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THE INFLUENCE OF A POLYETHYLENE FILM COVERED HOUSE ON THE COLD HARDINESS AND SUBSEQUENT PLANT CONDITION OF CONTAINER-GROWN NURSERY STOCK

presented by

Kathleen Marie Kelley

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N Curtis Peterson

Major professor

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THE INFLUENCE OF A POLYETHYLENE FILM COVERED HOUSE ON THE COLD HARDINESS AND SUBSEQUENT PLANT CONDITION OF CONTAINER-GROWN NURSERY STOCK

By

Kathleen Marie Kelley

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ABSTRACT

THE INFLUENCE OF A POLYETHYLENE FILM COVERED HOUSE ON THE COLD HARDINESS AND SUBSEQUENT PLANT CONDITION OF CONTAINER-GROWN NURSERY STOCK

By

Kathleen Kelley

Polyhouses provide winter protection for nursery stock in northern climates. Selected container-grown nursery stock was subjected to three overwintering treatments. Plants were placed in a polyhouse in October (early treatment), and in December (late treatment), plus stored pot-in-pot under natural conditions. Controlled temperature freezing studies were conducted to determine shoot hardiness during the acclimation, mid-winter, and deacclimation phases of the 1995/1996 and 1996/1997 test periods. Acclimation was interrupted for plants placed in the polyhouse in October which prevented maximum hardiness from being achieved. The pot-in-pot treatment was the hardiest and also deacclimated slower than the two polyhouse treatments. Periods of warm temperatures during the 'midwinter thaw' had an impact on the hardiness of each cultivar. Plants overwintered in the polyhouse were affected more by the warm temperatures. Whole plant performance was used as an indication of root injury when subjected to controlled warming temperatures and natural deacclimation. In general, plant performance ratings declined as days of warming increased and as freezing temperatures decreased. Performance for plants exposed to controlled warming increased from 30 to 60 days during the 1995/1996 test period. Ratings declined from 30 to 60 days during the 1996/1997 test period. Ratings for plants subjected to natural deacclimation did not change from 30 to 60 days.

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TABLE OF CONTENTS

Table

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LIST OF TABLES

CHAPTER I

LIST OF TABLES (CHAPTER I, CONT.)

Table **Page**

LIST OF TABLES

CHAPTER II

Table Page

Figure

LIST OF FIGURES

CHAPTER I

Figure

Figure

Figure

LIST OF FIGURES

CHAPTER II

Figure

LIST OF FIGURES (CHAPTER II, CONT.)

Figure

2.12 Vi
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2.13 B
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2.14 V
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2.15 Vi
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LIST OF FIGURES (CHAPTER II, CONT.)

LIST OF FIGURES

APPENDIX A

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SIGNIFICANCE TO THE NURSERY INDUSTRY

Protecting container-grown nursery stock during the winter months is a priority for nurseries. The roots of container-grown nursery stock are more cold tender than shoots and must be protected if exposed to below freezing temperatures. Insufficient protection may result in the loss of nursery stock. Polyethylene-covered hoophouses (polyhouses), which are commonly used in the north, help avert this damage. Plant material placed in polyhouses will be protected from severe cold ambient air temperatures which occur and can persist during the winter months.

A key concern exists for nurseries employing polyhouses for winter protection. If nursery stock is covered too early in the fall it may not be exposed to cold temperatures necessary for acclimation and may actually be less cold hardy during the midwinter period. Short-term warming temperatures in midwinter ('midwinter thaw') may further reduce the cold hardiness of these container plants. Results to date indicate that timing of polyhouse covering influences both plant cold hardiness and plant growth performance in the spring, since extended warming can delay bud break and have an adverse effect on plant vigor.

Thus, the issue associated with choice of protection method and the timing of imposing protection methods are of key economic interest to nursery stock producers in Michigan and other similar climatic regions.

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INTRODUCTION

Environmental conditions dictate when plants begin to acclimate in the fall. Proper acclimation is imperative for winter survival. Woody plants which are exposed to environmental signals such as shorter day lengths and freezing temperatures stop growing and acclimate (7). Along with the cessation of growth, physiological changes also take place which help plants survive the annual minimum midwinter temperatures. Throughout the fall, winter, and spring months, woody plants are vulnerable to periods of warming and cooling temperatures. Temperatures below freezing can cause damage to both the shoots and vulnerable root systems of container-grown nursery stock. Several overwintering systems have been developed to help protect plants. In USDA Hardiness Zone 5 (annual minimum temperatures of -23.3°C/-10.0°F to -29.0°C/-20.0°F) and Zone 6 (-17.8°C/0°F to -23.3°C/ -10.0°F), the most common overwintering system is an opaque polyethylene-covered hoophouse (polyhouse) (2). Temperatures in polyhouses are warmer than ambient field temperatures during the holding phase which helps prevent plant roots from freezing (34). Polyhouse temperatures, however, encourage plants to continue to grow into the late winter months and to begin growth in early spring. Plant tissue may not be as hardy as plants overwintered outdoors and can be injured if exposed to freezing temperatures during the protection phase.

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To help avoid injury or death, woody plants acclimate during the fall in response to environmental signals. As the fall season progresses, the day lengths become shorter. The decrease in day length is considered to be the first stage of acclimation. Shorter day lengths help with the initiation and rate of acclimation. Plants which are not properly hardened can have difficulty surviving the annual minimum temperatures during the midwinter period (19). Cold hardiness of some species can increase by a few decrees after exposure to short days (19, 33). This slight increase, however, helps prevent plant death if an early frost occurs (33). Acclimation in response to low temperature is also faster after exposure to a period of shorter days (30).

Research has shown that a hardiness promoting factor is produced in red-osier dogwood leaves exposed to short days and that this promoting factor is translocated from the leaves to the bark of defoliated branches. Just as a promoter is produced, a hardiness inhibitor is produced in leaves exposed to long days (7). This promoter was shown to exist in tart cherry trees. Tart cherry trees which were defoliated by June were 10.0°C (18.0°F) less hardy than those trees defoliated by either a killing frost in November or hand defoliated in September. Howell and Stackhouse wrote that when tart cherry trees loose their leaves prematurely, the trees can no longer measure day length. As a result, carbohydrate concentration decreases and the tree's ability to survive the winter is reduced. The removal of long day leaves promotes hardening while the removal of short day leaves inhibits hardiness (13).

The second stage of acclimation is exposure to low temperatures, usually a frost (33). As the acclimation period progresses, and temperatures decrease, woody plants become even more hardy and can survive temperatures well below freezing. There seems to be a relationship between the plant's killing temperature and the mean temperature of the preceding two days (26). This second stage of acclamation may also involve changes in concentration of sugars, proteins, as well as changes in tissue hydration and cell membranes (33).

Plants have mechanisms which help prevent cell death. Plant death can occur when ice forms in cells before acclimation occurs. When plants are properly hardened and ice forms outside the cell, water leaves the cell and goes into the extracellular spaces and freezes. Hardier plants can tolerate a greater amount of water loss compared to more tender cultivars. When temperatures rise above freezing the ice thaws and the water moves back into the cell (33). Plants can also survive by supercooling, a process where the cell fluids do not freeze when temperatures fall below the fluid's freezing point. Once ice forms, death occurs instantly. Rhododendron and azalea flower buds can supercool and survive temperatures of -20.0°C to -30.0°C (-4.0°F to -22.0°F) (33).

A tree or shrub has a greater chance of surviving the midwinter period with an adequate amount of carbohydrates (27). An increase in hardiness and total sugar content in English Ivy leaves was observed when exposed to 5.0°C (41.0°F), however, the rate of the increases did not coincide. Starch content also increased during the seven-week period, but again the increase did not coincide with either an increase in hardiness or total sugar concentration (29). Starch levels also increased when apple shoots were exposed to lower storage temperatures. In contrast to the experiments conducted with English Ivy, T_{50} curves paralleled curves for sorbitol and total sugars (27).

A reduction in water content also increases plant hardiness. Water stressed red-osier dogwood plants were hardier than control plants by at least 8.0-10.0°C (14.4-18.0°F) when exposed to long and short days, respectively. Plants which gained hardiness when water stressed lo

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stressed lost most of the induced hardiness when placed under long day conditions. Plants which remained under short days lost a small amount of hardiness when they were rewatered (22). Similar results occurred when azalea plants were tested. Azaleas subjected to three weeks of water stressed conditions significantly increased in hardiness compared to control plants. After three weeks of rewatering, the water stressed and control plants had similar hardiness levels which differed by less than 1.0°C (1.8°F) (1).

Cooling and warming rates as well as depth of cold exposure may greatly influence plant cold hardiness and development at different times of the year (12). Temperature fluctuations are necessary for shade trees in Minnesota to acclimate before the minimum ambient temperature falls below freezing (24). Fluctuating temperatures also affect hardiness levels during the spring. At this time plants are vulnerable to periods of warming and cooling (14). The plant appears to respond to deacclimating temperatures more rapidly than acclimating temperatures (14, 21). The decrease in hardiness is dependent on the stage of bud development and temperature (21). *Forsythia X intermedia* Zrabel dehardened in six days after exposure to 27.0°C (80.6°F) in December, whereas significant dehardening took place in January after only four days o exposure to 15.0°C (59.0°F). Even warm weather during the midwinter period can cause red-osier dogwood to deharden and become injured (17). If dehardening does occur, in order to survive, the plant must be able to reharden.

The roots are the most cold tender plant organ followed by flower buds, vegetative buds, and stems. Roots and shoots can differ in hardiness by as much as 20.0°C (40.0°F) (9). While hardy stems of *Cornus stolonifera* can survive -196.0°C (-321.0°F) (15), the mature roots of *Picea glauca* survive only to -23.3°C (-10.0°F) (11) and young roots of *Euonymus alatus* 'Compactus' can only survive temperatures to -7.0°C (19.0°F) (30). In addition, establis

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established plants in containers have most of their young roots between the substrate interface and the edge of the pot, making them more vulnerable to freezing damage (11).

Roots do not respond to the acclimation signals such as shorter days and low temperatures (10). Instead, the roots respond to the surrounding soil temperature. As the soil temperature decreases, the roots begin to acclimate. When the soil warms, the root system deacclimates (32). A prolonged period of warm temperatures at this time can actually cause the root system to grow. This process can occur in as little as 24 hours. These roots can then be injured and/or damaged when cold temperatures reoccur (10).

Root hardiness must be considered when overwintering container-grown nursery stock. The roots of plants are influenced by surrounding soil temperatures. Since the roots of container-grown nursery stock are above ground (9), and due to the limited amount of substrate material in containers, the roots are not buffered from low temperatures as field-grown root systems are (10, 21). Temperatures can differ by up to 9.0°C (16.2°F) between roots of field-grown plants and roots in the middle of a 20cm (8in) container (30).

Limited water is available to roots in containers, necessitating watering during warm periods and before freezing occurs. A wet container substrate protects the root system by freezing at a slower rate than dry substrate (3). Warm leaf and air temperatures accompanied by low ambient relative humidity accelerates moisture loss. This condition commonly occurs during the protection phase, therefore, growers have recognized the need for supplemental irrigation during this holding period (2).

Plants nutrition is a key factor in production so that optimal growth occurs in the spring producing healthy plants, which survive the winter as well. Healthy plants have the highest rate of survivability when exposed to freezing temperatures. Excess fertilizer applied in the late summer or early fall can stimulate late season growth, delaying acclimation (2). This tender, new growth is easily injured or killed when freezing temperatures occur. The use of slow release fertilizer is still an area of dispute. Whether slow release fertilizers are a benefit remains to be determined. Slow release fertilizer is dependent on high temperature and moisture levels for release (8). A concern is the possible release into the container substrate when exposed to high polyhouse temperature throughout the holding season, which may cause soluble salt injury to the root system and perhaps stimulate hardiness loss.

The most common overwintering system used in northern climates is a quonset-style polyethylene-covered hoophouse, known as a polyhouse. Polyhouses can help protect roots from being injured at higher temperatures than the minimum annual temperature in their area (3). The use of opaque polyethylene reduces the amount of infrared radiation which is transmitted through the structure as compared to clear polyethylene. This reduction will prevent rapid temperature increases during the day light hours (16). When ambient field temperatures approach -32.0°C (-25.0°F), interior temperatures of opaque polyhouses have been recorded at -12.0°C (10.0°F) (25). The configuration of the containers in the polyhouse help trap ground heat which keeps the temperatures around the roots system warmer (18). The polyethylene covering also protects stems from being broken by heavy snow or ice load. Hardier plants can be overwintered in a pot-in-pot system. A potted nursery plant is placed into a pot submerged into the ground (4). The root system is protected while the shoots of container-grown nursery stock obtain maximum hardiness when exposed to the minimum annual field temperatures.

With the large variety of nursery stock available, growers should only produce plants hardy enough to survive the nursery location. The plant's ability to acclimate as a response to photoperiod and temperature changes, is based on its genetic background (6). Plants may be able to survive the mid-winter period, but may not acclimate quick enough to survive sudden temperature drops (18). Plants which are slow to acclimate can be protected from sudden drops in temperature in polyhouses. It is advised, however, that plants should not be placed in a polyhouse until they have completely acclimated (5). As a result of the warmer polyhouse environment, plants can grow twice as fast as those overwintered outdoors (25). Certain species may not acclimate as quickly as those overwintered outdoors and as a result, they may not reach their maximum mid-winter hardiness level (28). They may also break bud several weeks before those overwintered outdoors and can be damaged if exposed to cold temperatures after the covering is removed in early spring (25). However, early bud break can be a benefit to growers who usually retrieve plants from polyhouses for shipments in late winter to more southern locations.

Plant species is a general guide to the hardiness level, however, cultivars within a species may vary in their response to different cold temperatures. For example, differences of up to -6.4°C (11.5°F) occur among red raspberry cultivars grown in Cambridge, Ontario (36). Similar results were seen during cold hardiness experiments with *Forsythia X intermedia* cultivars (20). Bud hardiness levels varied from 2.0-4.0°C (4.0-7.0°F) for *Forsythia* cultivars in that study. Management strategies for overwintering may vary depending upon the cold hardiness of the cultivar. During the last 10-15 years, new cultivars have been created to be more bud hardy, however, little is known about the shoot hardiness (20). If the cold hardiness of a new cultivar is not known, laboratory cold hardiness tests can be used to determine this value (5).

Production of nursery stock in containers has revolutionized the nursery industry. Growers can produce more plants per unit are and use less expensive substrate material. The plant material is also readily available throughout the growing season (4, 9). However, the material must be protected from freezing temperatures during the winter months. The most popular protection method, a polyhouse, is not the ideal overwintering structure. Concerns exist on the continued use of polyhouses and their effect on cold hardiness. The objective of this research was to investigate the effect of polyhouse environment and its influence on overwintering of container-grown nursery stock. The approaches will be to answer the following questions: Should plants be covered in polyhouses early in the fall or later after more acclimation has occurred? Will early covering have an influence on the plant hardiness and affect plant growth in the spring? What influence will a warm January or February midwinter temperature fluctuation have on the cold hardiness of these plants? Are there differences in shoot hardiness amongst cultivars and if so do cultivars need to be overwintered differently? What influences do warm temperatures have on root systems and will root injury effect whole plant performance?

LITERATURE CITED

1. Anisko, T., and O.M. Lindstrom. 1996. Cold hardiness of evergreen azaleas is increased by water stress imposed at three dates. J. Amer. Soc. Hort. Sci. 121(2):296-300.

2. Beattie, D.J. 1986. Principles, practices, and comparative costs of overwintering container-grown landscape plants. Southern Cooperative Series. Bulletin 313.

3. Clark, W.S. 1988. Overwintering container-grown ornamentals. Long Island Horticulture News. pp. 4-6.

4. Davidson, H., R. Mecklenburg, and C. Peterson. 1994. Nursery Management: Administration and Culture. Prentice Hall, Inc. p. 236.

5. Dirr, M.A., and O.M. Lindstrom, Jr. 1993. Cold hardiness estimates of *Acer* L. taxa. J. Environ. Hort. 11(4):203-205.

6. Fretz, T.A., and E.M. Smith. 1978. Woody ornamental winter storage. HortScience. 13(2):139-140.

7. Fuchigami, L.H., D.R. Evert, and C.J. Weiser. 1974. A translocatable cold hardiness promoter. Plant Physiol. 47:164-167.

8. Gartner, J.B. 1981. Container plants require special fertilization and overwintering systems. Amer. Nurs. 140(5):655-658.

9. Good, G.L., P.L. Steponkus, S.C. Wiest, and E.J. Studer. 1977. Overwintering container-grown ornamentals. New York's Food and Life Sciences. 10(2):15-17.

10. Green, J.L., and L.H. Fuchigami. 1985. Principles: Protecting container-grown plants during the winter months. Ornamental Northwest Newsletter. 9(2):10-22.

11. Havis, J.R. 1976. Root hardiness of woody ornamentals. HortScience. 11(4):385-386.

12. Hayes, C.L., O.M. Lindstrom, M.A. Dirr. 1992. Cooling and warming effects on cold hardiness estimations of three woody ornamental taxa. HortScience. 27(12):1308-1309.

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13. Howell, G.S., and S.S. Stackhouse. 1973. The effect of defoliation time on acclimation and dehardening in tart cherry (*Prunus cerasus* L.). J. Amer. Soc. Hort. Sci. 98(2):132-136.

14. Howell, G.S., and C.J. Weiser. 1970. Fluctuations in the cold resistance of apple twigs during spring dehardening. J. Amer. Soc. Hort. Sci. 95(2):190-192.

15. Howell, G.S., and C.J. Weiser. 1970. Similarities between the control of flower initiation and cold acclimation in plants. HortScience. 5(1):18-20.

16. Iles, J.K., N.H. Agnew, H.G. Taber, and N.E. Christians. 1993. Evaluation of structureless overwintering systems for container-grown herbaceous perennials. J. Environ. Hort. 11(2):48-55.

17. Litzow, M., and H. Pellett. 1980. Relationship of rest to dehardening in red-osier dogwood. HortScience. 15(1):92-93.

18. McHugh, E., J. Robbins, and D. Hensley. 1988. Overwintering ornamental plants. Kansas Nursery Notes. 20:1-3.

19. McKenzie, J.S., C.J. Weiser, and M.J. Burke. 1974. Effects of red and far red light on the initiation of cold acclimation in *Cornus stolonifera* Michx. Plant Physiol. 53:783-789.

20. McNamara, S., and H. Pellett. 1993. Flower bud hardiness of *Forsythia* cultivars. J. Environ. Hort. 11(1):35-38.

21. Mityga, H.G., and F.O. Lanphear. 1971. Factors influencing the cold hardiness of *Taxus cuspidata* roots. J. Amer. Soc. Hort. Sci. 96(1):83-86.

22. Parsons, L.R., and P.H. Li. 1979. Changes in frost hardiness of stem cortical tissues of *Cornus stolonifera* Michx. after recovery from water stress. Plant Physiol. 64:351-353.

23. Pellett, H., M. Gearhart, and M. Dirr. 1981. Cold hardiness capability of woody ornamental plant taxa. J. Amer. Soc. Hort. Sci. 106(2):239-243.

24. Pellett, H., S. Moe, and K. Vogel. 1985. Cold tolerance of shad tree species and cultivars in the upper Midwest. J. Environ. Hort. 3(2):58-62.

25. Pellett, N.E., D. Dippre, and A. Hazelrigg. 1985. Coverings for overwintering container-grown plants in norther regions. J. Environ. Hort. 3(1):4-7.

26. Proebsting, E.L. 1963. The role of air temperature and bud development in determining hardiness of dormant Elberta peach fruit buds. Proc. Amer. Soc. Hort. Sci. 83:259-269.

27. Raese, J.T., M.W. Williams, and H.D. Billingsley. 1978. Cold hardiness, sorbitol, and sugar levels of apple shoots as influenced by controlled temperature and season. J. Amer. Soc. Hort. Sci. 103(6):796-801.

28. Regan, R.P., R.L. Ticknor, D.D. Hemphill, Jr., T.H.H. Chen, P. Murakami, and L.H. Fuchigami. 1990. Influence of winter protection covers on survival and hardiness of container-grown *Ilex crenata* Thunb. 'Green Island' and *Euonymus fortunei* (Turcz.) 'Emerald 'n Gold'. J. Environ. Hort. 8(3):142-146.

29. Steponkus, P.L., and F.O. Lanphear. 1968. The relationship of carbohydrates to cold acclimation of *Hedera helix* L. cv. Thorndale. Physiol. Plant. 21:777-791.

30. Studer, E.J., P.L. Steponkus, and G.L. Good. 1978. Root hardiness of container-grown ornamentals. HortScience. 13(2):172-174.

31. van Huystee, R.B., C.J. Weiser, and P.H. Li. 1967. Cold acclimation in *Cornus stolonifera* under natural and controlled photoperiod and temperature. Bot Gaz. 128:200-205.

32. Wildung, D.K., C.J. Weiser, and H.M. Pellett. 1973. Temperature and moisture effects on hardening of apple roots. HortScience. 8(1):53-55.

33. Wright, R.D. 1980. How plants respond to freezing. Amer. Nurs. 141(8):16, 84-85.

34. Wynstra, J.A., and E.M. Smith. 1970. A comparison of white vs aluminum poly for overwintering woody ornamental landscape plants. pp. 16-19.

35. Young, R.E., J.L. Dunlap, Jr., P.J. Smith, and S.A. Hale. 1987. Clear and white plastics for freeze protection of landscape plants in the southern to mid-Atlantic region. J. Environ. Hort. 5(4):166-172.

36. Zatylny, A.M., J.T.A. Proctor, and J.A. Sullivan. 1996. Assessing cold hardiness of red raspberry genotypes in the laboratory and field. J. Amer. Soc. Hort. Sci. 121(3):495-500.

CHAPTER I

THE TIMING OF POLYHOUSE COVERING AND MID-WINTER WARMING ON SHOOT COLD HARDINESS

ABSTRACT

The Timing of Polyhouse Covering and Midwinter Warming on Shoot Cold Hardiness

The timing of polyhouse covering and its impact on shoot cold hardiness during the acclimation, midwinter, and deacclimation periods was studied using selected container-grown nursery stock during the 1995/1996 and 1996/1997 test periods. Container-grown plants were subjected to three overwintering treatments. Plants placed in a polyhouse in October (early treatment), and in December (late treatment), plus stored pot-in-pot under natural conditions. Acclimation was interrupted for plants placed in the polyhouse in October which prevented maximum hardiness from being achieved. The pot-in-pot treatment was the hardiest and also deacclimated at a slower rate than the two polyhouse treatments. Hardy cultivars such as *Weigela florida* 'Java Red' and *Euonymus alatus* 'Compactus' obtained lower midwinter hardiness levels, while *Hibiscus syriacus* 'Jeanne d' Arc' was a more cold-sensitive cultivar. *Forsythia X intermedia* cultivars achieved different levels of hardiness depending upon the overwintering treatment. *Euonymus* and *Forsythia* cultivars 'Northern Gold' and 'Lynwood' placed in the polyhouse late vs. early had higher plant performance ratings even though bud break occurred on the same day. Periods of warm temperatures during the 'midwinter thaw' impacted the hardiness of each cultivar. Plants overwintered in the polyhouse were affected more by the warm temperatures.

INTRODUCTION

Survival of plants during the winter months in northern areas is dependent upon their ability to endure freezing temperatures (18). There is concern that warming and cooling temperatures can also cause a substantial amount of injury throughout the entire overwintering phase. Polyethylene-covered hoophouses (polyhouses) can give some protection against these temperature extremes. Polyhouse temperatures are considerably warmer than minimum annual field temperatures and as a result plants can continue to grow well into the late fall months. Plants also begin growth earlier in the spring (14). A longer growth period can be an advantage for growers, however, the plants may not be as hardy as those exposed to colder temperatures during the protection phase.

Cooling and warming rates influence plant cold acclimation and level of hardiness at different times of the year (11). Periods of freezing followed by warming in the fall allows the second stage of dormancy to progress naturally. The absence of this temperature fluctuation prevented shade trees in Minnesota from acclimating fast enough to tolerate the cold midwinter period (18). During the spring months, plants are vulnerable to continual changing periods of hardening and dehardening (12). Loss of hardiness appears to occur more rapidly than gains in hardiness (12, 20). The decrease in hardiness is dependent on stage of bud development and temperature (20). *Forsythia X intermedia* Zabel dehardened in six days after exposure to 27.0°C (80.6°F) in December, whereas significant dehardening took place in January after only four days of exposure to 15.0°C (59.0°F). As the dehardening period progressed, plant deacclimation accelerated as temperatures decreased.

Although cooling and warming rates and temperatures have an influence on acclimation and deacclimation (11), it has been reported that warm weather during the winter months can cause red-osier dogwood to deharden and become injured (13). The survival of plants at times of high temperatures during the winter months not only depends upon its ability to withstand dehardening, but to reharden. For Elberta peach fruit buds, temperatures below -2.2 to -1.1°C (28.0 to 30.0°F), stimulate hardening while temperatures above this range will cause plant material to deharden (20).

Storing plant material in an overwintering structure may help limit plant injury throughout the holding phase. One of the most common overwintering structures in USDA Hardiness Zones 5 (annual minimum temperature of -23.3°C/-10.0°F to -29.0°C/0°F) and 6 (-17.8°C/0°F to -23.3°C/-10.0°F) is a polyethylene-covered hoophouse, known as a polyhouse. Opaque coverings with a 4-6 mil thickness keep interior temperatures at -12.0°C (10.0°F), when the ambient field temperatures are -32.0°C (-25.0°F) (19). The use of a white polyethylene covering reduces the amount of infrared radiation which is transmitted through the covering as compared to clear polyethylene (2, 5).

It has been suggested that plant material be allowed to acclimate as much as possible outdoors before overwintered (5, 10). These plants, however, should be covered once they have acclimated to prevent freezing injury (23). Hardier plant material which can survive low shoot killing temperatures can be overwintered in a pot-in-pot system. Such a system allows the roots of plants to be protected from killing temperatures by placing potted nursery plants into another pot submerged into the ground (7). The shoots of such a plant are exposed to the ambient air and obtain its maximum hardiness level.

