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THE SURVIVABILITY AND POST-FREEZE PERFORMANCE OF OVERWINTERED CONTAINER-GROWN NURSERY STOCK

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THE SURVIVABILITY AND POST-FREEZE PERFORMANCE OF OVERWINTERED CONTAINER-GROWN NURSERY STOCK

By

Jennifer Leigh Dwyer

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ABSTRACT

The Survivability and Post-Freeze Performance of
Overwintered Container-Grown Nursery Stock

By

Jennifer Dwyer

The nursery industry continues to develop improved methods for successfully overwintering container-grown nursery stock. The influence of several overwintering systems and controlled temperature evaluations was tested on selected plant cultivars. During the winter of 1993-94, plant injury was less for cultivars hardy in USDA Hardiness Zone 5 and greater for cold-sensitive cultivars. Root survival of some cultivars was influenced by the overwintering system used, but the influence was cultivar-dependent. Cold-sensitive cultivars were not significantly influenced by the overwintering systems. Controlled freezing evaluations and visual observations of the post-stress performance of container-grown nursery stock showed the differences in deacclimation among plants ranging from cold hardy to cold-sensitive. Plants overwintered in a polyhouse exhibited reduced hardiness levels compared to those overwintered in an outdoor pot-in-pot system. All cultivars were more cold tolerant in 1993-94 than they were in 1994-95. Significant shoot injury occurred in cultivars which are native to warmer regions. Generally, cultivars overwintered in a polyhouse deacclimated earlier than they did in the pot-in-pot system. However, the polyhouse system did not necessarily influence the rate of deacclimation. The response of cultivars evaluated in a controlled deacclimation study was similar to the response of those cultivars overwintered in a polyhouse.

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SIGNIFICANCE TO THE NURSERY INDUSTRY

Cold temperatures frequently limit the production of container-grown nursery stock in northern regions. Roots in container culture are susceptible to injury during extreme cold periods. Various systems of overwintering protection are used by growers to reduce injury to container-grown plants. Some plants receive too much protection and are injured if removed from the overwintering system too soon after shoots have deacclimated. Injury can be avoided if plants are protected after full acclimation and managed properly to prevent early deacclimation. This study investigates different types of overwintering systems and their influence on the acclimation, mid-winter hardiness, and deacclimation of roots and shoots of several container-grown cultivars. Variation in hardiness levels of plants influenced by different overwintering systems and the deacclimation rates of these cultivars were evaluated. My results suggest that the influence of overwintering systems depends on plant cultivar. Also, the rate of plant deacclimation varies when influenced by different overwintering systems.

INTRODUCTION

The nursery industry is concerned with successfully overwintering container-grown nursery woody ornamentals. Overwintering is the most limiting factor for nurseries growing container stock in northern regions (12). The use of container-grown nursery stock has increased over the past few decades. Plant production using container-grown stock was introduced in California and became widely used in the southern regions of the United States (17). Cultural and marketing advantages of container-grown stock make it a desirable practice in the northern regions. Container-grown plants allow for increased plant quantity and variety, decreased labor costs and increased control of the environmental factors influencing the plants.

The change from field to container stock has created some difficulties. Low temperatures and sudden fluctuations in temperatures present problems for the root and shoot systems (18). Several overwintering systems, which reduce injury caused by low temperatures, have been tested. None of these systems are suitable to protect the extensive range of plant materials and hardiness qualifications that exist in USDA Hardiness Zones 5 through 8 (1). Each system offers a different level of protection for plant species and cultivars, which vary from cold hardy to cold-sensitive. Many overwintering systems are designed to protect the root systems because previous research indicates that they are less hardy than the shoots and stem (8). Roots are less hardy because the soil environment in a container is less severe than the air conditions to which the shoot system must acclimate (16). Magness (11) showed that roots which were exposed to air during the summer were hardier in the fall and winter than roots in soil. Previous research on *Pyracantha coccinea* `Lalandi' showed that the leaves and stem can survive when exposed to an air temperature of -26°C (-15°F), mature roots can survive to -17°C (-2°F), and young roots can survive to -6°C (22°F) (6). Although roots are more sensitive than shoots, they are only one factor which must be considered when overwintering plants.

The difference in hardiness between roots and shoots is attributed to the environmental signals each receives. The rate and level of shoot hardiness is a function of the plant's environmental conditions and genetic potential, and specifically, short days and low temperatures are the signals which induce hardiness and dormancy in the shoots.

Root hardiness increases as low temperatures become more constant. Roots do not become dormant, but their growth is inhibited as they are exposed to low temperatures (8). The degree of root injury at a given temperature varies among genera, species, and cultivars. Container-grown plants with warm root-killing temperatures are commonly stored in energy conserving overwintering systems (7). These systems should protect roots from the minimum nightly temperatures during the winter. Root injury can be minimized by storing plants at a temperature at least 3-5°F above the killing temperature for a given genus (3). One system, the polyethylene storage structure or quonset style polyhouse, has become the standard protective measure for overwintering. Polyhouses utilize the insulating effects of the ground to warm the surrounding air (2). These structures protect plants from wind and snow and reduce desiccation injury. In polyhouse storage, growers have easy access to plants which allows for efficient transport during early spring shipments.

The buildup of warm air in the polyhouse in the spring can induce early deacclimation of shoots. Late spring frosts can injure the shoots of the plants if the protective cover is removed too early. The well-protected roots may result in reduced quality shoots, which is very costly to the grower. In studies of different polyethylene film opacities to determine their effects on heat buildup and plant quality, clear (5-10% opacity) and white (30, 55, or 70% opacity) films were compared (18). Clear films resulted in increased air and soil temperature fluctuations which reduced plant quality. Smith (14) concluded that plants stored under 70% opacity white film demonstrated high performance. White films reduced variations between the minimum and maximum daily ambient air and media temperatures (19). Other reports indicated that black film (100% opacity) caused defoliation of some species (18).

Once researchers concluded that plants stored under white films resulted in acceptable plant quality, studies were focused on the timing of winter protection. Researchers stressed the importance of full natural acclimation prior to overwintering in a polyhouse (1,13). Occasional severe winters and mid-spring frosts present a challenge to polyhouse storage when plants have not been adequately acclimated. Previous winter temperatures and species' root and shoot hardiness should dictate the timing of application and removal of the polyethylene film.

Overwintering plants in polyhouses allows nurseries to make shipments of plant material in late winter and early spring (4). The demand for plants in early spring has provided an incentive for growers to determine how to deacclimate their plants for early shipments. Polyhouse structures are the primary storage structures for plants which require deacclimation for early shipments. Species vary in their timing of deacclimation, so storing species with similar deacclimation rates together permits the grower to time the removal of polyethylene film so that all plants will be at the same growth stage.

Little information about the geographic origin and the cold hardiness of new cultivars is available to the grower. Previous research has shown that variations in hardiness exist within plant species having wide geographic ranges (5). Smithberg and Weiser (15) found that *Cornus stolonifera* plants collected from 21 geographical areas varied in average annual minimum hardiness from -16°C to -54°C (-3°F to -66°F). The *Cornus* plants all eventually hardened to -90°C (-130°F), but the plants from southern sources acclimated more slowly. This study and other similar reports indicate the necessity for acclimation rates and timing for the purpose of increasing the effectiveness of protection of popular species and cultivars.

Some species do not require overwintering protection. Species of *Rhododendron*, Juniper, *Pyracantha*, and *Cotoneaster* were successfully overwintered to a minimum outdoor temperature of -33°C (-28°F) (17). Other species, which are cold-sensitive, perform well if protected in polyhouse storage (10). The amount of protection for each species depends on the root-killing temperatures reported for those species (8,9).

This research presents results of an evaluation of root and shoot-killing temperatures of several popular genera and cultivars in Michigan. Knowledge of root and shoot-killing temperatures will contribute to the selection of cold tolerant salable nursery stock in Michigan. The examination of several overwintering systems and their effects on plant quality and root and shoot survival will lend insight to growers who are attempting to protect their nursery stock most effectively. The rates and timing of acclimation and deacclimation should aid in determining the amount and timing of protection required by several cultivars. Protecting plant roots without injuring the shoots and eliminating protection of plants which do not require it will reduce protection costs and loss of plant material.

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CHAPTER I

THE INFLUENCE OF OVERWINTERING SYSTEMS ON ROOT CONDITION AND WHOLE PLANT PERFORMANCE.

ABSTRACT

The Influence of Overwintering Systems on Root Condition and Whole Plant Performance

The nursery industry continues to develop improved methods for successfully overwintering container-grown nursery stock. Systems under which plant shoots adapt and survive may not provide adequate protection for the less cold tolerant roots. Overwintering systems used to protect many plant cultivars ranging from cold hardy to cold-sensitive are chosen based on previously reported shoot tissue hardiness. In the pot-to-pot system under ambient field conditions, the percentage of dead plants was high for cultivars native to warmer regions and low for those native to northern regions. The majority of plant injury for most cultivars occurred when minimum temperatures ranged from -21°C (-5°F) to -29°C (-20°F). Root tissue condition of *Weigela florida* 'Java Red', *Physocarpus opulifolius* 'Dart's Gold', and *Spiraea* X *bumalda* 'Anthony Waterer' was significantly influenced by different overwintering systems, however, the influence depended on plant cultivar. Lowest root hardiness levels of the hardy cultivars occurred in the pot-to-pot system, however, the hardiness differences between systems were not always significant. For cold-sensitive cultivars, the overwintering systems did not significantly influence the levels of root hardiness. The controlled freezing of small and large potted plants demonstrated similar results between controlled laboratory freezing and field assessments.

INTRODUCTION

Container production of ornamentals in nurseries increases each year. However, successful overwintering of many genera, species, and cultivars is difficult because of the threat of root injury. Root injury caused by low temperature stress is problematic when overwintering container-grown ornamentals in northern regions (6). Container-grown nursery stock are more sensitive to root injury than field-grown plants because container plants are exposed to more harsh conditions. The root is one of the most sensitive of plant tissues to lower temperatures and temperature fluctuations. The above-ground roots of container-grown plants are more vulnerable because the media freezes and thaws more frequently, which increases the susceptibility to root injury (10).

During the onset of winter, the roots are exposed to continually decreasing temperatures and the rate of hardiness increase is 1-2°C per day (13). However, during the period of acclimation, high daily temperatures may sometimes follow low daily temperatures. Temperature fluctuations may cause container media to thaw and quickly freeze again over a period of a few hours. Thawing reduces plant hardiness, but plants can regain hardiness if re-exposed to low temperatures (3). Although roots do not acquire dormancy, root growth will stop below a threshold temperature (4). Roots should be maintained in this state during the duration of low temperatures.

Cold tolerance varies depending on the location in the root system (11). The root area near the base of the stem is most tolerant of cold temperatures, while the area near the root tips is less cold tolerant. If kept low throughout the winter, temperatures in the container medium can prevent new roots from forming. Mityga and Lanphear (11) concluded that young roots do not substantially acclimate and the injury of those located near the container surface does not significantly affect shoot growth.

Nursery growers need to know root hardiness estimates for genera, species, and cultivars when planning protective systems for overwintering. Root hardiness levels of several genera have been reported previously (6,7,11,12). However, the difficulty of collecting roots from frozen media during the winter is a deterrent for such studies (16). There remains a need for additional estimates of root-killing temperatures for commercially important species and cultivars.

Root hardiness variations among species and specifically, cultivars, have been the focus of too few studies (4,6,11). Many cultivars are introduced each year without an adequate assessment of their hardiness capabilities (2). Frequently, plants are selected for sale based on their reported performance in different geographic regions. Therefore, plants may be more or less hardy than suggested in previous studies. Precise and accurate hardiness information will allow growers to choose an overwintering system that would best protect their selection of plant material.

The optimum overwintering system for container-grown plants depends on several factors. Geographic region, seed source, and plant genus, species, or cultivar influence the grower's choice of a protective system. Of the several types of overwintering systems currently utilized for the survival of roots, unheated white polyethylene (poly)-covered structures, or polyhouses, are the most common. The white poly on polyhouse structures provides partial protection by reducing some infrared light energy from the sun, helping to prevent heat buildup inside the structure (9). The heated air, in combination with ground heat, warms the container media and protects the plants from being exposed to the minimum ambient air temperatures. However, polyhouses may warm container media too much, so that roots are less hardy than those plants not protected (14). If the polyhouse were damaged during the winter, the root systems may not be able to withstand the ambient air temperatures.

The pot-in-pot system is gaining a strong following among growers. Plants overwintered pot-in-pot are protected from the fluctuating temperatures that occur during the sunny winter days and cold winter nights. The ground under and surrounding the pots builds up heat and warms the media in the container. This overwintering system minimizes the variation between the minimum and maximum daily media temperatures and reduces the freezing and thawing of roots in the container.

Another overwintering system which is used by some growers involves storing plants pot-to-pot under ambient field conditions. Plants are placed closely together and heat is trapped in the air spaces between the pots and in the ground under the pots. In this system, plants are exposed to the winter sun, snowfall, winds, and low temperatures.

In addition to plant survival, the quality of growth and development following overwintering is important. Temperatures that cause a significant amount of root injury are as important as root-killing temperatures. Previously reported root-killing temperatures suggested low temperature thresholds for certain genera. However, temperatures warmer than the root-killing temperatures may cause significant injury to roots, thus causing plant shoots to be affected. The protective limits of the overwintering structures used and their effects on several species and cultivars must be known to ensure top quality nursery stock (5).

This research was conducted to determine the influence of different overwintering systems on root injury. In conjunction with the overwintering systems, roots of different cultivars were exposed to temperatures manipulated by controlled temperature freezing. Plants were observed for bud break and quality of growth after exposure to low temperatures.

MATERIALS AND METHODS

Exp I. Container-grown plants listed in Tables 1.1 and 1.2 were stored above ground in two locations in Michigan from August through April, 1993-94. Chatham represented an area within USDA Hardiness Zone 4, -29°C to -34°C (-20°F to -30°F) and Lansing represented an area within Zone 5, -23°C to -29°C (-10°F to -20°F). Nursery grown plants of salable size in 20 cm (8 in) nursery pots were acclimated to ambient field conditions and manually protected from snow cover. Cultivars ranging from cold hardy to cold-sensitive were selected based on observations from a similar study during 1992-93 (Table 1.3). Minimum and maximum daily air and media temperatures were recorded and stored at the Horticulture Teaching and Research Center in Lansing by a datalogger (Campbell Scientific, Model CR10, Logan, Utah). Temperature probes were placed four inches from the media surface between the container and the media. Minimum and maximum daily ambient air temperatures were recorded in Chatham from a weather station and media temperatures were recorded by soil thermometers placed in the container media. After reaching six natural outdoor minimum temperature treatments, plants were transported in a truck from Chatham to Lansing on February 1. Plants from Lansing were collected after each of six minimum temperature treatments. Each group of plants was completely randomized with nine plants per cultivar and was placed in a greenhouse with a 21°C (70°F) day temperature and 17°C (63°F) night temperature to visually observe bud break and shoot growth.

Plant quality in each group for both locations was visually rated after 30 and 60 days of growth in the greenhouse. The plants were rated on a scale of 1 to 5, as described

Table 1.1. Naturally acclimated plants were exposed to -29°C(-20°F) on January 19, 1994. Plant condition of 18 cultivars was visually rated. Ratings are an average of nine plants. Plants were overwintered under ambient field conditions in Lansing, MI.

Plant name	**Days in greenhouse**	
	30 days	**60 days**
Euonymus alatus **'Compactus'**	3.7	1.0
Forsythia X **'Meadowlark'**	5.0	4.0
Hibiscus syriacus **'Red Lucy'**	1.7	1.0
Lonicera xylosteum **'Emerald Mound'**	3.7	3.3
Physocarpus opulifolius **'Dart's Gold'**	3.7	3.0
Potentilla fruticosa **'Goldfinger'**	5.0	3.3
Prunus X cistena	5.0	4.0
Rhamnus frangula **'Columnaris'**	3.7	3.0
Spiraea japonica **'Shirobana'**	3.3	2.3
Spiraea X bumalda **'Anthony Waterer'**	3.7	3.3
Syringa X **'Ludwig Spaeth'**	4.0	3.3
Taxus X media **'Dark Green Spreader'**	4.0	5.0
Taxus X media **'Densiformis'**	4.0	3.3
Viburnum carlesii	2.7	2.7
Viburnum lantana **'Mohican'**	3.0	1.3
Viburnum p.t. **'Mariesii'**	1.7	1.7
Weigela florida **'Bristol Ruby'**	5.0	4.0
Weigela florida **'Java Red'**	5.0	4.0

Where:
1=Dead (no leaves; no buds; shoot and stem tissue are brown)
2=Slight chance of surviving (leaves are few and brown; few or no buds; considerable amount of twig dieback)
3=Probable chance of surviving (buds are forming; a lot of twig dieback, with buds forming at the base of the plant)
4=Healthy plant, but some twig dieback (leaves are full-sized; large amount of shoot growth; many buds are forming)
5=Healthy plant (no twig dieback; vigorous shoot growth)

Table 1.2. Naturally acclimated plants were exposed to -29°C(-20°F) on January 19, 1994. Plant condition of 14 cultivars was visually rated. Ratings are an average of nine plants. Plants were overwintered under ambient field conditions in Chatham, MI.

