HNS 1

Investigations of winter damage in container-grown plants, and methods for their protection

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INVESTIGATIONS OF WINTER DAMAGE IN CONTAINER-GROWN PLANTS, AND METHODS FOR THEIR PROTECTION

H.D.C. PROJECT:	HO/1
LOCATION:	IHR, Littlehampton (and IER)
DATES:	1.4.87 - 6.5.90
PROJECT COORDINATORS:	J Richardson and R Currie
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SUMMARY

The following information relevant to UK production has been obtained during HDC research at Littlehampton on frost resistance levels in nursery stock species, and on methods for their protection against winter damage.

- There is a large range in shoot frost resistance between species, so the tables of frost resistance data should be consulted to give species priority when allocating limited protected space.

- Different nutrient feed treatments are unlikely to produce measurable increases in hardiness and may even render shoots more frost susceptible. Development of hardiness was not hampered by late-season feeding.

- Plants raised in the warmer environment of a polytunnel developed less hardiness than plants raised outside, increasing their susceptibility to frosts should the protection be removed (eg. when sold).

- Plants of several species responded to cold conditioning treatment by developing a small increase in frost resistance compared to that developed naturally in ambient temperatures.

- Young roots have very little resistance to frost and the limit of survival for the oldest roots of many species is no more than -12 to -15^{o}C. Roots have no significant ability to harden.

- Covering materials delay the freezing of containers compared to no protection, but will fail if the period of cold is prolonged. Additional heat will then be required.

Therefore, in the context of winter injury, it is more important to consider **where** plants are grown rather than **how** they

are grown. In the normal nursery situation they should be maintained in as cool conditions as possible, using protection during very cold weather only to delay the onset of compost water freezing. When this happens both low temperature and lack of water greatly increase the risk to roots and shoots and heat must be provided. If growers wish to resort to heated overwinter protection, possibly with a view to continuing growth under supplementary lighting, they must realise that their plants will be extremely sensitive to spring frost damage when taken outside.

INTRODUCTION

The main difficulty in establishing guidelines for frost protection of nursery stock lies in the unpredictable nature of the UK winter. The rare occurrence in this country of severe winters which lead to heavy crop losses does not itself warrant the expense of large heated glass structures. This contrasts with requirements in parts of Europe and America where sub-freezing winters recur annually. Also, on these continents winters are characterized by predictable temperature profiles; gradual cooling during the autumn allows progressive hardening of nursery stock, then, following the sub-freezing winter months, warming during the spring marks the end of the dormant season. In the UK the unpredictability is characterised by sudden freezing conditions in autumn without prior opportunity for plant hardening, and by late spring frosts after dehardening. These are the uncertain conditions which must be catered for by protection methods aimed at ensuring plant survival over winter and maintenance of quality during the spring.

In order to investigate the protection of nursery stock it is first necessary to establish which species are most at risk from frost damage. Therefore, a primary research objective must be the development of a convenient screening technique which can quickly identify the lethal freezing temperature for different species. The variability in climate requires that the protection systems should be sufficiently simple to install at short notice following forecasts of harsh weather. Thus, rather than recommending stringent procedures, research should aim to understand the mechanisms controlling the efficiency of different protection systems so that appropriate measures can be taken according to the expected severity of the weather.

Two experimental projects were undertaken. At the Institute of Engineering Research the mechanics of container freezing and the effect of windbreaks were investigated. At the Institute of Horticultural Research (now ~~BSHR~~) investigations concentrated on aspects of plant hardiness (or frost resistance) and measurements of heat loss from under various cover systems. Work at IHR is reported here.

The frost resistance of plants is a characteristic controlled by complex factors. These include changes in sugar and protein concentrations, alteration in cell membrane composition and changes in ambient temperature and day length. Despite extensive research, no single set of criteria has been found to relate to the acclimation of frost resistance in all species. The objectives of this project were, therefore, to establish which of the following factors play an important role in influencing the cold tolerance of ornamental nursery stock species in the UK:

- The temperatures at which shoots are killed.
- The temperatures which destroy roots. Is the whole root system equally affected?
- The effect of the environment on hardiness development and whether frost resistance can be increased by certain treatments.
- The extent to which covering materials delay heat loss from containers. Which materials are most efficient and how long can they support compost temperatures before the input of additional heat is required?

METHODS

The IHR site at Littlehampton was chosen because of the facilities available. Air and compost temperatures were continually monitored by two recording systems around the experimental container unit, which consisted of several 2 x 7 m sand beds situated both under a polythene tunnel and outside. Two large freezers were utilized also; one with a glass lid was used as a temperature controlled conditioning chamber for light-grown plants, the other was programmable and allowed cooling at a predetermined rate for frost resistance measurements.

Experimental arrangements and treatments

In the 1988/89 season experiments were arranged so that the development of shoot frost resistance could be determined under the influence of different temperature environments (outside and under polythene) and different lengths of nutrient feeding to prolong or curtail soft growth in the autumn.

Plants were potted into 3 litre containers with 80:20 peat:grit mix, containing magnesium limestone, fritted trace elements and controlled release fertilizers where appropriate. The plants for each species were split into two batches, one laid out in a polytunnel, the other on an outside sand bed. A stock solution of balanced liquid feed, containing ammonium nitrate (74.3 g l^{-1}), monoammonium phosphate (24.5 g l^{-1}) and potassium nitrate (78.9 g l^{-1}) was prepared. The stock solution was diluted x 200 and 200 ml of this was applied weekly to appropriate pots. Treatments were as follows:-

1. Liquid feed applied until 1st August.
2. Liquid feed applied until 1st October
3. Liquid feed applied until 1st December
4. Controlled release fertilizer (CRF)

Some of the species did not receive all the treatments owing to an insufficient number of plants.

In October (12.10.88 to 22.10.88), December (16.12.88 to 21.12.88) and April (10.4.89 to 24.4.89) small-scale measurements of shoot frost resistance were made. For these, a few shoots only were tested at each sub-freezing temperature (see Figure 1 in Appendix) and results were recorded qualitatively by describing the injury sustained. The frost resistance of young roots was assessed by the conductivity method (see below for details).

A more detailed appraisal of shoot hardiness was made in January (18.1.89 to 10.2.89) in which several shoots, representing each feed treatment and environment type, were examined for damage sustained at each test temperature. A scoring system was used to describe the severity of damage suffered.

Scoring System - Index of Injury

< 1.5	- No injury
1.5 - 2.4	- First signs of injury to leaves and/or stem
2.5 - 3.4	- Browning damage to all leaves and stem
> 3.4	- Severe damage or death

This system, along with the high replication of shoots, enabled statistical analysis of the results to be undertaken.

