PC 234
Bedding Plants:
Benchmarking current transport and distribution practices with the aim of identifying factors that determine plant quality during transit and methods to maintain quality

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Year 1 Report

Project Title	Bedding plants: Benchmarking current transport and distribution practices with the aim of identifying factors that determine plant quality during transit and methods to maintain quality.
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The results and conclusions in this report are based on a series of experiments 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.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Headline

No one single factor was directly associated with loss of quality in bedding plants during the transport stage, but extremes of temperature, humidity and ethylene were recorded in commercial conditions, albeit infrequently.

Background and expected deliverables

- Loss of quality of bedding plants can occur during the transport and retail chain.
- Poor quality plants undermine consumer confidence and loyalty to a retail chain or nursery.
- The extent to which transport conditions contribute to loss of quality in bedding plants is undetermined.
- Identifying reasons for loss in quality will clarify where responsibility lies and help avoid litigation.
- The research aims to identify the key stress factors that result in loss of crop quality during transit, and what practical techniques growers may be able to adopt either to reduce the incidence of stress, or increase crop tolerance to it.
- Protocols need to be developed that will help growers, hauliers and retailers ensure that high quality crops reach the market place without deterioration.

Summary of the project and main conclusions

- Transportation profiles (‘runs’) for bedding plants could be quantified and characterised.

- The majority of transport runs were recorded at temperatures between 11°C and 16°C, although some runs in summer were warmer 18-21°C.

- Data from previous literature suggests transporting bedding plant species 'as cool as possible' without risking chilling injury, but specific recommendations vary between different authors.

- In general, temperatures in excess of 20°C should be avoided. Loss of quality due to the build up of ethylene and dark respiration are likely to get worse as temperatures rise.

- The project showed there were a few 'untypical' runs, where recorded temperature and humidity may be potentially stressful to bedding plants.

- Both refrigerated and non-refrigerated wagons were commonly used to transport bedding.

- Variation can occur between the temperature a driver believes the crop is held at and the actual temperature, (possibly by as much as 4°C).

- On moving plants during transit they can be exposed to rapid transitions of temperature and humidity (e.g. from 11 °C to 35°C in a few minutes).

- During transportation, plants are effectively in the dark, for periods of up to 48 hours (and possibly longer although this was not recorded). According to the literature 36-48 hours in darkness is at about the limit for some bedding plant species.

- During these longer runs relative humidity may be 100%, with temperatures as high as 21 or as low as 11°C throughout.

- Data for canopy air temperature and temperature of the growing medium were similar for pack bedding. Any deviations were usually associated with watering of the medium.

- Sensitivity to ethylene during transportation is strongly dependant on cultivar, exposure time, temperature and even carbon dioxide levels.

- Levels of ethylene recorded in bedding crops in this project were in the range of 1-2.5 ppm. Data from the literature would suggest that these levels are potentially injurious over prolonged exposure periods. There was no direct evidence of ethylene injury, however, when commercial crops were removed from wagons.

- High ethylene levels were recorded in re-distribution centers 'hubs', but these were associated with the presence of a decaying crop (> 20 ppm) or diesel powered machinery (>2.5 ppm).

- Ethylene levels tended to be promoted by the use of enclosed packaging materials, such as shrink-wrapped trolleys or enclosure in cardboard boxes.

- Watering of the crop is an issue for concern – there were examples of crops arriving at their destinations with dry growing media (beginning to wilt) and crops with foliage (and flowers) drenched in water.

Financial benefits

- Differentiating loss in quality due to transportation *per se* and to that of subsequent management issues (e.g. lack of watering at the garden centre) is difficult to determine.

- Nevertheless, studies in the USA (Armitage, 1993) suggested that up to 20% of floricultural products in the USA could become damaged during transit and retail.

- Although it is unlikely that such high losses occur in the UK, even a 5% loss of sale of bedding plant material could equate to a retail value of approx. £7 million p.a. (Anon, 2002).

Action points for growers

- Growers / retailers need to recognise that light levels at dispatch points, hubs etc. are probably not contributing to any energy gain in the crop. (i.e. the plants have the potential to start deteriorating once removed from the growing environment). Crops need to be moved through dispatch and transportation stages as quickly as possible. Avoid transportation runs > 48 hours.

- Plants should be removed from Danish trolleys by the retailer, as light levels are so low in the middle that plants will quickly stretch and deteriorate.

- Evidence to date suggest growers should strive to water a crop well (to ensure a moist medium), but some time before loading so as to allow the foliage to dry off. High humidity levels during transit will result in little evaporation of water from the leaves. Water before loading, but allow foliage to dry before being placed on wagons.

- Growers and retailers need to be careful to avoid external sources of ethylene. Damaged crop material and petroleum / diesel powered machinery needs to be eliminated from any crop growing or handling environments.

- Ethylene itself is produced in some food and flower crops and growers need to be sure that bedding plants are not being placed in environments that may have residual high levels of ethylene (e.g. Ethylene can remain absorbed onto the walls and other hard surfaces of the lorry wagon). Take action to avoid mixed crop types and enquire from haulage companies what previous loads were, if you have any concerns.

- Hauliers need to be aware that temperature settings on wagons may not be particularly accurate and that temperatures can be 3 to 4°C different from the set point.

- Until further research is conducted growers should avoid shipping crops at temperatures ≥ 20°C. Detrimental effects due to ethylene, lack of light and high humidity are worse at higher temperatures.

- Care needs to be maintained when transporting chilling sensitive species (e.g. impatiens, marigold or zinnia) in mixed loads, as wagon temperatures may be low enough to cause chilling injury.

- Ensure crops are disease free before transport; high temperatures and humidity will encourage disease development and spread.

Science Section

Introduction

Quality is a key issue for any retailed product, not only to ensure customer satisfaction for a given sale, but also to maintain customer / retailer confidence and loyalty in the product in future. Unlike non-perishable goods;- shoes, televisions, cars, etc. bedding plants are a living product and hence, particularly vulnerable to injury from inappropriate environments or handling. Even relatively short periods in sub-optimal conditions can result in injury and loss of crop quality. Thus to ensure customer satisfaction, growers not only have to produce a high quality crop in the first instance, they need to be able to ensure it reaches the market place without deterioration.

Although the majority of bedding reaches market in good quality, anecdotal evidence suggests loss in crop quality can occur on occasions, and batches can be rejected by retailers. Previous research has confirmed that high quality plant material can suffer significant reductions in quality over short time intervals when transported in commercial vehicles (Langton *et al*., 2002; Edmondson and Parsons, 2005). A key element identified in PC 200 was that bedding plants in flower can leave a nursery in good quality, yet arrive at the retail site with a considerable reduction in quality. Armitage (1993) estimated that as a result of poor handling during transit and retail, up to 20% of floricultural products in the USA could become damaged, reduced in price or even become unsaleable. Although it is unlikely that such high losses occur in the UK, even a 5% loss of sale of bedding plant material could equate to a retail value of approx. £7 million p.a. (Anon, 2002). Also an improved understanding of the factors that influence crop quality during transportation, will help clarify where responsibility lies, should crops be rejected and litigation procedures take place.

This research aims to identify the key stress factors that result in loss of crop quality during transit, and what practical techniques growers may be able to adopt either to reduce the incidence of stress, or increase crop tolerance to it. The research is divided into 2 phases:

1. Data acquisition from commercial transport and distribution chains, investigating typical variations in temperature, humidity, light and ethylene levels that occur from the point of dispatch on the nursery through to the point of sale. (Year 1)

2. Using controlled environmental facilities, clarify which environmental variables are critical in determining crop quality and whether there are practical techniques growers and transport companies might adopt to improve crop robustness and minimise the effects of stress post-production. (Years 2 & 3).

During year 1 (Phase 1) the dynamics of bedding plant transport in commerce were studied in an attempt to collate information on:

- The range of temperatures and humidities experienced in the transport and distribution chain over the course of a year, and identify the frequency of extremes.

- Common handling protocols that influence exposure to light, water availability or leaf wetting.

- The types of transport commonly used (e.g. lorry size, presence of temperature control etc.) and typical duration of transport 'runs'.

- Crop exposure to ethylene during transport / distribution and its possible impact on bedding species.

In an attempt to put the information gained in context, a review of the literature was carried out covering previous research into the transport of bedding and other ornamental plants.

Review of current literature relating to the transport of bedding plants and other ornamentals

Previous research dedicated solely to the transport of bedding plants is limited, certainly compared to the literature relating to pot-grown ornamentals (flowering and non-flowering) used primarily as house-plants. Armitage (1993) states that less than 5% of research dealing with post-production quality in ornamentals actually involves bedding plant species. Despite production systems often being different between pot-plants and bedding (esp. modular or pack bedding), important information can be gleaned from data on the transport of pot-plants. As such, relevant information from the pot-plant sector is included in this review, and where appropriate used to address some of the problems encountered with the transport of bedding plants.

Bedding plant studies

Experiments focused exclusively on the transport of bedding material have been carried out primarily by the University Extension services in the USA. For example, Armitage (1993) highlighted temperature and ethylene as being the key factors that bedding species are likely to be vulnerable to during transit and retail. He divided species into 2 groups based on temperature optima:- 10-13°C for e.g. *Calendula officinalis*, *Viola x wittrockiana* (pansy), *Petunia x hybrida* and 15-17°C e.g. for *Begonia semperflorens*, *Impatiens wallerana, Celosia plumosa*. Groupings that appear to align closely with differences in chilling tolerance between the species. Although Armitage (1993) advocates keeping temperatures cool during shipping, the temperatures he recommends are higher than those recommended by Nell and Reid, (2000) for comparable species. For example, these authors claim that pansy and *Petunia* can be stored at 2-4°C, *Begonia* 2-13°C and *Impatiens* 10-16°C. Indeed, they claim that in the USA

"Temperature during storage and transportation are too high in the industry today"

In this scenario, however, they are discussing all ornamental crops, cut flowers, pot-plants and bedding. Nevertheless, there seems to be some ambiguity, about specific temperatures for individual bedding plant species.

Excessively high temperatures can cause reduced shelf-life and loss of quality (see later section), but specific studies on bedding are limited. High temperature (20°C) during post-production stages was cited as causing plant collapse in *Primula*, although only in one, red flowered variety (Høyer and Kristensen, 1991). In this particular study, the authors suspected that that root damage induced by sciarid fly larvae during production was the cause, but that this was only expressed when plants were later placed under warmer temperatures during transit:- There was no wilting when other plants were kept at 13°C.

Armitage (1993) also alludes to the effects of ethylene, although data on commercial crops has not been quantified. Nevertheless, experiments under controlled environments showed that there were variations in sensitivity to ethylene between species. For example, *Calendula officinalis*, *Lobularia maritima* (alyssum), *Tagetes* spp. (marigold), *Zinnia elegans* were considered insensitive; *Begonia semperflorens*, *Solenostemon scutellaroides* (coleus) and *Petunia x hybrida* classed as moderately sensitive and *Impatiens wallerana*, *Pelargonium x hortorum* (geranium), *Salvia splendens* and *Antirrhinum majus* as highly sensitive to ethylene (Armitage, 1993; Smith, 2001). Results also indicated that higher transportation temperatures and poor ventilation would increase the risk of ethylene injury. Most research studies support this position (see section on other crops types), but one study on *Petunia* suggested that in this species at least, lower growing temperatures (17°C day / 12°C night) were associated with higher ethylene production (Shvarts, *et al.*, 1997). Ethylene concentrations as low as 0.01-5 ppm (= 0.01-5 $\mu l\ l^{-1}$) may induce injury in some species (Willumsen and Fjeld, 1995) but extent of damage is often a function of exposure time, highlighting the need for good ventilation during transport and storage (Høyer, 1984).

In his review of bedding plant production, Armitage, (1993) ranked the factors that strongly influenced post-production quality and divided these between production issues and handling and transport issues. Although some of these factors may relate to conditions in the USA, they are a useful reference point for this study (Tables 1 and 2).

The lack of watering during post-production stages and hence loss of quality through drought has been a concern for many bedding plant growers, especially since there is limited volume of media associated with most pack and other bedding plant containers. The use of wetting gels and surfactants have been investigated, both in an attempt to retain moisture in the peat based media, and to help re-wetting at the retail stage. Million *et al.*, (2001) working on *Chrysanthemum* and *Petunia* concluded that surfactants needed to be added as a drench immediately prior to shipping the crop, to obtain any effect.

Table 1. Production factors that influence bedding plant shelf life (reproduced from Armitage, 1993 and Armitage, 1986).

Factors	**Comments**	**Importance**
1. Beginning production		
Sowing time	The later the sowing and higher temperatures, the more stress on plants in the retail shelf. Late sowings should be planted in larger containers.	3
Container volume	Should be as large as economically possible – helps overcome infrequent watering at retail	5
Medium	If the mix is well-drained and well-aerated, so that a good crop can be produced, this is of little importance. Research showed though that adding 10% soil helped shelf-life	2
Hydrogels	May be effective but research results contradictory	3

2. During production period		
Growth regulators	If grown in warm conditions without growth regulators, plants will be leggy and decline rapidly	4
3.Toning practices (acclimatization)		
Temperature	Reduce temperature by 3 to 5°C when flower bud is visible	4
Fertility	Reduce fertility concentration by 50% when flower bud is visible	5
Water	Reduce watering frequency by 50% when flower bud is visible	5
4. Out the door		
	Ensure all dead leaves and flowers are removed and the medium is moist	5

Rating: 5 = very important; 1 = little importance

Table 2. Dispatch and transportation factors that influence bedding plant shelf-life (reproduced from Armitage, 1993).

Factors	**Comments**	**Importance**
1. Dispatch area		
No petrol or diesel engines	Engines emit large amounts of ethylene – use electrical / battery operated machinery	5
Keep cool	Cool temperatures reduce sensitivity to ethylene	3
Keep well-ventilated	Air movement and ventilation will reduce the risk of ethylene build up	4
2. In the truck		
Handle plants gently	Rough handling breaks stems, leaves and flowers and promotes ethylene release	4
Keep truck cool (12-16°C)	Cooling reduces transpiration, respiration and the effects of ethylene. If a non-refrigerated truck is used then travel in evening / early morning when coolest	5

Rating: 5 = very important; 1 = little importance

Armitage (1993) claims the effects of adding wetting gels is non-conclusive, but that the addition of soil or green compost (e.g. *Impatiens*; Klock-Moore, 2001) to the medium may help water retention and avoid hydrophobic conditions in the peat. Antitranspirants applied to the foliage of bedding species has been attempted too, but with only limited success in extending shelf-life (Gehring and Lewis, 1980). Snider *et al.*, (2003) however, claimed that spraying *Impatiens* with lysophosphatidylethanolamine (LPE), a natural occurring lipid, increased flower retention after drought stress. The use of buffered phosphate fertilisers applied during production have also been cited as improved tolerance to drought, through their action of extending root proliferation within the module and promoted more compact shoot growth, i.e. lower transpiration rates (Borch *et al.*, 1998; Borch *et al.*, 2003).

Studies not specific to bedding

Transport

Research investigating problems with the transport of pot-plants (Høyer, 1997a) indicated that recorded temperatures in the wagon could vary significantly compared to the set-point value. Temperatures were monitored during 66 delivery trips in 2 trucks which were transporting potted plants. Compared with the thermostat set point of 16°C, the mean delivery trip temperatures varied between 11.3 and 21.6°C with up to 3°C differences within the body of a truck at any one time. The temperature in the body of one of the trucks was found to be strongly influenced by the time of year. The data collected suggested that air circulation was poor and under these conditions water may condense on plants. Høyer (1997a) concluded that the lack of temperature management in trucks would reduce the post-production life of plants, but without any evidence of direct physical damage to the plants. Improved air circulation appeared to help alleviate the problem and it was concluded that warm air must be supplied from the bottom of the body of the truck and cooler air from the top.

Ventilation is also critical in determining exposure to ethylene. Again Høyer's work (1989 and 1995) covering 70 deliveries suggested that the build-up of ethylene during pot-plant transport appeared to be dependent on (1) adequate ventilation, (2) the rate of ethylene production by the load, (3) ethylene production from the material of which the walls were made, and (4) residual ethylene adsorbed onto the truck lining from previous loads and high-ethylene-producing crops. Two trucks were monitored and in one truck, 0.05 $\mu l\ l^{-1}$ (0.05 ppm) ethylene was reached occasionally, while in the other this level was exceeded on 12 occasions for more than 24 hours. Interestingly, damage received by pot-plants during transport did not cause complaints from wholesalers. There is no comment on what consumers thought!

Simulated transport studies on pot plants have shown that extended storage periods and higher temperatures have caused increased bud drop (Al-Saqri *et al.*, 2003), bud deformation and longer internodes (Sterling and Molenaar, 1986) and shorter flower and plant longevity (Hartley, *et al.* 1995; Leonard *et al.*, 1995). Borch *et al.,* (1996) carried out studies in an attempt to simulate transport conditions imposed on potted rose. The main causes of reduced postharvest longevity were wilted flowers, infection by *Botrytis* and an increased number of yellow buds. The authors found that when plants were assessed 18 days after treatment there were no differences in the percentage wilted flowers for all plants subjected to 0-2 days simulated transport, but there were increases in some cultivars after 4 days simulated transport. The degree of wilting was also dependent on the origin of the plants, and was generally less severe in summer than in winter. Other studies by this group showed large effects between different cultivars of roses, for example, flowers on *Rosa* cv. Elegant Parade were badly damaged by simulated transport (e.g. 4 days), whereas those in *R.* cv. Dreaming Parade were not. Indeed, some un-opened buds could develop normally in this cultivar as long as the transport period was not excessive (Høyer, *et al.*, 1996). Work by Nell and Noordegraaf, (1992), however, showed that flowering potential in potted rose could be inhibited by simulated transport treatments, but the effects were minimised by exposing the crop to higher light levels during the post-production period. The developmental stage of the rose crop at the time of transport appears to affect the number and quality of flowers produced subsequently (Williams *et al.*, 1995).

Early work investigating transport simulation in poinsettia has been shown to reduce shelf-life by approximately 2 weeks compared to plants that were moved directly from growing to household conditions (van Dijk and Barendse, 1991) Treatments, however, included storage in darkness for 7 days, which is probably extreme by bedding plant standards.

