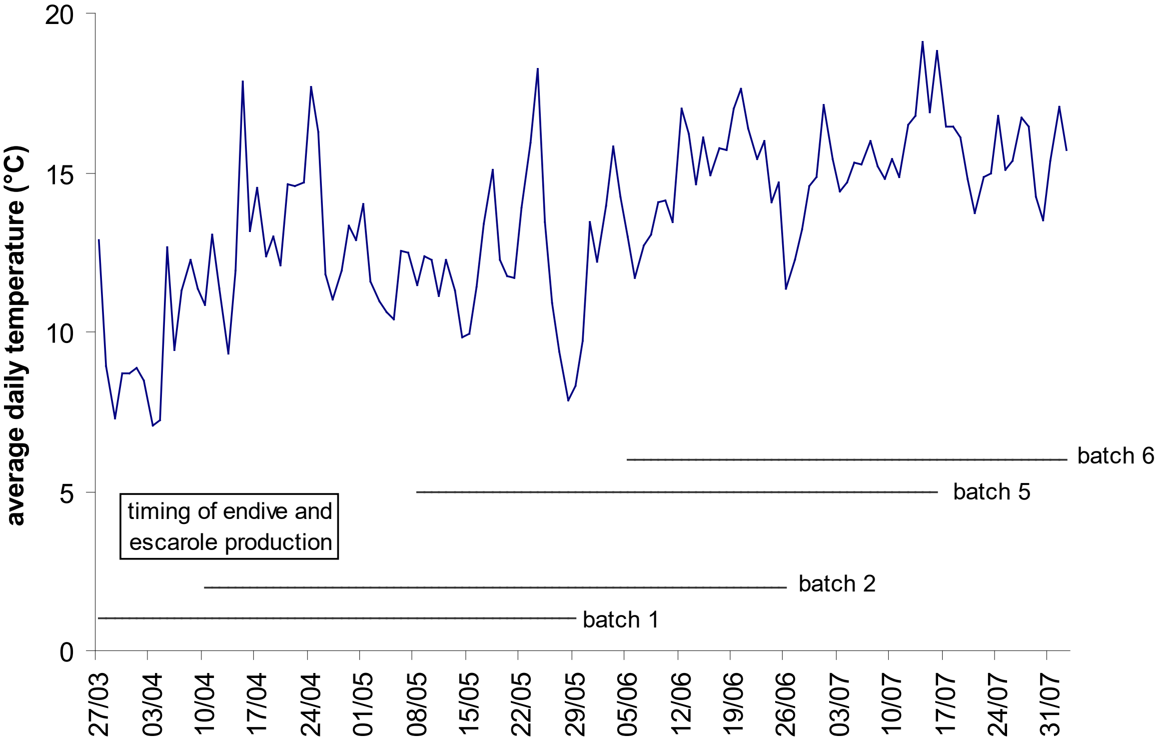


Figure 6. Average temperatures during field production compared with the timing of propagation of batches of endive and escarole plants.

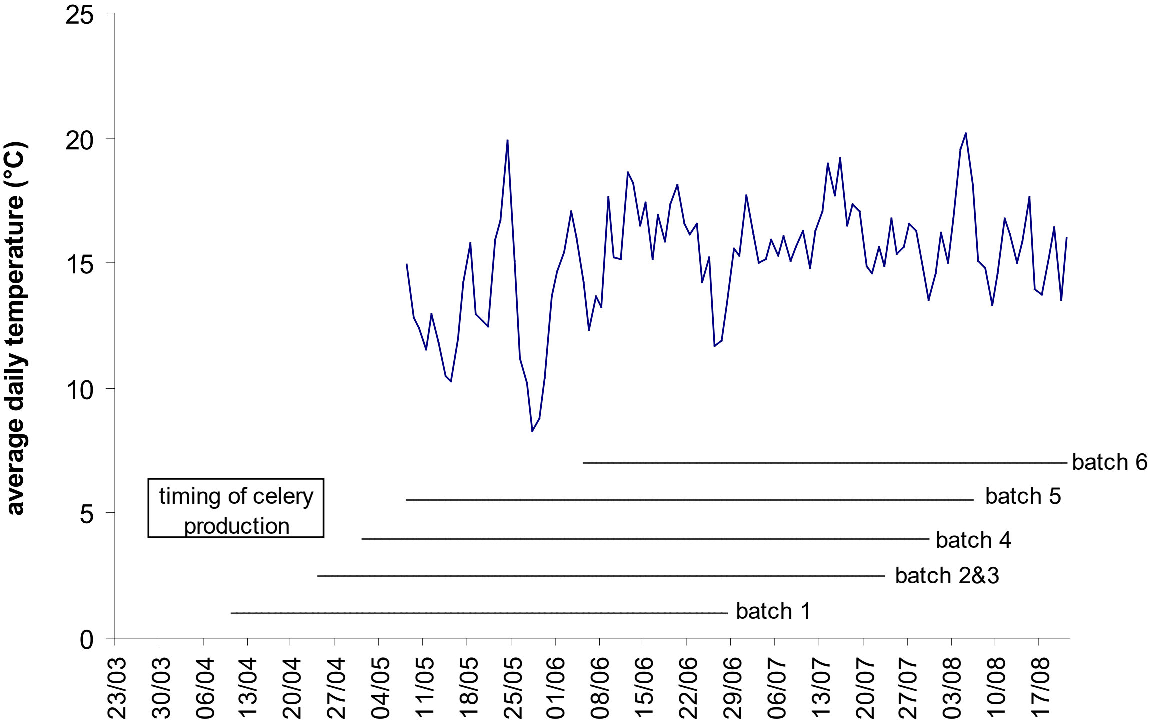


Figure 7. Average temperatures during field production compared with the timing of propagation of batches of celery plants.

Dissection data

Plants from the first, third and fifth sowing dates were grown continuously within the glasshouse compartments whilst the main experiment was ongoing to determine when plants would initiate within each of the three temperature treatments. Many of the batches of plants failed to show signs of initiation before the main treatments were completed at the end of May when plants had to be removed from the glasshouse compartments for the end of the experiment.

Floral initiation

From apical dissection assessments, celery apparently remained vegetative throughout the time that plants were raised in the glasshouse compartments. Hence for the earliest sowing date (30/01/07), there were no signs of initiation after 128 days from sowing for plants in the lowest temperature treatment (14°C heat set point or 16.1°C achieved temperature over the total time in the glasshouse compartment). This period of study exceeds the expected length of time for propagation with the longest propagation period being 55 days from sowing for plants of a normal commercial size (i.e. the standard planting stage).

Only plants grown in the 14°C treatment from the first batch (sown 06/02/07) of Chinese cabbage initiated within controlled conditions; 100% initiation occurred at around 86 days from sowing (from an achieved average temperature of 16.3°C). This initiation occurred after the date that plants from the main experiments were moved out of propagation compartments for planting into the field which occurred at 27 days from sowing for plants of a normal commercial size.

Escarole and endive sown 06/02/07 initiated in all three temperature treatments by the end of May (figure 8). Both species initiated in the 14°C treatment first (at around 79 days from sowing for both species), followed by the 16°C treatment which initiated at around 93 days. Within the 18°C treatment endive initiated at 113 days from sowing and escarole at 100 days from sowing. By comparison, endive and escarole sown 06/02/07 were planted out after 35 days from sowing.

Hence plants from the first third and fifth sowing dates in all temperature treatments could be expected to have had vegetative apices at the transplanting stage, but the extent of progression towards flowering would have varied with temperature treatment. Bolting date however would then be further influenced by achieved temperatures after planting out.

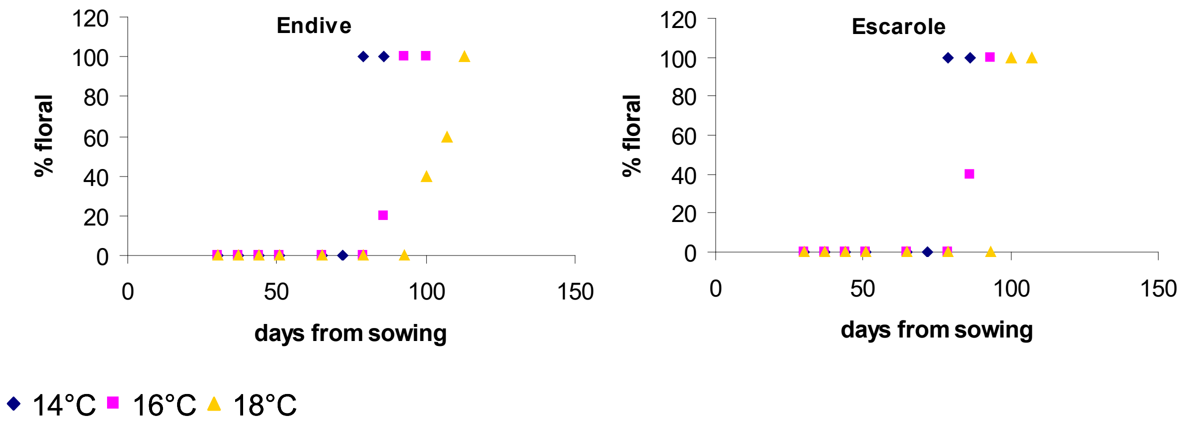


Figure 8. Initiation of endive and escarole sown 06/02/07 and grown at different propagation temperatures as indicated by the proportion of dissected plants with floral apices.

Leaf initiation

The delay in floral initiation resulting from higher temperature increased the total (i.e. visible and microscopic) number of leaves produced prior to bolting. At 100% floral initiation, endive had around 113, 155 and 161 leaves at 14°C, 16°C and 18°C respectively and escarole had around 58, 95 and 112 leaves at 14°C, 16°C and 18°C respectively (figure 9). Similar comparisons are not possible for celery and Chinese cabbage since only one treatment reached 100% initiation whilst within the controlled environment of the glasshouse compartments.

As noted previously, transplanting occurred much earlier than the point of 100% floral initiation and total leaf (i.e. visible plus leaf primordia) counts at transplanting stage were 10-14 for celery, 23-25 for Chinese cabbage, 9-13 for endive and 10-13 for escarole across the three temperature treatments. Propagation temperature for the first batch of plants sown had only a small impact (2-4 leaves) on total leaf count at transplanting stage.

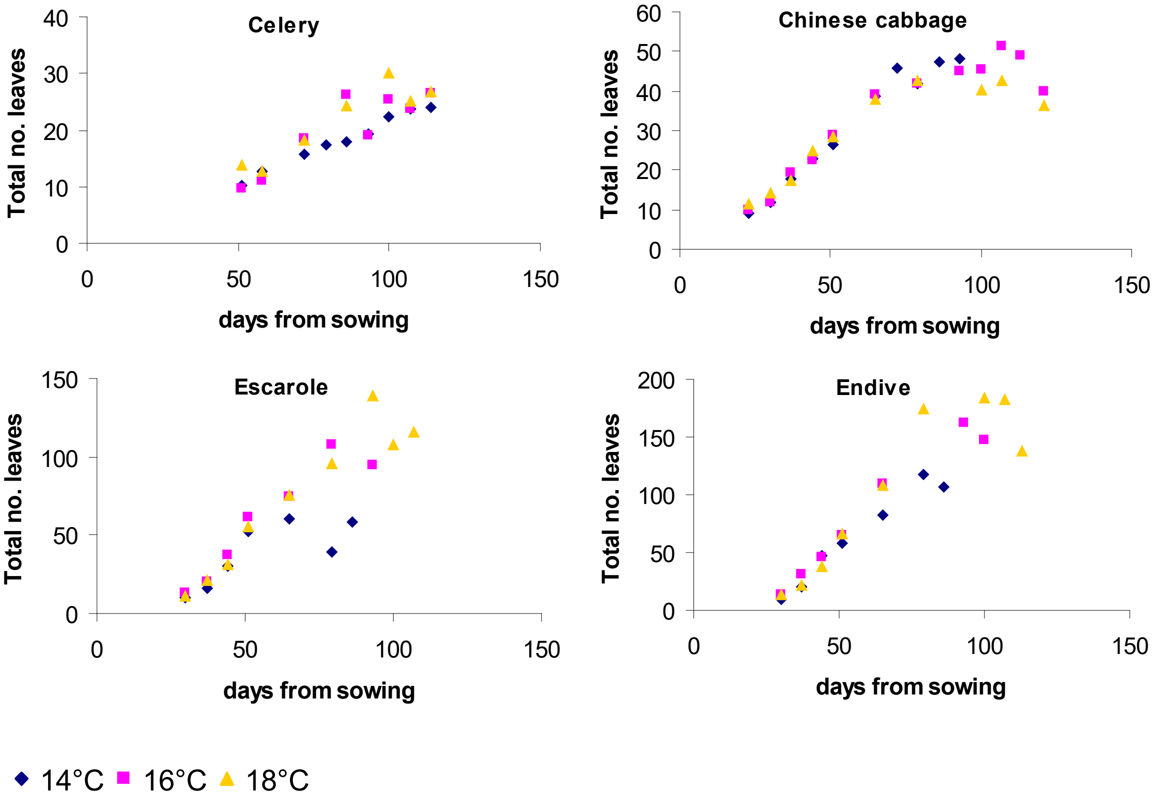


Figure 9. Total leaf count of plants sown 06/02/07 (endive, escarole and Chinese cabbage) or 30/01/07 (celery) and grown at different propagation temperatures.

Assessments at transplanting stage

Transplanting date (i.e. batch of plants) had a significant influence on the average fresh weight (P<0.001), height (P<0.001) and number of visible leaves (P<0.001) for all four species (figures 10 to 12). This reflects the change in environmental conditions and hence light integral received as well as achieved temperature due to the effects of solar gain. Hence initially (batches 1-3), plant size increased as batches were sown later and light and temperature increased. For batches 5 and 6 however, size decreased when the propagation schedule was adjusted in line with the increasing plant size noted. These differences had a smaller impact on the number of visible leaves per plant than on shoot fresh weight or height.

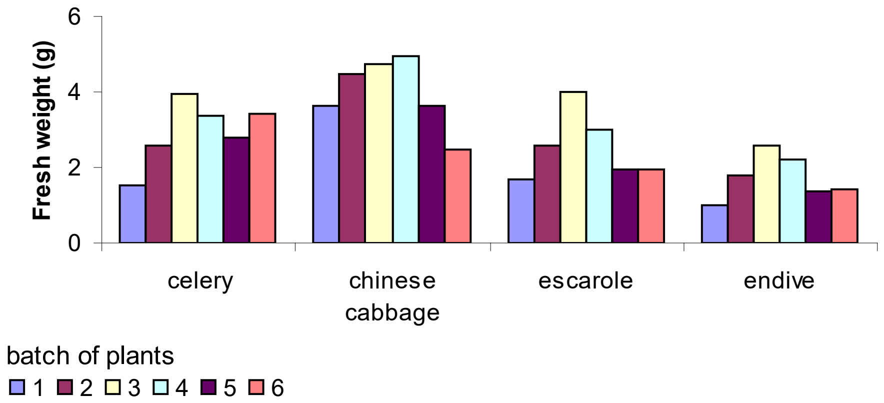


Figure 10. The influence of transplanting date (batch) on shoot fresh weight at transplanting (L.S.D. = 0.32 for celery, 0.63 for Chinese cabbage, 0.24 for escarole and 0.19 for endive).