During the winter of 1989/90 new experiments concentrated on evaluating the frost resistance of root systems. Shoot frost resistance determinations were repeated, this time examining the effects of potassium applications. Plants were potted-up and set out in the container unit as before. A stock solution of potassium sulphate was diluted to give a liquid feed of 400 mg l^{-1} potassium, of which 200 ml was applied weekly to half the plants of each species during September and October. Shoot hardiness was assessed in January (9.1.90 to 18.1.90) and observations were scored using the Injury Index previously described.

Detailed measurements of root hardiness were made in November (1.11.89 to 8.11.89) and January (9.1.90 to 18.1.90). Roots were collected from the edge of the root ball (young roots) and from near the base of the stem (old roots). The roots were frozen (see Figure 2 in Appendix) and then tested by the conductivity method. In addition the viability of old roots was assessed by the Tetrazolium Stain Test (see Appendix). Root sections, cut longitudinally in half, were examined for presence or absence of pink staining indicating live or dead tissue respectively.

Plants of some species were subjected to a period of cold ambient temperature to discover if this conditioning treatment could enhance the degree of hardening. After the conditioning period shoots were tested for frost resistance in the usual manner.

Techniques for measuring frost resistance

The freezing tests for root and shoot material were performed in a programmable freezer. Shoot or root samples were placed in labelled polythene bags. Thermocouples were inserted deep into the tissue of some samples to check that the plant material reached the desired sub-freezing test temperatures. Crushed ice was added to the bags following previous observations that without an ice nucleating agent small segments of tissue supercool, thereby overestimating their real frost resistance.

The bags were immediately placed in the freezer and the cooling programme initiated (programmes in Appendix, Figures 1 and 2). When the freezer had reached the required test temperature the appropriate bags were quickly removed and thawed at +4°C. For the shoots the thawed ice was removed from the bags which were subsequently stored at +20°C for injury symptoms to develop. Unfrozen control shoots were included in this incubation. After 48 hours the shoots were visually scored.

Root damage was measured by a modified form of the conductivity method (Flint *et al.* 1967, Zhang and Willison 1987). Root samples (consisting of 3 or 4 young roots or a single section of old root) were frozen and thawed as above but the thawed ice was not discarded. Instead this was transferred along with the roots to test tubes and the volume increased to a standard. The roots were left for 24 hours to leak ionic cell contents from freeze-damaged areas. Unfrozen controls were included. The conductivity was measured after this period and again after boiling the roots. Relative root damage was indicated by the difference in conductivity before and after boiling.

Measurement of heat loss from beneath covered structures

Several low structures were erected, each covered with a different protective material. An uncovered control was included. Beneath each structure close-packed containers of compost were positioned. Temperatures at various compost depths in one of the central pots, and air temperatures under the different covers, were logged hourly. Comparison of heat loss was also recorded using net radiometers.

RESULTS

The frost resistance of shoots

a. Degree of frost resistance in different species

One of the most valuable aspects of this work has been the quantification of the frost resistance of shoots in terms of absolute temperatures which cause death, information which had before been largely subjective. The findings are given in Tables 1 and 2 as the Injury Index of the shoots at each test temperature, the lower the value the less the injury. The scores are averages of the results for environment and feed treatments. In the second year the shoot scores from the two environments and potassium treatments were not significantly different at each test temperature, so averaging is acceptable. For 1988/89, the feeding treatments did not produce significantly different results but scores of shoots from the two environments were statistically different. However, the difference between the test temperatures was much greater, so averaging the scores is still acceptable for the purpose of placing species in ascending order of resistance.

Table 1. Frost resistance of shoots, winter 1988/89

SPECIES	TEST TEMPERATURE				
	UNFROZEN	-10°C	-15°C	-20°C	-25°C
Hebe 'Carl Teschner'	1.0	2.2	3.8	4.0	4.0
Hebe franciscana	1.2	2.7	3.4	4.0	4.0
Pittosporum	1.1	1.4	3.2	4.0	4.0
Ceanothus thyrsiflorus	1.0	1.4	2.9	4.0	3.9
Escallonia	1.0	1.7	2.9	3.1	*
Rosmarinus officinalis	1.2	1.9	2.8	3.7	3.9
Camellia 'Debbie'	1.0	1.4	2.3	3.4	3.9
Elaeagnus pungens	1.0	*	2.3	3.0	3.4
Choisya ternata	1.0	1.1	2.2	3.4	3.8
Garrya elliptica	1.1	1.3	1.9	3.0	3.6
Aucuba japonica	1.0	1.3	1.8	3.0	4.0
Cistus corbaryensis	1.0	1.1	1.7	3.0	3.9
Cupressus macrocarpa	1.0	1.0	1.7	3.0	3.3
Elaeagnus x ebbingei	1.0	*	1.6	2.2	3.1
Phillyrea decora	1.0	1.1	1.6	2.8	3.5
Pyracantha 'Golden Charmer'	1.0	1.0	1.1	2.1	3.5

Table 2. Frost resistance of shoots, winter 1989/90

SPECIES	TEST TEMPERATURE				
	UNFROZEN	-10°C	-15°C	-20°C	-25°C
Hebe 'Autumn Glory'	1.1	2.2	4.0	4.0	4.0
Olearia macrodonta	1.0	1.6	3.6	3.7	3.9
Ceanothus thyrsiflorus	1.0	1.3	3.0	3.4	3.5
Rosmarinus officinalis	1.1	1.4	2.7	3.7	3.8
Choisya ternata	1.0	1.1	2.6	3.5	3.9
Cupressus macrocarpa	1.0	1.2	2.4	3.7	4.0
Cotoneaster conspicuus	1.1	1.1	2.4	3.5	3.8
Garrya elliptica	1.0	1.0	1.5	3.2	3.9
Pyracantha 'Orange Glow'	1.1	1.1	1.3	3.1	4.0

Significance of the injury represented by the scores;

No damage:	Less than 1.5
Slight damage:	1.5 - 2.4
Severe damage:	2.5 - 3.4
Death:	More than 3.4

It should be noted that whilst death in these "Hardy" ornamentals sometimes did not occur unless they were subjected to a temperature of -20°C, severe or unsightly damage may often occur after night-time temperatures of -10 or -15°C which render the plants unsaleable, so it is from these temperatures that containerized plants must be protected. As an arbitrary rule, scores above 2.4 are likely to represent financial loss.

b. Effect of the Environment

Generally, species developed the same depth of hardiness in each of the two years of experimentation. It is clearly seen from Tables 1-3 in the Appendix that there were measurable increases in the frost resistance of shoots of nearly all species between October and December and marked dehardening by April. Both winters were relatively mild and it is possible that greater acclimation of frost resistance could occur in a colder season. Evidence for this was borne-out by the comparison of hardiness development in the two environments providing different ambient temperatures. During the winter of 1988/89 the frost susceptibility of shoots from plants raised in the warmer polytunnel environment was significantly higher than that of shoots from plants raised outside, for the majority of species. However, differences in hardiness between shoots from the two environments disappeared in the second year of assessment, or, for some species, the trend was reversed. The most likely reason was that differences in temperature between the environments were much less pronounced during the second year.