Plant name	**Days in greenhouse** **30 days**	**60 days**
Euonymus alatus **'Compactus'**	3.7	3.3
Forsythia X **'Meadowlark'**	5.0	5.0
Hibiscus syriacus **'Red Lucy'**	1.7	1.7
Lonicera xylosteum **'Emerald Mound'**	3.3	3.0
Physocarpus opulifolius **'Dart's Gold'**	NA	NA
Potentilla fruticosa **'Goldfinger'**	4.0	3.0
Prunus X cistena	5.0	3.7
Rhamnus frangula **'Columnaris'**	4.0	3.3
Spiraea japonica **'Shirobana'**	3.0	2.3
Spiraea X bumalda **'Anthony Waterer'**	3.3	3.0
Syringa X **'Ludwig Spaeth'**	5.0	4.0
Taxus X media **'Dark Green Spreader'**	NA	NA
Taxus X media **'Densiformis'**	NA	NA
Viburnum carlesii	NA	NA
Viburnum lantana **'Mohican'**	3.7	3.0
Viburnum p.t. **'Mariesii'**	1.7	1.7
Weigela florida **'Bristol Ruby'**	5.0	4.3
Weigela florida **'Java Red'**	5.0	4.3

NA=Plants used in Lansing, but not available for Chatham

Where:
1=Dead (no leaves; no buds; shoot and stem tissue are brown)
2=Slight chance of surviving (leaves are few and brown; few or no buds; considerable amount of twig dieback)
3=Probable chance of surviving (buds are forming; a lot of twig dieback, with buds forming at the base of the plant)
4=Healthy plant, but some twig dieback (leaves are full-sized; large amount of shoot growth; many buds are forming)
5=Healthy plant (no twig dieback; vigorous shoot growth)

Table 1.3. Naturally acclimated plants were exposed to -22°C(-7°F) on January 2, 1993. Plant condition of 18 cultivars was visually rated. Ratings are an average of 30 plants. Plants were overwintered under ambient field conditions in Chatham, MI.

Plant name	Days in greenhouse 30 days	90 days
Cornus sericea 'Isanti'	2.7	2.7
Cotinus coggygria 'Royal Purple'	2.1	2.1
Forsythia viridissima 'Bronxensis'	2.1	2.1
Hibiscus syriacus 'Jeanne dArc'	1.9	1.4
Hibiscus syriacus 'Red Lucy'	2.3	2.0
Hydrangea macrophylla 'Nikko Blue'	2.7	2.5
Hydrangea macrophylla 'Pink Beauty'	2.4	2.3
Lonicera xylosteum 'Emerald Mound'	4.2	4.3
Prunus X cistena	2.2	2.2
Spiraea X bumalda 'Anthony Waterer'	4.9	4.9
Spiraea X bumalda 'Crispa'	4.2	4.4
Syringa meyeri 'Palibin'	2.2	2.1
Syringa patula 'Miss Kim'	3.5	3.2
Viburnum carlesii	2.6	2.7
Weigela florida 'Bristol Ruby'	5.0	4.7
Weigela florida 'Bristol Snowflake'	5.0	4.8
Weigela florida 'Pink Princess'	5.0	4.7
Weigela florida 'Variegata'	4.7	4.0

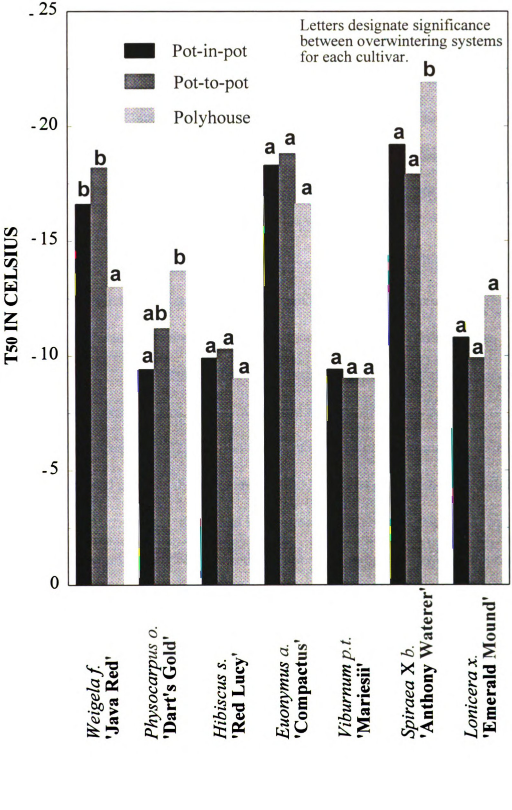
Where:
1 = Dead (no leaves; no buds; shoot and stem tissue are brown)
2 = Slight chance of surviving (leaves are few and brown; few or no buds; considerable amount of twig dieback)
3 = Probable chance of surviving (buds are forming; a lot of twig dieback, with buds forming at the base of the plant)
4 = Healthy plant, but some twig dieback (leaves are full-sized; large amount of shoot growth; many buds are forming)
5 = Healthy plant (no twig dieback; vigorous shoot growth)

in Table 1.1. The percentage of dead plants exposed to two minimum ambient air temperatures in each location was also determined.

Exp II. Seven cultivars, listed in Figure 1.1, were stored in Lansing from mid-August through January 1994. Nursery grown plants of salable size in 20 cm (8 in) nursery pots were placed in one of three overwintering treatments: pot-in-pot (below the ground), pot-to-pot (above the ground), and inside a polyhouse. Plants were stored in the center of an 18' x 96' polyhouse covered with 55% opacity white polyethylene in an east-west orientation. Plants in the pot-in-pot and pot-to-pot treatments were exposed to ambient field conditions. All plants overwintered above ground outside and inside the polyhouse were placed on a gravel surface. Minimum and maximum daily ambient air and media, pot-in-pot media, and polyhouse air and media temperatures were collected by a datalogger, as previously described. On January 23, 1994, three plants per cultivar per treatment method were collected. The 63 plants were soaked in water at 21°C (70°F) for eight hours to allow the potting media to thaw. After thawing, the stems were cut at the soil surface and the potting media was washed away from the roots. Each rootball was placed into a separate poly bag with moist gauze to prevent the roots from drying. The rootballs were placed in a cooler at 3°C (37.4°F) overnight.

In preparation for controlled temperature freezing, the rootballs were cut open and samples were collected from the largest, centrally located mature roots. For each overwintering treatment, 15 roots were collected from each pot. Each root was excised into three 5 cm (2 in) piece samples. Root diameter varied among cultivars. The root samples were placed on masking tape templates and prepared using the method previously developed and described (8,15). Each temperature treatment was represented

Figure 1.1. Mean root tissue T_{50}s in celsius of seven cultivars influenced by three overwintering systems. Plants were exposed to an ambient air temperature of -29°C (-20°F) on January 19, 1994.


Letters designate significance between overwintering systems for each cultivar.
Pot-in-pot
Pot-to-pot
Polyhouse
T50 IN CELSIUS
-25
-20
-15
-10
-5
0
b b a
a ab b
a a a
a a a
a a a
a a b
a a a
Weigela f. 'Java Red'
Physocarpus o. 'Dart's Gold'
Hibiscus s. 'Red Lucy'
Euonymus a. 'Compactus'
Viburnum p.t. 'Mariesii'
Spiraea X *b.* 'Anthony Waterer'
Lonicera x. 'Emerald Mound'

by three replications, with three observations per replication wrapped in bundles. Controlled temperature freezing was manipulated in a Revco Ultralow freezer with a temperature controller (Omega Engineering, Stamford, CT). The temperature inside the freezer was programmed to decline at a 4°C interval each hour for four hours. Temperature treatments ranged from a temperature at which roots would show no tissue injury to a temperature that would cause tissue death, as well as a control at 3°C (37.4°F). The temperature treatments were chosen based on concurrent research of shoot tissue from these cultivars.

When each critical temperature within the freezer was reached, three bundle replications were placed in the cooler, where the control bundles were stored, to thaw overnight. The root samples were stored in the humidity chamber for five days, as previously described (8). The temperature which caused browning and/or water soaking in the cambial and phloem tissues in 50% of the root samples (T_{50}) was determined using the Spearman-Karber method (1). The T_{50} values of the cultivars protected by different systems were analyzed using analysis of variance (ANOVA) to determine the influence of each system on plant quality. Statistical significance using chi-square analysis was determined from the amount of live versus dead root tissue over the temperature range.

Exp III. The eight cultivars listed in Table 1.4 were exposed to warming at 21°C (70°F) from one to eight days followed by storage at 0°C (32°F). Groups of nursery grown salable sized plants in 20 cm (8 in) nursery pots were separated based upon the number of warming days to which they had been exposed. Each group, consisting of six plants per cultivar and eight cultivars, was placed in a controlled temperature freezer. Two temperature treatments were determined for each cultivar, based on previous observations of their shoot and root minimum and maximum hardiness levels.

Temperature treatments are summarized in Table 1.4. Control plants remained in storage at 0°C (32°F).

Table 1.4. Maximum and minimum temperatures used in the controlled temperature evaluation of plants in 20 cm (8 in) pots.

PLANT NAME	MAX TEMP	MIN TEMP
Weigela florida **'Java Red'**	-12°C (10°F)	-36°C (-33°F)
Physocarpus opulifolius **'Dart's Gold'**	-9°C (16°F)	-27°C (-17°F)
Hibiscus syriacus **'Red Lucy'**	-6°C (21°F)	-24°C (-11°F)
Euonymus alatus **'Compactus'**	-12°C (10°F)	-30°C (-22°F)
Spiraea X bumalda **'Anthony Waterer'**	-12°C (10°F)	-30°C (-22°F)
Lonicera xylosteum **'Emerald Mound'**	-9°C (16°F)	-27°C (-17°F)
Forsythia X **'Meadowlark'**	-12°C (10°F)	-33°C (-28°F)
Taxus X media **'Dark Green Spreader'**	-12°C (10°F)	-36°C (-33°F)

The temperature treatments represented a temperature at which the plants would survive (maximum) and a temperature at which they would show injury or death (minimum).

Following the controlled temperature freezing, all plants were placed overnight in storage at 0°C (32°F). Plants were placed in a greenhouse at a 21°C (70°F) day temperature and 17°C (63°F) night temperature for three months and visually evaluated.

Plants were rated after 60 days in the greenhouse for bud break and shoot growth on a scale of 1 (dead) to 5 (healthy), as previously described (Table 1.1).

Exp IV. During the winter of 1994-95, three cultivars were selected for further studies on whole plant freezing. The cultivars in Table 1.5 were selected because of their range of hardiness levels as determined in previous shoot tissue hardiness evaluations. Nursery grown plants in 2 1/4"pots were used in this experiment. Temperature treatments, including a control, were represented by three plants per cultivar and were chosen based on previous evaluations of shoot and root tissue. The control and minimum temperature treatments are listed in Table 1.5.

Table 1.5. Control and minimum temperature treatments used in the controlled temperature evaluation of plants in 2 1/4"pots.

	Weigela f. **'Java Red'**	*Euonymus a.* **'Compactus'**	*Hibiscus s.* **'Red Lucy'**
Control	3°C (37.4°F)	3°C (37.4°F)	3°C (37.4°F)
Minimum	-30°C (-22°F)	-30°C (-22°F)	-27°C (-17°F)

The plants were placed in a greenhouse, with a 21°C (70°F) day temperature and 17°C (63°F) night temperature, and visually rated for quality and shoot growth once a week for eight weeks. They were rated on a scale of 1 to 5, as reported previously (Table 1.1).

RESULTS AND DISCUSSION

Exp I. The level of plant injury that occurred during the winter of 1993-94 was similar for plants in Lansing and Chatham. The coldest field temperature, -29°C (-20°F), occurred on January 16 and 19 in Chatham and Lansing, respectively. In Lansing on January 19, the minimum container medium temperature of plants stored in the outdoor pot-to-pot system was -16.5°C (2°F), which varied from the air temperature by 12.5°C. The variation between the minimum and maximum daily ambient air temperatures on this date was 9°C, and 8°C for the pot-to-pot container medium. Although the variation between air and medium temperatures differed by only 1°C on this date, the overall daily variations between the minimum and maximum medium temperatures were much lower than that of the ambient air temperatures. Daily medium temperatures were warmer and fluctuated less than air temperatures.

The percentage of plant injury varied depending on plant cultivar (Tables 1.6 and 1.7). In general, plant injury was below 35% for all cultivars in Chatham and Lansing before the minimum temperature was reached, with the exception of *Viburnum plicatum tomentosum* 'Mariesii'. Its 89% injury was probably due to slow or incomplete acclimation prior to the minimum temperature for that winter.

In Lansing, those cultivars known to adapt to the Michigan climate survived when exposed to temperatures -21°C (-5°F) and warmer. The percentage of survival was also high for these cultivars exposed to -29°C (-20°F). Cultivars native to warmer climates did not perform very well.

The survival of plant shoots is not a good indicator of the survival of the roots.

Table 1.6. Visual assessment of plant condition expressed as the percentage of dead plants for 18 cultivars on April 1, 1994. Nine plants were exposed to the following ambient field temperatures in Lansing, MI.

Plant name	**-21°C(-5°F)**	**-29°C(-20°F)**
Euonymus alatus **'Compactus'**	0%	100%
Forsythia X **'Meadowlark'**	0	0
Hibiscus syriacus **'Red Lucy'**	33.3	100
Lonicera xylosteum **'Emerald Mound'**	0	66.6
Physocarpus opulifolius **'Dart's Gold'**	0	66.6
Potentilla fruticosa **'Goldfinger'**	0	0
Prunus X cistena	0	0
Rhamnus frangula **'Columnaris'**	0	66.6
Spiraea japonica **'Shirobana'**	0	66.6
Spiraea X bumalda **'Anthony Waterer'**	11.1	88.8
Syringa X **'Ludwig Spaeth'**	33.3	77.7
Taxus X media **'Dark Green Spreader'**	0	0
Taxus X media **'Densiformis'**	0	11.1
Viburnum carlesii	0	11.1
Viburnum lantana **'Mohican'**	22.2	100
Viburnum p.t. **'Mariesii'**	33.3	100
Weigela florida **'Bristol Ruby'**	0	11.1
Weigela florida **'Java Red'**	0	0

Table 1.7. Visual assessment of plant condition expressed as the percentage of dead plants for 14 cultivars on April 1, 1994. Nine plants were exposed to the following ambient field temperatures in Chatham, MI.

Plant name	-20°C(-4°F)	-29°C(-20°F)
Euonymus alatus **'Compactus'**	11.1%	77.7%
Forsythia X **'Meadowlark'**	0	0
Hibiscus syriacus **'Red Lucy'**	33.3	100
Lonicera xylosteum **'Emerald Mound'**	0	0
Physocarpus opulifolius **'Dart's Gold'**	NA	NA
Potentilla fruticosa **'Goldfinger'**	0	0
Prunus X cistena	0	0
Rhamnus frangula **'Columnaris'**	0	33.3
Spiraea japonica **'Shirobana'**	33.3	22.2
Spiraea X bumalda **'Anthony Waterer'**	11.1	66.6
Syringa X **'Ludwig Spaeth'**	0	0
Taxus X media **'Dark Green Spreader'**	NA	NA
Taxus X media **'Densiformis'**	NA	NA
Viburnum carlesii	NA	NA
Viburnum lantana **'Mohican'**	0	33.3
Viburnum p.t. **'Mariesii'**	88.8	100
Weigela florida **'Bristol Ruby'**	0	0
Weigela florida **'Java Red'**	0	0

NA=Plants used in Lansing, but not available for Chatham

Plant condition after exposure to cold temperatures is more related to root survival because roots are less hardy than shoots. Air temperatures should not be used as the only measure for root survival because roots may not be exposed to the actual ambient field temperatures.

