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CONTENTS

Grower Summary

Background and objectives

Accurate plant scheduling has become a critical requirement of successful bedding plant production in recent years. Customers increasingly demand more numerous batches of plants of varying species and varieties, delivered on a range of dates in order to satisfy fluid market demands. This applies to both plant propagators supplying young plants and to growers supplying finished plants. Through the spring months each year, the situation is compounded by the effects of the prevailing weather conditions, which not only affect rates of plant growth but also dictate the intensity of demand and the demand period for bedding plants. Scheduling techniques are critical through this period to maximise sales and minimise wastage.

Various techniques to delay plant development and manipulate growth are currently used within the bedding plant industry including: the use of sub-optimal growing temperatures, adoption of lean watering regimes, nutrient restriction (specifically phosphorus) at key stages of production, physical means, such as pinching and cutting back and the use of various chemical plant growth regulators.

Low temperature storage of bedding plant plugs is not a novel means of delaying growth and development of bedding plants; it is used by bedding plant growers in the USA and in part by a number of bedding plant propagators in the UK. However, the procedure is not fully understood by growers and its potential applicability, including the financial benefits of cold storage are not yet appreciated by the industry as a whole.

The objectives of this study are to:

1. investigate low temperature responses in a range of bedding plant species
2. examine the effects of low temperature storage on plug and final plant quality
3. identify practical and cost effective storage regimes for bedding plants.

This interim report provides a review of the literature on cold storage of bedding plants, an update on current practice and a cost-benefit analysis. Trial work on cold storage of bedding plant plugs will be carried out in Spring/Summer 2003 and a grower factsheet will be prepared by the end of 2003.

Summary of review and main conclusions

- The potential for effective cold storage of bedding plant plugs is clear in concept and the limited research work from the USA goes some way to confirming this potential, although the information is restricted and lacking in practical detail.
- Suitable storage conditions for a number of species have been identified by previous research, largely from the USA, and the derived technology may be immediately applicable to the UK industry.
- Bedding plant species, which can be successfully stored will be those that are not subject to chilling injury and are tolerant of the storage temperatures employed. In this regard tolerance is identified as exhibiting normal growth and development, within an acceptable time-span, following return to normal growing temperatures.
- Past research appears to indicate that several bedding plant species including; alyssum, fibrous begonia, cyclamen, geranium, lobelia, pansy, petunia, primrose and salvia can be stored at a common temperature (around 5°C) for up to 4 weeks without light. Several of the above mentioned species (alyssum, cyclamen, geranium pansy, petunia and primrose) can be stored at a slightly lower temperature (2.5°C) if required. However, a higher storage temperature (10-12°C) will be required for the more tender plant species; New Guinea impatiens, impatiens, celosia etc. Excluding the very tender plant species, a possible compromise temperature may be 7.5°C. The introduction of a low level of lighting (0.2 to 1.0 W/m^2 PAR) is beneficial for longer term storage and for storage at sub-optimal temperatures.
- Experimental modification of storage conditions, informed by an understanding of the general hardiness of the plant subject, is likely to expand the list of plants that, as plugs, are amenable to low temperature storage.

- The issue of build-up of *Botrytis cinerea* infection during storage needs to be addressed, but the likelihood is that a combination of cultural practices and possibly fungicide treatments will be effective.
- There is still however, a need for ‘proving experiments’ in the UK to provide confidence of applicability and provide current, reliable information gathered from plant material out of modern production facilities and with species appropriate to the UK industry.
- Appropriate cold-store facilities are available. Purpose built stores are the most costly, depending upon specification, but it is likely that, for many purposes, refurbished low-temperature, lorry bodies / transport containers would be just as suitable. These are available with modifications to allow them to function as simple cold rooms at relatively low cost.
- The storage conditions derived from this study can also be easily translated into transport conditions. This conversion is most readily done where static storage and transport are carried out in similar containers, but conditions in purpose-built low temperature storage facilities can be relatively easily reproduced in transport containers.

Action points for Growers

Growers are advised to await the outcome of new trial work on the cold storage of bedding plant plugs during Spring/Summer 2003. A HDC factsheet on the cold storage of bedding plants is scheduled for Winter 2003.

SCIENCE SECTION

Background & Introduction

The low temperature storage of bedding plant plugs has the potential to be a robust, flexible and commercially valuable technique for storing material over a relatively short period of time, once the procedure is fully understood and can be successfully exploited.

The rationale for the use of low temperature storage is that it can provide a measure of developmental stasis for the stored plug plants, using accessible and relatively low cost, cold room technology. However the reality of storage at low, non-freezing temperatures is not uniformly simple and may not supply the balanced suspension of plant development that is looked for.