c. The influence of feeding treatments

The feeding treatments designed to alter the resistance of shoots to frost damage did not achieve critical effects. The results for the first year showed that all shoots developed the same depth of hardiness, irrespective of the lateness into autumn in which they were given nutrient feeds. In the second year's experiments, applications of potassium during the autumn did not bring about consistent improvements in frost resistance either. Shoots of *Olearia*, Rosemary and *Hebe* supplied with potassium suffered less injury than those untreated, but treated shoots of *Cupressus* were more tender and the other species showed no difference in frost resistance whether or not given potassium.

d. Cold conditioning of plants

Plants were conditioned in a low temperature environment at 4°C for a month then at -1°C for a week to attempt to induce hardening to the maximum possible for the species. The frost resistance of these shoots was compared to that in shoots taken from plants grown outside. After several repetitions of the trial it was clear that small but notable increments in resistance to injury occurred in some species. *Choisya ternata*, *Aucuba japonica*, *Escallonia* and *Hebe* varieties demonstrated increases of 3 to 7°C in frost resistance over comparable shoots raised outside in temperatures of 3 to 10°C.

The Frost Resistance of Roots

a. Depth of root hardiness

The study of root frost resistance consistently highlighted the lack of freezing tolerance in roots in contrast to shoots. Initially it was believed that this very low hardiness might only exist in the young roots, but following detailed research during the second winter it became clear that no part of the root system was as hardy as the shoots (Table 3).

Table 3. Comparison of frost resistance in young and old roots in terms of leakage of ionic root cell contents (1989/90)

SPECIES	TEST TEMPERATURE							
	CONTROL		-3°C		-6°C		-9°C	
	Yg	Old	Yg	Old	Yg	Old	Yg	Old
Cotoneaster horizontalis	23	24	96	35	100	80	101	82
Choisya ternata	20	34	95	80	99	99	100	101
Cupressus macrocarpa	40	40	90	57	97	88	100	94
Pyracantha	39	32	88	44	96	81	97	86
Cotoneaster conspicuus	29	33	80	50	96	74	98	80
Olearia macrodonta	28	21	77	43	85	68	90	81
Hebe 'Autumn Glory'	31	43	41	47	89	77	92	78

Results expressed as averages of % Leakage where:

$$\% \text{ Leakage} = \frac{\text{Leakage caused by temp treatment}}{\text{Total leakage after boiling}} \times 100$$

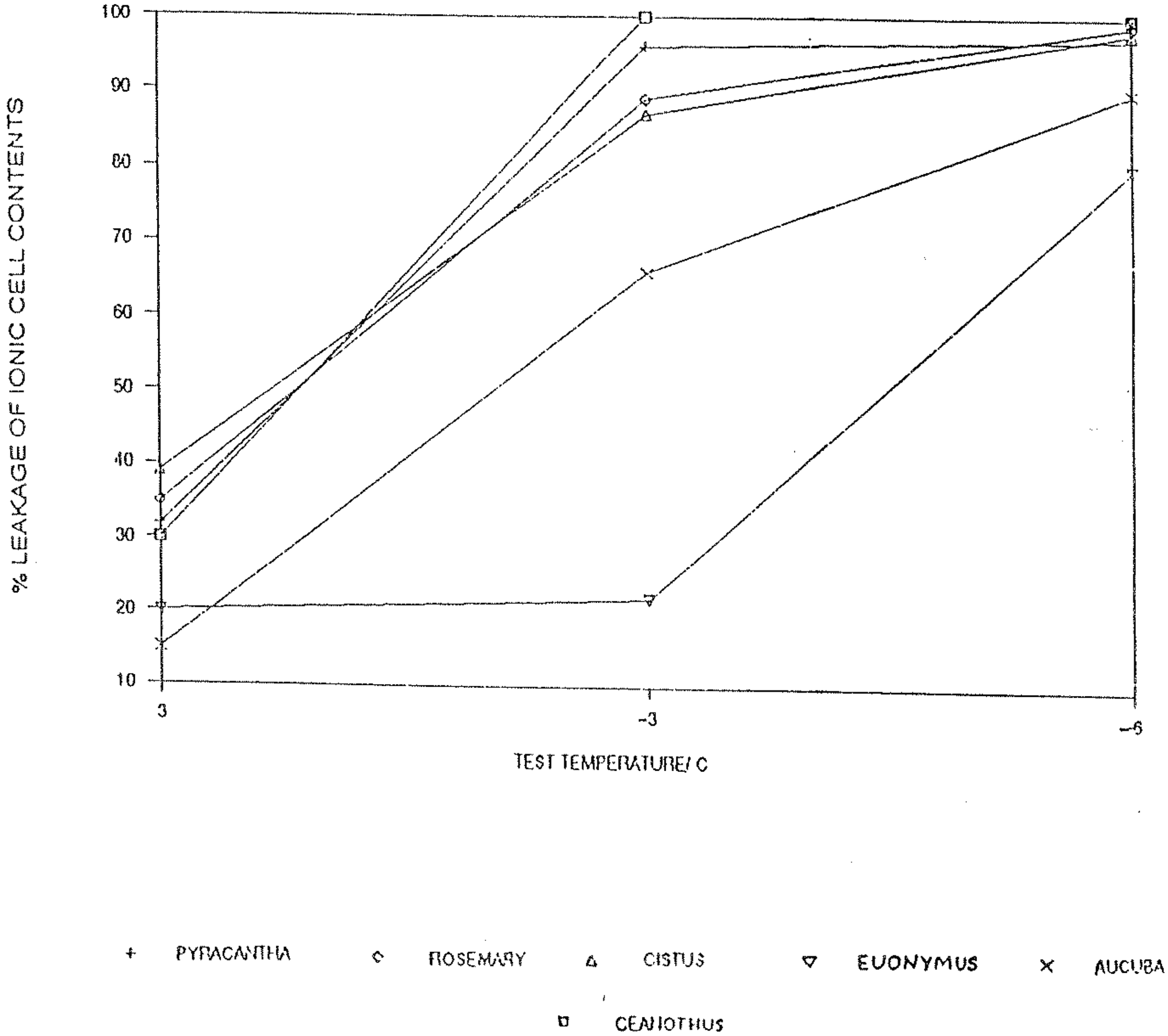
* Underlined values represent death of the roots at that test temperature.

The conductivity method may have been less accurate for old roots because their thickness prevented leakage from the centre of the tissue. Nevertheless, the results obtained followed the same pattern as for the young roots, in that a gradual increase in percent leakage was obtained from roots exposed to progessively lower temperatures.