Ethylene

The effects of ethylene on plant development are well-documented (e.g. Woltering, 1987; Willumsen and Fjeld, 1995; Høyer, 1996). Symptoms of damage include premature dropping of foliage and flowers or premature flower death (Smith 2001). Flower petals become translucent, some plants develop adventitious stem roots, and petioles may twist (epinasty). Sources of ethylene include; exhaust from cars, trucks and non-electric forklifts; pollutants such as cigarette smoke; plants and flowers that are under stress; fungi such as *Botrytis* and some bacteria; incomplete combustion and / or poorly ventilated heaters located in enclosed greenhouses; and from fruits and vegetables. Generally, reproductive tissues produce more ethylene than vegetative parts. Interestingly, buds themselves are a source of ethylene but also a source of auxins, which promote and inhibit bud abscission, respectively (van Meeteren and van Gelder, 1995). Often the higher the temperature, the less ethylene it takes to induce plant disorders.

Previous studies involving ethylene and transportation have concentrated on cut flowers and pot-plants. Woltering evaluated responses in various foliage and flowering potted plants back in 1986. Plants were exposed to 0 to 15 ppm ethylene for 24 or 72 h at 20°C darkness. Toxicity symptoms on foliage plants were characterised by abscission and yellowing of leaves. Flowering pot-plants showed abscission of flowers, flower buds or of whole inflorescences. In general, abscission of leaves was only observed when plants were exposed to ethylene for 72 h while abscission of flowers and flower buds appeared after 24 h of ethylene treatment. Woltering (1986) could divide the species under test into classes based on ethylene sensitivity.

Post-production longevity and sensitivity to short-term ethylene exposure has been studied in minature roses (*Rosa hybrida*). Twelve different cultivars were treated with a continuous flow of 1 ppm ethylene at 20°C for 24 h, when plants were at marketable stage (3-5 open flowers) (Leonard *et al*., 2005). The magnitude of ethylene injury, the time before injury was evident and the plant part affected was found to be cultivar-dependent. For most cultivars, it took several days before the effects of ethylene were apparent, although sometimes injury was noticeable after 24 h. Short lasting cultivars were consistently found to be sensitive to ethylene, while most, but not all, long lasting cultivars were tolerant. In a study by Muller *et al.*, (2000) rose plants subjected to simulated transportation stress, had reduced shelf-life (In *R* cv. Bronze from 7 to 6 days and in *R*. cv. Vanilla from 23 to 17 days). In *R*. cv. Bronze, the stress resulted in a modest increase in ethylene production, but in Vanilla, it had no effect on the low ethylene production by flowers. Nevertheless, pre-treatment with the ethylene action inhibitor 1-methylcyclopropene (1-MCP) before transport simulation improved display life of both cultivars.

Higher temperatures have been shown to acerbate the effects of ethylene, with quicker leaf drop noted in *Radermachera sinica* at 15°C compared to 10°C (Labouriau and Høyer, 2001). One paper studying *Capsicum* transplants (Kays *et al.*, 1976) also suggested that higher CO_2 levels could increase ethylene release from the crop. Presumably CO_2 will increase in most crops when they are enclosed during transit and ventilation is poor. Similarly, other studies suggest temporary water stress and wilting can be a precursor to ethylene evolution from the tissues (Mayak and Faragher, 1986).

Some species may be very sensitive to ethylene. *Hibiscus rosa-sinensis* had extensive abscission of flower buds after 24 h of exposure to 0.05 ppm. In addition to the ethylene response, extensive bud drop was caused by darkness or low light levels (Høyer, 1997b).

A number of chemical, anti-ethylene products have been used in the protection of cut flower and pot-plant crops. Particularly, the use of silver thiosulphate (STS) to offset ethylene induction has been used in a wide range of crop types (e.g. Moe and Smith-Eriksen, 1986; Høyer, 1986, 1998a; Custódia *et al.*, 2001). Leaf abscission caused by ethylene can be reduced by STS (Høyer, 1998a). Treatment with 4.05 mM STS, 1 or 11 days before ethylene exposure, considerably reduced the ethylene induced abscission, but with little noted effect of the treatment when applied 21 days before ethylene exposure.

Of bedding species, *Impatiens* has been identified as relatively susceptible to ethylene damage. Exposure to exogenous ethylene caused corolla abscission in New Guinea impatiens (*Impatiens* x *hawkeri* cv. Sunfire), with 80-100% abscission resulting even after only 4 hours exposure to 1 ppm ethylene. Simulated shipping of untreated control plants caused approximately 65% abscission. (Dostal *et. al.,* 1991). Pre-treating plants with STS or (aminooxy)acetic acid before simulated shipping gave positive results, with either substance reducing abscission to approximately 20% when applied at 1.0 mM. When pre-treated plants were exposed to set concentrations of ethylene (1 ppm) however, (rather than simulated transport *per se*), responses were markedly different and only the STS reduced corolla abscission. This suggests that the (aminooxy)acetic acid may be involved in minimising corolla abscission during transport, but this may not relate to an anti-ethylene response. Variations in results between simulated transport experiments and those where plants are simply exposed to an ethylene concentration, may again suggest (see Høyer, 1997b) that other factors contribute to loss of quality, or that there are interactions between ethylene and some of these other factors (light, humidity, temperature, pathogen presence etc.).

Temperature and humidity

In an attempt to determine the best packing sleeve for potted cyclamen, Geoffroy and Vial, (2004) evaluated changes in environmental condition during transit and distribution. At the time of conditioning, temperature was 19°C and relative humidity (r.h.) 80%. During the waiting phase before, and during transport itself, r.h. was 100% and the temperature decreased to 16°C. The authors found that the duration of exposure to 100% r.h. varied with the type of film used (pre-stretched, classical, perforated or net).

Work on *Kalanchoe blossfeldiana* showed that post-production quality was significantly affected by flowering stage and transport temperature during transit (YounJung, *et al.*, 2003; Leonard and Nell, 2000). Plants transported at 18°C had shorter longevity, but increased flowering rate, than those at 12°C. Plants that had low flower rates at time of transportation (5%), had greater longevity than those that were already well into bloom (50% flower cover).

Inappropriate humidity during production has been linked with quality problems (Hendriks, 2001), and it must be assumed that this factor during transit also may influence shelf-life, especially if the crop is exposed to too high or too low a humidity for a prolonged duration. Responses again may be species specific, for example high humidity during production caused loss of quality in cut roses, but no affect in *Chrysanthemum*, *Euphorbia* (poinsettia) or *Begonia* (Mortensen, 1998), and even appeared to improve shelf-life in *Argyranthemum* (Høyer, 1998b). In contrast to Mortensen (1998), Fjeld (1986) found high humidity (90%) during production of *Begonia* induced stem elongation and loss of quality. It is recognised that high humidity will induce the spread the *Botrytis* and other pathogens, especially if plants have been stressed excessively or physically damaged, but direct effects of high humidity associated with transit are not well-documented. Problems may not be restricted to high humidity; low humidity (e.g. < 80% r.h.) can result in bud drop in some flowering pot-plants (Song and Lee, 1994).

Light

Unlike foliage, pot plants where light acclimatization is important, it is generally considered that high light levels should be maintained over bedding plants during production and on the retail bench (Armitage, 1993; Fjeld, 1986). Interestingly, work on pot rose, showed that bud drop was increased after transport, when plants were placed in a simulated retail environment with only 1 W m^{-2} light provided. The authors concluded that bud drop can be minimized by high post-production irradiance levels following transport (Nell and Noordegraaf, 1992).

A lack of light during shipping was attributed to leaf drop in *Ficus*, but the experimental periods examined (7 and 14 days darkness, Mulderij, 1991.) were in excess in what would be considered appropriate for bedding. Nell and Reid (2000), suggest that 2-3 days is the maximum storage / transport time for a range of bedding, possibly because lack of light and ethylene become significant factors after this. This is broadly in line with specific crop information provided by Armitage (1993), where, for example leaf chlorosis can occur after 48 darkness (*Pelargonium*), or young flower buds abscise after 36 hours (*Impatiens*).

Nutrition and irrigation

There appears to be a consensus that high fertiliser feeds (particularly nitrogen, Druege, 2001; ter Hell and Hendiks, 1995) during production of both flowering and foliage ornamentals can reduce shelf-life and encourage physiological disorders (Nell and Barrett, 1990). Armitage (1993), however, is clear to point out that this should not be interpreted as giving no feed during the latter stages of production. Work on *Petunia*, suggested that flower quality at retail was enhanced when the normal fertiliser rate of 200 ppm was reduced to 100 ppm at the first flower bud stage (Armitage, 1986). Information on nutritional responses and transportation in other bedding species appears limited. Armitage (1993) suggests that nutrition levels can be reduced in line with lower irrigation frequencies during the last week or so of production (see toning practices, Table 1).

Due to problems associated with drought, many growers may wish to thoroughly irrigate the crop prior to transport, however, work from PC 200 (Edmondson and Parsons, 2005). suggested that irrigation prior to dispatch did not necessarily maximise quality and more work is required to determine the advantages / disadvantages associated with irrigation before transport and leaving flowers / foliage wet.

Vibration

The extent to which vibration during transport causes injury appears to vary with crop, and packing materials employed. Bulle *et al.*, (2000) stated that vibration caused severe damage to leaves and open flowers of pot-plants with greater than 40% of the open flowers of *Achimenes*, *Impatiens* and *Streptocarpus* being damaged after 2 days treatment. They found no long term physiological effect though, and concluded that shelf-life appeared to be more influenced by a dark period than by vibration. In contrast, in *Kalanchoe*, YounJung, *et al.*, (2003) found little direct damage from vibration in transit.

Concluding points

The literature suggests that a range of environmental variables can act independently, or in combination to affect ornamental plant quality during transit. One of the next steps in this project will be to correlate information gained from the commercial practices for bedding in the UK (Phase 1) to the information supplied from the literature. Information specific to bedding is scarce, but unfortunately, even what is available can be contradictory (e.g. tolerance to chilling and dark durations). This possibly reflects the wide variety of cultivars grown and different cropping techniques employed. Nevertheless, it is hoped that Phase 2 of this project can help clarify some of the key factors involved, especially in the context of the UK bedding plant industry.

Materials and Methods

From a period between April 2005 and July 2006, approximately 25 separate transport movements (transit runs or runs) were monitored and information collected on crop temperatures (temp.), relative humidity (r.h.) and logistics of the movement (nursery location, destination, timings etc).

Temperature and humidity data was collected via probes (TinyTag, Extra-3580, Gemini Data Loggers, Chichester, UK) placed onto a pack of bedding plants, which had been located on a 'Danish trolley' (or occasionally a card board box or pallet). Probes were usually placed in a central location in the middle shelf of the trolley, although they could be placed elsewhere to look at variations in temperature due to location within the load. The probes were set to record data every 10-15 minutes and could be programmed for a duration of 55 days. On a number of runs, media temperature was recorded in parallel with air temperature at the crop canopy level.

Nurserymen and drivers were requested to place probes within their crops and to return these for downloading after a single, or series of transport runs. In addition, they were also asked to fill in a short questionnaire to provide supplementary information on time of loading, departure, arrival, no of intervening stops, weather conditions and type of crop and lorry (wagon). Data from these questionnaires were then used to interpret alterations in the temperature and humidity data sets, derived from the probes.

On a limited number of occasions, information from these sources were augmented by visual inspection of crop quality, by one or more consultant being present when a crop arrived at its intermediate or final destination.

Six nurseries and one retailer actively took part in the project and helped co-ordinate the collection of data. In the vast majority of cases, the crop was a bedding plant type, although other crops could also be included in the cargo, for example, containerised roses. Nevertheless, probes were always placed on a pack or pot of a bedding plant species. A range of different lorry types were examined (e.g. from 13 to 38 tonne vehicles, refrigerated v non-refrigerated) and different durations of runs and numbers of deliveries.

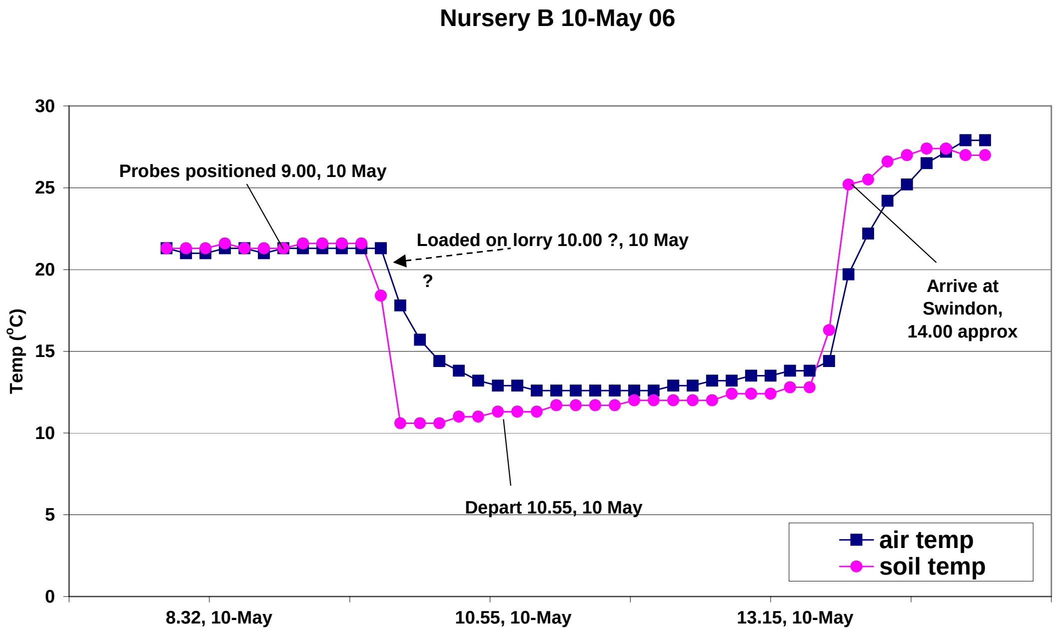
Results and Discussion

Characteristics of the ‘average’ run

One of the first objectives of the project was to understand the temperature and humidity changes that crops were exposed to during transportation. No two runs were identical, however, generic information could be gained by comparing a number of different data sets. For example, it was clear that the crop would often be exposed to a sharp temperature decline when it was loaded. This was either due to the wagon being naturally cooler (shaded, damp etc) or it had been pre-chilled by the lorry’s refrigeration unit. In addition, some of the downward temperature trends may be related to watering the crop in dispatch, just prior to loading. Often (but not exclusively), the temperature in the wagon itself was relatively stable, with very few sharp transitions, although ‘troughs and peaks’ could occur when doors were opened. A typical (or ‘average’) data set is depicted in Figures 1 (temperature) and 2 (relative humidity, r.h.). In the majority of cases the reduction in temperature when the crop is placed in the wagon is matched with a rise of r.h., often to 100%.

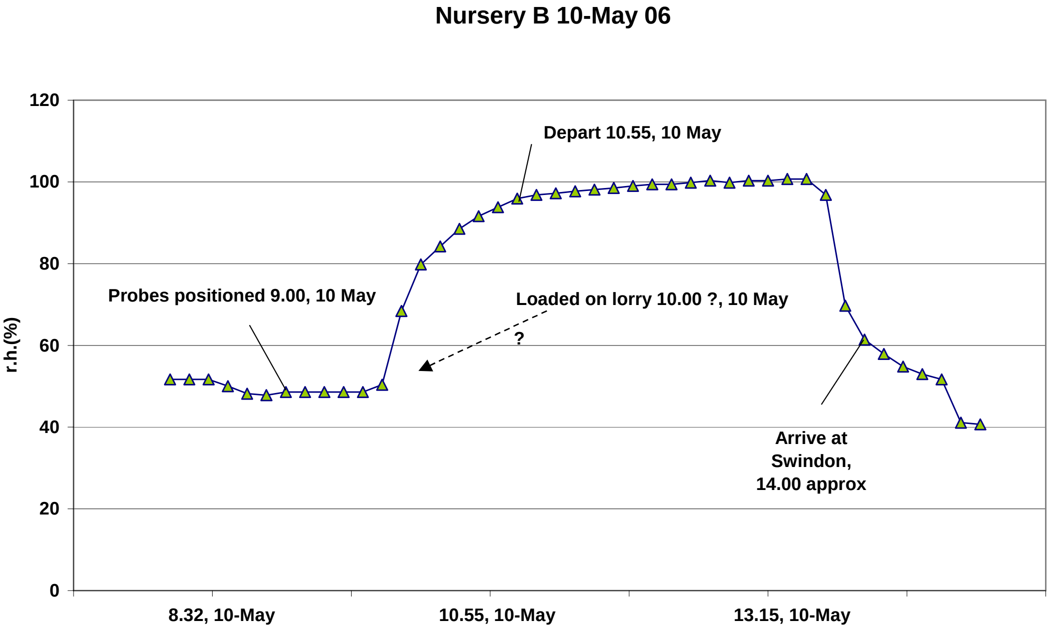
For this particular run on 10 May 2006, weather conditions at time of departure were quoted as overcast and cool (10-14°C), and once the crop (38 trolleys of *Antirrhinum*) was placed inside the wagon, temperatures were approx 12.5°C for air and 12°C for roots during transit. Outside temperatures at arrival, however, were 21.5°C, but this did not appear to have influenced those within the wagon. It was not clear in this scenario whether the wagon’s refrigeration unit was operating. On arrival, plants were scored for quality and were deemed to be top quality (10 / 10 score) implying no immediate loss of quality during transit.

Figure 1. Nursery B - Crop (*Antirrhinum*). Air and soil temperature. Articulated rigid-body



(refrigeration not stated). Single run to Swindon, Wilts.

Figure 2. Nursery B - Crop (*Antirrhinum*). Relative humidity. Articulated rigid-body (refrigeration not stated). Single run to Swindon, Wilts.



Stored the night before

For a number of nurseries it was more convenient to load a lorry the night before departure, so as to allow a quick departure the following morning. Temperatures during this night storage period could be relatively high , or relatively low, depending on time of year, weather conditions and whether the chilling unit was being employed. In some cases the back door of the lorry was left open to help reduce temperature and humidity. The lowest recorded night temperature was approx. 11°C (Figure 3), with 100% r.h. (Figure 4) and highest was 23°C (Figure 5) with again r.h. reaching 100% (Figure 5). In both these cases a non-refrigerated wagon was used and in the case of the higher temperatures, the wagon doors were left open in an attempt to avoid excessive heat.

Variability in temperature and humidity during transit.

Lorry type (and in non-refrigerated lorries, weather) had a strong influence over the temperatures the crop experienced during transit. For example, temperatures were often stable, when chilling units were used (Figure 6), but more variable when they were not (Figure 3 and Figure 8). Similarly, r.h. was more uniform (Figure 7) under more stable temperatures and more variable as temperatures oscillated (Figure 9).