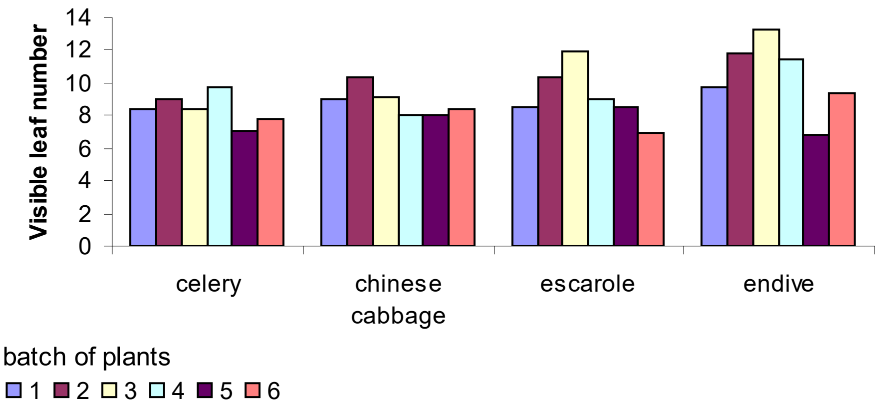


Figure 11. The influence of transplanting date (batch) on visible leaf number at transplanting (L.S.D. = 0.25 for celery, 0.46 for Chinese cabbage, 0.52 for escarole and 0.61 for endive).

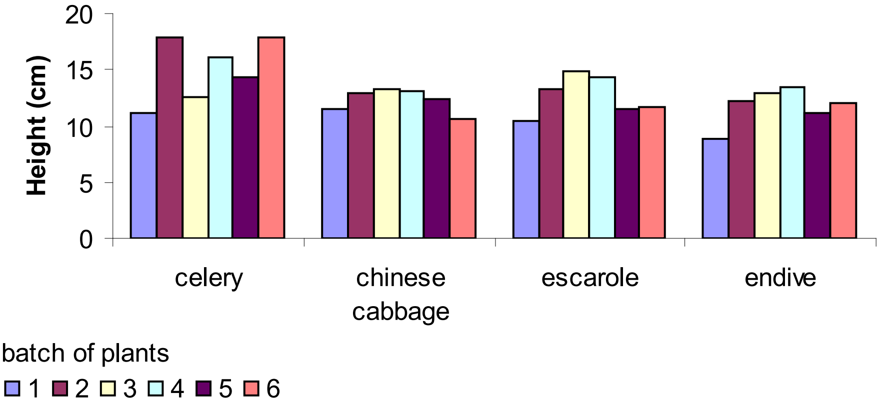


Figure 12. The influence of transplanting date (batch) on shoot height at transplanting (L.S.D. = 0.56 for celery, 0.58 for Chinese cabbage, 0.35 for escarole and 0.42 for endive).

Propagation temperature significantly influenced shoot fresh weight, height and visible leaf number at transplanting for data averaged across all batches sown (figures 13 to 15). For celery, which had the longest propagation time, a heat set point of 18°C increased fresh weight by 60% compared with 14°C. For Chinese cabbage, endive and escarole propagation at 18°C increased fresh weight by 27-28% compared with 14°C. Propagation temperature had a smaller proportional effect on plant height with a 31% increase for 18°C compared with 14°C for celery, 11%

increase for Chinese cabbage and 24-27% for endive and escarole. Although statistically significant, propagation temperature had negligible effects (less than 1 leaf) on number of visible leaves produced per plant. This agrees with dissection data summarised previously where higher temperature had only a small effect on the total number of microscopic and visible leaves per plant prior to initiation.

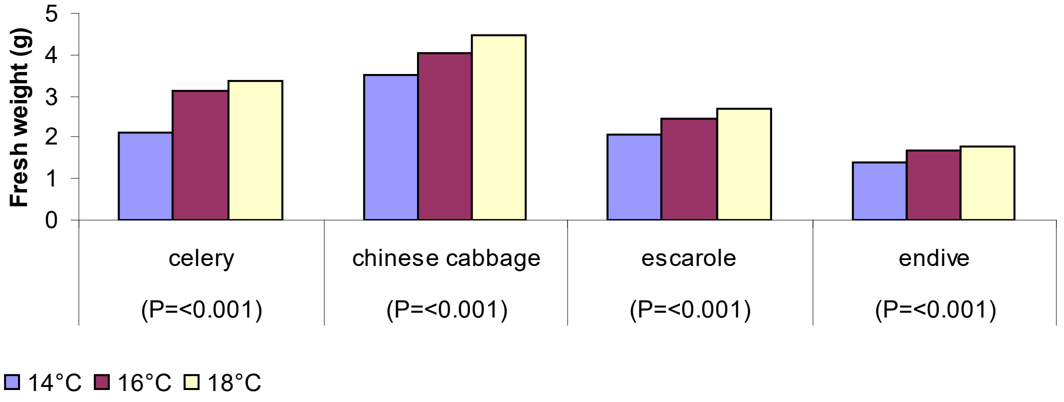


Figure 13. The influence of propagation temperature on shoot fresh weight at transplanting (L.S.D. = 0.22 for celery, 0.45 for Chinese cabbage, 0.17 for escarole and 0.14 for endive).

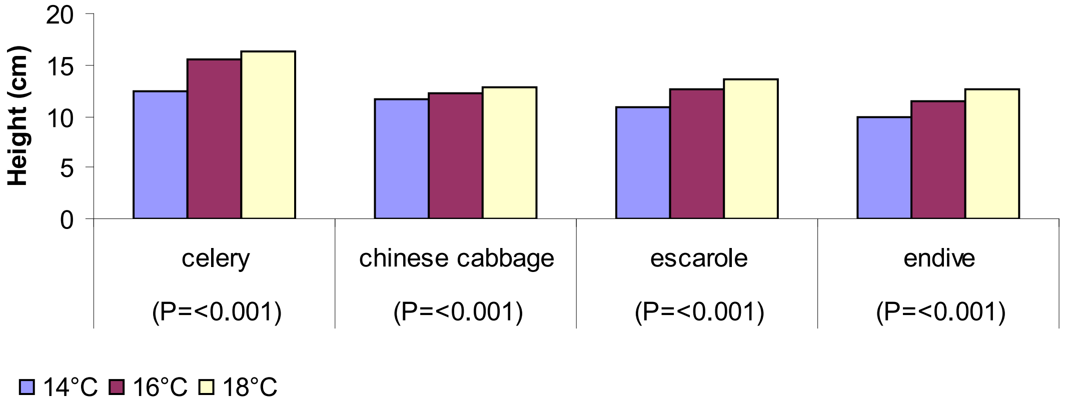


Figure 14. The influence of propagation temperature on visible shoot height at transplanting (L.S.D. = 0.40 for celery, 0.41 for Chinese cabbage, 0.25 for escarole and 0.30 for endive).

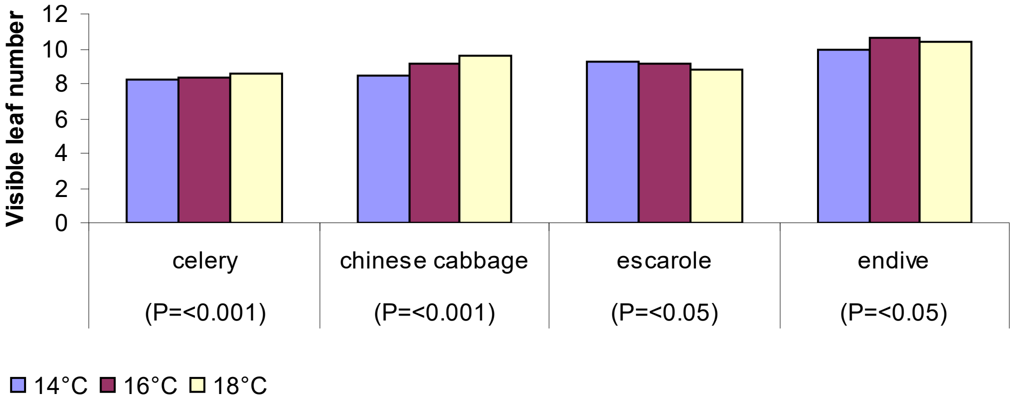


Figure 15. The influence of propagation temperature on visible leaf number at transplanting (L.S.D. = 0.18 for celery, 0.33 for Chinese cabbage, 0.37 for escarole and 0.43 for endive).

Stage of plant growth had a significant influence over the average (across batches) fresh weight, height and number of visible leaves of plants at transplanting stage (figures 16 to 18); and differences were greater than were found for average temperature effects discussed above. Average fresh weight of celery plants transplanted 'early', for example, was 1.6g (60%) less than of standard plants. 'Late' celery plants were 2.6g (99%) heavier than standard plants.

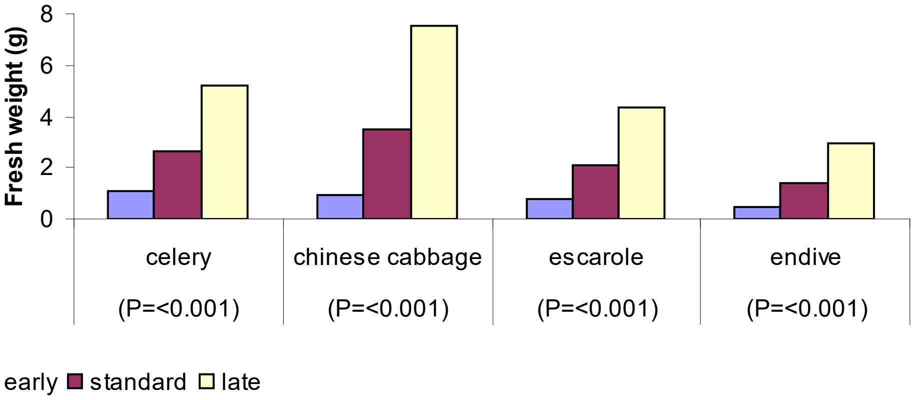


Figure 16. The influence of stage of growth at transplanting on shoot fresh weight ((L.S.D. = 0.22 for celery, 0.45 for Chinese cabbage, 0.17 for escarole and 0.14 for endive).).

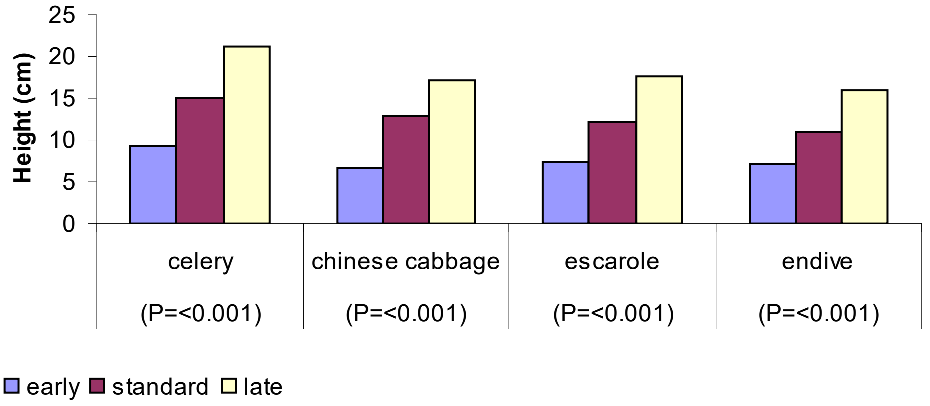


Figure 17. The influence of stage of growth at transplanting on shoot height (L.S.D. = 0.40 for celery, 0.41 for Chinese cabbage, 0.25 for escarole and 0.30 for endive).

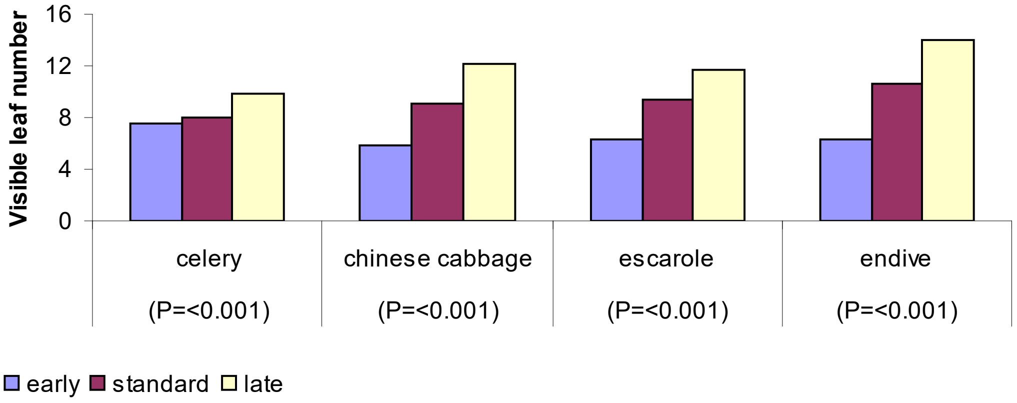


Figure 18. The influence of stage of growth at transplanting on visible leaf number (L.S.D. = 0.18 for celery, 0.33 for Chinese cabbage, 0.37 for escarole and 0.43 for endive).

There was a significant interaction between planting stage and batch (i.e. transplanting date). The differences in fresh weight, height and leaf number between stages varied with transplanting date (figures 19 to 21). This interaction effect appears to be related to rate of growth since transplanting stages were mainly separated by 1 week intervals (i.e. early 1 week earlier than standard and late 1 week later than standard) and 1 week of growth was less in the early stages of the experiment when ambient temperatures and light levels were lower than in the later stages.

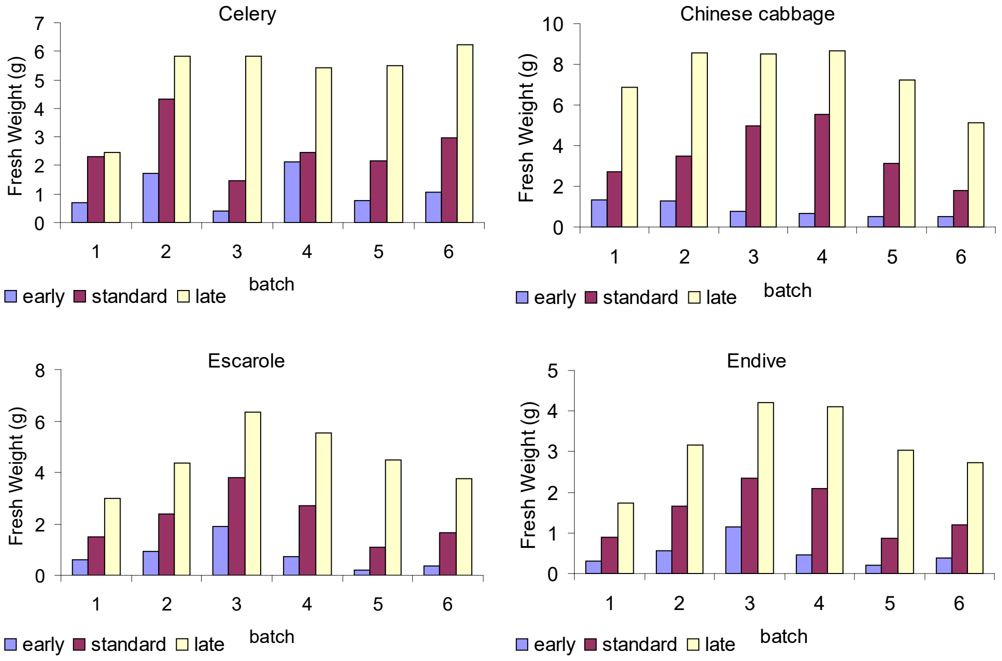


Figure 19. The interaction (P<0.001) between stage of growth at transplanting and transplanting date (batch) on fresh weight (L.S.D. = 0.55 for celery, 1.10 for Chinese cabbage, 0.41 for escarole and 0.34 for endive).

