LITERATURE REVIEW OF FACTORS AFFECTING GERMINATION OF PRIMULA AND PANSY AND A DESIGN SPECIFICATION FOR A GERMINATION ROOM TO IMPROVE SPACE UTILISATION AND IMPROVE GERMINATION RATES

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ADAS

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1. INTRODUCTION

The development of the plug has led to a greater awareness among growers of the need for high germination rates and to produce a uniform stand of plants with the potential for mechanical transplanting. In the USA in 1981 the average number of usable seeding (in plug trays was 57%; by 1987 this number had risen to 75% (Karlovich 1992). Future increases are predicted to be slower. Environmental conditions are seen as one of the most important areas for this improvement.

Temperature, moisture, light, media/pH/nutrient levels have previously been identified as critical to improving germination:

This report is concerned with temperature, moisture and light only. Work funded by the Horticultural Development Council (Finch-Savage et al 1991a & b) on germination of bedding plants identified a number of species of special concern including Primulas. In addition, many growers are known to have experienced problems with Pansies in the previous 2 years, thought to be due to high summer temperatures.

Recent work (Finch-Savage 1991) on bedding plant species identified as having germination problems concluded, "there is only limited potential for bedding plant seed treatments to eliminate the effects of non-optimal environmental conditions likely to be experienced in seedling production practice". It is clear that, in order for growers to improve germination percentages and to maximise the number of usable plants, work should look at the optimisation of environmental conditions. Traditionally, seeds have been germinated in the greenhouse where the grower has little influence over the conditions, the seed and young plants will experience. It was recognised by Stoutemyer and Close (1946) writing on both cutting and seed germination that:

"Insulated opaque structures offer many advantages in the rooting of cuttings if suitable artificial light can be supplied at reasonable cost. Accurate temperature control is assisted at all seasons of the year and the cost of heating is greatly reduced. The humidity can be maintained at a high level without mechanical apparatus. The construction cost of such structures can be relatively low and space can be saved by the vertical tiering of the plants, since artificial light sources are used. Light of any desired spectral quality may be

applied and also the periods of illumination may be regulated precisely."

This statement equally applies to the production of seedlings. Carlson et al (1992) observed in America the increasing use of controlled environment chambers for germination and early growth to provide the desired light, temperature and humidity levels regardless of outside conditions.

2. THE EXISTING SYSTEMS

A wide range of different names are used within the literature to describe facilities presently used for germination and growing on of seedlings. In order to avoid confusion, the following summarises the important features and the names adopted in this review.

2.1 Germination Room

An enclosed, insulated space from which light is excluded but in which temperature can be controlled, the structures being large enough to allow the grower to enter.

[This is called in America a 'Sweat Chamber' (Koranski and Laffe 1985)]

2.2 Germination Cabinet

Is identical to a germination room except that access is only possible to the grower standing outside.

Both these facilities can have light added for those species which require light for germination. Seedlings must be removed rapidly from both units on germination to avoid excessive elongation of the seedlings (Koranski and Laffe 1985 and Anon 1987).

3) Growth Room

This is a facility used for research purposes in which light, temperature and humidity can be accurately controlled, the structures being large enough to allow staff to enter. (Evans 1959.) This is termed a Growth Cabinet or chamber in some of the literature (Anon 1987). In this review Cabinet is reserved for units which can only be accessed from outside and Room for those large enough to enter. Chamber is used as an embracing term to describe aspects common to both systems.

4) Growing Room

This is a commercial facility in which sufficient light, heat and humidity are

maintained to grow a crop to a commercially acceptable standard. The stage at which the crop is removed, ie developed seedling, finished plug or finished box is not important. This facility is unfortunately termed a Growth Room in America (Mastalerz 1985). The key difference between this and a lit Germination Room or Cabinet is the ability to leave plants in the room without excessive elongation. Access is possible. There are two variations on the growing room, the tiered-bench growing room and the linear growing room (Anon 1987).

The tiered room uses benches with the lights placed directly above each bench. With the linear room, only a single layer of plants is grown and one set of lights used.

5) **Growing Cabinet**

This is as for a growing room but access is not possible to staff.

6) **The Linear Rig (Anon 1987)**

This is a mobile unit which is placed over an area of plants or seedlings to provide replacement lighting sufficient to improve growth compared to conventionally raised seedlings. Because the rig is used in the glasshouse, no specific control of temperature and humidity has been designed to accompany the system. Thus, there is no possibility of manipulating temperature and humidity other than by altering that of the greenhouse.

3. THE NEED FOR A REVIEW

3.1 Introduction

Many growers and researchers have identified the potential benefits of artificial structures for improving germination and manipulation of the environment, but no single blueprint exists as to the most suitable cost effective design for the commercial grower producing plugs. Furthermore, the advent of the plug and "Danish" trolley has altered growers' perceptions for the need for growing rooms.

3.2 The Vertical Lit Growing Room - A New System?

The development of the "Danish" trolley has allowed growers to place their plug trays directly on to a highly mobile unit which they can move in or out of the growing room. This has immediately altered the basic design requirements of the growing room. No longer is it easily possible to fit lights above each bench.

One system used in America involves mounting the lights vertically (Koranski and Laffe 1990). This system has been adopted by at least 2 growers in the UK. However, it raises a number of questions which this review investigates:

1) What effect does moving the direction of light source have, and how well does the light penetrate?

2) How does the use of Danish trolleys affect air movement?

In attempting to answer these questions for individual growers, it became clear that a number of fundamental questions also needed asking if a truly viable unit or units were to be produced.

1) How much light is needed or, alternatively, how little is necessary to produce an acceptable seedling (without excessive etiolation)?

2) How much light is needed just to chit the seed?

3) Where should the light be placed?

4) What light source is the most appropriate?

In addition the questions about lighting, other fundamental questions need to be answered:

1) How carefully does temperature need to be controlled?

2) How important is humidity control?

4. GERMINATION OF PRIMULA AND POLYANTHUS

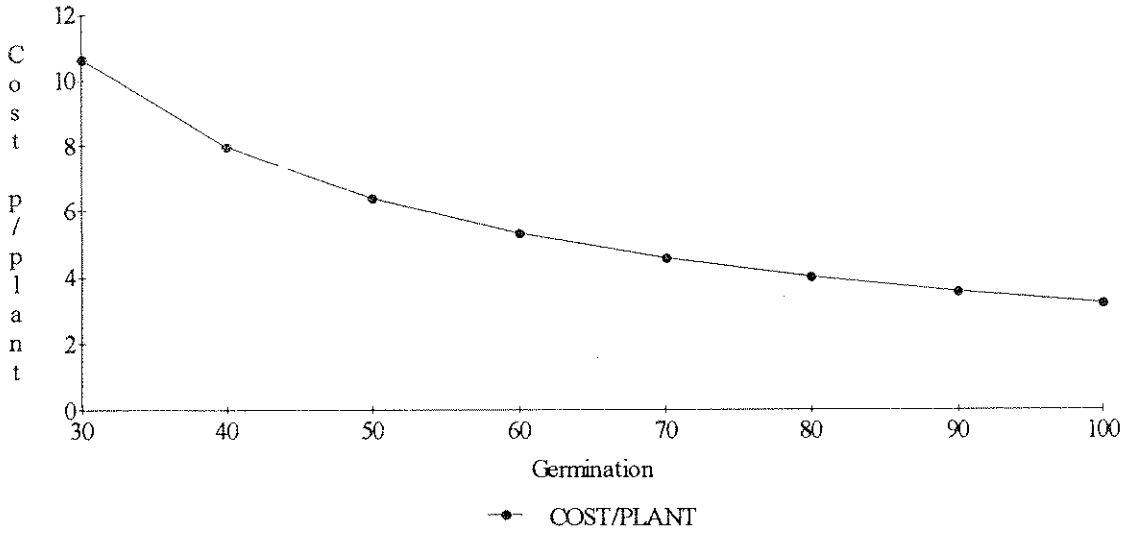
4.1 Introduction

A number of Primula species (*Primulaceae*) are important in UK cultivation grown as bedding and pot plants. This review has been restricted to the most important species, commonly referred to as primroses (Primula) and polyanthus. The primrose *Primula vulgaris* (syn. *P.acaulis*) and polyanthus *P.x polyantha Hort.* a hybrid of *P.veris*, *P.elatior* and *P.vulgaris* (Hammer 1985) have seen an increase in popularity world-wide. Although a popular crop, margins are relatively small and seed costs expensive at around £36/gram, depending on variety. Thus, for every percentage loss of germination, costs rise See Fig. 1. Figures as low as 20-50% for germination are not uncommon (Bruening and Koranski 1990). Experience of UK advisers in ADAS is that germination rates are commonly in the range 60-90% with some growers having rates significantly lower.

Figure 1

PRIMROSE PALOMA

Cost p/plant seed against % Germ



4.2 Value of UK Production

No published data is available on the numbers of primula and polyanthus grown in the UK. However, based on information supplied by a major plug producer, the following figures have been derived:

Total weight of primula seed sold - 133.3kg
Assume 1071 seeds/gramme (Linwick 1992)
Therefore approximately 142 m seeds are sold in the UK each year.
Assume only 70% germinate and are pricked out as usable plants gives 99.4 m. plants.
Further assume a total of 10% wastage in production and marketing.
This leaves 89.46 m. plants.
Given an average value of 29p per plant, then the total value of production equals £25.9 m per annum.
The total value of primula and polyanthus seed sold is estimated to be £4.8 m (based on value of £36/gramme).

The cost of a plug primrose is around 20-25% of the finished product and the cost of seed around 15% at 55% germination. The smaller grower is commonly advised to "buy in" young plants of primrose and polyanthus as the seed costs at low seed germination rates outweigh the additional expense of plugs.

4.3 Primula Seed Physiology

The *Primulaceae* are classified as having axillary linear embryos (Atwater 1980, Ellis et al 1985b). This group of endospermic seeds are characterised by the following morphological features:

embryo	-	linear in a central axillary position
cotyledons	-	minimal, thin, narrow and shorter than the stalks
endosperm	-	occupies half or more of seed and surrounds the central embryo
seed coat	-	thin, reticulous or fibrous; may be semi permeable
seed size	-	medium-large, 3-10mm long

In general, seeds in this group require embryo development before germination can occur. The use of potassium nitrate, light and Gibberelin may accelerate embryo growth in this group of seeds. Moderate temperatures 20°C are

optimal for most species.
Viability tests (using tetrazolium) have shown up to 95% of embryos are viable before planting (McNertney et al 1992).

4.4 Temperature and Germination

Temperature is recognised as the key factor in germination of primula (Bruening and Koranski 1990), high temperatures (over 20°C) are often stated as leading to failure of germination. Sowing of these species is commonly carried out in June and July when temperatures in the glasshouse frequently exceed this level. Temperature controlled stores or germination rooms are recommended for June and July sowings or, alternatively, seed may be germinated in a well ventilated, shaded building and covered with damp peat or shade material (Anon 1986).

Commercially, many growers germinate these species in a shed with little or no direct control of temperature. A few growers in the UK have adopted germination or growing rooms to allow more accurate control of temperature.

In order for growers to maximise the benefit of growing rooms, it is essential they have target temperatures. Bruening and Koranski (1990) report that American growers are urged to use temperatures in the range 59 to 62°C (15-16.7°F).