At the storage temperatures under consideration, typically between 2-10^{0}C, plant and cell functions are slowed but not halted (Grout and Morris, 1987; Levitt, 1972). Typically, taking bedding plant plugs from a growing temperature of 18^{0}C and placing them at 5^{0}C will slow metabolism by some 60-70% but will not suspend it all together. Major processes like respiration and protein synthesis continue at this reduced rate and, consequently, a level of growth and development are maintained (Lyons *et al*.,1979; Li, 1987). Even if sufficient light for photosynthesis is available, the process will be significantly slowed and may not compensate for carbohydrate energy losses due to respiration. If storage is in the dark for periods in excess of a few days it is probable that the photosynthetic structures within the plant will begin to degrade and these will take a significant time to regain their effectiveness once the plants are returned to normal, physiological conditions. Consequently, plants recovered from prolonged storage at low temperatures may have a reduced carbohydrate reserve and temporarily impaired photosynthesis, which will slow the rate of their recovery growth.

The diversity of plant and cellular mechanisms in a growing plant ensures that metabolic slow-down is not uniform and, consequently, some aspects of metabolism and development continue at a faster rate than others. This will be due, largely, to the different temperature optima of metabolic enzymes and the different effects on trans-membrane diffusion rates of metabolically significant molecules (Morris and Clarke, 1987).

The result may be imbalanced growth and development at the lowered temperatures that may become evident as abnormalities once the plugs are moved back to normal growth temperatures, for example reduced elongation growth and altered flowering times (Ueber and Hendriks, 1997). Clearly, these unwelcome problems may not be evident simply by a visual inspection of the stored material in the immediate post storage period.

Given the moderate storage temperatures being considered and the relatively short periods proposed for storage, the major problems are likely to be:

1. chilling injury
2. depletion of carbohydrate reserves by respiration
3. degradation of the photosynthetic apparatus within the plant

In this context chilling injury is defined as stress responses based upon membrane alterations, ethylene synthesis and changes in respiration, photosynthesis and protein synthesis (Heins *et al*., 1995; Lyons *et al.,* 1979). The observed symptoms range from wilting and a general lack of vigour of recovered plants, to water soaked leaf tissue, leaf spotting and necrosis and, in severe cases, plant death.

Depletion of carbohydrate reserves by respiration, together with the absence of net photosynthesis, will reduce carbohydrate energy reserves in the plant. If the photosynthetic system has become degraded during storage and is not immediately effective upon return to normal growth conditions, then a lag in recovery and resumption of normal patterns of growth may be expected.

In the context of bedding plant species, a range of plant responses must be anticipated. A small number of subjects, such as New Guinea impatiens, will be sensitive to classic chilling injury. This is a genetically determined character that cannot be altered and the growers must ensure that the critical temperature limit for the plant concerned is not breached. Typically, temperatures in excess of 10^0C will avoid this difficulty but practitioners need to be aware that an exposure of a very few hours is enough to induce the injury, from which plants rarely recover to a saleable condition. Chilling injury may not be expressed for several days after the temperature stress and can lead to high levels of plant death.

Similarly other spring / summer bedding plant species are, by their very nature, likely to be less forgiving of low temperature stress than those produced for the autumn to early spring market. Consequently, when selecting an average storage temperature to suit a range of plant types, higher values are likely to be more appropriate in the spring and values towards the lower end of the spectrum more applicable in the autumn.

Review of Research

Despite anecdotal suggestions of a large quantity of research work from the USA, there is relatively little hard information available, many of the publications listed are simply versions of earlier information. The book chapter by Styer and Koranski (1997) is the most recent, detailed publication that covers the subject area in scientific detail, based largely upon the pioneering work of Heins *et al* (1992, 1995) that reported successful low temperature storage of a range of bedding plant plugs.

Information is provided by Heins and his colleagues for 19 plant subjects and covers a range of storage temperatures from 0-15^{0}C and storage periods from 1-6 weeks. Optimum temperatures and maximum storage periods are derived (Tables 1 and 2) from data collected on days to flowering under glasshouse conditions and percentage mortality of plugs following the storage period.

The time to flowering after transplanting was not affected by the duration of storage within the recommended periods at the optimum temperature, which confirmed earlier data for pansy, petunia, salvia and geranium (Kaczperski and Armitage, 1992; White and Quatchak, 1985). However, storage outside the optimum range is likely to increase the time to flower and at suboptimal temperatures this may be due to chilling injury (Herner, 1990; Heins *et al.*, 1995). Heins also presents data for French marigold (1995) showing high levels of plug mortality if storage extends to two weeks outside the optimal storage temperature. Whilst no further data are provided, the authors suggest this is a general phenomenon, indicating that 'deviations from the optimum, reduced overall plant quality and survivability'.