Polyhouses can also be used as a growing structure. As a result of higher interior temperatures, plants overwintered in a polyhouse can grow twice as fast as those overwintered outdoors (19). The warmer interior temperatures can stimulate plant growth well into the late fall months. Plants stored in polyhouse can also break bud earlier than plants overwintered outdoors (19). Early plant growth is attractive to growers who access plant material in late winter for shipment to more southern locations (6). Plants, however, may not become as cold hardy as those overwintered outdoors. New growth can be injured by cooler ambient field temperatures in the spring when the poly covering is removed (19).

Growers must consider the origin of ornamental plants when deciding on management strategies for overwintering. With the large number of plants available to growers and as new cultivars are produced, special attention must be given to successfully overwinter nursery stock. Growers should produce plants which are hardy for their market area. Plants introduced from many habitats may not have the ability to properly harden in the nursery location depending upon seasonal effects. The plant's timing and rate of acclimation in response to a change in photoperiod and temperature are based on its genetic code (9). Many plants can survive the mid-winter period but acclimate slowly and can be injured when temperatures suddenly drop (17). Polyhouses provide protection for plants which acclimate slowly. The extended warming environment in a polyhouse can delay acclimation for some species and accelerate deacclimation for others. Some species may respond to the extended fall environment by continuing to grow and not reach it maximum hardiness level.

New cultivars are created to be more appealing to consumers or possess a characteristic which may help the plant survive better, such as an increase in flower bud hardiness (15). Since the flower buds are one of the least hardy parts of a plant, researchers have developed breeding programs to improve this characteristic. Introduction of new *Forsythia X intermedia* species in the past 10-15 years has helped prevent the problem of flower bud death. Brainerd et al. (4), found that the bud hardiness of *Forsythia X intermedia* 'Lynwood' was significantly less hardy than *F. Mandschurica* and *F. ovata*. In May 5% of the 'Lynwood' flower buds bloomed as compared to 50-60% for the other two species. New species have developed with an improvement in bud hardiness, but little is known about the shoot hardiness during the acclimation, mid-winter, and deacclimation periods (15). Laboratory cold hardiness experiments can be used to discover the maximum hardiness level of these new cultivars (8).

This research was conducted to determine the influence of the polyhouse environment on selected container-grown nursery stock when covered early in the acclimation period verses later in the fall season. Other questions which are of concern include: How will plant cold hardiness be influenced by early polyhouse covering? How will subsequent plant growth be effected in the spring? Will a January or February midwinter temperature fluctuation effect the hardiness of these plants? Finally, will shoot hardiness vary amongst cultivars and if so do these cultivars need to be overwintered differently?

MATERIALS AND METHODS

OVERWINTERING Three cultivars of container-grown nursery stock: *Weigela florida* 'Java Red', *Hibiscus syriacus* 'Jeanne d' Arc', and *Euonymus alatus* 'Compactus', were overwintered at the Michigan State University Horticulture Teaching and Research Center in Lansing, Michigan, USDA Hardiness Zone 5, -23.0°C to -29.0°C (-10.0°F to -20.0°F), from October to April 1996. The nursery stock was grown in 20.0 cm (8.0 in) black nursery pots and was subjected to three overwintering treatments: (1) Plants held in the center of a 55 percent transmission, opaque, 18' x 96' polyhouse in an east-west orientation, early on October 12, 1995, during the acclimation period; (2) Plants held in the polyhouse late on December 5, 1995, after more acclimation was acquired; and (3) Plants stored pot-in-pot under natural conditions. In the pot-in-pot treatment, a potted plant is placed into a pot submerged into the ground to protect the root system (Figure 1.1). Polyhouse and ambient minimum and maximum air temperatures were recorded daily. The datalogger (model CR10, Logan, Utah) malfunctioned on October 12, 1995, resulting in 19 days of missing temperatures; therefore, temperature data from October 12 to October 31 was not recorded. Controlled temperature freezing was conducted weekly from October 10 to November 21, 1995, biweekly from December 21 to March 5, 1996 and weekly again from March 12 to April 14, 1996. Controlled temperature freezing was not conducted from November 28 to December 21, 1995 due to a malfunction with the Revco Ultralow freezer (Omega Engineering, Stamford, CT).

Shoots were collected for each cultivar on each testing date. Each shoot was cut into three pieces, which were approximately 3.0 to 4.0 centimeters (1.18-1.58 inches) long and

Figure 1.1. Photographs of the pot-in-pot overwintering treatment. (top) An empty 20 cm (8 in) black nursery pot is submerged into the ground, (bottom) a potted plant is then placed into it.

attached to a masking tape template. A 26 ga copper-constantan thermocouple was then inserted into one of the twigs in the center of the template. The template was then placed on top of a moist piece of gauze to prevent supercooling, placed in contact with an aluminum foil heat sink, and placed in a Revco Ultralow freezer. The thermocouple was then connected to a potentiometer (21). The temperatures within the freezer were controlled and monitored by an Omega temperature controller. The bundles were kept in the freezer overnight at a constant -3.0°C (26.6°F). The next morning the temperature of the freezer was programed to drop in 3.0°C (5.4°F) increments every hour.

Nine freezer temperatures, replicated three times, were used including a control which remained in a 3.0°C (37.4°F) freezer. Freezing temperature ranges varied from -3.0°C to -39.0°C (26.6°F to -38.2°F) to fit the stages of the acclimation, midwinter, and deacclimation. At each temperature regiment the bundles were removed and placed in a 3.0°C (37.4°F) freezer to slowly thaw overnight. This process continued until all eight temperatures occurred. Bundles were removed the next day from the aluminum foil and gauze and placed into an aerated humidity chamber for five to seven days (12), after which samples were dissected for evaluation and evidence of oxidative browning. T_{50} values (the temperature at which 50% of the samples were killed) were calculated using the Spearman-Karber method (3). The T_{50} values were then subjected to analysis of variance (ANOVA).

Bud break was recorded in the spring and analyzed using analysis of variance. Visual plant performance was recorded each week from March 18 through June 10, 1996. The means of three plants per treatment were rated using a scale of 1-5 where: 1=Bud scale not broken, tissue was brown and/or dead; 2=Bud scale was broken, leaves visible; 3=Uniform new growth, new leaves were formed; 4=Leaves were fully expanded; and 5=Leaves fully expanded on elongated shoots. Plants were rated either alive or dead on June 10, 1996, as percentages. Analysis of variance was used to determine significance between treatments of each cultivar during the acclimation, midwinter, and deacclimation periods.

The experiment was conducted again from September to April 1997 with the following container-grown nursery stock: *Euonymus alatus* 'Compactus' and three *Forsythia X intermedia* cultivars ('Sunrise', 'Lynwood', and 'Northern Gold'). The nursery stock was again subjected to one of three overwintering treatments: (1) Plants held in a polyhouse early on October 15, 1996; (2) Plants held in the polyhouse late on December 5, 1996; and (3) Plants held pot-in-pot under natural conditions. Weekly controlled temperature freezing was conducted from September 10 to December 17, 1996, biweekly from January 2 to March 12, 1997, and weekly again from March 26 to April 15, 1997. Controlled temperature freezing was conducted as previously described. Freezing temperature ranges varied from -9.0°C to -45.0°C (15.8°F to -49.0°F) to fit the stages of the acclimation, mid-winter, and deacclimation. Date of leaf drop and stem color changes were recorded in the fall. Bud break and visual plant performance were recorded each week from March 1 to June 3, 1997.

MIDWINTER TEMPERATURE FLUCTUATION Most winters in Michigan experience warming in January or February known as the 'midwinter thaw'. Shoots were collected from the cultivars used in the previously described experiment. This experiment was executed to study the adverse influence of warming on shoots. Warming in 1996 occurred from January 17 to January 23. The maximum ambient field temperature was 16.0°C (60.8°F) with a minimum of -14.0°C (6.8°F), while the maximum temperature in the polyhouse was 22.0°C (71.6°F) with a minimum of -11.0°C (12.2°F). Controlled temperature freezing (as previously described) was conducted every other day, to determine the influence of warming on shoot hardiness.

Controlled temperature freezing was again conducted every other day during the warming of 1997 which occurred between February 18 and February 25. The maximum ambient field temperature was 13.0°C (55.0°F) with a minimum of -16.0°C (3.0°F), while the maximum temperature in the polyhouse was 21.0°C (69.8°F) with a minimum of -12.0°C (10.4°F). The T_{50} values were calculated and recorded for both years (3) and subjected to analysis of variance.

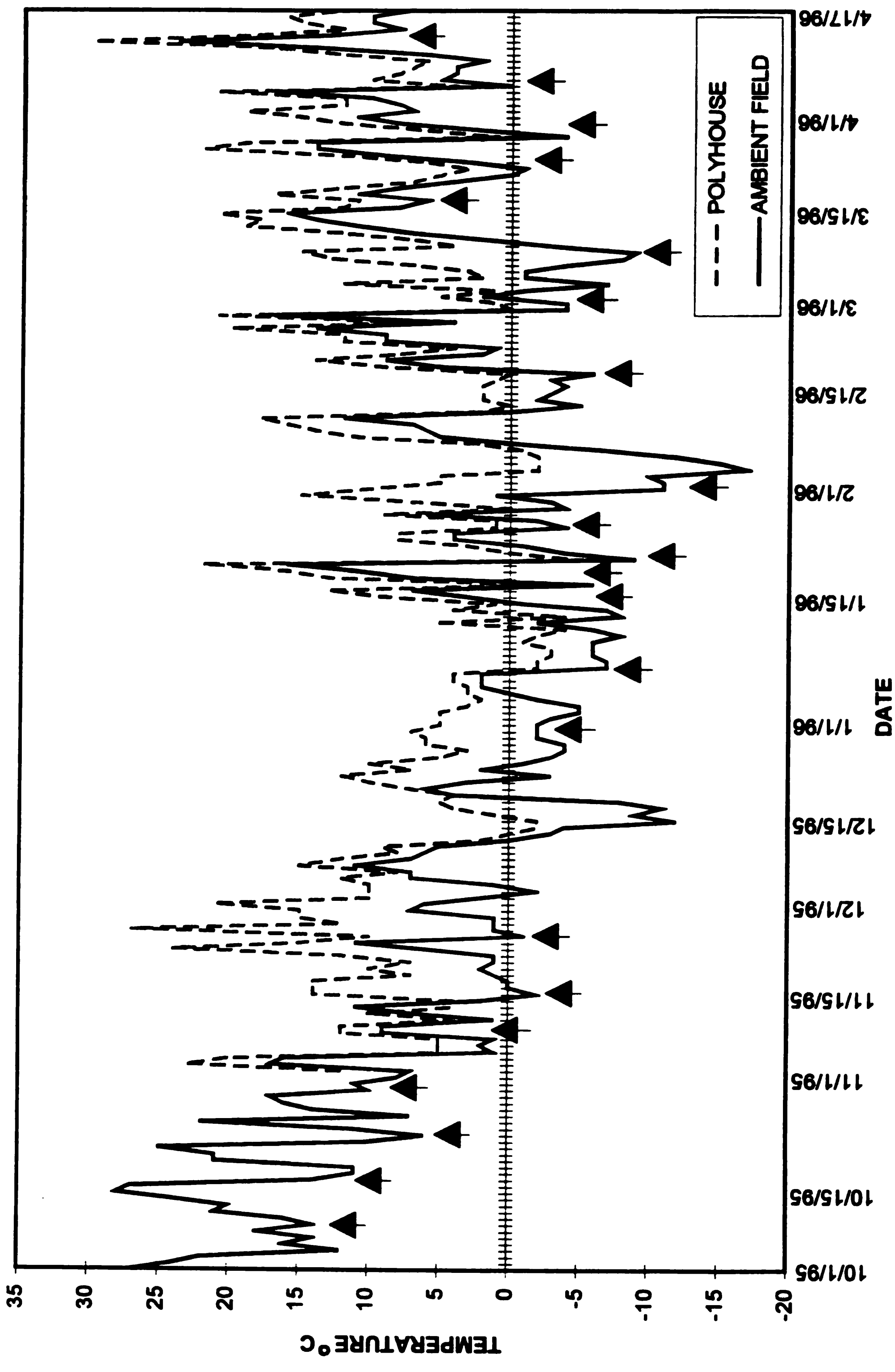
RESULTS AND DISCUSSION

Minimum and maximum ambient field and polyhouse temperatures were recorded daily at plant level during the fall, winter, and spring (test periods) of 1995/1996 and 1996/1997. The maximum polyhouse temperature experienced during the 1995/1996 test period was 27.0°C (80.6°C) on November 23, while the maximum ambeint field temperature was 28.0°C (82.4°F) on October 13 (Figure 1.2). The lowest minimum polyhouse temperature during this test period was -13.0°C (8.6°F) on February 19, the lowest ambient field temperature was -25.0°C (-13.0°F) on February 3 (Figure 1.3).

Maximum polyhouse and ambient field temperatures were higher during the 1996/1997 test period, 35.0°C (95.0°F) on October 15 and 31.0°C (87.8°F) on September 5, respectively (Figure 1.4). Minimum polyhouse temperatures were lower during the 1996/1997 test period, -16.5°C (2.0°F) on January 19, however, the minimum ambient field temperatures were warmer, -23.0°C (-9.4°F) also on January 19 (Figure 1.5).

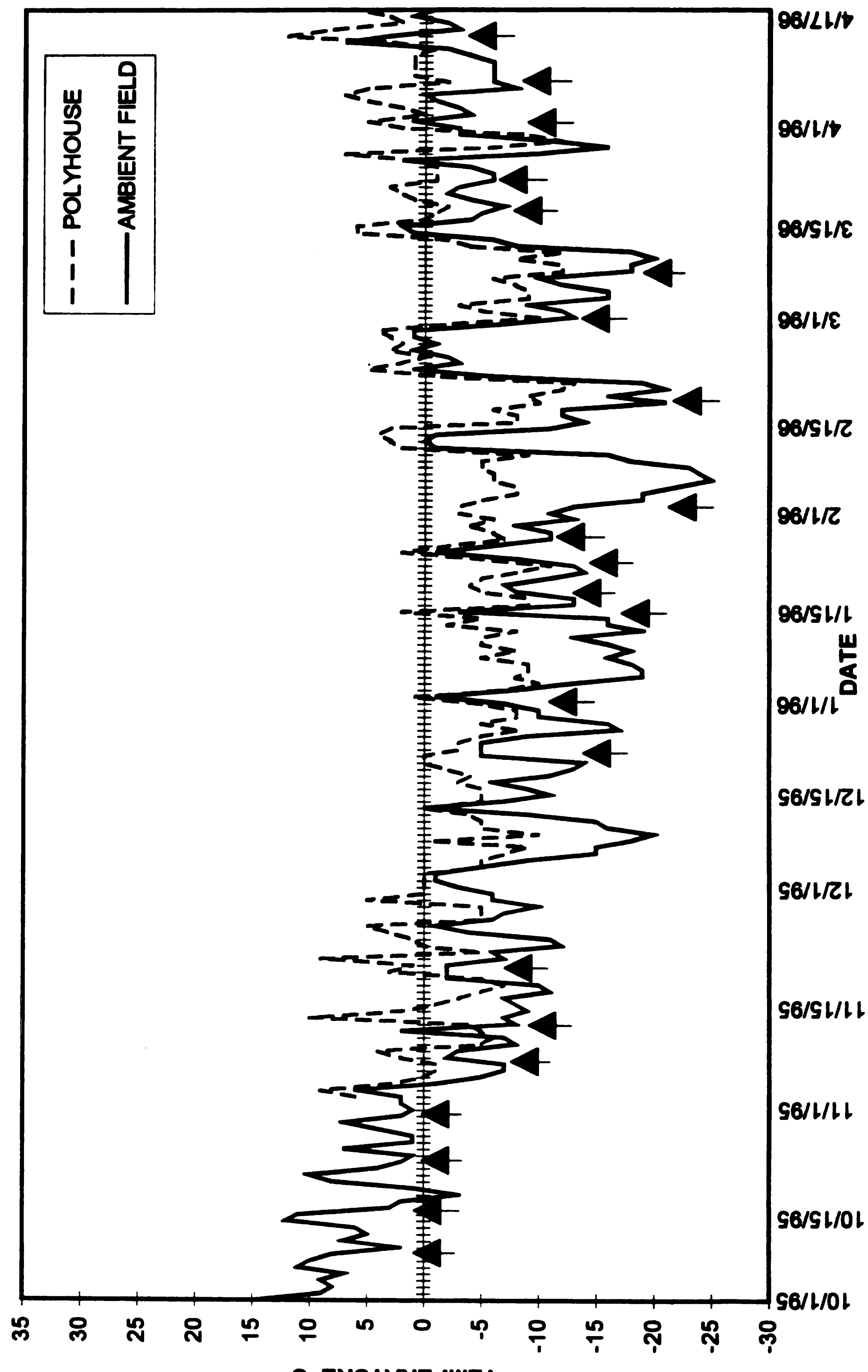
OVERWINTERING The results during the 1995/1996 test period demonstrated that for all three overwintering treatments, hardy *Weigela florida* 'Java Red' and the more cold-sensitive *Hibiscus syriacus* 'Jeanne d' Arc' cultivars were highly responsive to decreasing temperatures during the acclimation period (Figures 1.6 & 1.7). Changes in hardiness for *Weigela* were most noticeable between October 24 and November 1, for the late and pot-in-pot treatments, while a similar response was not seen for the early treatment until November 14. For all three overwintering treatments, a noticeable increase in hardiness for *Hibiscus* occurred between October 10 and 17. All three overwintering treatments of *Euonymus alatus* 'Compactus' increased in hardiness by only 0.5-1.0°C (0.9-1.8°F), each week from October

Figure 1.2. Maximum daily polyhouse and ambient field temperatures were measured at plant level during the 1995/1996 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.



POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
DATE
35
30
25
20
15
10
5
0
-5
-10
-15
-20
10/1/95
10/15/95
11/1/95
11/15/95
12/1/95
12/15/95
1/1/96
1/15/96
2/1/96
2/15/96
3/1/96
3/15/96
4/1/96
4/17/96

Figure 1.3. Minimum daily polyhouse and ambient field temperatures were measured at plant level during the 1995/1996 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.



POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
DATE
10/1/95
10/15/95
11/1/95
11/15/95
12/1/95
12/15/95
1/1/96
1/15/96
2/1/96
2/15/96
3/1/96
3/15/96
4/1/96
4/17/96

Figure 1.4. Maximum daily polyhouse and ambient field temperatures were measured at plant level during the 1996/1997 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.

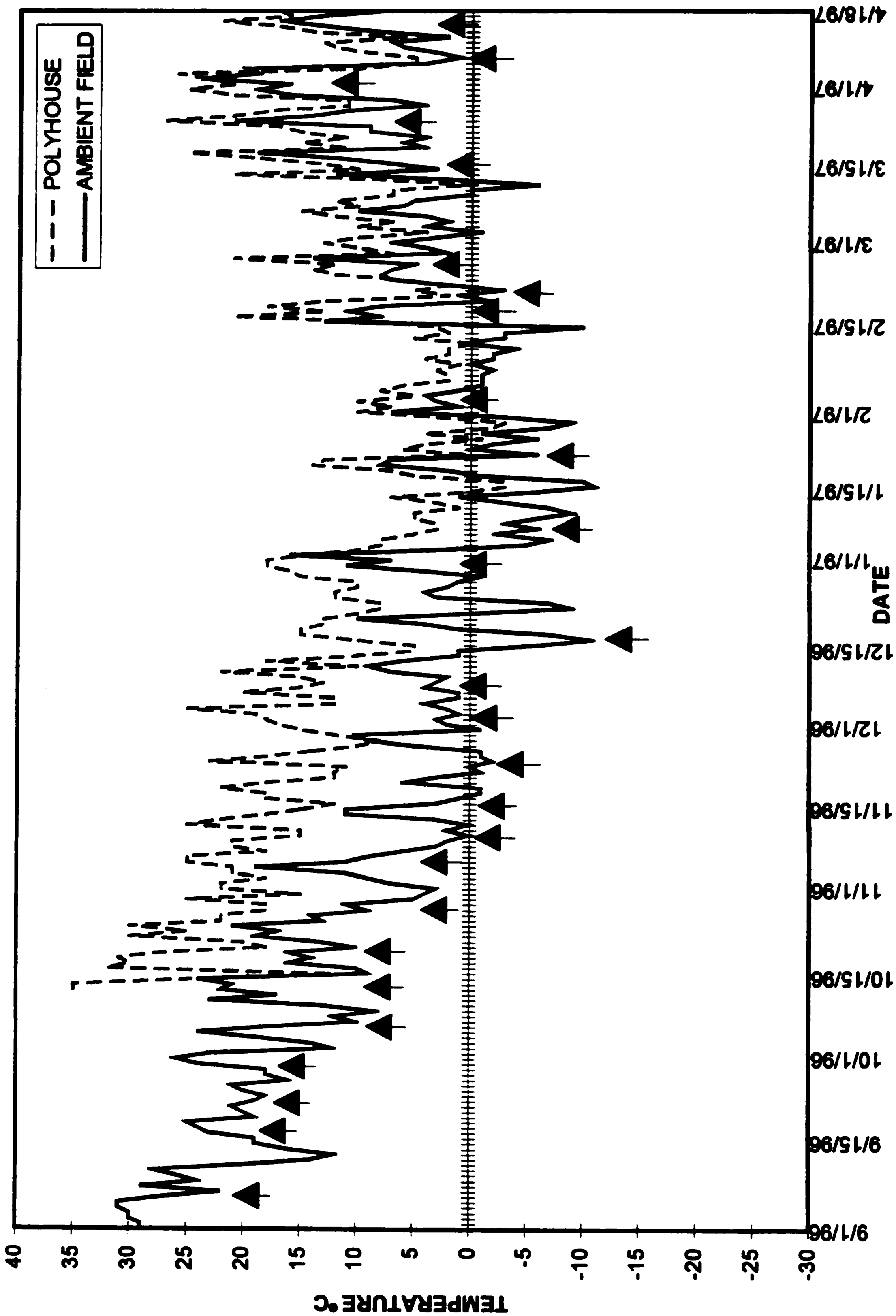
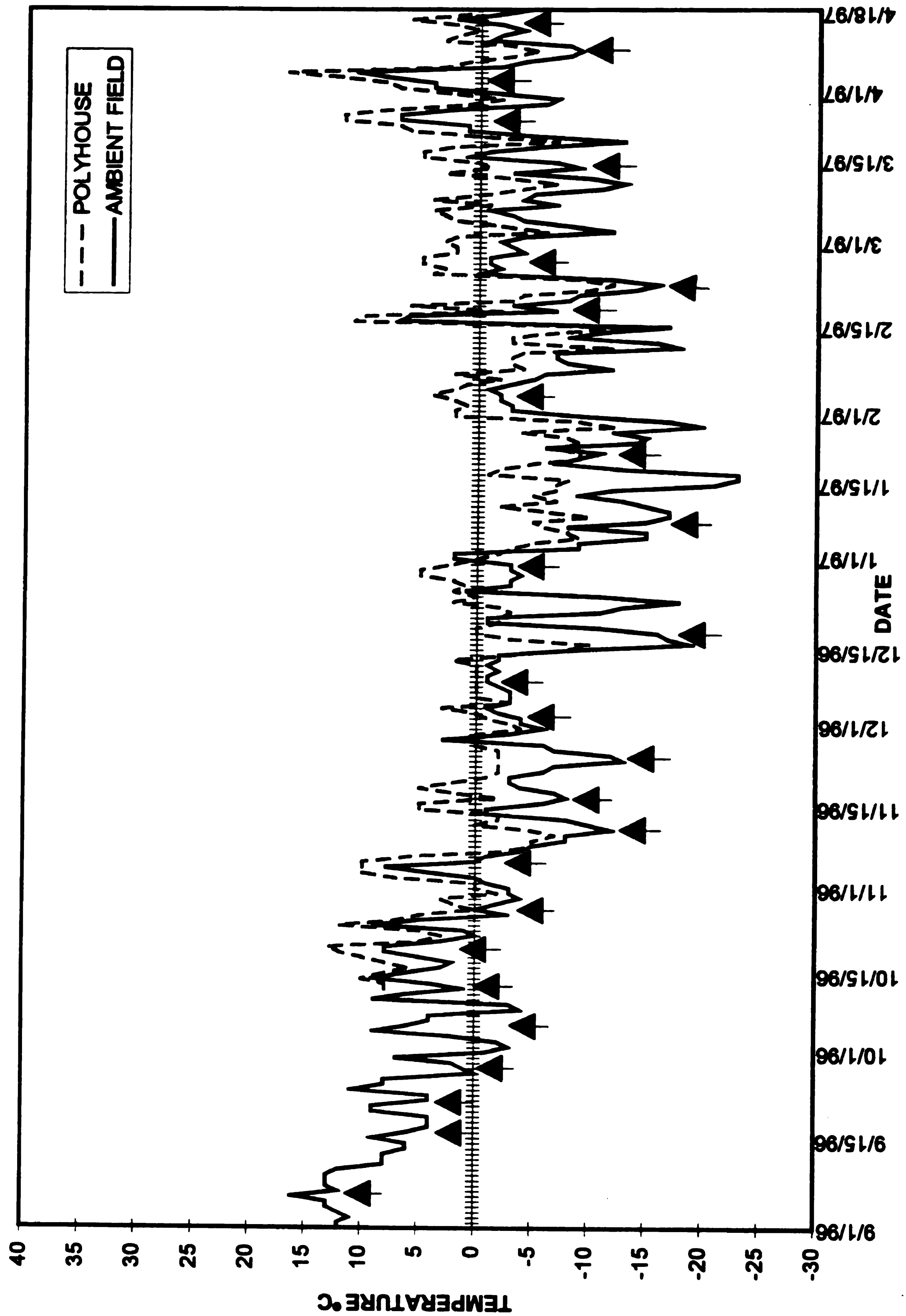

POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
DATE
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
9/1/96
9/15/96
10/1/96
10/15/96
11/1/96
11/15/96
12/1/96
12/15/96
1/1/97
1/15/97
2/1/97
2/15/97
3/1/97
3/15/97
4/1/97
4/18/97

Figure 1.5. Minimum daily polyhouse and ambient field temperatures were measured at plant level during the 1996/1997 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.



POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
DATE
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
9/1/96
9/15/96
10/1/96
10/15/96
11/1/96
11/15/96
12/1/96
12/15/96
1/1/97
1/15/97
2/1/97
2/15/97
3/1/97
3/15/97
4/1/97
4/18/97

Figure 1.6. Killing temperature (T_{50}, °C), of *Weigela f.* 'Java Red' during the 1995/1996 test period as influenced by time of placement in a protective structure (early-10/12/95 or late-12/5/95) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Weigela f*. 'Java Red' during the 1995/1996 acclimation, midwinter, and deacclimation periods, A, B, C, respectively

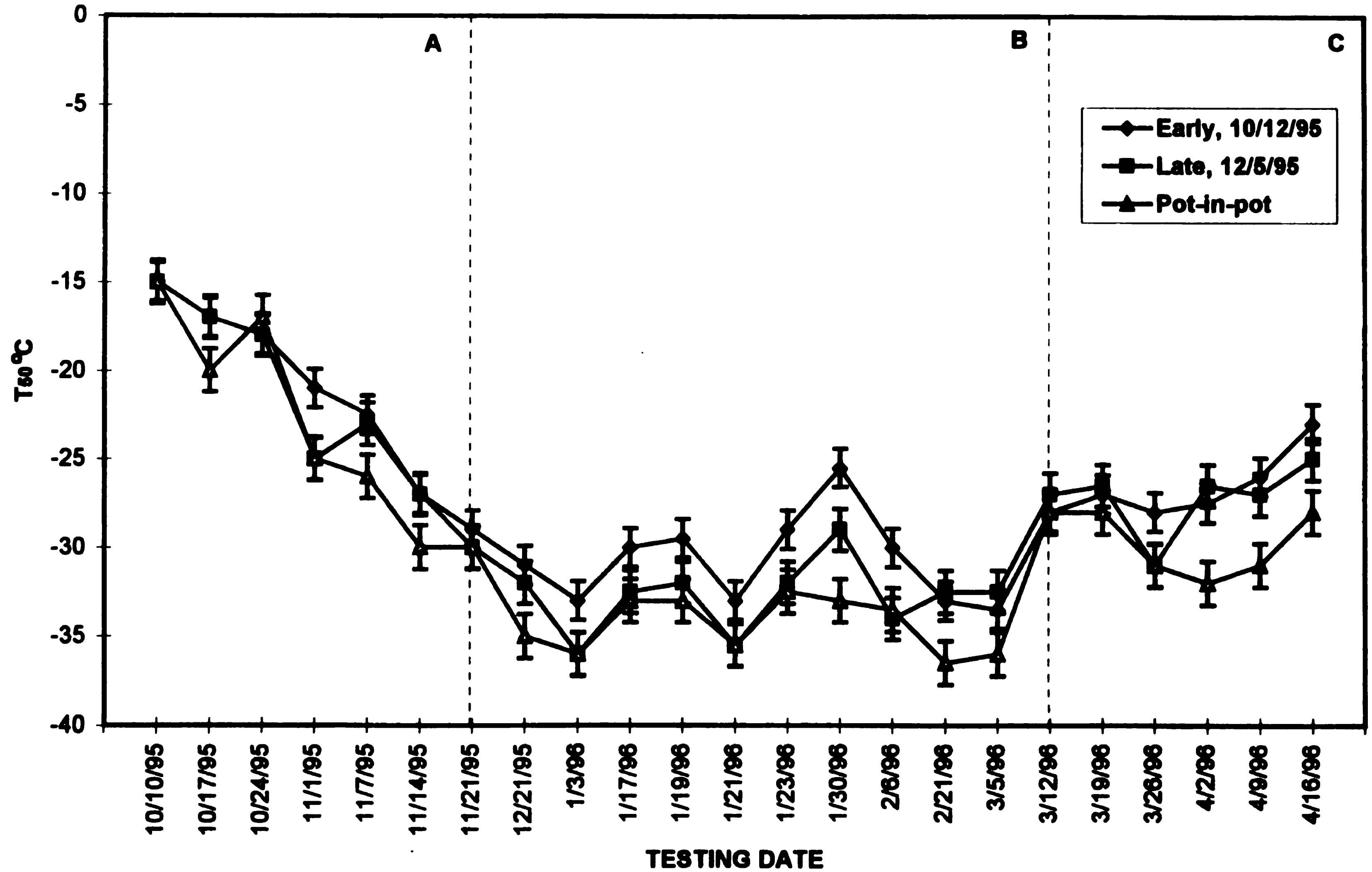
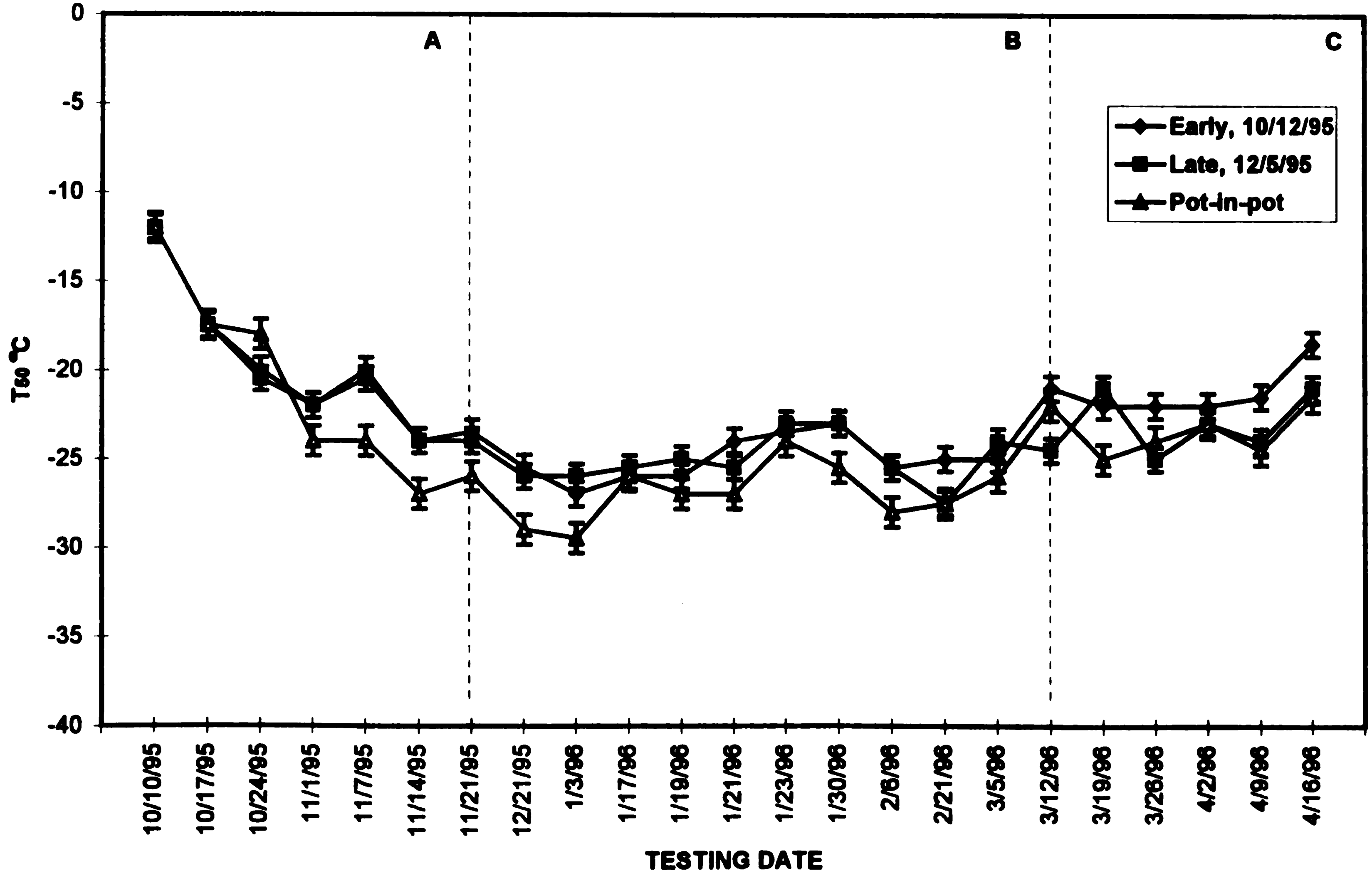


Figure 1.7. Killing temperature (T_{50}, °C), of *Hibiscus s.* 'Jeanne d' Arc' during the 1995/1996 test period as influenced by time of placement in a protective structure (early-10/12/95 or late-12/5/95) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Hibiscus s*. 'Jeanne d' Arc' during the 1995/1996 acclimation, midwinter, and deacclimation periods, A, B, C, respectively



10 through November 17 (Figure 1.8). During the months of November and December the rate of acclimation accelerated in response to colder temperatures.

Maximum midwinter hardiness levels were observed either on December 21 or January 3. The pot-in-pot treatment was the hardiest, followed by the late and early treatments, respectively. *Weigela* acquired maximum hardiness levels of -33.5°C (-28.5°F), -35.7°C (-32.5°F), and -36.7°C (-33.8°F), for the early, late, and pot-in-pot treatments. For the *Hibiscus* cultivar the early treatment had a maximum hardiness level of -26.0°C (-14.8°F), the late treatment was hardy to -27.5°C (-17.5°F), and the pot-in-pot treatment was hardy to -28.0°C (-18.4°F). *Euonymus* in the early polyhouse treatment was hardy to -29.7°C (-21.5°F), those placed in the polyhouse late were hardy to -33.5°C (-28.5°F), while those overwintered in the pot-in-pot treatment were hardy to -36.5°C (-34.0°F). Aside from being the hardiest, the pot-in-pot treatment was also the slowest to deacclimate. The influence of the overwintering system on hardiness during the 1995/1996 testing period was significant depending on the period of the controlled temperature freezing and the cultivar (Table 1.1).

In the spring, *Euonymus* was the first cultivar to break bud in all treatments followed by *Weigela* and *Hibiscus*, respectively (Figure 1.9). For all three cultivars, the nursery stock placed in the polyhouse early and late broke bud on the same day. *Euonymus* and *Weigela* in the pot-in-pot treatment broke bud 32 days following the bud break of the nursery stock overwintered in the polyhouse. *Hibiscus* in the pot-in-pot treatment broke bud 37 days after those in the polyhouse.

All three cultivars in the pot-in-pot treatment had the highest percentage of mortality, while both polyhouse treatments had the same amount of plant mortality (Table 1.2). Based on the visual plant performance ratings growth on the *Euonymus* placed in the polyhouse late

Figure 1.8. Killing temperature (T_{50}, °C), of *Euonymus a.* 'Compactus' during the 1995/1996 test period as influenced by time of placement in a protective structure (early-10/12/95 or late-12/5/95) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Euonymus a*. 'Compactus' during the 1995/1996 acclimation, midwinter, and deacclimation periods, A, B, C, respectively

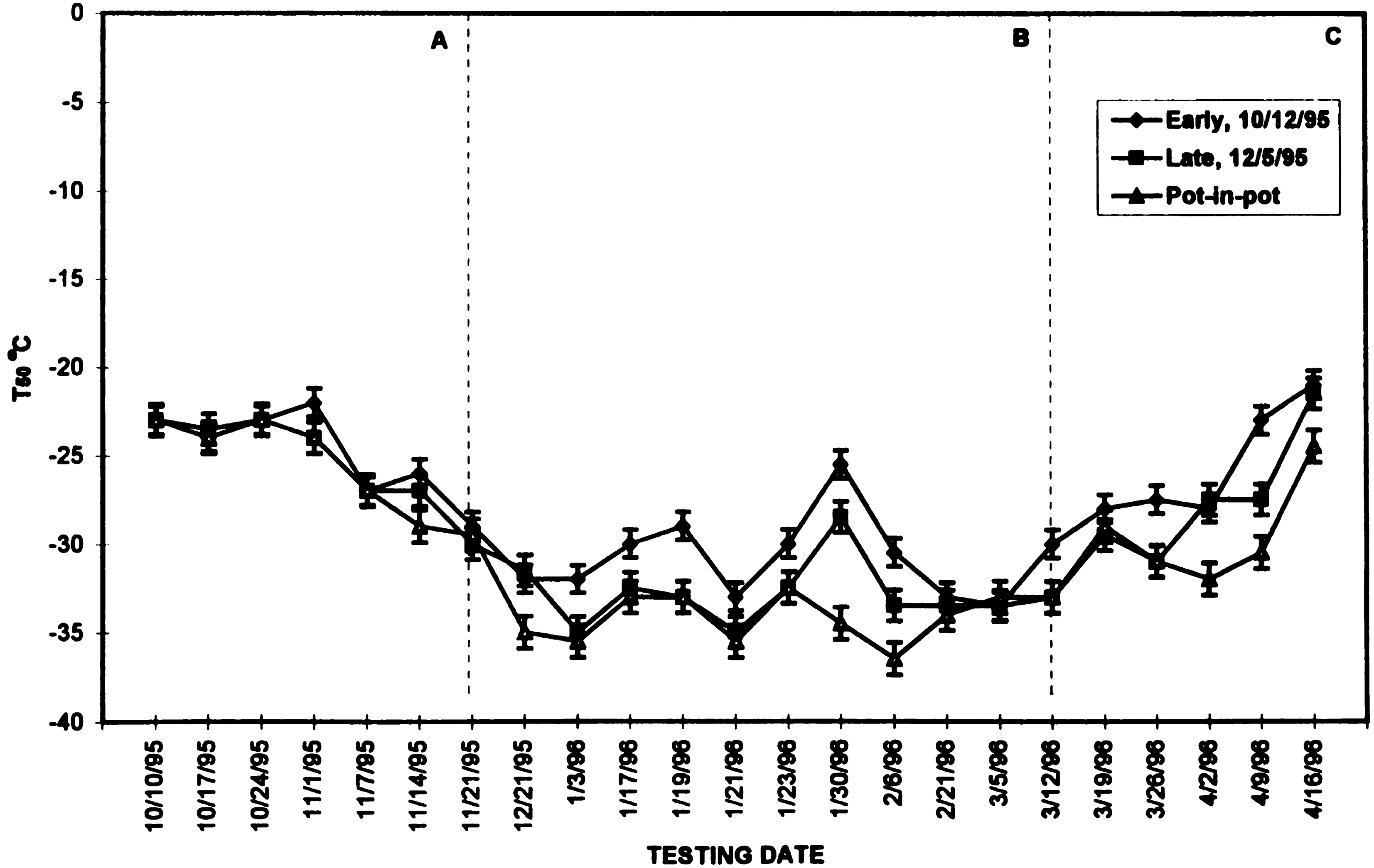


Table 1.1. Influence of placement of container-grown nursery stock in a protective structure (early-10/12/95 or late-12/5/95) or held pont-in-pot under ambient field temperatures on shoot cold hardiness during the acclimation, midwinter, and deacclimation periods. Data are T_{50} means of three replicates analyzed by analysis of variance.

	ACCLIMATION 10/10/95-11/21/95				MIDWINTER 12/21/95-3/5/96				DEACCLIMATION 3/12/96-4/16/96			
PLANT NAME	Early	Late	Pot-in-pot	*P*	Early	Late	Pot-in-pot	*P*	Early	Late	Pot-in-pot	*P*
Weigela florida 'Java Red'	-21.5	-22.0	-23.5	NS	-31.0	-33.0	-34.5	**	-26.5	-27.0	-29.5	**
Hibiscus syriacus 'Jeanne d' Arc'	-20.0	-20.0	-21.0	NS	-25.0	-25.0	-27.0	*	-21.0	-23.5	-23.5	**
Euonymus alatus 'Compactus'	-25.0	-25.5	-26.0	NS	-31.0	-33.0	-34.0	**	-26.0	-28.0	-25.0	**

NA, *, ** Not significant at P=0.05 or 0.01, respectively

Figure 1.9. Influence of three overwintering systems on the date of bud break of three cultivars during the 1995/1996 test period. Date of bud break is expressed as date of first noticeable shoot elongation. Data analyzed by analysis of variance and mean separation by LSD.

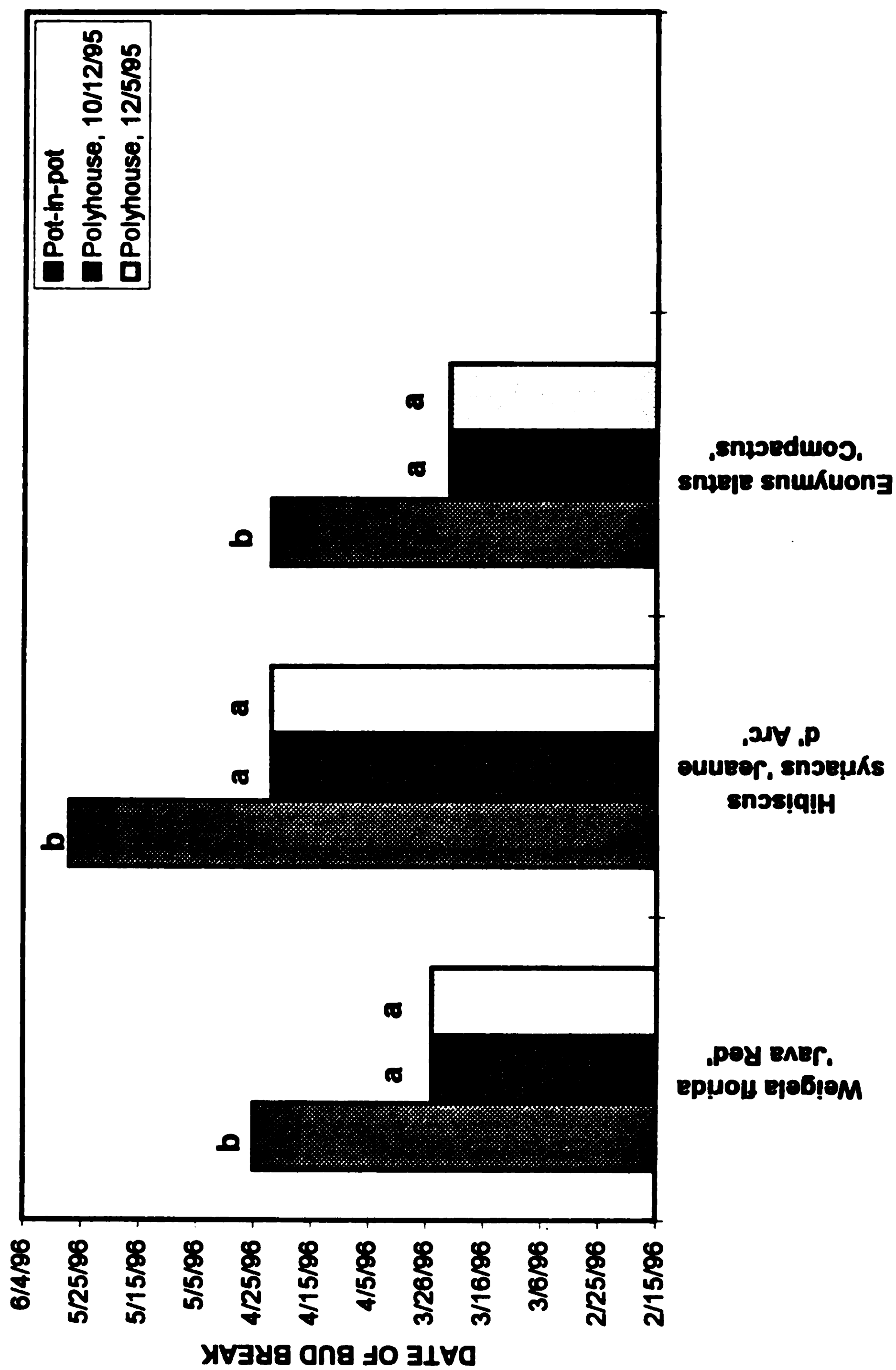

Pot-in-pot
Polyhouse, 10/12/95
Polyhouse, 12/5/95
DATE OF BUD BREAK
6/4/96
5/25/96
5/15/96
5/5/96
4/25/96
4/15/96
4/5/96
3/26/96
3/16/96
3/6/96
2/25/96
2/15/96
Weigela florida
'Java Red'
Hibiscus
syriacus 'Jeanne
d' Arc'
Euonymus alatus
'Compactus'
b
a
a
b
a
a
b
a
a

Table 1.2. The mortality of three cultivars during the 1995/1996 test period as influenced by placement in a protective structure (early-10/12/95 or late-12/5/95) or held pot-in-pot under ambient field temperatures, were recorded as percentages. Plants were rated as either alive or dead on June 10, 1996. Observations were based on 70 plants per cultivar per treatment. Data was analyzed by analysis of variance and mean separation by LSD.

PLANT NAME	OVERWINTERING TREATMENT	DATE OF BUD BREAK	PERCENTAGE OF DEAD PLANTS
Weigela florida 'Java Red'	Early	3/25/96	5.0% **a**
	Late	3/25/96	5.0% **a**
	Pot-in-pot	4/25/96	9.0% **a**
Hibiscus syriacus 'Jeanne d' Arc'	Early	4/22/96	9.0% **a**
	Late	4/22/96	9.0% **a**
	Pot-in-pot	5/27/96	30.0% **b**
Euonymus alatus 'Compactus'	Early	3/22/96	0% **a**
	Late	3/22/96	0% **a**
	Pot-in-pot	4/22/96	30.0% **b**

had superior growth compared to those placed in the polyhouse early (Table 1.3). The foliage on the late treatment plants had a darker green appearance and the leaves were more fully expanded. No difference in growth or appearance existed between the early and late treatments of *Weigela* or *Hibiscus*. All three cultivars in both polyhouse treatments had more advanced growth during the evaluation period than those held in the pot-in-pot treatment.

The results of the experiment during the 1996/1997 test period showed that during the first week of October, all cultivars experienced an apparent increase in cold hardiness. A change in stem color from green to brown was observed on *Forsythia X intermedia* 'Northern Gold' and 'Lynwood' on October 8 (Table 1.4). 'Northern Gold' increased in hardiness by 15.0°C (27.0°F), while 'Lynwood' increased in hardiness by 11.0°C (19.8°F). Hardiness increased by 9.0°C (16.2°F) for Euonymus and 5.0°C (9.0°F) for 'Sunrise' without any noticeable change in stem color.

'Lynwood' was the least hardy of the three *Forsythia* cultivars in all three treatments. 'Northern Gold' was the hardiest *Forsythia* cultivar in the pot-in-pot treatment, while 'Sunrise' was the hardiest in both polyhouse treatments. All four cultivars were at their maximum hardiness levels during the period of January 15 through February 4, 1997. The maximum hardiness levels for 'Lynwood' were as follows: -37.3°C (-35.2°F) in the early treatment, -37.9°C (-36.4°F) in the late treatment, and -38.2°C (-37.0°F) in the pot-in-pot treatment (Figure 1.10). Pot-in-pot 'Northern Gold' was hardy to -41.7°C (-43.1°F), while the hardiness level of the early treatment was -40.3°C (-40.5°F), and the late treatment was hardy to -40.5°C (-40.9°F) (Figure 1.11). The 'Sunrise' polyhouse treatments were hardy -41.2°C (-42.4°F), while the pot-in-pot treatment was hardy to -41.5°C (-42.7°F) (Figure 1.12). The acclimation, mid-winter hardiness, and deacclimation patterns for the three *Euonymus*

Table 1.3. Visual post-stress performance ratings[z] for three cultivars of container-grown nursery stock during the 1995/1996 test period as influenced by time of placement in a protective structure (early-10/12/95 or late-12/5/95) or held pot-in-pot under ambient field temperatures.

	Weigela florida 'Java Red'			Hibiscus syriacus 'Jeanne d' Arc'			Euonymus alatus 'Compactus'		
	VISUAL PERFORMANCE RATINGS								
DATE OF RATING	EARLY	LATE	POT-IN-POT	EARLY	LATE	POT-IN-POT	EARLY	LATE	POT-IN-POT
3/18/96	1	1	1	1	1	1	1	1	1
3/25/96	1.33	1.33	1	1	1	1	1.66	2	1
4/1/96	2	2	1	1	1	1	2	2.33	1
4/8/96	2.33	2.33	1	1	1	1	2	3	1
4/15/96	2.66	2.66	1	1	1	1	2.33	3.33	1
4/22/96	3	3	1	1.33	1.33	1	2.66	4	1
4/29/96	3.33	3.33	1	1.33	1.33	1	3.33	4.33	1.33
5/6/96	4	4	1.66	1.66	1.66	1	3.66	5	2
5/13/96	4.33	4.33	2.33	2.33	2.33	1	4.33	5	2.66
5/20/96	5	5	3	3.33	3.33	1	5	5	3
5/27/96	5	5	3.33	4	4	1.33	5	5	4
6/3/96	5	5	4	5	5	2	5	5	5
6/10/96	5	5	5	5	5	2.33	5	5	5

[z]1= Bud scale was not broken, tissue was brown and/or dead.
2= Bud scale was split, leaves visible.
3= Uniform new growth, new leaves were formed.
4= Leaves were fully expanded.
5= Leaves fully expanded on elongated shoots.

Table 1.4. *The date of leaf drop, change in bark color, and date of bud break of four cultivars during the 1996/1997 test period as influenced by placement in a protective structure (early-10/15/96 or late-12/5/96) or held pot-in-pot under ambient field temperatures, were recorded as percentages. Plants were rated as either alive or dead on May 6, 1997.* Observations were based on 100 plants per cultivar per treatment.