Table 1

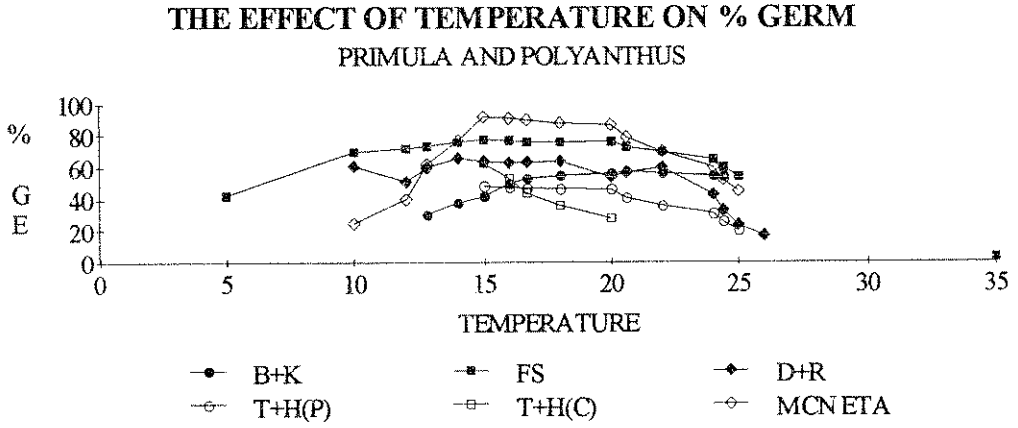
Common recommendations in the commercial literature

	Recommended Temperatures		Maximum Temperatures	
Source	°C	°F	°C	°F
ADAS (1986)	17	62.6	20	68
Linwick (1992)	15.6-18.3	60-65	20	68
Koranski (1990)				
Stage 1 (radicle emergence)	16.7-20.	62-68	-	-
Stage 2 (stem and cotyledon emergence	15.6-18.3	60-65	-	-
Colegrave (Anon)	17-20	62.6-68	-	-
Breeders Seeds	15-18	-	18	-
Hamer	15-18	-	-	-

From Table 1 it can be seen that there is a degree of uniformity as to the maximum temperatures used but that there is a relatively wide range of temperatures recommended.

Detailed study of research work carried out (Bruening and Koranski 1990, Dotterweich and Röber 1988, Finch-Savage et al 1991a, Turner and Heydecker 1974 and McNertney et al 1992) produces a similar picture of response to temperature (see Fig. 2). Broadly, there is an optimum of 15 to 20°C for the varieties tested under ideal conditions using laboratory germination facilities. It is however notable that, when the same treatments were repeated with compost, the germination percentage was depressed. At 20°C compared to 15°C, germination was 34.5% lower for those seed sown on the surface. Such a significant reduction in germination would be unacceptable commercially. Similar indications can be found in the work by Finch-Savage (1991) although unnoted.

Figure 2



Bruening and Koranski 1990 (Yellow Pageant), Finch Savage et al 1991 (Improved Biedermier, Dotterwich and Rober 1988 (Blutenkappchen), Turner and Heydecker 1974 (Polyanthus various), McNerty et al 1992 (cvs not stated),

A number of organisations have produced recommendations for temperatures for seed testing purposes, summarised by Ellis et al (1985) ranging from alternating 20/30°C regime (ISTA 1985) to 15°C (AOSA). Work done by Atwater (1980), based on work at the Ransom seed laboratory, suggests a temperature of 20°C. Ellis et al (1985) suggest the most successful regimes for *Primulaceae* are 15-20°C; 10-30°C or 20/30°C. Such treatments are usually carried out on paper media.

4.5 Effect of Alternating Temperatures

Of the work reviewed, only Turner and Heydecker (1974) studied the effect of alternating temperatures. There was no significant benefit from alternating temperature between 15 and 20°C every 12 hours in terms of percentage germination. A lower temperature, ie 15°C, tended to counterbalance a higher one of 25°C compared to a 20-25°C alternating regime. Germination was generally as rapid with a 15-25°C regime as a 15°C one.

4.6 Speed of Germination in relation to Temperature

Data from studies relating to temperatures all found the optimum to be 20°C.

4.7 Affect of Light on Germination

The *Primulaceae* are classified as endospermic seeds with an axillary linear embryo (Ellis et al 1985). Species in this group may require light to hasten germination (Atwater 1980). It is often indicated that light is a requirement for germination of primula (Hammer 1992). Finch-Savage et al (1991a) found, for the variety cv Improved *Biedermier*, a positive effect of light even at the optimum range of temperatures of 15-20°C. Germination was increased by about 18% in the lit treatment. McNerty et al (1992) also found an increase of 10 - 15% for seedlings which were lit to an irradiance of 1076 - 4304 lux. Conversely, no effect of light was found on the varieties of polyanthus tested by Turner and Heydecker (1974). However, they may have supplied sufficient light when undertaking recording. It has been shown (Ellis et al 1989) that doses of light as low as $4x10^{-6}$ mol m-2 d^{-1} can stimulate germination in certain species. A unit producing 1 Wm^{-2} at seed level would provide $2.94x10^{-4}$ mol m-2 d^{-1} if switched on for just 60 seconds a day.

No other comparative data was found for those species concerned in this report. Work by Thompson (1969) and Cathey (reported by Hammer 1992) show a positive effect of light on all of the species of *Primulaceae* they looked at. Unfortunately, they did not look at *P.vulgaris* or *P.polyantha*.

4.8 Seed Covering

Growers are generally advised not to cover the seeds of these species except under hot weather (Anon 1986) or, if covered, to use a medium grade vermiculite (Colegrave). It has been shown (Farthing 1988) that increasing the depth of vermiculite by more than 1-2mm to 5mm leads to a significant reduction in germination. No benefit was gained comparing the covered and uncovered treatments. Coarse grade vermiculite was found to provide the most satisfactory covering material.

Covering with sand or compost had been shown to reduce germination rates by a significant amount compared to no covering (Turner and Heydecker 1974, Farthing 1988).

4.9 Effect of Compost Moisture

Only two experiments were found on the effects of moisture on germination of primula. Koranski and Kessler (1992a) categorise primula as requiring a dry compost for optimum germination. Dry is defined as a media with virtually no added moisture either before or after sowing. They state that as little as a 1% change in oxygen may be harmful to sensitive plants such as primula. Wet media is defined as "saturated so that it glistens and is wet to the touch".

Finch-Savage (1991) presented limited data on the effect of moisture and temperature on germination. At high temperatures (25°C) germination appears to be optimum at compost moisture contents above 50%. A similar if less clear pattern seems to be true as temperature decreases to 15°C. Optimum germination was achieved in the compost at 15°C and 100% compost moisture content (equivalent to a water potential of <0.005 MPa).

Turner and Heydecker (1974) found that a mist treatment improved germination where seed was covered but had little effect where seed was kept uncovered, compared to plants covered with polythene only.

4.10 The Effect of Gibberelins on Germination

Primulas belong to a group of species which are known to respond to applications of Gibberelins. A 400 ppm treatment with GA_3 is recommended by Atwater (1980) to improve germination. Only a limited amount of work has looked at the effect of Gibberelins on germination of *Primulaceae*. Recent work (McNertney et al 1992) found a benefit of a 24 hour soak in a GA solution up to 500 ppm. The main benefit was an increase in rate of germination compared to dry seed but at 700 ppm the rate and percentage germination decreased. At low or zero rates (the data is insufficiently clear to determine which) there was virtually no benefit in the percentage final germination. A gain of approximately 10% was achieved over dry seed. This may indicate some benefit of pre-soaking seed for 24 hours. A similar effect (although not statistically significant) of pre-soaking seed for 2 days was found by Bruening and Koranski (1990) compared to non soaked seed.

A series of papers by Finch-Savage and co-workers (1991) details the results of experiments on plant growth regulator treatments and priming. In the first

experiments

(Finch-Savage et al 1991b) showed again the benefit of a 10^{-4}M and 10^{-3}M $GA_{4/7}$ soak for seeds germinated in the dark but the light control still out performed both treatments. When combined with other priming treatments, no benefit was gained of the $GA_{4/7}$ compared to the lit control.

Subsequent experiments Finch-Savage et al (1991a) found that applications of $GA_{4/7}$, applied as a soak for 48 hours at 5°C improved germination in the dark but did not affect those germinated in the light. Finch-Savage (1991c) found a positive benefit once more of treating with $GA_{4/7}$ in the dark even at 10^{-5}M. Adding the $GA_{4/7}$ to a priming solution of Polyethylene glycol (PEG) proved more effective than a pre-soak treatment with $GA_{4/7}$. The best treatment was found to be a combination of oxygen enriched priming with $GA_{4/7}$ at 10^{-5}M. This gave both higher seedling emergence and faster emergence compared to untreated seed. Under non optimal conditions, the treatments, whilst improving germination, did not prevent a decrease in the germination rates. It was concluded that such treatments have limited benefit to eliminate the effects of non optimal treatments.

Miller and Holcomb (1982) found no effect on germination percentage or rate of GA_3 on *Primula vulgaris* but a significant increase in both rate and percentage germination for *Primula polyantha* at 250 ppm GA_3. Seeds were soaked for 21 hours in a 0, 150, 250, 350 ppm GA_3 solution.

4.11 DISCUSSION AND FURTHER WORK

Primula seed represents an important part of the cost of primula production and is in itself expensive. Many growers achieve less than optimum levels of germination even though the seed can have the potential to give 95% germination rates.

Key factors highlighted by this literature search:

Temperature, Light, Moisture.

4.12 Temperature

Primula seed is usually sown during the summer when temperatures typically reach super optimal levels. Broadly, there is a common relationship between temperature and percentage germination in the experiments looked at. Optimum germination occurs between 15-20°C with a decline in percentage germination either side of these temperatures. However, the majority of this work has been done in petri dishes on moist paper. There is limited evidence that in compost the optimum may be nearer 15°C than 20°C. Future work should investigate the effect of compost temperature on germination and be carried out with a broader range of temperatures in order to determine the complete shape of the curve and the optimum speed of germination. If it is found that in compost the optimum germination percentage is below 20 then it becomes even more important that in summer at least some form of cooling is used.

There is however evidence from work with other species of bedding plants. Ellis (Personnel Communications) that many species respond to alternating temperatures giving higher levels of germination compared to single temperature regimes. Facilities now exist to test the effect of a broad range of alternating temperatures. The use of a lower temperature for part of the 24 hour period may be beneficial in saving energy and increasing percentage germination.

4.13 Light

There would appear to be a clear and unarguable case that light benefits germination in *Primula vulgaris* but possibly not polyanthus hybrids. Unfortunately, no consistent approach as to level of light has been adopted. Levels vary from 12,750 lux to 1,076 lux. As will be discussed elsewhere in this report, for some species it has been found that high light levels inhibit germination. Further work should assess the optimum level of light for germination.

No data was found on the specific effects of light levels on growth and development immediately post emergence.

4.14 Moisture

The limited extent of trials data suggests this area is worthy of deeper investigation at greater length, given the trends picked up contra to the recommendations of Koranski and Kessler (1992).

4.15 CONCLUSION

In general, work on primula and polyanthus germination has been sporadic, leading to uncertainty as to optimum temperatures, lighting, and compost moisture. A systematic approach could help to resolve some of the problems highlighted.

Raising seed germination rates by just 10% equates to around £480,000 a year saving to the industry. For an individual grower, raising germination from 50% to 60% saves £10.39 per 1000 plants or 3.25% of crop value at 32p per pot. For a grower producing a 100,000 plants, raising germination rates from 50% to 80% represents a saving of £2,339 a season on seed only (excluding bulk order discounts).

4.16 Recommendations for Primula

1) Provide light during germination of Primula.

2) Avoid temperatures over 20°C for prolonged periods.

3) Avoid covering seed with sand or compost.

4) When covering with vermiculite avoid depths of greater than 1-2 mm.

5. GERMINATION OF PANSY

5.1 Introduction

The last 20 years has seen the rise in the scale of production pansies to a point where it now dominates autumn bedding plant sales.

The current garden pansy is the result of extensive breeding carried out in Britain and Europe since the beginning of the last century. Due to the complexity of crosses with other viola species the name *Viola wittrockiana* was proposed in 1925 as a collective name for garden pansies (Crane 1951).