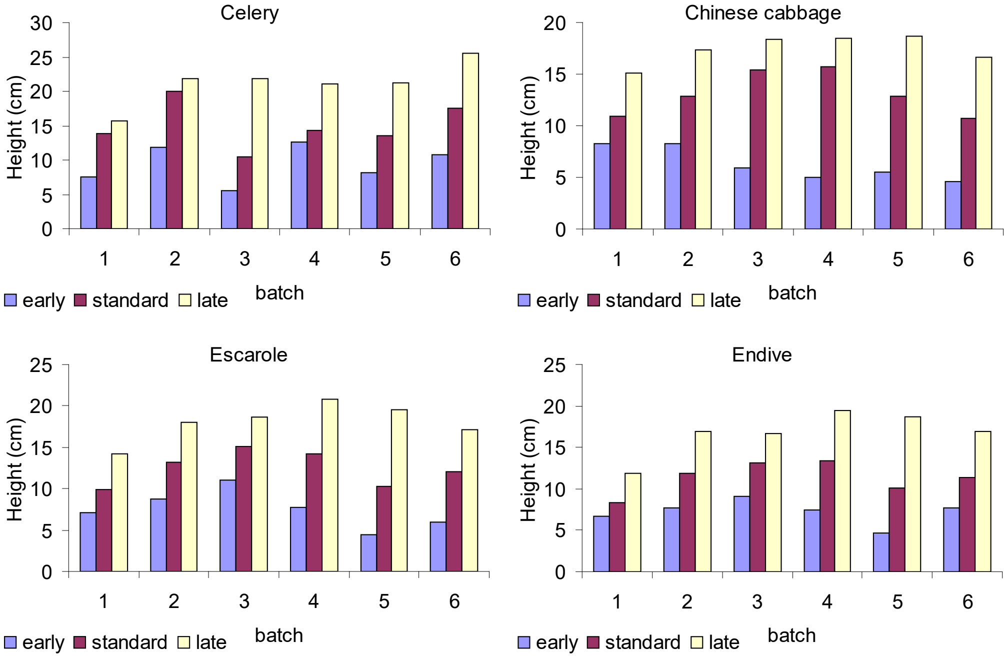


Figure 20. The interaction (P<0.001) between stage of growth at transplanting and transplanting date (batch) on plant height (L.S.D. = 0.97 for celery, 1.00 for Chinese cabbage, 0.61 for escarole and 0.73 for endive).

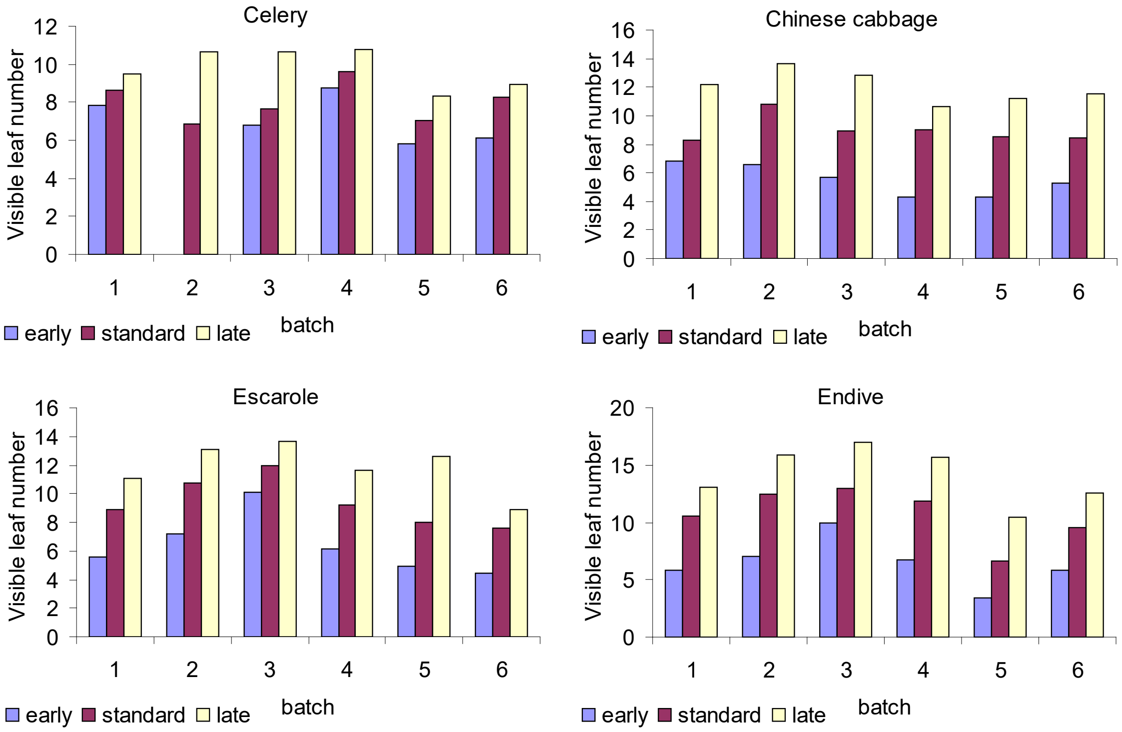


Figure 21. The interaction (P<0.001 for celery, Chinese cabbage and escarole, P<0.05 for endive) between stage of growth at transplanting and transplanting date (batch) on visible leaf number (L.S.D. = 0.44 for celery, 0.80 for Chinese cabbage, 0.90 for escarole and 1.01 for endive).

Assessments at harvesting stage

Of the six batches of plants transplanted into commercial field plots, two each of Chinese cabbage, escarole and endive were ploughed in before records had been taken (table 2). Whilst plot perimeters were marked with tapes at planting, the tapes and canes had to be sited very low to allow fleecing by machine after planting and hence markings were apparently not sufficiently visible to operators harvesting commercial crops. In future the potential for improving the visibility of plot marking tapes will be explored with the commercial sites. Table 2 summarises which plots remained available for final assessments.

Table 2. Summary of transplanting and harvesting schedules, gaps in the table indicate where plots were ploughed in before samples had been taken.

	sowing date	planting date	harvest date	days to harvest
Celery	30-Jan	10-Apr	29-Jun	80
	16-Feb	24-Apr	23-Jul	90
	02-Mar	24-Apr	23-Jul	90
	12-Mar	01-May	30-Jul	90
	23-Mar	08-May	06-Aug	90
	11-Apr	05-Jun	21-Aug	77
Endive & Escarole	06-Feb	27-Mar	29-May	63
	02-Mar	10-Apr	26-Jun	77
	14-Mar	17-Apr	-	-
	29-Mar	01-May	-	-
	13-Apr	08-May	16-Jul	69
	01-May	05-Jun	02-Aug	58
Chinese cabbage	06-Feb	23-Mar	17-May	55
	06-Mar	05-Apr	05-Jun	61
	22-Mar	17-Apr	-	-
	05-Apr	01-May	-	-
	23-Apr	17-May	05-Jul	49
	09-May	05-Jun	26-Jul	51

Each harvest sample was timed to fall one week after the commercial harvest of crops planted around each trial plot area to maximise the opportunity for bolting. All treatments within each plot (or batch) planted were harvested on the same date, hence carry over effects of treatments on plant size and marketability would be determined on differences between treatments at this fixed point in time. An alternative approach would be to harvest each treatment as plants reach the correct size but, for accuracy, this approach would require more frequent inspection (approx 3 times a week) than the logistics of the experiment would permit and potentially both plant size and hence time to harvest could vary, making data interpretation difficult.

Head weight

Whilst batch (i.e. time of transplanting) had a significant influence on plants at transplanting stage, it did not significantly influence head weight at final harvest for endive or celery (figure 22). Production time of endive in the field varied through the season (table 2) and hence adjustments made in the commercial schedules for length of production time in the field may have helped to standardise head weight from batch to batch. For celery, however production time was 90 days for 4 of the 6 batches assessed and hence variation in production time from batch to batch can not explain the lack of difference between batches that might be expected from seasonal variation in factors such as light integral and temperature.

Head weight of Chinese cabbage and escarole was significantly influenced (P<0.001) by batch. The second batch of escarole had the heaviest (1.21kg) heads and plants from the first batch had the lightest (0.73kg). Later batches of Chinese cabbage had smaller fresh weight than earlier batches which again reflects the reduction in propagation time associated with the later planted crops.

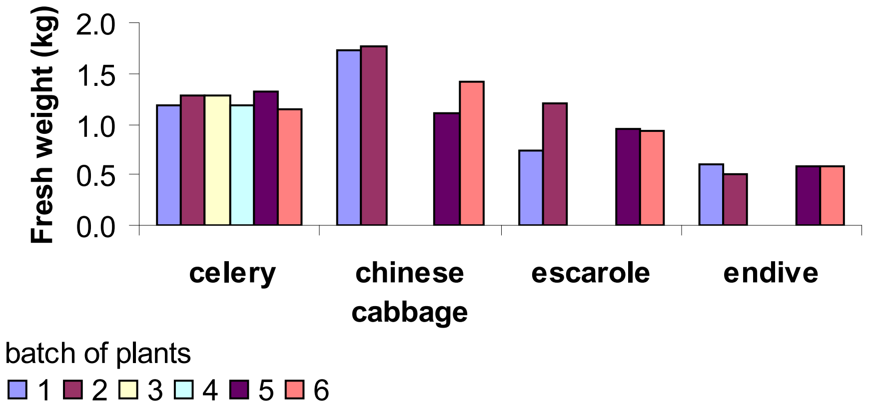


Figure 22. The influence of transplanting date (batch) on head weight at harvest (L.S.D. = 1.04 for Chinese cabbage and 0.94 for escarole).

Main temperature effects on head weight were significant (P<0.001) for escarole only. Average head fresh weight was 9-12% smaller for plants propagated at 14 to 16°C compared with 18°C (figure 23). Plants of escarole raised commercially were also significantly heavier than experimental plants by 17% across the 4 batches harvested.

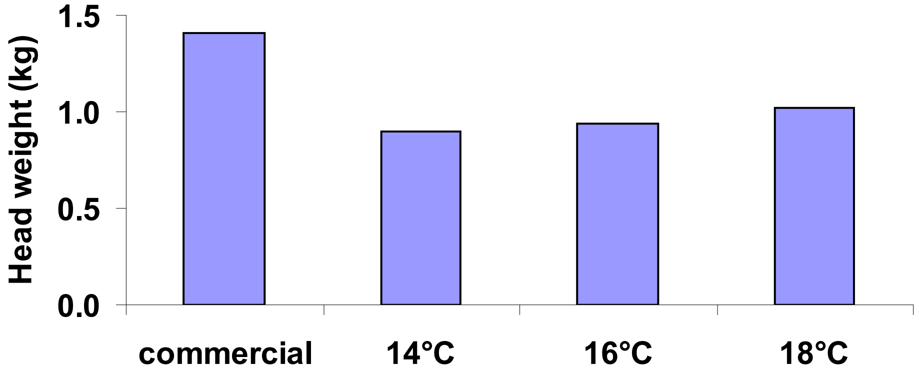


Figure 23. The influence of propagation temperature/commercial production on escarole head weight at harvest (L.S.D. = 0.07).

There was a significant (P<0.001) interaction between batch and temperature for endive (figure 24). That is, heads were heavier for plants raised at 18°C than at 14°C and were also heavier than commercially raised plants from the first batch of plants harvested. Head weight was not influenced by propagation temperature / commercial propagation for the other three batches of plants harvested.

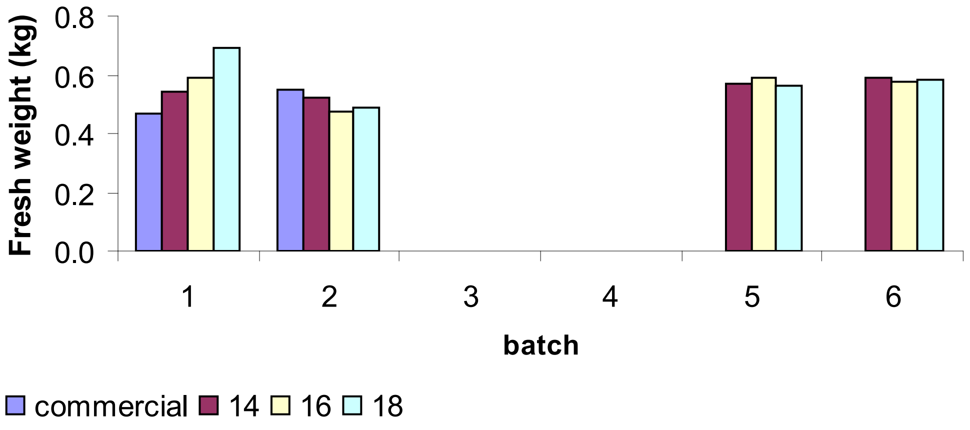


Figure 24. The influence of transplanting date (batch) and propagation temperature/ commercial production on endive head weight at harvest (L.S.D. = 0.10).

There were no main effects of plant stage on head weight at harvest for any of the species tested. There was a significant interaction between batch and planting stage for escarole and endive. For escarole, the smallest transplants (early stage) were significantly (P<0.01) heavier than the transplants grown to a standard or large (late) size within the second batch of plants at harvest despite the fact that plants were heavier from the later transplanting stage at the end of propagation (figure 25).

For endive, the experimental transplants from all three planting stages produced significantly (P<0.01) heavier heads at harvest than the commercial transplants when planted in the first batch (figure 26). There was no significant difference between commercial and experimental transplants within the second batch sown, and commercial plants were not available for comparison against the other batches assessed at harvest.

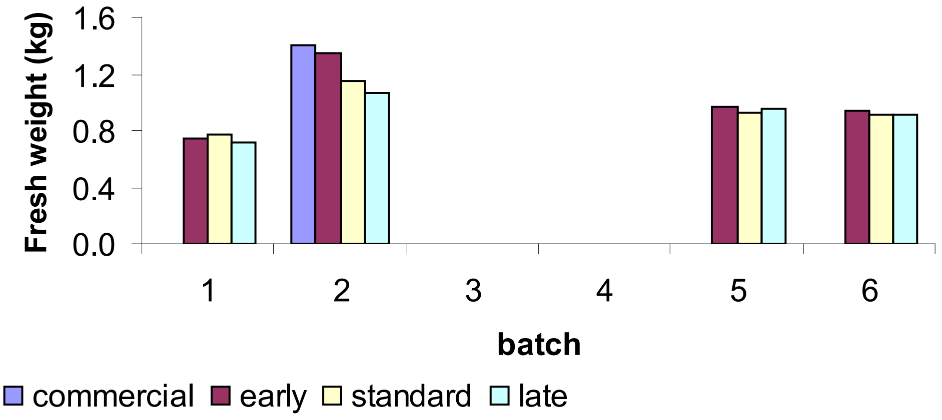


Figure 25. The influence of plant stage at transplanting and transplanting date (batch) on escarole head weight at harvest (L.S.D. = 0.16).