PLANT NAME	OVERWINTERING TREATMENT	DATE 50% OF LEAVES DROPPED	DATE BARK COLOR CHANGED	DATE OF BUD BREAK	PERCENTAGE OF DEAD PLANTS
Forsythia X intermedia 'Sunrise'	Early	11/11/96	NA	3/12/97	0%
	Late	11/11/96	NA	3/12/97	0%
	Pot-in-pot	11/11/96	NA	4/16/97	0%
Forsythia X intermedia 'Lynwood'	Early	12/2/96	10/8/96	3/9/97	0%
	Late	11/23/96	10/8/96	3/9/97	0%
	Pot-in-pot	11/23/96	10/8/96	4/4/97	0%
Forsythia X intermedia 'Northern Gold'	Early	12/2/96	10/8/96	3/15/97	0%
	Late	11/23/96	10/8/96	3/15/97	0%
	Pot-in-pot	11/23/96	10/8/96	4/8/97	0%
Euonymus alatus 'Compactus'	Early	12/2/96	NA	3/10/97	0%
	Late	11/23/96	NA	3/10/97	0%
	Pot-in-pot	11/23/96	NA	4/5/97	0%

Figure 1.10. Killing temperature (T_{50}, °C), of *Forsythia X intermedia* 'Lynwood' during the 1996/1997 test period as influenced by time of placement in a protective structure (early-10/15/96 or late-12/5/96) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Forsythia X intermedia* 'Lynwood' during the 1996/1997 acclimation, midwinter, and deacclimation periods, A, B, C, respectively

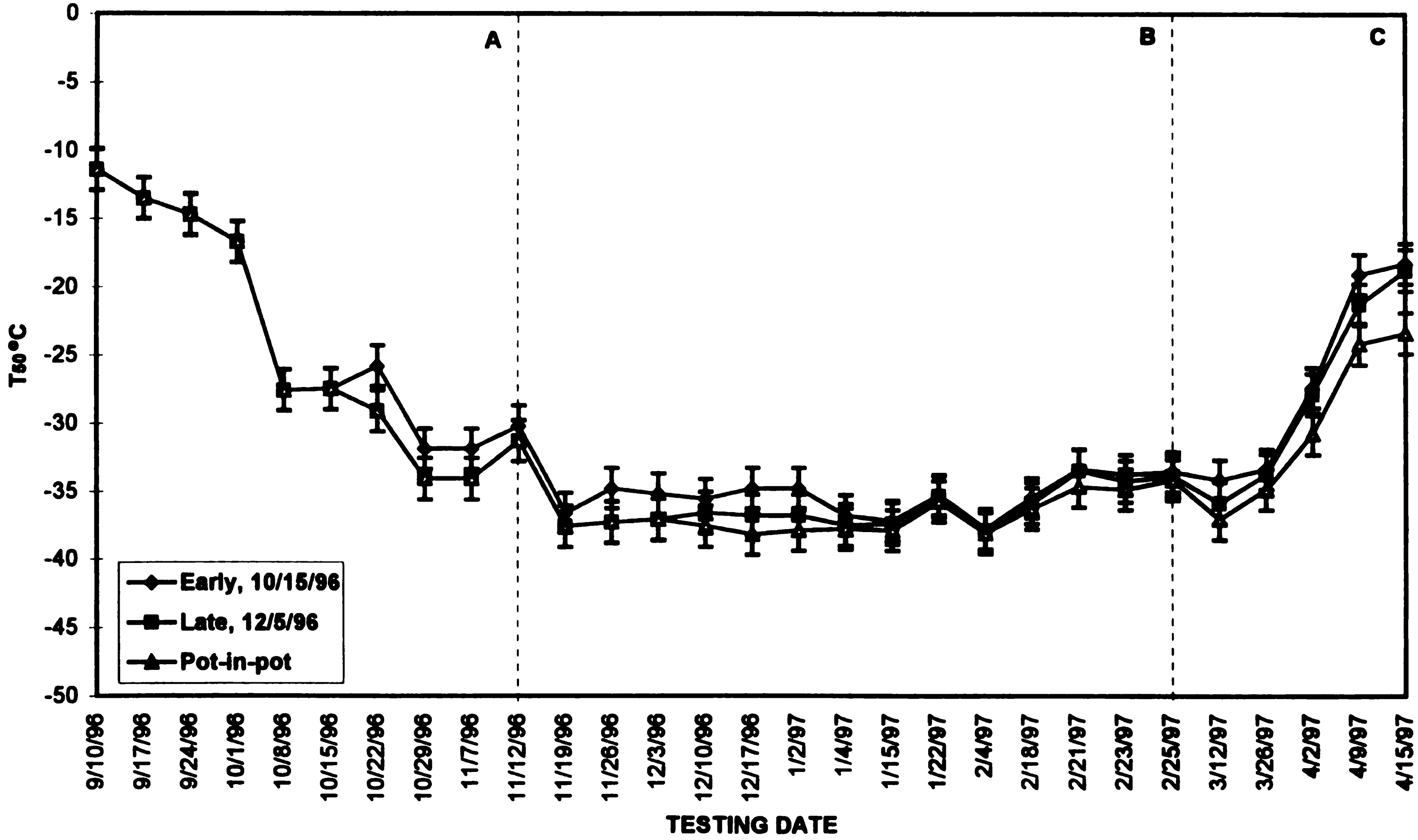


Figure 1.11. Killing temperature (T_{50}, °C), of *Forsythia X intermedia* 'Northern Gold' during the 1996/1997 test period as influenced by time of placement in a protective structure (early-10/15/96 or late-12/5/96) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Forsythia X intermedia* 'Northern Gold' during the 1996/1997 acclimation, midwinter, and deacclimation periods, A, B, C, respectively

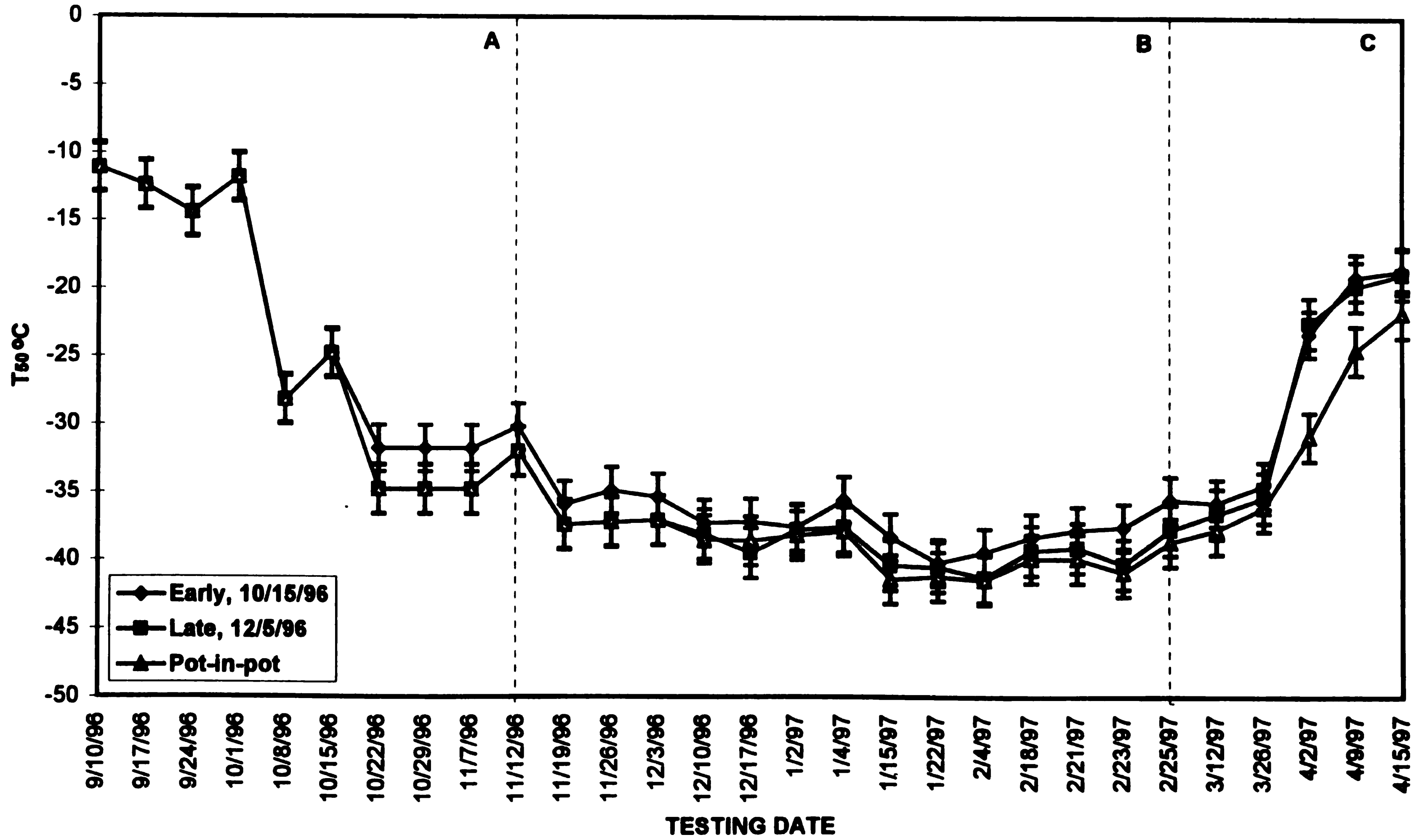
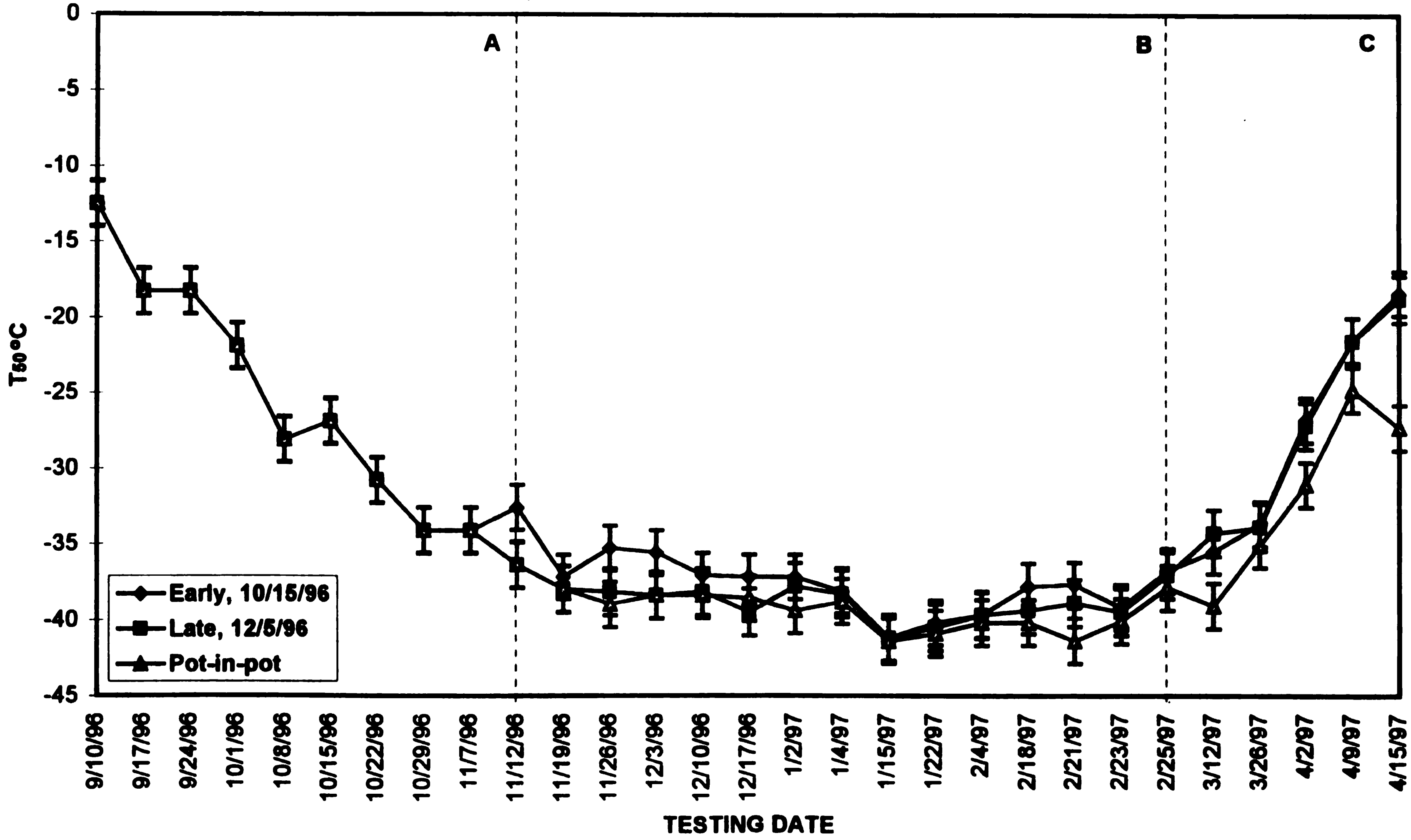


Figure 1.12. Killing temperature (T_{50}, °C), of *Forsythia X intermedia* 'Sunrise' during the 1996/1997 test period as influenced by time of placement in a protective structure (early-10/15/96 or late-12/5/96) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Forsythia X intermedia* 'Sunrise' during the 1996/1997 acclimation, midwinter, and deacclimation periods, A, B, C, respectively



treatments were similar to those seen during the 1995/1996 test period. Hardiness levels for *Euonymus* in the early, late, and pot-in-pot treatments were as follows: -40.2°C (-40.4°F), -40.6°C (-41.4°F), and -43.3°C (-46.1°F), respectively (Figure 1.13).

As seen during the 1995/1996 test period, the pot-in-pot treatment acclimated the fastest, was the hardiest during the mid-winter period, and deacclimated slower than the early and late treatments. Again, the influence of the overwintering system on hardiness during the 1996/1997 testing period was significant depending on the period of the controlled temperature freezing and the cultivar (Table 1.5).

Bud break was recorded for the four cultivars during the months of March and April (Figure 1.14). Bud break for each cultivar occurred on the same dates for plants placed in the polyhouse either early or late. Bud break occurred naturally in the pot-in-pot treatment 36 days later for 'Sunrise', 27 days later for 'Lynwood' and *Euonymus*, and 25 days later for 'Northern Gold'.

Visual plant performance ratings were conducted as previously stated and recorded from March 2 through June 3, 1997 (Table 1.6). 'Sunrise' in both polyhouse treatments received the same visual plant performance ratings. 'Lynwood', 'Northern Gold', and *Euonymus* placed in the polyhouse late vs. early had higher plant performance ratings even though bud break occurred on the same day. The cultivars in the late treatment had darker green foliage and more fully expanded leaves that the nursery stock placed in the polyhouse early. For all four cultivars, the visual plant performance ratings for plants held in both polyhouse treatments had a greater amount of growth during the evaluation period than those held in the pot-in-pot treatment.

Figure 1.13. Killing temperature (T_{50}, °C), of *Euonymus alatus* 'Compactus' during the 1996/1997 test period as influenced by time of placement in a protective structure (early-10/15/96 or late-12/5/96) or held pot-in-pot under ambient field temperatures. The T_{50} values are separated by ±SE.

Hardiness data for *Euonymus a.* 'Compactus' during the 1996/1997 acclimation, midwinter, and deacclimation periods, A, B, C, respectively

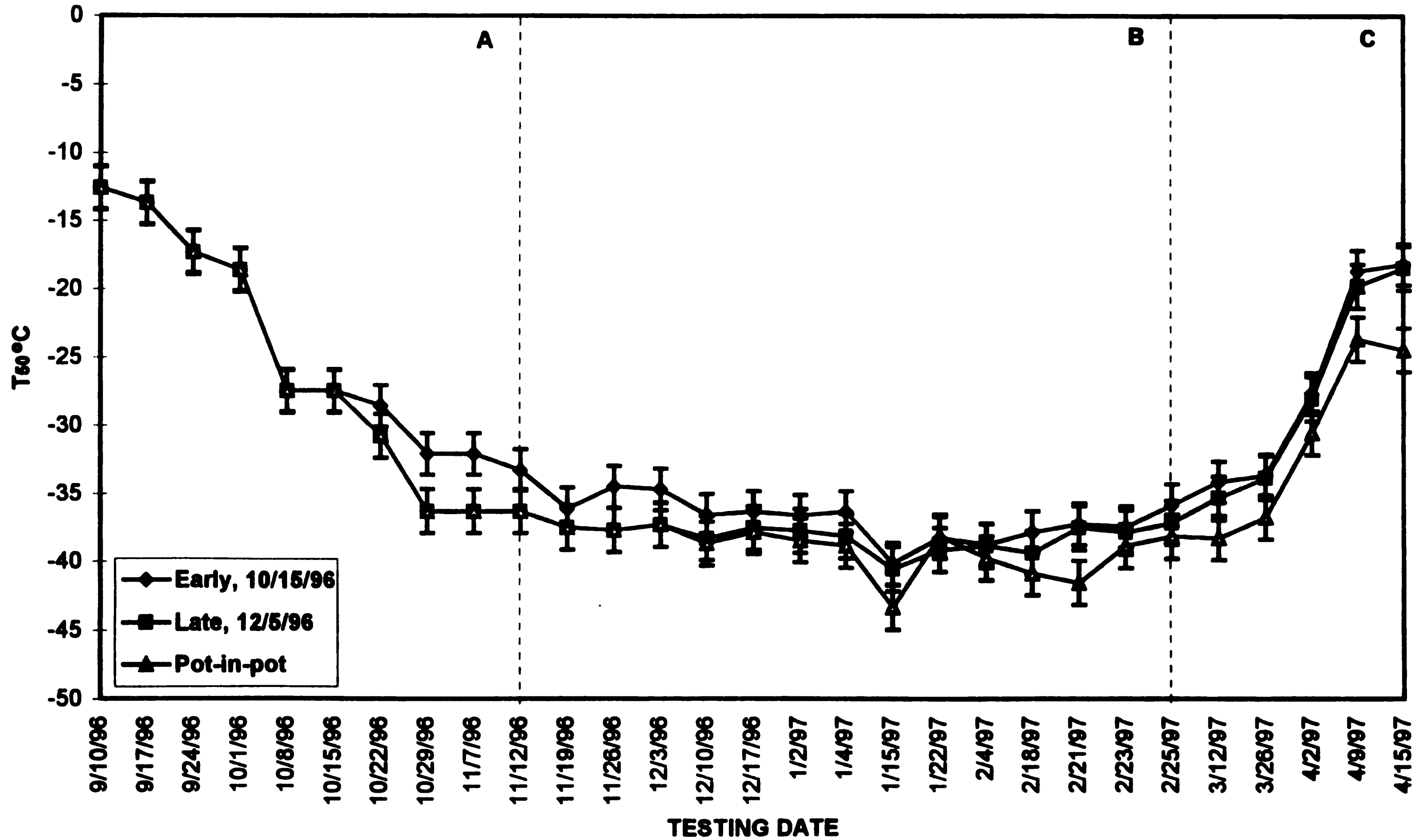


Table 1.5. Influence of placement of container-grown nursery stock in a protective structure (early-10/15/96 or late-12/5/96) or held pont-in-pot under ambient field temperatures on shoot cold hardiness during the acclimation, midwinter, and deacclimation periods. Data are T_{50} means of three replicates analyzed by analysis of variance.

	ACCLIMATION 9/10/96-11/12/96				MIDWINTER 11/19/96-2/23/97				DEACCLIMATION 2/25/97-4/15/97			
PLANT NAME	Early	Late	Pot-in-pot	*P*	Early	Late	Pot-in-pot	*P*	Early	Late	Pot-in-pot	*P*
Forsythia X intermedia 'Northern Gold'	-25.4	-26.0	-26.0	NS	-38.0	-39.0	-39.5	NS	-29.0	-29.0	-32.5	*
Forsythia X intermedia 'Northern Gold'	-23.0	-24.0	-24.0	NS	-35.5	-36.5	-37.0	NS	-28.0	-28.0	-30.0	*
Forsythia X intermedia 'Northern Gold'	-22.0	-23.0	-23.0	NS	-37.5	-38.5	-39.0	NS	-37.0	-27.5	-32.0	**
Euonymus alatus 'Compactus'	-24.0	-25.0	-25.0	NS	-37.5	-38.0	-39.0	NS	-28.5	-28.5	-32.0	**

NS, *, ** Not significant at P=0.05 or 0.01, respectively

Figure 1.14. Influence of three overwintering systems on the date of bud break of four cultivars during the 1996/1997 test period. Date of bud break is expressed as date of first noticeable shoot elongation. Data analyzed by analysis of variance and mean separation by LSD.

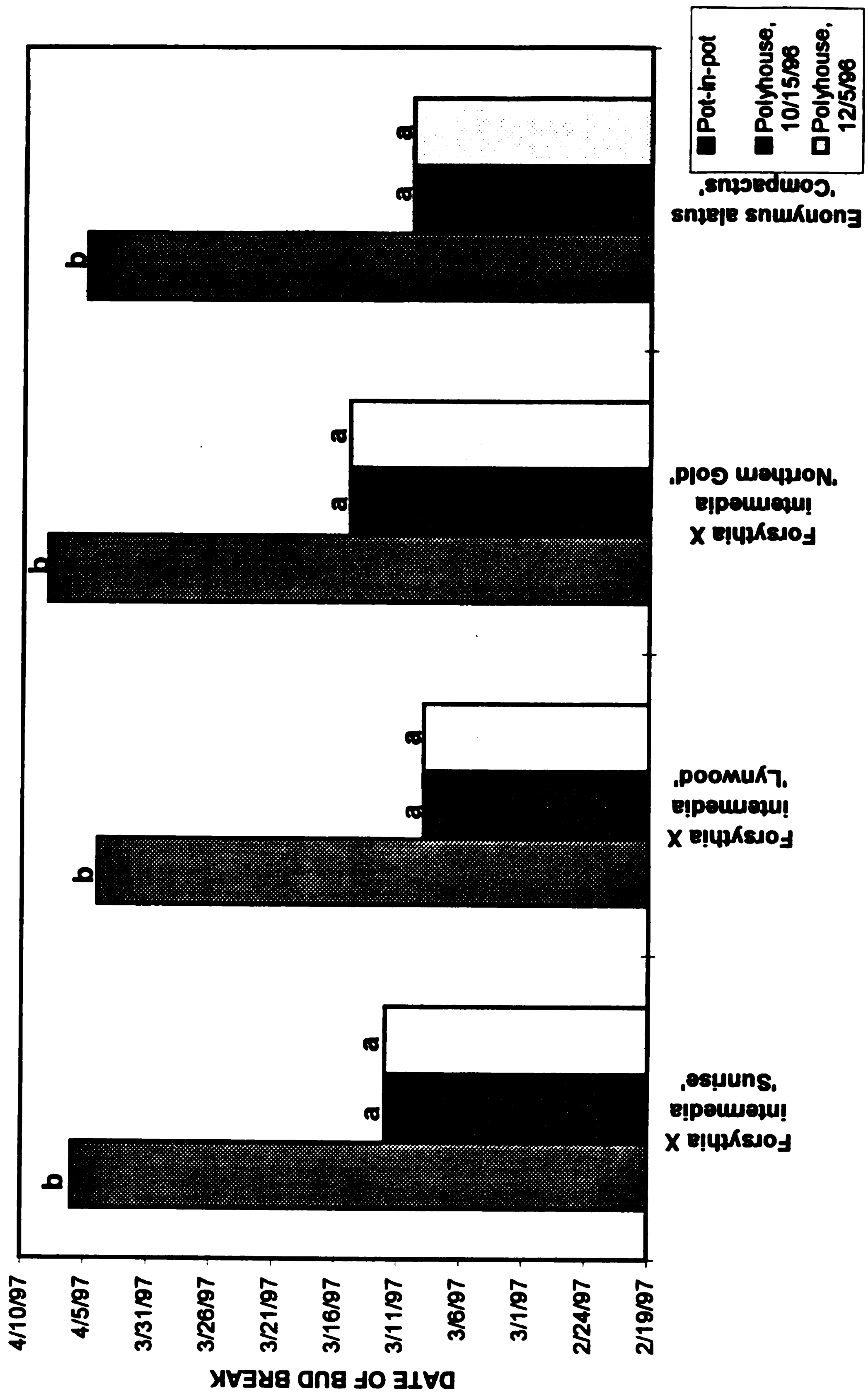

DATE OF BUD BREAK
4/10/97
4/5/97
3/31/97
3/26/97
3/21/97
3/16/97
3/11/97
3/6/97
3/1/97
2/24/97
2/19/97
Forsythia X intermedia 'Sunrise'
Forsythia X intermedia 'Lynwood'
Forsythia X intermedia 'Northern Gold'
Euonymus alatus 'Compactus'
Pot-in-pot
Polyhouse, 10/15/96
Polyhouse, 12/5/96
a
b

Table 1.6. Visual post-stress performance ratings^z four cultivars of container-grown nursery stock as influenced by time of placement in a protective structure (early-10/15/96 or late 12/5/96) or held pot-in-pot under ambient field temperatures.