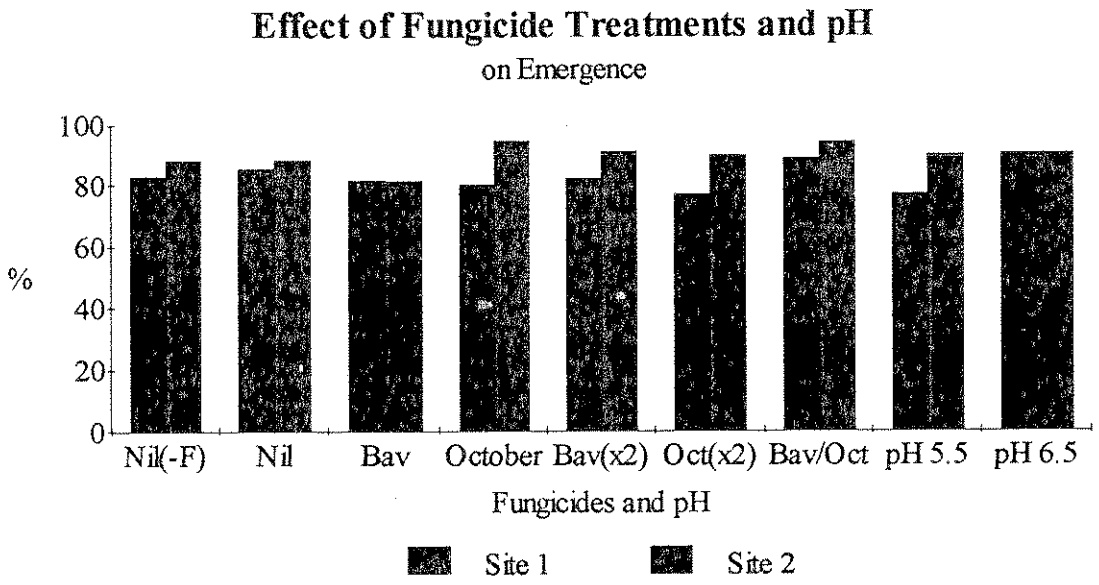
5.2 Value of UK Production)

UK sales of pansy seed was estimated in 1991 (Krause 1991) at around £5m at grower level, with 200 kg of F_1 hybrid seed and 2 tonnes of open pollinated seed sold. The above data was based on a survey of seed companies (Krause personal communications).

With each gramme of seed containing approximately 700 seeds this equates to 140 million F_1 pansies and over 700 million open pollinated pansies. Allowing for wastage and poor germination of around 30% for F_1 seed this will still give some 98 million plants. Typically pansies in pots fetch 25 pence and F_1's in tape trays about 15 pence each. This would suggest a value around £22 million. Open pollinated plants are worth about 5 pence each, and assuming 70% usable plants this equates to some 12.25 million trays of 40's or £25m. This latter figure seems on the high side as the industry is currently only valued at around £10 million per annum.

A small ADAS survey of growers found on average, growers reporting 89% germination rates. This ranges from claimed germination rates of 100% by several growers down to 60%. Results from ADAS trials on fungicide found average germination rates as in Figure 3.

Figure 3



5.3 Pansy Seed Physiology

The *Violaceae* are classified as axial foliar embryos with thin, mucilaginous seed coats. (Atwater 1980, Ellis et al 1985 b). This group of non-endospermic seeds are characterised by the following morphological features:

embryo	-	spatulate or beat and fills most of seed covering
cotyledons	-	large, thickened and dominant over the stalk
seed coat	-	this may exude mucilage (when wet or contain a mucilanginous thin layer within seed size - small-medium 1-6mm long.

In general as the seed absorbs water the coat becomes impermeable to oxygen and other gasses. The use of potassium nitrate and gibberelins may accelerate germination. Seeds may be sensitive or insensitive to light. Temperatures of 15-20°C are most beneficial or alternating temperatures of 15/25°C or 10/30°C.

5.4 Temperature and Germination

Germination is frequently stated to be best at "cool temperatures". Cathey (1976) gave the optimum temperature as 65°F (18.3°C). Carlson (1992) recommends 63-68°F (17.2-20°C) as do Koranski and Polking (1991).

Styer and Laffe (1990) suggest optimum germination can be obtained anywhere between 62-78F (16.7-25.6) but above 80°F (26.7°C) germination will be reduced. They claim once radical emergence has occurred temperatures should be dropped to 68-75°F.

These impirical observations would appear to be supported by research by Cushman et al (1990) who found 92% germination of Crystal Bowl Yellow at 18°C but only 80% at 30°C. Unfortunately only two temperature treatments were used. However, work by Koranski (1990) casts doubt on this consensus. Primed and non-primed seed of Universal Blue was compared at four temperatures (59°F, 66°F, 73°F and 80°F). An optimum of 80°F (26.7°C) was found (79% germination) compared to 54%, 76%, and 68% for 59°F, 66°F and 73°F respectively.

Germination was also found to be more rapid at 80°F compared to all the other treatments.

The work by Koranski unlike that by Cushman et al (1990) was carried out on compost rather than on filter paper. Koranski germinated the seeds in a controlled humidity environment.

Further work by Koranski and Kessler (1992b) suggests there may be an inter-relationship between temperature and moisture with a dry regime at 75°F and performing wet or moist requires at the same temperature. Increasing moisture made the seedlings more susceptible at higher temperatures.

Work by Cathey (Reported by Holcomb and Mastalerz 1985) on the variety Lake of Thun found a double peak at 65°F. When germination occurred in the dark, no such peak was found in the light treatment. In the light an optimum of 60°F was found.

5.4.1 Effect of Light on Germination

Both Cathey (1976) and Carlson et al (1992) recommend germinating seed in the dark as do most commercial seed firms.

The only data found to back this recommendation up was done by Cathey (1985) on the variety Lake of Thun. Cathey found that there was a reduction in a germination of around 12% but that the optimum was at a lower temperature (60° F) and no double peak was observed.

5.4.2 Effect of Compost Moisture

No clear or consistent results were found in the literature as to the optimum level of moisture for pansy germination. This is best highlighted by Koranski and Kessler (1992a & b) publishing work which directly contradicts itself. They state (1992a) that pansy has a requirement for moist compost but (1992b) they found "pansy seed germinated best under the dry regime". Under the dry regime they found a higher percentage germination, larger roots and greater root hair development. Styer and Laffe (1990) on the other hand suggest moisture levels should be high (95-100%) until radical emergence. At this point it is critical to reduce the moisture to 75-80%. This substantiates that if pansies are kept too wet for too long total after radicle emergence? germination will be reduced very erratically.

5.4.3 Discussion and further Work

The relatively high germination rates reported indicate that pansies are, relatively easy to germinate. However, there is room for improvement among growers achieving sub optimal levels.

The broad range of temperatures producing optimum or near optimum germination makes clear recommendations difficult to make. Both light and moisture appear to have an interaction with temperature. The work by Cathey (1976) many years ago needs to be substantiated by further work using modern varieties using similar systematic evaluation with a broad range of temperatures in both light and dark.

The most likely explanations of poor germination appear to be extremes of

temperature below 60°F and the presence of light. The latter is surprising as *Violaceae* are believed to be either insensitive to light rather than inhibited by light. If there is such a profound effect of light at even low levels then it may make it unwise to germinate pansies alongside primulas. Further investigation should be made to establish at what level of light this response is triggered. The broader breadth of optimum temperatures is less of a problem provided a temperature at the higher end of the primula range is chosen ie 18-20°C.

6. LIGHT - PRINCIPLES

6.1 Introduction

All seedlings show developmental responses to light associated with the transition from a seedling to a young plant with photosynthetic leaves (Kendrick & Frankland 1976). Light has two important roles in the germination of and subsequent growth of young plants that will be dealt with in this report.

(1) to effect germination;

(2) to effect growth and development.

The commercial grower when using a growth room can affect both these factors by altering the quality and quantity of light provided.

6.2 Light for germination

Critical data for individual species is seldom available on suitable light regimes (Ellis et al 1985). Species have been classified into 3 groups, those were

(a) germination inhibited by light;

(b) germination promoted by light;

(c) germination unaffected by light.

This is an over-simplification as they report that many species which germinate at low light levels may be inhibited by higher light levels for prolonged periods. Furthermore, the actual response to light may depend on the seed lot, storage period, variation within a seed and the conditions given for germination, eg temperature. They have therefore proposed a regime which will promote germination in a broad range of species.

Although there is a large variation between minimum light for germination and inhibition, there is a sufficiently wide range over which germination is provided.

6.3 Light sources

The source of light used can directly affect seed germination by the wavelength of the light emitted. The wavelength of light affects the response of phytochrome. The main wavelengths which influence seed germination are 600-680nm (red light) which generally promote germination, and 700-760 nm (far red) which generally inhibits germination. Blue light may be both inhibiting or stimulating in a few cases (Ellis et al 1985a).

6.4 Phytochrome

Phytochrome is a photoreceptor involved in simple light detection and indirectly in measurement of light duration and occurs in two forms Pr and Pfr. Pr absorbs mainly red light (peak absorption 660 nm approximately) and Pfr which absorbs far red light (peak absorption at 720-730mm approximately).

When Pr absorbs red light, it is converted to Pfr and when Pfr absorbs far red light, it is converted to Pr. During periods of dark, Pfr will revert to Pr. Germination is promoted when Pfr levels are high, ie under a high red light to far red light ratio. Under red light the ratio of Pfr to total phytochrome is typically 0.75, compared to far red light of 0.03, and under sunlight (which contains equal amounts of red and far red light) is about 0.60.

To maximise germination, a source with a high red to far red ratio is desirable but at only a low irradiance. This rules out incandescent lamps, which emit a higher level of far red compared to red light (Anon 1987). However, fluorescent tubes, eg warm white, have a greater output in the red spectrum. Ellis et al (1985a) propose a level of 1 W/m^2 for 8-12 hours a day (approximately 370 lux) for maximum germination (0.14-0.21 $mol/m^2/d$). Ellis et al (1989) showed that such levels would be suitable for 3 genera of *Compositae* but that further work is required to extend their knowledge for species from other families.

For those species which germinate in the dark, exposure to far red light can also inhibit germination. Where light is known to inhibit germination, light treatments should be avoided.

Ellis et al (1989) have shown that high irradiances can, if given for continuous

periods, inhibit germination. (This is termed the HIR) Irradiances greater than 1 mol m^{-2} d^{-1} and inhibited germination of *Lactuca serriola*. Increasing the photoperiod also inhibited germination, presumably due to the increase in irradiance.

6.5 Discussion

Light plays a central role in germination for many species in maximising germination rates. It is desirable therefore that all germination units should be supplied with light. The best source of light available is produced by warm white fluorescent tubes.

Recent work has highlighted that there is insufficient data to be categorical about species requirements. Ellis et al (1985 a) have therefore suggested a single level of 1 wm^{-2} per 8-12 hours per day which will be promotary for most species. Given greater understanding of the sensitivity of species to light it would be desirable to re-evaluate Cathey's work (reported by Holcomb and Mastalerz 1985).

6.6 Light, Growth and Development

Growers aim to produce a short, stocky plant which can easily be handled. Keeping plants in the dark leads, in many species, to excessive elongation. This may either be due to hypocotyl or internodal elongation (Kendrick & Frankland 1976). In many dicotyledons, eg Sunflower, shoot extension occurs in the hypocotyl, which forms a hook, and is inhibited by light. The light causes the hook to unfold and the cotyledons to expand. In some species, eg Pea, extension is the result of internode elongation. Light inhibits first internode extension but promotes extension of later internodes, causes the hook to unfold and promotes expansion of the leaves. In order to avoid excessive elongation, light needs to be provided.