The beneficial effects of light at low levels, provided by cool white fluorescent bulbs at an intensity of 1μmol m^{-2} s^{-1} (0.22 W/m^2 PAR), are recorded in the work by Heins and his colleagues (1995) and they further indicate that increasing the light levels up to 25μmol m^{-2} s^{-1} (~ 5.5 W/m^2 PAR), did not increase the practical benefit (Heins *et al.*, 1995; Lange et al., 1991a, b). This suggests that 1μmol m^{-2} s^{-1} is the threshold level that prevents dark degeneration of the cellular photosynthetic apparatus. As well as reducing the plant mortality that can increase as the storage period is extended, this minimal illumination also reduces unwanted extension and chlorosis in plugs stored for longer periods.

Further, it improves recovered plant quality and regrowth when plugs are stored for longer periods. The use of light during storage also greatly improves seedling quality when storage temperatures outside the optimum are employed.

In this study, Heins and his co-workers used the simplest of transplanting procedures from storage, simply taking the plants back to a minimum of 20^{0}C in the glasshouse, using soil-less compost in 10cm pots (Heins *et al.*, 1995). It is possible that improvements in results may be obtained by modifying the transplanting procedure (for example by providing shade to the plants post transplanting), for transplanting surely adds additional stress to the stored plugs.

Kaczperski and Armitage (1992) also stored plugs for up to 21 days at 5 or 10^{0}C with continuos light from 1-12µmol m^{-2} s^{-1} (~ 0.2 to 2.6 W/m^2 PAR). Their conclusions were that temperature was, generally, more important than irradiance in maintaining a commercially acceptable product for the species they investigated (pansy, petunia and salvia), at least up to a storage period of 21 days. They concluded that petunia and viola could be stored for up to 21 days and salvia for 14 days, both at 5^{0}C. White and Quatchak (1985) found that geranium could also be stored successfully at 5^{0}C for 21 days.

From the data it should be noted that New Guinea impatiens is not amenable to low temperature storage, at least below 12.5^{0}C (Armitage, 1994; Heins *et al*., 1995). This is because the plant is markedly susceptible to chilling injury, a genetically controlled character, that cannot be easily modified by conventional plant breeding. It is a property found in a significant number of plants of tropical or semi-tropical origin and must be considered if storage of such material is being considered.

Table 1 Optimal plug storage temperature and maximum durations. (Adapted from Heins *et al*., 1995; Styer and Koranski, 1997)

Species	Optimal storage temperature °C	Maximum storage in dark (wks)	Maximum storage in light (wks)*
Ageratum	7.5	6	6
Alyssum	2.5	5	6
Begonia (fibrous)	5.0	6	6
Begonia (tuberous)	5.0	3	6
Celosia	10.0	2	3
Cyclamen	2.5	6	6
Dahlia	5.0	2	5
Geranium	2.5	4	4
Impatiens	7.5	6	6
Lobelia	5.0	6	6
Marigold (French)	5.0	3	6
NG Impatiens	12.5	2	3
Pansy	2.5	6	6
Petunia	2.5	6	6
Portulaca	7.5	5	5
Salvia	5.0	6	6
Tomato	7.5	3	3
Verbena	7.5	1	1
Vinca	10.0	5	6

* Minimum of 1μmol m^{-2} s^{-1} irradiance (= 0.22 W/m^2 PAR)

Table 2 Maximum duration in weeks for 19 bedding plant species stored at 0, 2.5, 5.0, 7.5, 10.0 or 12.5 ^{0}C and at 0 or 1μmol m^{-2} s^{-1} irradiance (0.22 W/m^{2} PAR). All plant plugs were stored in 406 trays, except where indicated (*), these species stored in 84 trays.

D = stored in dark; L = stored with light at 1 μmol m^{-2} s^{-1} irradiance (0.22 W/m^{2} PAR).