Hardier cultivars probably had a higher amount of initial root survival after deacclimation. As a result, their percentage of survival was higher than cold-sensitive cultivars, which probably had a lower initial root survival. Ratings of each cultivar after warming for 30 and 60 days at 21°C (70°F) indicate that cultivars with 100% survival did not necessarily retain their quality (Tables 1.1 and 1.2). *Potentilla f.* 'Goldfinger', *Forsythia* X 'Meadowlark', and *Weigela f.* 'Java Red' exhibited 100% survival, but showed a decline in performance between 30 and 60 days. Root injury may have been too severe to support full shoot growth. The survival of plant tops, as measured by visual observations, did not indicate the degree of root damage. For *Spiraea* X *b.* 'Anthony Waterer' plants, 11.1% of the plant tops were dead at -21°C (-5°F) and 88.8% were dead at -29°C (-20°F) in Lansing, but average performance only declined by 0.4 (Table 1.6). This suggests that those plants that survived had a increased chance of surviving because of new bud formation from surviving roots.

Exp II. The influence of the three overwintering systems on the degree of hardiness for seven cultivars was cultivar-dependent. Data in Figure 1.1 and Table 1.8 demonstrate the relationship between root hardiness and overwintering systems for the winter of 1993-94. Plants were exposed to the following minimum temperatures on January 19, 1994: container medium in the pot-in-pot system (-1.2°C, 30°F); container medium (-16.6°C, 2°F) and ambient field (-29°C, -20°F) in the pot-to-pot system; and

Table 1.8. Mean root tissue T_{50}s of seven cultivars influenced by three overwintering systems. Roots were collected on January 19, 1994 for controlled temperature freezing and evaluation.

Plant name	System	Mature root hardiness T_{50} °C(°F)
Weigela f. 'Java Red' **x	Pot-in-pot	-16.6 (2)+/- 0.8 b[y]
	Pot-to-pot	-18.2(-1) +/- 1.3 b
	Polyhouse	-13.0(8) +/- 1.3 a
Physocarpus o. 'Dart's Gold' *	Pot-in-pot	-9.4(15) +/- 0.8 a
	Pot-to-pot	-11.2(12) +/- 0.8 ab
	Polyhouse	-13.7(8) +/- 1.7 b
Hibiscus s. 'Red Lucy' NS	Pot-in-pot	-9.9(14) +/- 1.5 a
	Pot-to-pot	-10.3(13) +/- 1.3 a
	Polyhouse	-9.0(16) +/- 0.0 a
Euonymus a. 'Compactus' NS	Pot-in-pot	-18.3(-1) +/- 4.0 a
	Pot-to-pot	-18.8(-2) +/- 3.9 a
	Polyhouse	-16.6(2) +/- 2.0 a
Viburnum p.t. 'Mariesii' NS	Pot-in-pot	-9.4(15) +/- 0.6 a
	Pot-to-pot	-9.0(16) +/- 0.0 a
	Polyhouse	-9.0(16) +/- 0.0 a
Spiraea X b. 'Anthony Waterer' *	Pot-in-pot	-19.2(-3) +/- 0.8 a
	Pot-to-pot	-17.9(0) +/- 0.8 a
	Polyhouse	-21.9(-7) +/- 2.0 b
Lonicera x. 'Emerald Mound' NS	Pot-in-pot	-10.8(13) +/- 0.8 a
	Pot-to-pot	-9.9(14) +/- 1.6 a
	Polyhouse	-12.6(9) +/- 3.4 a

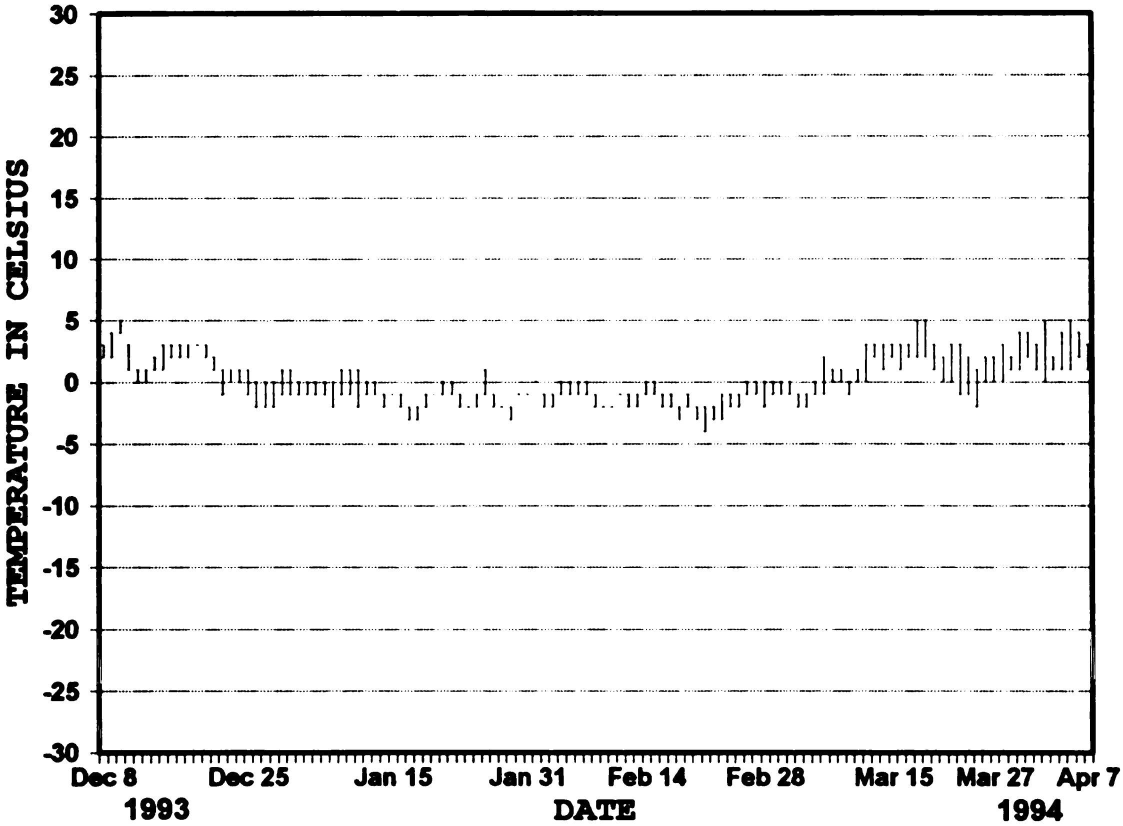
x=F values significant at 5% (*); 1% (**); or not significant (NS)
y=Significance within columns between overwintering systems for each cultivar determined by chi-square analysis. Data followed by the same letter are not significantly different.

container medium (-15.3°C, 5°F) and air (-16.8°C, 2°F) inside the polyhouse (Figures 1.2-1.6). Previous research indicated that root injury of *Ilex* plants was less for the plants overwintered inside a polyhouse than those stored uncovered (14). Overwintering systems had a significant effect on the hardiness levels of two hardy cultivars, 'Java Red' and 'Anthony Waterer'. The two hardy cultivars responded differently to the pot-to-pot and polyhouse systems. 'Java Red' overwintered pot-to-pot was an average of 5°C hardier than those in the polyhouse and 'Anthony Waterer' was an average of 4°C hardier in the polyhouse. This information suggests that each cultivar may respond differently to overwintering systems and that all cultivars which are hardy in USDA Hardiness Zone 5 may not require the same degree of protection.

Physocarpus o. 'Dart's Gold', which is marginally hardy in USDA Hardiness Zone 5, was significantly influenced by the type of overwintering system used. The effect of overwintering systems on the other four cultivars, three of which were cold-sensitive, was not significant. Although the type of overwintering system significantly influenced the root hardiness of some cultivars, there was not one system that provided improved root hardiness for all cultivars.

Exp III. Generally, cultivars survived the exposure to their warmer temperature treatment and were killed at the low temperature treatment. Plant condition declined as the number of warming days to which plants had been pre-exposed increased (Table 1.9). With the exception of *Lonicera x.* 'Emerald Mound', all ratings for plant condition were at least a 3, which indicated that plants had many buds forming, although some twig dieback occurred. As plants received additional days of warming, hardiness was reduced and plants probably were not fully rehardened prior to the freezing tests. Low

Figure 1.2. Minimum and maximum daily temperatures collected during 1993-94 from the container medium for plants overwintered pot-in-pot under ambient field conditions.


TEMPERATURE IN CELSIUS
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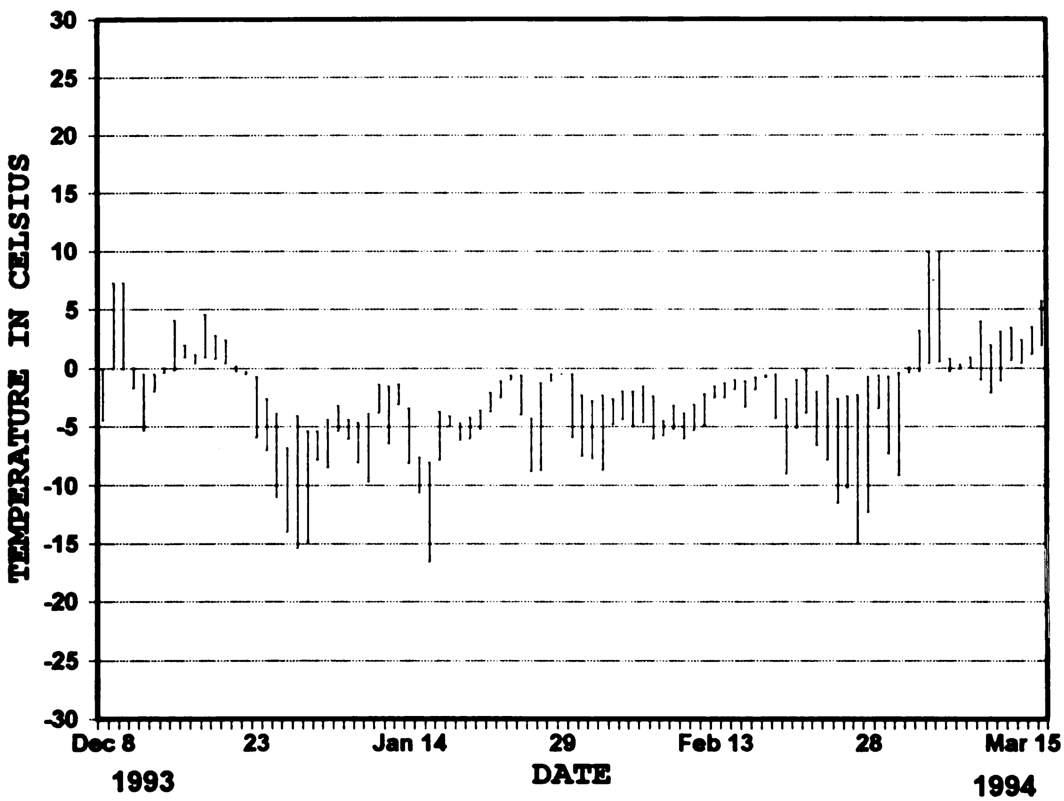
Jan 15
Jan 31
Feb 14
Feb 28
Mar 15
Mar 27
Apr 7
1993
DATE
1994

Figure 1.3. Minimum and maximum daily temperatures collected during 1993-94 from the container medium for plants overwintered pot-to-pot under ambient field conditions.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TEMPERATURE IN CELSIUS
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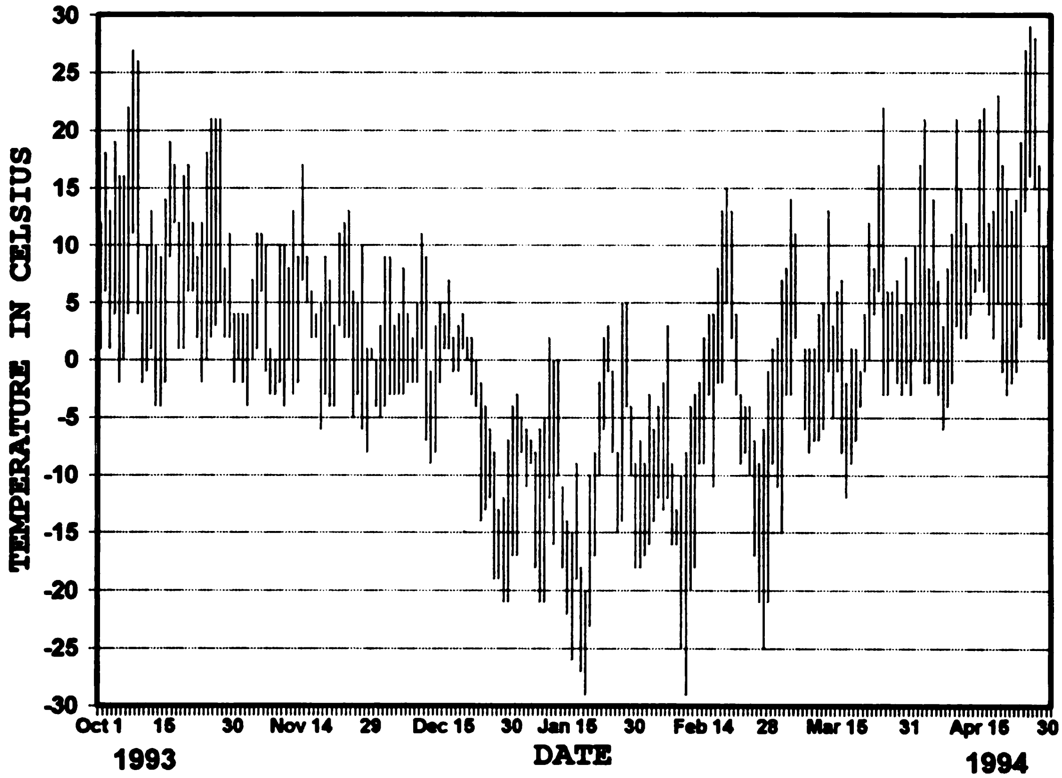
Figure 1.4. Minimum and maximum daily ambient field temperatures collected during 1993-94 at plant level.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TEMPERATURE IN CELSIUS
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1993
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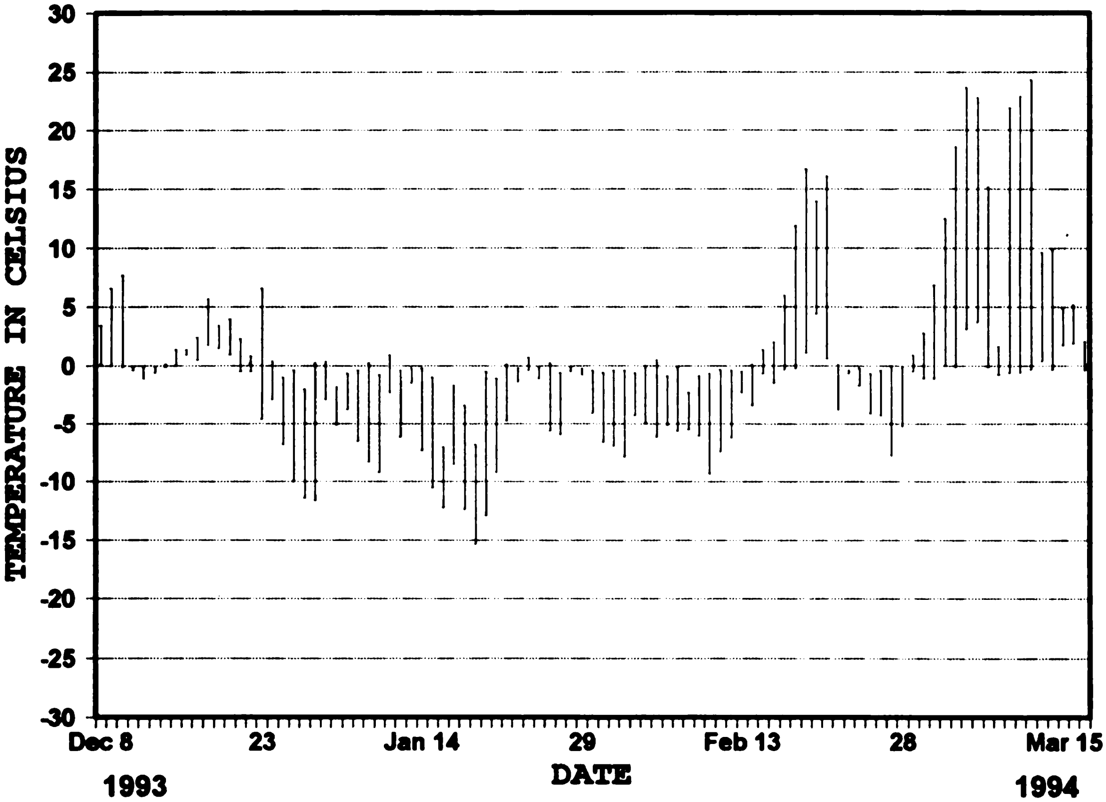
Figure 1.5. Minimum and maximum daily temperatures collected during 1993-94 from the container medium for plants overwintered pot-to-pot inside a polyhouse.