Lighting has two important components affecting plant growth:

(a) Quality

(b) Quantity

6.7 Light Quality

Light quality is a measure of the spectral output of a light source and, in particular, in horticulture the effect that it has on plant growth and development. It has already been noted that the absence of light leads to excessive elongation, as with the seed germination this is in part a phytochrome mediated response (Moe and Heins 1990). Plants kept in the dark only have Pr present, whilst those kept in the light have 80% Pfr. The presence of Pfr results in shorter plants, ie less etiolation, than those with a high Pr level. Moe and Heins (1990) claim (although no reference or data is shown) that this response is satisfied by 1-2µmol/s/m². If this is the case, then this figure is of the same order of magnitude with those for optimum germination (Ca<5 µmol/s/m²). Further data on the duration of the response time would be of value. This would be of particular use in evaluating plug storage treatments.

6.8 Light quality in relation to light source

The two main candidates for use as light sources for use in growing rooms are (1) incandescent lamps and (2) fluorescent tubes. Incandescent lamps have a lower red to far red ratio than fluorescent lamps. Thus, for germination, incandescent sources are not suitable as they increase stem elongation (unless this is considered desirable). In addition, the fluorescent lights will tend to reduce petiole etiolation, and increase lateral branching (Erwin and Heins 1992).

Canham (1966) argued that at low light levels red light inhibits elongation more than blue, but that at higher levels the reverse is true, the point at which they cross over being critical intensity. Plants may be categorised into two groups - those with a high critical intensity and those with a low one.
Canham (1966) noted that it is also the order in which plants "see" the light which affects the response. Thus, if it "sees" far red light last before darkness then the plants will etiolate, whereas if it "sees" red light it will not.

6.9 Blue Light

Blue light is known to be involved in stem elongation (Canham 1966). Canham (1975) showed that adding blue light, from blue fluorescent tubes to sources low in blue light, ie SOX (low pressure sodium) lamps gave results equal to

those for 12W fluorescent tubes alone for Tomato and Lettuce. Under SOX only both Tomato and Lettuce seedlings showed stem elongation and leaf epinasty, although dry weights were higher than for fluorescent tubes. The maximum effect of blue light was achieved by adding between 4 and 6W/m^2 for the duration of the trial (approximately 10-20% of the visible irradiance). Shorter periods gave little benefit. Nor was it possible to use the blue light as a night break treatment.

Mercury sources, eg MB/u and HLRG (high pressure mercury) produced poor, spindly plants which grew more slowly. The high pressure sodium lights (SON) gave poor results for Lettuce with straggly plants and long, narrow leaves. This was however countered to some extent by the addition of blue light, but did not appear as promising as that for SOX plus blue light.

Unfortunately, Canham did not investigate the effect of combining blue and white fluorescent tubes. Stoutmeyer and Close (1946) reported a beneficial effect of combining blue light with "3500 degree white tubes" but did not go on to establish the best combination.

6.10 Light Quantity

Most designs of growing rooms with light have attempted to provide sufficient light to grow the crop to a state of maturity or semi-maturity. Thus light levels between 20 and 40wm^{-2} have been recommended (Anon 1987). (Higher light levels are used for research purposes but are not of practical interest to most growers). Light levels of 20-40 wm^{-2} represent a considerable investment in lights and running costs for electricity and have not widely been adopted by growers. However lower levels of illumination to stop elongation would be considered desirable by many growers wishing to germinate seeds in a germination room.

Recent work on plug storage (Anon 1992) has illustrated that elongation can be reduced by the addition of relatively low levels of light (50-500 lux) at low temperatures. Erwin and Heins (1992) have established a relationship between increasing irradiance and stem height and branching, in geraniums. Thus at light levels over 10,000 lux plants are more compact and stocky. Unfortunately no indication is given as to what temperature was used for the light experiments.

6.11 Discussion

Having germinated and achieved stem emergence the grower has a number of choices,

(1) To remove seedlings immediately

(2) To provide sufficient light to grow healthy plants to "maturity"

(3) To hold plants without etiolation whilst allowing following seedlings to emerge.

In order to maximise germination it is desirable to hold the seedlings in the germination room until all usable seedlings have emerged. However if no light is provided the seedlings rapidly stretch and become unusable. The addition of relatively high levels of light will prevent this but as has been indicated may be detrimental to some species. Therefore a third way is needed ie lower holding levels. Unfortunately little work has been carried out to establish accurate levels for bedding plants where grown at normal temperatures. Information on plug storage and work by Moe and Heins (1990) suggests low levels may be tolerated but further work is required. Clearly if lower levels are possible these savings may be made in the number of lights needed and electricity use plus improved germination.

As with germination there is good evidence to recommend the use of fluorescent tubes as the primary light source, as they contain an optimum balance of red to far red. In trials by Canham (1975) they gave better results compared to average of other light sources. However some desirable affects may be gained by combining white and blue tubes and this requires further investigation.

6.12 Recommendations on Lighting

(1) Quality of fluorescent tubes of light is required.

(2) Examine the light requirement of a broader range of species including re-examining the work by Cathey.

(3) Establish at what light level(s) etiolation is reduced.

(4) Investigate the benefit of combining blue with white fluorescent lights.

7. THE EFFECTS OF COMPOST MOISTURE ON GERMINATION

7. Introduction

The control of moisture available to the seed may be the most important component of germination (Koranski 1992). In a greenhouse environment the grower can influence compost moisture in two ways by:

(1) The amount of water applied to the compost pre or post sowing; and

(2) Controlling evaporative loss from the compost.

Within a glasshouse the grower has less control over the degree of evaporative loss from the compost than in a germination room. In the glasshouse there are two important factors influencing evaporative loss from the compost:

(1) Relative humidity;

(2) Temperature;

both of which are difficult to control in a greenhouse environment.

7.2 Experimental Work

Work by Koranski and Kessler (1952a) has shown that the more accurate the control of moisture levels the greater the percentage of usable seedlings. In an uncontrolled environment they obtained 69% usable Impatiens seedlings, as opposed to 84% in a controlled moisture environment Impatiens. In addition, water particle size also influenced germination. Koranski and Kessler (1992b) found reducing particle size from 500 microns (handwatering) to 15 microns (fog) increased both percentage germination and speed of germination in Petunia.

Furthermore, they went on to classify bedding plant species by their soil moisture requirements. Pansy was found to favour a moist (medium) regime at 65°F and a dry regime at 75°F (Koranski and Kessler (1992b). However, Pansy in another paper is classified as favouring a moist regime by Koranski and Kessler (1992a), whereas Primula is said to favour a dry regime (dry is

defined as a media with virtually no added moisture before or after sowing). Unfortunately, little or no methodology or results are presented to support this claim.

Soil moisture content has been shown to have a negative linear effect on the percentage germination for Spring Wheat (Khah et al 1986) and Onions, except in very dry soils (Wheeler and Ellis 1992). No interaction in Onion germination was found between temperature and soil water content. The rate of emergence of seedlings was unaffected by soil moisture above a critical value (7.6% ≡ -0.15 MPa) with germination percentage optimum at 5.5% ≡ -1.0MPa.

In Spring Wheat germination percentage declines more rapidly above 18% soil moisture content. Karlovich et al (1992) suggested that at water potentials as high as -0.1MPa Impatiens germination is delayed and -0.6MPa completely inhibited germination.

Work by Finch-Savage (1990) and Finch-Savage and Phelps (1993) on vegetable crops established a critical period for soil moisture in relation to radical growth. Once the seed has come into contact with the moist soil there was a rapid imbibation of water and, within a matter of hours, come into a long phase of moisture uptake. Seeds can be held in this stage for extended periods without harm. However, if moisture levels fall below a given level, deterioration can rapidly occur. Once radical emergence occurs, there is a rapid uptake of water. It is at this stage that most seedling losses occur and lose desiccation tolerance.

7.3 Discussion

In the experiments by Khah et al (1986) and Wheeler and Ellis (1992) soil moisture levels were obtained by applying a pre-determined amount of water to a soil of a known soil moisture content and placed in a sealed container. The use of a sealed container is analagous to the practice of shrink-wrapping "Danish" trolleys to seal in moisture. This could form the basis of one system, provided the correct moisture content of the dry peat and the desired moisture content is known and the appropriate amount of water applied. Work by Finch-Savage on field vegetables may provide greater information on the timing of water application in relation to germination. A lack of water at a critical time, ie just at or before radical growth may delay germination. Often with

germination rooms, trays are removed once the first few seedlings emerge, but when others may be at a critical stage. The sudden reduction in relative humidity could then lead to a reduction in soil moisture and so delay germination and widening the spread of emergence. Thus, the longer the seedlings are kept at the optimum soil moisture content the greater the percentage germination and the narrower the spread of germination. Conversely when a seed is desiccated during the germination process, the timing and co-ordination of metabolic events is disrupted. The result - poor and irregular germination (Karlovich 1992).

It has been found that increasing soil moisture above a critical threshold reduces percentage germination for Onion and Spring Wheat. No specific work was found on bedding plant species. However, it has been observed that the oxygen/water balance is critical in the early stages of germination (first 8-12 hours), with changes of as little as 1% being harmful to Primula (Koranski and Kessler 1992a). Unfortunately, no experimental data is given to back this conclusion up.

7.4 Further Work

Research is required to establish the soil moisture contents for optimum germination in a broad range of bedding plant species. The current impirical approach adopted by Koranski and others, whilst apparently grower friendly, lacks repeatability. No two growers are likely to judge wetness and dryness the same. Studies similar to those by Wheeler and Ellis (1992) should be undertaken.

If a clear range of soil moistures could be identified then suitable systems should be investigated to produce these.

Work is required to establish the critical moisture levels for each phase of seed germination. In order to establish what, if any, need there is to alter compost moisture levels during germination.

8. EFFECT OF ATMOSPHERIC HUMIDITY ON SEEDLING DEVELOPMENT POST EMERGENCE

Once seedlings emerge, humidity can affect a number of physiological processes, (summarised by Grange and Hand 1987). The loss of water from leaves is governed by the vapour pressure gradient from leaf to air, and mainly depends on the VPD of the air.

In principle, the following effects have been found:

(1) At humidities between 1.0KPa and 0.2KPa VPD (55-90%RH) there is little effect on physiology and development of horticultural crops.

(2) At levels below this, water stress occurs so reducing growth.

(3) At levels above 90%, growth disorders and diseases may occur, eg stem ascination, reduced growth or death of the apex.

8.1 Experimental Work

Only one significant paper was found on the effect of humidity on bedding plant seedlings (Krizek et al 1971). Humidity levels of 40% restricted growth of Ageratum and Marigold seedlings. Raising the relative humidity to 65% led to increases in height of the main stem, fresh weight, dry weight and leaf area. Increasing the humidity to 90% gave no further increase.

8.2 Humidity control within the germination room

Precise humidity levels are difficult to obtain and also difficult to maintain over long periods of time (Tibbits 19). Estimates of typical relative humidities in uncontrolled units range from 50% to 30-80% and varying by up to ±15% depending on ambient conditions (Acock 1974). Facilities described in the literature tend to be of an academic nature and as such may be over-specified for the purposes required of a germination room.

The key function of any system used for germinating seedlings is to maintain a relative humidity (vapour pressure deficit) which prevents drying out of the compost below an as yet unknown critical threshold but avoids saturating the

compost. This is likely to be of the order of 95%. Applications of water to the compost prior to placing it in the germination room is clearly critical, in order to ensure cells start with the correct level of moisture.

8.3 Conclusion

Once the seedlings have emerged, humidities can be maintained anywhere between 65-90%RH. However, in order to obtain maximum germination, it is likely that levels around 90% will be required to ensure complete emergence. Furthermore, the difficulty of maintaining adequate compost moisture levels at low relative humidities may make it easier to maintain these higher levels.

9. GERMINATION ROOM DESIGN PARAMETERS

9.1 Objective

To provide an ideal environment for the germination of seed raised bedding plants in a plug production system to ensure the lowest number of failed cells.