These findings were verified by the Tetrazolium test. In this viability test, the staining still visible following freeze treatments of -9°C was only very pale, indicating that the roots were barely viable. Moreover, in separate freezing tests to -12°C and -15°C performed on old roots with subsequent assay using the Tetrazolium indicator, the stain did not react at all and the roots of all species were obviously dead after exposure at -15°C.

During the previous winter a broader spectrum of species was evaluated even though only young roots were tested. Despite the low threshold of freezing tolerance in roots, they still exhibited a range of hardiness as demonstrated in Figure 1 below. The roots of *Euonymus* and to some extent *Aucuba* were not killed outright until -6°C rather than -3°C as for the other species.

Figure 1. Comparison between species in the frost resistance of young roots



The detailed analysis of root system hardiness in the second year was carried out twice, once in autumn (1.11.89 to 8.11.90) and again in winter (9.1.90 to 18.1.90). Statistical comparison of the two tests revealed that there were increases in the frost resistance of roots (indicated by a reduction in the % leakage of ionic cell contents) between the test dates. This suggested a minor hardening capacity in roots, but there was still no significant increase in root survival at -9°C.

Comparison of heat loss from under covering materials

The data shown as graphs in Figure 2 were collected during a particularly cold February with two periods of severe frosts between the 6th and 13th and between the 19th and 28th of the month. The top set of graphs shows the maximum, minimum and mean air temperatures recorded under different covering materials, compared to an unprotected system measuring ambient air temperature. The lower set of graphs indicates temperatures within the compost of packed pots as influenced by the covers above them.

During the periods of severe frost the compost temperatures exhibited a plateau at 0°C. This represents the freezing of water in the compost during which the release of latent heat maintained the temperature at zero. In the unprotected container all the water had frozen by 20th February, thus allowing compost temperatures to fall sharply towards the lethal values for roots during the second series of hard frosts. The same pattern of freezing was apparent in the containers under white polythene, although the freezing of water delayed sharp decreases in temperature until 26th February. The fleece-like material, Coravin, prevented the compost from complete freezing throughout the cold period, but had the frosts persisted, protection under this material would have failed too as the compost was almost frozen solid. Under the clear polythene freezing temperatures were averted because any ice that formed overnight was thawed the following day, owing to very high daytime temperatures, obvious in the top graph.

Other air temperature profiles are given in the Appendix (Figures 3-6) which demonstrate that the shading material PLS 50 (Ludvig Svensson) made with polyester and aluminium strips shows the same efficiency as another fleece-like material, Base UV40 (Mylan Products), in preventing heat loss around containers

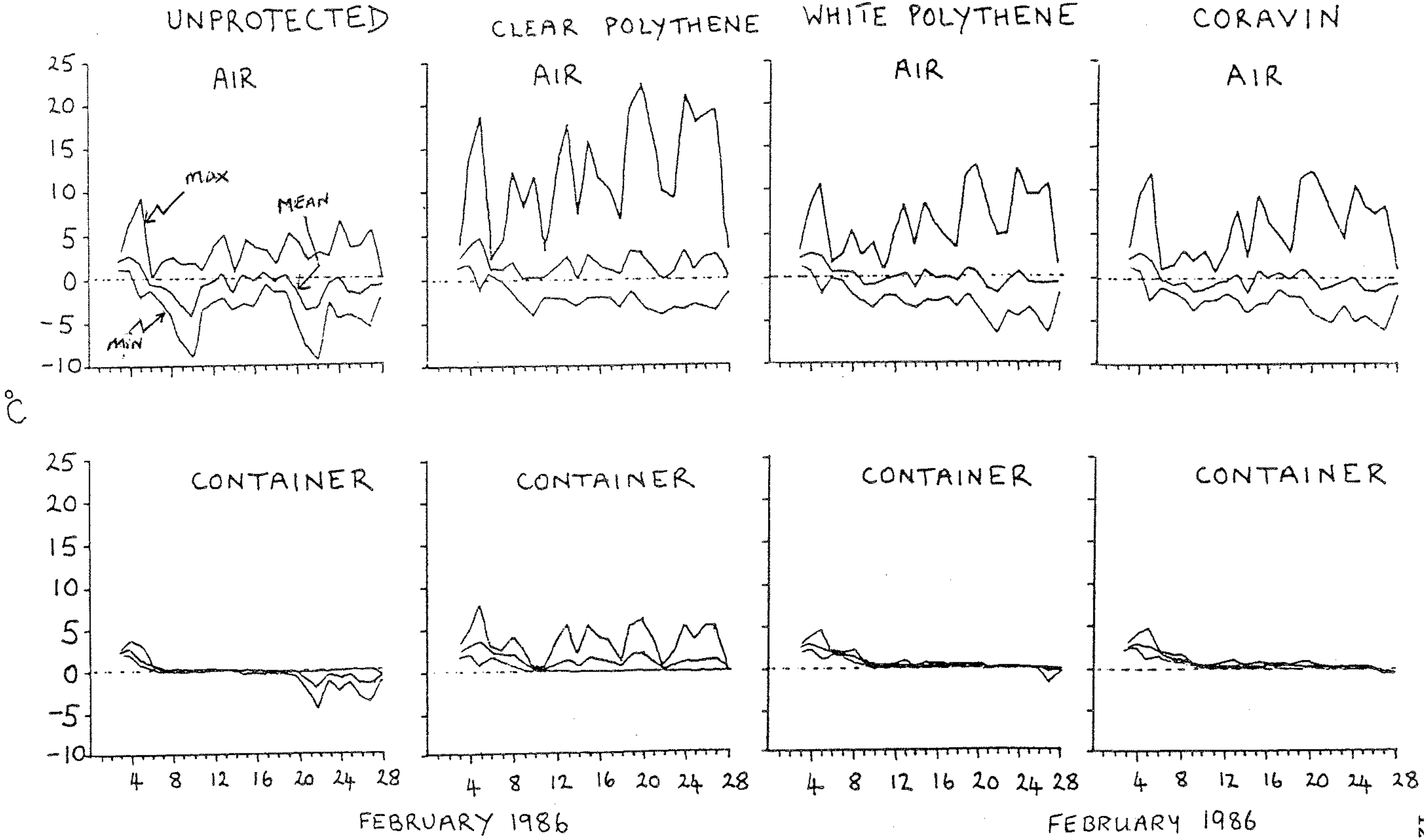
CONCLUSIONS

The work carried out in this project has highlighted some important facts concerning the cold tolerance of nursery stock species. Similar investigations have been made by other workers (Pellett *et al.* 1981, Sakai 1982) but these studies concentrated on other species or varieties grown in different climates to those of interest here. The HDC research has pinpointed which sub-freezing temperatures result in economically important damage to species commonly grown in the UK. In conjunction with these findings, direct comparison of the thermal mechanics of different covering materials has indicated which are best able to maintain temperatures above lethal values.