	Forsythia X intermedia 'Sunrise'			**Forsythia X intermedia** 'Lynwood'			**Forsythia X intermedia** 'Northern Gold'			**Euonymus alatus** 'Compactus'		
	VISUAL PERFORMANCE RATINGS											
DATE OF RATING	EARLY	LATE	POT-IN-POT	EARLY	LATE	POT-IN-POT	EARLY	LATE	POT-IN-POT	EARLY	LATE	POT-IN-POT
3/2/97	1	1	1	1	1	1	1	1	1	1	1	1
3/9/97	1	1	1	2	2	1	1	1	1	1	1	1
3/16/97	2	2	1	2.66	2.66	1	2	2	1	2	2	1
3/23/97	2	2	1	2.66	3	1	2.66	3	1	2.33	2.33	1
3/30/97	2.33	2.33	1	2.66	3	1	2.66	3	1	2.33	2.66	1
4/8/97	2.66	2.66	1	3	3.33	2	3	3.33	2	2.66	3	2
4/15/97	3	3	1	3.33	3.66	2.33	3.33	3.66	2.66	3.33	3	2
4/22/97	4	4	2	4	4	2.66	4	4	3	4	3.66	2.33
4/29/97	4.33	4.33	2.66	4.66	4.66	3	4.66	4.66	3.33	4.33	4	2.66
5/6/97	5	5	3	5	5	3.33	5	5	4	5	4.33	3
5/13/97	5	5	3.33	5	5	3.66	5	5	4.33	5	4.66	3.33

Table 1.6. (Cont'd)

5/20/97	5	5	3.66	5	5	4.33	5	5	4.66	5	4.66	3.66
5/27/97	5	5	4.33	5	5	5	5	5	5	5	5	4.33
6/3/97	5	5	5	5	5	5	5	5	5	5	5	5

[z]1= Bud scale was not broken, tissue was brown and/or dead.
2= Bud scale was split, leaves visible.
3= Uniform new growth, new leaves were formed.
4= Leaves were fully expanded.
5= Leaves fully expanded on elongated shoots.

Acclimation was interrupted for plants placed in the polyhouse in October which prevented maximum hardiness from being achieved. According to Weiser (22), the second stage of acclimation is triggered by low temperatures. The warm polyhouse environment extended the acclimation period. The change in stem color of 'Northern Gold' and 'Lynwood' from green to brown may be evidence of a change in hardiness. 'Sunrise' was the only cultivar that increased in hardiness when it lost 50% of its leaves. Plant responses such as these may be related to an increase in hardiness. Parker (16), reported a noticeable accumulation of reddish leaf pigment when *Hedera helix* L. increased in hardiness. Similar leaf color changes with *Rhododendron* cv. Springtime occurred in response to an increase in hardiness (1).

During the mid-winter hardiness period plants in the warmer polyhouse environment were not as hardy as those stored pot-in-pot under natural conditions. Pot-in-pot plants were exposed to colder temperatures and obtained a greater maximum shoot hardiness level. The polyhouse environment accelerated bud break by at least 25 days when compared to bud break of pot-in-pot plants.

Euonymus and *Forsythia* cultivars 'Northern Gold' and 'Lynwood' had improved plant performance ratings when placed in the polyhouse late vs. early, resulting from more exposure to colder temperatures during the acclimation period. Pot-in-pot plants had higher percentages of mortality than plants in the polyhouse during the 1995/1996 test period. Minimum temperatures of -3.2°C (25.0°F) were recorded from April 22 through the 26, 1996. Tender stem tissue in the pot-in-pot treatment was injured by freezing temperatures, whereas cultivars in the polyhouse were protected. Cold-sensitive cultivars such as *Hibiscus* should probably be overwintered in a polyhouse to prevent plant injury. Cultivars such as *Euonymus*, 'Northern Gold', and 'Lynwood' which experienced poor growth when covered early should probably be overwintered later in the fall.

MIDWINTER TEMPERATURE FLUCTUATION During the 1996 'midwitner thaw' test period from January 17 through the 30th, the hardiness of each cultivar changed during the warmer weather. Cultivars were less hardy at the end of the experiment, with the exception of *Weigela* and *Euonymus* in the pot-in-pot treatment (Figure 1.15-1.17). Plants overwintered in both polyhouse treatments were less hardy than those overwintered in the pot-in-pot treatment and had greater changes in hardiness during the test period. The cold-tender *Hibiscus* cultivar, in all three overwintering treatments, was not as responsive as the other two cultivars to decreaseing temperatures. Therefore, *Hibiscus* is less adaptive to northern climates where sudden drops in temperature normally occur. As seen in the previous experiment, *Hibiscus* needs to be placed in a protective covering during the winter months. The T_{50} values recorded at the beginning and at the end of the experiment for *Weigela* in all three overwintering treatments were as follows: -30.0°C (-22.0°F)/-25.5°C (-14.0°F) for the early treatment, -32.5°C (-26.5°F)/ -29.0°C (-20.2°F) for the late treatment, and -33.0°C (-27.4°F)/-33.0°C (-27.4°F) for the pot-in-pot treatment. *Hibiscus* had hardiness levels of -26.0°C (-14.8°F)/-23.0°C (-9.4°F) for the early treatment, leves of -25.5°C (-13.9°F)/ -23.0°C (-9.4°F) for the late treatment, while the pot-in-pot treatment had hardiness levels of -26.0°C (-14.8°F)/-25.5°C (-13.9°F). The T_{50} values for *Euonymus* were as follows: -30.0°C (-22.0°F)/-25.5°C (-13.9°F) for the early treatment, values of -32.5°C (-26.5°F)/ -28.5°C (-19.3°F) for the late treatment, while the pot-in-pot treatment had T_{50} values of -33.0°C (-27.4°F)/-34.5°C (-30.1°F).

Figure 1.15. Killing temperature (T_{50}, °C), of three cultivars from January 17 to January 30, 1996 as influenced by placement in a protective structure (early-10/12/95), and minimum and maximum polyhouse temperatures. The T_{50} values are separated by ±SE.

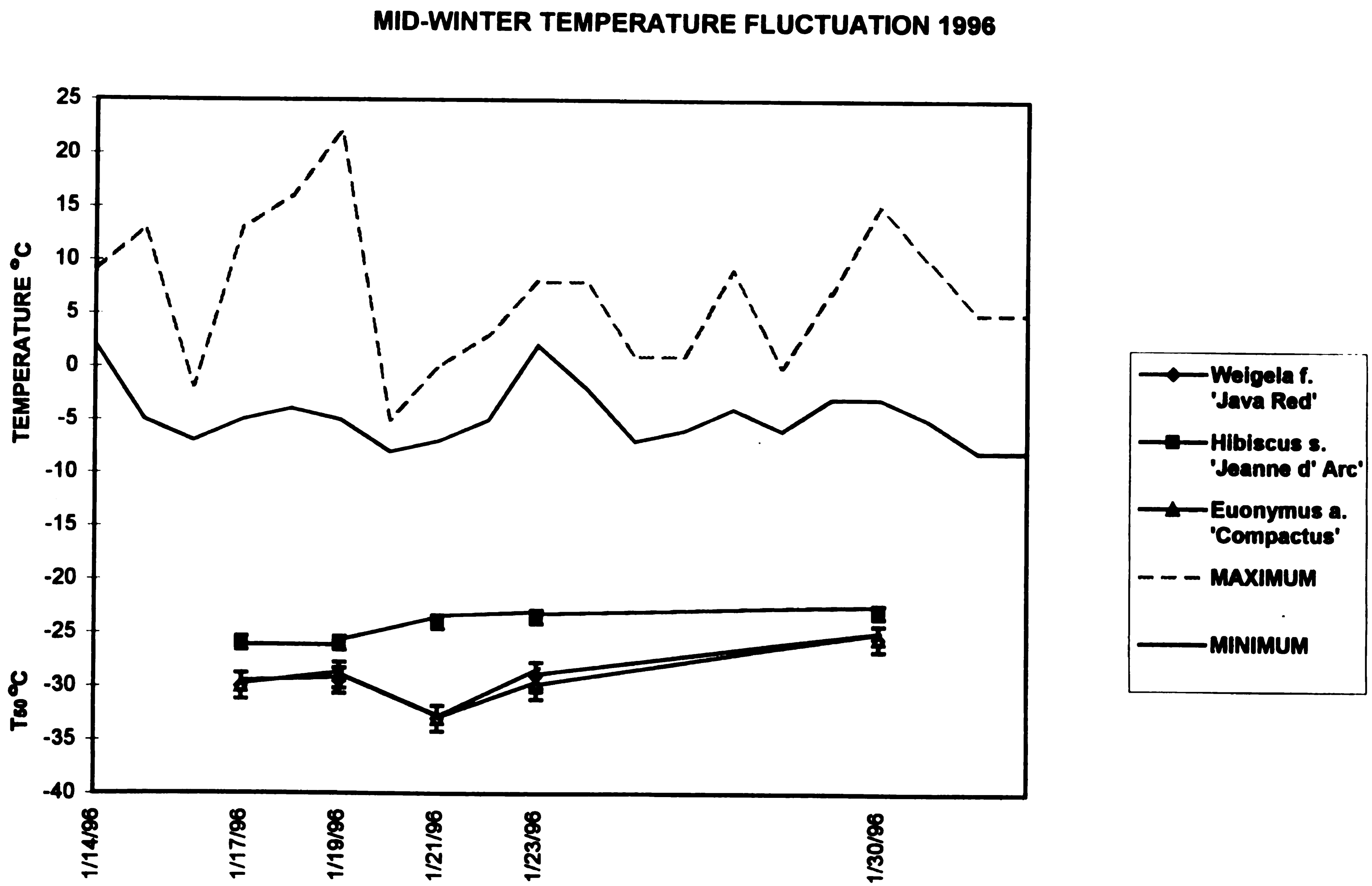

MID-WINTER TEMPERATURE FLUCTUATION 1996
TEMPERATURE °C
T50 °C
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
1/14/96
1/17/96
1/19/96
1/21/96
1/23/96
1/30/96
Weigela f. 'Java Red'
Hibiscus s. 'Jeanne d' Arc'
Euonymus a. 'Compactus'
MAXIMUM
MINIMUM

Figure 1.16. Killing temperature (T_{50}, °C), of three cultivars from January 17 to January 30, 1996 as influenced by placement in a protective structure (late-12/5/95), and minimum and maximum polyhouse temperatures. The T_{50} values are separated by ±SE.

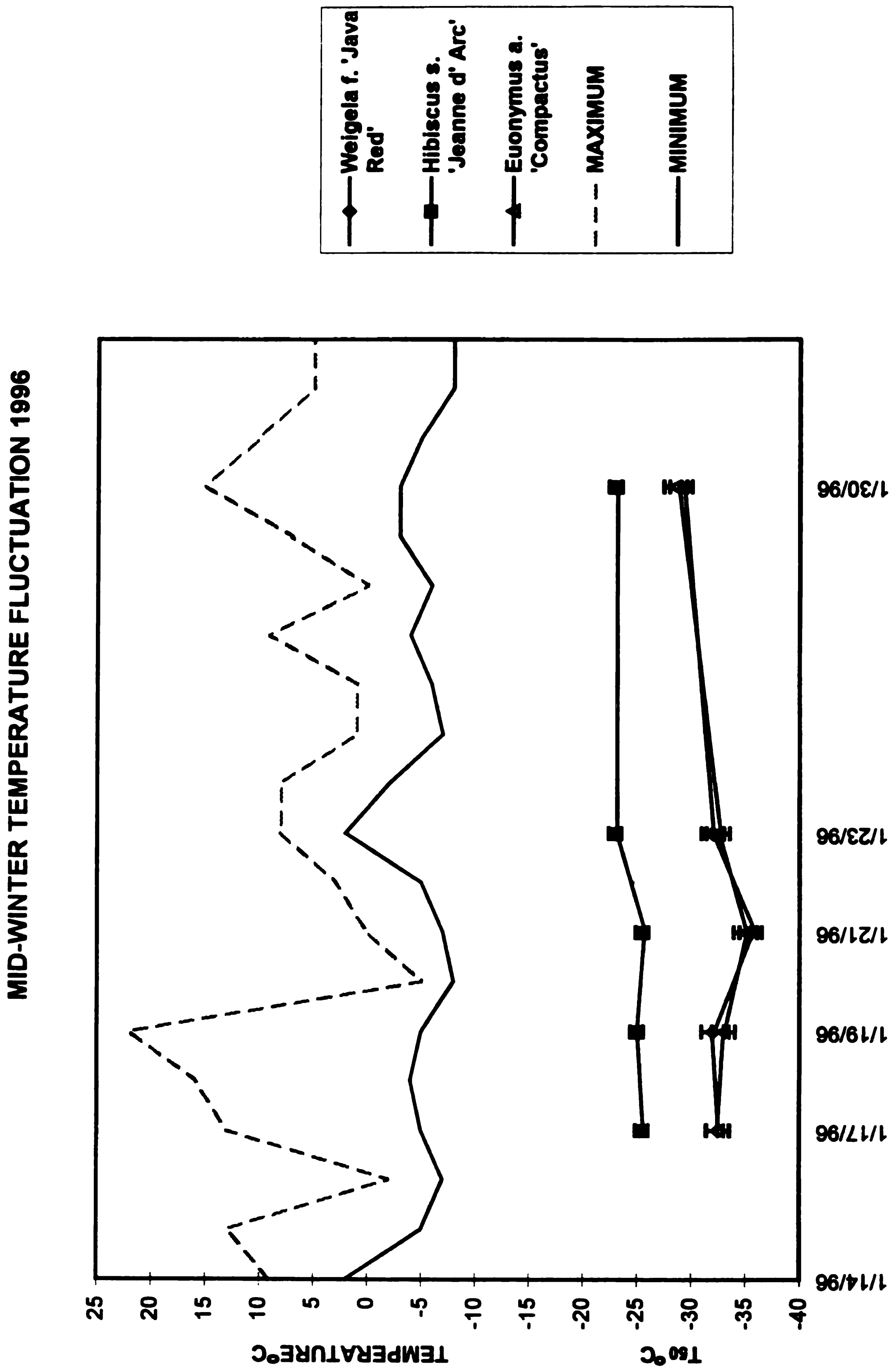
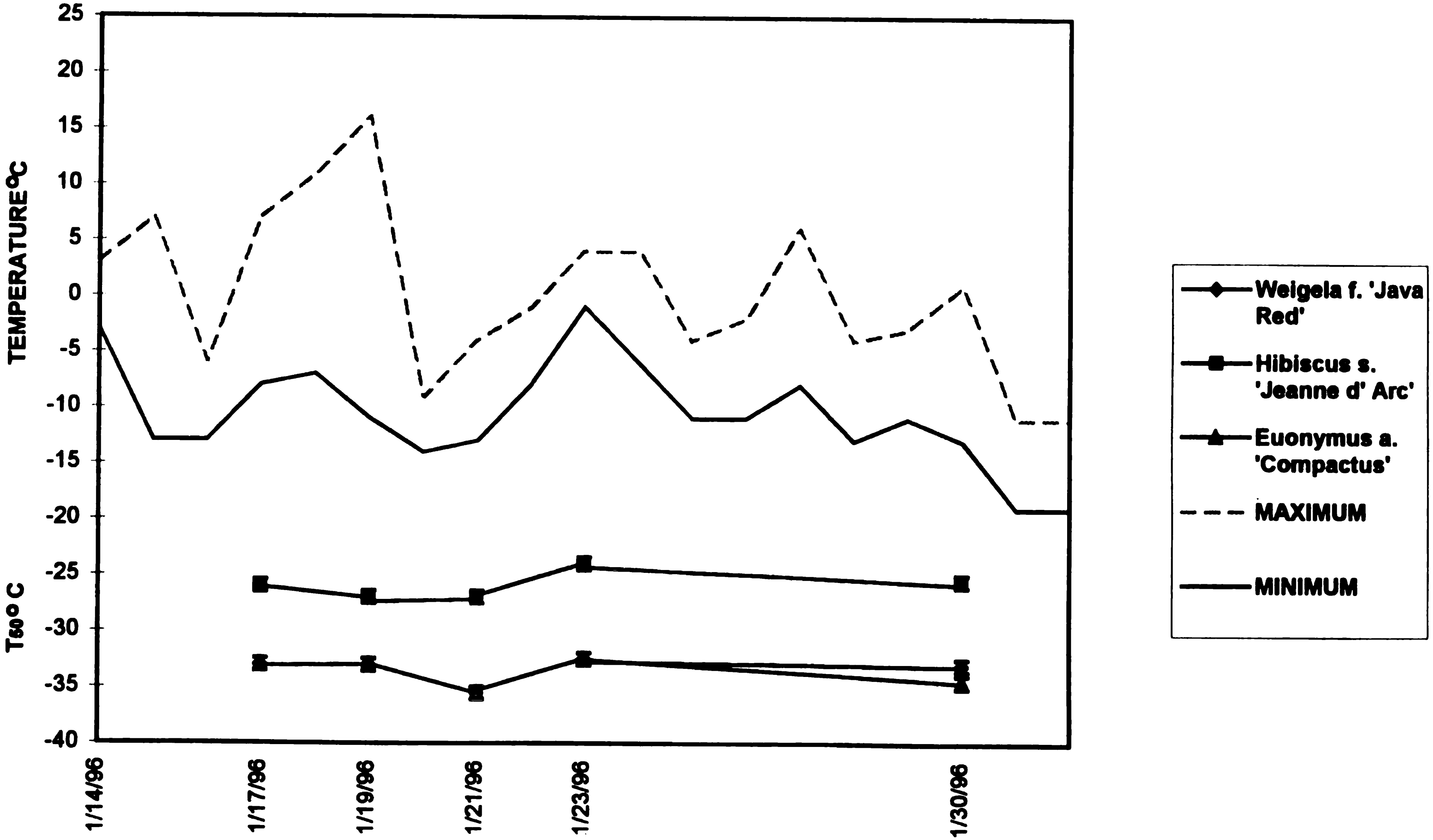

MID-WINTER TEMPERATURE FLUCTUATION 1996
TEMPERATURE°C
T₅₀°C
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
1/14/96
1/17/96
1/19/96
1/21/96
1/23/96
1/30/96
Weigela f. 'Java Red'
Hibiscus s. 'Jeanne d' Arc'
Euonymus a. 'Compactus'
MAXIMUM
MINIMUM

Figure 1.17. Killing temperature (T_{50}, °C), of three cultivars from January 17 to January 30, 1996 as influenced by placement in a pot-in-pot treatment under natural conditions and ambient minimum and maximum field temperatures. The T_{50} values are separated by ±SE.

MID-WINTER TEMPERATURE FLUCTUATION 1996



Similar results were seen during the 1997 test period from February 18 through the 25th (Figures 1.18-1.20). Again, the hardiness of each cultivar gradually changed during the warmer weather and was less hardy at the end of the experiment, with the exception of 'Northern Gold' in the pot-in-pot treatment. For all four cultivars, plants overwintered in both polyhouse treatments were less hardy than the pot-in-pot treatment. The T_{50} values for the *Forsythia* cultivar 'Sunrise' at the beginning and the end of the experiment were: -37.8°C (-36.8°F)/ -36.8°C (-34.2°F) for the early treatment, -39.4°C (-38.9°F)/-37.1°C (-34.8°F) for the late treatment, and -40.2°C (-40.4°F)/-37.9°C (-36.2°F) for the pot-in-pot treatment. 'Lynwood' had T_{50} values of -35.9°C (-32.6°F)/-33.8°C (-28.8°F), -35.9°C (-32.6°F)/ -33.9°C (-29.0°F), and -36.3°C (-33.3°F)/-34.2°C (-29.6°F), for the early, late, and pot-in-pot treatments, respectively. The T_{50} values for 'Northern Gold' in the early treatment were -38.3°C(-36.9°F)/-35.6°C (-32.1°F), -39.3°C (-38.7°F)/-37.8°C (-36.0°F) for the late treatment, while the T_{50} values for the pot-in-pot treatment were -39.4°C (-38.9°F)/-40.6°C (-41.1°F). *Euonymus* had hardiness levels of -37.9°C (-36.2°F)/-35.9°C (-32.6°F), -39.4°C (-38.9°F)/-37.2°C (-35.0°F), and -40.9°C (-41.6°F)/-38.2°C (-36.8°F), for the early, late, and pot-in-pot treatments, respectively.

The cold tolerance of azalea florets also fluctuated when exposed to warming temperatures during the months of January and February (10). Similar results were seen by Howell and Weiser (12), and Proebsting (20). As colder temperatures resumed, plants obtained hardiness similar to levels prior to the warming period. Some cultivars exposed to the 'midwinter thaw' exhibited a slight decrease in hardiness. Extended period of warming temperatures may result in greater losses of cold hardiness. These predisposed plants could be more susceptible to sudden cold temperature drops below their hardiness levels.

Figure 1.18. Killing temperature (T_{50}, °C), of three cultivars from February 18 to February 25, 1997 as influenced by placement in a protective structure (early-10/15/96), and minimum and maximum polyhouse temperatures. The T_{50} values are separated by ±SE.

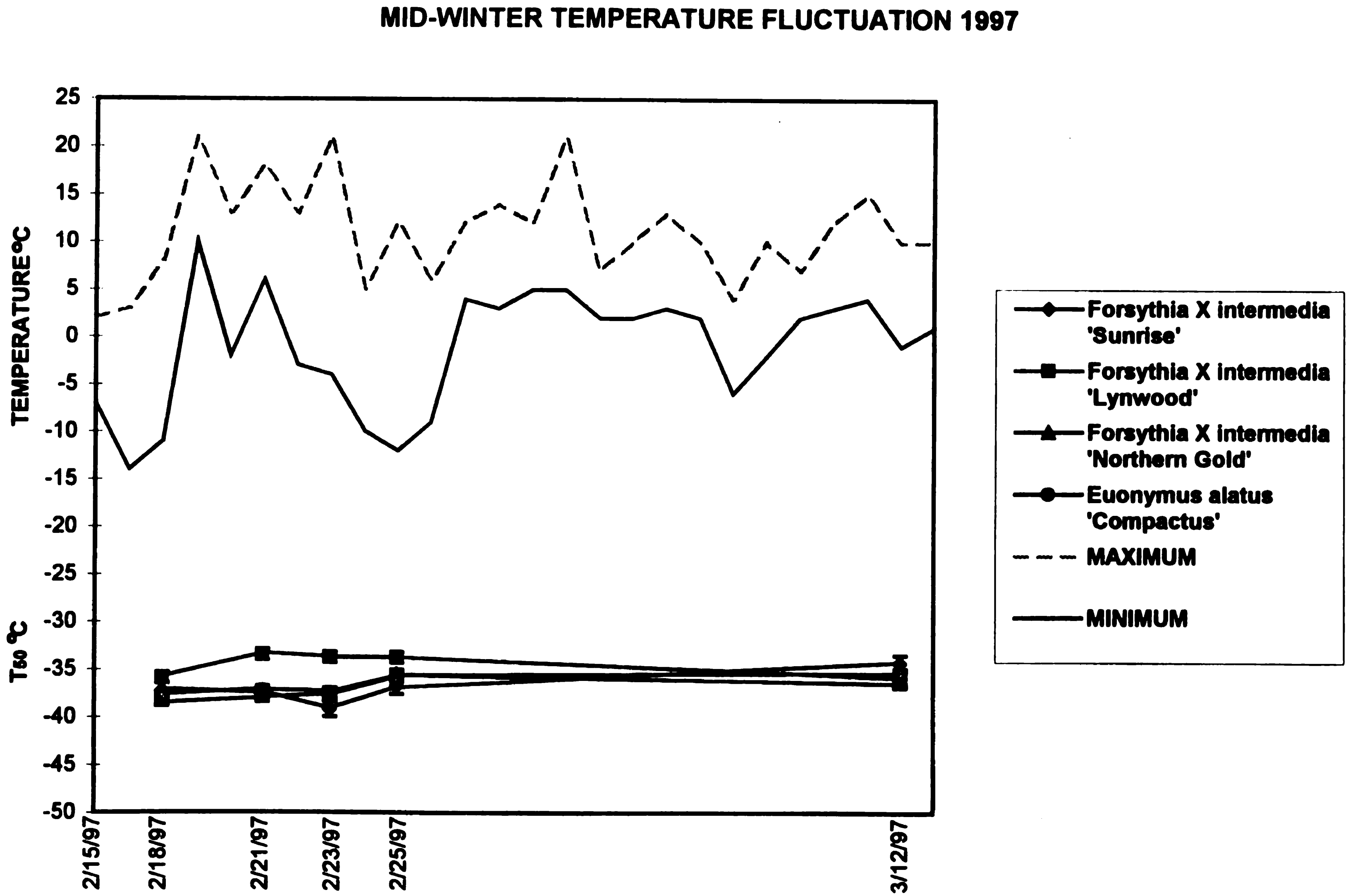

MID-WINTER TEMPERATURE FLUCTUATION 1997
TEMPERATURE°C
T50 °C
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
2/15/97
2/18/97
2/21/97
2/23/97
2/25/97
3/12/97
Forsythia X intermedia 'Sunrise'
Forsythia X intermedia 'Lynwood'
Forsythia X intermedia 'Northern Gold'
Euonymus alatus 'Compactus'
MAXIMUM
MINIMUM

Figure 1.19. Killing temperature (T_{50}, °C), of three cultivars from February 18 to February 25, 1997 as influenced by placement in a protective structure (late-12/5/96), and minimum and maximum polyhouse temperatures. The T_{50} values are separated by ±SE.