9.2 The System

Cell trays are compost filled, seeded, and covered with more compost or some other medium if necessary the trays are watered and loaded onto Danish (or similar) trolleys. Once germinated the trays are placed onto heated benches or floors for growing on. Often germination takes place on the benches or floors with trays being covered with polythene or netting. The attraction of germination rooms is leaving more growing space for production, quicker emergence and most importantly more even and successful germination.

9.3 Research Facilities

Germination and growing rooms are used by research establishments to give repeatable conditions at any time during the year. Often the rooms are very sophisticated with computer control for heating, cooling, humidity light and in some cases the constituents of the atmosphere eg Carbon dioxide and oxygen. Frequently these rooms are very small because only small numbers of plants are required. A typical room may be 2 m by 2 m though some are as small as 1 cubic metre. Generally these are not termed germination or growing rooms but controlled environment chambers (cabinets). The establishments that have these facilities have formed the "Controlled Environment Users Group" for exchange of ideas. Whilst these facilities are interesting they are too complex and costly for most commercial growers.

9.4 Handling, Size, Location

The industry standard for handling is the Danish trolley. Whatever facilities are built it is essential that the design does not compromise their use, for two main reasons. Firstly, if the trolley cannot be used there is some risk of double handling either onto another handling system or onto shelves within the room. Secondly, there will be a cost penalty if another system has to be purchased.

The Dutch trolley is larger, and whilst it has better wheels it will struggle to be adopted merely because of the universal acceptance of the Danish trolley. Therefore a room design need not consider the Dutch trolley any further.

The size of the room will be determined by simple calculation. However there are a number of important factors to consider. Assuming the Danish trolley is to be used then the fit of the plug tray onto the shelves and subsequently onto benching must be considered. For example the Plantpak cell trays are all 530 mm by 320 mm which fit four onto a trolley shelf. If however a tray that size makes poor use of the glasshouse benching some of the benefit of the room will have been lost.

Having chosen a tray size the plug size must be defined, which fixes the number of cell in each tray. Coupled with the number of plants required the number of shelves can be calculated. Some allowance must be made for seeds not germinating or germinated plugs being below standard. If the spacing of the shelves is known then the number of trolleys required can be found. Shelf spacing is a compromise between maximum space use of the room, and the space between shelves. Wider spacing should give a more uniform environment across a shelf but reduces the number of trays on a trolley. Wider spacing also helps light to reach the centre of each shelf. The number of trolleys that the room must contain is based upon the production rate required and the germination rate of the seeds.

An important factor regulating the room size is the arrangement of trolleys within. There would seem to be little guidance to suggest if the trolleys should be butted together or left spaced. From an air flow consideration spaces between the trolleys may be desirable. Without further information at present it will be assumed that each trolley requires at least 150 mm of space around all sides. (See Controlled functions - general principles, below).

The arrangement of trolleys now dictates the size of the room. The diagram (Appendix 2) show a number of arrangements which could be considered. Note however that in the smallest unit containing only four trolleys the space utilisation is poor. Always with such a layout there is the temptation to use the space at the end of the path (shown as "limited parking"). Under some circumstances this space can be used. If the trolleys on either side are "in" for

four days then a 2 or 3 day germinating variety could be germinated on a trolley placed at the end of the path.

The above makes the assumption that complete trolleys of seeds are germinated at once, but this may not be the case. If only one trolley shelf is filled during a seeding session it must be placed in the room and is best supported by a trolley. Any form of fixed shelving may compromise the space utilisation, so the room should be designed to take Danish trolleys, and those used as the shelving system.

The location of the room is as much a matter for choice as any other factor. The movement of trolleys to and from must be carefully considered. Before trying to find a location the space used for existing tasks needs to be defined and marked on the floor, thus "no go" areas will be indicated. Remaining space can now be used for the germination room. If space within the seeding area is limited the room could be built outside, but this will have a marked influence on the construction cost. An advantage of building inside an existing structure comes from the protection from extreme weather. This will reduce the size of heating and cooling equipment required and reduces capital and running costs.

9.5 **Construction** - general principles

When discussing germination room the first parameter considered is always heat. Assuming the room is within a cropped glasshouse the "ambient" temperature should not fall below 10°C and may be much higher at 15°C. The room temperature will be 22°C maximum suggesting a maximum temperature difference of 12°C. If summer production is required the situation may be reversed with an environmental temperature of 28°C suggesting a temperature difference of 6°C, but the room temperature may be 16°C giving a difference of 12°C. The indication is that maximum heating and cooling loads will be very similar. Note however that during the summer period only day ambient temperatures will be high. It may be possible to use lower night temperatures to provide the cooling required. Whatever the room and ambient temperatures there is a need to maintain a difference so good insulation will be essential.

Research has demonstrated the need for high humidity in the room. Given that the room is insulated maintaining high levels becomes much easier because of the steady state condition within. Loss of humidity will be caused by air

leaking in during heating and condensation on cold surfaces. During the time when heating is required air leakage is most important. The ambient air may be 15°C at 70% relative humidity (R/H) if this should leak into the room being maintained at 21°C its RH will fall to 48%. Assuming the requirement is to maintain 95+% RH this entering air must have a considerable quantity of water added to raise its RH level. Also, since the room is warmer than the ambient conditions there is some risk of condensation forming on cold surfaces. This condensation is removal of water from the air which lowers its humidity, and so must be replaced. The requirement of high humidity levels indicates the need to seal the room to prevent air leakage and vapour sealing (polythene) to reduce condensation on cold surfaces.

Cooling the room using a fridge plant will lower the humidity because of condensation on the cooling coils. Replacing this lost water may be difficult. However maintaining high humidity during the summer may provide a means of cooling by evaporation. Fogging of water for humidity control may provide enough cooling.

The handling in and out of the room will at times use fully laden trolleys. These are very heavy and difficult to handle and bumping into the structure is inevitable. Therefore the structure must be durable.

The floor must be durable and so probably concrete. If a new floor is to be constructed a 25 mm thickness of polystyrene insulation under the slab will reduce running costs and help to reduce the problem of condensation on the floor lowering humidity. A drain at some point will be valuable during washing down for disease control. Since the concrete will always be wet it should be sealed to prevent ingress of water. A final refinement is to mark the trolley locations on the floor to ensure correct loading. Proper spacing will be important to ensure the correct environment around the trays. (See above).

A final important requirement is to have a framework or structure to which fittings can be attached eg hanging lights, fans etc.

9.6 **Controlled Functions** - general principles

9.6.1 **Heating**

The simplest function to control is heating. This can be done in many ways, but since the heat load will be small an electrical system will be most appropriate. At its most simple a domestic fan air heater could provide heating. The problem is that it is strictly on-off, ie when there is a heat demand the heater comes on until the demand is satisfied. In such a regime the air temperature will rise and fall between the upper and lower limits of the thermostat. It would be possible to reduce the difference between these limits but the heater would be turned on and off more frequently which may damage the switch gear. However, the air temperature fluctuates, it is compost temperature in the plugs that is most important. Currently, there seems to be little data to show the response of the plug to changes in air temperature. At this stage it is felt that heat distribution may not be the duty of the heating system.

9.6.2 **Cooling**

Cooling is much harder to provide. There is no simple direct method of cooling unless cool night ambient air can be used. The most economic way of providing a cooling system is to install a small domestic air conditioning unit. (This could also provide heating and air movement). Mentioned previously is the prospect of using a fogging system to provide some cooling. To raise humidity, the fogged water must be evaporated which takes heat from the room air. A controlled exchange with the air surrounding the room may provide adequate cooling.

9.6.3 **Humidity**

Humidification can be provided by commercial fogging systems. However, only a few nozzles would be required making the system cost very high. (The smallest system available would cost over £2,000). Another method that may provide adequate evaporation is to wet the floor. A line of seephose along each wall could be used assuming the floor has a fall. The problem with this is providing the floor with heat to evaporate the water. Placing an electrical heating cable in the concrete could provide the necessary heat and prevent the

floor becoming a heat sink. Another method is to use a fan and pad system. In this arrangement air is blown through a wetted gauze mesh raising its humidity. This could be incorporated into the air movement system and provided with heat. By careful design the same arrangement could be used for some summer cooling.

9.6.4 **Air Movement**

Air movement over the trays may be required and so must be provided by a fan system. Obtaining even air flow over all the shelves is very difficult. Many suggestions have been made, eg "letter box" walls and peg board walls, but these are costly and in the case of "letter boxes" inflexible. The amount of air movement required is not known. No air movement over the trays may be acceptable, demonstrated by many growers wrapping whole trolleys in cling film. From a point of view of obtaining uniform environmental conditions forced air movement is essential. To obtain even air movement within the room a ducted system is required. By design this system could be made to provide an air flow over the trays. (See diagram Appendix 3).

9.6.5 **Lighting**

Lighting may or may not be required, but only low levels are necessary. The most simple way of providing light is to use vertical fluorescent tubes. If the control equipment for the tubes remains in the compartment then significant heating will be provided.

The major two functions to control are heat (cooling) and humidity, and lights if necessary.

9.7 **Construction** - details

9.7.1 **The Chamber**

The floor should be a smooth and hard faced concrete. Smooth to allow easy cleaning and hard to resist water ingress. The surface should be sealed using a proprietary compound eg Chel Bond PVA. The concrete needs to be 100 mm thickness of C20 p mix including a single layer of 200 mm by 6 mm reinforcing mesh. This gives a very strong slab which is necessary to resist the high wheel

loadings of a fully laden Danish trolley. The sub-base should consist of 150 mm of MOT grade hard core, with 25 mm thickness of HD polystyrene insulation and a polythene membrane. Given the situation of building a complete germination room then this floor construction is ideal. However, most concrete floors in glasshouses and potting areas will be satisfactory as a germination room floor provided it is sealed. A refinement to be considered in a new floor is the inclusion of an electric heating cable. The value of a slightly heated floor was discussed above, but its real value is not known. The cost of a cable is about £100 for 1 kW output so its inclusion makes economic sense and is recommended.

The floor must have a slight slope to allow for some drainage. A new floor should have a drain within the room. During germination periods there should not be any drainage but at times the room will require washing to ensure good hygiene. The drain must have a water trap to prevent unnecessary air exchange.

The actual chamber as discussed must have good insulation. Possible construction materials may be from purpose made cold store panels at the most expensive to a simple wooden frame with polystyrene panels.

Cold store panels are available from many suppliers. The panels often have polyurethane insulation which has twice the insulation of polystyrene, and are plastic or aluminium coated. Vapour barriers and joint seals are provided but the cost is high. A package cold store 4 m by 5 m with a sliding door for construction on an existing floor costs about £4500.

Some companies offer second-hand cold and freezer stores which are ideal as germination rooms. Small rooms from as little as £1000 are available. Usually these have sliding doors which is ideal.

Another source of second-hand chambers is old freezer lorry bodies. Whilst these have good insulation they tend to be rather long and narrow resulting in much wasted space and making environmental control very difficult. A further problem arises from the hinged doors. (See doors). However, small units may be useful.

Most second-hand cold stores and lorry bodies are often supplied with their

original cooling equipment. Whilst this may seem attractive the cooling plant is often far too big for the duty necessary in a germination room.

Another alternative for germination room constructed is from timber sections and polystyrene panels. Construction is not difficult and apertures for doors and other equipment can be made where required. A frame of 50 mm by 100 mm treated sawn timber is required. Internal height is normally 2.4 m to take 1.2 m by 2.4 m without the need for cutting. A chamber of nominal dimensions 3.6 m by 3.6 m makes economic use of the 100 mm thick EHD polystyrene panels. The basic chamber would cost about £300. The room must be lined in some way to prevent humid air leaking out and provide a vapour barrier. This can be done using white polythene film but jointing is difficult because of the humid atmosphere. A more durable lining can be provided using plastic, aluminium, or galvanised steel sheets. Another alternative is to purchase composite panels consisting of plastic coated polystyrene. A light reflective surface is ideal if lights are to be used to assist with uniform distribution. A further advantage of a hard inner surface is allowing washing down.