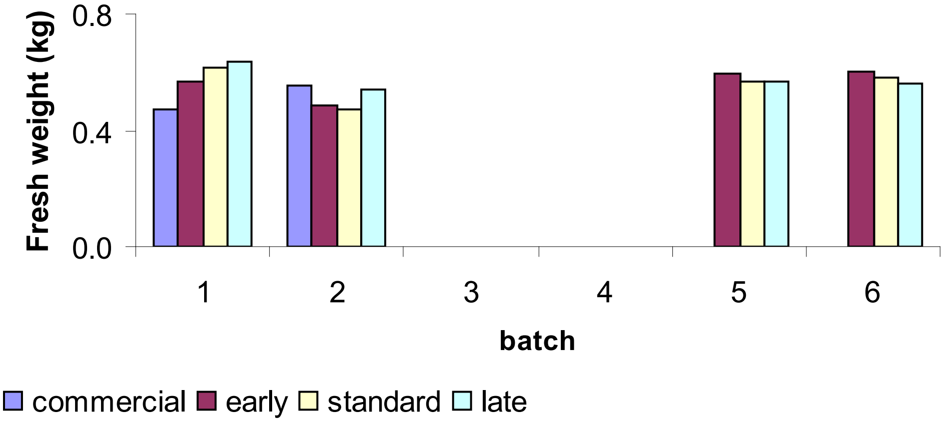


Figure 26. The influence of plant stage at transplanting and transplanting date (batch) on endive head weight at harvest (L.S.D. = 0.10).

Apex length

Celery and Chinese cabbage were dissected at harvest to determine apex length as an indication of progression towards bolting. Transplanting date (batch) significantly (P<0.001) influenced apex length of both species (figure 27), with the earliest transplanting (batch 1), which was exposed to the lowest temperatures in the field, producing the tallest apices in both species.

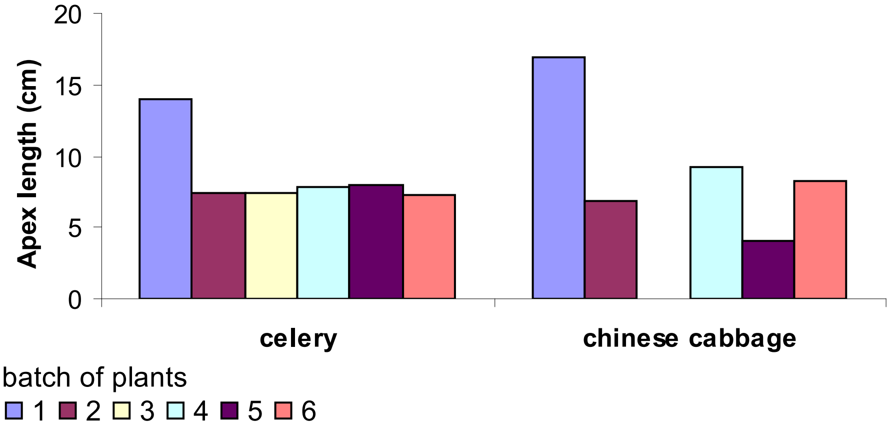


Figure 27. The influence of batch (transplanting date) on apex length at harvest (L.S.D. = 0.95 for celery, L.S.D. = 0.80 for Chinese cabbage).

Chinese cabbage planted from batch 1 and propagated at 14°C produced significantly (P<0.001) taller apices at harvest than plants propagated at 16°C or 18°C (figure 28). At 8cm, apex length was also greater for the 18°C propagated plants than for the commercial material planted as a control which had 6 cm apices. There were no effects of propagation temperature on apex length for the remaining batches of plants tested.

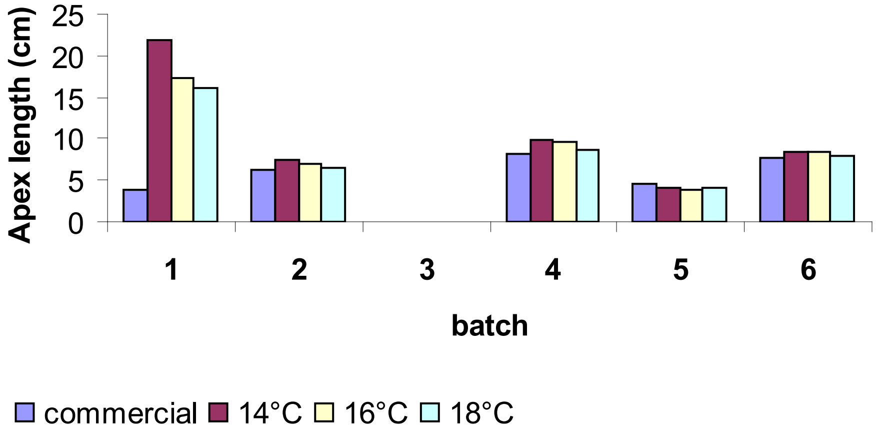


Figure 28. The influence of propagation temperature and transplanting date (batch) on apex length of Chinese cabbage at harvest (L.S.D. = 1.4).

Planting stage also significantly (P<0.001) influenced apex length of the first batch of Chinese cabbage planted (figure 29). The earliest planting stage (i.e. smallest plants) produced the tallest apices (22cm in length) at final harvest. The standard planting stage produced shorter apices (17cm) than the late planting stage (16cm) and the commercial plants had the shortest apices (4cm) overall (figure 30). As well as being smaller at transplanting, early stage plants were also moved out of the heat of propagation earlier than the standard and late stages in the first batch of plants transplanted and hence spent longer in inductive conditions.

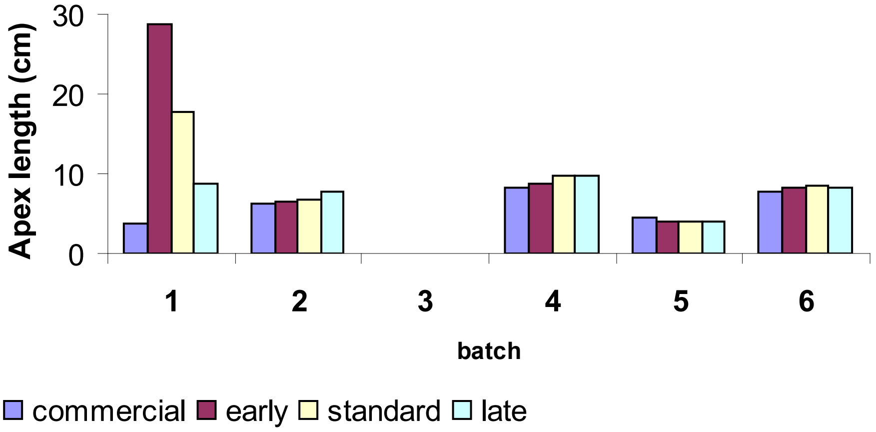


Figure 29. The influence of planting stage and batch (transplanting date) on apex length of Chinese cabbage at harvest (L.S.D. = 1.4).

There was also a significant interaction (P<0.05) between planting stage and temperature on apex length in Chinese cabbage (figure 30). That is, later planting stages reduced apex length and within each planting stage, propagation at a higher temperature further reduced apex length at final harvest.

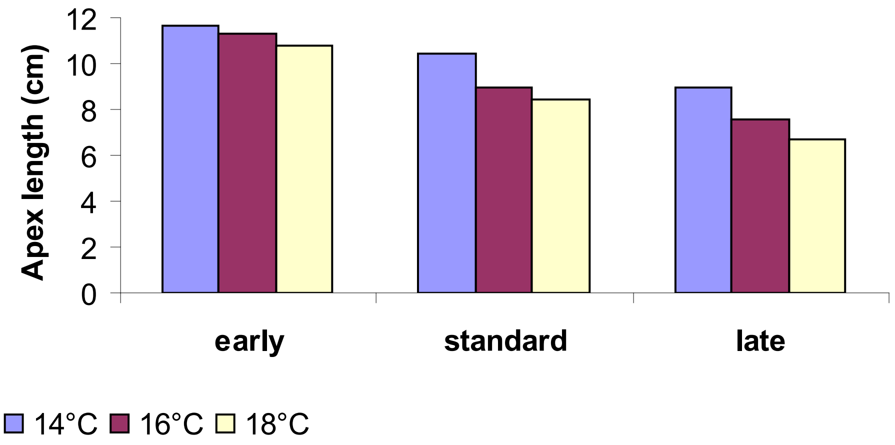


Figure 30. The influence of propagation temperature and batch (transplanting date) on apex length of Chinese cabbage at harvest (L.S.D. = 0.70).

Neither temperature nor planting stage had a significant influence on apex length for celery.

Bolting

Counts of number of plants showing external signs of bolting at harvest were used to indicate extent of bolting for endive and escarole and to supplement the apex length reviewed above for Chinese cabbage and celery.

Temperature and planting stage significantly ($P<0.001$) influenced bolting in plots of endive from the first and second planting dates (batches 1 and 2). There was in excess of 94% bolting in plots of endive raised at 14 and 16°C in the first two batches of plants grown (figure 31). There was 55 and 23% less bolting in plants raised at 18°C in for the batch 1 and batch 2 plants respectively. There was less bolting for the fifth and sixth batches of plants grown later in the season under higher external temperatures. Propagation at 14°C increased bolting by around 12% compared with propagation at 16 or 18°C for these later batches of plants. Commercial plants were only available as controls in the first two of the batches planted and in both cases; the % bolting in commercial plants was lower at 0 and 51% for batches 1 and 2 respectively than in any of the experimental treatments.

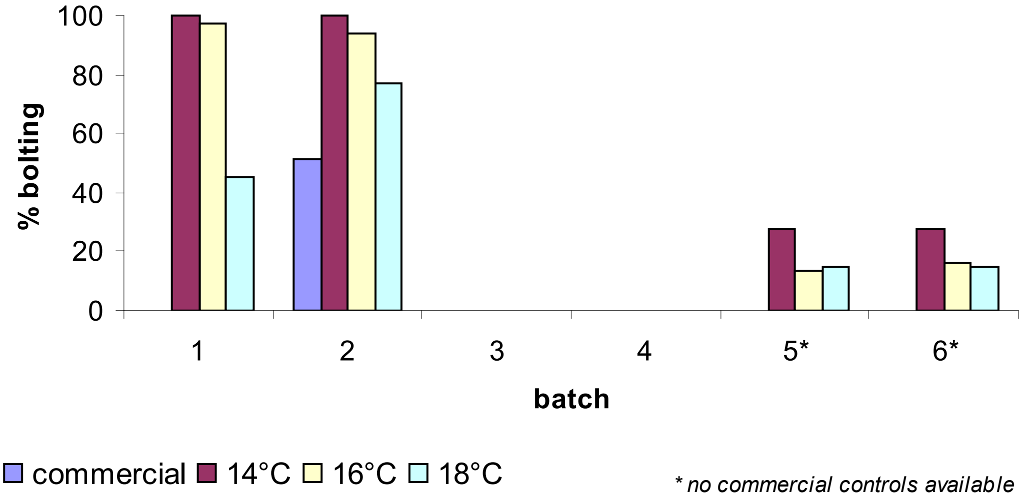


Figure 31. The influence of propagation temperature and batch (transplanting date) on % bolting in endive at harvest (L.S.D. = 10.1).

As with endive, temperature had a significant influence over % bolting in escarole; with high levels (90-100%) of bolting in plants raised at 14 and 16°C and planted early in the season (batches 1 and 2, figure 32). Incidence of bolting was higher overall for escarole with plants raised at 18°C suffering comparable levels of bolting to those raised at 14 and 16°C in the second batch planted and also higher levels of bolting was experienced later in the season (batches 5 and 6). Even in the sixth batch of plants planted, propagation at 14°C increased bolting by 50% compared with propagation at 18°C. Commercial plants were only available for the second batch of plants over those plots that were available for final assessments and these plants had no bolting recorded.

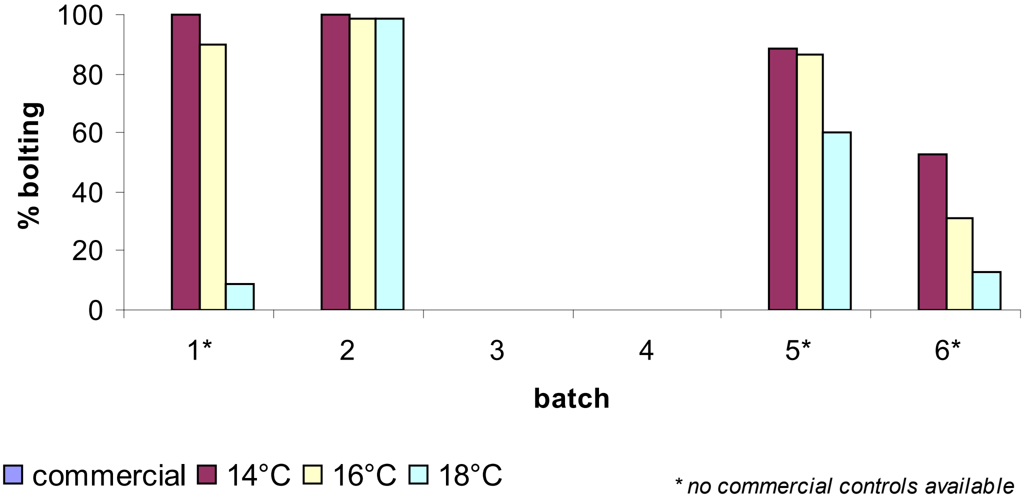


Figure 32. The influence of propagation temperature and batch (transplanting date) on % bolting in escarole at harvest (L.S.D. =12.0).

Planting date also influenced the incidence of bolting in relation to propagation temperature in Chinese cabbage (figure 33). Hence temperature had a significant (P<0.001) influence over percentage of plants bolting from the first batch planted with plants having 28 and 10% more bolting when raised at 14 and 16°C respectively compared with 18°C; but temperature had no significant influence over % bolting on the second batch planted. There was no bolting in commercially raised plots of plants from any of the batches of plants harvested. Later batches of plants from experimental treatments also had no bolting and hence only the data from the first two harvests is presented here.

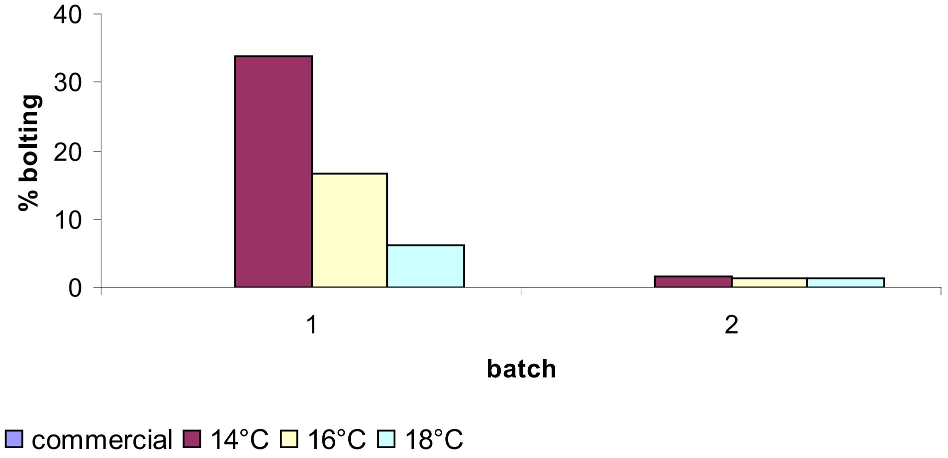


Figure 33. The influence of propagation temperature and batch (transplanting date) on % bolting in Chinese cabbage at harvest (L.S.D. = 4.9).