MID-WINTER TEMPERATURE FLUCTUATION 1997

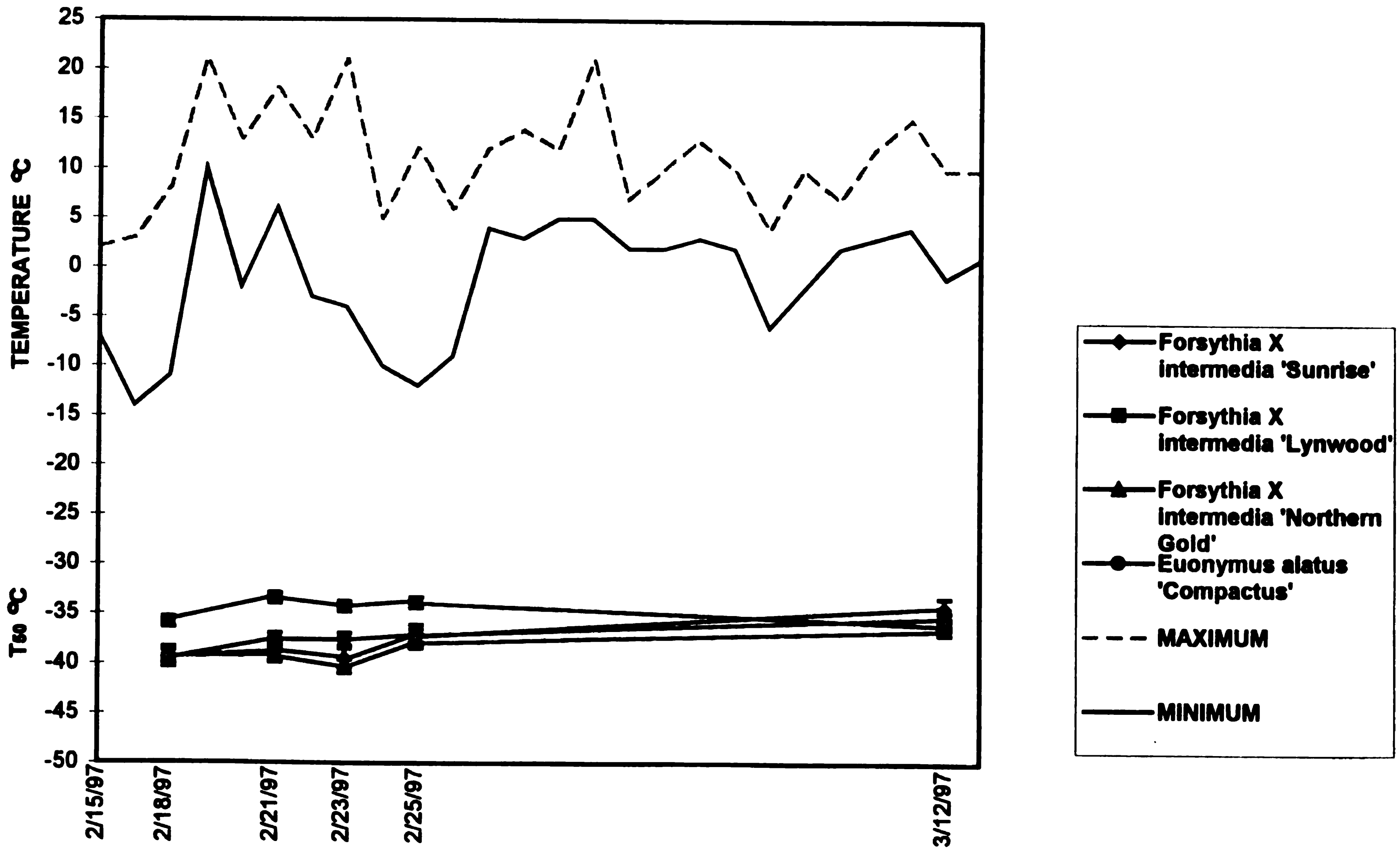
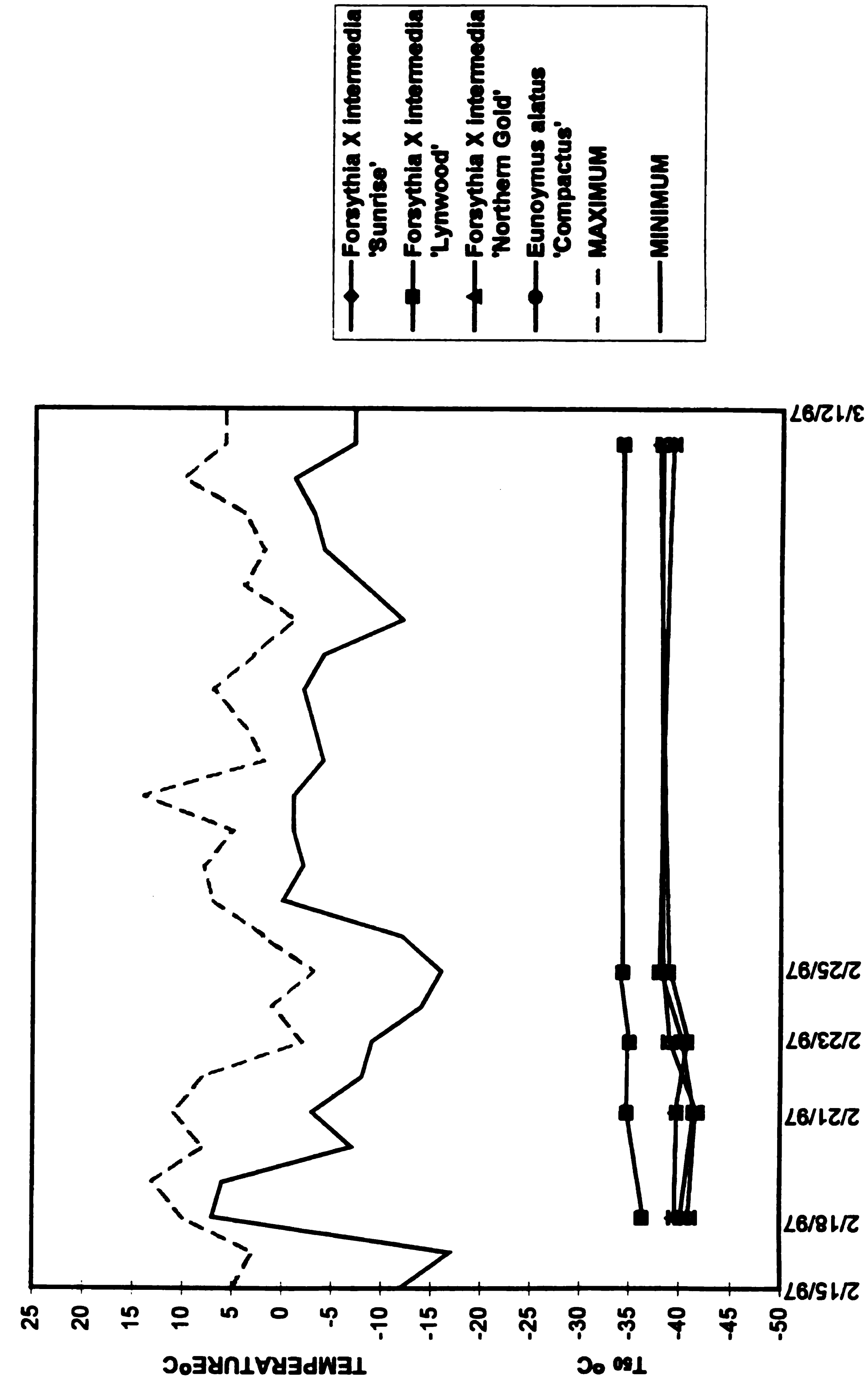


Figure 1.20. Killing temperature (T_{50}, °C), of three cultivars from February 18 to February 25, 1997 as influenced by placement in a pot-in-pot treatment under natural conditions and ambient minimum and maximum field temperatures. The T_{50} values are separated by ±SE.

MID-WINTER TEMPERATURE FLUCTUATION 1997



CONCLUSION

Plant material should not be produced in new market areas if they have difficulty surviving the annual minimum air temperature. Since new cultivars are continually being developed to survive areas with colder winters, it is crucial that these cultivars are evaluated given the weather condition of the nursery and zone of culture. If the cold hardiness of container-grown nursery stock is not assessed, the proper overwintering method may not be used during the winter months. As a result, plant material can be killed and subsequently growers can loose profits.

The protocol employed in this thesis detected differences in hardiness for cultivars in three overwintering treatments. It was shown cultivars placed in a polyhouse early (in October) were less hardy than plants overwintered in the other two treatments. The early polyhouse treatment also adversely affected plant growth of three of the cultivars tested. Future experiments should continue to screen plants to determine their acclamation and deacclimation patterns as well as their maximum hardiness levels. If early polyhouse covering is desired the cold hardiness of the cultivars, as influenced by this overwintering system, must be tested. A method using chlorophyll inflorescence can be used which may detect more exact killing temperatures.

The cold hardiness of new cultivars must also be tested during the warm 'midwinter thaw' period which usually occurs during the months of January or February in Michigan. If necessary growers may choose to vent polyhouses when temperatures are considerably higher than ambient field temperatures.

During the dehardening period of both years, there was a difference in hardiness between the two polyhouse treatments. Future experiments should focus on this period to determine if this difference is common for other cultivars. Just as the timing of polyhouse covering was studied, the timing of polyhouse uncovering should also be studied.

LITERATURE CITED

1. Alexander, L.A., and J.R. Havis. 1980. Root temperature effects on cold acclimation of an evergreen azalea. HortScience 15(1):90-91.

2. Beattie, D.J. 1986. Principles, practices, and comparative costs of overwintering container-grown landscape plants. Southern Cooperative Series. Bulletin 313.

3. Bittenbender, H.C., and G.S. Howell. 1974. Adaptation of the Spearman-Karber method for estimating the T_{50} of cold stressed flower buds. J. Amer. Soc. Hort. Sci. 99(2):187-190.

4. Brainerd, K.E., D.R. Evert., and N.E. Pellett. 1979. *Forsythia* flower bud cold hardiness. HortScience 14(5):623-624.

5. Clark, W.S. 1988. Overwintering container-grown ornamentals. Long Island Horticulture News. pp. 4-6.

6. Davidson, H. 1981. Winter storage of plants. Michigan State University Coop. Ext. Bull. 2(4):1-4.

7. Davidson, H., R. Mecklenburg, and C. Peterson. 1994. Nursery Management: Administration and Culture. Prentice Hall, Inc. p. 236.

8. Dirr, M.A., and O.M. Lindstrom, Jr., 1993. Cold hardiness estimates of *Acer* L. taxa. J. Environ. Hort. 11(4):203-205.

9. Fretz, T.A., and E.M. Smith. 1978. Woody ornamental winter storage. HortScience. 13(2):139-140.

10. Graham, P.R., and R. Mullin. 1976. A study of flower bud hardiness in azalea. J. Amer. Soc. Hort. Sci. 101(1):7-10.

11. Hayes, C.L., O.M. Lindstrom, M.A. Dirr. 1992. Cooling and warming effects on cold hardiness estimations of three woody ornamental taxa. HortScience. 27(12): 1308-1309.

12. Howell, G.S., and C.J. Weiser. 1970. Fluctuations in the cold resistance of apple twigs during spring dehardening. J. Amer. Soc. Hort. Sci. 95(2):190-192.

13. Litzow, M., and H. Pellett. 1980. Relationship of rest to dehardening in red-osier dogwood. HortScience. 15(1):92-93.

14. McHugh, E., J. Robbins, and D. Hensley. 1988. Overwintering ornamental plants. Kansas Nursery Notes. 20:1-3.

15. McNamara, S., and H. Pellett. 1993. Flower bud hardiness of *Forsythia* cultivars. J. Environ. Hort. 11(1):35-38.

16. Parker, J. 1962. Relationships among cold hardiness, water soluble protein, anthocyanins and free sugars in *Hedera helix* L. Plant Physiol. 37:809-813.

17. Pellett, H., M. Gearhart, and M. Dirr. 1981. Cold hardiness capability of woody ornamental plant taxa. J. Amer. Soc. Hort Sci. 106(2):239-243.

18. Pellett, H., S. Moe, and K. Vogel. 1985. Cold tolerance of shade tree species and cultivars in the upper Midwest. J. Environ. Hort. 3(2):58-62.

19. Pellett, N.E., D. Dippre, and A. Hazelrigg. 1985. Coverings for overwintering container-grown plants in norther regions. J. Environ. Hort. 3(1):4-7.

20. Proebsting, E.L. 1963. The role of air temperatures and bud development in determining hardiness of dormant Elberta peach fruit buds. Proc. Amer. Soc. Hort. Sci. 83:259-269.

21. Stergios, B.G., and G.S. Howell. 1973. Evaluation of viability tests for cold stressed plants. J. Amer. Soc. Hort. Sci. 98:325-330.

22. Weiser, C.J. 1970. Cold resistance and acclimation in woody plants. HortScience. 5(5):403-410.

23. Williams, C. 1970. Overwintering containerized nursery stock. U.N.H. Coop. Ext. Bull.

CHAPTER II

WARMING TEMPERATURES ON THE ROOT COLD HARDINESS OF CONTAINER-GROWN NURSERY STOCK

ABSTRACT

Warming Temperatures on the Root Cold Hardiness
of Container-Grown Nursery

Selected container-grown nursery stock was allowed to reach mid-winter hardiness levels during the 1995/1996 and 1996/1997 test periods. Plants were subjected to 12 hours of 21.0°C (69.8°F) followed by 12 hours of 0°C (32.0°F) for up to 16 days. Controlled temperature freezing was conducted after every 48-hour period to determine the levels of root hardiness. Viability was determined by measuring days to bud break and visual plant performance ratings which were cultivar dependent. Ratings were assigned to the cultivars after 30 and 60 days of growth in the greenhouse. In general, plant performance declined as days of warming increased and as freezing temperatures decreased. Plant performance ratings for *Weigela florida* 'Java Red', *Hibiscus syriacus* 'Paeonyflorus', and *Euonymus alatus* 'Compactus' improved from 30 to 60 days during the 1995/1996 test period. Ratings for *Forsythia X intermedia* cultivars declined from 30 to 60 days during the 1996/1997 test period. In comparison to the controlled warming temperatures, the effect of natural deacclimation on root cold hardiness was studied during the spring of 1996. Days to bud break for *Weigela florida* 'Java Red' and *Euonymus alatus* 'Compactus' steadily increase during the deacclimation period as controlled freezing temperatures decreased. Visual plant performance ratings declined as the deacclimation period progressed and controlled freezing temperatures declined. Ratings for both cultivars did not change from 30 to 60 days of growth.

INTRODUCTION

Loss of nursery stock during winter months may be due to lack of root cold hardiness when freezing temperatures occur (6). Though container production is attractive to growers, root systems in the small pots are predisposed to stress. The container substrate is not like field soil which can protect the roots against low temperature (3, 17). Instead the substrate freezes and thaws quickly, injuring the root system (9). To exacerbate the stress on container-grown root systems, roots do not become dormant and are readily influenced by surrounding ambient soil and air temperatures. Roots cannot survive temperatures that shoots are exposed to and acclimate at a much slower rate (5). There is even a reported difference in hardiness between young and mature roots (8, 15). Overwintering structures were created to help protect these vulnerable root systems from freezing temperatures.

The limited amount of substrate material in containers greatly influences the root system (5). Since roots are influenced by soil temperatures, this creates a large difference between how the roots are affected in the field and in containers (5, 11). Temperatures can differ between the roots in the field and those in the middle of 20 cm (8 in) containers by as much as 9.0°C (16.2°F) (15). Root systems of container-grown plants are above ground and are subjected to temperatures almost as low as air temperatures (4). Root systems of field grown plants are insulated by the surrounding soil which prevents them from being exposed to these low temperatures.

Unlike the shoots, the roots do not respond to the acclimation signals of shorter days and low air temperatures (5). Instead, roots appear to respond to surrounding soil temperature. These soil temperatures change in response to the warming and cooling of air around the plant (16). Soil temperatures also dictate when the roots harden and deharden. Hardiness is achieved at a certain temperature specific to every plant. When temperatures above this level of hardiness are encountered, the roots can begin to grow, while lower temperatures prevent this from occurring. Warm temperatures during the winter will actually cause the root system to deacclimate and begin growth. This can occur in as little as 24 hours and when freezing temperatures recur, the roots can be damaged (5).

Root hardiness levels and shoot hardiness levels on the same plant have different values, and values can differ by as much as 70.0°C (158.0°F) in White Pine, 28.0°C (82.4°F) in *Taxus cuspidata*, and by at least 15.0°C (59.0°F) in ornamental shrubs (5). Just as the hardiness of shoots and roots differ, plant roots also have varying degrees of cold hardiness. Roots near the stem of the plant are the most cold hardy, while young root tips are considerably less hardy (11). Reports have suggested that young roots (defined as the section immediately adjacent to and including the root tip) did not survive when girdled prior to controlled temperature freezing, whereas the more mature roots (darker and with a larger diameter) achieved T_{50} values similar to those of leaves (11). Mature roots of *Cotoneaster microphylla* are reported to be hardy to -13.0°C (9.0°F), while the young roots only tolerate temperatures to -4.0°C (25.0°F) (15). If enough young roots die, the survivability of the plant could be affected. Young roots which grow near the container boundary will most likely die during the winter months (8). Water uptake the following spring may be reduced which may cause growth to cease (11, 15).

To help protect the root system from cold temperatures, plants can be overwintered under polyethylene-covered hoophouses (polyhouses). Interior temperatures are commonly well above minimum ambient field temperatures during the winter months. Root systems often injured by the minimum ambient field temperatures can be sheltered by this structure (1). There are, however, disadvantages to overwintering systems. Plant material overwintered in polyhouses may not get as root hardy as plants overwintered outdoors (14). Subsequently, plants can be injured by the much cooler ambient field temperatures when they are uncovered (13).

Root killing temperatures of established plants are difficult to assess when the surrounding soil is frozen (16). If the root system is dug from the ground in the winter and the soil surrounding that root system is allowed to thaw, the root tissue is likely to deacclimate and the correct root killing temperatures cannot be obtained. It has been reported that roots can be detached from plants in the fall before acclimation begins and can be stored under high humidity conditions. These root samples can then be used to determine root killing temperatures. It has been suggested that root systems which are severed prior to storagc can achieve the same level of root hardiness as intact stored plants (12).

It would be desirable to study the cold hardiness of an intact container-grown root system surrounded by the container substrate. This would allow roots to acclimate and deacclimate as they would in a nursery. Nursery stock with intact roots in the container may survive lower killing temperatures and respond differently than severed roots. Bud break and plant vigor could then be used as an indication of the survival of the root.

Plant roots support many plant processes. Water uptake and whole plant performance are dependent on the viability of the root system (16). The following experiments were conducted to answer the following questions: Do warming temperatures have an influence on the cold hardiness of the root system? Will the root injury effect whole plant performance? Lastly, will bud break and plant performance decline as the warming period progresses?

MATERIALS AND METHODS

CONTROLLED WARMING TEMPERATURES Well-rooted plants in 5.7 cm (2.25 in) pot of *Weigela florida* 'Java Red', *Hibiscus syriacus* 'Paeonyflorus', and *Euonymus alatus* 'Compactus' were allowed to acclimate naturally outdoors at the Michigan State University Horticultural Teaching Research Center (HTRC), in Lansing, USDA Hardiness Zone 5,-23.0°C to -29.0°C (-10.0°F to -20.0°F) from September 24 to November 3, 1995. Plants were placed in the center of a 55 percent transmission, opaque, 18' x 96' polyhouse until December 26, 1995, when they were moved into a temperature control chamber set at 0°C (32.0°F) for 12 hours in the Plant and Soil Science Building at Michigan State University. The plants were divided into nine groups (a control and eight treatments). A second control group stayed in the 0°C (32.0°F) temperature control chamber throughout the experiment.

On the second day, the treatment plants were moved into a 21.0°C (69.8°F) control chamber for 12 hours. Every 12 hours plants were moved from the 21.0°C (69.8°F) control chamber and placed into the 0°C (32.0°F) chamber. This process continued in 12 hour increments. After each 48-hour interval from two to 16 days, a treatment group of plants (with a control) was placed in the 0°C (32.0°F) chamber for another 24 hours. A 26 ga copper-constantan thermocouple was placed in the pot medium while they were in a Revco Ultralow freezer (Omega Engineering, Stamford, CT) to monitor temperatures when connected to a potentiometer. Temperatures within the freezer were controlled and monitored by an Omega temperature controller. The plants were kept in the freezer overnight at a constant -3.0°C (26.6°F).

The next morning the freezer temperature was programmed to drop in 3.0°C (5.4°F) increments every hour. Nine freezer temperatures were used and replicated three times, including a control which was placed in a 3.0°C (37.4°F) freezer. Freezing treatments from -6.0°C to -27.0°C (21.2°F to -16.6°F) were chosen to represent similar root killing temperatures as reported by Havis (8) and Studer (15). At each temperature regime, the plants were removed and placed in a 3°C (37.4°F) chamber until all groups had been subjected to the appropriate controlled temperature freezing level. The plants were placed in a greenhouse on January 15, 1996 with a 27.0°C (80.6°F) day and 17.0°C (62.6°F) night temperature to observe bud break and visual plant performance for 30 and 60 days. Analysis of variance was used to determine significance for days to bud break. Visual plant performance ratings were assigned as follows: 1=Bud scale not broken, tissue was brown and/or dead; 2=Bud scale was broken, leaves visible; 3=Uniform new growth, new leaves were formed; 4=Leaves were fully expanded; and 5=Leaves fully expanded on elongated shoots. Analysis of variance was also used to determine significance of ratings from 30 to 60 days.

Well-rooted plants in 5.7 cm (2.25 in) pot of three *Forsythia X intermedia* cultivars ('Sunrise', 'Lynwood', and 'Northern Gold'), were again placed outdoors at the HTRC to acclimate naturally from October 24 to November 25, 1996. Plants were placed in the center of a 55 percent opaque 18' x 96' polyhouse until December 26, 1996. Plants were then subjected to the fluctuating temperature and freezing regimes as described previously. Freezing treatments from -9.0°C to -30.0°C (15.8°F to -22.0°F) where chosen based on a hardiness evaluation by McNamara and Pellett (10). On January 26, 1997, the plants were placed into a greenhouse to observe bud break and visual plant performance after 30 and 60 days.

NATURAL DEACCLIMATION Well-rooted plants in 5.7 cm (2.25 inch) pot of *Weigela florida* 'Java Red', *Hibiscus syriacus* 'Paeonyflorus', and *Euonymus alatus* 'Compactus' were overwintered at the HTRC and transported to the Plant and Soil Science Building for a weekly controlled temperature freezing from February 22 to April 11, 1996. A 26 ga copper-constantan thermocouple was placed into each of the pots and the plants were subjected to controlled temperature freezing as previously described. Nine freezer temperatures were used and replicated three times, including a control which was placed in a 3.0°C (37.4°F) freezer. Freezing treatments from -6.0°C to -33.0°C (21.2°F to -27.4°F) were chosen to determine root hardiness. The freezer temperature was programed to drop in 3.0°C (5.4°F) increments. After each freezer run, the liners were placed in a 3.0°C (37.4°F) freezer until all treatments were performed. On May 11, 1996 all of the plants were placed in a greenhouse to observe bud break and visual plant performance. Plants were rated on a scale from 1 to 5 as previously described. Again, analysis of variance was used to determine if there was a significant difference between days to bud break.

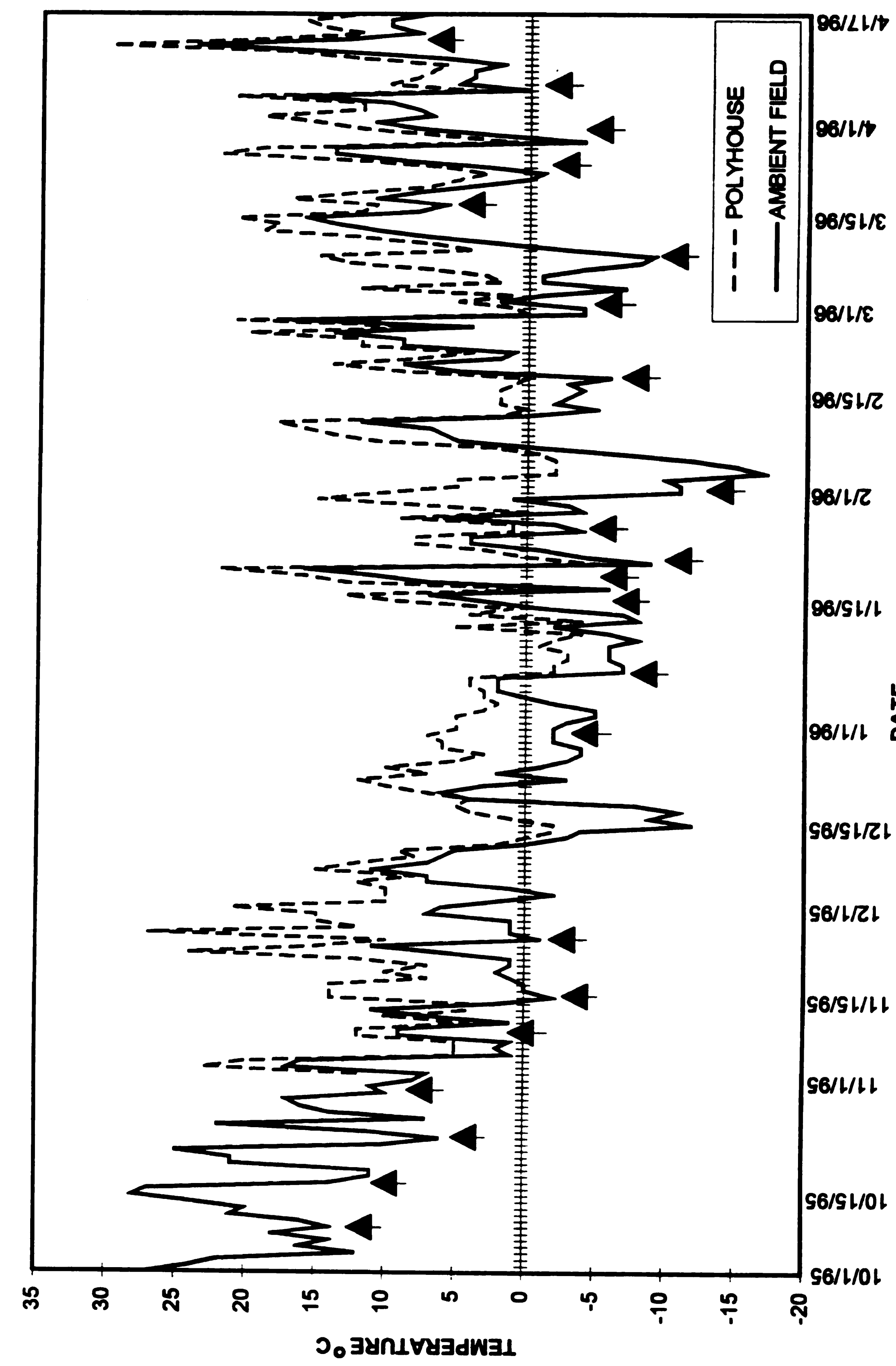
RESULTS AND DISCUSSION

Minimum and maximum ambient field and polyhouse temperatures were recorded daily at plant level during the fall, winter, and spring (test periods) of 1995/1996 and 1996/1997. The maximum polyhouse temperature experienced during the 1995/1996 test period was 27.0°C (80.6°C) on November 23, while the maximum ambient field temperature was 28.0°C (82.4°F) on October 13 (Figure 2.1). The lowest minimum polyhouse temperature during this test period was -13.0°C (8.6°F) on February 19, the lowest ambient field temperature was -25.0°C (-13.0°F) on February 3 (Figure 2.2).