The final common type of germination room encountered is built in the same way as a mushroom tunnel. The basic frame is of curved steel hoops covered with two layers of polythene sandwiching 100 mm of glass fibre insulation. Since there is little to fix a door on to, a block wall is built at the front end. Sometimes a block wall is built at the back for fixing heating and ventilation equipment.

9.7.2 **Doors**

The most difficult area to provide is the door. Most cold store, either new or second-hand will have sliding doors. Such doors are ideal because no room air is drawn out during opening. However, compared to hinged doors the construction is difficult requiring specialised tracking. A hinged door is much easier and cheaper to fit but upon opening large volumes of air are drawn out. Ambient air entering the room will probably need heating (or cooling) and humidifying. An improvement can be made by fitting the chamber with a very simple polythene film air lock, which is recommended whatever door is used. The door must be well sealed to the room when closed. Many forms of seal are available but brush walls (as used in glasshouses) are the most appropriate being flexible and cheap. A double row of seals is strongly recommended.

9.7.3 Heating

The actual amount of heat required will depend on the location of the room, size, insulation and the temperature required. For a room as discussed above, in a glasshouse at 10°C and being maintained at 21°C the heating load is only 2.5 kW. A domestic electric fan air heater could be used as long as it is thermostatically controlled. The accuracy of control of air temperature may not be very good but fluctuations of plug temperature may be acceptable. A possible improvement could be made by heating with a domestic oil filled electric radiator. These have a much greater thermal mass and so can be controlled to closer limits. A 2 kW fan air heater costs about £22 and a 1 kW oil filled radiator about £40.

Assuming the nursery has a hot water heating system then this could be used to heat the chamber. An advantage of using hot water for heating is the potential of having proportional control ie the heat supply matches the heat demand. The major problem with this is the cost of the control and distribution system.

9.7.4 Ventilation

Having decided upon the source of heat a means of distributing that heat must be considered. With a domestic type fan air heater there is a certain amount of air movement. The problem being that the air flow is very turbulent and its effect close to the fan great and further away, much less. A solution to this is to fit the fan with a polythene distribution duct. With holes suitably spaced even air flow in the chamber can be achieved. Doing this will reduce the air passing across a fan air heater so the air movement fan should be separate from the heater.

If air flow over the trays is required it may be possible to do this relatively simply. Diagram "Appendix 3" shows the air flow direction to do this. Note that the trolleys would have to be butted together and the gaps between the trolley and room side filled. Further the space under the trolley would have to be closed. Study of mushroom tray ventilation may help to refine the layout but the spaces between trays is very large, about 200 mm.

9.7.5 Humidification

The indication from research is that high humidity is essential. The most simple

means of achieving this is to install a fogging plant. Those used for glasshouse fogging are too large and costly, but small systems used to humidify offices are available. Control of high humidities is very difficult and can only be done accurately using wet and dry temperatures. Even the most basic controller costs over £250. Another approach is to operate the humidifcation plant on a time basis. With experience this could be adjusted to give the desired conditions. The alternative to control is to humidify continuously, which will give very high levels but the running costs will also be high.

Another approach is to humidify in conjunction with the heating. If the floor can be heated, as discussed above, and kept wet then high humidity levels will be provided. The only obvious drawback is the increase in heating of the bottom shelf of a trolley, but this could be left empty.

Humidification could also be provided by blowing the ventilation air across a wetted mesh or pad. The only problem being the cooling effect upon the air, but the heating system will adjust accordingly.

9.7.6 Lighting

This may or may not be required. If required it can be provided by vertical fluorescent tubes. The number of tubes required will have to be determined by trial. Two potential problems arise. Firstly, heat is produced from both the tube and its controls. Since the room is well insulated overheating is possible. An improvement can be made by placing the controls outside the room. However, by careful selection of the insulation and light levels the lights could meet all of the heat demand the only drawback being lack of heat control. The second problem is one of safety. Operating lights (or any electrical equipment) in a damp atmosphere can be dangerous. The fans and heaters once installed should not need moving, but the lights will have to be moved as trolleys, shelves and trays are brought in and out.

9.7.7 Conclusion

For the small grower a home built germination room will cost about £1000, and provide space for 4 trolleys. Further work is required to determine the most suitable way of humidification and the practicalities and value of lighting.

10. COST BENEFIT ANALYSIS

The benefits of using germination rooms lie in the ability to improve the percentage of plugs per tray that are usable plants. In respect to the number of trays required for a set production that has a large effect.

The tables in Appendix 4-7 show the effect of germination on both plug price and effective price per tray.

10.1 Key Assumptions

The following assumptions were made in the production of the cost/benefit analysis:

a) The cost or producing the plug trays includes a charge for depreciation of a Hamilton Natural Seeder.

b) The plug production was for 1,000 trays per annum.

c) The crop is costed as if it is the only crop produced ie the depreciation overheads are totally carried by the 1000 trays of production.

d) Danish type trolleys are already available at no extra cost.

e) Plug trays are only used once.

f) Overhead costs are taken from Farm Business Survey data.

g) Opportunity cost only covers the weeks when the plug crop occupies the bench space.

10.2 Two types of germination room were taken into account. The calculated costs of building and running these per annum is shown in Appendices 5a and b.

10.3 The cost of producing a tray was arrived at using data similar to that shown in Appendices 6a and b

10.4 The effect of using a germination room is to improve the percentage germination of the tray. The results of the analysis show a figure for the plug cost, and also a figure for the tray cost. This figure is the result of the cost of each plant that is produced at a given germination multipled up to give a germination per tray.

Eg at 90% germination with a germination room a pansy plug will cost £0.0265 if the tray is `gapped up` to 10% the tray will cost £15.28 plus the labour cost of gapping up.

10.5 Whether or not a germination room is beneficial is dependent on an individual holding. If we take as an example a holding that wishes to produce 564480 pansy plants (1000 trays at 98% germination).

Assuming that without a germination room only 75% germination can be achieved the estimated cost of producing these plants will be £15,473. If a low cost germination room is used then the cost of producing the same number of plants will be £13,675, a saving of £1,798 and this calculation includes all the cost of building and running a germination room. If the low cost germination room can produce plug trays with at least 85% germination for pansies then it will be a financial benefit. (Assuming germination without is only 75%).

A similar effect can be noted with both the expensive germination room and the primrose production.

In Appendices 7a and b there are 4 graphs which show the cost of producing the following number of plugs:

Pansies	564480
Primroses	280280

In order to calculate the minimum germination required by either germination room draw a horizontal line from the top of the bar corresponding to the germination rate without a germination room. When the bars of the graph for the production with germination room fall below this then the use of the germination room becomes worthwhile.

10.6 The calculations made here are very generalised. Clearly in order to implement such an operation individual assessments should be carried out.

10.7 **Summary**

With the costs and production levels used in this study it can be seen that a modest improvement in germination brought about by the use of a germination room can render such a facility financially viable.

11. ACKNOWLEDGEMENTS

The contribution to this review is acknowledged to Peter Stearne of ADAS Chichester on the practical designs of germination rooms and Simon Edwards of the same Unit for his economic appraisal of these rooms is acknowledged.

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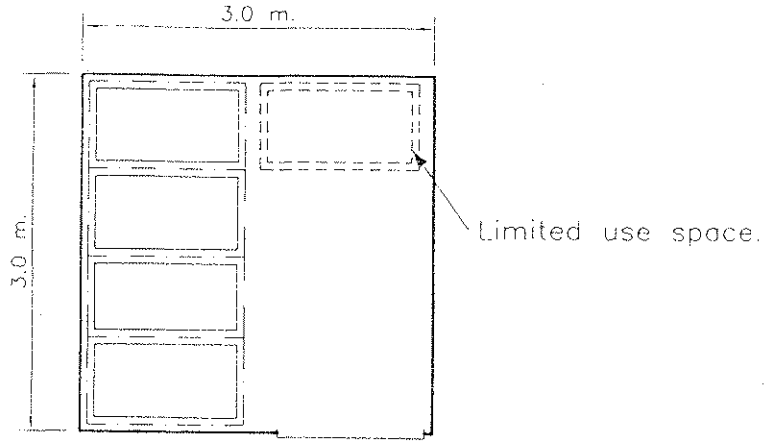
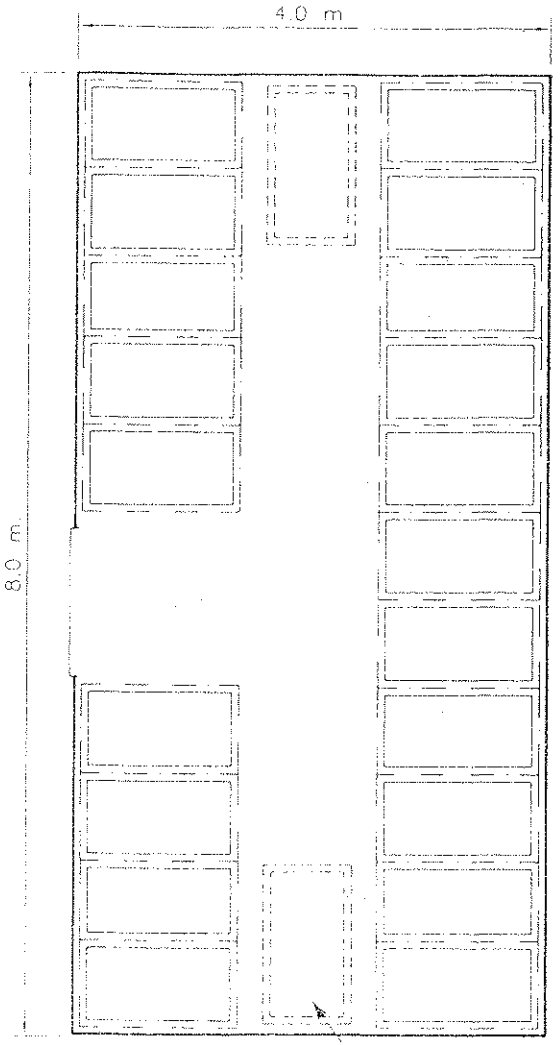




Costs. (Room only on existing base)

Small room hinged door.	£2,338
Small room sliding door.	£3,177
Large room hinged door.	£3,515
Large room sliding door.	£4,354

Appendix 2

Small & Large Germination Room Layout.

scale	drawn
N.T.S.	P.M.S.

ADAS

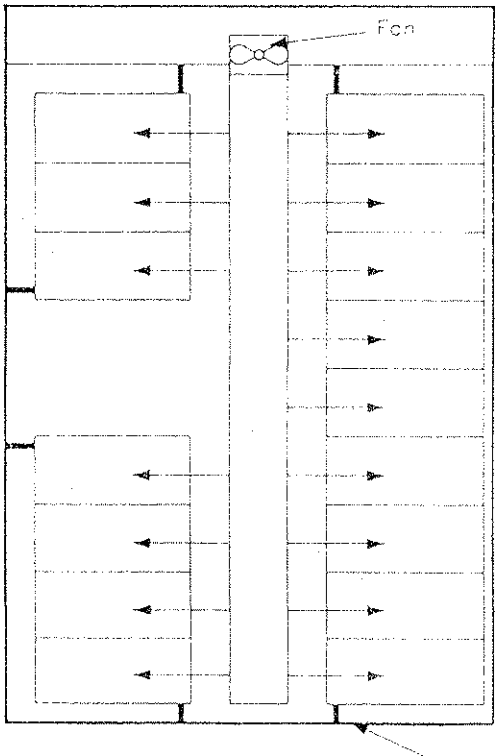
APPENDIX 2

Appendix 3

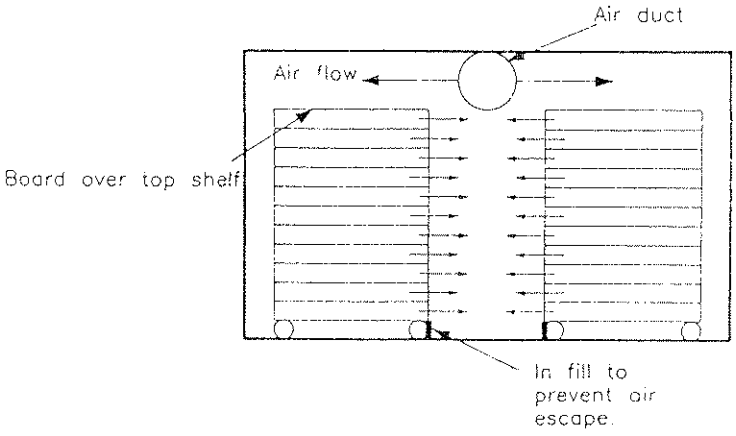
Germination Room Ventilation.

scale N.T.S. drawn P.M.S.