(Adapted from Heins et al., 1995; Styer and Koranski, 1997)

Species	**0 ^{0}C**		**2.5 ^{0}C**		**5.0 ^{0}C**		**7.5 ^{0}C**		**10.0 ^{0}C**		**12.5 ^{0}C**	
	D	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**
Ageratum	1	1	1	2	5	6	6	6	3	6	3	6
Alyssum	5	6	4	6	4	6	2	6	1	3	1	3
Begonia (fibrous)	0	0	4	6	6	6	5	6	5	6	0	4
Begonia (tuberous)*	3	3	3	4	3	6	4	6	3	4	3	4
Celosia	0	0	1	1	1	1	1	1	2	3	2	3
Cyclamen	6	6	6	6	6	6	5	6	5	6	4	6
Dahlia	1	1	2	4	2	5	2	6	2	6	2	5
Geranium	4	4	4	4	4	4	4	4	4	4	2	4
Impatiens	0	0	2	2	3	3	6	6	5	6	4	6
Lobelia	0	0	5	5	6	6	5	5	4	4	0	4
Marigold (French)	0	0	1	3	3	6	3	6	2	5	2	3
NG Impatiens*	0	0	0	0	0	0	0	0	0	0	2	3
Pansy	6	6	6	6	6	6	6	6	6	6	6	6
Petunia	6	6	6	6	6	6	5	6	5	6	4	6
Portulaca	1	1	3	3	5	5	5	5	6	6	6	4
Salvia	0	0	0	0	6	6	6	6	4	6	4	6
Tomato	0	0	1	1	2	2	3	3	1	1	1	1
Verbena	1	3	2	2	1	1	1	1	1	4	1	4
Vinca	0	0	2	2	3	3	4	6	5	6	5	6

Storage of bedding plant species at 0^0C is not to be recommended, for bulk cold stores achieve their set temperature as an average value, cycling regularly and to a limited extent above and below the required temperature. Excursions below zero present a very real risk of freezing injury.

If storage of several types of summer bedding plant plugs is envisaged, then a temperature of 7.5^0C is an acceptable compromise, using continuous light at the low intensity indicated above (bearing in mind the previously mentioned exceptions). However, two temperature regimes, one around 3-5°C the other around 7-10°C may be more appropriate depending upon the species produced and stored. The lower temperature regime would also be more appropriate for the storage of most autumn bedding plant species. The low light intensity is best provided by a 40W cool white fluorescent lamp positioned at approximately 1 metre from the plug tray. A range of light intensities from 1-5 μmol m^{-2} s^{-1} (~ 0.2 to 1.0 W/m^2 PAR) across the tray is acceptable, which allows for differences in positioning of the light source depending upon circumstances. Provision of a low level of light appears to be beneficial for plants stored over a longer time period (over 2-3 weeks) or at sub-optimal temperatures for the species in question (for example, if an average storage temperature is used for a number of different species).

To ensure the best temperature control, the air in the storage space should be circulating continuously, but this will accelerate drying of the plug growing medium and mean that watering may need to be undertaken. The ideal watering method will ensure that the foliage is not wetted as this will raise the humidity in the storage space and encourage the development of *Botrytis* infections. Each of the key researchers mentions *Botrytis* as a serious, practical problem that can compromise effective storage and it is probably best practice to:

1. ensure plug plant material is adequately watered prior to storage whilst allowing time for the foliage to dry before actually placing it into store
2. use a routine fungicide regime to minimise any potential risk.

The risk of *Botrytis* is also increased when storing higher plug density trays as the higher foliage density raises humidity at the leaf surface.

Styer and Koranski (1997) also suggest that a hardening procedure prior to storage might be advantageous, provided that it did not conflict with the production process. They suggest that lowered temperatures in the glasshouse (10-16^0C) and / or a level of water stress may harden plugs to better withstand the further stresses of storage. They warn strongly against the use of ammonium-based fertiliser for material likely to be cold-stored and suggest that calcium and potassium nitrate fertilisers are preferable. However, no evidence is presented to support this assertion. They also note that a risk associated with attempts at hardening is premature plug flowering. The positive correlation between lush growth, resulting from high fertiliser application, and a high incidence of *Botrytis* is noted by Heins *et al.* (1995).

Derived from the Heins observations and their own, previous publications, the general recommendations made by Styer and Koranski (1997) include:

1. Use only healthy plugs which have received any beneficial pre-treatment that is available
2. Ensure adequate root moisture but avoid wet foliage
3. Treat all trays to be stored with an anti-*Botrytis* fungicide regime
4. Use an appropriate temperature with continuous air circulation
5. Use continuous light at low levels (1μmol m^{-2} s^{-1} = 0.22 W/m^2 PAR)

Review of plant transport conditions used in the USA

In the USA, plant material is often transported by land over long distances. During transportation, material is usually stored at low temperatures to reduce potential plant spoilage, therefore relevant literature on plant preparation / acclimatisation and transport conditions used for bedding and pot plant crops was also reviewed to ascertain if any further practical detail on low temperature storage had been published.