Broadleaved evergreen species suffer more stress during the winter than deciduous shrubs because retention of leaves allows

FIGURE 2.

Temperature Profiles Under Covers



continued transpirational water loss on sunny days which cannot be supplied if the roots are bound in frozen compost. The foliage itself suffers more damage than the leaf and flower primordia of deciduous species which are protected in buds with specialized frost resistance mechanisms (Graham and Mullin 1976, Quamme 1978). Also, many of our popular species have originated from climates without harsh winters.

An important feature, previously suspected and now highlighted in these results, was the large range in hardiness between species. Certain species must take precedence when removal to sheltered buildings is being considered and the order of priority can be seen in the tables of frost resistance. For instance, lowest survival temperature ranged from -10^{o} to $-15^{o}C$ in three *Hebe* varieties to $-25^{o}C$ for *Elaeagnus*.

The length of nutrient feeding programme had no effect on the development of frost resistance. The expectation had been that soft, tender growth encouraged by late feeding would reduce hardiness acclimation since growth cessation is a prerequisite for hardiness development. The results contrast with the experience of Stimart and Goodman (1985), who found that nitrogen application to newly rooted cuttings of *Acer palmatum* markedly increased overwintering losses owing to insufficient cold acclimation. However it is possible that these ammonium nitrate (N only) treatments had different effects to the balanced feed applied in the HDC experiment.

The experiment involving potassium application was carried out because some growers had claimed such a treatment increased hardiness. Following this hypothesis, plants treated with potassium should have scored less damage than untreated plants. It was found that the application of potassium could increase the resistance to freezing damage in some species but not all and in a minority could render shoots more susceptible to injury. This corresponds to the findings of Beattie and Flint (1973) who also discovered that higher levels of potassium had no benefit and could reduce hardiness.

The acclimation of frost resistance was affected by temperature environment. Plants developed less hardiness in the warmer environment of a polytunnel than their counterparts raised outside, as demonstrated by consistently higher damage scores in shoots taken from the polytunnel. This observation is significant because while plants may be safe in the nursery protected from temperatures below the lethal threshold, if sold in spring and left unprotected at their new site, their inherently lower frost resistance may be inadequate for survival outside. Similar risks may become more frequent in the future if nurserymen persist in the recent trend of growing containerised plants in heated glasshouses during the winter to force extra growth. The hardiness of these plants may be dangerously low and at risk from late frosts.

In the second year's trial the differences in hardiness between environments was not reproduced and for some species shoots from the polytunnel were less injured than shoots from outside plants. Reference to air temperature records, though, revealed that the temperatures in the two environments were quite similar, possibly explaining why the same depth of hardiness development was achieved in both sets of plants. Also, some plants may have suffered desiccation injury on the outside standing ground but were protected from wind in the polytunnel.

The effect of ambient temperature on hardiness development suggests that further acclimation of frost resistance could be induced by a naturally harsher winter or artificial conditioning in a colder environment. This was indeed observed for some species during experimentation but the increases in frost tolerance gained do not warrant the expense of the treatment. It emphasises, however, firstly, that the milder the autumn and early winter, the higher the risk of damage from later severe weather, and secondly, that improvements in frost resistance are inherent and could be explored by further research.

The results of the root cold resistance measurements indicate that the inability of roots to survive through winter if compost is frozen poses a major threat to the viability of whole plants. The hardiness of young roots was found to be very low, in fact root cells were completely disrupted in nearly all species at -6°C and even at -3°C in some others. Whilst the oldest roots of the plants were found to be hardier, the viability test on these, frozen to -12°, -15° and -20°C, proved the limit of root survival to be no lower than -15°C for the majority of species. These results show agreement with root hardiness tests on American-grown ornamentals (Havis 1976, Studer *et al* 1978).

A noticeable feature of the tests on root frost resistance shows that some species with quite tender shoots such as *Hebe* can have roots with comparatively large freezing resistance. In contrast, the shoot-hardy *Pyracantha* had young and old roots that were severely damaged at relatively high freezing temperatures. Despite apparent increases in resistance to root cell damage in a test later in winter, old and young roots barely displayed any capacity to harden during the season, unlike the aerial parts of the plant.

The observed lack of hardiness in roots stresses the importance of preventing containers becoming completely frozen. The release of latent heat during ice formation provides a good buffer, protecting roots from plummeting temperatures. So, whilst trying to avoid waterlogged compost in winter, keeping the medium moist rather than dry increases the benefit from this method of protection. Another factor is the risk of desiccation injury in shoots which continue to transpire water that cannot be replaced from frozen compost. The temperature data in Figure 2 indicate that most types of covering material help to delay container freezing compared to the unprotected situation, but if the cold period is sufficiently prolonged even these forms of protection will fail and additional heat must be supplied. The clear polythene appeared to provide good protection against freezing, but the exceedingly high day-time temperatures could eventually prove dangerous. Firstly, there could be risk of desiccation injury because warmth around the shoots encourages transpiration, but water cannot be supplied from roots bound in frozen compost, and secondly, the development of hardiness in plants in this warm environment would be far from efficient, so if the protection was removed too soon the plants would be very susceptible to further frosts.

Similar recordings of air and compost temperatures on 26th November 1989 (Appendix, Figures 3 and 4 respectively) demonstrated again that sunshine trapped under clear polythene during the day helped to offset heat loss at night but that these maximum temperatures could be excessive. The graphs also indicate that Base UV40, a polypropylene, "fleece-like" material maintained the compost above $0^{\circ}C$, whereas the unprotected compost fell to a temperature of $-3^{\circ}C$. Although the compost under the shade material PLS50 started to freeze on that occasion, net radiation measurements indicate that the rate of heat loss from the two materials is very similar. In contrast, clear polythene allows greater long wave radiation loss from beneath it than PLS50 did (Appendix, Figure 6) emphasising that it is not really as efficient as it may appear.