Figures 8 and 9 represent one of the most variable data sets recorded. This wagon was non-refrigerated and the crop appeared to be largely influenced by the ambient conditions outside. There was a slow reduction in temperature (reaching 9.2°C) during the night following loading, then a progressive increase as the lorry proceeded to deliver its load to a number of garden centres. At the final destination, air temperature was 27°C and soil temperature was 22°C. Humidity fluctuated during the delivery period, but generally decreased with time and with the removal of the load in batches. One of the biggest drops in r.h related to the delivery at Brocksworth, and this correlated with the lorry doors being open for longer than at other deliveries (45 minutes compared to the more usual 20 minutes). This may also relate to a greater proportion of the crop being removed at this destination (hence, higher temperatures and lower r.h. afterwards).

Figure 3. Nursery B - Crop (bedding and roses). Air and soil temperature. 18 tonne, rigid-body with opaque roof (no refrigeration). Multiple run with final destination High Wycombe, Bucks

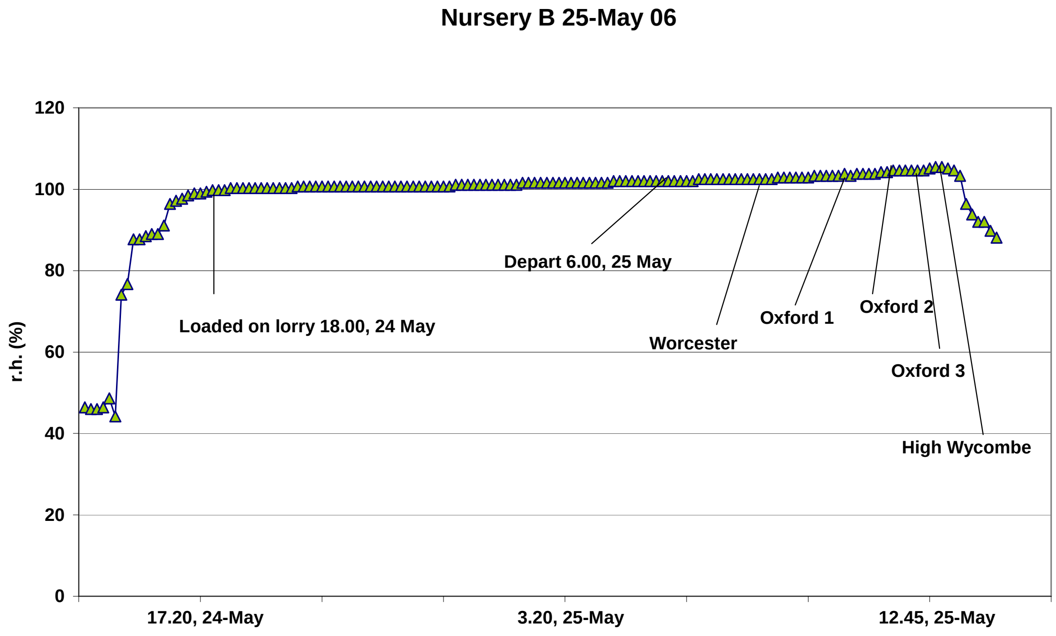


Figure 4. Nursery B - Crop (bedding and roses). Relative humidity. 18 tonne, rigid-body but opaque roof (no refrigeration). Multiple run with final destination High Wycombe, Bucks.

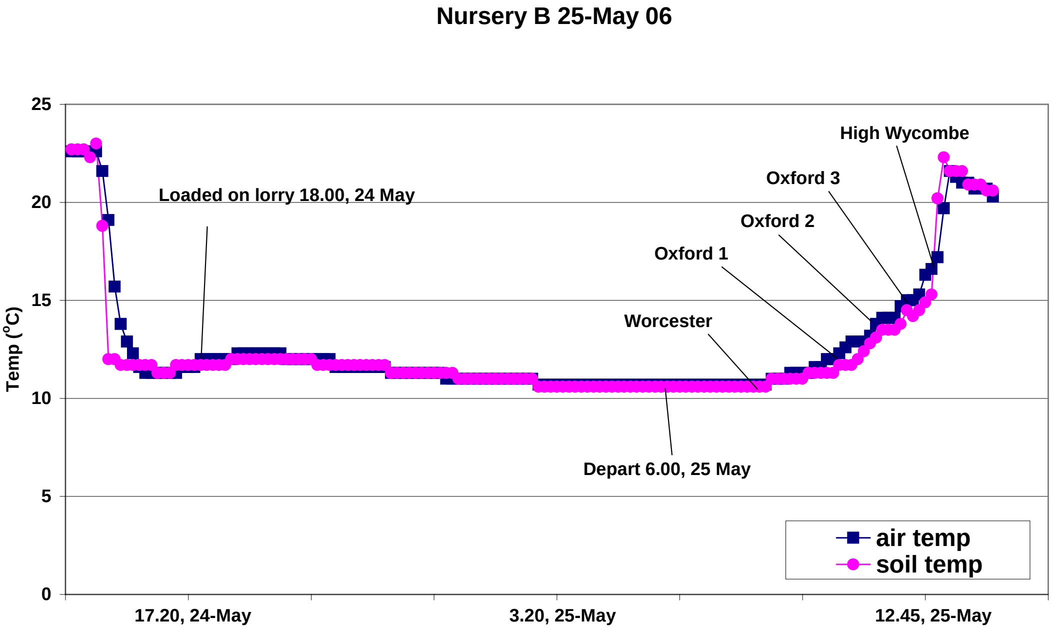


Figure 5. Nursery G - Crop (mixed bedding). Air temperature and relative humidity. 13 tonne, rigid-body and no refrigeration. Multiple run around East Anglia – warm weather.

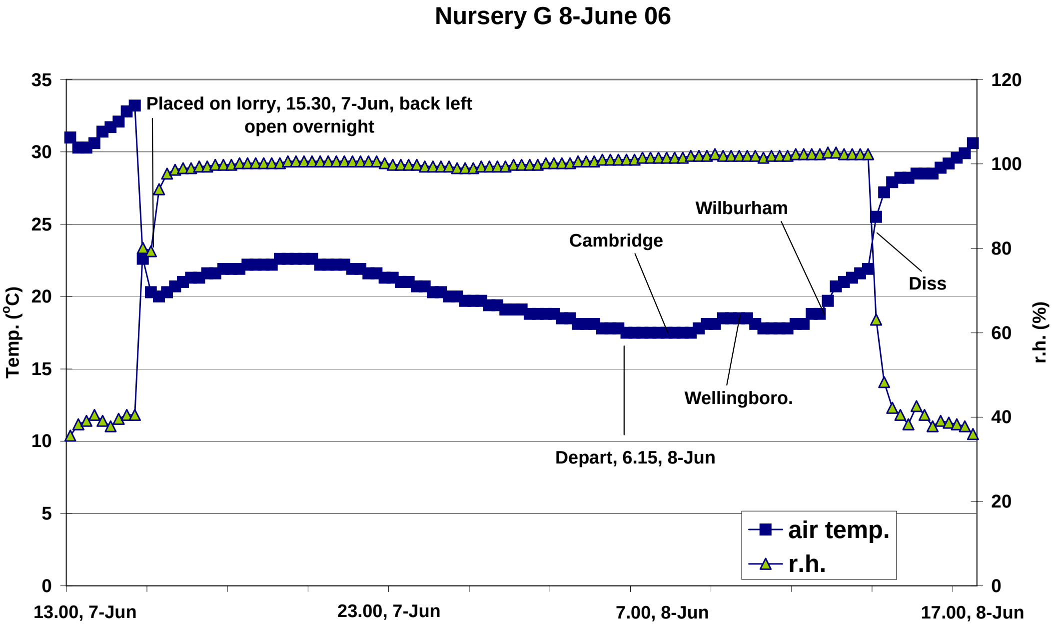


Figure 6. Nursery A - Crop (unknown). Air and soil temperature. 18 tonne, rigid-body, refrigerated lorry (refrigeration unit on – not verified). Short, multi-drop run to Wokingham, Berks.

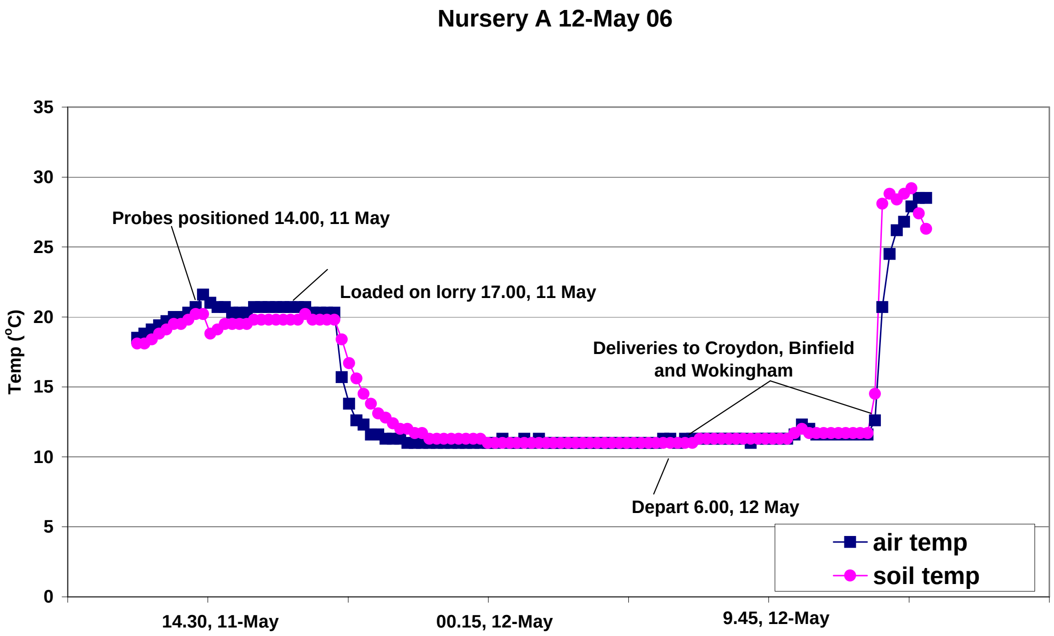


Figure 7. Nursery A - Crop (unknown). Relative humidity, 18 tonne, rigid-body, refrigerated lorry (refrigeration unit on – not verified). Short, multi-drop run to Wokingham, Berks.

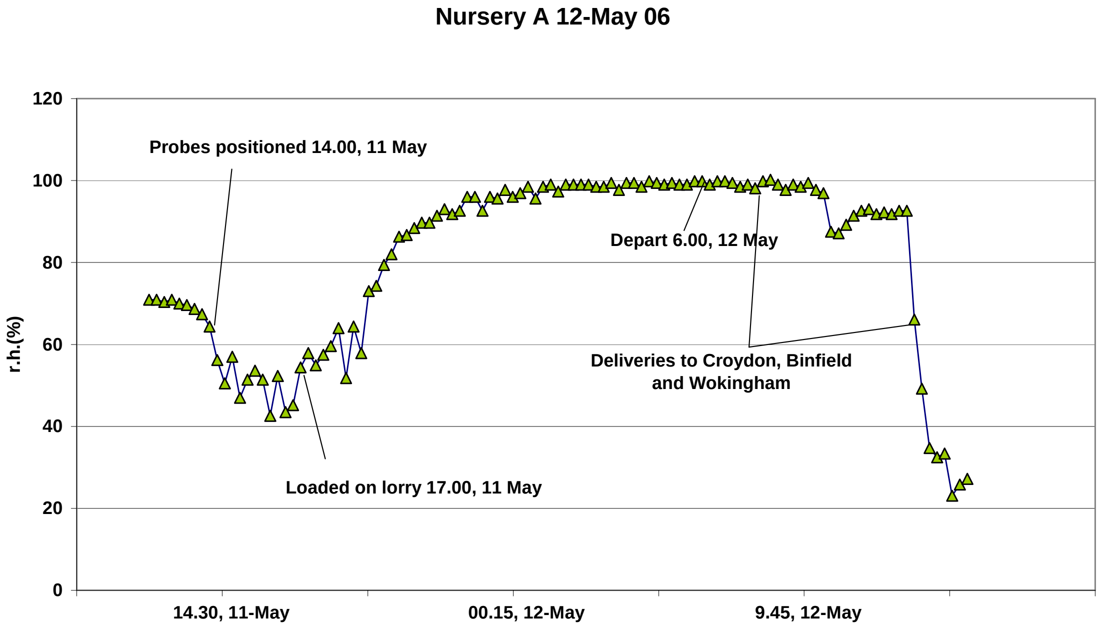


Figure 8. Nursery A - Crop (unknown) Air and soil temperature. 18 tonne, rigid-body, non-refrigerated lorry. Multi-drop run to Hazelfield (Glos.).

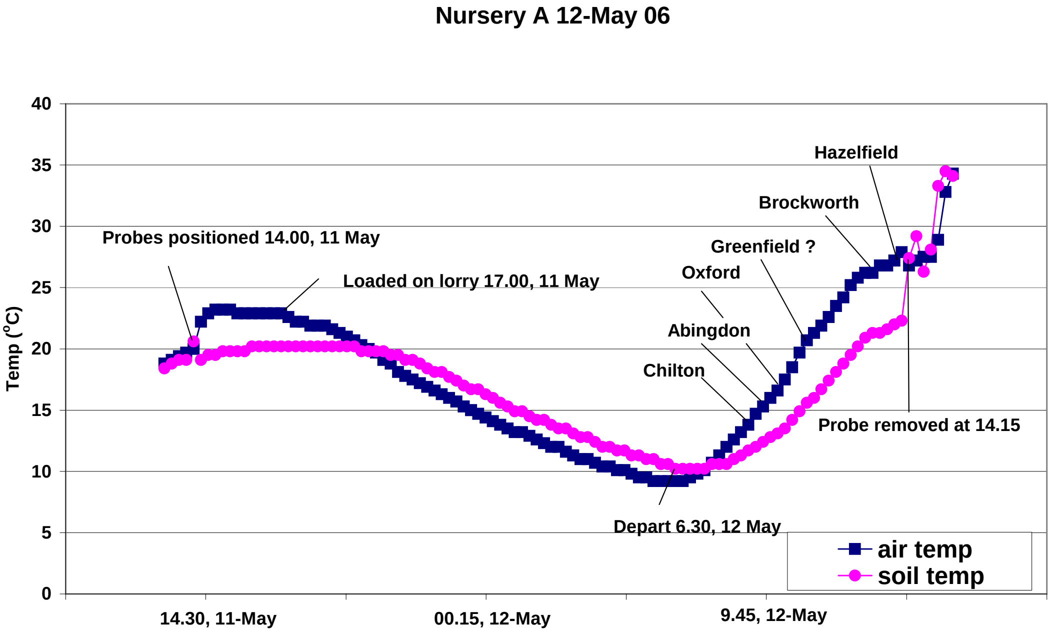
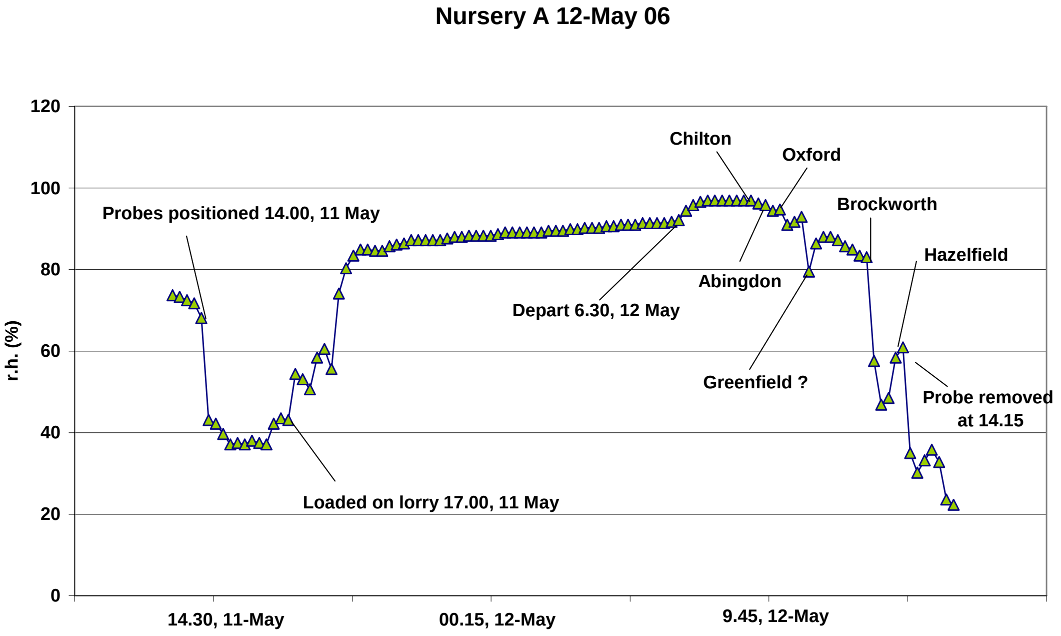


Figure 9. Nursery A - Crop (Unknown). Relative humidity. 18 tonne, rigid-body, non-refrigerated lorry. Multi-drop run to Hazelfield (Glos.).



It is interesting to note that although the data comparisons contrasted strongly between Figures 6 & 7 and those of Figure 8 & 9, the data sets are from the same nursery recorded over the same day. This highlights, the extent to which vehicle type and transport dynamics may vary even within the one company. Indeed, another data set was also recorded from this nursery over the same period (Figures 10 and 11). It is less clear in this run as to whether the crop was artificially chilled, as the temperature decreased more gradually compared to that in Figure 6. (Questionnaires stated that both were lorries with refrigeration units, but the information provided did not verify, if and when the refrigeration units were switched on).

Although all the facts cannot be confirmed, these data sets imply that temperature is more variable when there is no artificial chilling, and that crops may be exposed to relatively high temperatures (e.g. 27°C just before Hazelfield – Figure 8), at least during part of their journey.

Highest and lowest absolute temperatures recorded during transit

The lowest temperature recorded for a crop in the wagon occurred on 21 November 2005, when a temperature of 4.8°C was recorded (Figure 12B). Unfortunately, the information from this questionnaire was limited and there was no information on crop type or whether the wagon was temperature controlled. Because the delivery was late in the autumn, it was likely the crop type was hardy, and temperature control was not considered necessary. A previous run, approximately 10 days earlier (Figure 12A) recorded a lowest temperature of 10.2°C (in the media) and the variation between the two runs may suggest that a non-temperature controlled wagon was being used for these distribution runs. In both cases there are large temperature and r.h. fluctuations, once the crops have reached their destinations. (e.g. in A from 12.3 to 26.5°C and from 95 to 36 % r.h.).