There have been some studies on the low temperature transport of flowering pot plants (Sterling and Molinar, 1982; Nell and Barrett, 1990), providing optimal temperatures between 3 and 10^0C for a number of plant species over a transport period of 6 days. This information warns of the need to identify subjects that exhibit chilling injury, where temperatures below 10^0C will cause very significant damage. Koranski *et al*. (1989) recommend that bedding plant plugs should be 'toned' for 1 week before transporting, meaning that a controlled level of stress should be applied to the plant, under controlled conditions, to minimise any further stress that might result from the transport environment. The treatments they recommend for the preparatory week include:

1. Reducing the water level of the growing medium
2. Lowering the light intensity
3. Lowering the temperature
4. Lowering the amount of fertiliser used
5. Use of growth regulators as necessary

Styer and Koranski (1997) make some more detailed recommendations specifically for plugs that mirror those given above, but do not present experimental evidence. They suggest a transport temperature of 7.5^0C as a compromise for plugs of all types, provided they are not susceptible to chilling injury, which echoes the previous recommendations of Koranski *et al. (*1989).
Their recommendations prior to transport are:

1. Start with well-toned, healthy plugs
2. Avoid applying ammonium based fertilisers (ammonium is not broken down at low temperatures and can build up to toxic levels)
3. Pre-cool plug trays, especially during hot times of the year
4. Set temperatures in the lorry body to 7.5°C with continuous operation

5. Transport plugs with moist roots but dry leaves
6. Treat sensitive crops with a recommended fungicide for *Botrytis*
7. Try not to use any chemical growth regulators within five days of transportation.

Review of Cold Storage facilities

The establishment of suitable low temperature storage facilities for bedding plant plugs is usually achieved in one of two ways, namely by the purchase or lease of a refurbished / modified refrigerated lorry body / transport container or by the construction of a purpose built facility. In the UK, lorry body / transport containers suitable to provide cold storage may be located on the Internet (see Table 3 for examples of such companies). The units supplied, range from 10ft to 40ft in length with fan circulation and compressor-driven, direct expansion cooling systems (the refrigeration coil is in direct contact with the store air), easily capable of producing temperatures of 0-10^{0}C. The chief disadvantage of this type of cooling system is the drying effect of the refrigeration coil on the store air. The amount of moisture removed is dependent upon the coil operating temperature; the closer this is to the store temperature, the less moisture it will remove. Obviously if air with a low water potential is circulated then it will tend to accentuate water loss from the plugs and is likely to increase the need for irrigation / watering during more extended storage periods. Typically, units are available for lease or sale with purchase prices from approximately £500 for the smallest units to more than £4000 for a 20ft, refurbished unit with a number of safety features and refinements. Such a 20ft unit might typically be leased for approximately £100-£150 per week plus charges for delivery, installation and removal.

Purpose built facilities are likely to be significantly more expensive than modified containers (see Cost-benefit of cold stores section and Appendix 2) and construction costs in the tens of thousands of pounds are realistic. Many stores (especially those available for renting) like the lorry bodies / transport containers are direct expansion stores, however other store types are available. The air inside 'wet air cooled' stores is cooled by direct contact with chilled water. As such the store air does not lose moisture and it is impossible to cool the store below freezing, so frost sensitive species are generally protected. The other type of cold store is the jacketed store, so called because the cold air from the cooler circulates between the outer insulated shell of the store and a metal-walled inner shell. The plants in store are separated from the refrigeration coils by a waterproof membrane, so any drying effect of the evaporator coil cannot be transferred to the plant material.

However, it must be borne in mind that in the case of the latter two stores the speed of the circulating air will still have a drying effect.

If a cooling unit is present in a germination room, and the room is adequately insulated, then the germination room may have the potential to also act as a low temperature store.

The efficiency of any type of store can be reduced significantly if it is poorly packed, such that the air-flow is restricted or diverted in an unhelpful way, resulting in uneven cooling of the plants and possibly interfering with the effective operation of the temperature monitor.

Table 3 Contact addresses of companies supplying refrigerated lorry bodies

Grenco Articstore, Oliver Road, West Thurrock, Essex RM20 3ED. Website – www.grenco-articstore.com
Seven Asset Management, Cardinal Court, 35-37 St Peters Street, Ipswich, Suffolk. Website – www.sevenasset.co.uk

Grower Case studies

The three case studies presented below confirm, to a limited extent, the potential that is evident from the US research work. Each of the growers has found that relatively short storage times at low temperature can be exploited to give real benefits in operational terms.

Case study 1

W. J. Findon and Sons, Bordon Hill Nurseries, Stratford-upon-Avon, Warwickshire CV37 9RY

W.J. Findon and Sons are one of the UK's largest young plant propagators, producing a wide range of seed and cutting raised bedding and pot plant material. The company supplies Ball Colegrave with much of their young plant material. Spot crops of finished plants are also produced by the company.