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APPENDIX

Figure 1. Cooling programme for frost resistance test on shoots

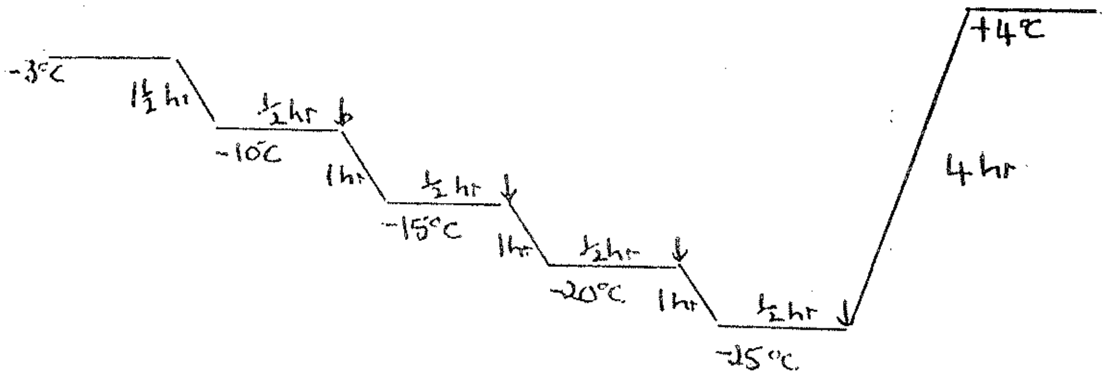


Figure 2. Cooling programme for frost resistance test on roots

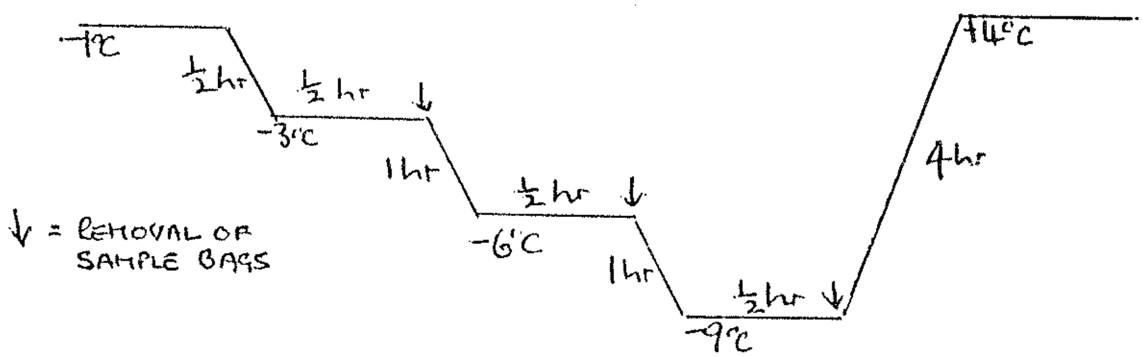


Table 1. Frost resistance of shoots in October 1988 - Summary of descriptions of damage

SPECIES	TEST TEMPERATURE						
	-3°C	-6°C	-9°C	-10°C	-12°C	-15°C	-20°C
Ceanothus thyrsiflorus	Min	Dam	Damage				
Camellia 'Debbie'	Dam	Dam	Death				
Choisya ternata	Min	Dam	SevDamage				
Euonymus fortunei		Min	Damage				
Escallonia		Min	Damage				
Hebe franciscana		Min	Dam	Death			
Hebe 'Carl Teschner'		None	Min	Dam	Death		
Myrtus communis			Dam	Dam	Death		
Rosmarinus			Min	Min	Damage		
Cistus corbaryensis					Min	Min	SevD
Elaeagnus pungens					None	Dam	SevD
Elaeagnus x ebbingei					None	Min	Dam
Aucuba japonica					None	Min	SevD
Pyracantha						None	Min

Table 2. Frost resistance of shoots in early December 1988 - Summary of descriptions of damage

SPECIES	TEST TEMPERATURE			
	-6°C	-8°C	-10°C	-12°C
Hebe franciscana	Minor	Damage	Death	
Hebe 'Carl Teschner'		None	Minor	SevDam
Escallonia		None	Minor	SevDam
Rosmarinus officinalis		Minor	Minor	Damage
Myrtus communis		Minor	Minor	Damage
Ceanothus thyrsiflorus		None	Minor	Damage
Camellia 'Debbie'		None	Minor	Minor
Choisya ternata			None	Minor
Euonymus fortunei				None

KEY for abbreviations

Min = Minor damage (Injury to some leaves)
Dam = Damage
SevD = Severe Damage (Extensive browning of leaves and stem)

Table 3. Frost resistance of shoots in April 1989 - Summary of results in terms of average damage scores

SPECIES	TEST TEMPERATURE UNFROZEN	-5°C	-10°C	-15°C	-20°C
Aucuba japonica	1.0	1.6	4.0	4.0	4.0
Elaeagnus x ebbingei	1.0	1.0	4.0	4.0	4.0
Escallonia	1.0	1.5	3.9	4.0	4.0
Camellia 'Debbie'	1.0	1.4	3.7	4.0	4.0
Euonymus fortunei	1.0	1.2	3.5	4.0	4.0
Hebe franciscana	1.1	1.1	3.2	4.0	4.0
Elaeagnus pungens	1.0	1.0	3.0	4.0	4.0
Pittosporum	1.2	1.2	2.9	4.0	4.0
Ceanothus thyrsiflorus	1.0	1.4	2.9	3.9	4.0
Choisya ternata	1.0	1.1	2.4	3.9	4.0
Hebe 'Carl Teschner'	1.0	1.1	2.3	4.0	4.0
Cistus corbaryensis	1.0	1.0	2.7	3.8	4.0
Rosmarinus officinalis	1.2	1.1	2.1	3.9	4.0
Pyracantha	1.0	1.1	1.9	3.6	4.0
Garrya elliptica	1.1	1.0	1.3	3.3	4.0
Cupressus macrocarpa	1.0	1.1	1.9	3.6	4.0

Significance of the injury represented by the scores:

No damage	Less than	1.5
Slight damage		1.5 - 2.4
Severe damage		2.5 - 3.4
Death	More than	3.4

Table 4. Frost resistance of roots in October 1988 - Results of conductivity test as graphed in the text

SPECIES	TEST TEMPERATURE UNFROZEN	-3°C	-6°C
Ceanothus thyrsiflorus	30	<u>100</u>	<u>100</u>
Pyracantha	32	<u>96</u>	<u>97</u>
Rosmarinus officinalis	35	<u>89</u>	<u>99</u>
Cistus corbaryensis	39	<u>87</u>	<u>98</u>
Escallonia	27	79	<u>98</u>
Elaeagnus x ebbingei	20	74	<u>101</u>
Elaeagnus pungens	16	63	<u>106</u>
Aucuba japonica	15	66	<u>90</u>
Hebe franciscana	32	48	<u>94</u>
Hebe 'Carl Teschner'	30	46	<u>99</u>
Euonymus fortunei	20	22	80

* Underlined values represent death of the roots at that test temperature.