In addition to the 27°C recorded for a relatively short period (prior to Hazelfield, Figure 8), high temperatures in wagons could be recorded for relatively prolonged periods. (Figures 13 to 18 demonstrate data collected during warm periods in July 2006). In these cases, temperature could be held at or above 20°C for almost 6 hours (Figure 17). During such periods the crop would be held in the dark and at high humidity (Figures 14, 16 and 18). It was also evident it took some time for crops to lose their heat once placed on the wagon (e.g. Figures 13 and 15). The sharp drops in soil temperature (e.g. Figure 13) are possibly watering events, but if so these have not lowered canopy temperatures as rapidly as the rootzone.

Figure 10. Nursery A - Crop (unknown) Air and soil temperature. 18 tonne, rigid-body, refrigerated lorry (refrigeration unit on – not verified). Multi-drop run to Brynawel, Wales.

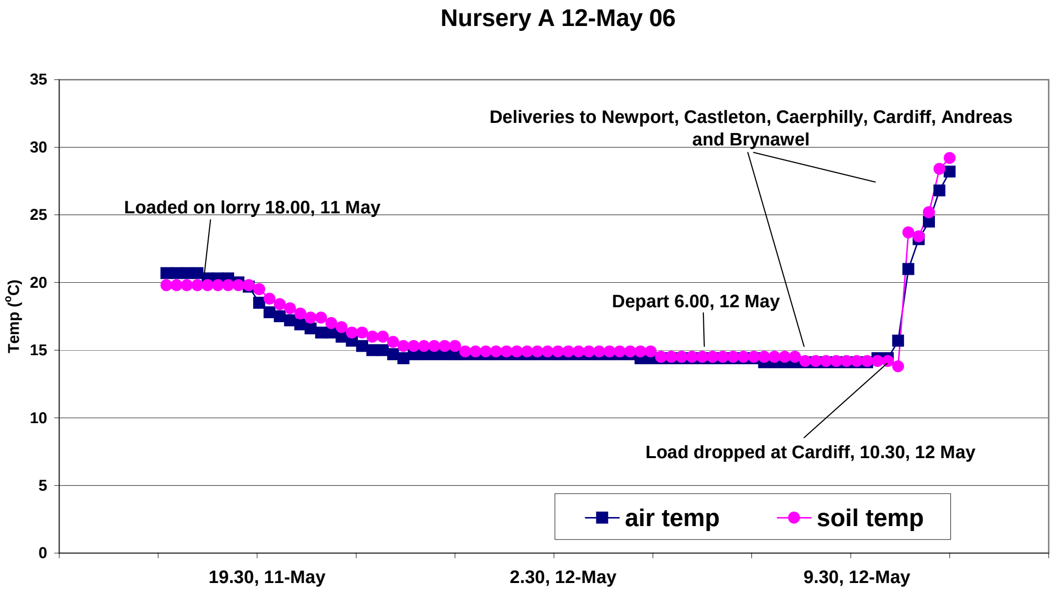


Figure 11. Nursery A - Crop (unknown). Relative humidity. 18 tonne rigid-body, refrigerated lorry (refrigeration unit on – not verified). Multi-drop run to Brynawel, Wales.

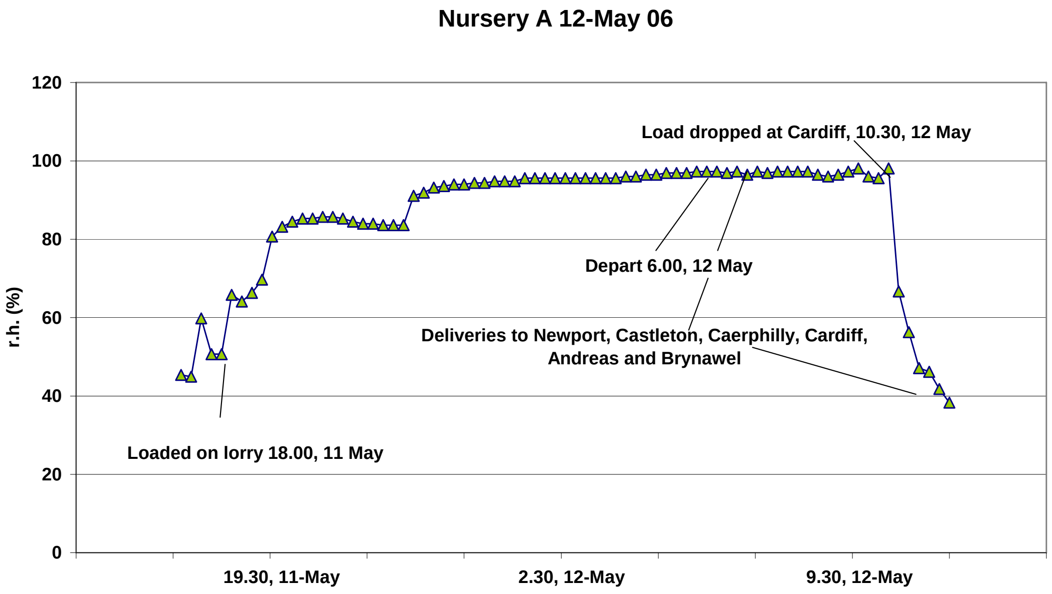


Figure 12. Nursery D - Crop (unknown) Air and soil temperature and relative humidity. Two separate runs – lorry and crop type unknown. Single destinations unrecorded.

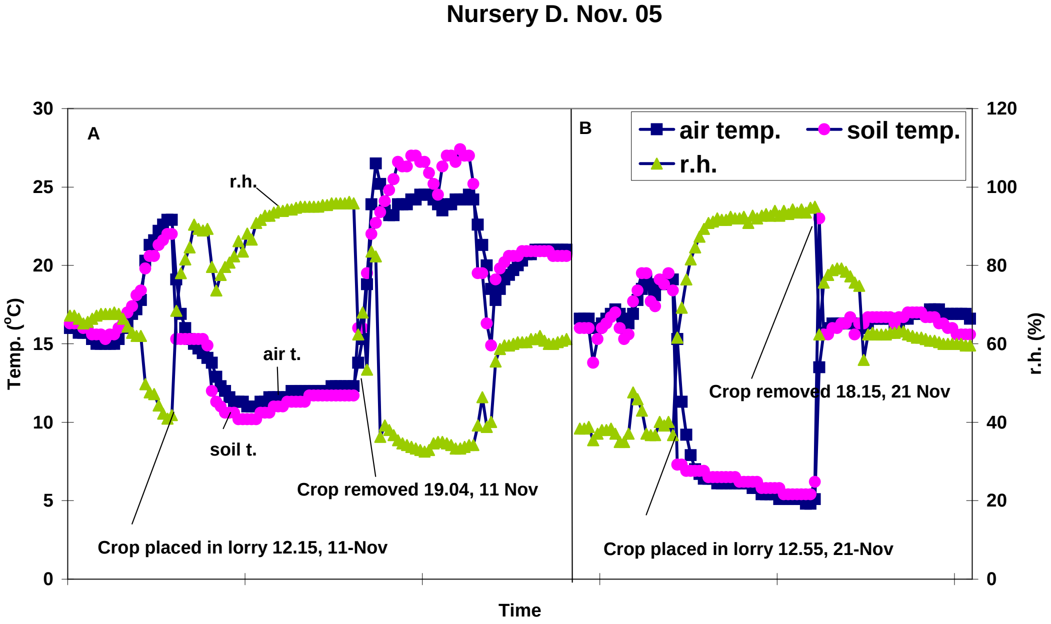


Figure 13. Nursery D - Crop (unknown) Air and soil temperature. 26 pallet refrigeration lorry but refrigeration unit not running. Single destination to Bradford – weather very hot.

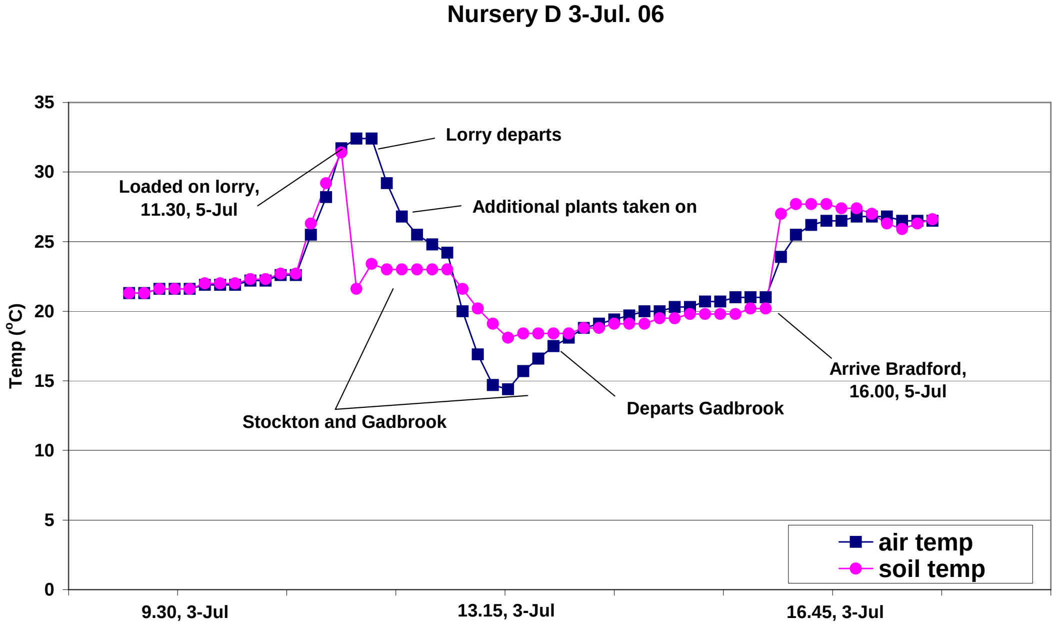


Figure 14. Nursery D - Crop (unknown). Relative humidity. 26 pallet refrigeration lorry but refrigeration unit not running. Single destination to Bradford – weather very hot.

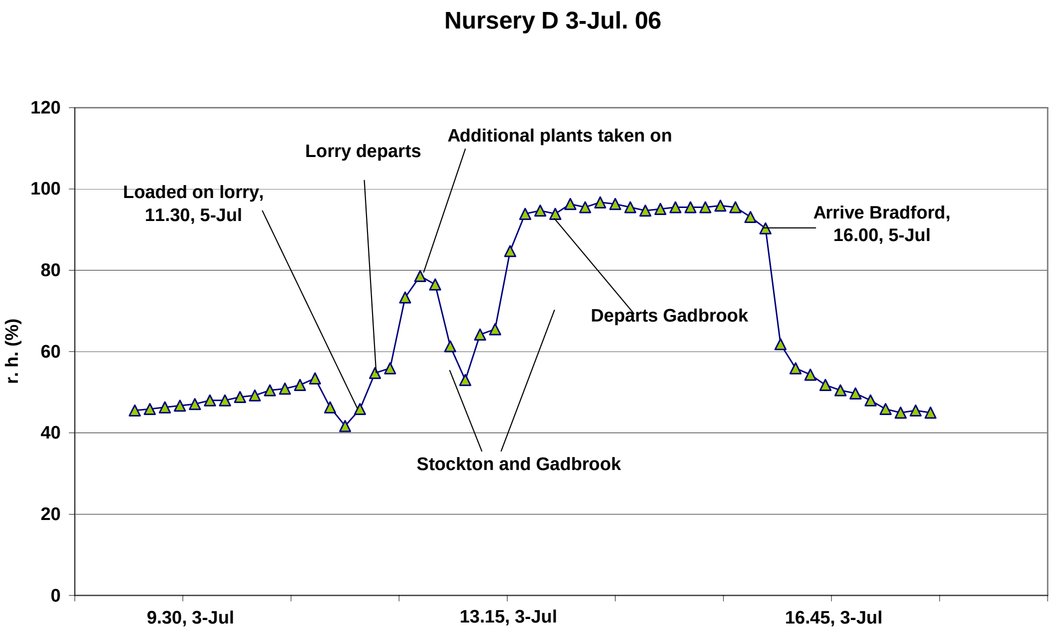


Figure 15. Nursery D - Crop (unknown). Air and soil temperatures. 26 pallet refrigeration lorry but refrigeration unit not running. Single destination to Bradford – weather very hot.

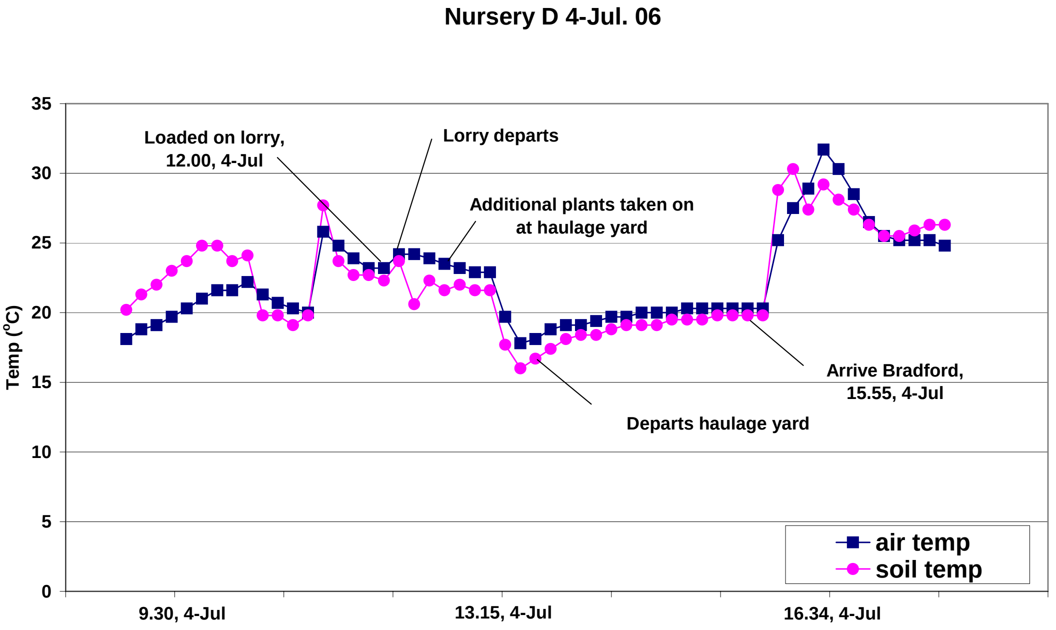


Figure 16. Nursery D - Crop (Unknown). Relative humidity. 26 pallet refrigeration lorry but refrigeration unit not running. Single destination to Bradford – weather very hot.

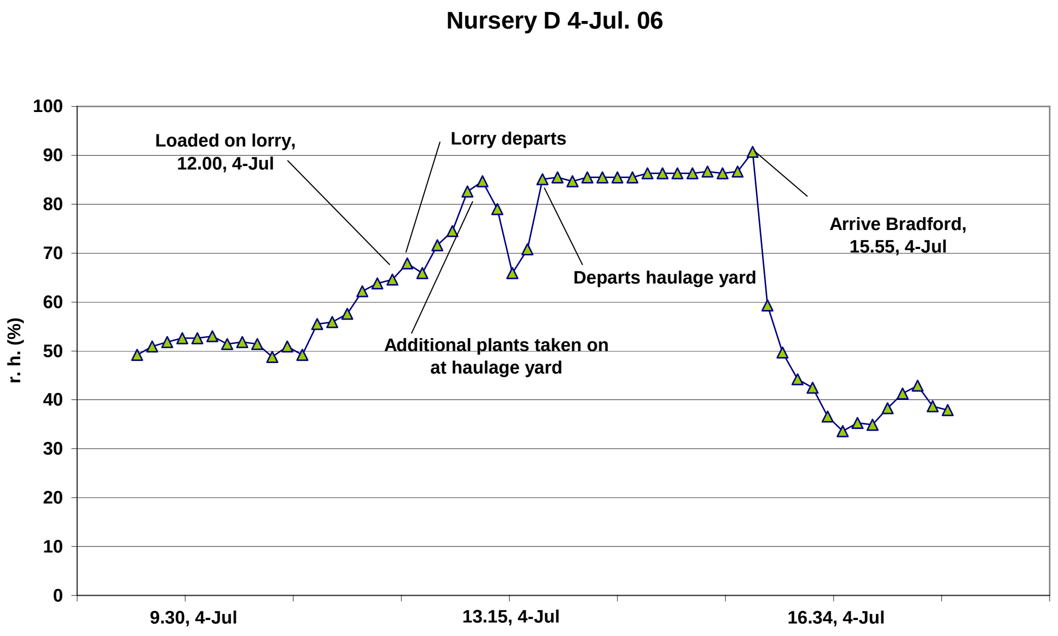


Figure 17. Nursery D - Crop (unknown). Air temperature. Articulated refrigeration lorry with refrigeration set to 12°C, but where driver claimed that temp was approx 16°C. Single destination to Northwich – weather warm and humid.