As noted previously, earlier planting (batches 1 and 2) resulted in higher levels of bolting in endive (figure 34). Whilst planting stage significantly (P<0.001) influenced % bolting within these two early batches of plants, response was mixed. That is, within the first batch, early stage plants produced 15% more bolting and late stage plants produced 15% less bolting than standard stage plants; and all treatments produced significantly more bolting than the commercial plants. Within the second batch of plants however, early stage plants produced 10% less bolting and late stage plants produced 7% more bolting than standard stage plants. The approach to scheduling used for the first crop was changed after the first batch of plants had been propagated. Hence for the first batch of plants, a common sowing date was used and transfers out of the heat were staggered with plants held in weaning until all treatments in any one batch were ready for planting. For the remaining batches of plants however, sowing dates were staggered so that plants could be transferred out of the heat on the same day. This change in design may have altered the response to propagation treatments between the first and second batches of endive plants grown.

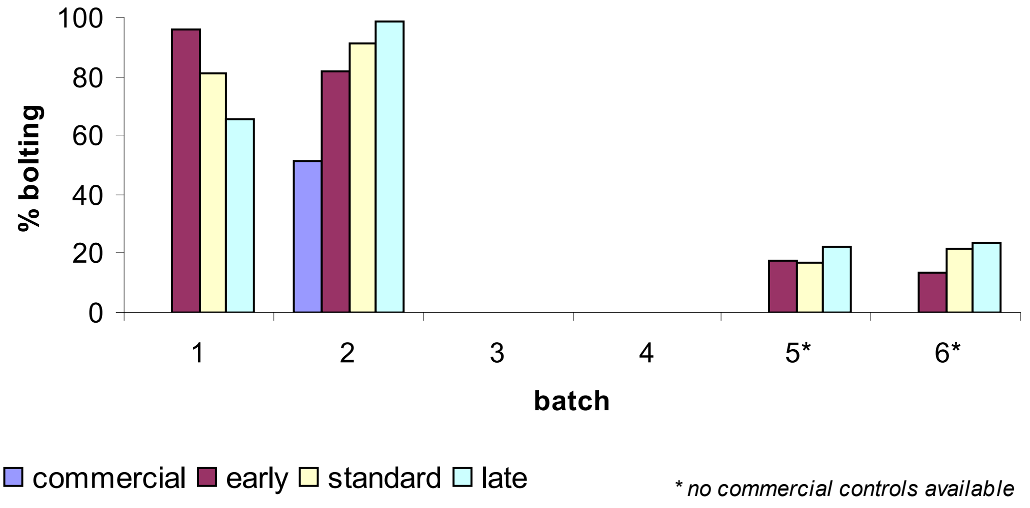


Figure 34. The influence of planting stage and batch (transplanting date) on % bolting in endive at harvest (L.S.D. = 9.8).

Planting stage significantly (P<0.001) influenced percentage bolting in escarole (figure 35). Transplanting at an early stage of growth increased bolting by 13% compared with a late stage of growth in the first batch transplanted but was not significantly different from transplanting at a standard stage of growth. All experimental treatments had high levels of bolting from the second batch planted and were all higher than the commercial plants (0% bolting). As with endive, planting stage produced unexpected results for 2 of the 4 batches planted; and for batches 5 and 6, transplanting late stage plants resulted in more bolting (20-50%) than transplanting early stage plants.

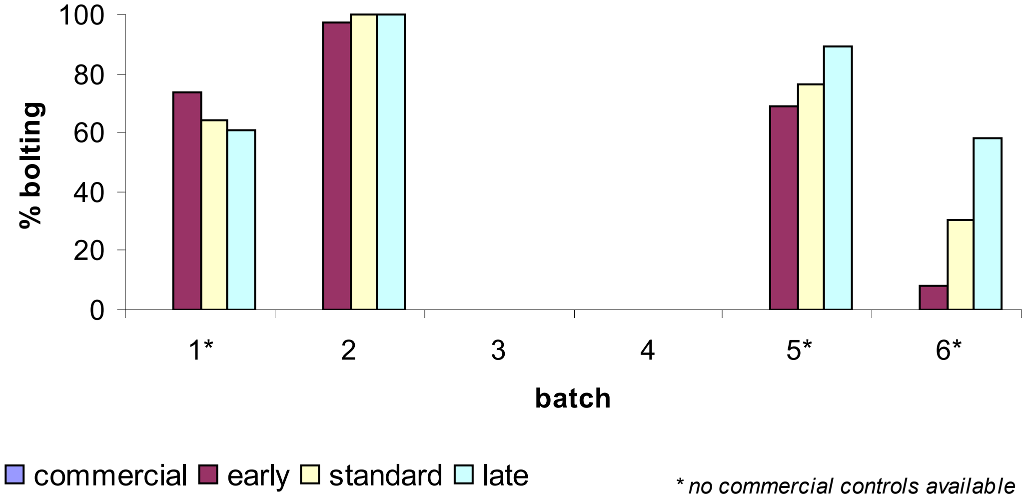


Figure 35. The influence of planting stage and batch (transplanting date) on % bolting in escarole at harvest (L.S.D. = 11.4).

Only plants from the first batch of Chinese cabbage transplanted produced significant levels of bolting at harvest (figure 36). Within this batch, transplanting at an early stage significantly (P<0.001) increased % bolting compared with both the standard and late transplanting stages.

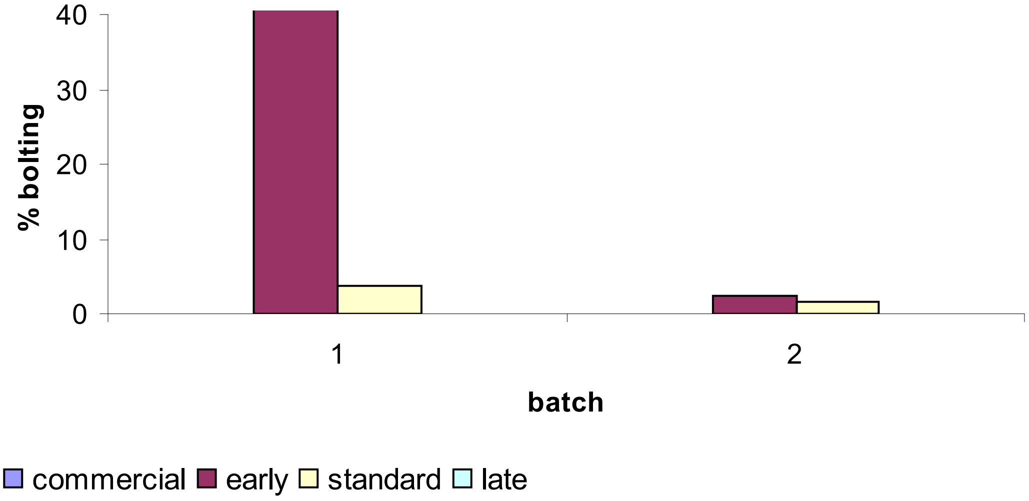


Figure 36. The influence of planting stage and batch (transplanting date) on % bolting in Chinese cabbage at harvest (L.S.D. = 5.7).

Data Modelling

Rate of floral initiation

Data collected from apical dissections of endive and escarole (i.e. the only species to initiate in all three propagation temperatures) were analysed as rate of initiation (1/time to initiation) against average achieved temperature. These analyses found that rate of initiation (1/time to 100% floral) was linearly related to average temperature in propagation for endive sown on 6th February 2007 (figure 37).

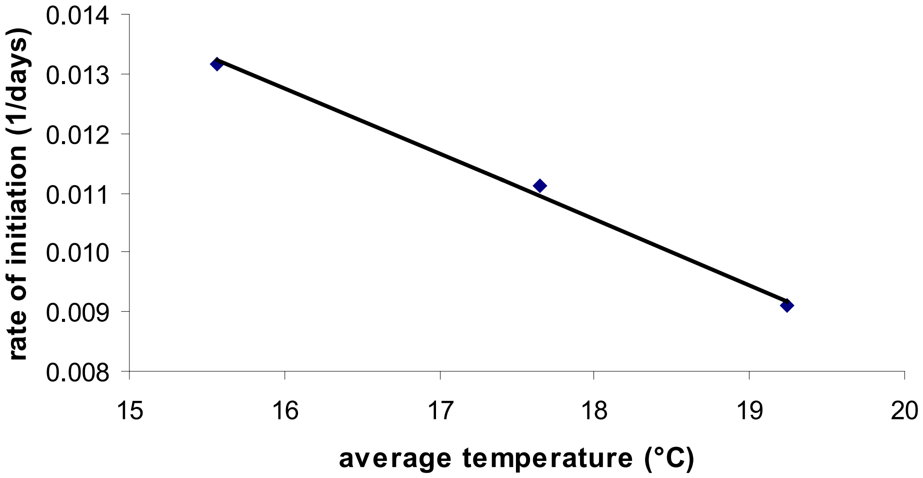


Figure 37. The influence of temperature on the rate of initiation as determined by apical dissection of endive sown 06/02/07, R^2=0.9945

The relationship modelled from this data;

rate of initiation = 0.0303-0.0011 x temperature,

can be used to predict expected time to initiation for other average temperatures within the range tested in these experiments (i.e. 14°C to 19°C for achieved average temperature). Hence predicted time for initiation within this range from the models derived from the batch 1 data is given in table 3.

Table 3. Prediction of time to initiation for endive based on average temperature

Average temperature (°C)	14	15	16	17	18	19
Predicted no. days to initiation	67	72	79	86	95	106

Whilst the predicted time to initiation is greater than expected time in propagation (31 days for the 06/02/07 sowing), it is clear that progression towards initiation (and hence bolting) would be much greater for an average temperature of 14°C than of 19°C at the end of propagation.

The predicted and actual time to initiation for temperatures achieved in the three propagation temperature treatments for the first batch of endive sown for apical dissection assessments in table 4 compare well, suggesting that the model predictions are realistic for this limited range of treatments.

Table 4. Prediction of time to initiation for endive based on achieved temperatures achieved in propagation of endive in the first batch of plants produced.

Achieved average temperature (°C)	**15.8**	**17.8**	**19.4**
Actual no days to 100% initiation	76	90	110
Predicted no days to 100% initiation	77	93	112

A linear relationship for escarole gave less accurate predictions compared with measured data and would need further data in order to define a suitable model. There was insufficient initiation in celery or Chinese cabbage to test if their initiation followed a similar relationship.

Rate of leaf initiation

Glasshouse temperature influenced rate of leaf production (i.e. number of leaves produced per day) of endive plants from batch one that had remained in the glasshouse until initiation (figure 38).

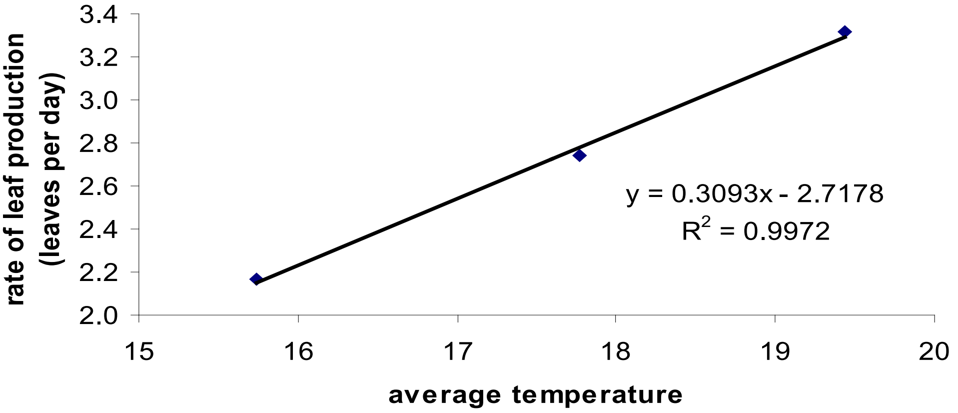


Figure 38. The influence of temperature on the rate of leaf initiation in endive sown 06/02/07.

The model presented in figure 38 (above) was derived from dissections carried out between 30 and 79 days from sowing. Within this period there is a linear relationship between total number of leaves produced and days from sowing, however extrapolation back to leaf development during propagation (which is likely to be less than 30 days) will require the collection of further dissection data.

Reducing glasshouse temperature in order to reduce energy consumption may increase production time to achieve a set size of plant, and hence energy saving per crop may be negated by the extra time (and hence days of heating supply) required. Whilst preliminary, the modelled data may be used to estimate how changing propagation temperature might impact the length of time required in propagation as indicated by the number of leaves produced. Table 5 presents some calculations made using the model to predict number of leaves produced for two different propagation temperatures:

Table 5. Prediction of time to produce set numbers of leaves in endive at two propagation temperatures

Target leaf no. per plant	No. days to target leaf number at 18°C	No. days to target leaf number at 14°C
5	29	30
10	30	33
15	32	36
20	34	39

Hence from the table 5, for a given size of plant such as one with 20 leaves, 34 days of growth would be required at 18°C or 39 days at 14°C using the model produced for rate of leaf production. The lower propagation temperature will therefore have only saved energy if the energy input to achieve 14°C for 39 days is lower than that to achieve 18°C for 5 fewer days. Using the initiation model at these two temperatures, plants propagated at 14°C might be expected to initiate 28 days earlier at 67 days than plants propagated at 18°C (at 95 days) if maintained within these temperatures until initiation occurs. In practise initiation will be sooner as plants move out into the lower average temperature conditions of field production. However the calculation illustrates that the lower temperature treatment would have progressed further towards flowering than the higher temperature treatment

Some of the experimental data upon which the two models have been based, has been used to test how predictions based on average temperatures compare with measurements made (table 6). Logged temperature data has been used to calculate average temperature from the start of propagation through to final harvest in the field. For the 14°C propagation treatment for example, average achieved temperature was 12.1°C from germination through to final harvest. Using the first model as described in figure 37, plants from this treatment may be expected to initiate at 59 days. In fact the crop was harvested 3 days later than the predicted time for initiation and had 100% bolting. By contrast, plants propagated in the 18°C treatment were predicted to initiate 5 days later than the actual harvest date and had 55% less bolting than the 14°C treatment.

Expected plant size, as indicated by leaf number, was predicted using the model from figure 38 along with the average achieved temperature as described above. Using these data predicted leaf number at harvest (63 days) was lowest (37 leaves) for the 14°C treatment and highest for the 18°C treatment (50 leaves). Differences in fresh weight at harvest (figure 24) reflected this trend in predicted leaf number with the heaviest plants produced from the highest propagation temperature treatment.

Table 6. Prediction of time to initiation and number of leaves produced for endive based on average achieved temperature from germination through to final harvest in the field.

Propagation temperature treatment (°C)	**14**	**16**	**18**
Average temperature across time in propagation and time in the field (°C)	12.1	12.8	13.3
Predicted time to initiation (days)	59	61	64
Actual time to harvest (days)	63	63	63
% plants bolted at harvest	100	97	45
Predicted leaf number at harvest	37	44	50

These predictions appear to fit in with observed differences from assessments made at final harvest, since more bolting was seen in plants propagated at 14°C and 16°C than 18°C, and that head weight at harvest was lower for plants propagated at 14°C than 18°C.