Low temperature storage of plugs is undertaken on this particular nursery to ensure adequate stocks of specific plant material are available at peak demand times. The nursery does not possess a purpose built cold store, but the germination room 'doubles up' as the low temperature storage area. However, temperatures (from 0 to 20°C) can be precisely controlled in the insulated room. The following plant species have so far been stored at low temperature; Cyclamen, Lobelia, Pansy, Petunia, Polyanthus and Primrose.

Several thousand plug plants may be stored at any one particular time, but usually only for certain weeks of the year;

- Summer bedding – weeks 14-18
- Cyclamen – weeks 30-32
- Primroses, polyanthus and autumn pansies – weeks 36-38.

Plant material has been stored for up to 3 weeks, however the typical storage period is 7-10 days. The young plants are stacked on Danish trolleys in the store and stored at a temperature of 5-7°C without light. They are watered a short while before going into store to allow the foliage to dry prior to storage. Minimal crop deterioration has been noted, *Botrytis* and leaf yellowing tend to be the main problems encountered, although maintaining uniform compost moisture in the plug trays can be a problem. No fungicides are applied to the plugs prior to storage.

As well as low temperature storage of young plant material destined for sale, plug material for internal use on the nursery has also been stored to ease management at pricking out. On one occasion, for trial purposes, a batch of 'double six pack' flowering pansies were stored for 2 weeks. The plants came out of store in a reasonably good condition, but hand cleaning was necessary in order to make them marketable.

Case study 2

Burston Nurseries Limited, North Orbital Road, St Albans, Hertfordshire, AL2 2DS.

Burston Nurseries produce a wide range of pack bedding and larger pot bedding, primarily for the garden centre market. The nursery also specialises in the production of almost 300,000 containerised roses.

Burston Nurseries possess a purpose built cold store, but the store is used primarily to house bare root roses, permitting the scheduled potting of plants over a longer time period. The store is a large direct expansion store, 25m by 10 m, capable of holding up to 120 tonnes of roses. It cost approximately £38,000 to construct.

For the first time this year the store was used as a method of scheduling the production of primrose and polyanthus pack grown plants. Plug plants of sufficient size, in 280 trays, were stacked onto Danish trolleys and placed into store. The store was run at 2°C, which is the optimal temperature for bare root rose storage, but not necessarily the optimum for primrose plug plants. A low level of fluorescent lighting occurred in store through the day (sufficient for staff to see by in store) but not at night or during the weekend.

Trays of plants were removed from store and potted on over a period of 9 weeks. The plants were laid down side by side to allow comparison. The plugs that had been in store for the longest period of time were pale and slightly yellow at removal, but they still established after potting. The plants are currently being monitored to discover the effect of the storage period on flowering and plant quality.

Case study 3

Roundstone Nurseries, Roundstone Lane, Angmering, Littlehampton, W. Sussex BN16 4BD.

Roundstone Nurseries are primarily producers of pack bedding for the retailers B&Q. They also produce young seed raised plants, which are marketed by Young Plants Limited, (retail) starter plants, pot bedding and pot plants. The company is currently based on three sites around Chichester.

The nursery recently acquired a purpose built direct expansion store, prior to which low temperature storage of plugs was undertaken using rented refrigerated lorry bodies. The store is about 10m by 10m and capable of holding up to 60 Danish trolleys. As well as low temperature storage, the store is also used to germinate primrose and polyanthus seedlings.

The store is used to hold primrose and polyanthus plugs as an aid to scheduling the production of finished pack grown plants and to occasionally store volumes of young plant material for short periods of time at peak periods of production. Primroses and pansies are typically stored at 5-6°C, impatiens at 8-9°C. The store is unlit. The plug trays are stacked (the plug trays used have legs, 264 cell trays for primroses, 405 cell trays for the other species) 80 per trolley. The material is watered 3-4 hours prior to storage, further watering is not generally necessary. All the plug material stored is for internal use on the nursery. Storage tends to occur during two periods during the year;

- Summer bedding – weeks 14-18
- Primroses, polyanthus and pansies – weeks 36-44

In the case of the primroses and polyanthus stored for scheduling, plug plant material has been held in store for up to 3 weeks, but the typical period is 7-14 days. Most of the other plant species, for example pansy, are held in store for only short periods of time, often only 2-3 days, to ease management at the pricking out stage. Impatiens have been stored for up to 7-10 days, however plant deterioration was noted if the young plants were stored any longer.