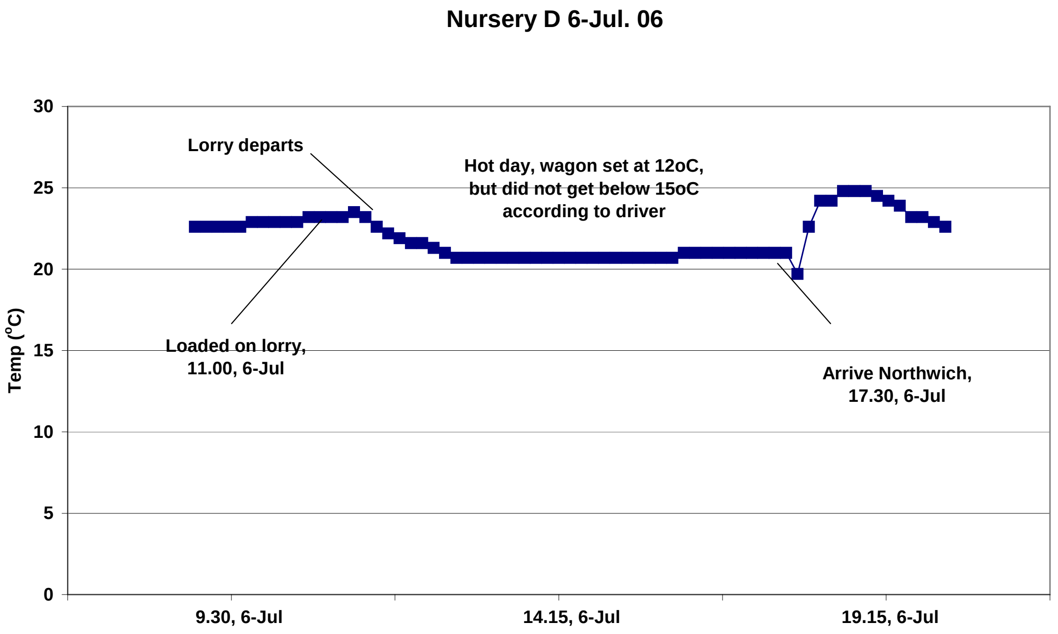
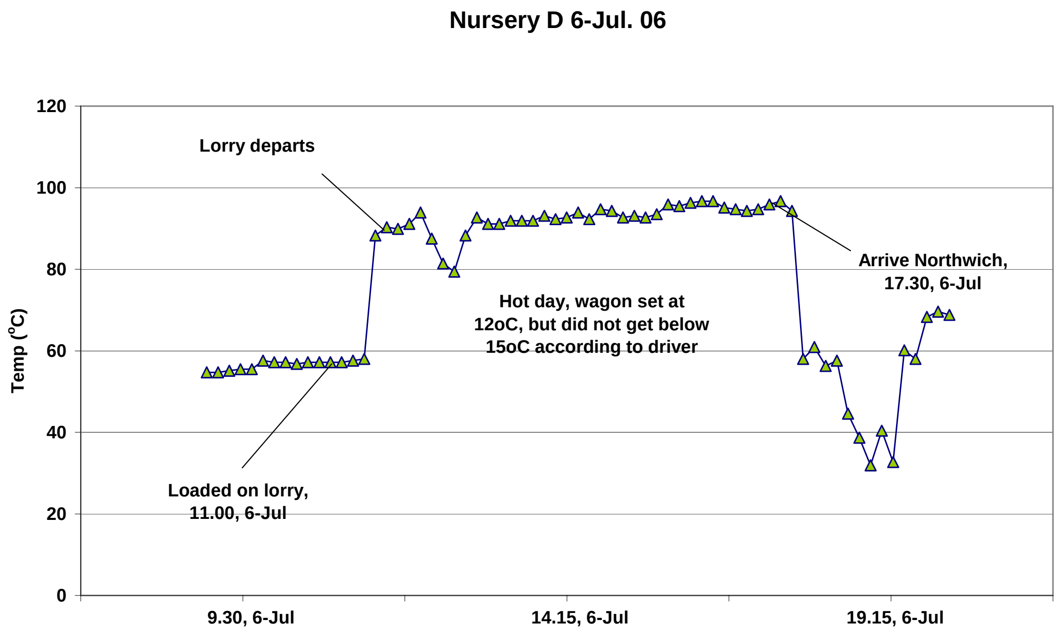


Figure 18. Nursery D - Crop (unknown). Relative humidity. Articulated refrigeration lorry with refrigeration set to 12°C, but where driver claimed that temp was approx 16°C. Single destination to Northwich – weather warm and humid.



One interesting point from Figure 17, was that although the driver acknowledging his chilling unit was not reaching the desired temperature of 12°C, he was still over-estimating its chilling capacity (he considered temperatures had reached 15°C, whereas the probe indicated that the lowest was only 20.7°C). This may relate to variations in positions of the two different temperature sensors (probe and cab sensor), but also highlights that cab readings may not be particularly accurate, or may not be representative of the entire load.

The lowest temperature recorded throughout the first year of the project, was associated with a crop run on 24 May, 2006. In this case, however, it was considered that the crop had been removed from the wagon and the probe was recording the environment of the empty wagon (2.7°C, Figure 19, soil temp. probe, after removal from the pack and placed back in empty wagon). It does raise the issue, however, as to why the chilling unit was being left on during the 'empty' return journey. Likewise, on the assumption that the refrigeration unit was left on prior to the next shipment, is it possible that crops are sometimes loaded onto wagons, where the walls, floor etc. are so cold that they may chill those plants placed adjacent to them?

Comparisons between growing, dispatch and transport environments.

One of the reasons behind the data collected in Figures 19 and 20, was to compare the temperature and r.h. recorded during transit to that of the glasshouse growing environment the crop had originated from and the dispatch area it had been prepared in, over the same time interval. This would provide information on how different or similar conditions in transit are to those it had previously been exposed to.

In addition to probes placed on the crop during transportation, other probes were tied to stanchions in the glasshouse and loading bay respectively and remained there throughout. The data collected showed that temperatures appeared to be considerably cooler (approx. 10°C) when plants were moved to the dispatch / loading bay area (Figure 19). Interestingly, the trolley itself was cooler than the dispatch area and this may have been due to greater shading of the probes in the trolley or that the crop had been recently watered, keeping the surrounding air cooler. The higher humidity values at this time may reflect the latter (Figure 20). The temperature of the crop dropped slightly once placed in the lorry, but stayed stable throughout the night – again this was associated with high humidity. The chilling unit in the lorry wagon was switched on at the time of departure and crop temperature (both air and soil) dropped to approx. 9°C. Once the crop was delivered to the garden centre, the temperatures of the air and soil probe diverge. This is because the air probe stayed with the crop on the trolley, and reflects the environment that the crop was being sold in; whereas the soil probe was removed and placed back in the lorry wagon (this time with no crop, and experienced low temperatures as discussed above).

The data sets suggest that the crop does not experience temperatures during transportation as high as those it would in a glasshouse. It does again indicate though, that r.h. can be consistently higher than the crop might experience in the glasshouse, at least during warm weather intervals.

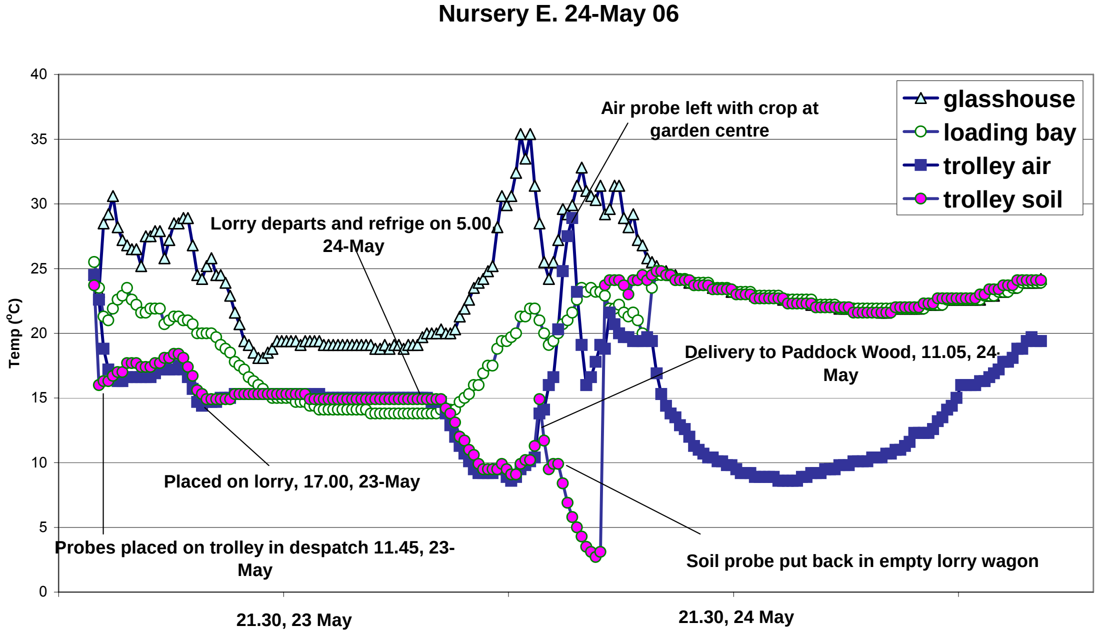
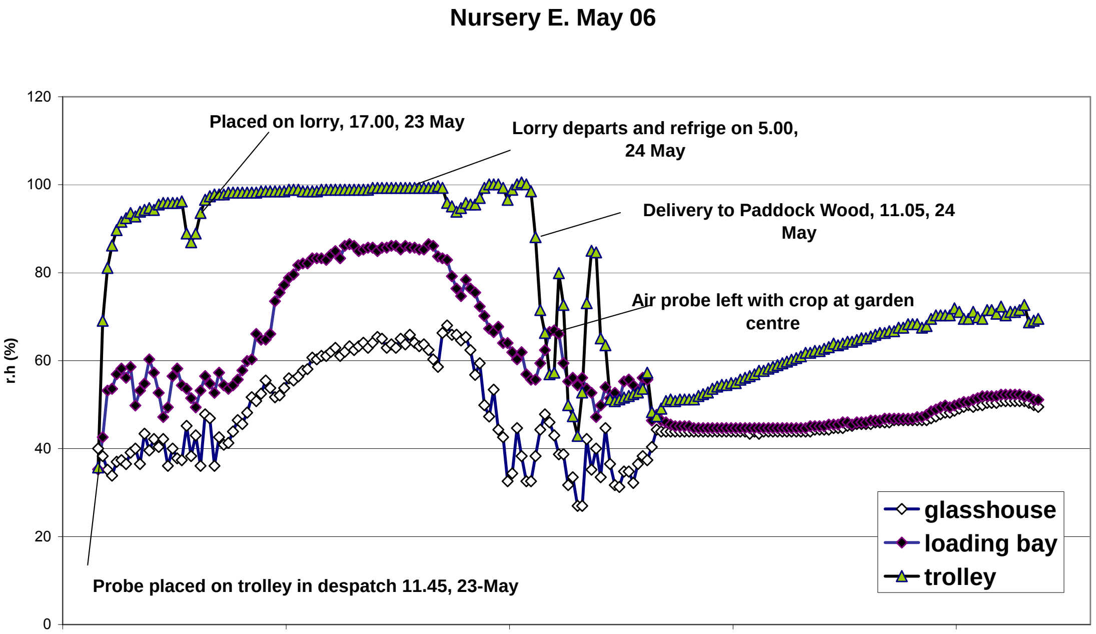


Figure 19. Nursery E - Crop (unknown). Temperature comparisons between glasshouse, dispatch area and air and soil temp. on a trolley. 18 tonne rigid-body, refrigerated lorry. Two destination run, with final = Paddock Wood, Kent.

Figure 20. Nursery E - Crop (unknown). Relative humidity comparisons between glasshouse, dispatch area and trolley. 18 tonne rigid-body, refrigerated lorry. Two destination run, with final = Paddock Wood, Kent.



Comparisons between transport environment and ambient conditions outdoors.

Data relating to weather conditions and ambient temperatures at any point outside the wagon during transit were often not specific enough to make valid comparisons to the data recorded in the inside of the wagon. One exception to this was when a driver noted down the readings of temperature from his cab when he arrived at different destinations. (Figure 21). Although the wagon is at similar temperatures to the outside air when it arrives at Exeter and Teignmouth, the information relating to arrival at Taunton confirms that temperatures can be considerably lower in the wagon, than outside. This data set also confirms how consistent temperature and r.h. (Figure 22) can be in the temperature-controlled wagons.

Duration of transport runs

Many of the data sets recorded short duration runs of only a few hours (e.g. Figure 23 and 24) and temperatures and r.h. would have little fluctuation. Note in this particular example though, again the variation between actual recorded temperature (15°C) and the setting the driver reported (5°C).

It was noted at the start of the project that transport durations of 2-3 days can take place (e.g. from SE England to Northern Ireland). The longest run recorded in the project was approx. 42 hours. An 18 tonne rigid body, refrigerated lorry was used for this run, but the refrigeration unit was not used. The driver stated outdoor temperatures were about 14-15°C during the earlier deliveries on day 1, with an increase to 19-20°C during the latter deliveries of day 1. This may correspond to the slight increase in temperature noticed in the crop after 14.30, but only to 16°C. (Figure 25). Humidity in the crop also dropped around this time (Figure 26), suggesting the doors had been open for a delivery.

Figure 21. Nursery A - Crop (unknown). Air and soil temperature. 18 tonne rigid-body, refrigerated lorry. Multi-drop run to Taunton, Somerset. Comparison between wagon and outside temperatures.

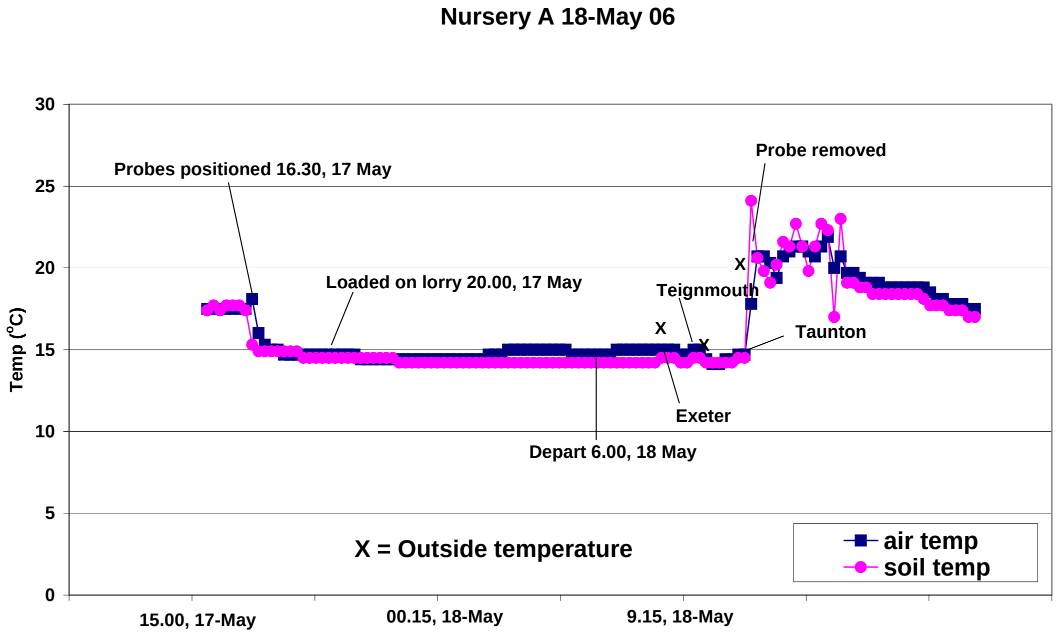


Figure 22. Nursery A - Crop (unknown). Relative humidity 18 tonne rigid-body, refrigerated lorry. Multi-drop run to Taunton, Somerset.

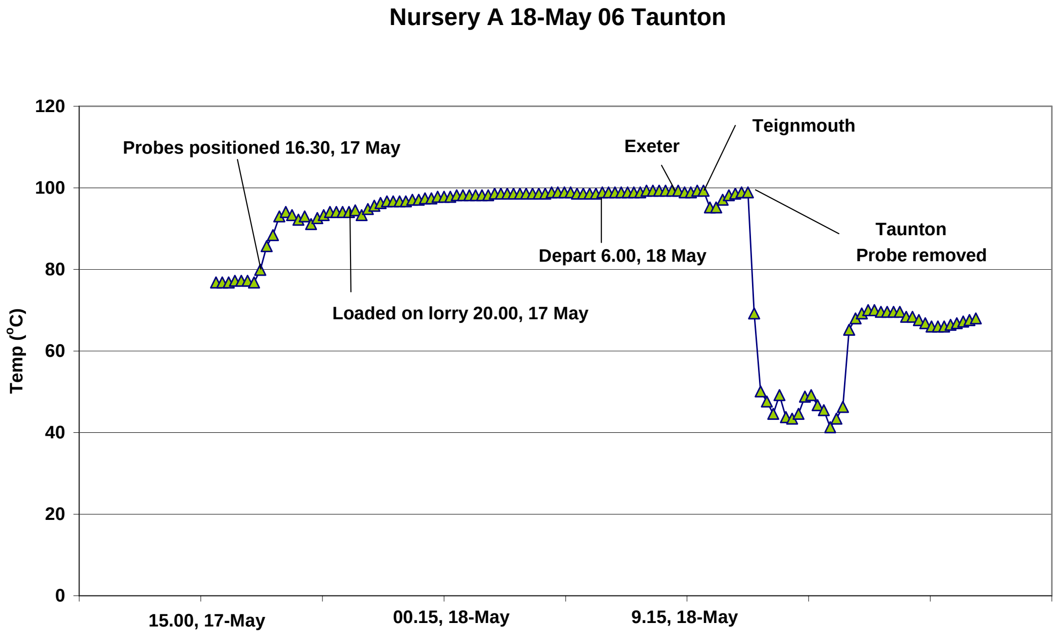
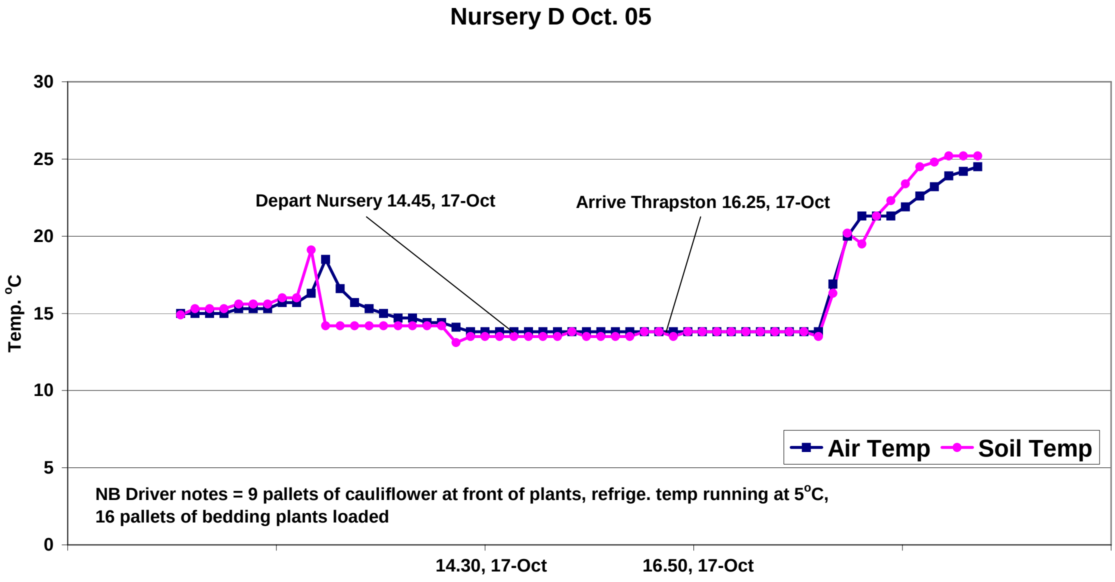
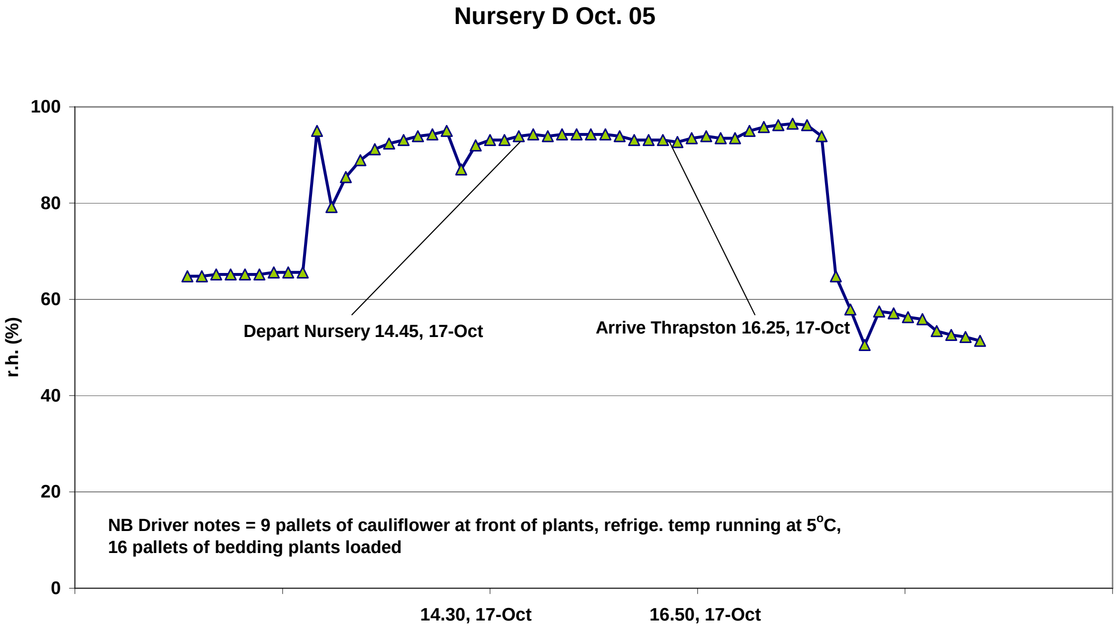


Figure 23. Nursery D - Crop (unknown). Air and soil temperature. 26 tonne rigid-body, refrigerated articulated lorry. Single destination to Thrapston.