ADAS



Part sectioned plan.



Cross section

APPENDIX 4A

LOW COST GERMINATION ROOM

GERMINATION ROOMS - SENSITIVITY ANALYSIS

PLUG COST

GERM.RATE	PANSY WITHOUT GERM.	PANSY WITH GERM	PRIM. WITHOUT GERM.	PRIM. WITH GERM
100	£0.0206	£0.0230	£0.0399	£0.0450
99	£0.0208	£0.0233	£0.0403	£0.0454
98	£0.0210	£0.0235	£0.0408	£0.0459
97	£0.0212	£0.0238	£0.0412	£0.0463
96	£0.0214	£0.0240	£0.0416	£0.0468
95	£0.0216	£0.0243	£0.0420	£0.0473
94	£0.0219	£0.0245	£0.0425	£0.0478
93	£0.0221	£0.0248	£0.0430	£0.0483
92	£0.0223	£0.0251	£0.0434	£0.0489
91	£0.0226	£0.0253	£0.0439	£0.0494
90	£0.0228	£0.0256	£0.0444	£0.0499
89	£0.0231	£0.0259	£0.0449	£0.0505
88	£0.0234	£0.0262	£0.0454	£0.0511
87	£0.0236	£0.0265	£0.0459	£0.0517
86	£0.0239	£0.0268	£0.0464	£0.0523
85	£0.0242	£0.0271	£0.0470	£0.0529
84	£0.0245	£0.0274	£0.0476	£0.0535
83	£0.0248	£0.0278	£0.0481	£0.0542
82	£0.0251	£0.0281	£0.0487	£0.0548
81	£0.0254	£0.0285	£0.0493	£0.0555
80	£0.0257	£0.0288	£0.0499	£0.0562
79	£0.0260	£0.0292	£0.0506	£0.0569
78	£0.0264	£0.0295	£0.0512	£0.0576
77	£0.0267	£0.0299	£0.0519	£0.0584
76	£0.0271	£0.0303	£0.0526	£0.0592
75	£0.0274	£0.0307	£0.0533	£0.0599

TRAY COST

GERM.RATE	PANSY WITHOUT GERM.	PANSY WITH GERM.	PRIM. WITHOUT GERM.	PRIM. WITH GERM.
100	£11.84	£13.27	£11.42	£12.86
99	£11.96	£13.41	£11.54	£12.99
98	£12.08	£13.55	£11.66	£13.12
97	£12.21	£13.69	£11.78	£13.25
96	£12.34	£13.83	£11.90	£13.39
95	£12.46	£13.97	£12.03	£13.53
94	£12.60	£14.12	£12.15	£13.68
93	£12.73	£14.27	£12.28	£13.82
92	£12.87	£14.43	£12.42	£13.98
91	£13.01	£14.59	£12.55	£14.13
90	£13.16	£14.75	£12.69	£14.29
89	£13.31	£14.92	£12.84	£14.45
88	£13.46	£15.08	£12.98	£14.61
87	£13.61	£15.26	£13.13	£14.78
86	£13.77	£15.44	£13.28	£14.95
85	£13.93	£15.62	£13.44	£15.13
84	£14.10	£15.80	£13.60	£15.31
83	£14.27	£15.99	£13.76	£15.49
82	£14.44	£16.19	£13.93	£15.68
81	£14.62	£16.39	£14.10	£15.87
80	£14.80	£16.59	£14.28	£16.07
79	£14.99	£16.80	£14.46	£16.27
78	£15.18	£17.02	£14.65	£16.48
77	£15.38	£17.24	£14.84	£16.70
76	£15.58	£17.47	£15.03	£16.92
75	£15.79	£17.70	£15.23	£17.14

APPENDIX 4B

EXPENSIVE GERMINATION ROOM

PLUG COST

GERM.RATE	PANSY WITHOUT GERM.	PANSY WITH GERM	PRIM. WITHOUT GERM.	PRIM. WITH GERM
100	£0.0206	£0.0239	£0.0399	£0.0466
99	£0.0208	£0.0241	£0.0403	£0.0471
98	£0.0210	£0.0244	£0.0408	£0.0476
97	£0.0212	£0.0246	£0.0412	£0.0481
96	£0.0214	£0.0249	£0.0416	£0.0486
95	£0.0216	£0.0251	£0.0420	£0.0491
94	£0.0219	£0.0254	£0.0425	£0.0496
93	£0.0221	£0.0257	£0.0430	£0.0501
92	£0.0223	£0.0260	£0.0434	£0.0507
91	£0.0226	£0.0262	£0.0439	£0.0512
90	£0.0228	£0.0265	£0.0444	£0.0518
89	£0.0231	£0.0268	£0.0449	£0.0524
88	£0.0234	£0.0271	£0.0454	£0.0530
87	£0.0236	£0.0274	£0.0459	£0.0536
86	£0.0239	£0.0278	£0.0464	£0.0542
85	£0.0242	£0.0281	£0.0470	£0.0549
84	£0.0245	£0.0284	£0.0476	£0.0555
83	£0.0248	£0.0288	£0.0481	£0.0562
82	£0.0251	£0.0291	£0.0487	£0.0569
81	£0.0254	£0.0295	£0.0493	£0.0576
80	£0.0257	£0.0298	£0.0499	£0.0583
79	£0.0260	£0.0302	£0.0506	£0.0590
78	£0.0264	£0.0306	£0.0512	£0.0598
77	£0.0267	£0.0310	£0.0519	£0.0606
76	£0.0271	£0.0314	£0.0526	£0.0614
75	£0.0274	£0.0318	£0.0533	£0.0622

TRAY COST

GERM.RATE	PANSY WITHOUT GERM.	PANSY WITH GERM	PRIM. WITHOUT GERM.	PRIM. WITH GERM
100	£11.84	£13.75	£11.42	£13.34
99	£11.96	£13.89	£11.54	£13.47
98	£12.08	£14.04	£11.66	£13.61
97	£12.21	£14.18	£11.78	£13.75
96	£12.34	£14.33	£11.90	£13.89
95	£12.46	£14.48	£12.03	£14.04
94	£12.60	£14.63	£12.15	£14.19
93	£12.73	£14.79	£12.28	£14.34
92	£12.87	£14.95	£12.42	£14.50
91	£13.01	£15.12	£12.55	£14.66
90	£13.16	£15.28	£12.69	£14.82
89	£13.31	£15.45	£12.84	£14.99
88	£13.46	£15.63	£12.98	£15.16
87	£13.61	£15.81	£13.13	£15.33
86	£13.77	£15.99	£13.28	£15.51
85	£13.93	£16.18	£13.44	£15.69
84	£14.10	£16.37	£13.60	£15.88
83	£14.27	£16.57	£13.76	£16.07
82	£14.44	£16.77	£13.93	£16.26
81	£14.62	£16.98	£14.10	£16.47
80	£14.80	£17.19	£14.28	£16.67
79	£14.99	£17.41	£14.46	£16.88
78	£15.18	£17.63	£14.65	£17.10
77	£15.38	£17.86	£14.84	£17.32
76	£15.58	£18.10	£15.03	£17.55
75	£15.79	£18.34	£15.23	£17.78

APPENDIX 5A

LOW COST GERMINATION ROOM

TRAYS PRODUCED	1000	
TOTAL AREA USED	12	
CAPITAL COST	£1,000.00	
TOTAL INTEREST	£662.00	
DEPRECIATION	£200.00	
INTEREST	£66.20	
OPPORTUNITY COST OF AREA	£924.00	
OVERHEADS	£127.44	
TOTAL PER ANNUM	£1,317.64	£1,317.64
TROLLEYS		
TRAYS/SHELF	4	
SHELVES/TROLLEY	11	
TRAYS/TROLLEY	44	
TROLLEYS/ROOM	4	
TRAYS/ROOM	176	
DAYS PER BATCH	3	
DAYS REQUIRED	17	
RUNNING COST PER DAY	£2.00	
RUNNING COST	£34.09	£34.09
TOTAL COST		£1,351.73
COST PER TRAY		£1.35

APPENDIX 5B

EXPENSIVE GERMINATION ROOM

TRAYS PRODUCED	1000	
TOTAL AREA USED	12	
CAPITAL COST	4500	
TOTAL INTEREST	2981	
DEPRECIATION	£450.00	
INTEREST	£298.10	
OPPORTUNITY COST OF AREA	£924.00	
OVERHEADS	£127.44	
TOTAL PER ANNUM	£1,799.54	£1,799.54
TROLLEYS		
TRAYS/SHELF	4	
SHELVES/TROLLEY	11	
TRAYS/TROLLEY	44	
TROLLEYS/ROOM	4	
TRAYS/ROOM	176	
DAYS PER BATCH	3	
DAYS REQUIRED	17	
RUNNING COST PER DAY	£2.00	
RUNNING COST	£34.09	£34.09
TOTAL COST		£1,833.63
COST PER TRAY		£1.83

COSTS TO PRODUCE A TRAY OF PANSY PLUGS WITHOUT GERMINATION ROOM

NO OF TRAYS PER ANNUM	1000	TOTALS
TRAY	£0.87	
SEED	£4.38	
COMPOST	£0.12	
LABOUR	£0.42	
SEEDER DEPN	£0.57	
SEEDER INT.	£0.34	
GERMINATION	£0.00	
TOTAL	£6.70	£6.70
OTHER COSTS		
PLANT AREA REQUIRED	184.44	
OPPORTUNITY COST/m2/WEEK	£1.45	
NO. OF WEEKS	7	
PLANT OPPORTUNITY COST	£1,872.11	
PER TRAY	£1.87	£1.87
EQUIPMENT AREA REQUIRED	15	
OPPORTUNITY COST/m2	£77.00	
TOTAL	£1,155.00	
PER TRAY	£1.16	£1.16
OVERHEAD COST /m2	£10.62	
OVER AREA REQUIRED	£2,118.10	
PER TRAY	£2.12	£2.12
TOTAL		£11.84