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TEMPERATURE IN CELSIUS
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Figure 1.6. Minimum and maximum daily air temperatures collected during 1993-94 at plant level from inside the center of a polyhouse.

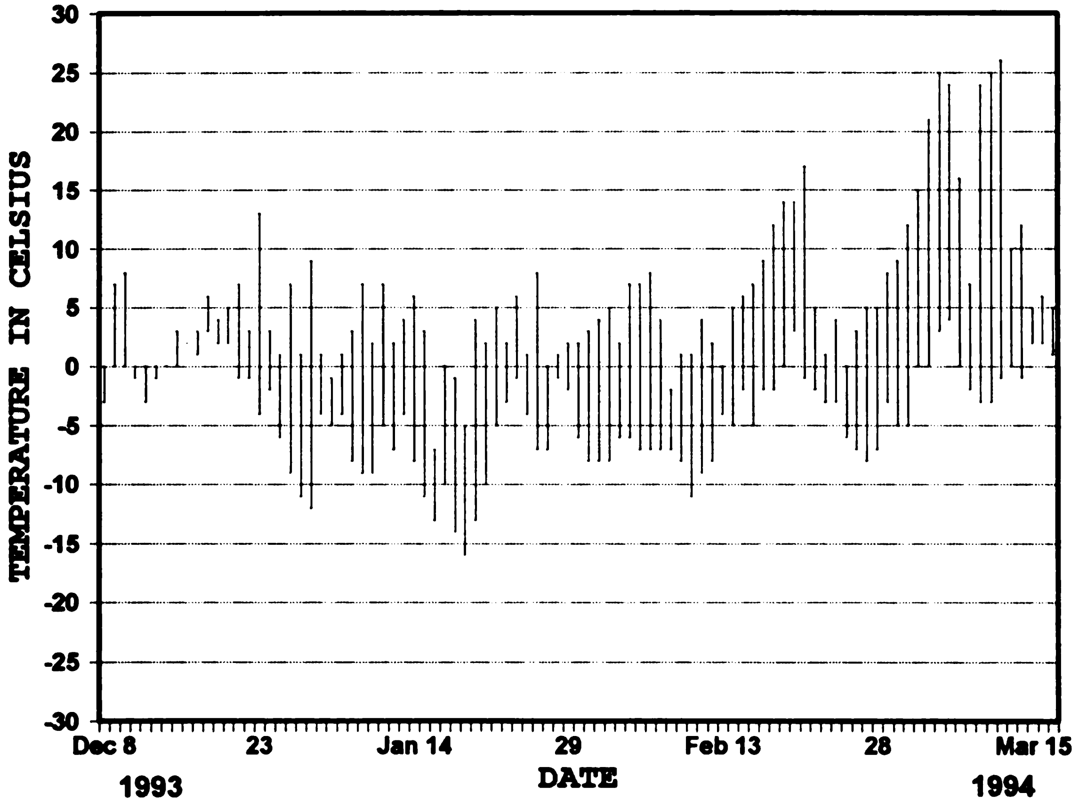
TEMPERATURE IN CELSIUS
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Table 1.9. Eight cultivars were exposed to 0 to 8 days of warming and controlled temperature freezing at the temperature treatments below. Plant condition was visually rated after 60 days at 21°C (70°F). Ratings are an average of six plants. Plants were overwintered under ambient field conditions in Lansing, MI.

		Days of Warming								
Plant name	**Temperature**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Weigela f.	-12°C(10°F)	5	5	5	5	5	5	5	4	4
'Java Red'	-36°C(-33°F)	1	1	1	1	1	1	1	1	1
Hibiscus s.	- 6°C(21°F)	5	5	4	3	3	3	3	3	3
'Red Lucy'	-24°C(-11°F)	1	1	1	1	1	1	1	1	1
Physocarpus o.	- 9°C(16°F)	4	4	4	4	4	3	3	3	3
'Dart's Gold'	-27°C(-17°F)	1	1	1	1	1	1	1	1	1
Euonymus a.	-12°C(10°F)	5	5	4	4	4	4	4	4	4
'Compactus'	-30°C(-22°F)	1	1	1	1	1	1	1	1	1
Forsythia X	-12°C(10°F)	5	5	5	5	5	5	5	5	5
'Meadowlark'	-33°C(-28°F)	1	1	1	1	1	1	1	1	1
Spiraea X *b.*	-12°C(10°F)	5	5	4	4	4	4	4	4	3
'Anthony Waterer'	-30°C(-22°F)	1	1	1	1	1	1	1	1	1
Lonicera x.	- 9°C(16°F)	4	4	4	3	3	3	3	3	2
'Emerald Mound'	-27°C(-17°F)	1	1	1	1	1	1	1	1	1
Taxus X *m.*	-12°C(10°F)	5	5	5	4	4	4	4	4	4
'Dark Green Spreader'	-36°C(-33°F)	1	1	1	1	1	1	1	1	1

Where:

1=Dead (no leaves; no buds; shoot and stem tissue are brown)
2=Slight chance of surviving (leaves are few and brown; few or no buds; considerable twig dieback)
3=Probable chance of surviving (buds are forming; a lot of twig dieback, with buds forming at the base of the plant)
4=Healthy plant, but some twig dieback (leaves are full-sized; large amount of shoot growth; many buds are forming)
5=Healthy plant (no twig dieback; vigorous shoot growth)

temperature treatments killed the root systems of each cultivar, as is evident by their ratings.

Exp IV. The three cultivars exposed to controlled temperature freezing tests displayed different rates and times of bud break (Figure 1.7). Hardy 'Java Red' plants exposed to temperatures between 3°C (37°F) and -12°C (10°F) deacclimated rapidly, and those plants exposed to temperatures from -27°C (-17°F) to -33°C (-27°F) deacclimated slowly or did not survive. 'Java Red' had the lowest cold hardiness level of the three cultivars. Marginally hardy *Euonymus a.* 'Compactus' plants exposed to temperature treatments between 3°C (37°F) and -24°C (-12°F) deacclimated steadily. Control plants broke bud after only one week at a constant temperature of 21°C (70°F). All 'Compactus' plants exposed to temperatures between -27°C (-17°F) and -33°C (-27°F) were dead. 'Red Lucy', which is cold-sensitive, slowly deacclimated for all temperature treatments. Plants exposed to -15°C (5°F) and -18°C (-1°F) required approximately 10 weeks to break bud.

In general, much of the container nursery stock grown and sold in Michigan is adaptable to the climates in USDA Hardiness Zones 4, 5, and 6. Certain cold-sensitive genera, species, and cultivars have survived many Michigan winters, but winters with cold temperatures at the low end of a zone's temperature range, like those during the winter of 1993-94, prove to be a challenge, even for marginally hardy plants.

The amount of protection needed and the timing of the application of the overwintering system may require modification every year due to inconsistent weather patterns. However, general knowledge of the root hardiness of container plants can help growers set a target date for the application of their protective system. Also, protecting

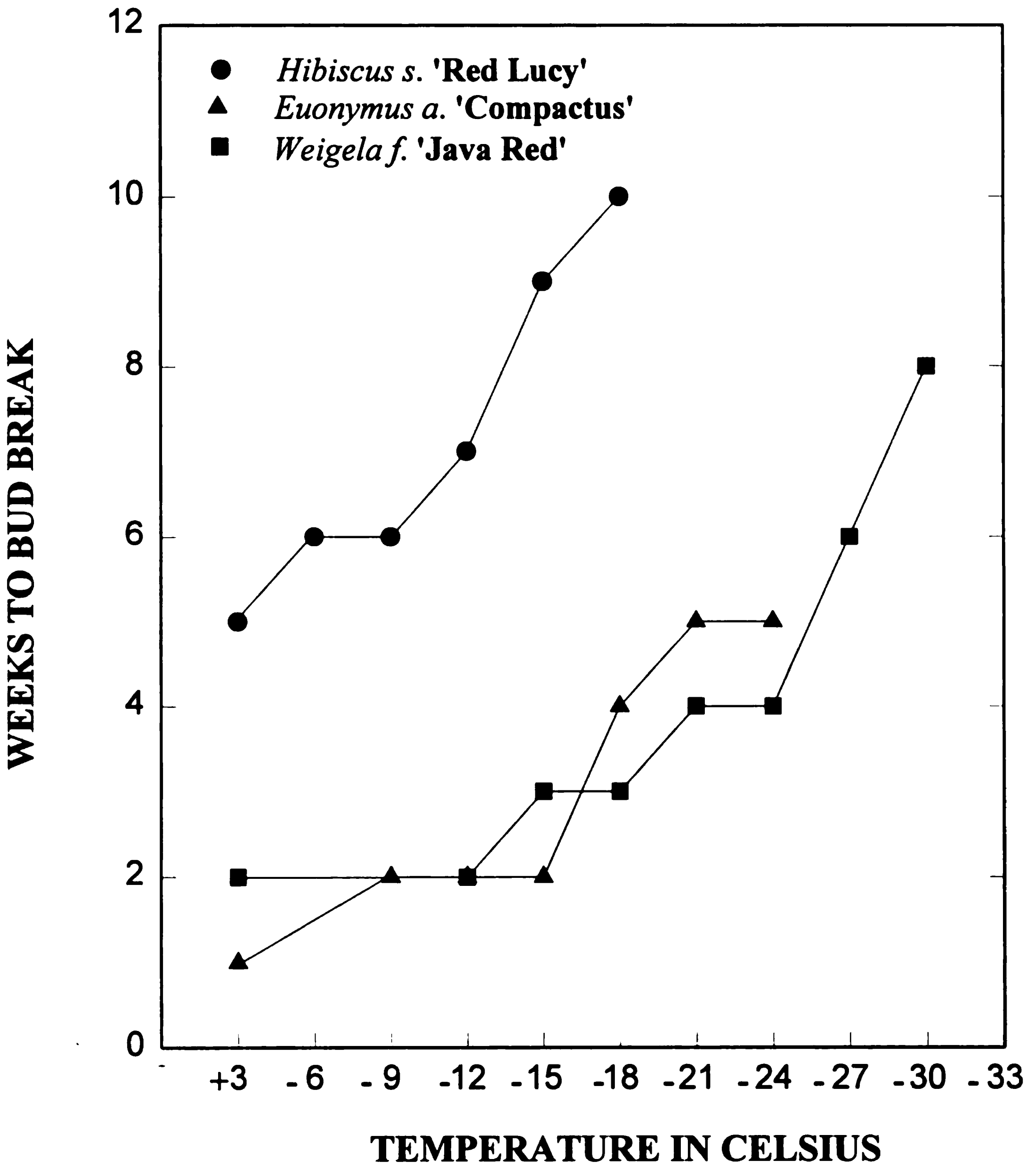

Figure 1.7. Bud break for three cultivars exposed to controlled temperature treatments.

hardy plants in polyhouses because of the fear of imminent low temperatures may not be necessary.

Observing plant shoots as a means for determining whole plant injury was not an effective method for certain cultivars in these studies. Partial injury to a small amount of roots may not be evident as the plant breaks bud, but may become apparent after weeks of growing. My research showed that injury to 'Compactus' and *Potentilla f.* 'Goldfinger' exposed to low ambient field temperatures was not visible until after two months of growth had occurred. Also, cold-sensitive plants with no visible growth after weeks of warming temperatures may develop buds and leaves at a later time. If visual observations are utilized to determine plant loss, the observations should extend over a period of at least six to eight weeks.

Although many genera, species, and cultivars adapt well to the Zone 5 climate, each genus, species, and cultivar adapts in its own way. The dissimilar responses of 'Java Red' and 'Anthony Waterer', both hardy cultivars, to several overwintering systems indicated that certain hardy cultivars adapt better than others to ambient field conditions. The goal for the grower is to determine the protective method which will produce container plants with the highest quality and performance.

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CHAPTER II

THE INFLUENCE OF OVERWINTERING SYSTEMS AND CONTROLLED TEMPERATURE EVALUATIONS ON ACCLIMATION, MID-WINTER HARDINESS, AND DEACCLIMATION OF SHOOT TISSUE.

ABSTRACT

The Influence of Overwintering Systems and Controlled Temperature Evaluations on Acclimation, Mid-Winter Hardiness, and Deacclimation of Shoot Tissue

Acclimation, mid-winter hardiness, and deacclimation of shoots of selected cultivars overwintered in different systems were evaluated using controlled freezing tests. Acclimation and deacclimation patterns of plants overwintered in an outdoor pot-in-pot system varied among cultivars. Mid-winter hardiness levels were lower for shoot hardy cultivars, such as *Weigela florida* 'Java Red', *Spiraea* X *bumalda* 'Anthony Waterer', and *Euonymus alatus* 'Compactus', and higher for cold sensitive cultivars, such as *Hibiscus syriacus* 'Red Lucy' and *Viburnum plicatum tomentosum* 'Mariesii'. The highest variation in hardiness among cultivars occurred during the acclimation period. Plants overwintered in a white polyethylene (poly) - covered storage structure (polyhouse) exhibited reduced hardiness levels when compared to those overwintered in an outdoor pot-in-pot system. Also, plants overwintered in the outdoor pot-in-pot system were more cold tolerant in 1993-94 than they were during 1994-95. Significant shoot injury occurred to those cultivars available in USDA Hardiness Zone 5, -23°C to -29°C (-10°F to -20°F), but native to warmer regions. Deacclimation of 'Java Red', 'Red Lucy', and 'Compactus' was accelerated in the polyhouse. However, 'Red Lucy' deacclimated slowly in both overwintering systems. Plants exposed to warming at a constant 21°C (70°F) temperature showed reduced hardiness depending on plant cultivar and the number of warming days. Plant response of cultivars evaluated in controlled

temperature deacclimation tests was comparable to the response of those cultivars overwintered in a polyhouse.

INTRODUCTION

Previous shoot tissue cold hardiness research has been focused on the minimum survival temperatures of woody ornamental genera, species, and cultivars (3,8,15). While mid-winter hardiness is important, the rates and timing of acclimation and deacclimation are critical to the survival and performance of container-grown plants. With the increase of container production and the frequent introduction of new cultivars, it is difficult for growers to select plants which are adaptable to their regions. As a result, many species and cultivars are sold in regions which may not promote their optimum growth. Many native species and cultivars have extended geographic ranges (10). *Fraxinus americana* L. trees, which are native from Michigan to Mississippi, were observed for mid-winter hardiness (5). The Michigan trees developed a -30°C (-22°F) hardiness while the Mississippi trees only developed a -15.5°C (4°F) hardiness level. Several other woody taxa demonstrating similar relationships have been studied (4,16).

The development of acclimation and deacclimation in a plant is controlled by many factors, however, it is ultimately dependent on the plant's genetic background. Physiological condition is also an important factor. Shoots and buds respond to various environmental signals which regulate plant growth stages and development in the tops of the plants (6).

Acclimation of shoots is affected by their stage of growth. Frequently, low temperature injury is a result of incomplete or slow acclimation caused by late pruning or fertilization. Many plants have the capacity to survive minimum mid-winter temperatures but slow acclimation reduces their hardiness (12). Plants known to slowly acclimate may require some level of overwintering protection. Determining acclimation rates and timing prevents plants from being protected too early. If protection is added too soon, plants may be overprotected and not allowed to fully acclimate to cold temperatures. Similarly, plant protection may be removed too early, which exposes plants to late spring frosts.