Figures 3 and 4. Comparison of air and compost temperatures under different covering materials including an unprotected system

Figures 5 and 6. Comparison of heat loss from under different types of covering material, measured by net radiometers

<u>KEY for Legends in Figures 3 - 6</u> (See over page)

UNPROT - Unprotected system

CPOLY - Clear Polythene

WPOLY - White Polythene

UV40 - Base UV40 (Mylan Products), a "fleece-like" fabric of bonded polypropylene

PLS50 - PLS50 (Ludvig Svensson), a shading material of polyester, interwoven with aluminium strips

FIG. 3

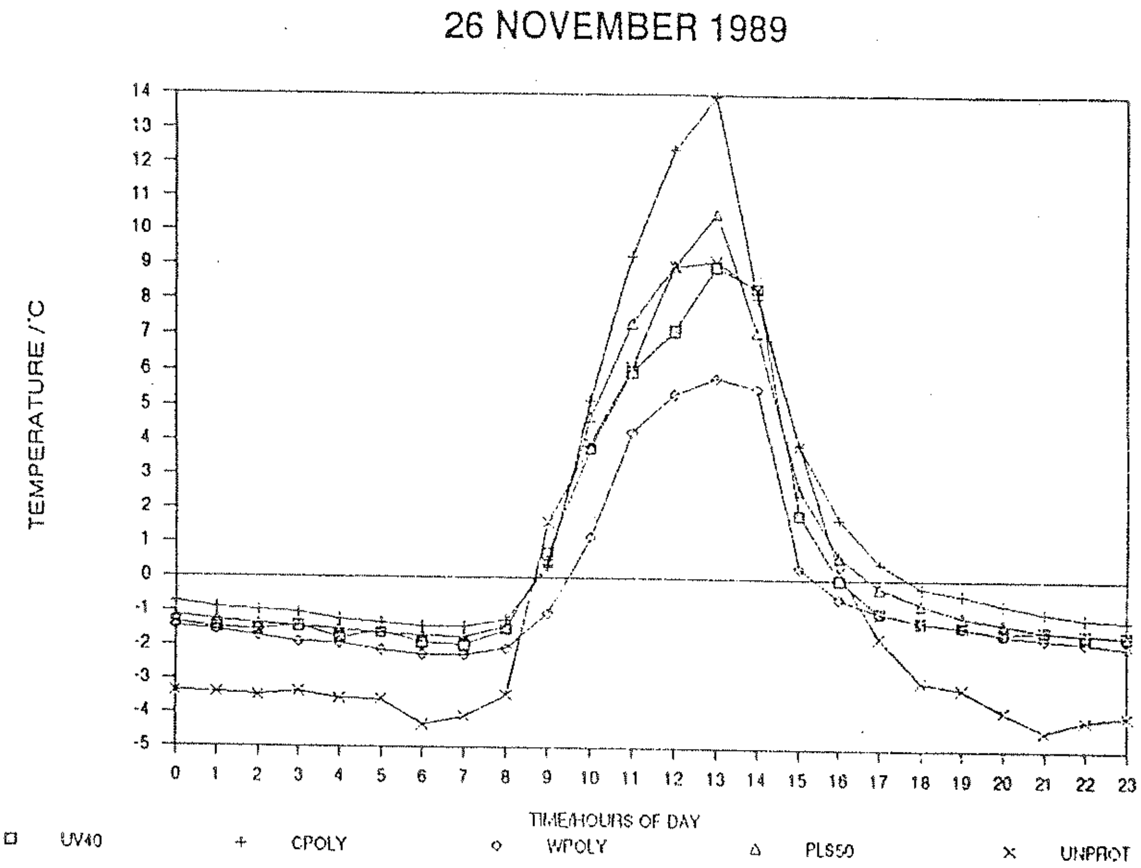

26 NOVEMBER 1989
TEMPERATURE /°C
TIME/HOURS OF DAY
UV40
CPOLY
WPOLY
PLS50
UNPROT

FIG. 4

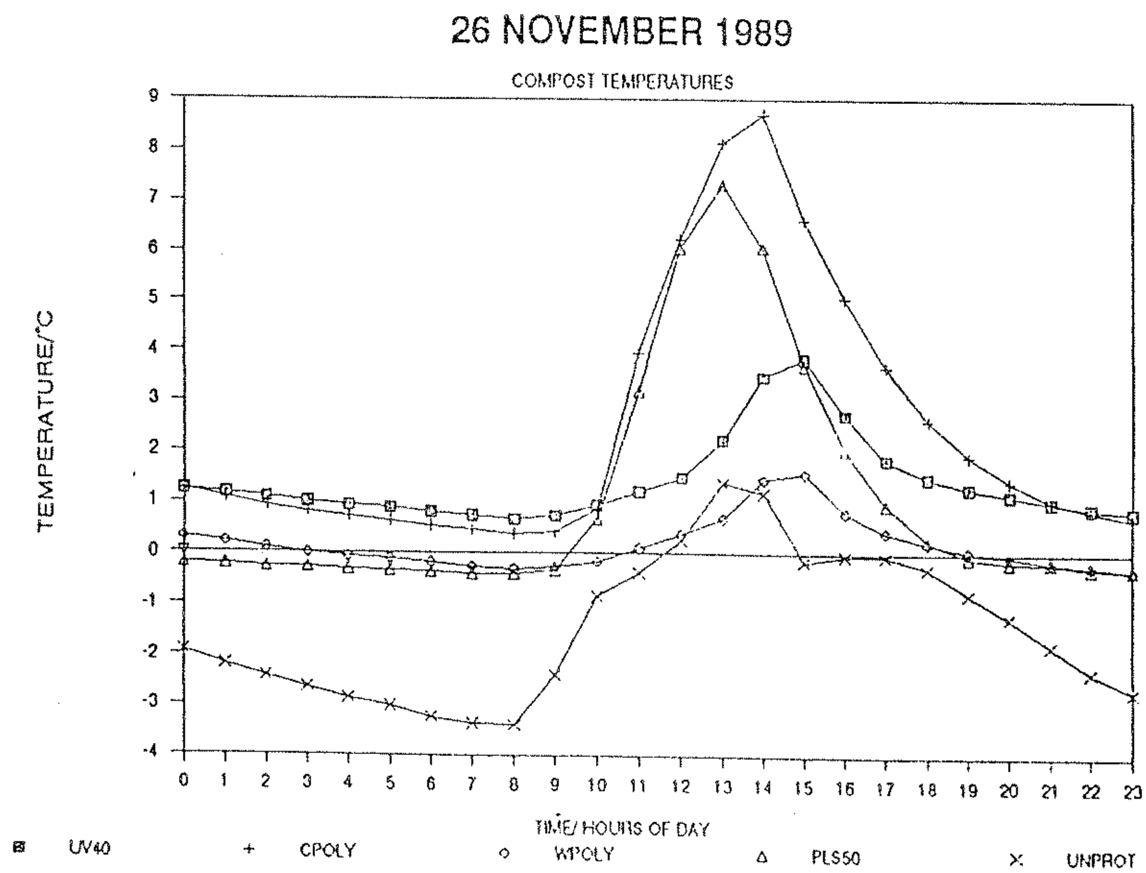

26 NOVEMBER 1989
COMPOST TEMPERATURES
TEMPERATURE/°C