Cost-benefit analysis of cold stores

This section aims to show by the use of simple models/examples, the cost-benefit of cold stores. The information on the cost of construction of a cold store facility is as variable as the types and sizes of cold store available. The degree of sophistication of the store will affect the overall cost and its running cost. This makes it difficult to give precise and accurate comparisons. Most of the following examples are based on hiring a refrigerated lorry body / transport container for six months. However, a permanent purpose built cold store or a permanent lorry body / transport container will be cheaper over a long period of time as the initial capital cost, written off over a period of time, will be less than the hire fees.

The cost of a purpose built cold store can vary from £140 to £234 per square metre (see Table 4). Taking the most expensive and working on a ten year life this gives an annual charge of £23.40 per square metre, when compared to the hired lorry body which costs up to £186 per square metre per year. The running costs and maintenance of a cold store are estimated at around £5 per square metre.

Table 4 Cold store costings

Cold store	**Area m^2**	**Total cost (£)**	**Cost (£) / m^2**	**Annual charge#**
1 (q)	420	69,500	165.48	£16.55
2	470	110,000	234.0	£23.40
3	250	37,500	150.0	£15.00
4 (c)	24.32	3,000	123.35	£12.34
5 *(c)	26.61	4,965	186.58	-
6 (q)	420	58,825	140.06	£14.01

- Annual charge based over a 10 year period.
(q) - quotation
(c) – container / lorry body
* - container hire for a 6 month period

Figures for cold store 2 are used in the cost-benefit calculations

Typical cost:benefit analysis

Costs if using a hired refrigerated container

Refrigerated transport container on 13 week hire plus transport each way = £4,965

Plus running costs of £5 per square metre (£133) = £5,098 [£4,965 + £133]

The container holds 40 Danish trolleys, with 80 trays per trolley. Therefore for a 264 cell tray, this represents 844,800 plugs in total or 1,296,000 plugs if using a 405 cell tray.

The container is used for 6 crops per year.

Average Cost per crop = £5,098 /6 crops = £849.67

Benefits analysis

1. Scheduling crops & reducing wastage

Crops can be typically held in cold store for 1 to 4 weeks, depending upon species, to extend the transplanting / marketing period of the finished crop, without suffering loss of quality at any stage.

In this example there are 80 trays per trolley in store, the plug trays used are 264 cell trays for primroses and 405 cell trays for other species. If the cost of replacing a primrose plug is 4.5p and the cost of replacing other species is 2.5p on average, then the number of plugs equivalent to the cost of the cold store is:

£849.67 / 2.5 p per plug = 33,986 other plugs

£849.67 / 4.5 p per plug = 18,881 primrose plugs

This is equivalent to 2.23% [18,881/844,800 plugs x 100%] of the primrose crop and 2.62% 33,986/1,296,000 plugs x 100%] of the other species. To show a cost-benefit the nursery only needs to increase yield or prevent losses of 2.23% and 2.62% in the case of each crop.

2. Holding crops prior to transplanting

Cold stores can be used to hold batches of plugs plants on Danish trolleys prior to pricking out to ease management, it being quicker to store plants on the trolley in the cold store than stand the plants down and reload them. If we assume plug plants are held over weekend periods in store to avoid plant stretch and that there are typically 13 weekends in the main production period, the cost per weekend of running the cold store would be £392 (£5098 divided by 13 weeks).

It takes approximately 2 hours to load and then unload 3 trolleys each containing 80 plug trays. The total time required for 40 trolleys = 26.67 hours.

If labour costs £8.00 per hour (taking in account salary, NI contributions etc) then the cost of standing down and reloading = £213.

In this case it is cheaper to lay out the trays in the greenhouse (£213) than it is to store the plugs over the weekend in the cold store (£392).

However, should a permanent store that can be costed over a longer period be available, then cost benefit will accrue. In this case the cost is estimated at £58 (this assumes the annual cost of a purpose built cold store is £28.40 per m^2). The area of the container in the example is $26.61m^2$. Therefore, the cost per year of the cold store for the equivalent area is £755.72, if used for 13 weekends this equates to £58.13 per weekend which gives a saving of £155 (=£213-£58).

3 Substitution for glasshouse space

A cold store can be used as a substitute for glasshouse space. Plants in a cold store can be stacked on Danish trolleys or other shelving thus decreasing the floor area required to hold the crop. In the example used with 80 trays per trolley stacked 20 high, laying them down on a production area would require 20 times the space.

It is difficult to give a direct cost comparison between cold stores and glasshouses as each structure will have a variety of different crops and uses throughout the year. However, if the problem is taken to its simplest level by comparing the cost of one square metre of glasshouse to one square metre of cold store it is possible to see where cost-benefit could occur.