Acclimation and deacclimation rates and timing differ among species and cultivars. Knowledge of the rates and timing of both processes for different species and cultivars can reduce shoot injury and increase the variety of plant material available to the grower. In a report by Alexander and Havis (1), several cultivars of *Rhododendron*, which differed in acclimation rates, exhibited injury as a result of late autumn low temperatures. Rapid cooling and warming rates have been shown to cause stem and leaf injury by raising their killing temperatures (7). However, the effects of these rates depends on the physiological stages of a plant's growth. Pellett et al. (13) studied shade tree cultivars during a fall period without fluctuating ambient air temperatures. Tissue damage that occurred must have been a result of the rate of acclimation.

Previous reports indicated that warm temperatures influenced deacclimation rates following a plant's rest period (9). After the rest period, three days of warm temperatures induced considerable deacclimation in red-osier dogwood (11). Proebsting (14) concluded that the daily hardiness fluctuations of dormant peach flower buds during deacclimation occurred in response to the previous day's minimum ambient air temperature. Once deacclimation occurred to some degree, it was unclear whether plants could reharden. Howell and Weiser (9) determined that deacclimation occurred more rapidly than rehardening and rehardening was limited if a threshold temperature in deacclimation had been reached. The ability of certain plants to reverse deacclimation when needed is an important factor in plant selection.

A close relationship between the cold hardiness of species and cultivars in the field and their hardiness values determined in the laboratory has been reported in previous work (3). The following experiments were designed to investigate this relationship and to determine the effects of different overwintering systems on the rates and timing of acclimation, mid-winter hardiness, and deacclimation of several cultivars. Controlled deacclimation followed by cold temperature exposure was conducted to determine the deacclimation and rehardening capabilities of different cultivars.

MATERIALS AND METHODS

Exp I. Container-grown woody ornamentals were overwintered at the Horticulture Teaching and Research Center in Lansing, Michigan from mid-August through April, 1993-94 and 1994-95. The experiment consisted of seven cultivars with 150 plants per cultivar. The seven cultivars denoted by an asterisk are representative of cultivars that are either hardy, marginally hardy or tender, as determined from previous evaluations (Table 2.1). Using a pot-in-pot system, nursery-grown plants of salable size in 20 cm (8 in) nursery pots were placed into 20 cm (8 in) nursery pots below the ground and exposed to ambient field temperatures. Minimum and maximum daily air and media temperatures were measured using a datalogger (Campbell Scientific, Model CR10, Logan, Utah). Temperature probes were placed into several pots four inches from the medium surface between the side of the pot and the rootball. Mature shoots were collected from October through April for both years to determine the variation in hardiness of each cultivar during the acclimation, mid-winter, and deacclimation periods. Twenty-seven shoots of each cultivar were collected on each collection date from randomized plants. Shoots which were approximately 20 cm (8 in) in length and 0.5 cm (0.25 in) in diameter were cut at their base and were placed in poly bags and stored in a cooler with ice. The cooler was stored overnight in a freezer at 3°C (37.4°F).

Shoots were prepared for controlled temperature freezing by removing the leaves and cutting each shoot into three five centimeter pieces. Shoot samples were placed on masking tape templates and prepared using the method reported previously (9,17). Each temperature treatment was represented by three replications, with three observations per

Table 2.1. Visual assessment of plant condition expressed as the percentage of dead plants for 18 cultivars on April 1, 1994. Nine plants were exposed to the following ambient field temperatures in Lansing, MI.

Plant name	-21°C(-5°F)	-29°C(-20°F)
Euonymus alatus* **'Compactus'	0%	100%
Forsythia X **'Meadowlark'**	0	0
Hibiscus syriacus* **'Red Lucy'	33.3	100
Lonicera xylosteum* **'Emerald Mound'	0	66.6
Physocarpus opulifolius* **'Dart's Gold'	0	66.6
Potentilla fruticosa **'Goldfinger'**	0	0
Prunus X cistena	0	0
Rhamnus frangula **'Columnaris'**	0	66.6
Spiraea japonica **'Shirobana'**	0	66.6
Spiraea X bumalda* **'Anthony Waterer'	11.1	88.8
Syringa X **'Ludwig Spaeth'**	33.3	77.7
Taxus X media **'Dark Green Spreader'**	0	0
Taxus X media **'Densiformis'**	0	11.1
Viburnum carlesii	0	11.1
Viburnum lantana **'Mohican'**	22.2	100
Viburnum p.t.* **'Mariesii'	33.3	100
Weigela florida **'Bristol Ruby'**	0	11.1
Weigela florida* **'Java Red'	0	0

*=indicates the cultivars which were used in Experiment 1.

replication wrapped in bundles. Controlled temperature freezing was manipulated in a Revco Ultralow freezer with a temperature controller (Omega Engineering, Stamford, CT). The temperature inside the freezer was programmed to decline at a 3°C (5.4°F) interval per hour. The temperature treatments varied depending upon the time of testing. In each test, temperature treatments included a control, a temperature at which the shoots would show no tissue injury, and a temperature at which they would show tissue death. Control bundles were placed in a cooler at 3°C (37.4°F).

When each critical temperature within the freezer was reached, three bundle replications were placed in a cooler at 3°C (37.4°F) to thaw overnight. The bundles were then stored in a humidity chamber, according to the process used by Howell and Weiser (9). The viability of shoot tissue was determined by the existence of oxidative browning. The shoot tissue was dissected and analyzed under a dissecting microscope. T_{50} values (temperature at which 50% of the samples were killed) were calculated using the Spearman-Karber method (2).

Exp II. Seven cultivars were evaluated during the winter of 1994-95 to approximately determine their rates and timing of acclimation, mid-winter hardiness, and deacclimation. The cultivars in full bold type with asterisks, listed in Table 2.1, were chosen based on their hardiness levels and patterns recorded during the winter of 1993-94. Plants were naturally acclimated to ambient field conditions and overwintered in a quonset-style structure, or polyhouse, beginning on December 1, 1994. Fifty-five percent opacity white polyethylene was used to cover the 18' x 96' structure with an east-west orientation.

Plants were acclimated to the conditions in the center of the polyhouse for one month. Minimum and maximum daily polyhouse air and media temperatures were collected by a datalogger (Campbell Scientific, Model CR10, Logan, Utah). Twenty-seven shoots of each cultivar were collected randomly on each of ten collection dates. Shoots were prepared for controlled freezing using the methods described in the pot-in-pot shoot tissue study. Shoot tissue was evaluated for oxidative browning and T_{50} values were calculated using the Spearman-Karber method (2,9). Statistical significance using chi-square analysis was determined from the live versus dead shoot tissue for each cultivar on each test date.

Exp III. Eight cultivars with either a rapid or slow rate of deacclimation were selected for a deacclimation study. The nursery grown plants of salable size, in 20 cm (8 in) nursery pots, were overwintered pot-in-pot and exposed to ambient air conditions until March 5, 1994. At that time, they were placed in a freezer at 0°C (32°F) in a randomized complete block design with nine blocks. Control plants remained at 0°C (32°F) while six replications per cultivar per warming treatment were placed in a chamber at 21°C (70°F) and removed after exposure to one to eight days of warming. Plants were placed back into the 0°C (32°F) freezer upon removal from the temperature controlled chamber. Controlled freezing evaluations of the shoot tissue were conducted and T_{50} values were determined using the Spearman-Karber method, as previously described (2,9).

RESULTS AND DISCUSSION

Exp I. The rates of acclimation and deacclimation and the onset of mid-winter hardiness varied among the seven cultivars during the winter of 1993-94 (Figure 2.1). The variation in shoot hardiness levels for all cultivars during the acclimation period was most notable between the first and second testing dates, October 7 and 21. Hardy cultivars, such as *Weigela f.* 'Java Red' and *Spiraea* X *b.* 'Anthony Waterer' had little initial hardiness on October 7, but increased in hardiness by mid-November. Cold hardy 'Java Red' and *Hibiscus s.* 'Red Lucy', which is cold-sensitive, exhibited an early acclimation response to decreasing temperatures. This suggests that acclimation rate may not always be related to a plant's geographic origin.

Generally, cultivars showed steady mid-winter hardiness by mid-December. 'Java Red' showed the greatest shoot hardiness level, -34.5°C (-30°F), during the winter. *Viburnum p.t.* 'Mariesii' was least hardy, -25.5°C (-14°F), and shoots died back to the media surface.

The rates and patterns of acclimation and deacclimation of all cultivars were similar for both 1993-94 and 1994-95 winters (Figures 2.1 and 2.2). However, the lowest hardiness level reached for each cultivar in mid-winter of 1994-95 was not as low as hardiness levels for those plants during the previous winter. Reduced hardiness in 1994-95 probably occurred because ambient field temperatures were not as cold as those in 1993-94 (Figures 2.3 and 2.4). With warmer air and media temperatures, the capacity for plant hardiness was probably not as high.

Exp II. Differences existed in the hardiness and times to deacclimate for most of

Figure 2.1. Mean shoot tissue T_{50}s in celsius of seven cultivars during acclimation, mid-winter hardiness, and deacclimation in 1993-94 for plants overwintered pot-in-pot under ambient field conditions.

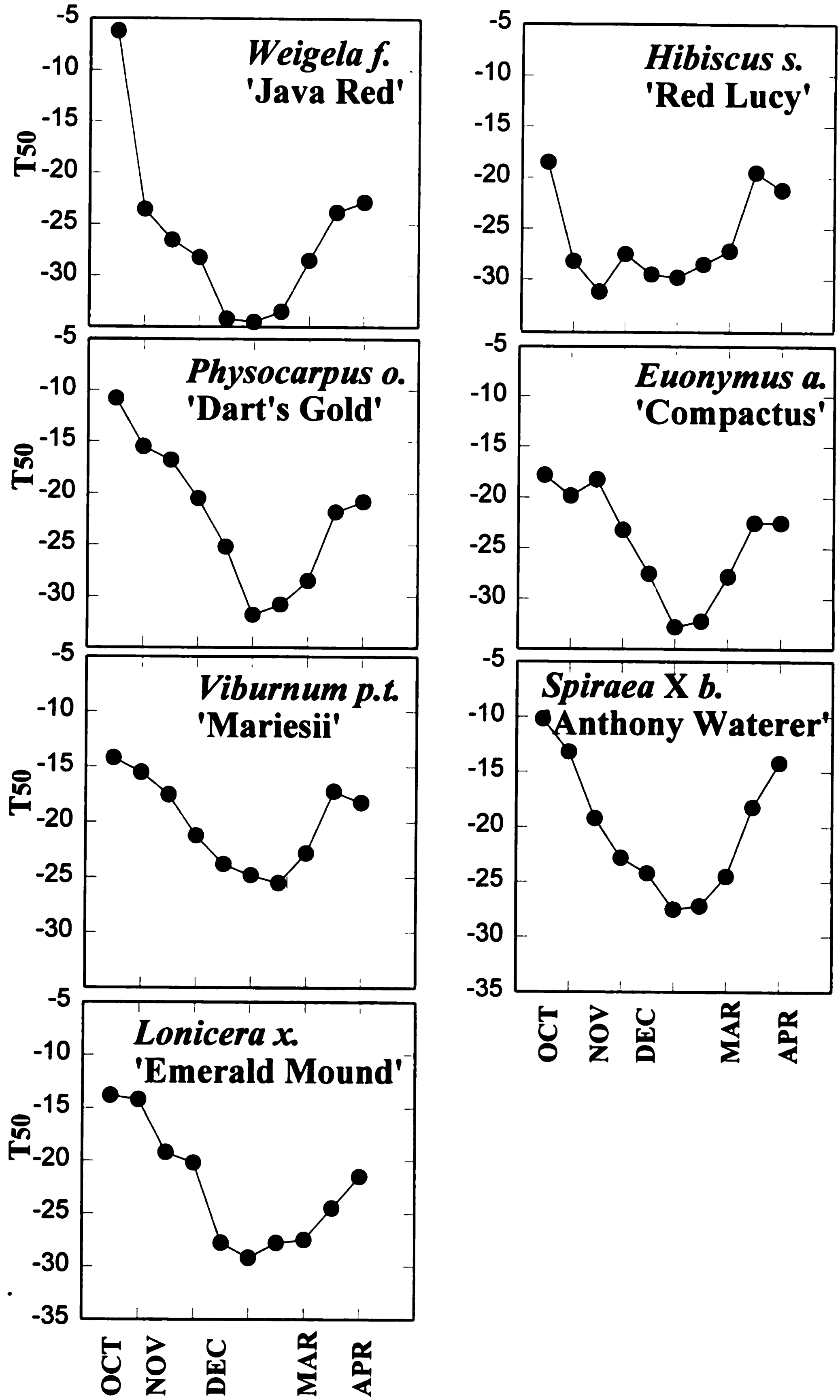
Weigela f. 'Java Red'
Hibiscus s. 'Red Lucy'
Physocarpus o. 'Dart's Gold'
Euonymus a. 'Compactus'
Viburnum p.t. 'Mariesii'
Spiraea X b. 'Anthony Waterer'
Lonicera x. 'Emerald Mound'
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Figure 2.2. Mean shoot tissue T_{50}s in celsius of seven cultivars during acclimation, mid-winter hardiness, and deacclimation in 1994-95 for plants overwintered pot-in-pot under ambient field conditions.