		COST/ PLANT	'COST'/ TRAY
NO OF PLANTS	576000	£0.02	£11.84
% GERMINATION	75		
PLANTS PROD	432000	£0.03	£15.79

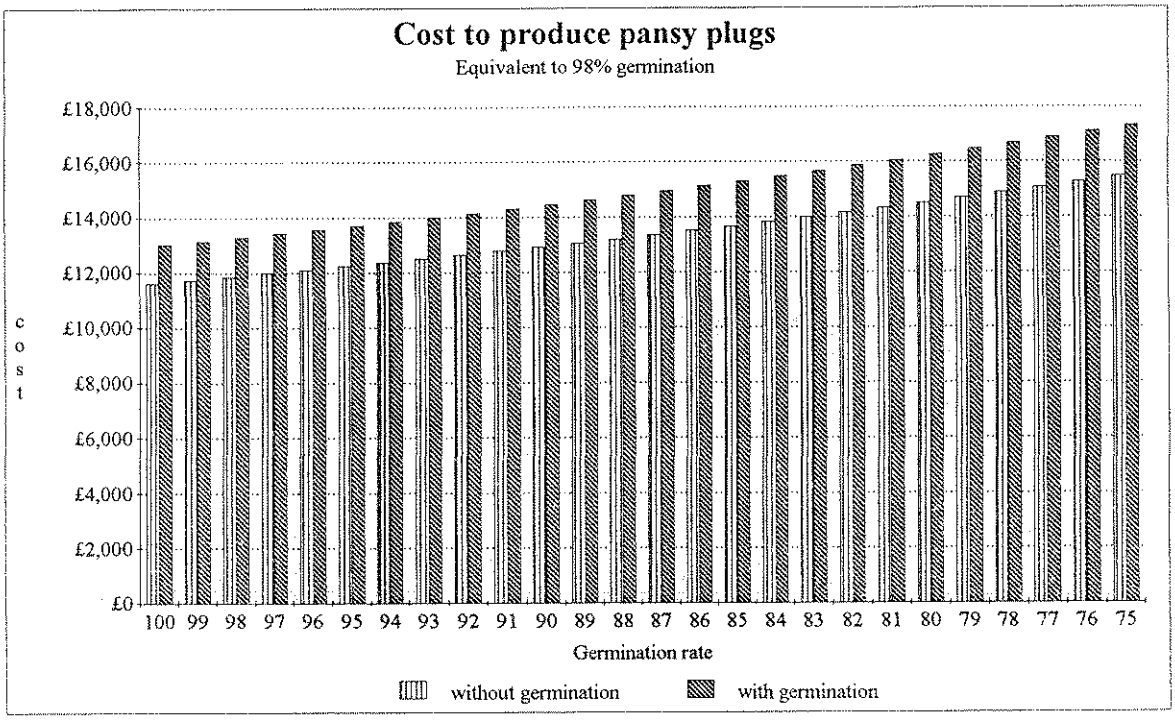
COSTS TO PRODUCE A TRAY OF PANSY PLUGS WITH GERMINATION ROOM

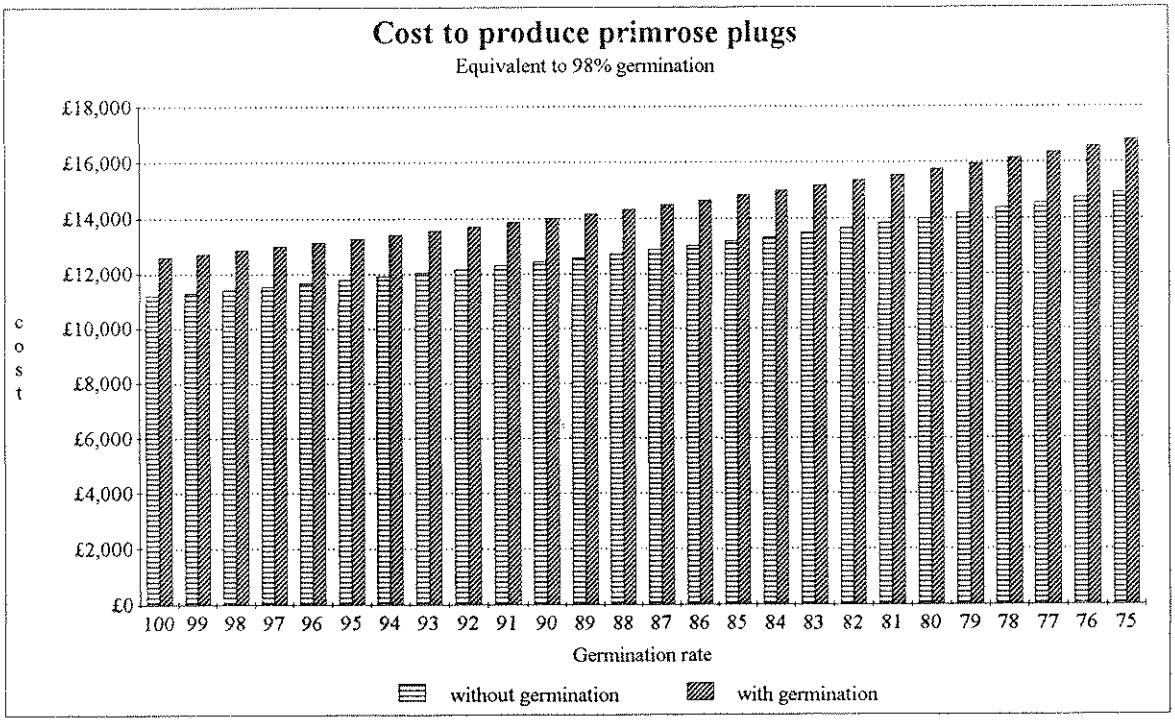
NO OF TRAYS PER ANNUM	1000	TOTALS
TRAY	£0.87	
SEED	£4.38	
COMPOST	£0.12	
LABOUR	£0.50	
SEEDER DEPN	£0.57	
SEEDER INT.	£0.34	
GERMINATION	£1.35	
TOTAL	£8.13	£8.13
OTHER COSTS		
PLANT AREA REQUIRED	184.44	
OPPORTUNITY COST/m2/WEEK	£1.45	
NO. OF WEEKS	7	
PLANT OPPORTUNITY COST	£1,872.11	
PER TRAY	£1.87	£1.87
EQUIPMENT AREA REQUIRED	15	
OPPORTUNITY COST/m2	£77.00	
TOTAL	£1,155.00	
PER TRAY	£1.16	£1.16
OVERHEAD COST /m2	£10.62	
OVER AREA REQUIRED	£2,118.10	
PER TRAY	£2.12	£2.12
TOTAL		£13.27

		COST/ PLANT	'COST'/ TRAY
NO OF PLANTS	576000	£0.02	£13.27
% GERMINATION	95		
PLANTS PROD	547200	£0.02	£13.97

APPENDIX 7A

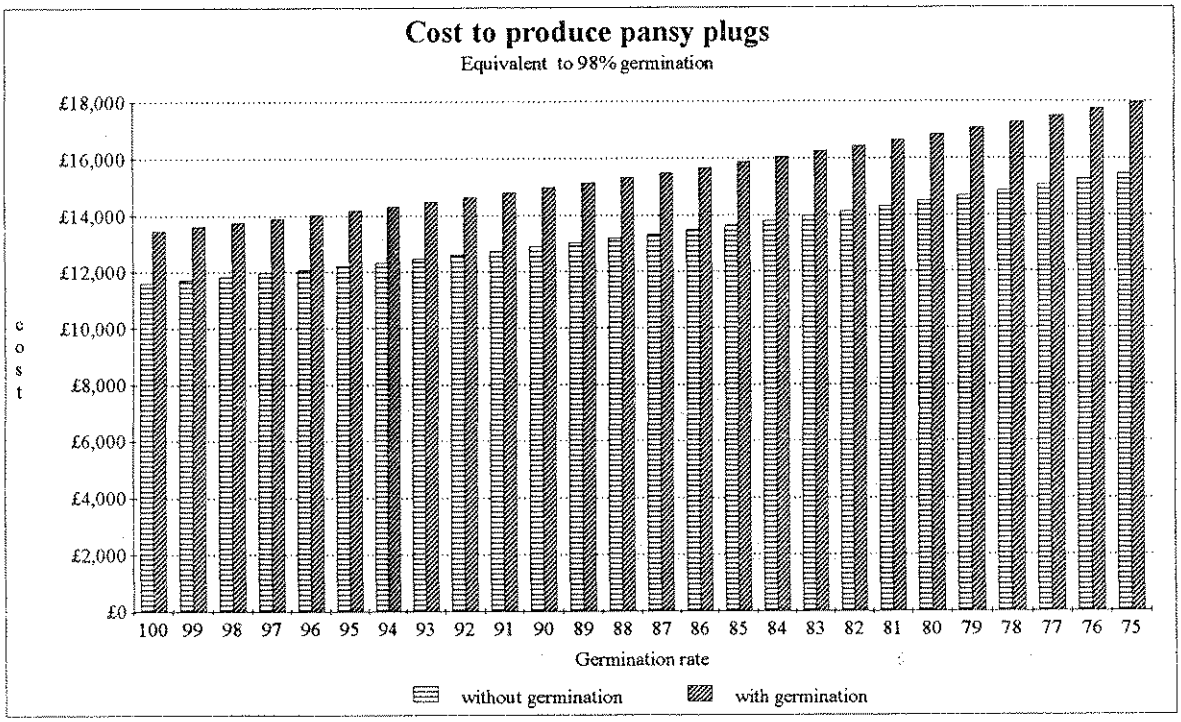
Cost of producing the equivalent amount of plants to a 98% germination rate over 1000 trays, in a cheap germination room.

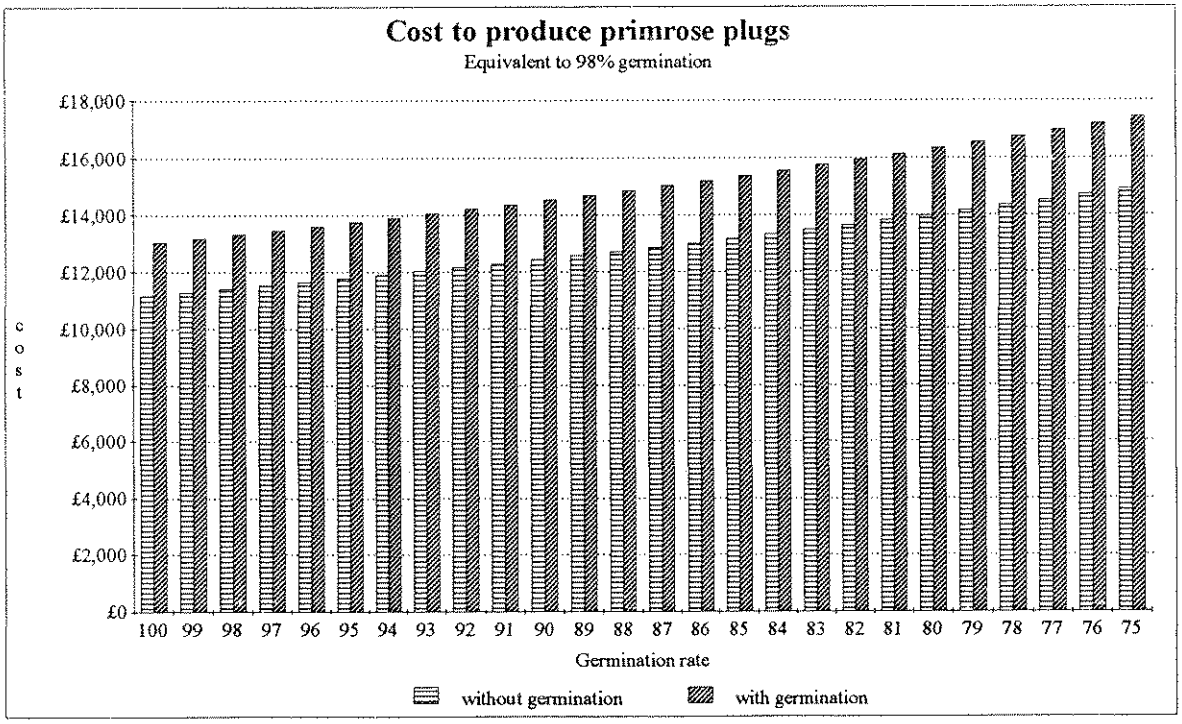




APPENDIX 7B

Cost of producing the equivalent amount of plants to a 98% germination rate over 1000 trays, in an expensive germination room.





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