The examples given above serve to illustrate how the preliminary models produced might be used to assist with propagation and production schedules in terms of optimising temperature for energy efficiency and also for maximising head weight in the field prior to the appearance of bolting. If of practical use to growers, further work would be necessary to extend the range of these models both in time (i.e. to fewer days in propagation when it appears there may be a more complicated relationship between time and leaf number) and in temperature (i.e. to account for the lower temperatures that result in field production).

Discussion

Propagation treatments produced a range of different plants for transplanting into the field. Planting stage (involving either one extra or one less week in propagation) had a greater effect on plant fresh weight, height and visible leaf number at transplanting than temperature. As would be expected, lower temperature propagation produced smaller, shorter plants, which may be better suited to machine transplanting, than higher temperature propagation.

Measurable carry over effects of transplanting treatments to plants at final harvest in the field were greatest for early batches of plants (planted 23/03/07 to 10/04/07) when ambient temperatures in the field were lower. The mild early season conditions in 2007 appear to have minimised the incidence of bolting, with few of the celery and Chinese cabbage plants showing signs of bolting prior to the commercially determined harvesting dates. Incidence of bolting was higher for endive and escarole. The change in scheduling approach described in the results section means that data from harvest of batch 1 plants is not directly comparable with that from subsequent batches. Having a common sowing date and moving plants out of propagation when they reached the required size according to the planting stage treatment, meant that plants were propagated in comparable environments (light and temperature) and were the same age (in terms of days from sowing) at any subsequent point of sampling. Moving plants out of propagation treatments to the variable and lower temperature environment of the polythene tunnel with frost protection at different times however meant that plants from comparable planting stages (i.e. early, standard and late) were exposed to different, uncontrolled, mean temperatures after propagation. With subsequent planting stages where sowing was staggered and transfers out of the heat took place on the same date, exposure to lower temperatures in weaning and in the field was identical for all treatments within one batch and species, but the plants were at different ages (i.e. days from sowing) at the transplanting stage. Both the staggered date of transfer to weaning and the staggered sowing date approach to scheduling would therefore be expected to impact initiation in different ways. In experiments planned for 2008, schedules have allowed for comparisons of plants from staggered sowing dates and from staggered dates of transfer to weaning from a common sowing date in order to compare how these two different factors influence plant size and bolting.

Apical dissections suggest that plants from all batches sampled (batch 1, 3 and 5) were vegetative at the transplanting stage; however when plants did initiate, lower temperature had increased the rate of flower initiation. Whilst plants were apparently vegetative at transplanting stage, progression towards flowering in these plants had therefore been influenced by propagation temperature and subsequent bolting in the field would be expected to be earlier with lower than higher temperature propagation. This was seen for the early batches of endive, escarole and Chinese cabbage with higher numbers of bolted plants from 14 and 16 °C propagation than 18°C propagation. Later batches of plants had higher average temperature in propagation (due to higher solar gain as the season progressed) which would have slowed down initiation; and temperatures in the field were also higher further helping to delay initiation. In these later batches of plants it seems likely that the delay in initiation was such that the harvest date preceded bolting and hence carry over effects from propagation were not apparent

Hence whilst plants propagated at lower temperature were more compact and potentially better suited to automated transplanting, they may suffer higher levels of bolting in early season production. Increasing time in propagation increased the number of leaves initiated before transplanting which helps to maximise the leaf number and hence size of plant in the field prior to bolting but will also increase plant size and therefore make automated transplanting more difficult. These differences may be illustrated by the main effects of temperature and planting stage on plants assessed at transplanting stage. The average number of visible leaves for celery grown at 18°C, for example, was 8.6 (fig 15) compared with 8.2 at 14°C, and the average number of visible leaves for plants transplanted early was 7.5 compared with 9.8 for those transplanted late (fig 18). Therefore plants propagated at lower temperature for a longer period may have more leaves at transplanting and also be more compact and suited to automated handling than plants propagated at higher temperature and planted out earlier to produce an equivalent size if transplant (where size is determined by leaf expansion as well as leaf number). The improvements in terms of leaf number and compactness from lower temperature production would have to be balanced against extent of progression towards initiation since as seen previously, predictions for initiation are earlier and therefore at a lower leaf number (and hence probably lower head weight) for lower temperature propagation. Taking the extremes from the treatments examined in year 1, 18°C early stage endive and escarole consistently had fewer (5-6) visible leaves at transplanting than 14°C late stage plants (12). However, where bolting was recorded in the field, incidence was higher for 14°C late stage plants than for 18°C early stage plants in early season production. Chinese cabbage, which suffered less bolting overall, also had more visible leaves from propagation at 14°C to a late stage (11) than at 18°C to an early stage (7). Chinese cabbage from the first planting date however had less bolting (at 0%) from 14°C late plants than from 18°C early plants (at 19%). Hence the best compromise between temperature and length of time in propagation will vary according to species, although in commercial areas producing a mixture of species, sufficient separately controlled growing zones would be required to optimise this balance for each species grown.

Since the experiments described are based on only one year of data when conditions were mild, it is too early to put forward recommendations for each species. For all but the earliest transplanting date, both Chinese cabbage and celery apparently coped with all three propagation temperatures combined with the earliest through to the latest propagation stages (i.e. smallest through to largest size of transplant) with bolting/significant apex extension only occurring from a week 15 planting for celery or a week 12 planting for Chinese cabbage. Further work should therefore continue to challenge plants with low propagation temperature in order to reduce energy inputs. However savings in energy per crop through reduced heating set-points should be balanced against the consequent increase in production time to produce a plant of an equivalent size. Initiation in endive and escarole was apparently more sensitive to bolting from lower temperature propagation than celery and Chinese cabbage, however energy saving may still be possible through an energy integration approach providing the periods of low temperature allowed in this approach do not hasten flowering excessively.

The extension of apical dissections beyond the conventional transplanting stage has produced useful data for some preliminary modelling of response of rate of initiation and rate of leaf production to temperature. The former model has potential to aid in predicting when plants in the field are likely to initiate and hence provide an early warning system as to when harvesting should take place in order to minimise losses due to bolting. The latter model could be used to assist in propagation planning to deliver plants to a specified leaf number which may be higher in early season production to protect against premature bolting. Such models could assist with determining a suitable compromise between maximising leaf number whilst minimising plant size to facilitate machine planting. Information about forecast temperatures (or using historical temperature data) to predict initiation date, and therefore determine the lowest suitable propagation temperature could be used for these purposes.

Conclusions

Length of time in propagation had a greater influence over plant size at transplanting than propagation temperature. Smaller plants at transplanting and lower temperature propagation increased the incidence of bolting in endive and escarole in particular.

Lower temperature propagation produced smaller, more compact plants which would be better suited to automated transplanting but since lower temperature also hastens initiation, a compromise needs to be found between temperature and size to minimise bolting, at least prior to predicted harvest date.

Carry over effects of propagation treatments were greater for early than late season crops, and endive and escarole were more susceptible to bolting than celery or Chinese cabbage for the varieties tested.

Apical dissections illustrated that while plants propagated in treatments between 14 and 18°C remained vegetative until transplanting, rate of initiation in endive, escarole and to a lesser extent, Chinese cabbage, was hastened by lower temperature. The consequence of this depends on average temperatures experienced after planting out and hence lower temperature propagation had a greater influence over early season than later season production.

Data produced from apical dissections have been used to produce preliminary models for predicting the effects of average temperature on initiation date and also on total number of leaves produced; with promising results generated for endive. This approach could assist with planning harvest dates and to plan suitable schedules for different given propagation temperatures in order to optimise plant size for the conflicting requirements of machine transplanting and optimising plant size at harvest.

Technology transfer

A formal review was held on 10th October 2007 which included the independent consultant who is also the grower co-ordinator for the project, and representatives from 2 commercial farms and 2 commercial propagators. Regular contact has also been maintained with these contacts as the project has progressed.

Glossary

Bolting: Bolting is the growth of an elongated stalk with flowers grown from plant's apex. This condition occurs in plants that are grown for their leaves.

Chitted: When the seed coat has split and the seedling is just beginning to emerge.
Floral initiation: When the apex has been triggered to produce flowers.

Juvenile: When plants are incapable of responding to signals that would normally promote flowering.

Leaf initiation: When the apex has been triggered to produce leaves.

Vernalized: When plants have received sufficient low temperature for floral initiation.

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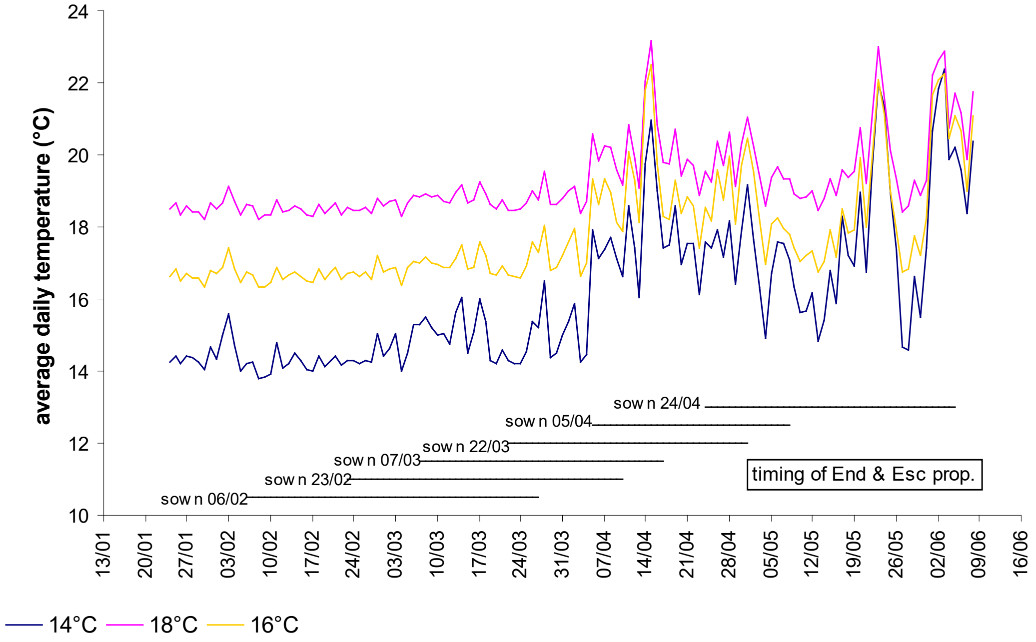
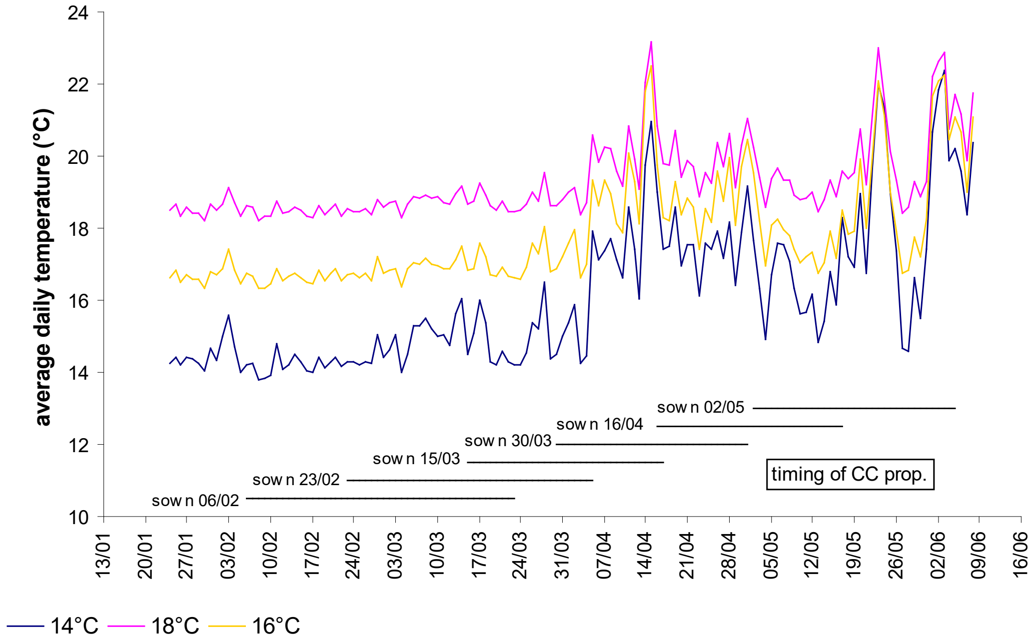
Appendix 1

Achieved temperatures in propagation compartments in relation to the timing of production of each batch of plants for endive, escarole and Chinese cabbage.