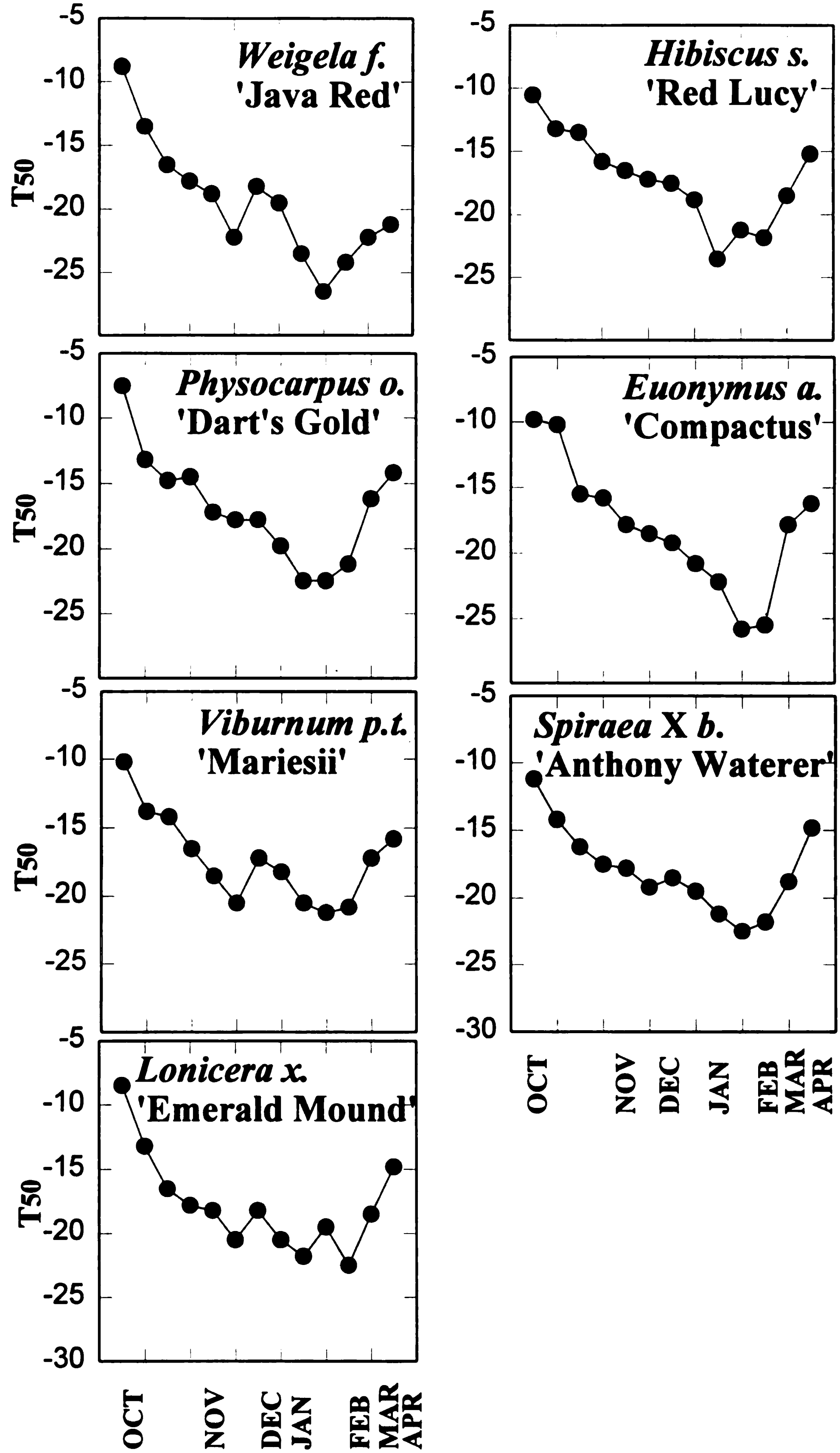
Weigela f.
'Java Red'
Hibiscus s.
'Red Lucy'
Physocarpus o.
'Dart's Gold'
Euonymus a.
'Compactus'
Viburnum p.t.
'Mariesii'
Spiraea X b.
'Anthony Waterer'
Lonicera x.
'Emerald Mound'
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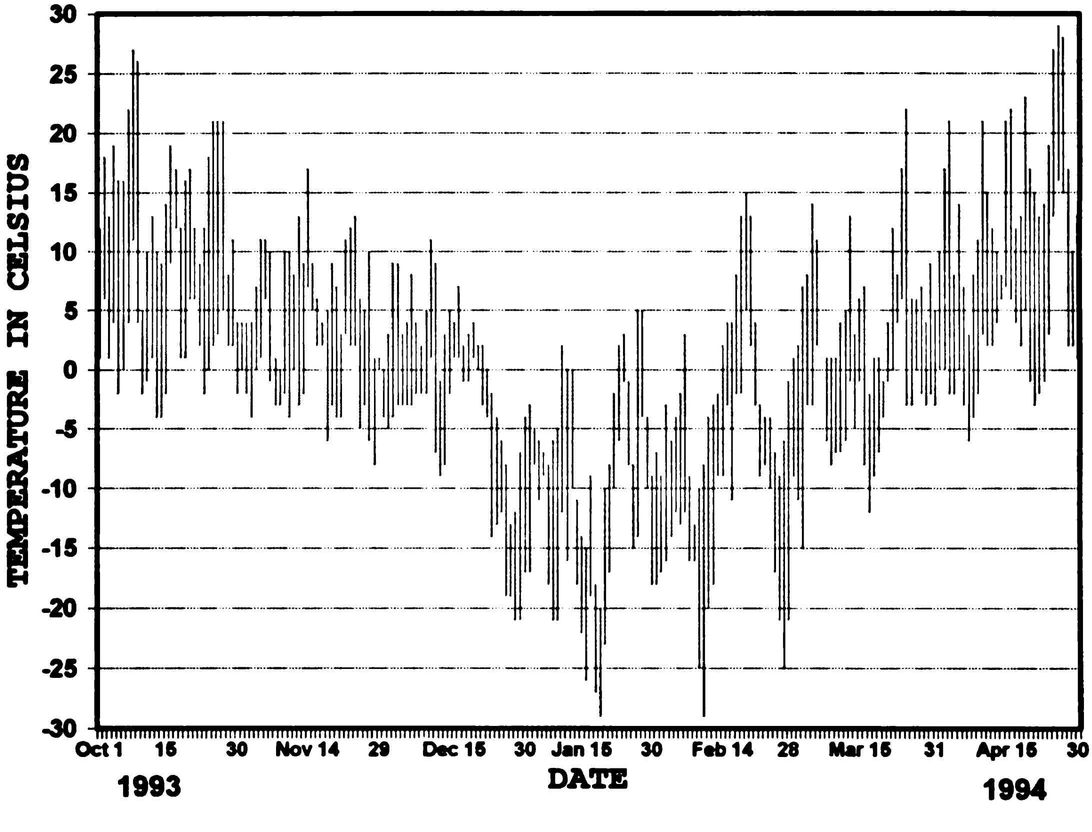
Figure 2.3. Minimum and maximum daily ambient field temperatures collected during 1993-94 at plant level.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TEMPERATURE IN CELSIUS
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Nov 14
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Dec 15
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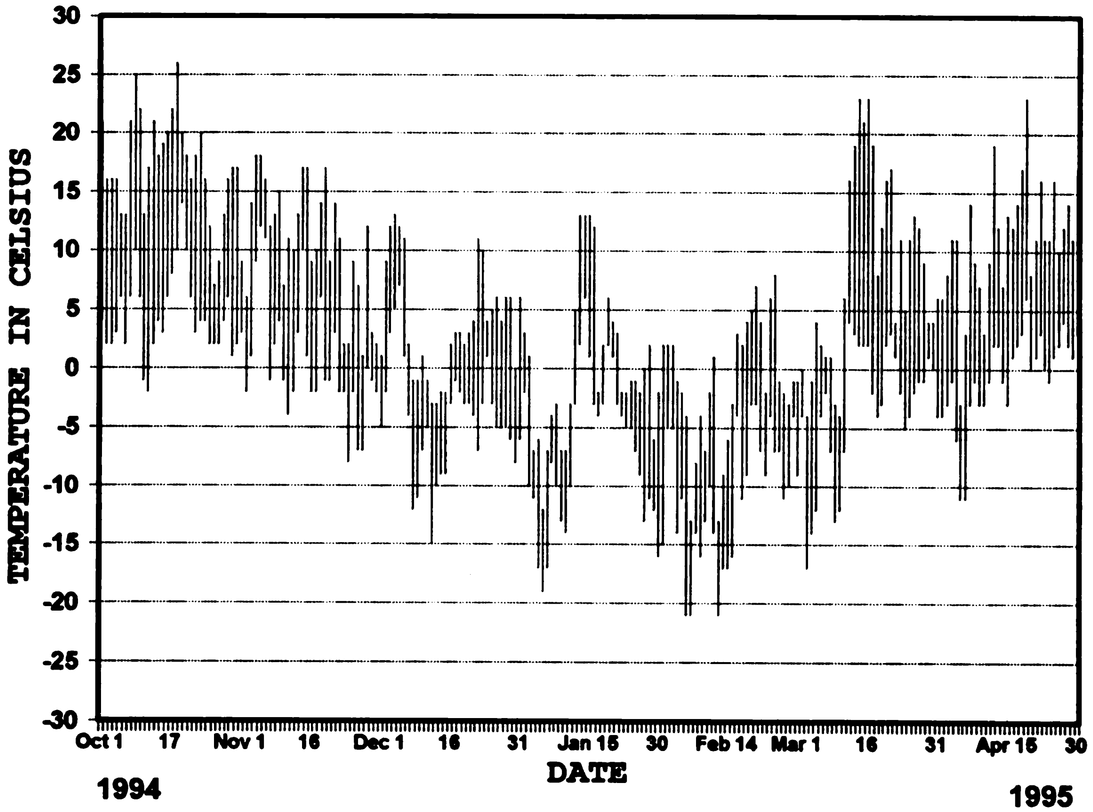
Figure 2.4. Minimum and maximum daily ambient field temperatures collected during 1994-95 at plant level.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the cultivars in two overwintering systems during 1994-95 (Figures 2.2 and 2.5). Controlled freezing evaluations of the shoots from January through March of 1995 indicated that the influence of overwintering systems on hardiness was significant depending on the test date and cultivar (Table 2.2). The influence of the systems on hardiness was more significant in March, as plants were deacclimating. With the exception of 'Anthony Waterer' and *Lonicera* x. 'Emerald Mound', the polyhouse system significantly increased the rate of hardiness loss. The same plants overwintered in the polyhouse deacclimated earlier than those stored pot-in-pot outdoors (Figure 2.6). The bud break for 'Anthony Waterer' occurred on the same day in both overwintering systems. 'Anthony Waterer' may not be influenced by overwintering systems because it naturally deacclimates in late winter or early spring. Deacclimation of 'Red Lucy' and 'Java Red' occurred three weeks and two weeks earlier, respectively, in the polyhouse. In Figure 2.7, medium temperatures for plants pot-in-pot fluctuated less than polyhouse medium temperatures.

Air temperatures at different locations within the polyhouse differed for both 1993-94 and 1994-95. Daily minimum air temperatures inside the northwest end of the polyhouse were an average of 2-5°C (5-9°F) lower than air temperatures in the center of the polyhouse (Figures 2.8-2.11). Results reported by Young et al. (18) indicate that daily minimum container medium temperatures of plants stored inside the northwest end of a polyhouse were an average of 3-5°C lower than medium from plants stored inside the center of the polyhouse. Container media inside the polyhouse showed reduced fluctuations and less variation between the minimum and maximum daily temperatures, as compared to the polyhouse air temperatures (Figures 2.12 and 2.13). Plants

Figure 2.5. Mean shoot tissue T_{50}s in celsius of seven cultivars during mid-winter hardiness and deacclimation in 1994-95 for plants overwintered pot-to-pot inside a polyhouse.

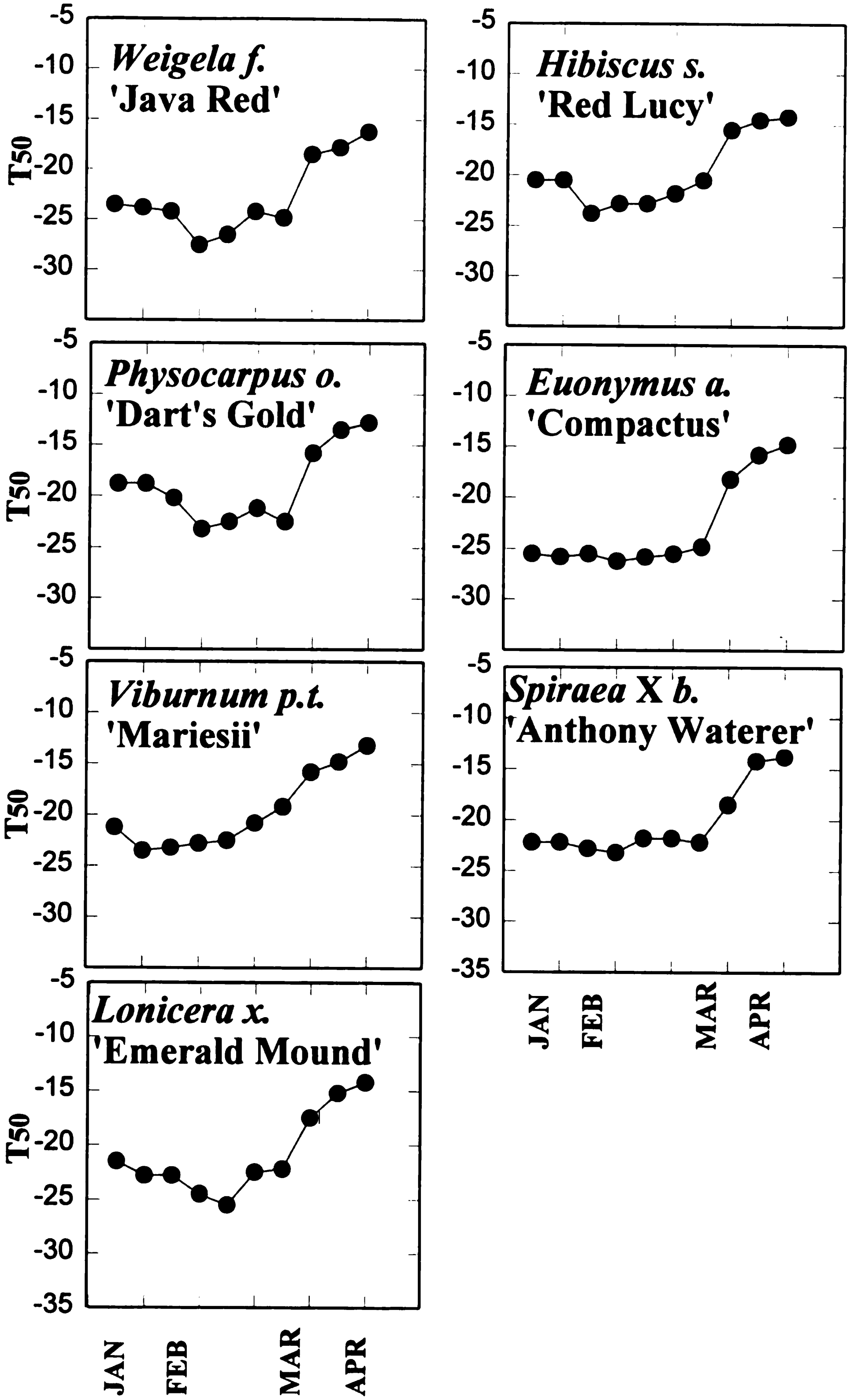
Weigela f.
'Java Red'
Hibiscus s.
'Red Lucy'
Physocarpus o.
'Dart's Gold'
Euonymus a.
'Compactus'
Viburnum p.t.
'Mariesii'
Spiraea X b.
'Anthony Waterer'
Lonicera x.
'Emerald Mound'
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Table 2.2. Mean shoot tissue T_{50}s in celsius of seven cultivars overwintered in two systems. Plants inside the polyhouse were overwintered pot-to-pot. Shoot tissue was evaluated on five dates during the winter of 1994-95.

	Jan. 18	Jan. 25	Feb. 22	Mar. 14	Mar. 23
Weigela f. **'Java Red'**					
Polyhouse	-23.5a x	-24.0a	-24.0a	-18.5a	-18.0a
Pot-in-pot	-23.5a	-26.5b	-23.0a	-22.0b	-21.0b
Hibiscus s. **'Red Lucy'**					
Polyhouse	-23.5a	-22.5a	-22.0a	-15.5a	-14.5a
Pot-in-pot	-23.5a	-22.0a	-21.5a	-18.5b	-17.0b
Physocarpus o. **'Dart's Gold'**					
Polyhouse	-22.5a	-21.0a	-21.0a	-16.0a	-13.5a
Pot-in-pot	-22.5a	-22.5b	-21.0a	-16.0a	-16.0b
Euonymus a. **'Compactus'**					
Polyhouse	-25.5b	-26.0a	-25.5a	-18.0a	-16.0b
Pot-in-pot	-22.0a	-26.0a	-26.5a	-18.0a	-17.0b
Viburnum p.t. **'Mariesii'**					
Polyhouse	-21.0a	-23.5b	-21.0b	-16.0a	-15.0a
Pot-in-pot	-21.0a	-22.0a	-19.0a	-17.0b	-17.0b
Spiraea X *b.* **'Anthony Waterer'**					
Polyhouse	-22.0a	-22.0a	-22.0a	-18.5a	-14.0a
Pot-in-pot	-22.0a	-22.5a	-22.0a	-19.0a	-15.0a
Lonicera x. **'Emerald Mound'**					
Polyhouse	-21.5a	-23.0a	-22.5a	-17.5a	-15.0a
Pot-in-pot	-22.0a	-24.0a	-24.0b	-18.5a	-16.0a

x=Significance within columns between overwintering systems for each cultivar determined by chi-square analysis.