NB Driver notes = 9 pallets of cauliflower at front of plants, refrige. temp running at 5°C, 16 pallets of bedding plants loaded

Figure 24. Nursery D - Crop (unknown). Relative humidity. 26 tonne rigid-body, refrigerated articulated lorry. Single destination to Thrapston.



NB Driver notes = 9 pallets of cauliflower at front of plants, refrige. temp running at 5°C, 16 pallets of bedding plants loaded

Figure 25. Nursery A - Crop (unknown). Air and soil temperature. 18 tonne rigid-body, refrigerated lorry, but run at ambient. Two day run, with final = Brecon, Powys.

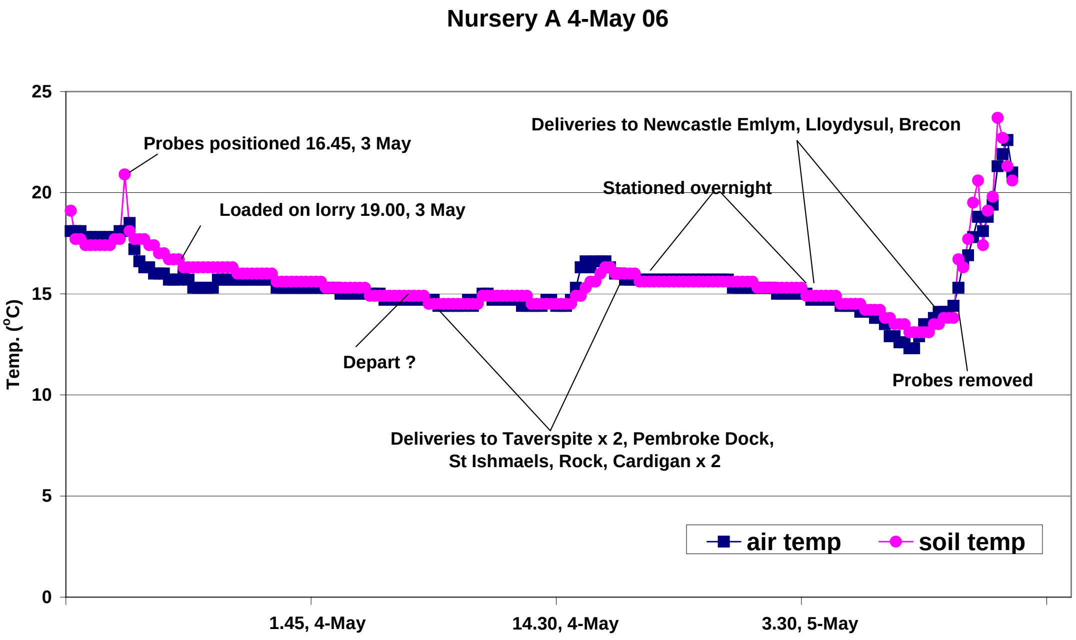
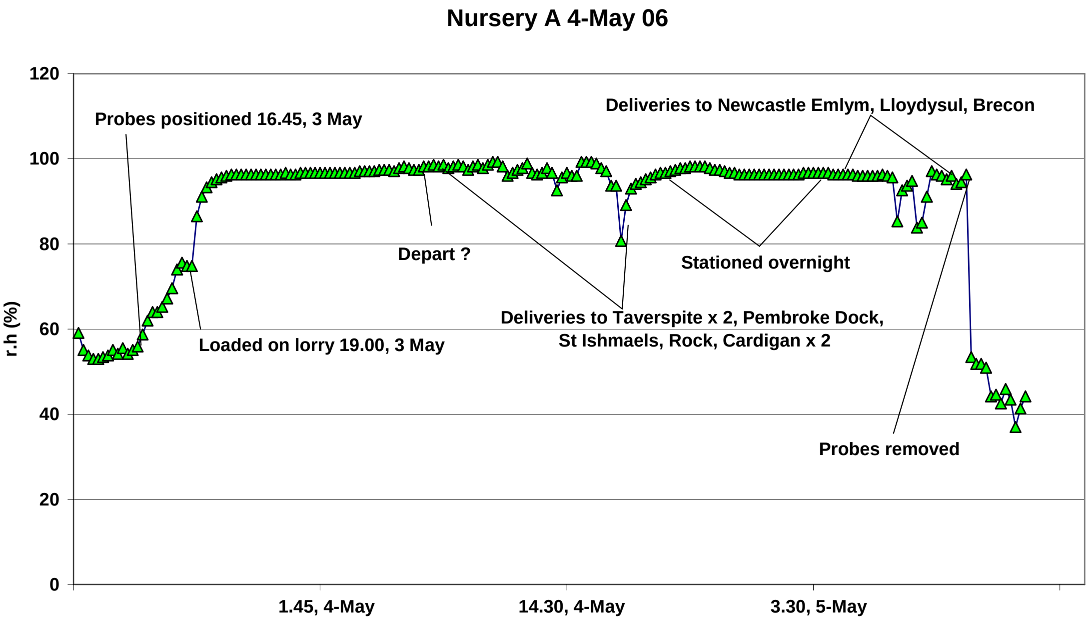


Figure 26. Nursery A - Crop (unknown). Relative humidity. 18 tonne rigid-body, refrigerated lorry, but run at ambient. Two day run, with final = Brecon, Powys.



The lorry was stationed overnight near Cardigan, before further deliveries the following day. Probe data suggested that the crop was held at approx 15°C and r.h. >95% - for the second night running. Deliveries the following day were associated with marginally lower temperatures 12°C recorded (and 9.0°C outside temperatures reported by the driver) and lower humidities – a possible consequence of the doors being open and the load in the trailer being much reduced (Figures 25 and 26).

Possibly the most interesting aspect of this run, was the fact that plants were held in the dark, for about 42 hours at moderate temperatures (15°C) and high humidity. Unfortunately, there is no data on crop quality after this run.

Media temperatures v crop air temperatures

The media temperature and the air temperature at canopy level of the crop were often comparable (e.g. see Figures 3, 10, 21 and 25). On the occasions where temperatures deviated markedly, differences could be related to the husbandry or the thermodynamics the crop was experiencing. For example, rapid changes and lower temperatures recorded in the roots could relate to watering events (e.g. watering just before loading, e.g. Figures 1 and 13). Additionally, the higher moisture content in the media, also provided some 'thermal buffering' and root temperatures were slower to respond to outside influences (e.g. in Figure 8, where the root / media temperatures lag the changes in air temperature; sometimes with difference of 5°C between actual temperatures).

Seasonal effects – autumn v spring / summer bedding

There were no consistent differences in data sets and questionnaire results, between those runs recorded in autumn and those in spring / summer. It seemed evident that crops were more likely to be loaded the night before departure in the autumn period, but this could be due to variations between nurseries too. Those nurseries without refrigerated lorries, appeared to load early in the morning during the summer, just an hour or so before departure, rather than risk keeping the crop enclosed for long periods in warm weather. Where loading was undertaken the night before, then back doors would be left ajar to minimise heat and humidity in the crop (e.g. Figure 27). The risk of doing this, of-course, is that there is no control of night temperature and in this instance one of the lowest night storage temperatures (8.6°C) was recorded (despite being in June).

Summer transit and storage temperatures were more likely to be higher than autumn (but again, variations due to lorry time and nursery were often as great within a season) (Table 3). The lowest transit temperature, however, was associated with an autumn (November) run.

Figure 27. Nursery G - Crop (mixed bedding). Air temperature and relative humidity. 13 tonne rigid-body and no refrigeration. Multiple run around London – warm weather.

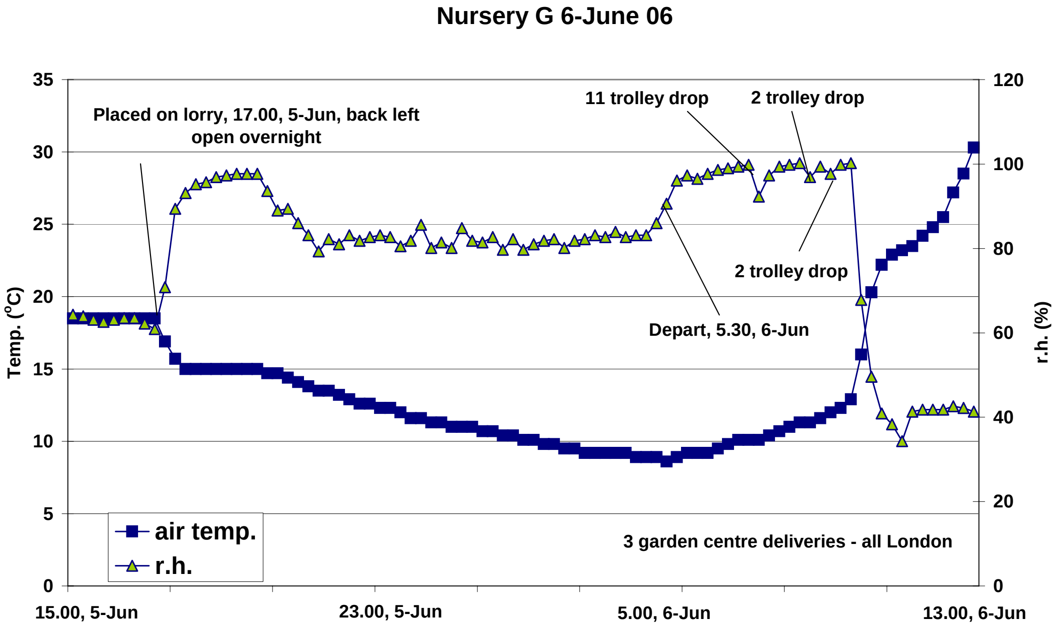


Table 3. Highest and lowest temperature recorded during storage the evening prior to departure, or during transit in both the autumn and spring / summer recording periods. (Data represent stabilised temperatures within each environment)

Measurement	**Autumn (°C)**	**Spring / Summer (°C)**
Max. Night temp (stored)	**19.5**	**22.6**
Min. Night temp (stored)	**16.3**	**8.6**
Max. Transit temp	**18.8**	**26.8**
Min. Transit temp	**4.8**	**8.6**

Exposure to light and darkness

Strong sunlight in the UK usually equates to 600-1200 µmol m^{-2} s^{-1}. Depending on the type of plant and type of leaf ('shade leaves' are more efficient) most light compensation points (when energy gained is equal to energy lost through respiration), occur between 10 and 85 µmol m^{-2} s^{-1}. In hubs and dispatch areas, light levels at crop canopy level were recorded in the region of 5-10 µmol m^{-2} s^{-1}. In the middle of a full trolley, they were 0-0.5 µmol m^{-2} s^{-1}. Therefore, it is unlikely that plants were photosynthesising during transit, or during periods where they were left on trolleys in artificially illuminated dispatch areas. Hence, in terms of photosynthesis, most plants would effectively be 'in the dark' from the point they were moved from the glasshouse and until they were placed on a retail bench at a garden centre.

Ethylene (C_2H_4) and other data from hub

A number of visits were made to a retailer's delivery and dispatch centre (hub) to monitor crop quality and ethylene released from crops after the initial phase of transport. The hub is a location where plants are received from the nursery (sometimes via a haulage company) and then sorted, stored and re-distributed to the retailer's own stores. This can extend the period crops are in transit, although most retailers will aim to re-distribute them within 24 hours of arrival. Conditions at a hub could be critical in determining final plant quality and information was sought on aspects such as typical temperature, light levels, ethylene levels as well as information on visual quality of crops arriving and departing.

Much of the data collection involved measuring ethylene levels either as background readings or close to the crop canopy. For reference, typical readings for ethylene (at 25°C) were outdoors = <0.1 ppm, office environment = 0.6 ppm and single ripening banana (a source of ethylene) enclosed in polythene bag = 6.7 ppm.

Most readings recorded in the hub and around crops were usually in the range 0.5-2 ppm ethylene, although on occasions levels could exceed these. Figure 28 shows typical values recorded in November in the warehouse (A) in which over-wintering bedding and some protected crop lines were being handled. Ethylene levels were low near the entrance point to the hub, due to the bay doors being open some of the time.

The highest recorded level of ethylene was associated with some discarded Christmas trees placed near the enclosed end of one of the hub bays. There were no bedding plants in this bay at this point, but the levels released from these decaying trees (22 ppm – Figure 29). were well in excess of those quoted in the literature as being phytotoxic to many plant species.

Even when bedding plants were the only crop type being handled, their position within the bay had an effect on background readings. There were two heating fans (electrical, so unlikely to be contributing to ethylene levels directly) located near the loading gates, and

Figure 28. Hub location, Warehouse A – temperate ornamentals (Nov 05). Ethylene readings at various locations and in crop canopies – typical values. Bay end is where the crops are moved off the lorry wagons and deposited – doors to outside can be open. Centre – redistribution and holding location. Closed end – furthest from the bay doors and probably least air movement and ventilation.

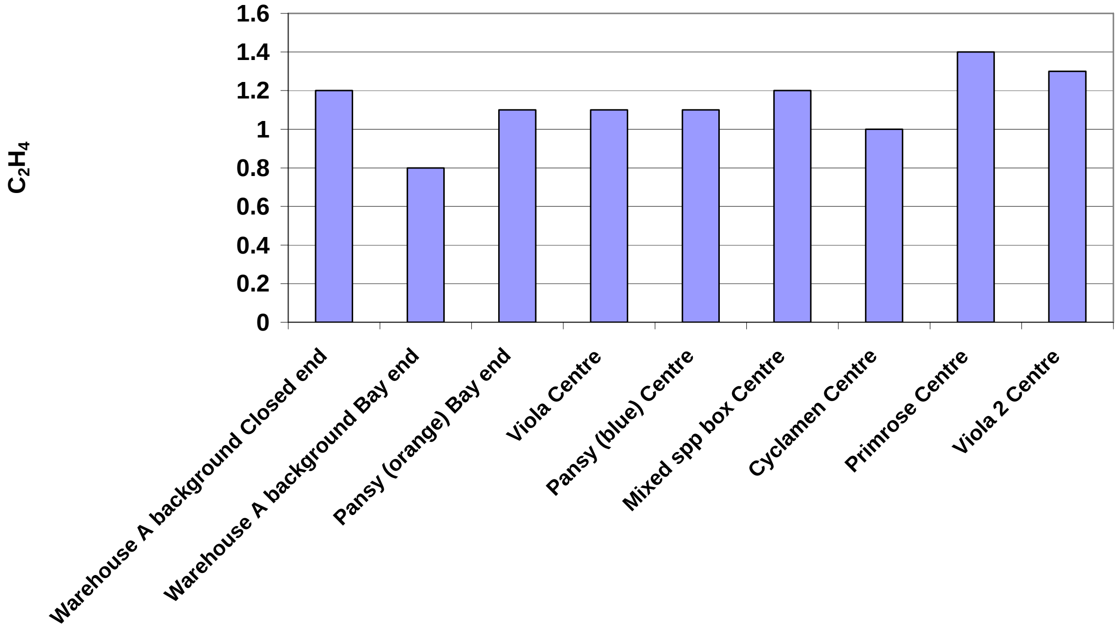
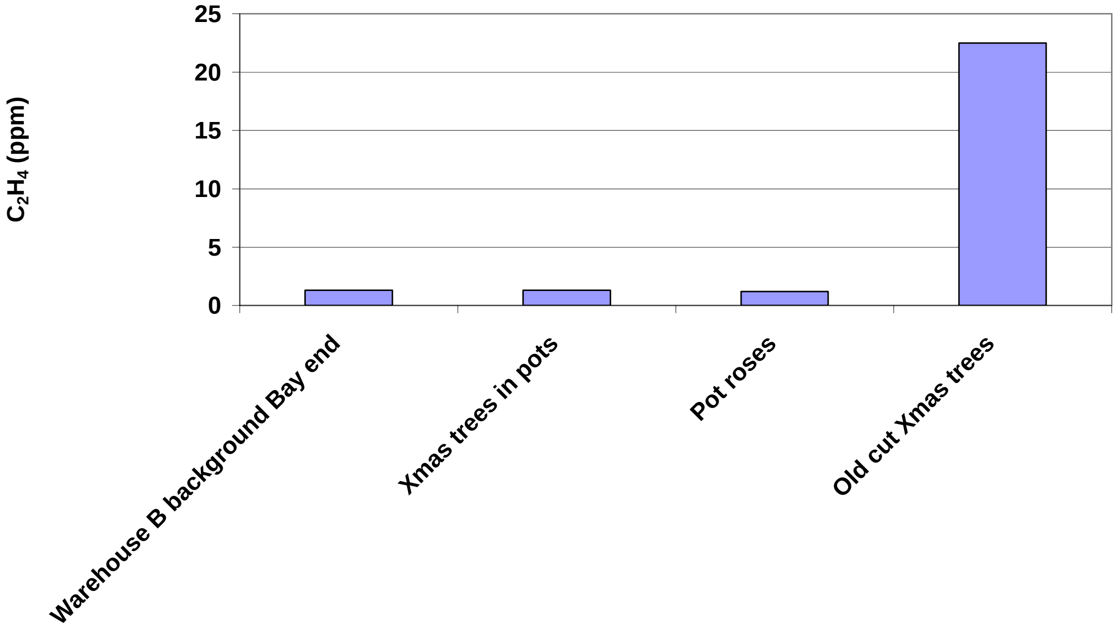


Figure 29. Hub location, Warehouse B – hardy ornamentals and Christmas trees (Nov 05). Ethylene readings at various locations and in crop canopies –typical values. Bay end is where the crops are moved off the lorry wagons and deposited – doors to outside can be open.



often highest ethylene readings were recorded here when a loaded trolley was stood in line with the fans. This was the area that trolleys were stood out after unloading and before being collected for de-stacking. Trolleys stood here for approximately 10-15 minutes before being moved on. Ethylene derived from the crops was also often highest around this location, i.e. once the crops were removed from the relative cool (but enclosed) lorry environment to this open, but warmer area (Figure 30). A number of crops (such as pansy in flower), but by no means all, showed this type of ethylene release trend.