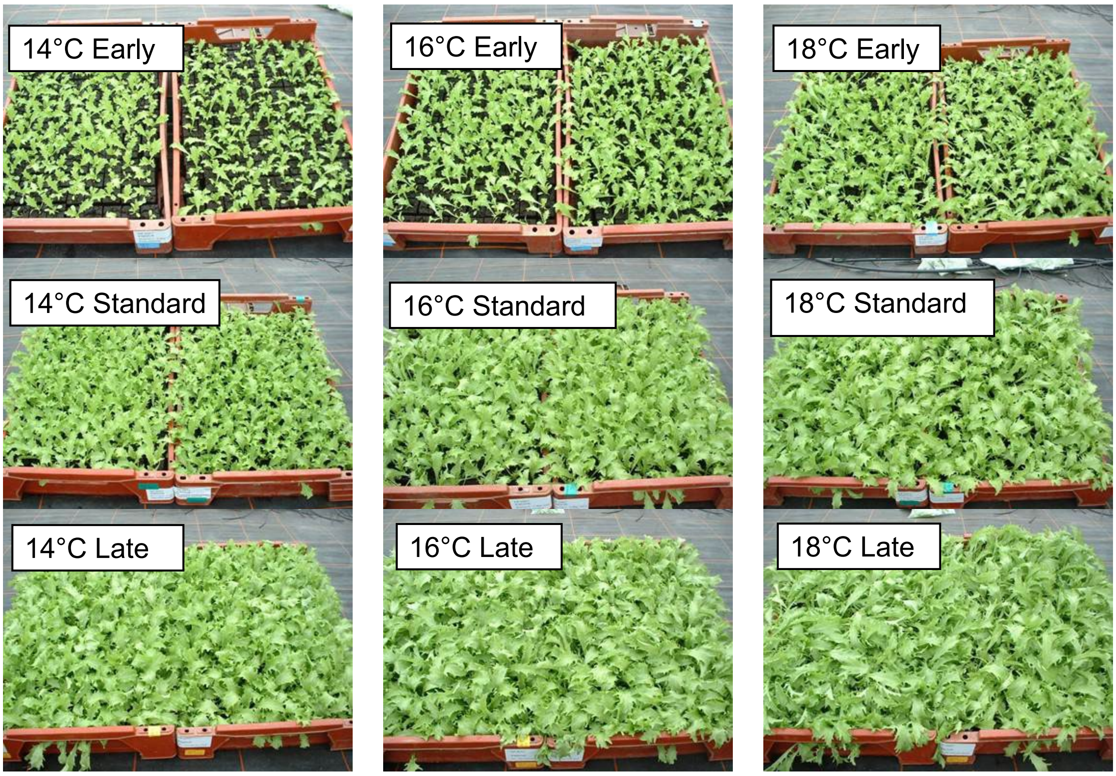




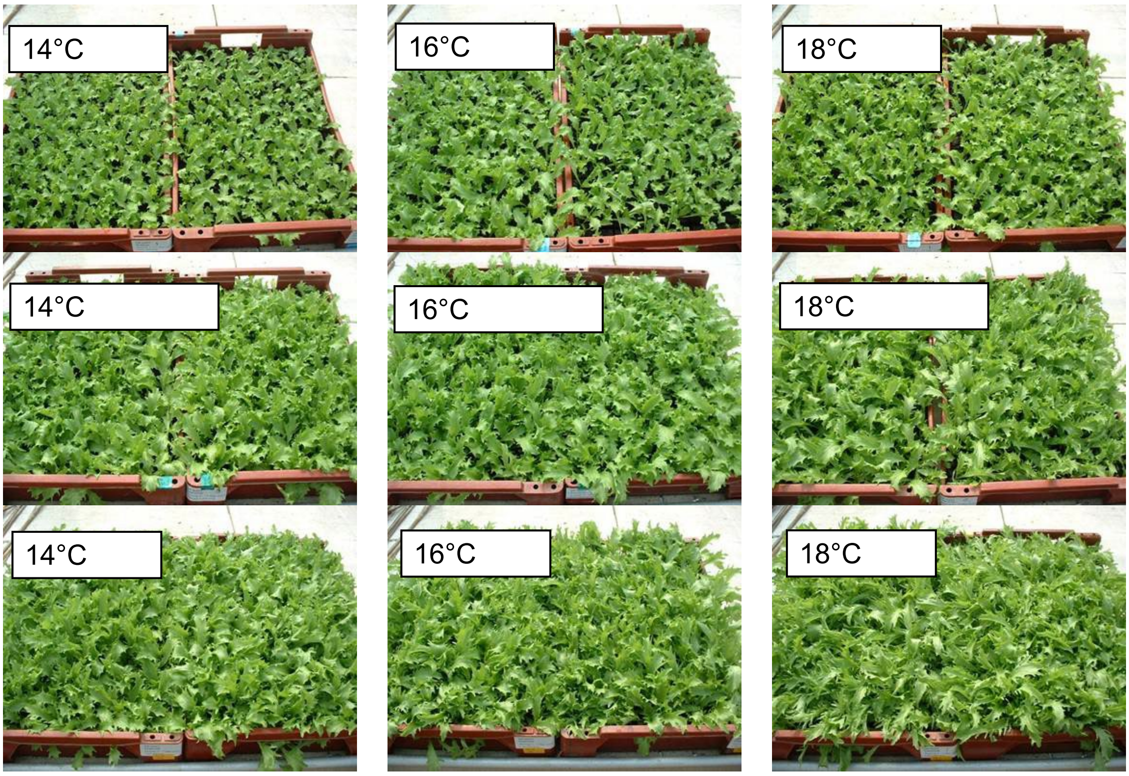
Appendix 2. Photographs of treatments at transplanting stage.