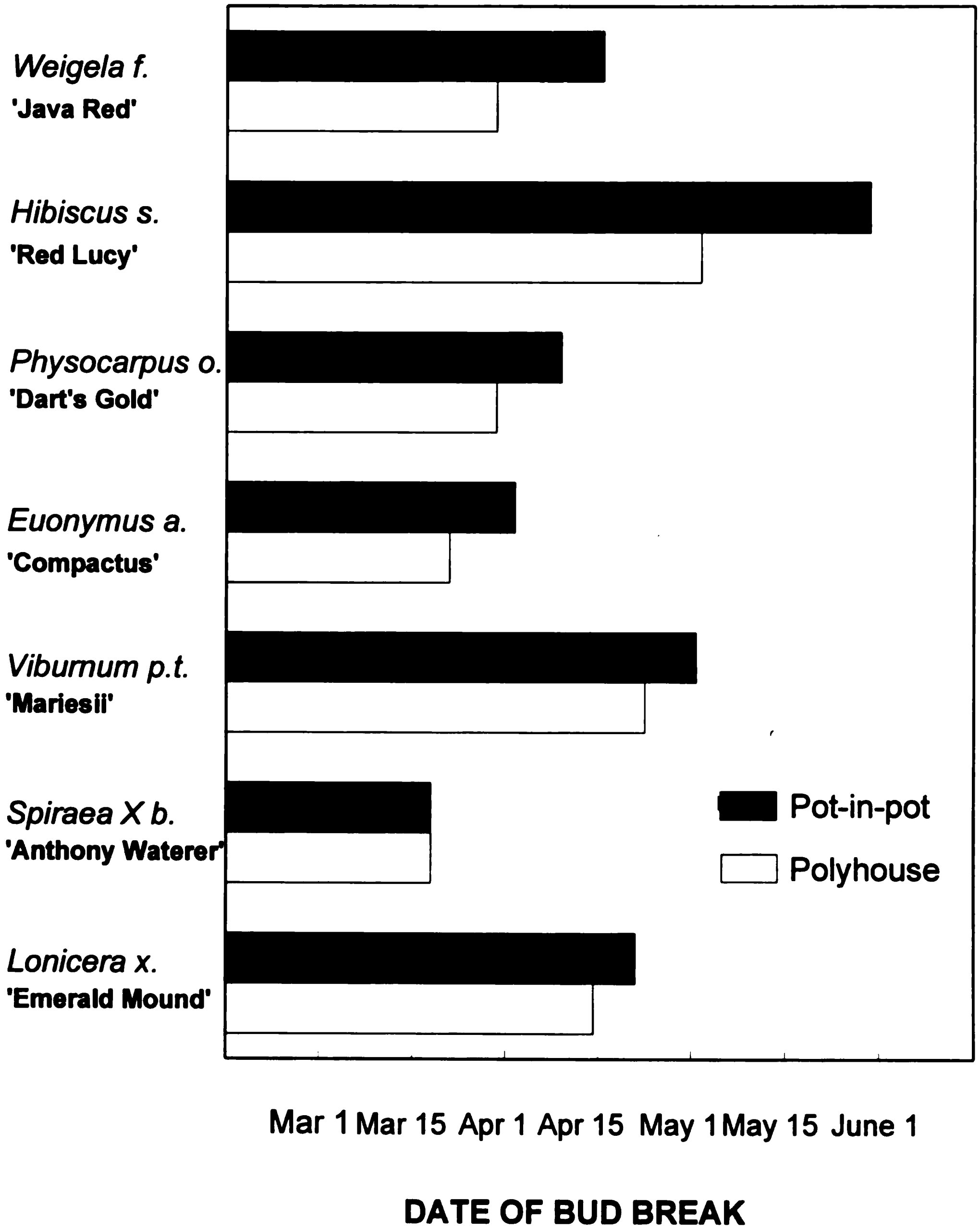

Figure 2.6. Bud break for seven cultivars influenced by two overwintering systems during 1994-95.

Figure 2.7. Minimum and maximum daily temperatures collected during 1994-95 from the container medium for plants overwintered pot-in-pot under ambient field conditions.

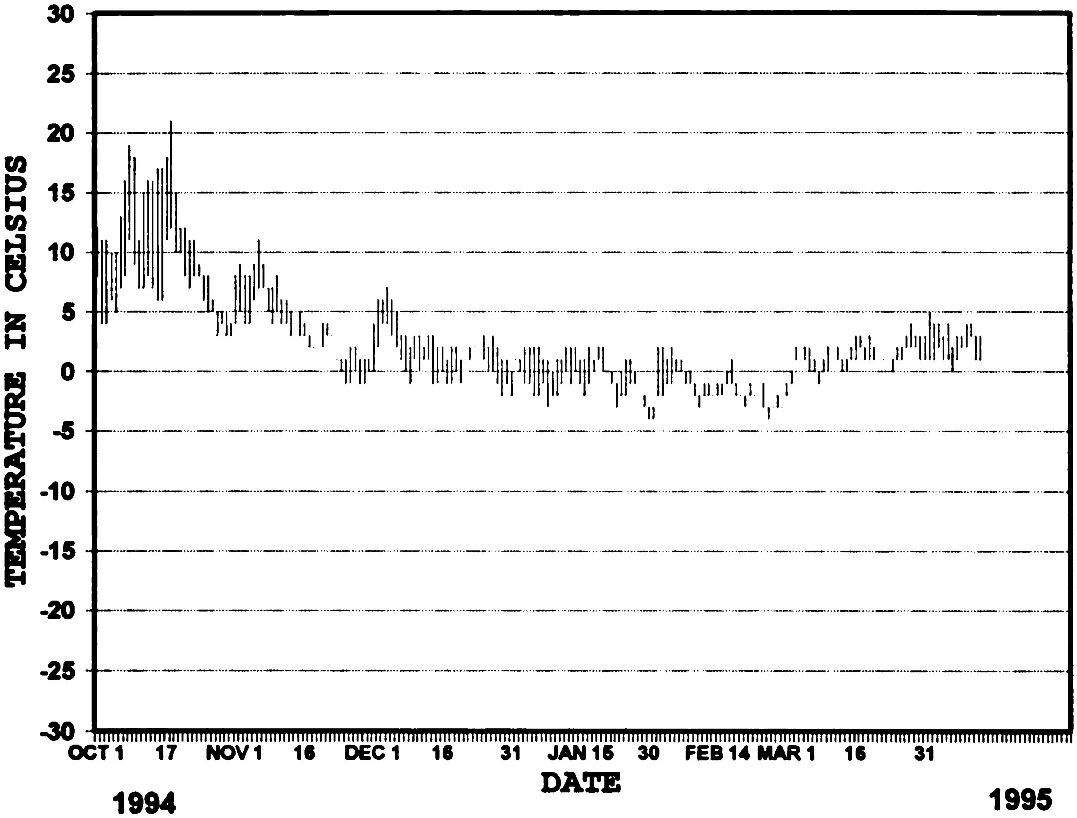

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Figure 2.8. Minimum and maximum daily air temperatures collected during 1993-94 at plant level from inside the center of a polyhouse.

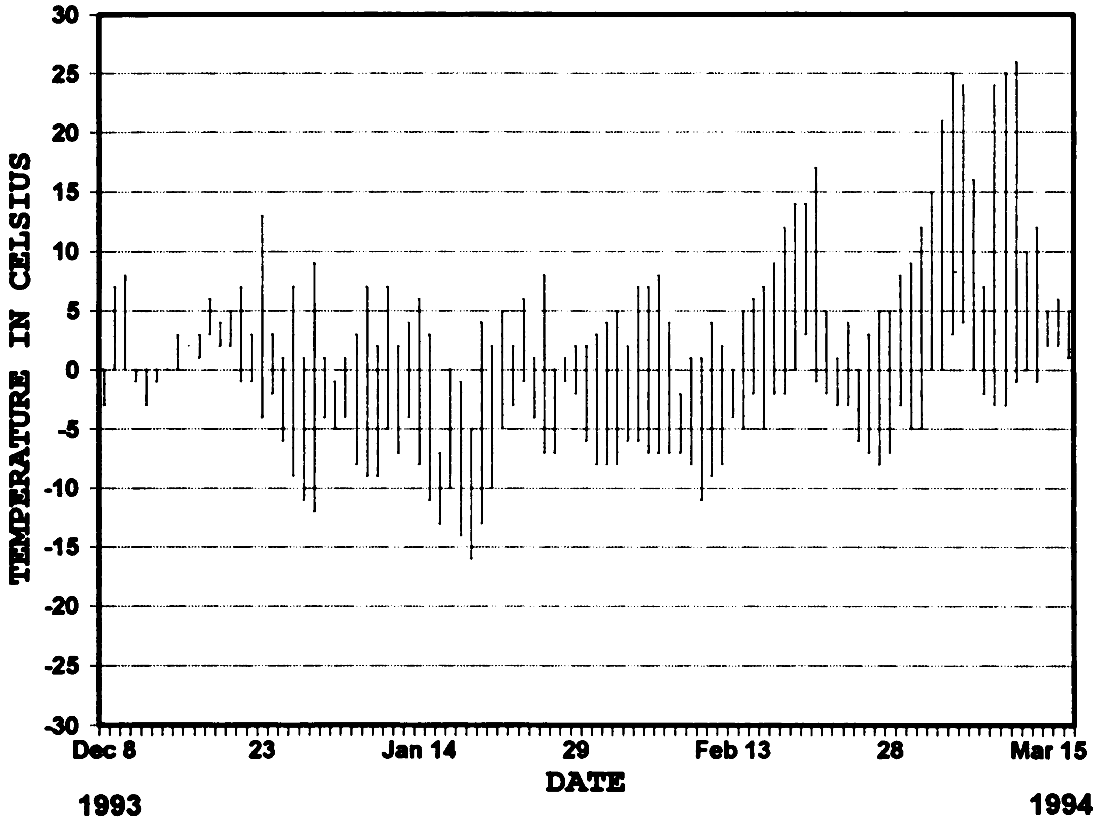
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Figure 2.9. Minimum and maximum daily air temperatures collected during 1993-94 at plant level from inside the west end of a polyhouse.

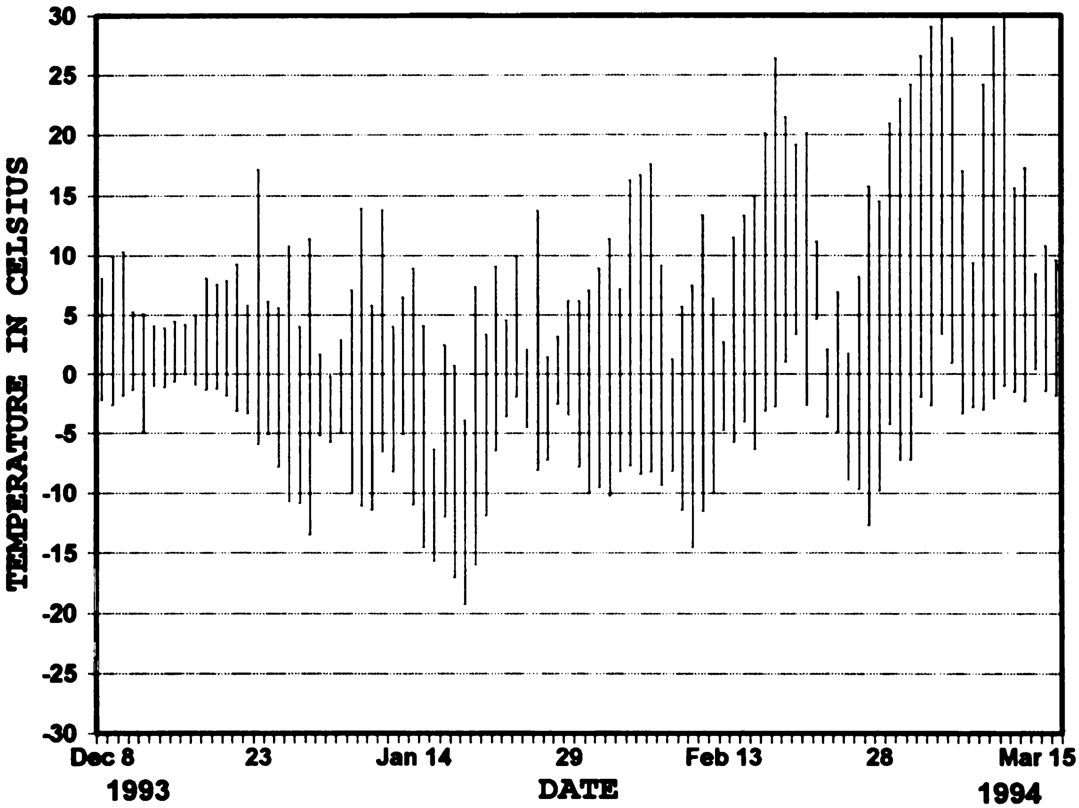

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Figure 2.10. Minimum and maximum daily air temperatures collected during 1994-95 at plant level from inside the center of a polyhouse.

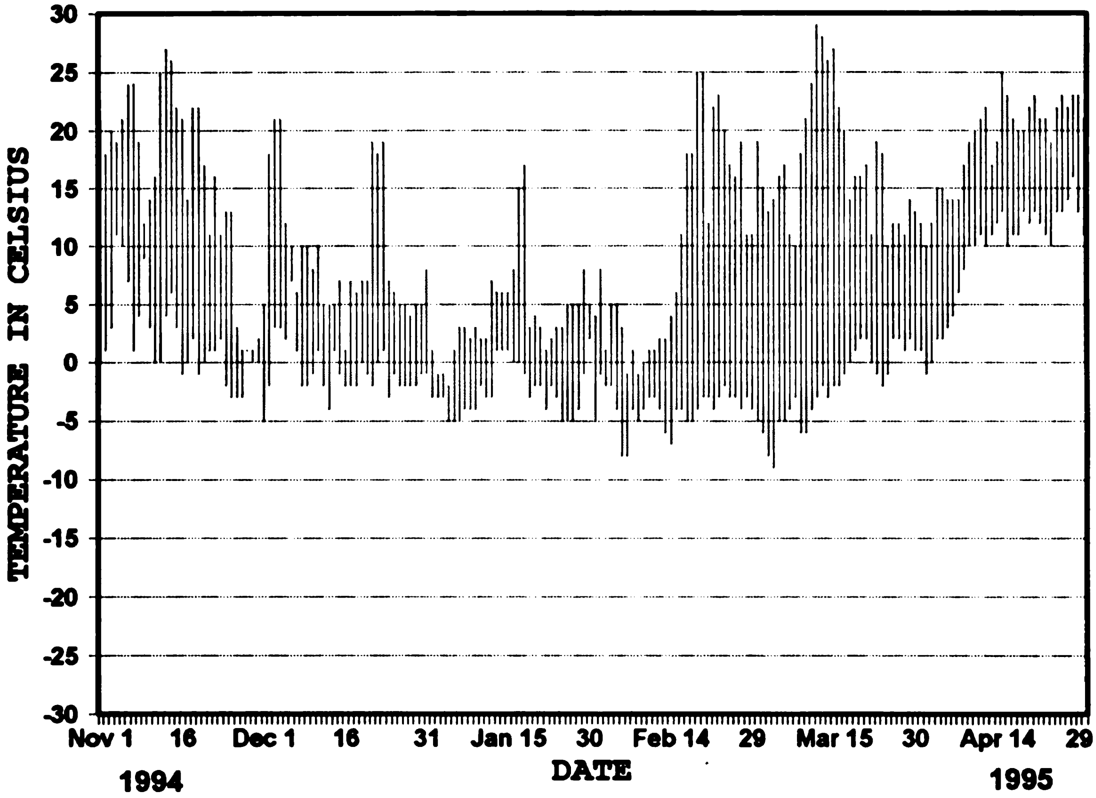
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Figure 2.11. Minimum and maximum daily air temperatures collected during 1994-95 at plant level from inside the west end of a polyhouse.

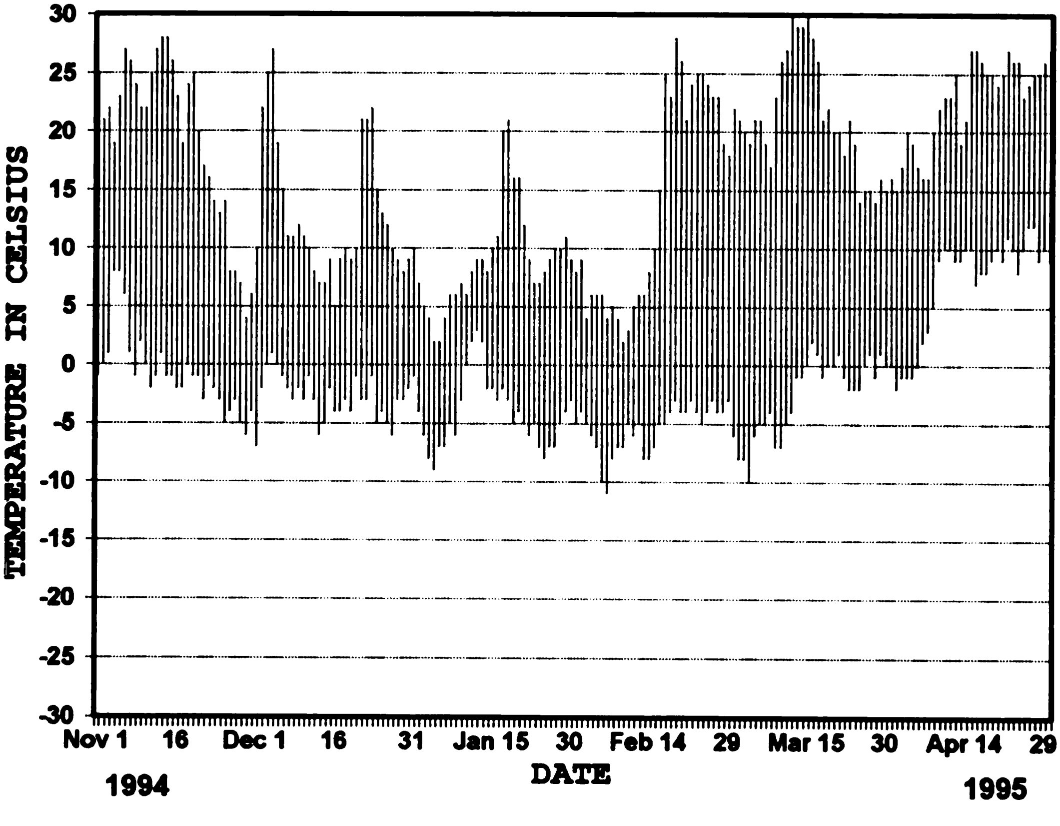
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Figure 2.12. Minimum and maximum daily temperatures collected during 1994-95 from the container medium for plants overwintered pot-to-pot inside a polyhouse.