Table 5 Cost comparison between a square metre of glasshouse and cold store.

	Glasshouse*	**Cold store**
Building cost	£42.50	£234
Annual cost (over 10 years)	£4.25	£23.40
Running cost (per year)	£0.31	£5.00
Total cost	£4.56	£28.40

*ADAS data.

Table 6 Comparative cost for a glasshouse

Glasshouse type	**Cost (£) / m^2**	**Annual charge (£) #**
Low tech house	35	3.50
High tech house	50	5.00
Mean		**4.25**

Annual charge based over a 10 year period.

If this were a direct comparison then plants would have to be stacked 7 layers high to give a cost benefit. For example, the cost of one square metre of cold store stacked 7 layers high = £28.40; the cost of the required area of glasshouse ($7m^2$) = £31.92. Thus the more layers the greater the cost benefit.

4. Use of cold stores for Primrose germination

To provide early batches of primroses, sowings must be made in the warmer months of the year but germination can be erratic. To ensure a better level of germination, seeds can be germinated in the cold store at 16°C. The cost of primrose seed is 1.5p per seed. The number of seeds equivalent to the cost per crop of the store (£849.67) is 56,644 seeds or 6.7% of the crop. Therefore it is only necessary to increase germination by 6.7% of the total crop to recoup the cost of the cold storage in seed cost alone.

Conclusion

Using these simplistic models/examples, it is possible to show a cost-benefit for the use of cold stores. However, it should be noted that a limited number of examples have been used and if considering investing in such a project more accurate figures, applicable to the specific situation, should be used.

Viewing the models/examples in isolation is slightly misleading in that many of the factors considered are inter-related and carrying out one task will lead to the introduction of another (for example scheduling crops and substitution of glasshouse space). It is therefore likely that the accrued cost-benefit will be additive and the overall benefit will be greater than that shown.

Consideration should also be given to what happens to the cold store throughout the whole period of time. If it can be used for other purposes (primrose germination, storage of other plant material such as cuttings etc) then these tasks will help to offset costs.

Priorities for research and development on cold storage of plug plants

- To assess the optimum storage conditions for a selected number of bedding plant subjects under UK conditions.
- To assess disease development in cold storage and evaluate methods to minimise any resulting plug plant losses.
- To investigate the quality of plug plants 'recovered' from extended low temperature storage.
- To investigate the advantages of modified weaning procedures following low temperature storage of plug plants.
- To evaluate in more detail the possible cost and operational benefits of low temperature storage for UK plug plant producers and plant finishers.

Overall Conclusions

- The potential for effective cold storage of bedding plant plugs is clear in concept and the limited research work from the USA goes some way to confirming this potential, although the information is restricted and lacking in practical detail.
- Suitable storage conditions for a number of species have been identified by previous research, largely from the USA, and the derived technology may be immediately applicable to the UK industry.
- Bedding plant species, which can be successfully stored will be those that are not subject to chilling injury and are tolerant of the storage temperatures employed. In this regard tolerance is identified as exhibiting normal growth and development, within an acceptable time-span, following return to normal growing temperatures.
- Past research appears to indicate that several bedding plant species including; alyssum, fibrous begonia, cyclamen, geranium, lobelia, pansy, petunia, primrose and salvia can be stored at a common temperature (around 5°C) for up to 4 weeks without light. Several of the above mentioned species (alyssum, cyclamen, geranium pansy, petunia and primrose) can be stored at a slightly lower temperature (2.5°C) if required. However, a higher storage temperature (10-12°C) will be required for the more tender plant species; New Guinea impatiens, impatiens, celosia etc. Excluding the very tender plant species, a possible compromise temperature may be 7.5°C. The introduction of a low level of lighting is beneficial for longer term storage and for storage at sub-optimal temperatures.
- Experimental modification of storage conditions, informed by an understanding of the general hardiness of the plant subject, is likely to expand the list of plants that, as plugs, are amenable to low temperature storage.
- There is still however, a need for 'proving experiments' in the UK to provide confidence of applicability and provide current, reliable information gathered from plant material out of modern production facilities and with species appropriate to the UK industry.
- Appropriate cold-store facilities are available. Purpose built stores are the most costly, depending upon specification, but it is likely that, for many purposes, refurbished low-temperature, lorry bodies / transport containers would be just as suitable. These are available with modifications to allow them to function as simple cold rooms at relatively low cost.

- The storage conditions derived from this study can also be easily translated into transport conditions. This conversion is most readily done where static storage and transport are carried out in similar containers, but conditions in purpose-built low temperature storage facilities can be relatively easily reproduced in transport containers.

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