Repeated measurements were taken across a range of crop types and in different locations to assess mean ethylene levels. Locations selected were; i. background in the wagon, ii. crop canopy in the wagon before unloading, iii. crop canopy in the hub 10 minutes after unloading and iv. crop canopy in hub 30 or more minutes after unloading. The data showed there was a significant increase in ethylene concentrations after the crops had been placed in the warmer hub environment for more than 30 minutes, compared to the background and crop levels in the (cooler) wagon. (Figure 31). Background levels in the hub itself were variable (0.5 to 1.2 being typical) and were dependant on factors such as volume of crop present, ambient temperature of the hub and the extent to which the bay doors were open. The data again suggest that recorded ethylene levels in the cooler wagons is relatively low, but that more ethylene becomes expressed once the crop is moved into the warmer environment of the hub. The build up of ethylene levels around the crop may be made worse when bay doors are closed (minimizing ventilation), and ambient temperatures are high.

There was considerable variation in ethylene levels, however, on crop type, how long the crop had been in the hub, type of packaging used and whether the crop were in flower. Figure 32, highlights some of the variations recorded on the 1 June 2006. It was noted that relatively high levels were associated with the presence of a mechanised (diesel) sweeping machine, and a crop of trailing *Pelargonium* where the media was dry. Interestingly, *Impatiens* crops also often demonstrated a relatively high ethylene reading.

Conclusions

The review of literature indicated a dearth of knowledge pertaining to the transport of bedding plant species, although likely relevant information is available from extensive research on house plants and other ornamental crops. The data gained from logging commercial conditions and environments in this study so far, has provided a useful platform to understand typical transport conditions specific for bedding species, as well as suggest one or two less typical conditions that may potentially provide a source of stress, and result in loss of crop quality.

Figure 30. Hub Location, Warehouse A – Bedding and herbaceous plants (5 April 2006). Ethylene readings at various locations in a potted pansy (*V. x wittrockiana*) crop (non-enclosed) over time.

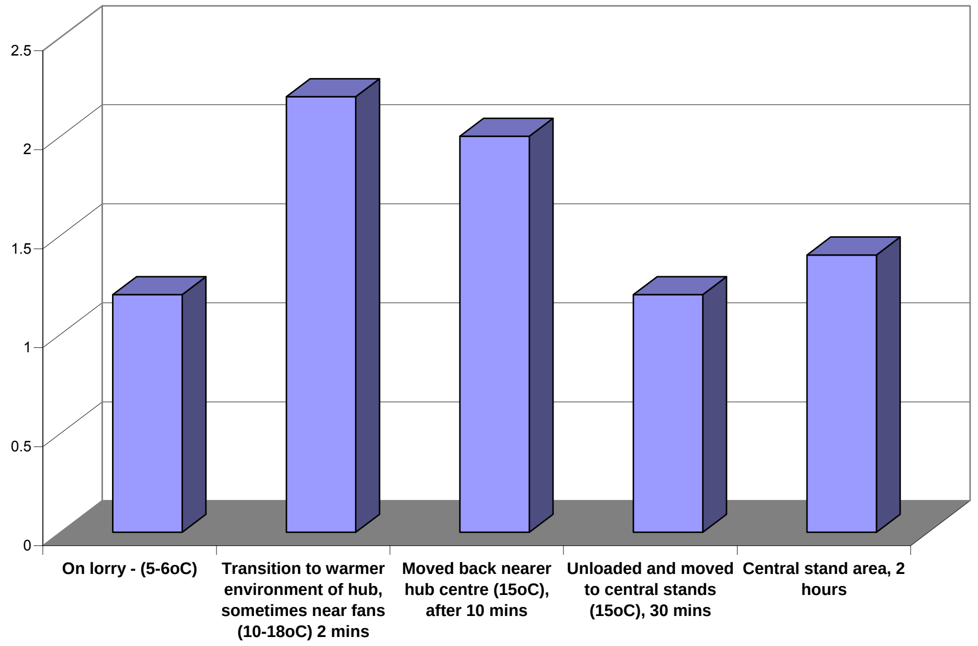


Figure 31. Hub Location Warehouse A – Bedding and herbaceous plants (5 April 2006). Ethylene readings from different locations averaged across a range of bedding crops and time. LSD at P<0.05, d.f.=64.

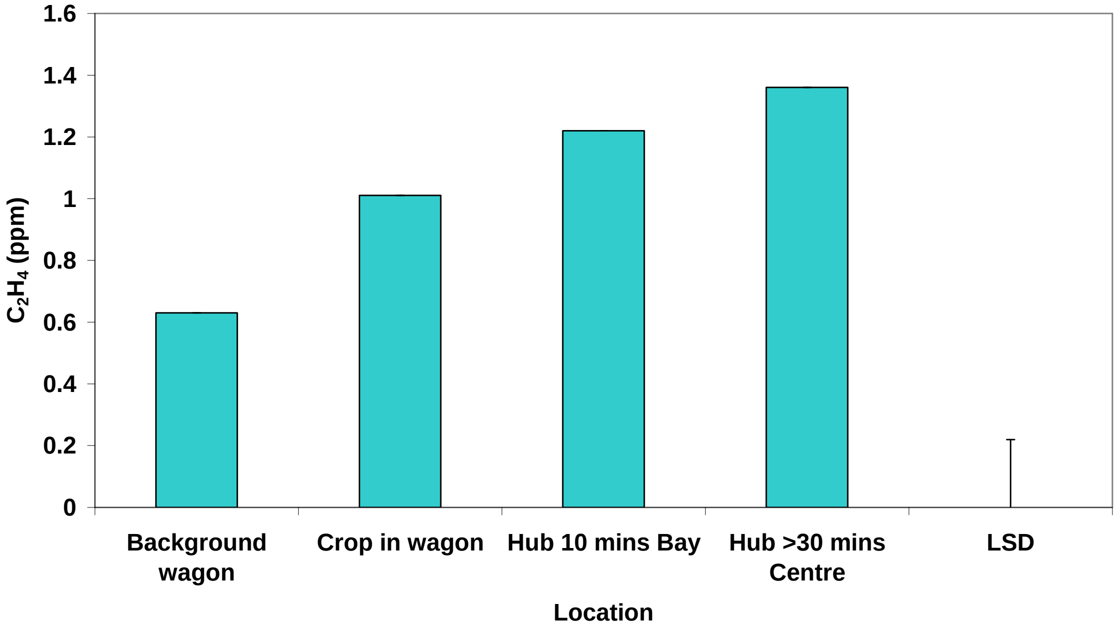
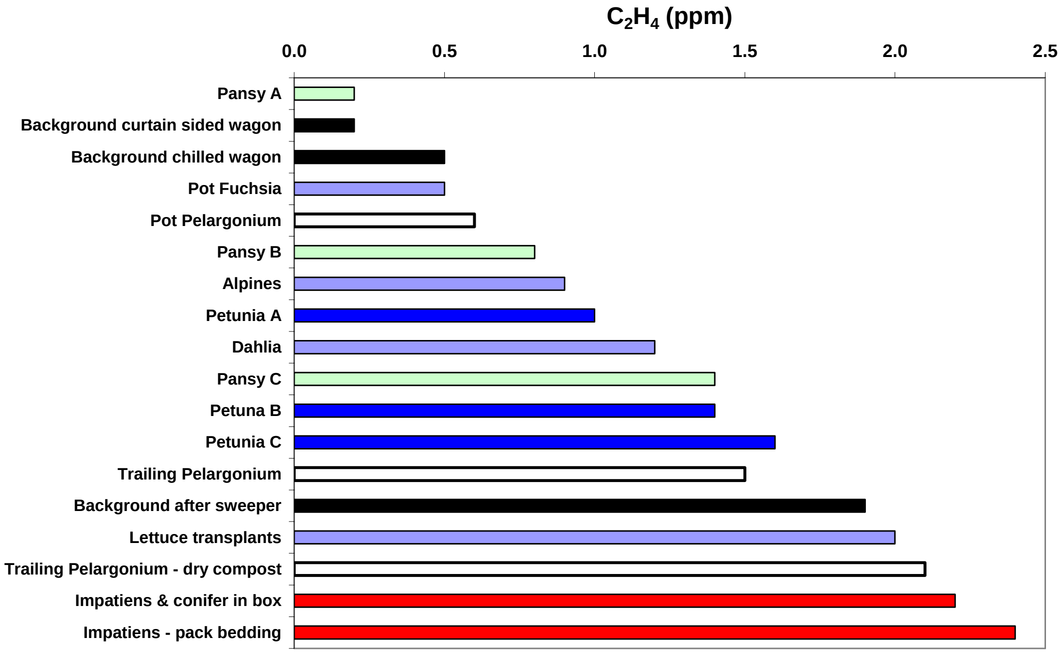


Figure 32. Hub Location, Warehouse A – Bedding and herbaceous plants (1 June 2006). Ethylene readings from different crops and locations. Temperature varied between 7 and 20°C.



It was evident that both refrigerated and non-refrigerated wagons were commonly used to transport bedding plants. When a nursery considered ambient conditions were suitable, non-refrigerated wagons could be used, or on some occasions wagons with chilling facilities, but with the chiller unit switched off. The vast majority of transport runs were carried out at temperatures between 11°C and 16°C, although some summer runs were recorded at 18-21°C. This included a run where the driver set the temperature control to 12°C, but considered temperatures of 15-16°C to be maintained, but in fact the data recorder actually logged temperatures of 21°C. This corresponds to the findings of Høyer, (1997a) where recorded temperatures in the wagon could vary significantly compared to the set-point value.

Extremes of temperature were noted during some transit runs. For example, 4.8°C was recorded in a crop in late November (crop type unknown) and 27°C for a run in mid May. Lower temperatures (2.7°C) were also recorded in a refrigerated wagon in May 2006, but it was considered that by that point all crop plants had been removed.

More common than extremes of temperature, were the rapid transitions of temperature and humidity bedding plants were exposed to. They could be stored in a lorry wagon in the dark at 11°C one moment, and then a short time later be placed directly in strong sunlight at 35°C.

Relative humidity was frequently high (>95%) for part or all of the run period, in the majority of transits recorded. There was no direct evidence of loss of quality associated with this, but the issue of relative humidity is worth further exploration in the project. Especially so, as high r.h. often coincided with periods of darkness and relatively high temperatures e.g. 20°C. In the longest run recorded, crops were held in the dark for over 42 hours at approx. 95 % r.h. and 15°C.

Data collected from air and media temperature probes often showed similar temperatures and consistent trends, however, there were a number of occasions where the addition on the media probe had provided interesting information regarding watering regime and responses to rapid temperature changes. For, example, very rapid reductions in media temperature suggested the crop had been irrigated, and slower transitions compared to air temperature indicated that the media tended to have had greater thermal buffering against rapid alterations in temperature.

Information gained from the literature suggested that some crops may be sensitive to ethylene during transit. However, the degree of injury can depend strongly on cultivar, exposure time, temperature and even carbon dioxide levels. Levels of ethylene recorded in bedding crops in this project were in the range of 1-2.5 ppm, (the higher levels according to the literature being potentially injurious if exposure times were prolonged). For example, *Impatiens x hawkeri* cv. Sunfire was shown to have 80-100% flower abscission after only 4 hours exposure to 1 ppm ethylene (Dostal *et. al.,* 1991). There was, however, no direct evidence of injury in any crops inspected in the hubs during this project.

The peaks in ethylene data correlating with the decaying Christmas trees and, to a lesser extent the activity of the mechanical floor sweeper, are potential causes for concern. It does highlight that both growers and retailers need to be careful to avoid external sources of ethylene having a detrimental impact on the crop. This also includes residual doses of ethylene associated with a previous cargo that has been shipped in the lorries used for bedding. (Ethylene can remain absorbed onto the walls and other hard surfaces).

Technology transfer

A presentation is being planned for the British Bedding and Pot Plant Association AGM in February 2007.

Acknowledgements

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Appendix 1

Additional data sets recorded, where the data duplicates points made earlier.

Figure I. Nursery A - Crop (pansy, *V. x wittrockiana*). Air temperature. 18 tonne rigid-body, refrigerated lorry. Multiple destinations.

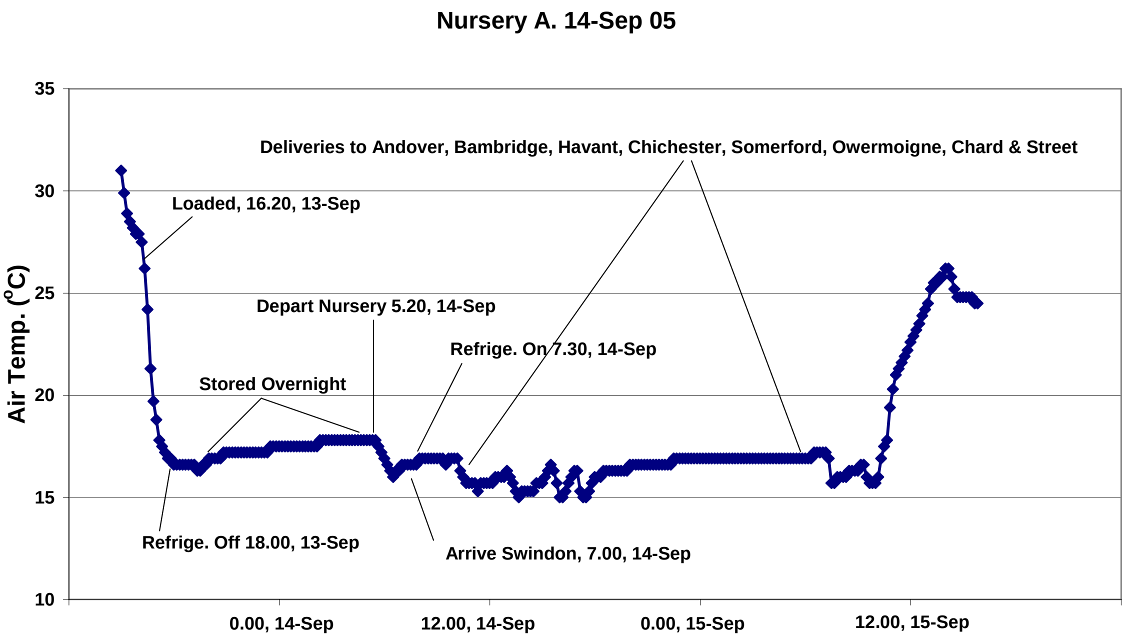

Figure II. Nursery A – Crop (pansy, *V. x wittrockiana*). Relative humidity. 18 tonne rigid-body, refrigerated lorry. Multiple destinations.

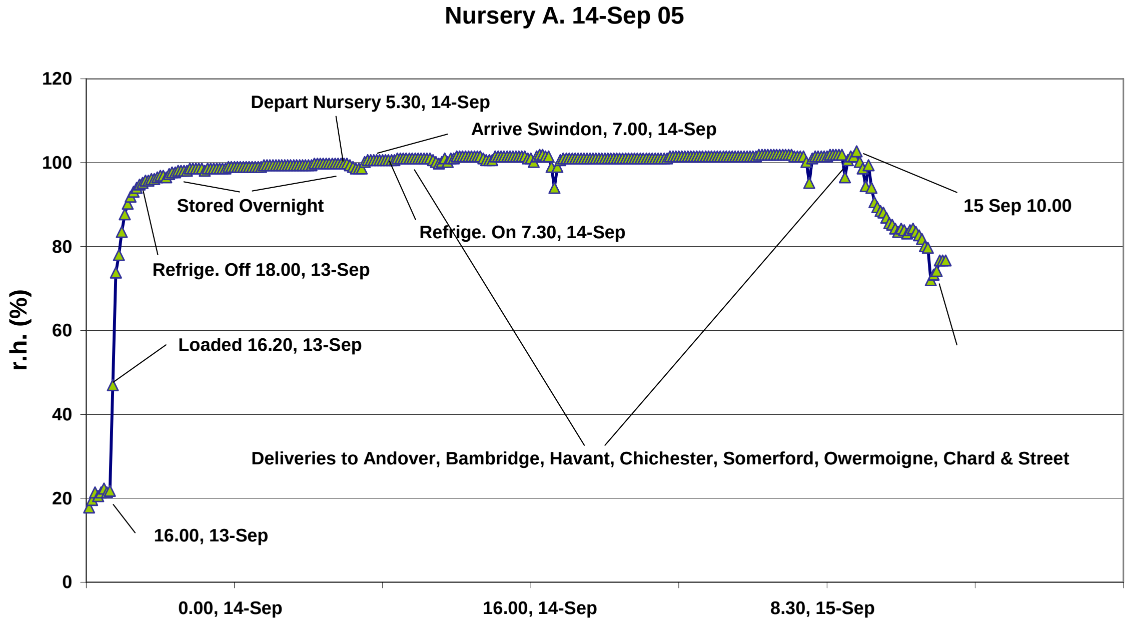

Figure III. Nursery E - Crop (unknown). Air temperature. 38 tonne rigid-body, refrigerated articulated lorry (Not verified). Multiple destinations.