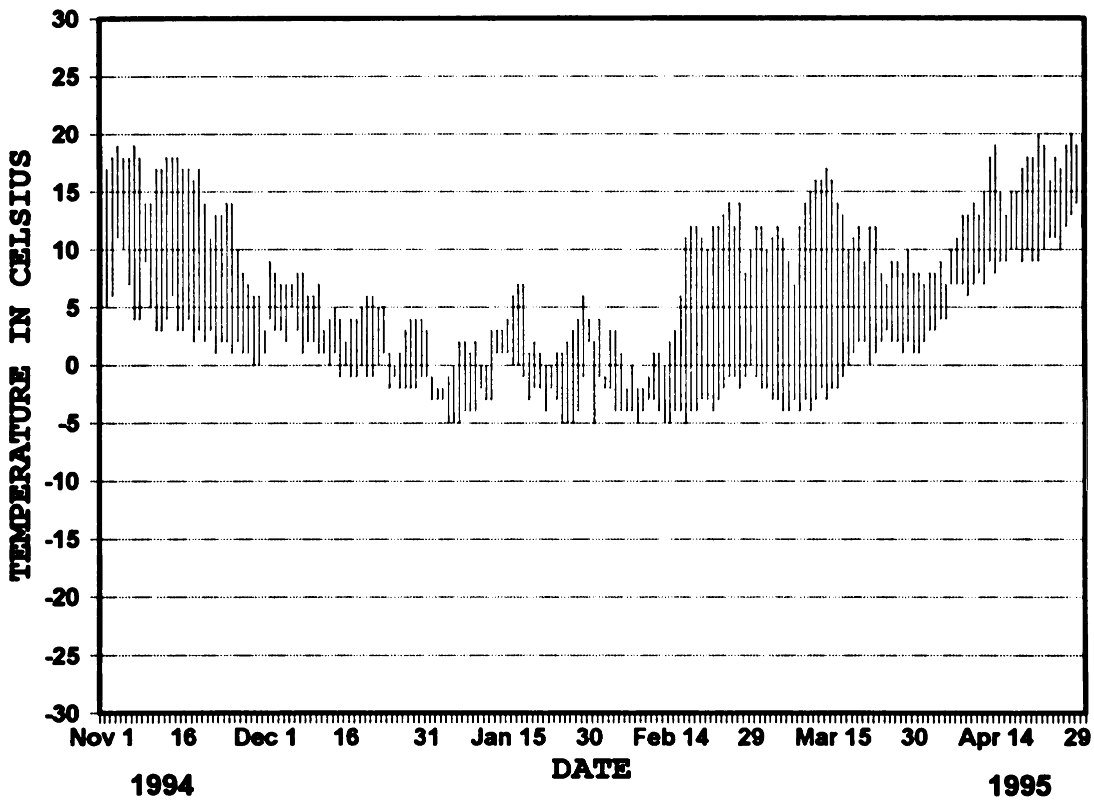
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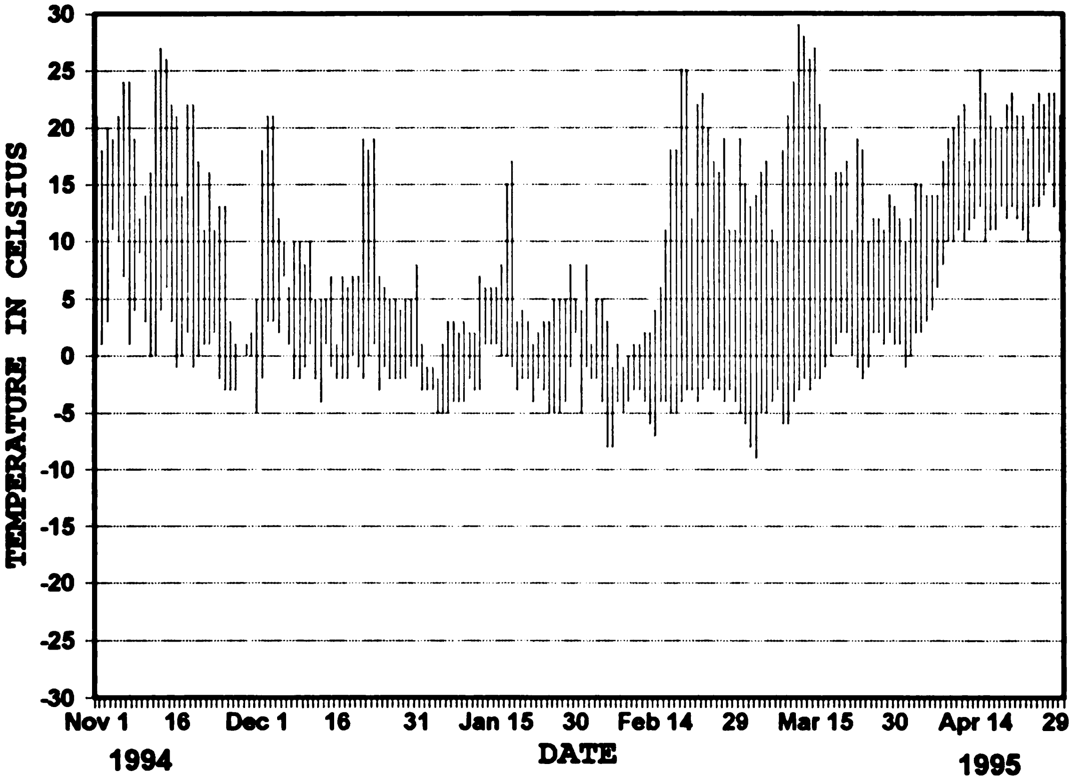
Figure 2.13. Minimum and maximum daily air temperatures collected during 1994-95 at plant level from inside the center of a polyhouse.



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overwintered inside the northwest end may need additional insulation against lower temperatures because they may acclimate at a different rate than those overwintered in the center of the polyhouse.

Polyhouse length can also influence the overwintering of many cultivars. Polyhouses which are 500 feet long are commonly used for overwintering in nurseries. When the polyhouse is this long, variations in air and medium temperatures are very frequent, especially during the deacclimation period. Plants bordering the ends and sides of polyhouses are exposed to colder temperatures than those placed toward the center of the house. Consequently, the closer plants are to the center of a long polyhouse, the warmer their temperature exposure. As a result, plants stored near the center may not acclimate to their fullest potential.

Minimum and maximum daily temperatures were collected from shoot tissue during 1994-95 from plants overwintered in a polyhouse and outdoors pot-to-pot (Figures 2.14 and 2.15). Shoot temperatures in both overwintering systems varied slightly on some days from the air temperatures to which plants were exposed. This data provided evidence that the air and shoot tissue temperatures were similar to each other on any given day.

The polyhouse system accelerated the deacclimation for most of the cultivars studied. This system will benefit growers who need to have deacclimated plants for late winter and early spring shipments.

Exp III. The influence of warming treatments was cultivar-dependent (Figure 2.16). Cold-sensitive cultivars, such as 'Red Lucy' and 'Emerald Mound', were very slow to deacclimate, even after eight days of warming. Loss of hardiness for 'Emerald

Figure 2.14. Minimum and maximum daily temperatures collected during 1994-95 from shoot tissue of a plant inside the center of a polyhouse.

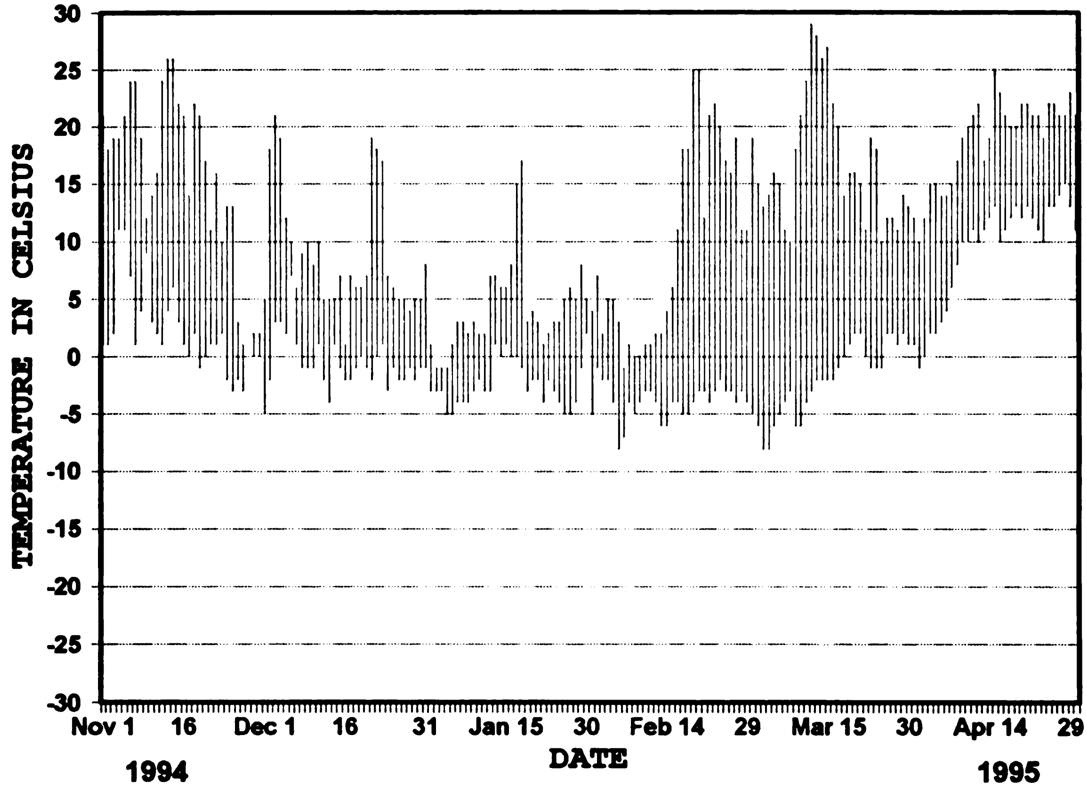

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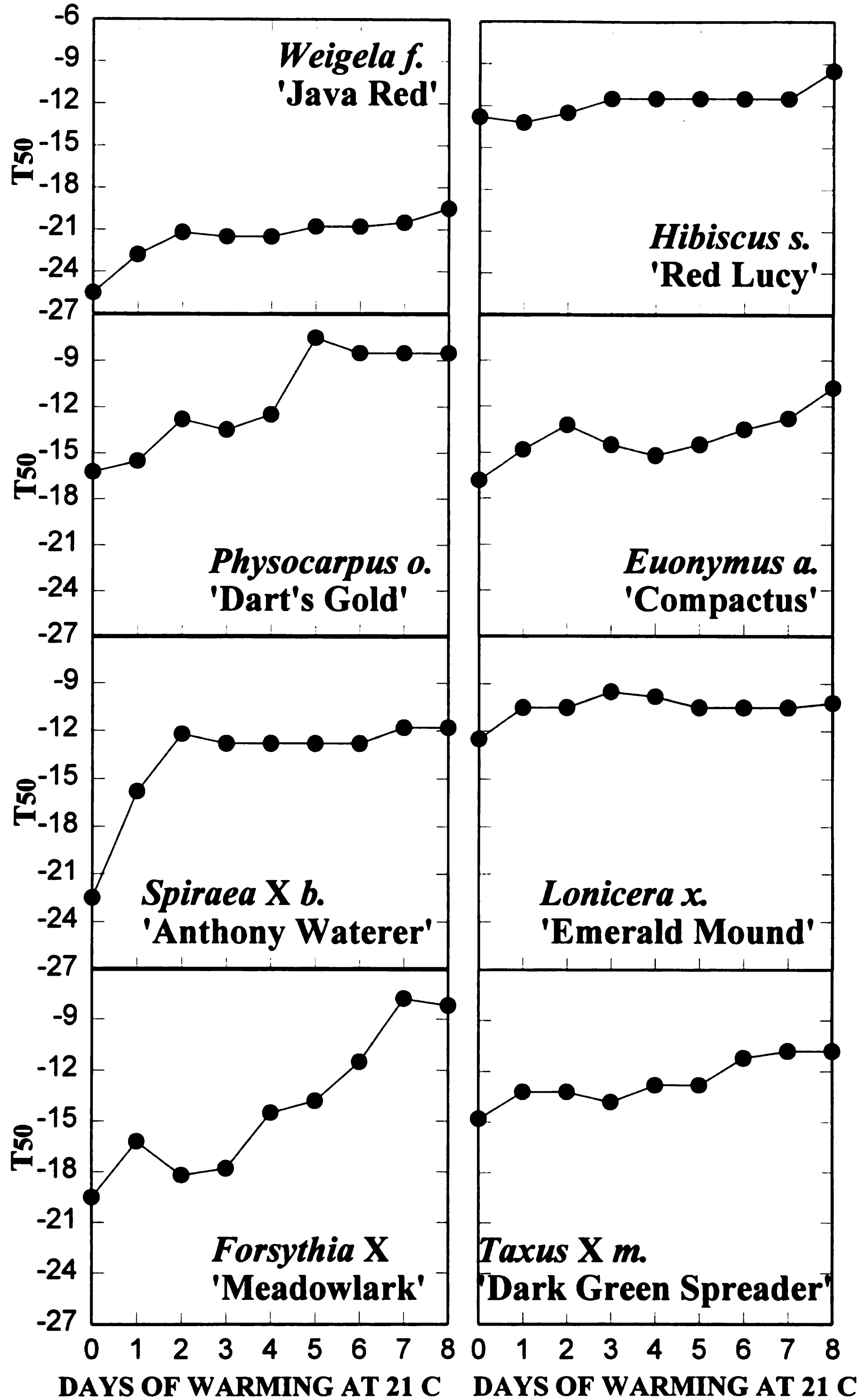
Figure 2.15. Minimum and maximum daily temperatures collected during 1994-95 from shoot tissue of a plant overwintered pot-to-pot under ambient field conditions.

Figure 2.16. Mean shoot tissue T_{50}s in celsius of eight cultivars exposed to a constant 21°C (70°F) temperature for up to eight days. Plants were overwintered pot-in-pot under ambient field conditions.


Weigela f.
'Java Red'
Hibiscus s.
'Red Lucy'
Physocarpus o.
'Dart's Gold'
Euonymus a.
'Compactus'
Spiraea X *b.*
'Anthony Waterer'
Lonicera x.
'Emerald Mound'
Forsythia X
'Meadowlark'
Taxus X *m.*
'Dark Green Spreader'
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DAYS OF WARMING AT 21 C
DAYS OF WARMING AT 21 C

Mound' between 0 and 8 days of warming was not greater than 3°C. *Taxus* 'Dark Green Spreader' showed a similar response, losing only 4°C of hardiness over eight days. 'Java Red' and 'Anthony Waterer', which are root and shoot hardy, rapidly deacclimated between 0 and 2 days of warming, but slowed until the seventh day of warming. 'Anthony Waterer' lost almost 12°C of hardiness during the first two days of warming. *Physocarpus o.* 'Dart's Gold' and *Euonymus a.* 'Compactus', which are marginally hardy in USDA Hardiness Zone 5, steadily deacclimated from 0 to 8 days of warming.

These results indicate that cultivars, such as 'Anthony Waterer' and 'Java Red', should be overwintered using a system which does not accelerate their deacclimation, if early deacclimation is not desired. The onset of their natural deacclimation appears to be rapid after only two days of constant warming. Since warming temperatures did not cause rapid deacclimation in the cold-sensitive cultivars, overwintering these plants in a polyhouse system would probably give adequate root protection without the occurrence of early deacclimation.

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