TIME/ HOURS OF DAY
UV40
CPOLY
WPOLY
PLS50
UNPROT

FIG. 5

20 JANUARY 1990

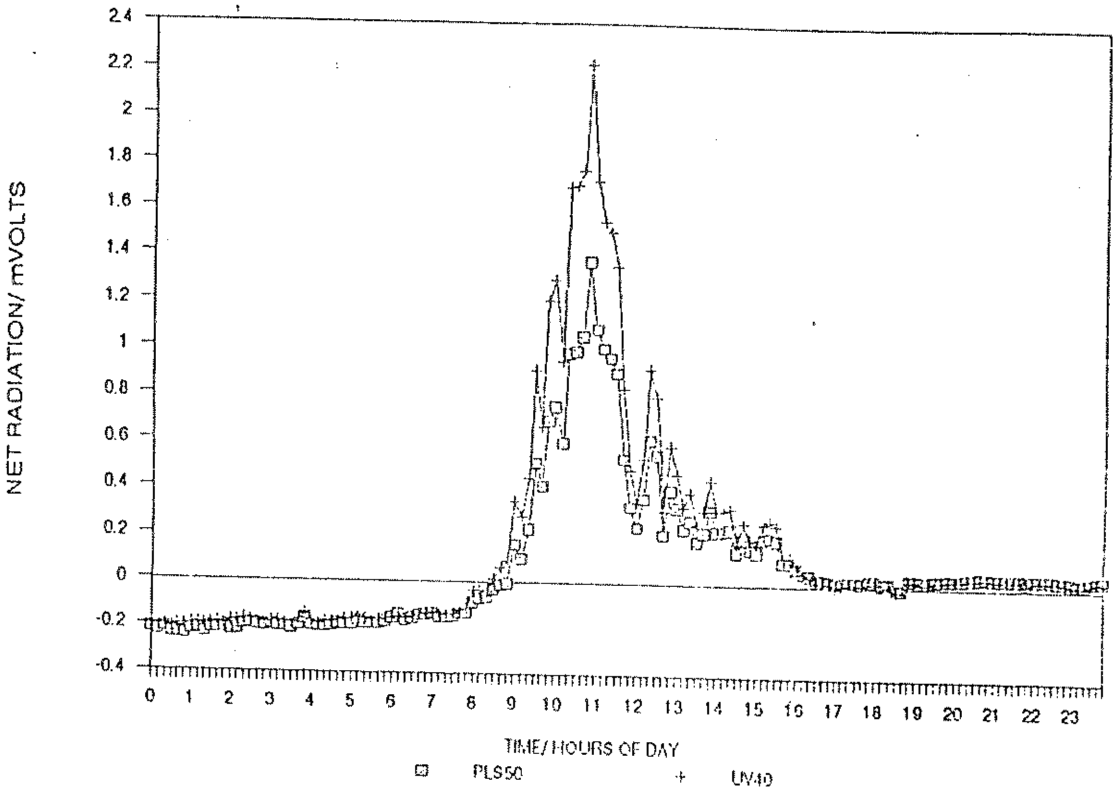
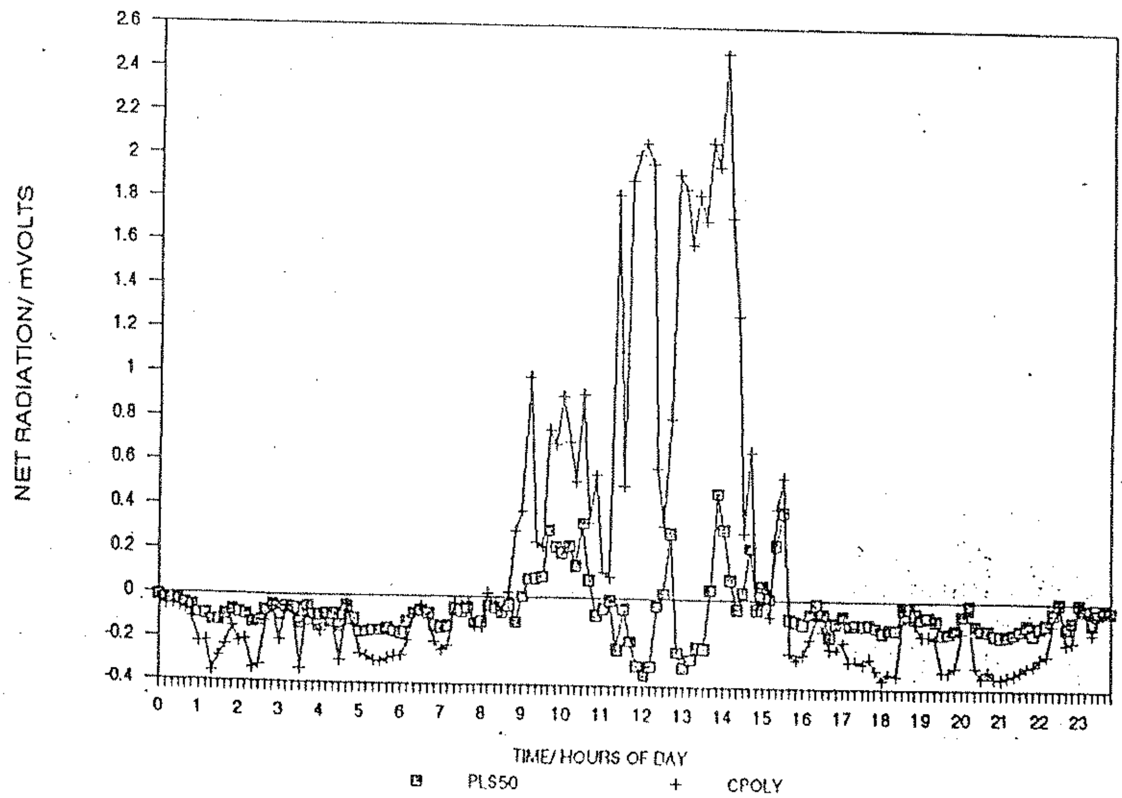


FIG. 6

2 FEBRUARY 1990



Tetrazolium Stain Test

Procedure

Prepare a fresh aqueous solution of 0.5% 2,3,5 triphenyl tetrazolium chloride (e.g. 5g/litre). This can be obtained from most major drug companies, e.g. Sigma Chemical Company, Fancy Road, Poole, Dorset BH17 7TG (£6.50 for 10 g, 1990 price).

Cut the shoot or root into thin slices and cover with the solution. Incubate at room temperature (10-30°C) for 24 hours in stoppered tubes or closed jars, in the dark.

The colour of the cut surfaces of viable tissue will be pink to bright red depending on the species and type of tissue. Dead tissue will not take the stain.