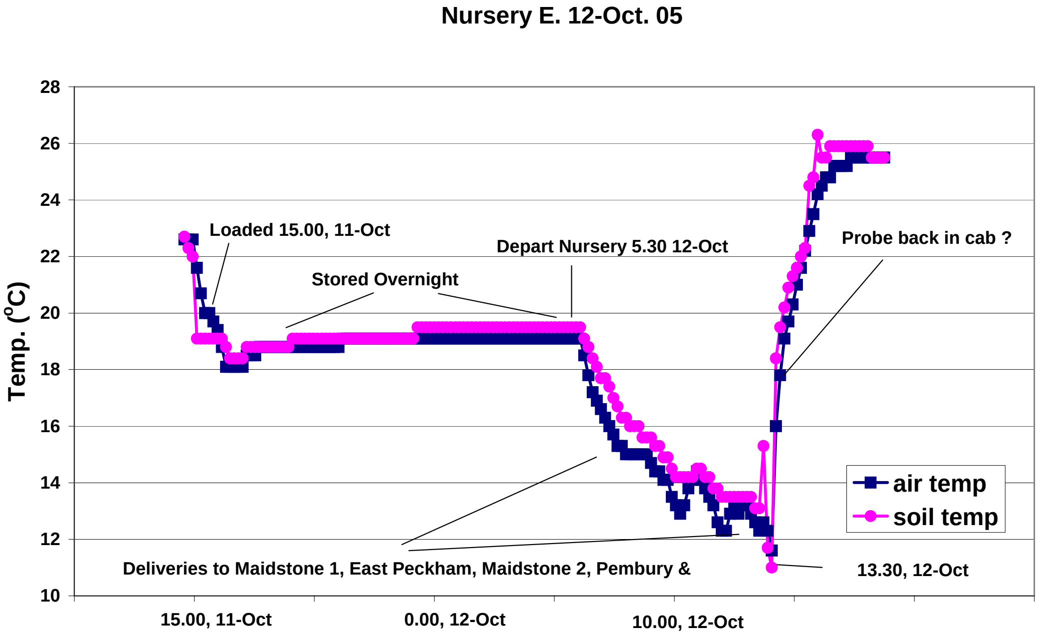

Figure IV. Nursery E - Crop (unknown). Relative humidity. 38 tonne rigid-body, refrigerated articulated lorry (Not verified). Multiple destinations.

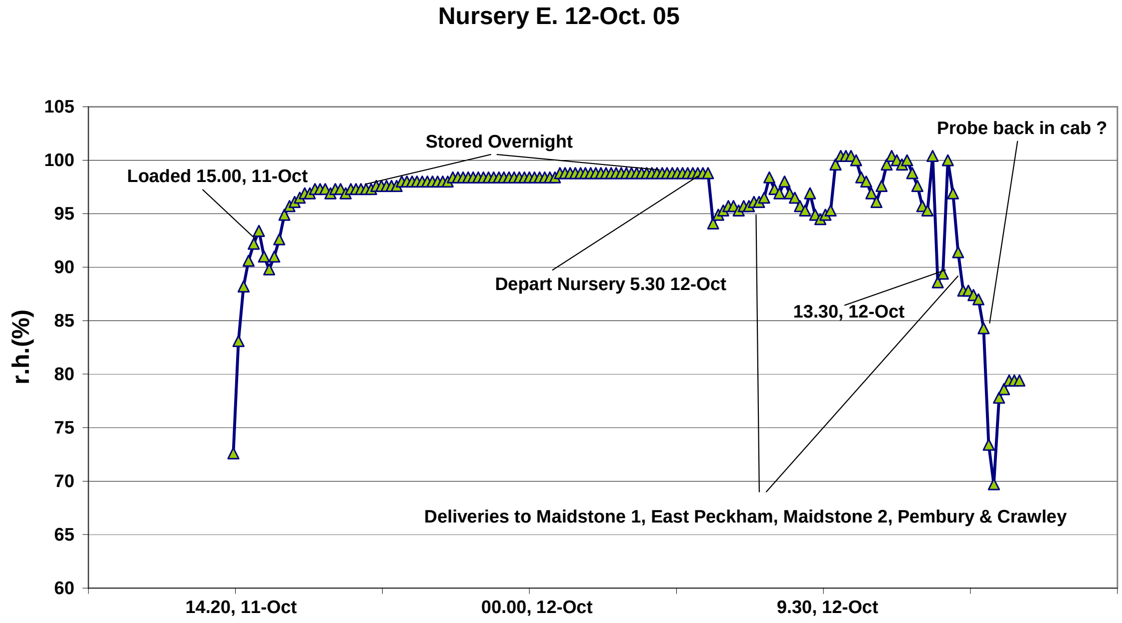

Figure V. Nursery E - Crop (unknown). Air temperature. 38 tonne rigid-body, refrigerated articulated lorry. Multiple destinations.

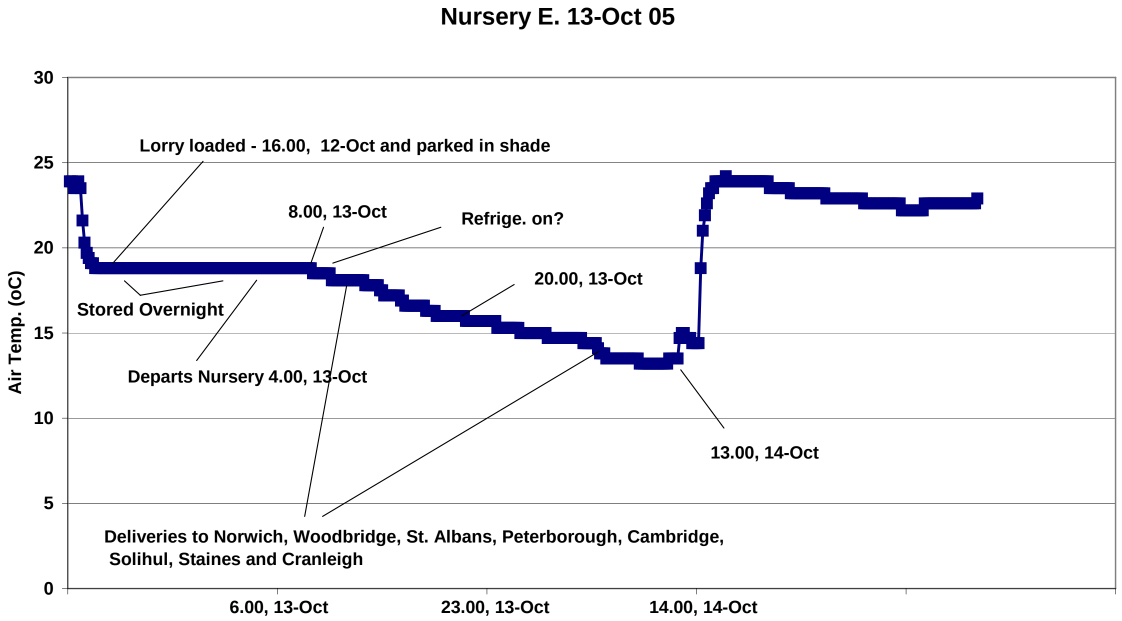

Figure VI. Nursery E - Crop (unknown). Relative humidity. 38 tonne rigid-body, refrigerated articulated lorry. Multiple destinations.

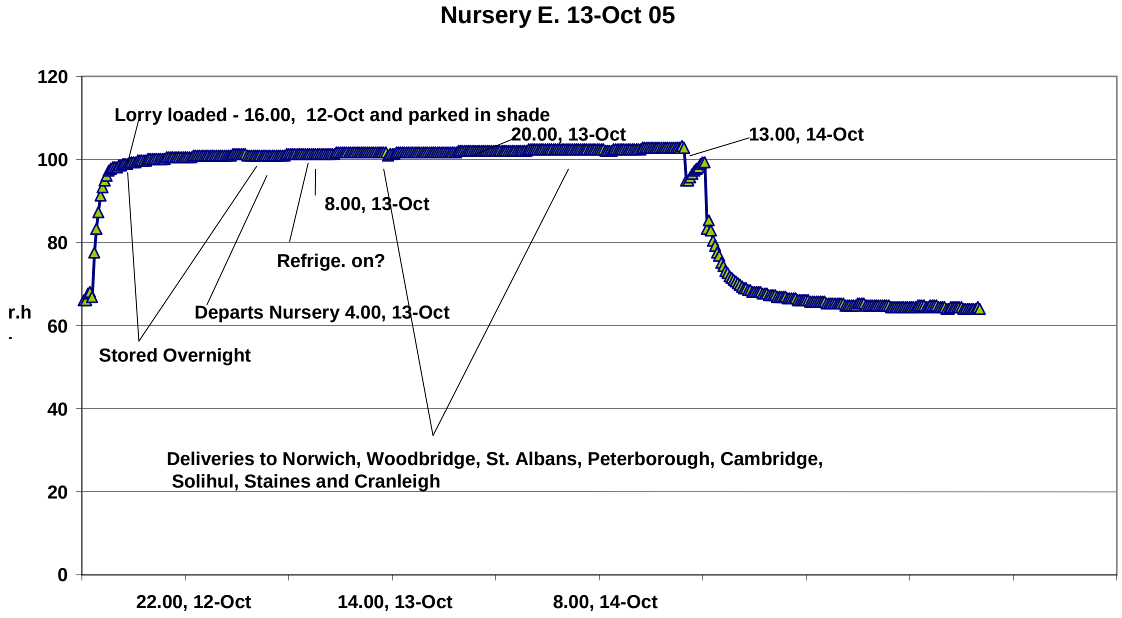

Figure VII. Nursery E - Crop (unknown). Temperature comparisons between glasshouse, dispatch area and soil temp on a trolley. 18 tonne rigid-body, refrigerated lorry. Two destination run, with final = Paddock Wood, Kent.

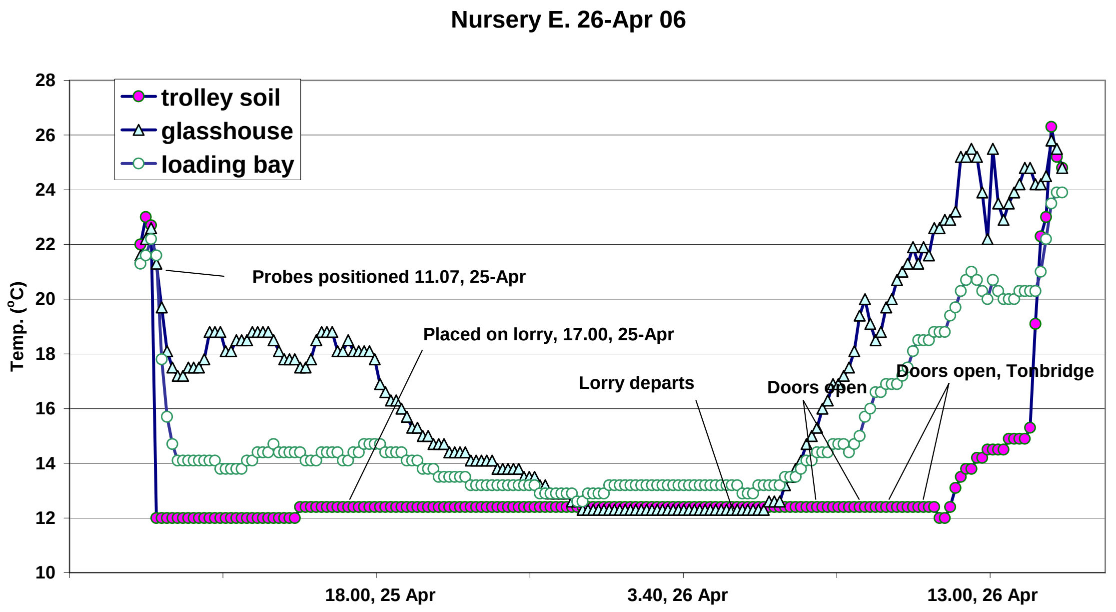

Figure VIII. Nursery E - Crop (unknown). Relative humidity comparisons between glasshouse and dispatch area. 18 tonne rigid-body, refrigerated lorry. Two destination run, with final = Paddock Wood, Kent.

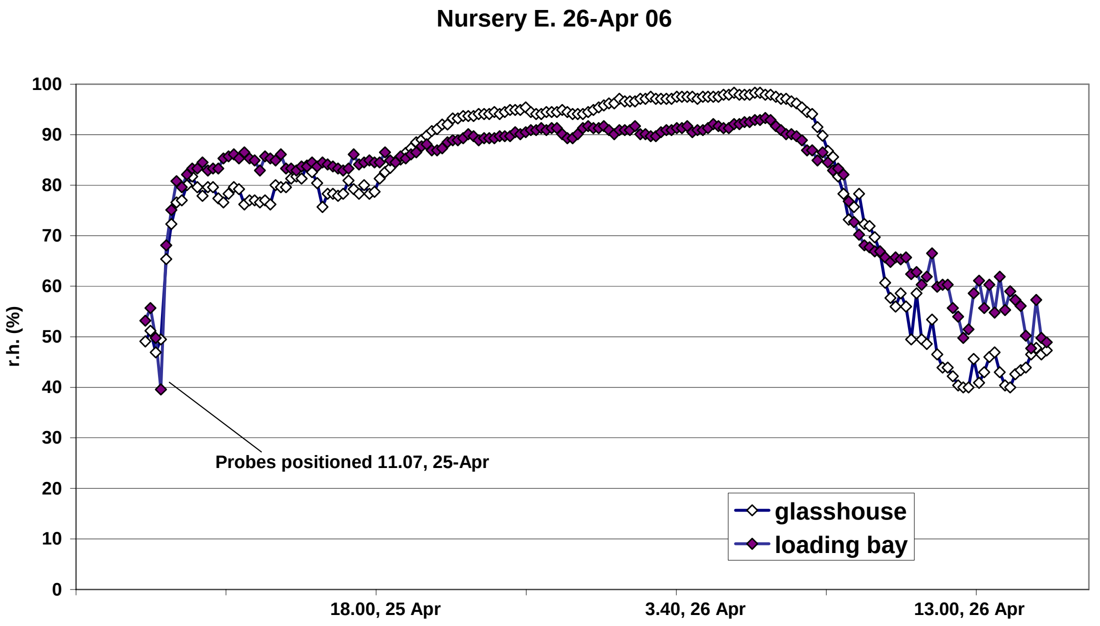

Figure IX. Nursery G - Crop (mixed bedding). Air temperature and relative humidity. 13 tonne rigid-body and no refrigeration. Multiple run around East Anglia – warm weather.

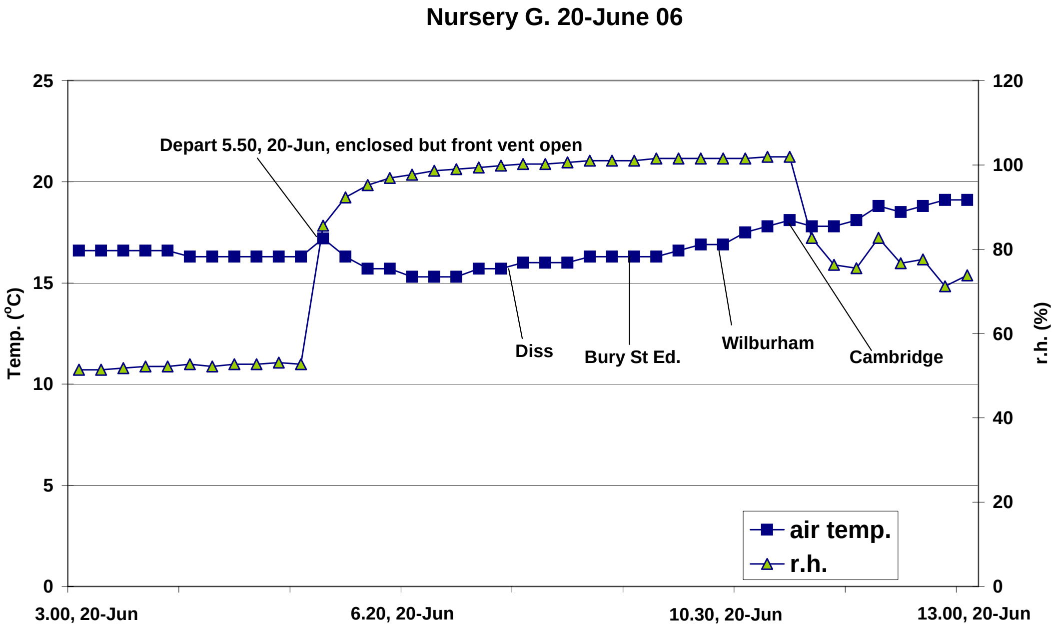
Nursery G. 20-June 06

Figure X. Nursery G - Crop (mixed bedding). Air temperature and relative humidity. 13 tonne rigid-body and no refrigeration. Multiple run around East Anglia – warm weather.

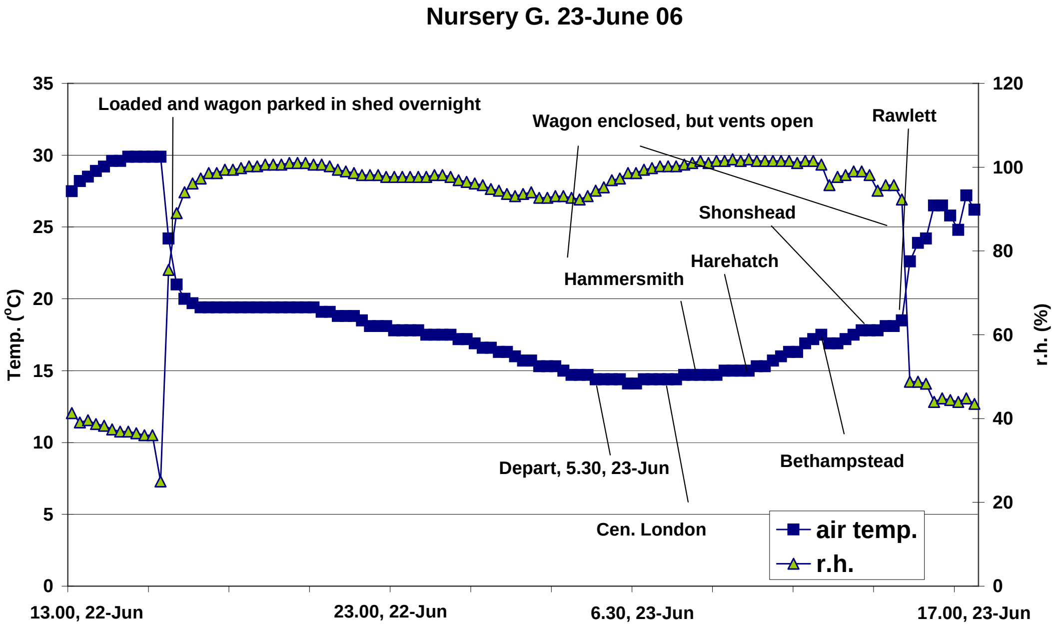
Nursery G. 23-June 06

Figure XI.- Nursery G - Crop (mixed bedding). Air temperature and relative humidity. 13 tonne rigid-body and no refrigeration. Multiple run around East Anglia – weather cool.