Endive planted 27/03

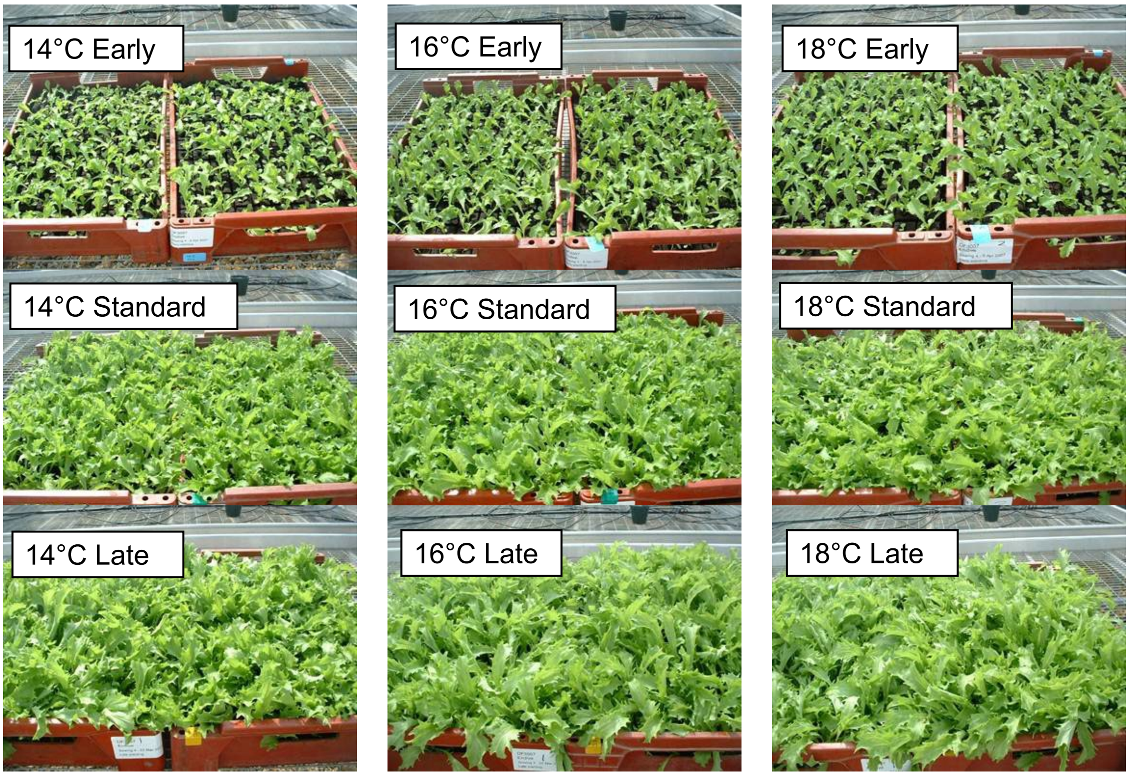
Endive planted 10/04



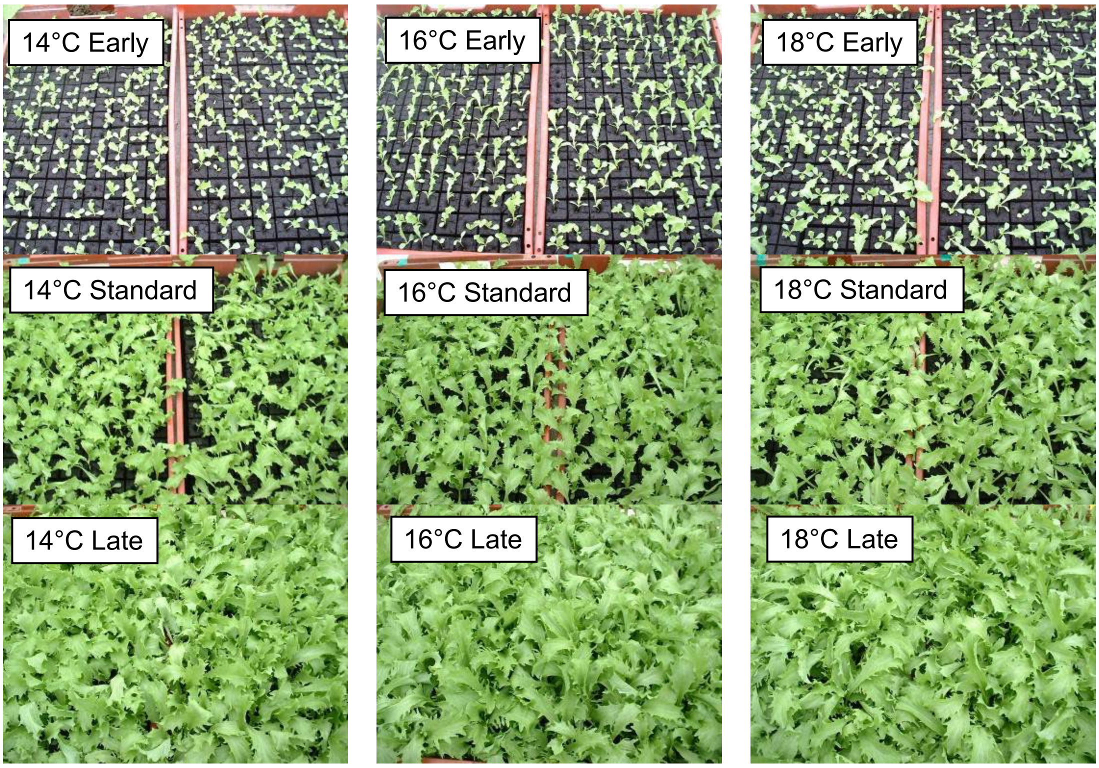
Endive planted 17/04



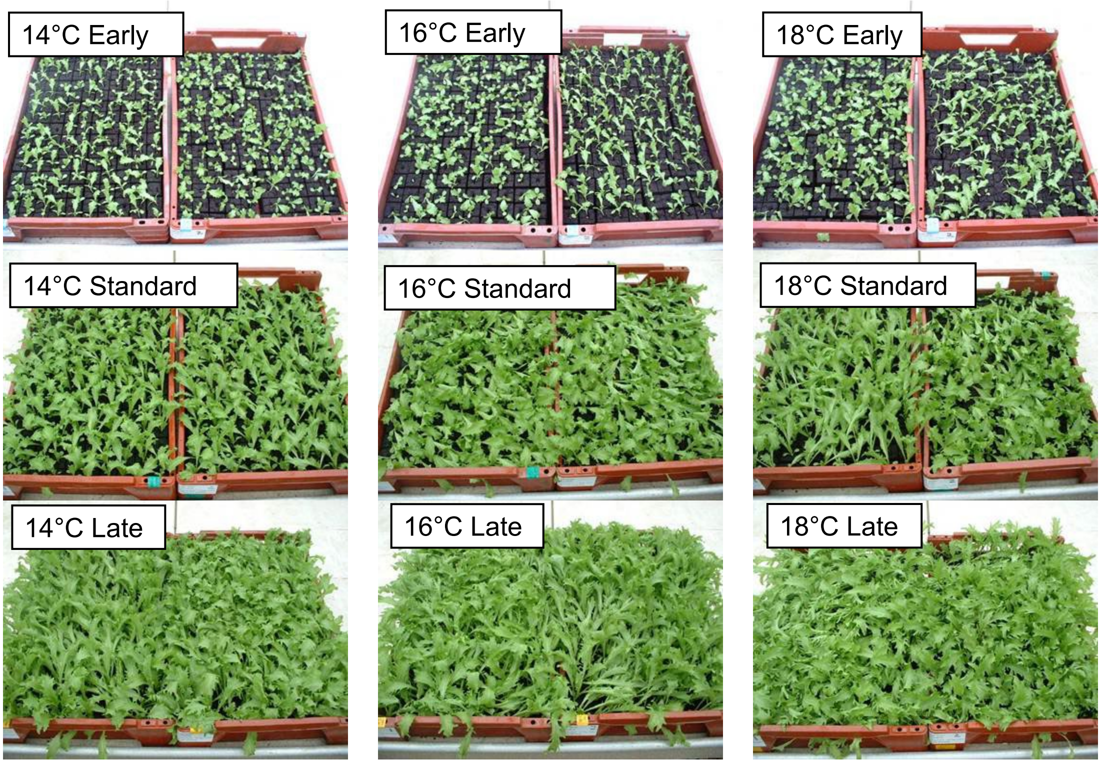
Endive planted 01/05



Endive planted 08/05

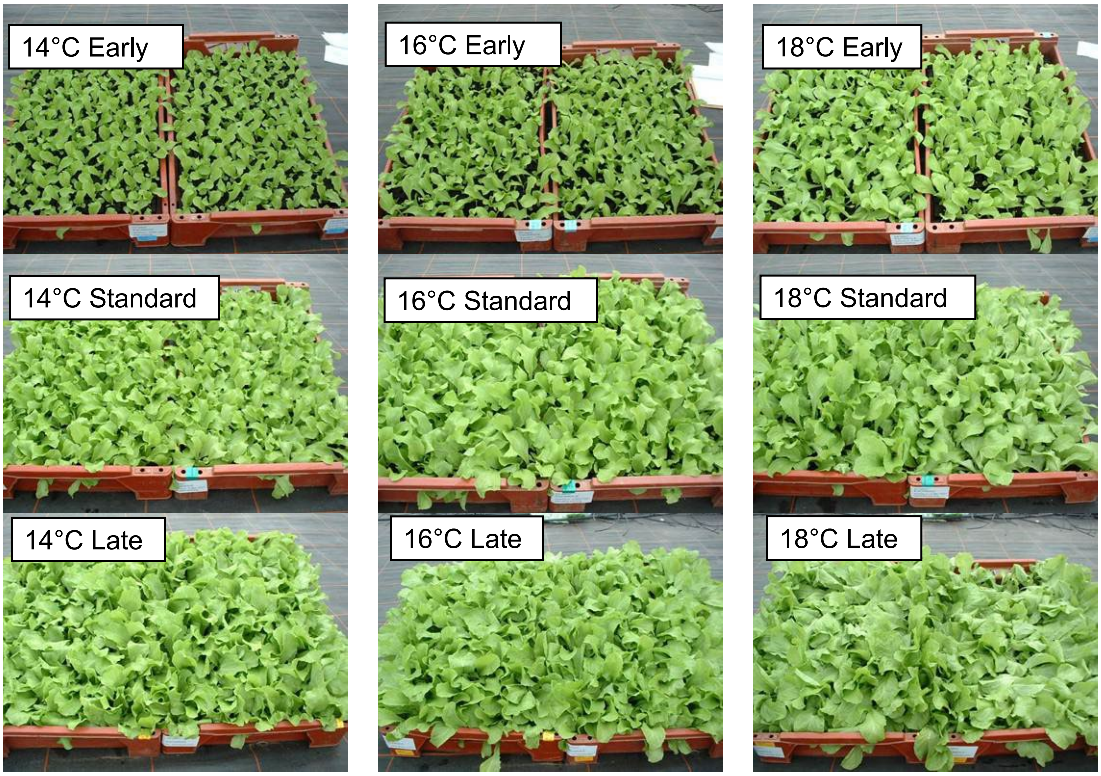


Endive planted 05/06



Escarole planted 27/03

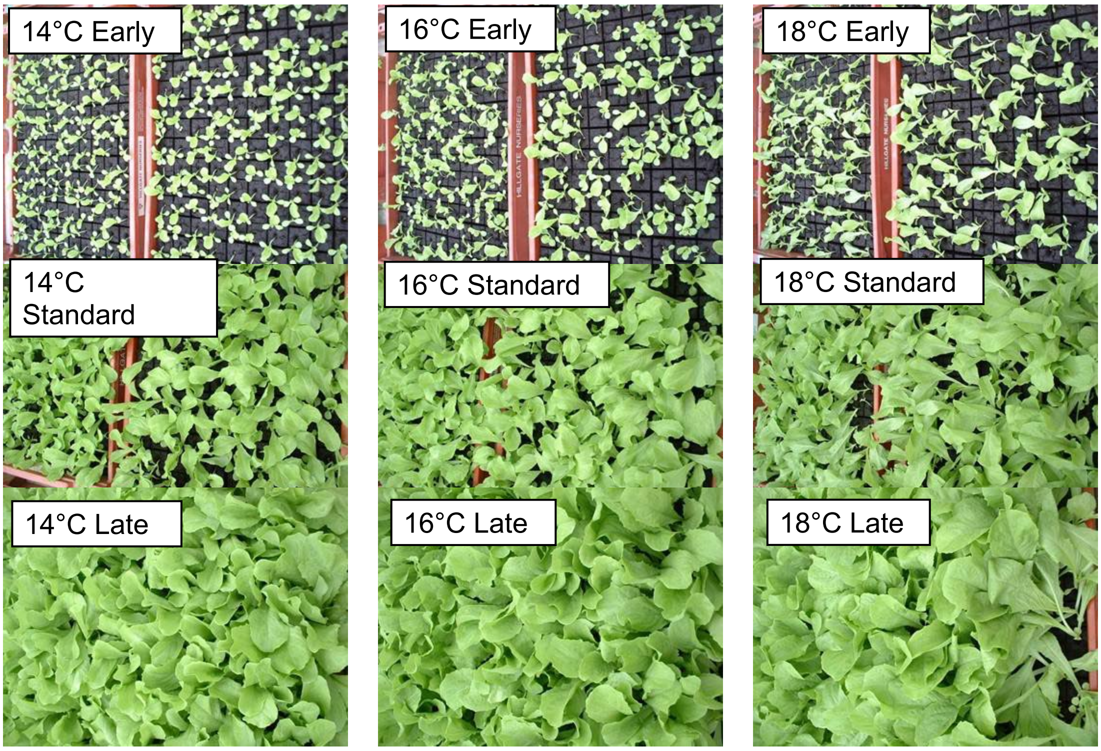
Escarole planted 10/04



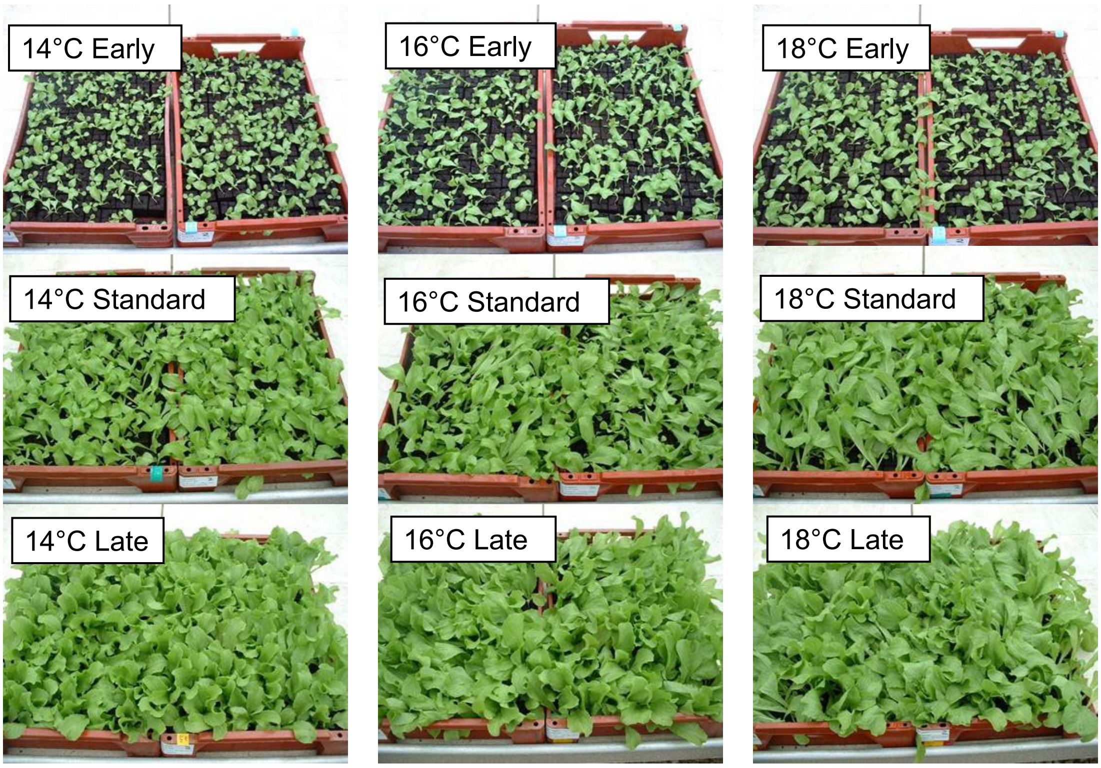
Escarole planted 17/04

Escarole planted 01/05

Escarole planted 08/05



Escarole planted 05/06



Chinese cabbage planted 23/03

Chinese cabbage planted

Chinese cabbage planted 17/04

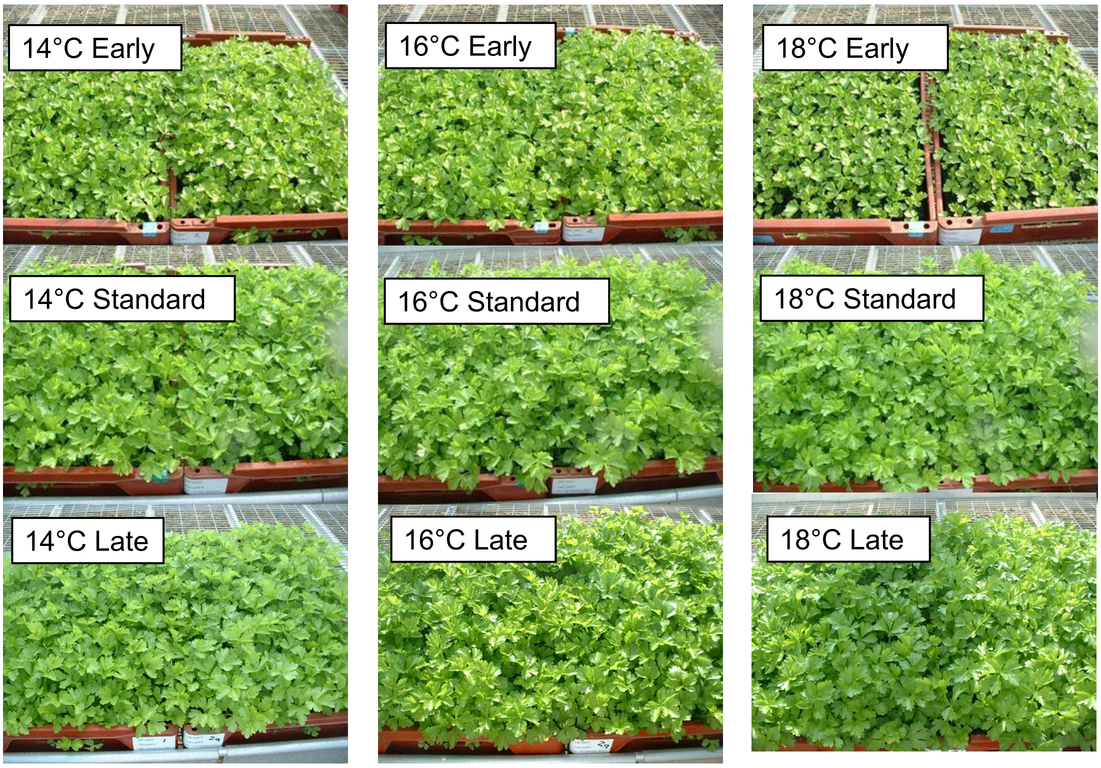
Chinese cabbage planted 01/05

Chinese cabbage planted 17/05

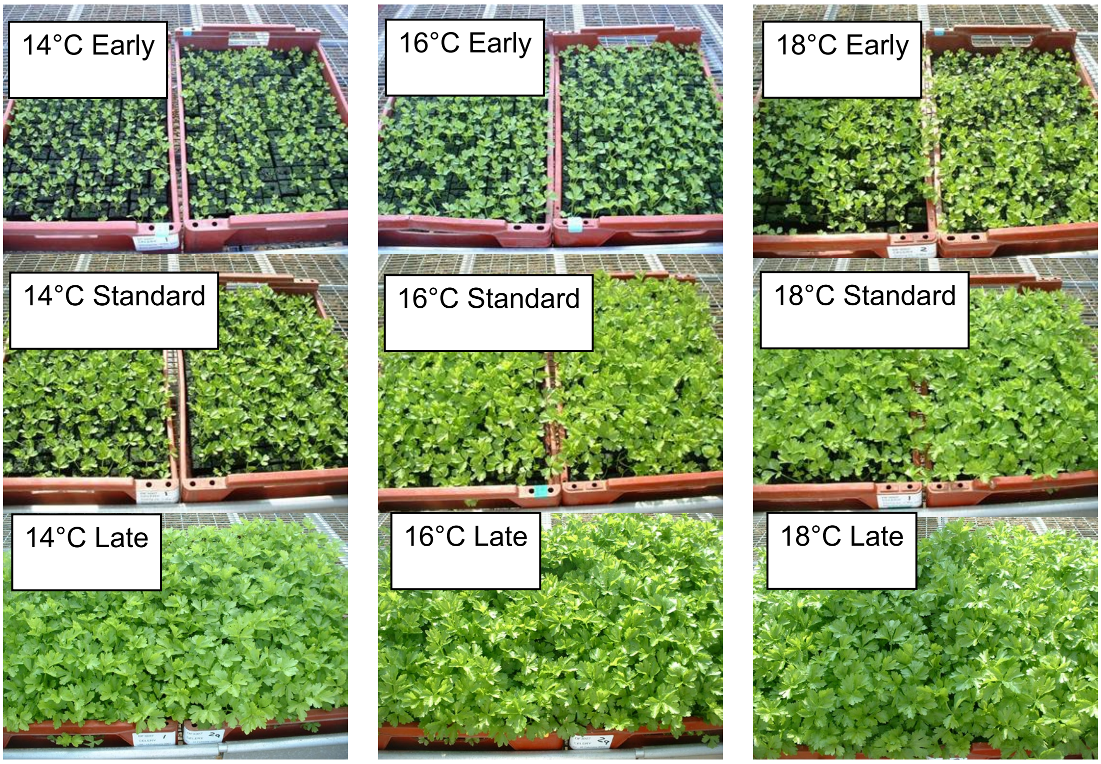
Chinese cabbage planted 05/06

Celery planted 10/04

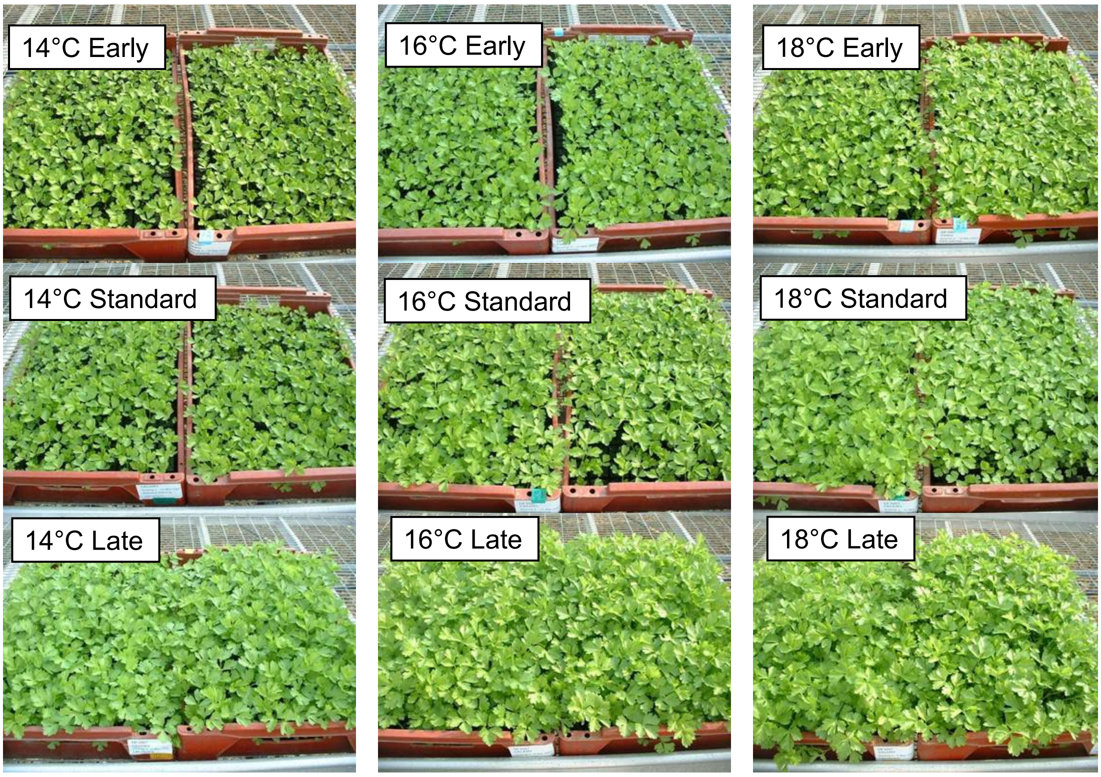
Celery planted 24/04



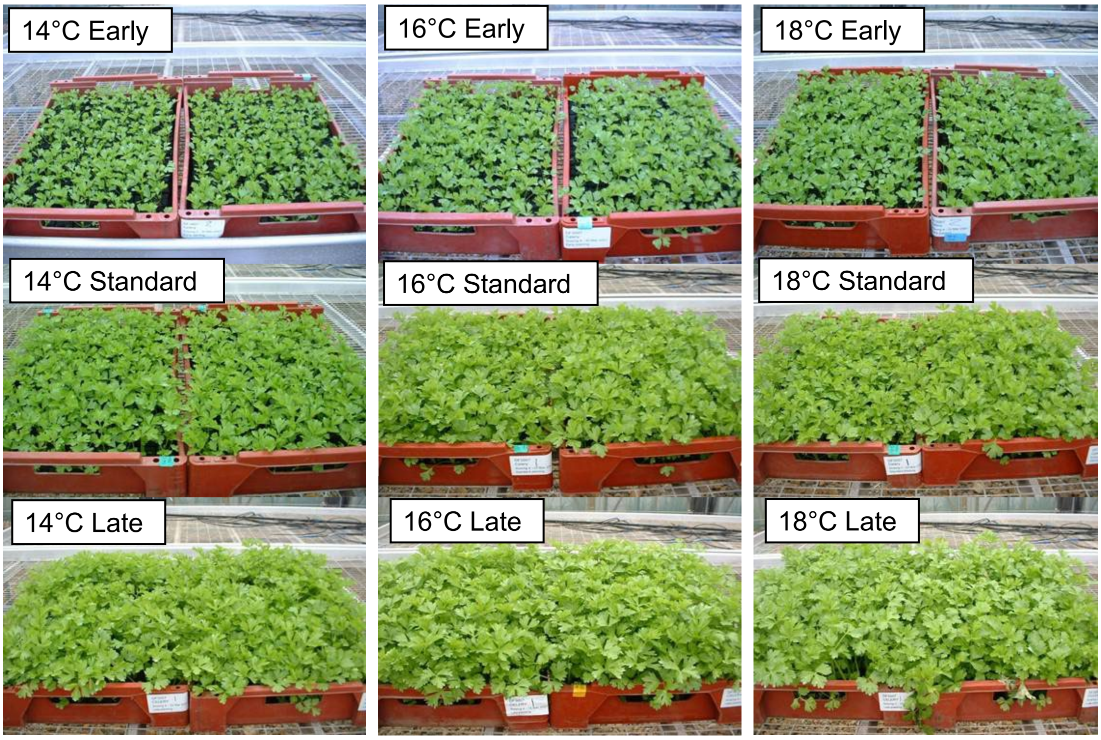
Celery planted 24/04 – 2a



Celery planted 01/05



Celery planted 08/05



Celery planted 05/06