Maximum polyhouse and ambient field temperatures were higher during the 1996/1997 test period, 35.0°C (95.0°F) on October 15 and 31.0°C (87.8°F) on September 5, respectively (Figure 2.3). Minimum polyhouse temperatures were lower during the 1996/1997 test period, -16.5°C (2.0°F) on January 19, however, the minimum ambient field temperatures were warmer, -23.0°C (-9.4°F) also on January 19 (Figure 2.4).

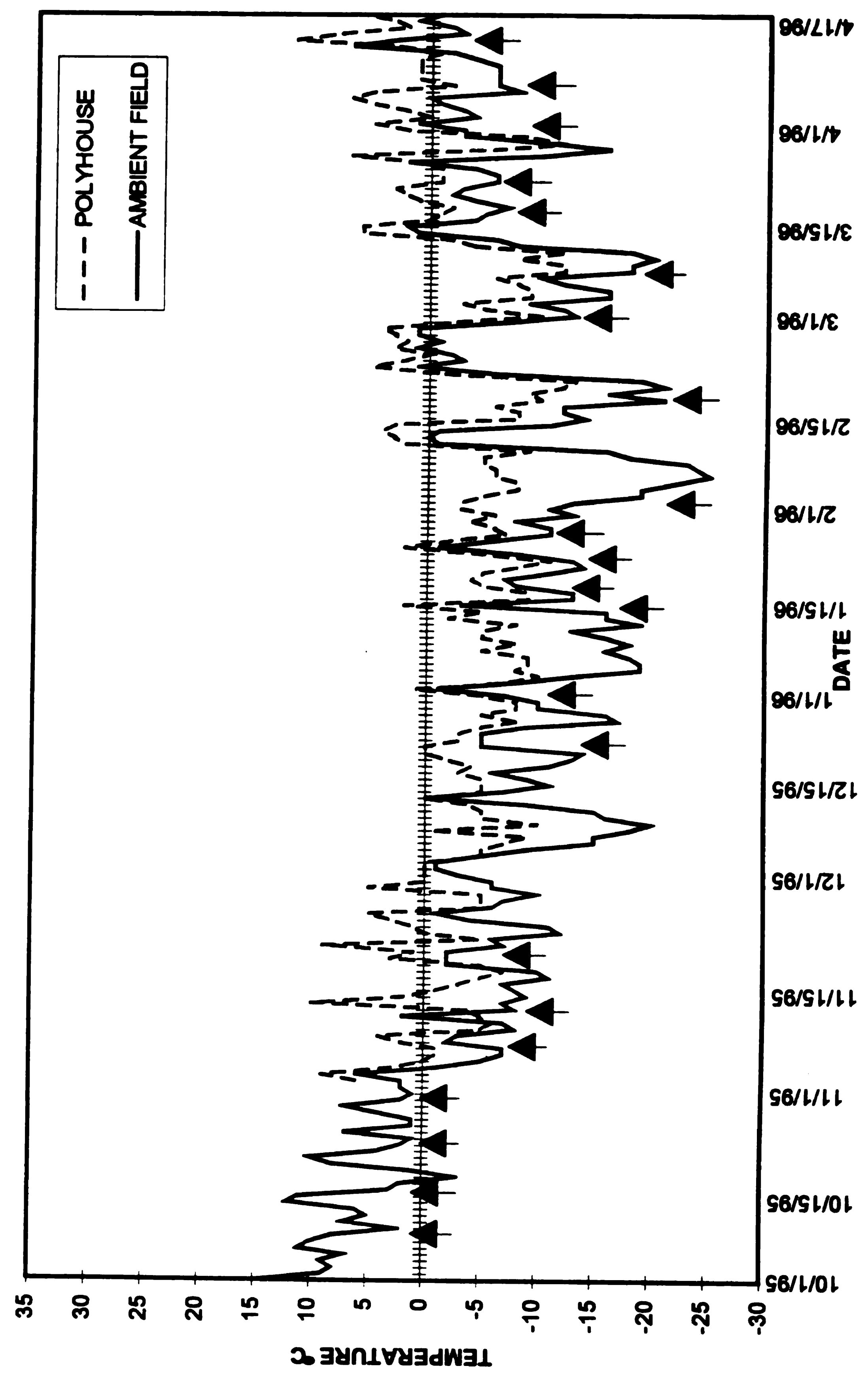
CONTROLLED WARMING TEMPERATURES Figure 2.5 shows bud break results of three cultivars subjected to periods of warming temperatures from two to 16 days during the 1995/1996 test period. *Weigela florida* 'Java Red' deacclimated slowly and exhibited delayed bud break after 12 days of warming. *Weigela* took 29 days to break bud after two days of warming at -27.0°C (-16.6°F), whereas the cultivar took 44 days to break bud at the same temperature after 16 days of warming. *Hibiscus syriacus* 'Paeonyflorus' took longer to break bud with little influence of warming temperatures and was a cold-sensitive cultivar which did not survive temperatures below -12.0°C (10.4°F). Deacclimation of hardy *Euonymus alatus* 'Compactus' plants steadily progressed to 16 days of warming. Analysis of

Figure 2.1. Maximum daily polyhouse and ambient field temperatures were measured at plant level during the 1995/1996 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.



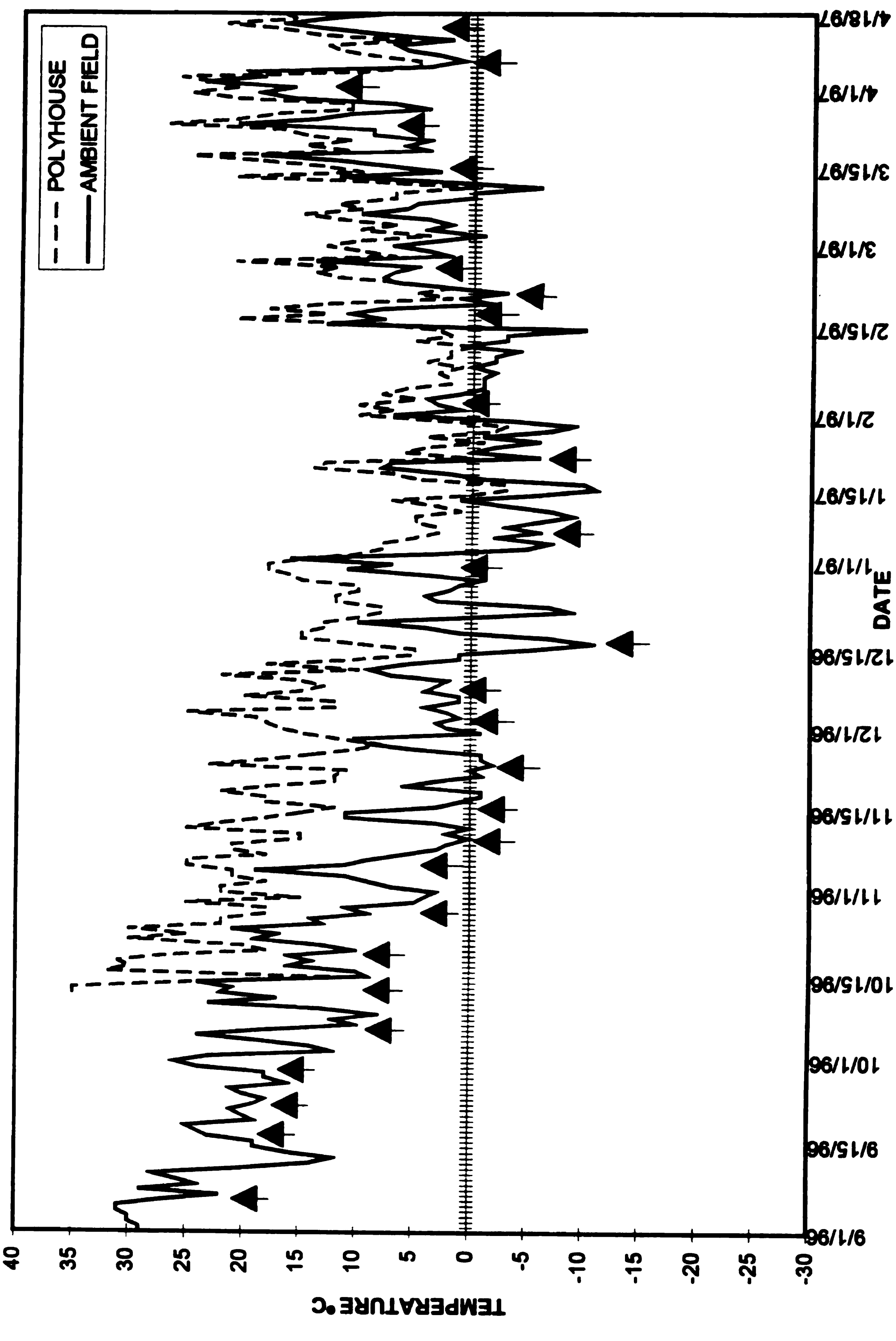
POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
DATE
35
30
25
20
15
10
5
0
-5
-10
-15
-20
10/1/95
10/15/95
11/1/95
11/15/95
12/1/95
12/15/95
1/1/96
1/15/96
2/1/96
2/15/96
3/1/96
3/15/96
4/1/96
4/17/96

Figure 2.2. Minimum daily polyhouse and ambient field temperatures were measured at plant level during the 1995/1996 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.



POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
DATE
10/1/95
10/15/95
11/1/95
11/15/95
12/1/95
12/15/95
1/1/96
1/15/96
2/1/96
2/15/96
3/1/96
3/15/96
4/1/96
4/17/96

Figure 2.3. Maximum daily polyhouse and ambient field temperatures were measured at plant level during the 1996/1997 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.



POLYHOUSE
AMBIENT FIELD
TEMPERATURE °C
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
DATE
9/1/96
9/15/96
10/1/96
10/15/96
11/1/96
11/15/96
12/1/96
12/15/96
1/1/97
1/15/97
2/1/97
2/15/97
3/1/97
3/15/97
4/1/97
4/18/97

Figure 2.4. Minimum daily polyhouse and ambient field temperatures were measured at plant level during the 1996/1997 test period. The ↓ indicates the date that shoot tissue was removed for controlled temperature freezing.

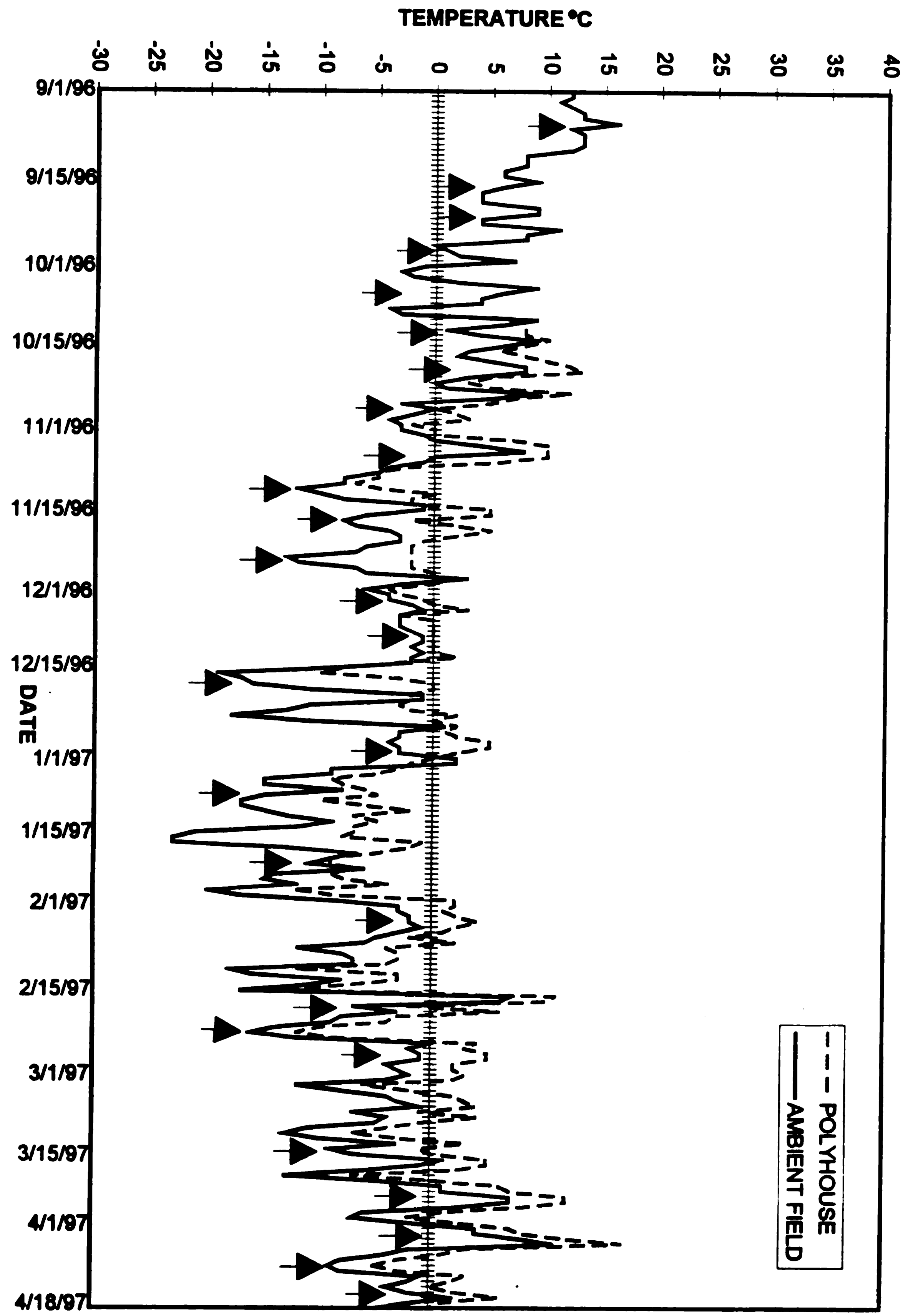
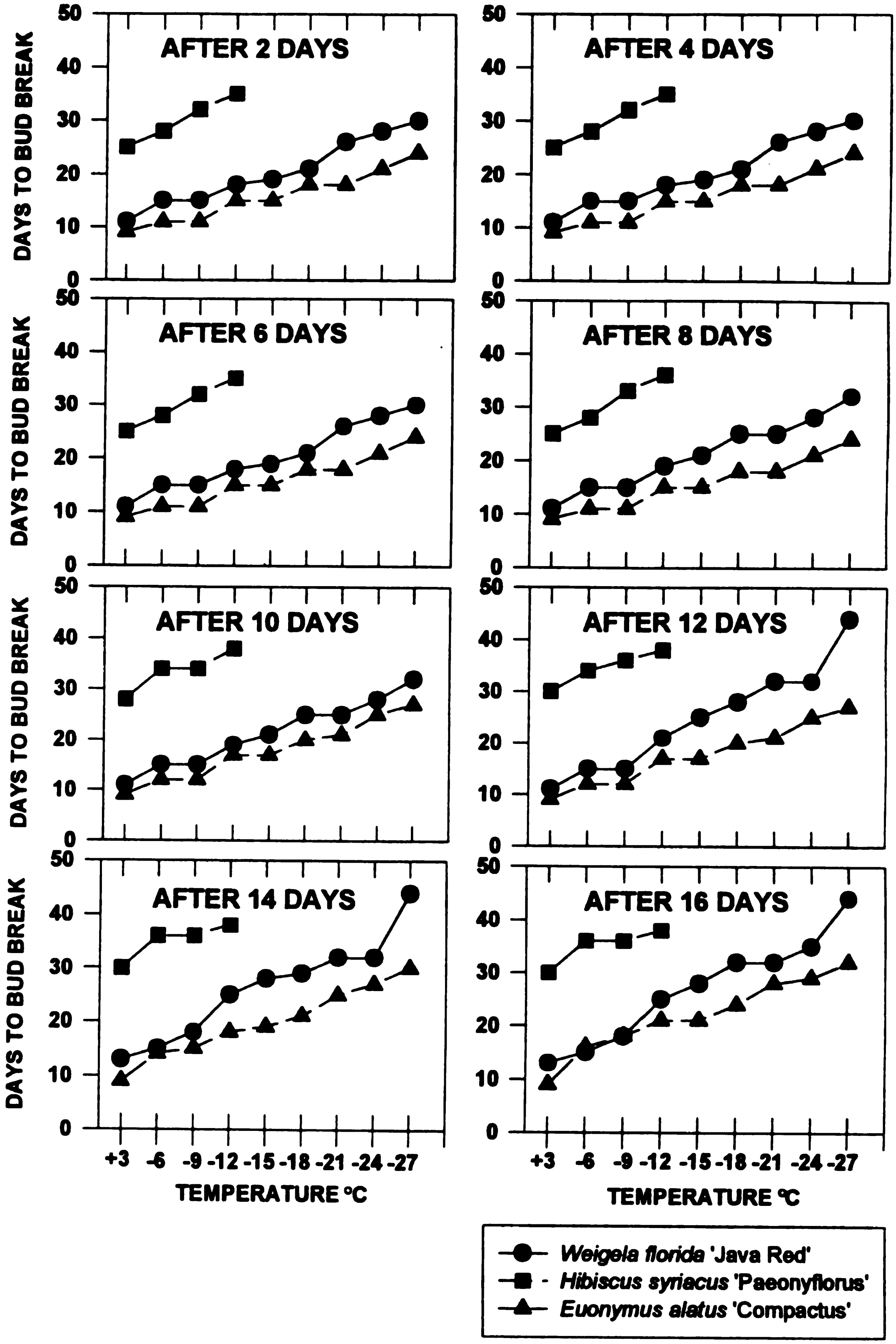

TEMPERATURE °C
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
9/1/96
9/15/96
10/1/96
10/15/96
11/1/96
11/15/96
12/1/96
12/15/96
1/1/97
1/15/97
2/1/97
2/15/97
3/1/97
3/15/97
4/1/97
4/18/97
DATE
POLYHOUSE
AMBIENT FIELD

Figure 2.5. Influence of warming temperatures and controlled temperature freezing from two to 16 days on the date of bud break of three cultivars during the 1995/1996 test period. Data of bud break is expressed as date of first noticeable shoot elongation.


AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
DAYS TO BUD BREAK
TEMPERATURE °C
+3 -6 -9 -12 -15 -18 -21 -24 -27
0 10 20 30 40 50
Weigela florida 'Java Red'
Hibiscus syriacus 'Paeonyflorus'
Euonymus alatus 'Compactus'

variance showed the different temperatures at which the warming pretreatment had an impact on timing of bud break (Table 2.1). Bud break was significant for *Weigela* at freezing temperatures of -12.0°C (10.4°F) and colder. Bud break was significant at all freezing temperatures *Hibiscus* was exposed to and survived, while bud break was significant for *Euonymus* at freezing temperatures of -6.0°C (21.2°F) and colder. In general, as warming increased and freezing temperatures decreased, the time to bud break increased for all three cultivars.

Visual plant performance ratings were assigned to the cultivars after 30 and 60 days of growth in the greenhouse. In general, plant performance declined as days of warming increased and as freezing temperatures decreased. *Weigela's* plant performance improved after 30 days of growth (Figure 2.6). Ratings for all *Hibiscus* plants improved greatly from 30 to 60 days at temperatures above -12.0°C (10.4°F) (Figure 2.7). Performance ratings for *Euonymus* differed slightly from 30 to 60 days of growth (Figure 2.8). Based on these results, 30 days of growth was not a long enough period to assess recovery from root damage. Instead a period of 60 days was required to indicate at what temperature root injury affected whole plant performance. Plant performance ratings below this temperature were an implication of severe root injury as a result of the warming and freezing temperatures. The root systems of both *Euonymus* and *Weigela* had an impact on plant performance at -12.0°C (10.4°F). *Hibiscus* roots had an impact on plant performance at -9.0°C (15.8°F). Significance between ratings form 30 to 60 days differed depending upon cultivar and freezing temperature (Table 2.2). *Weigela* had the greatest amount of significance while no significance was recorded for *Euonymus*.

Table 2.1. Influence of controlled warming from two to 16 days on date of bud break after controlled temperature freezing for three cultivars during the 1995/1996 test period. Data analyzed by analysis of variance.

	FREEZING TEMPERATURE								
PLANT NAME	+3.0°C (37.4°F)	-6.0°C (21.2°F)	-9.0° C (15.8°F)	-12.0°C (10.4°F)	-15.0°C (5.0°F)	-18.0°C (-0.4°F)	-21.0°C (-5.8°F)	-24.0°C (-11.2°F)	-27.0°C (-16.6°F)
Weigela florida 'Java Red'	NS	NS	NS	*	**	**	**	**	**
Hibiscus syriacus 'Paeonyflorus'	**	**	**	**	NA	NA	NA	NA	NA
Euonymus alatus 'Compactus'	NS	**	**	**	**	**	**	**	**

NS, *,** Not significant at P=0.05 or 0.01, respectively

Figure 2.6. Visual plant performance ratings for *Weigela florida* 'Java Red', after exposure of two to 16 days of warming temperatures and controlled temperature freezing. Performance ratings were conducted 30 and 60 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per warming period per freezing temperature.

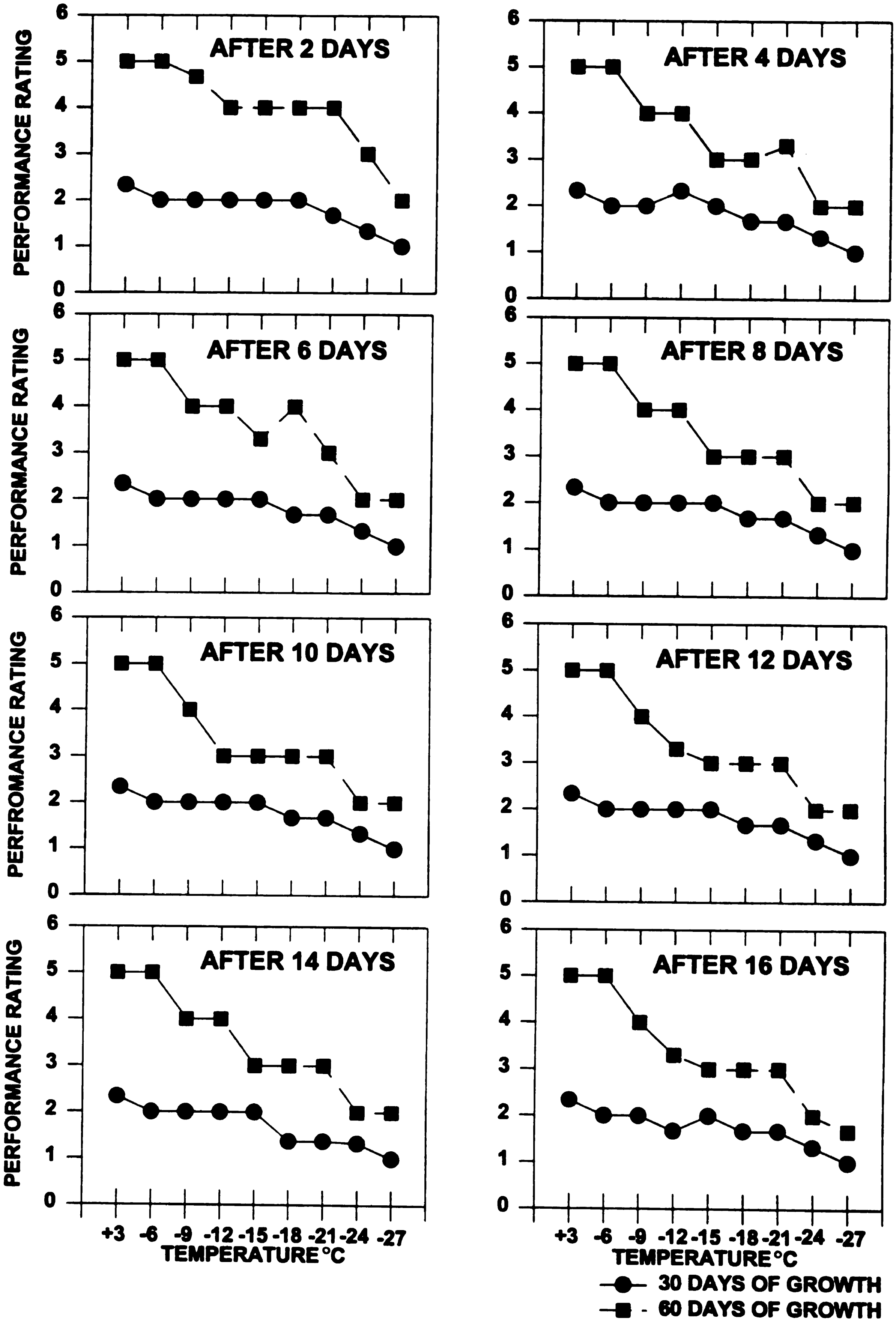
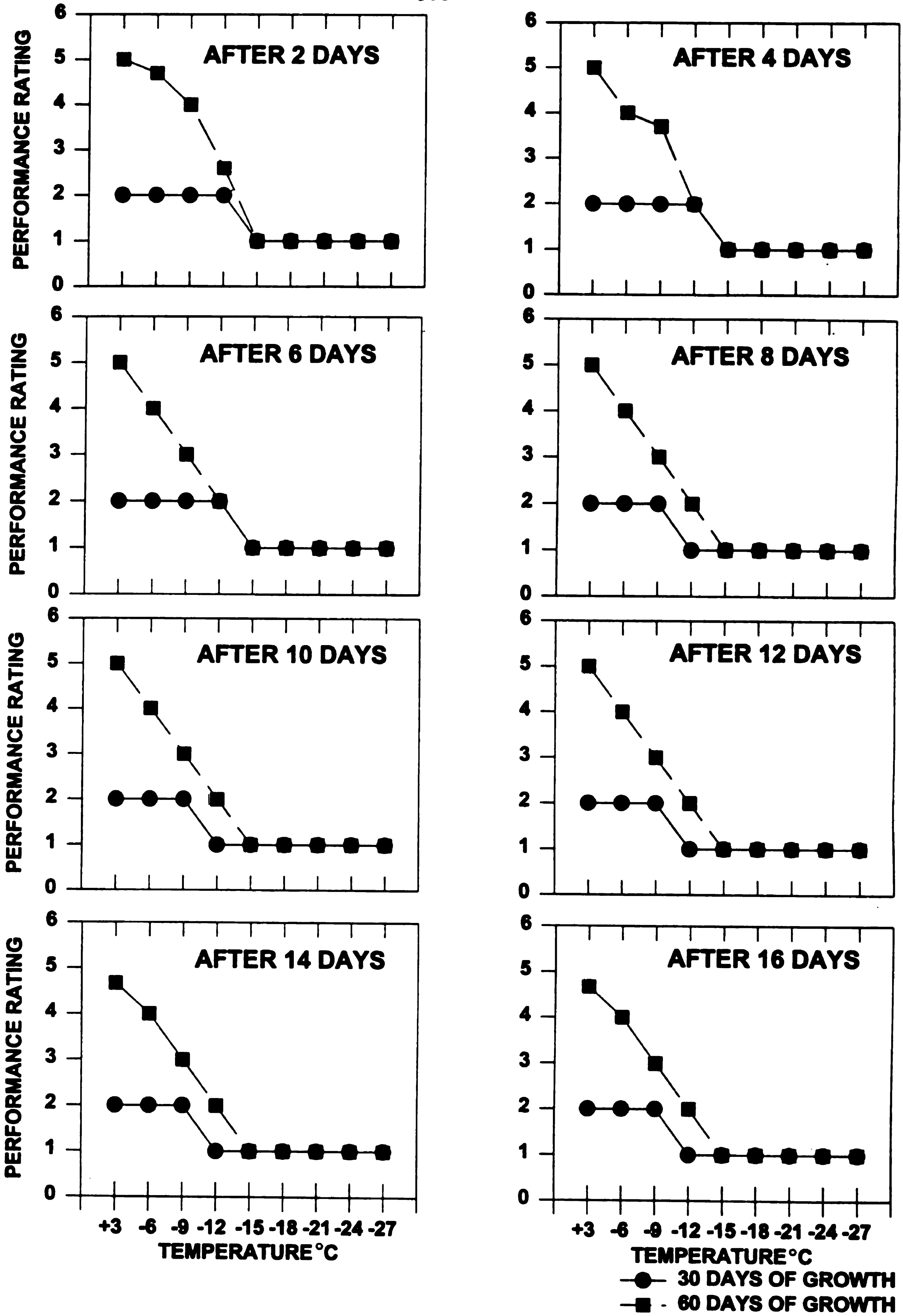

AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
PERFORMANCE RATING
PERFROMANCE RATING
0 1 2 3 4 5 6
+3 -6 -9 -12 -15 -18 -21 -24 -27
TEMPERATURE °C
30 DAYS OF GROWTH
60 DAYS OF GROWTH

Figure 2.7. Visual plant performance ratings for *Hibiscus syriacus* 'Paeonyflorus', after exposure of two to 16 days of warming temperatures and controlled temperature freezing. Performance ratings were conducted 30 and 60 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per warming period per freezing temperature.



AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
PERFORMANCE RATING
0
1
2
3
4
5
6
+3 -6 -9 -12 -15 -18 -21 -24 -27
TEMPERATURE °C
30 DAYS OF GROWTH
60 DAYS OF GROWTH

Figure 2.8. Visual plant performance ratings for *Euonymus alatus* 'Compactus', after exposure of two to 16 days of warming temperatures and controlled temperature freezing. Performance ratings were conducted 30 and 60 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per warming period per freezing temperature.

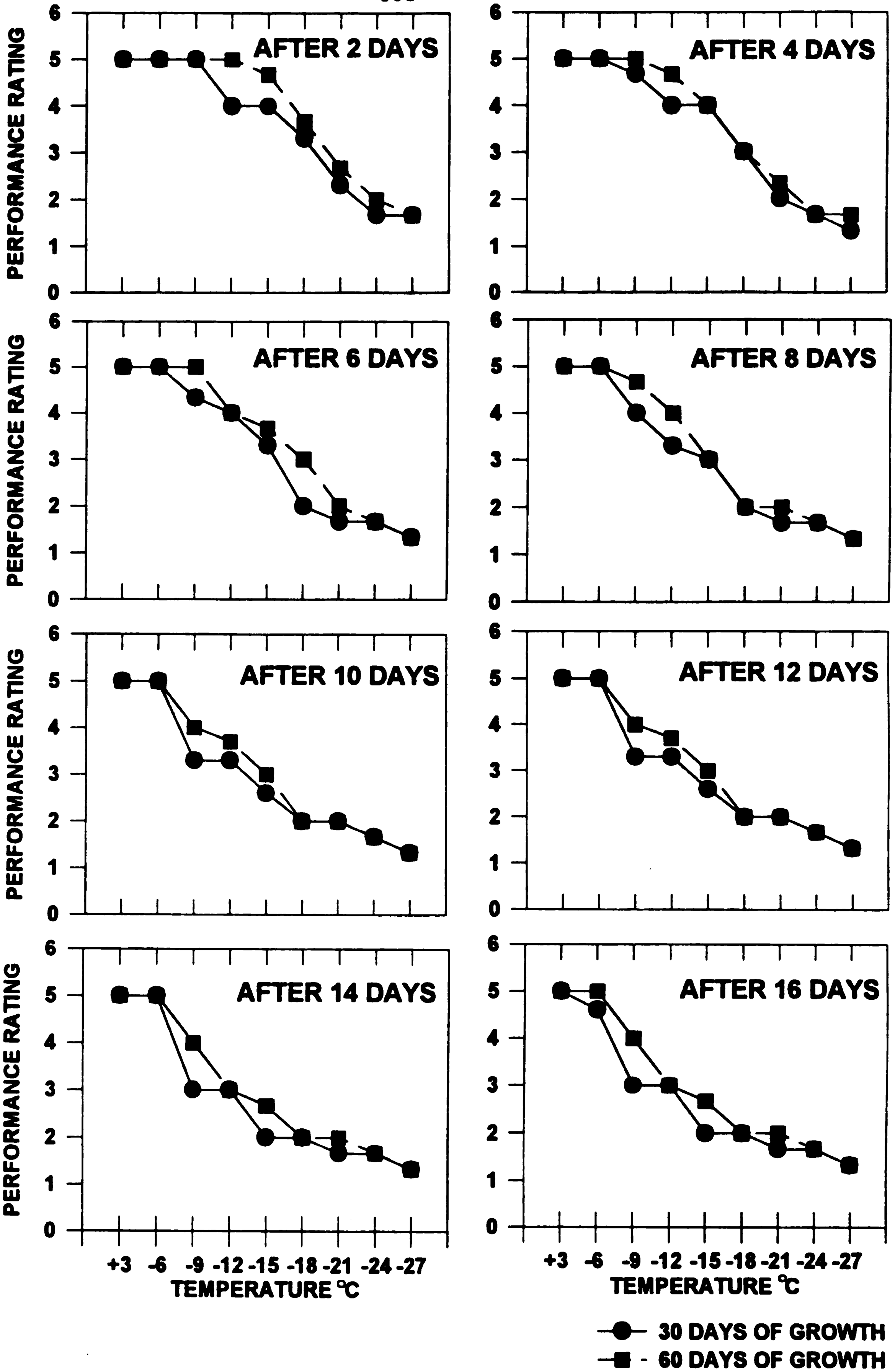

PERFORMANCE RATING
AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
+3 -6 -9 -12 -15 -18 -21 -24 -27
TEMPERATURE °C
30 DAYS OF GROWTH
60 DAYS OF GROWTH

Table 2.2. Influence of controlled warming from two to 16 days on growth from 30 to 60 days after controlled temperature freezing for three cultivars during the 1995/1996 test period. Data analyzed by analysis of variance.

FREEZING TEMPERATURE									
PLANT NAME	+3.0°C (37.4°F)	-6.0°C (21.2°F)	-9.0°C (15.8°F)	-12.0°C (10.4°F)	-15.0°C (5.0°F)	-18.0°C (-.04°F)	-21.0°C (-5.8°F)	-24.0°C (-11.2°F)	-27.0°C (-16.6°F)
AFTER 2 DAYS									
Weigela f. 'Java Red'	**	**	**	NS	NS	NS	**	NS	NS
Hibiscus s. 'Paeonyflorus'	**	**	NS	NS	NA	NA	NA	NA	NA
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS
AFTER 4 DAYS									
Weigela f. 'Java Red'	**	**	NS	**	NS	NS	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NA	NA	NA	NA	NA
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS
AFTER 6 DAYS									
Weigela f. 'Java Red'	**	**	NS	NS	NS	**	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NA	NA	NA	NA	NA

Table 2.2 (Cont'd).

Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS
AFTER 8 DAYS									
Weigela f. 'Java Red'	**	**	NS	NS	NS	NS	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NA	NA	NA	NA	NA
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS
AFTER 10 DAYS									
Weigela f. 'Java Red'	**	**	NS	NS	NS	NS	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NA	NA	NA	NA	NA
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS
AFTER 12 DAYS									
Weigela f. 'Java Red'	**	**	NS	**	NS	NS	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NA	NA	NA	NA	NA
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2.2 (Cont'd).

AFTER 14 DAYS									
Weigela f. 'Java Red'	**	**	NS	NS	NS	NS	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NA	NA	NA	NA	NA
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS
AFTER 16 DAYS									
Weigela f. 'Java Red'	**	**	NS	NS	NS	NS	NS	NS	NS
Hibiscus s. 'Paeonyflorus'	**	NS	NS	NS	NS	NS	NS	NS	NS
Euonymus a. 'Compactus'	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, ** Not significant at P=0.05 or 0.01, respectively

The results for the 1996/1997 test period showed that days to bud break for the three *Forsythia X intermedia* cultivars from two to 16 days of warming were similar at freezing temperatures warmer than -18.0°C (-0.4°F) (Figure 2.9). On each testing date 'Sunrise' broke bud quickly at warmer freezing temperatures, but was slower to break bud at temperatures below -18.0°C (-0.4°F). As the duration of warming progressed, 'Sunrise' failed to break bud at lower freezing temperatures. Bud break gradually took more time to occur from two to 16 days for the cold-sensitive 'Lynwood' cultivar. Survival of 'Lynwood' subjected to -30.0°C (-22.0°F) did not occur after two days of warming and after 14 days bud break did not occur at temperatures below -24.0°C (-21.2°F). Days to bud break for 'Northern Gold' gradually increased to 16 days of warming. After two days of warming there was a three day difference between bud break at 3.0°C (37.4°F) and -30.0°C (-22.0°F). After 16 days the difference escalated to seven days. All three *Forsythia* cultivars showed significance for days to bud break at each freezing temperature (Table 2.3). No significance existed for any cultivar at any freezing temperature from 30 to 60 days.

Visual plant performance ratings for *Forsythia* cultivars decreased slightly from 30 and 60 days of growth. Havis (7) reported that injury to the root system affects the viability of shoot growth. He observed that several deciduous shrubs leafed out after exposure to low temperatures but declined in vigor due to root injury. Again, the temperatures at which the root system had an impact on plant performance were recorded. The root system of the *Forsythia* cultivars had an impact on plant performance at the following temperatures: 'Sunrise' at -12.0°C (10.4°F) (Figure 2.10), 'Lynwood' at -9.0°C (15.8°F) (Figure 2.11), and 'Northern Gold' at -15.0°C (5.0°F) (Figure 2.12). For both years, the control group which remained in the 0°C (32.0°F) control chamber throughout the experiment broke bud on the

Figure 2.9. Influence of warming temperatures and controlled temperature freezing from two to 16 days on the date of bud break of three *Forsythia X intermedia* cultivars during the 1996/1997 test period. Data of bud break is expressed as date of first noticeable shoot elongation.

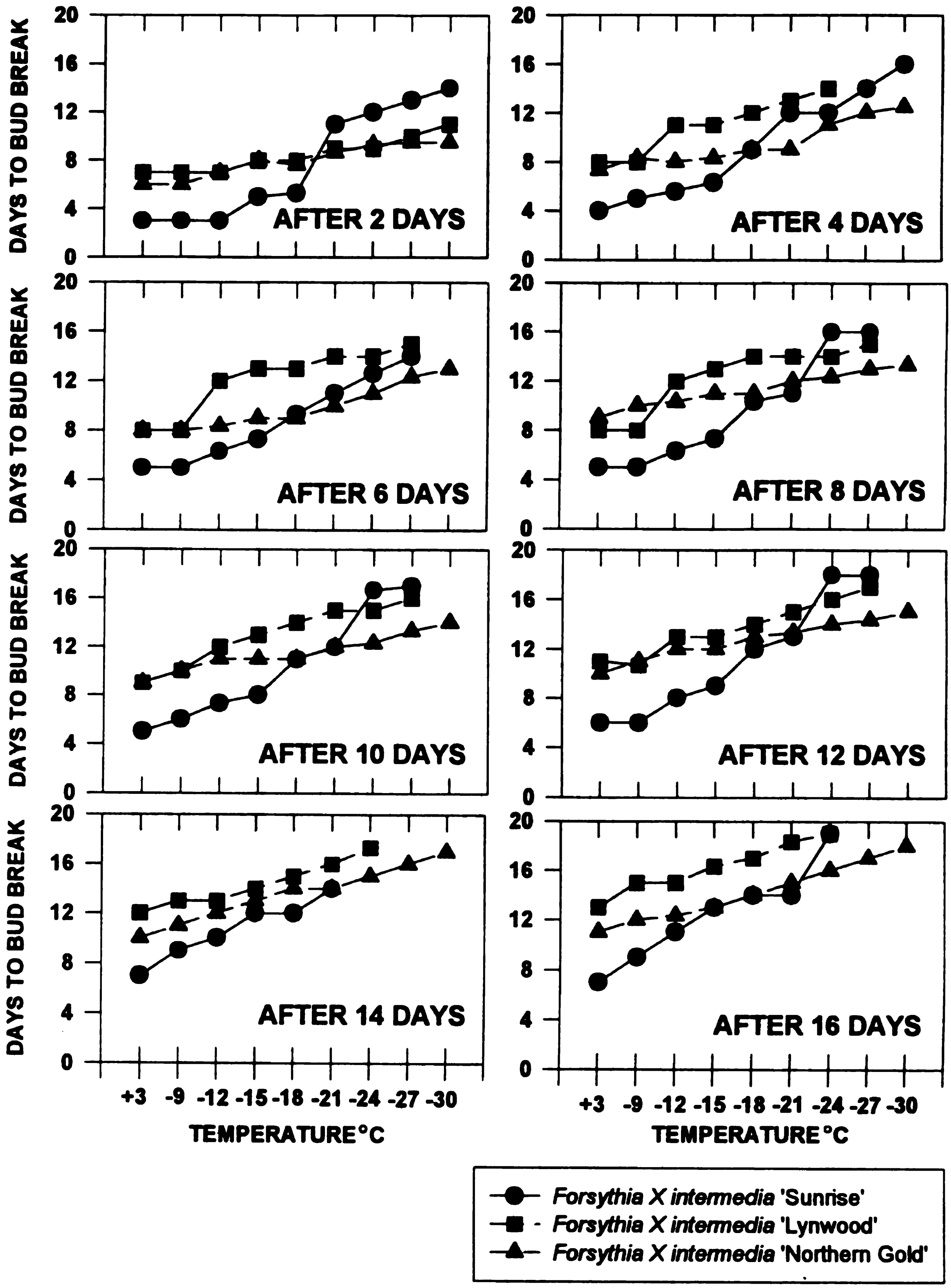

DAYS TO BUD BREAK
AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
0
4
8
12
16
20
+3 -9 -12 -15 -18 -21 -24 -27 -30
TEMPERATURE °C
Forsythia X intermedia 'Sunrise'
Forsythia X intermedia 'Lynwood'
Forsythia X intermedia 'Northern Gold'

Table 2.3. Influence of controlled warming from two to 16 days on date of bud break after controlled temperature freezing for three cultivars during the 1996/1997 test period. Data analyzed by analysis of variance.

	FREEZING TEMPERATURE								
PLANT NAME	+3.0°C (37.4°F)	-9.0° C(15.8°F)	-12.0°C (10.4°F)	-15.0°C (5.0°F)	-18.0°C (-0.4°F)	-21.0°C (-5.8°F)	-24.0°C (-11.2°F)	-27.0°C (-16.6°F)	-30.0°C (-22.0°F)
Forsythia X intermedia 'Sunrise'	NS	NS	**	**	**	**	**	**	**
Forsythia X intermedia 'Lynwood'	**	**	**	**	**	**	**	**	NA
Forsythia X intermedia 'Northern Gold'	**	**	**	**	**	**	**	**	**

NS, *,** Not significant at P=0.05 or 0.01, respectively

Figure 2.10. Visual plant performance for *Forsythia X intermedia* 'Sunrise', after exposure of two to 16 days of warming temperatures and controlled temperature freezing. Performance ratings were conducted 30 and 60 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per warming period per freezing temperature.

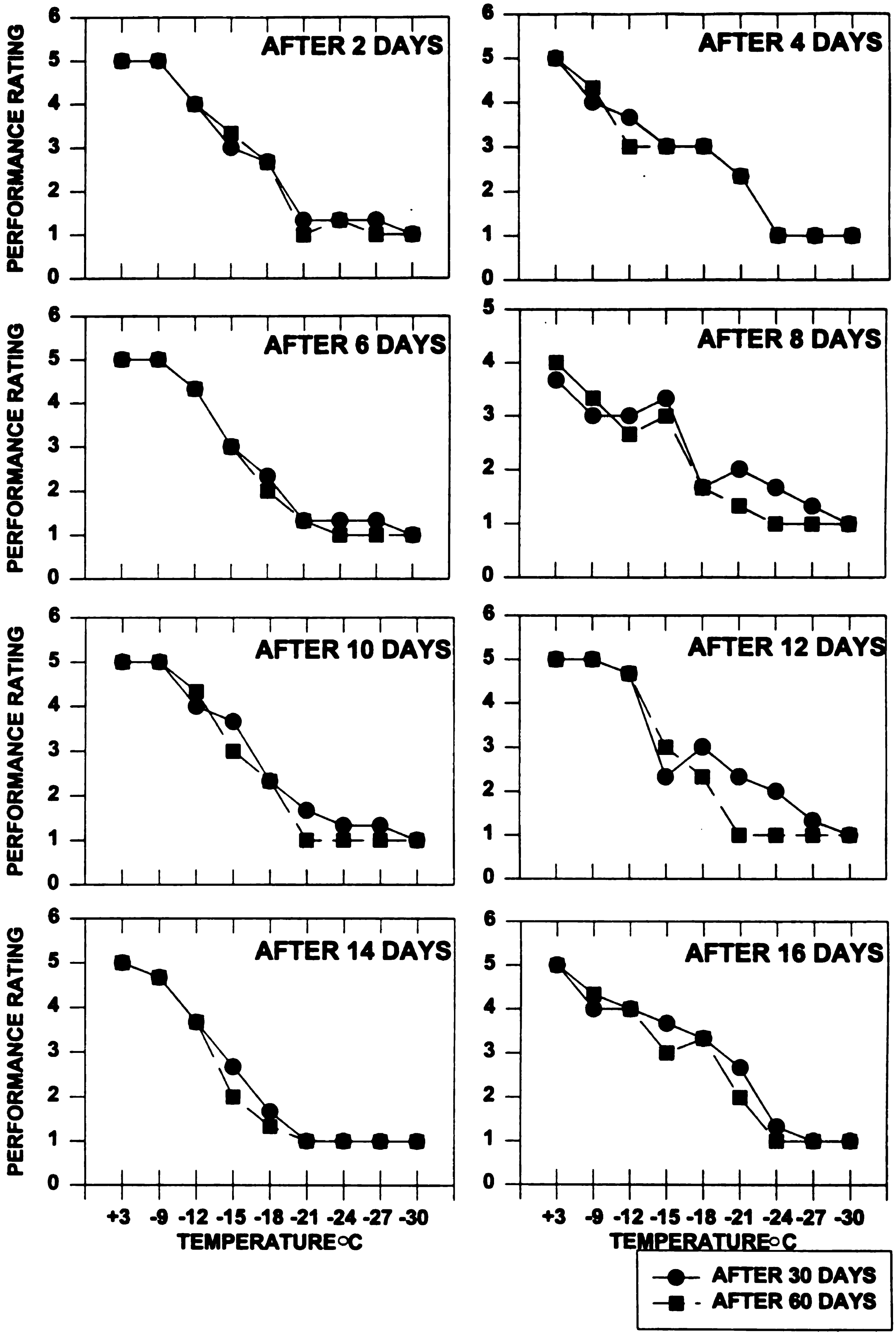

PERFORMANCE RATING
AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
+3 -9 -12 -15 -18 -21 -24 -27 -30
TEMPERATURE°C
AFTER 30 DAYS
AFTER 60 DAYS

Figure 2.11. Visual plant performance for *Forsythia X intermedia* 'Lynwood', after exposure of two to 16 days of warming temperatures and controlled temperature freezing. Performance ratings were conducted 30 and 60 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per warming period per freezing temperature.

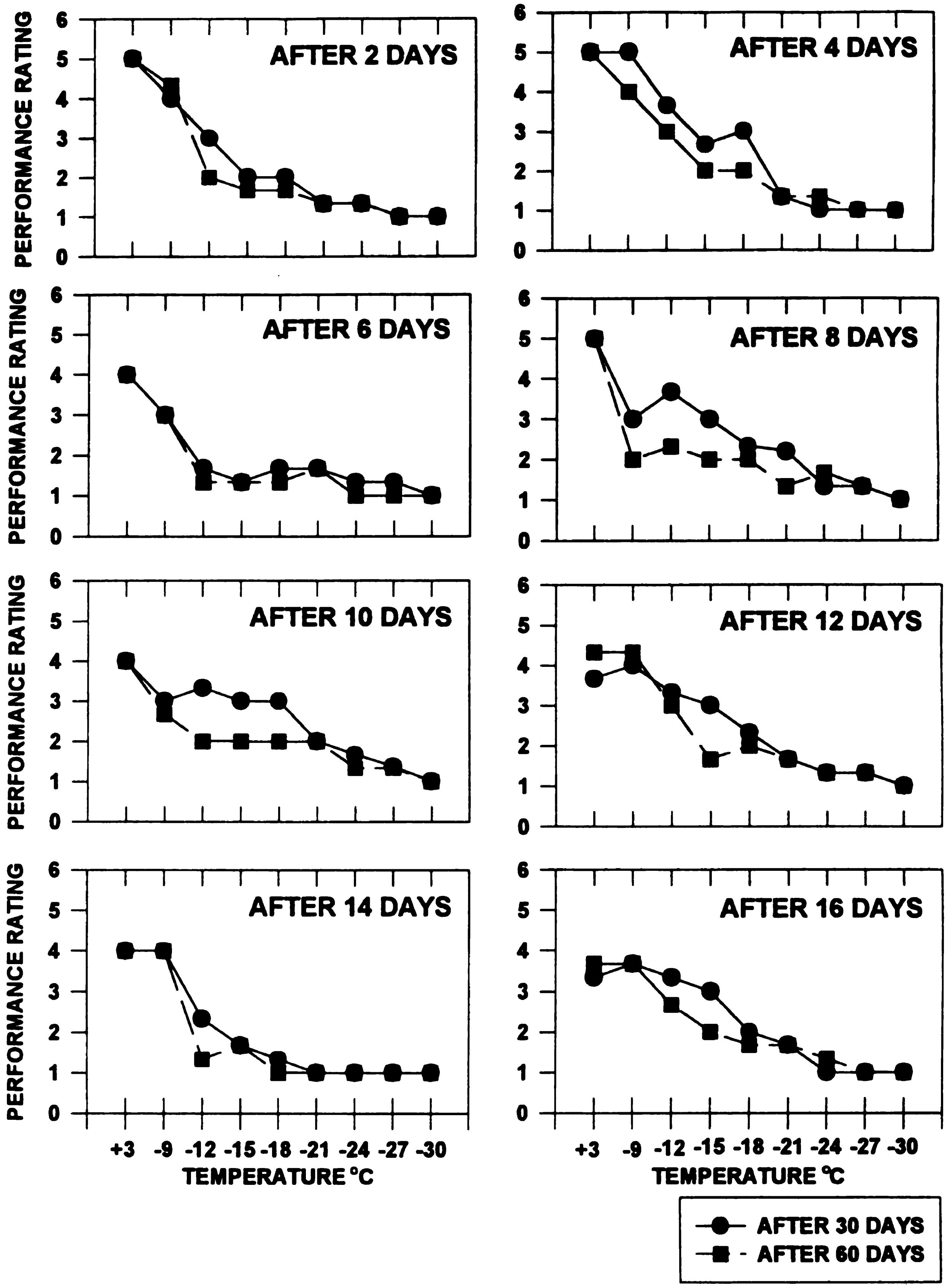
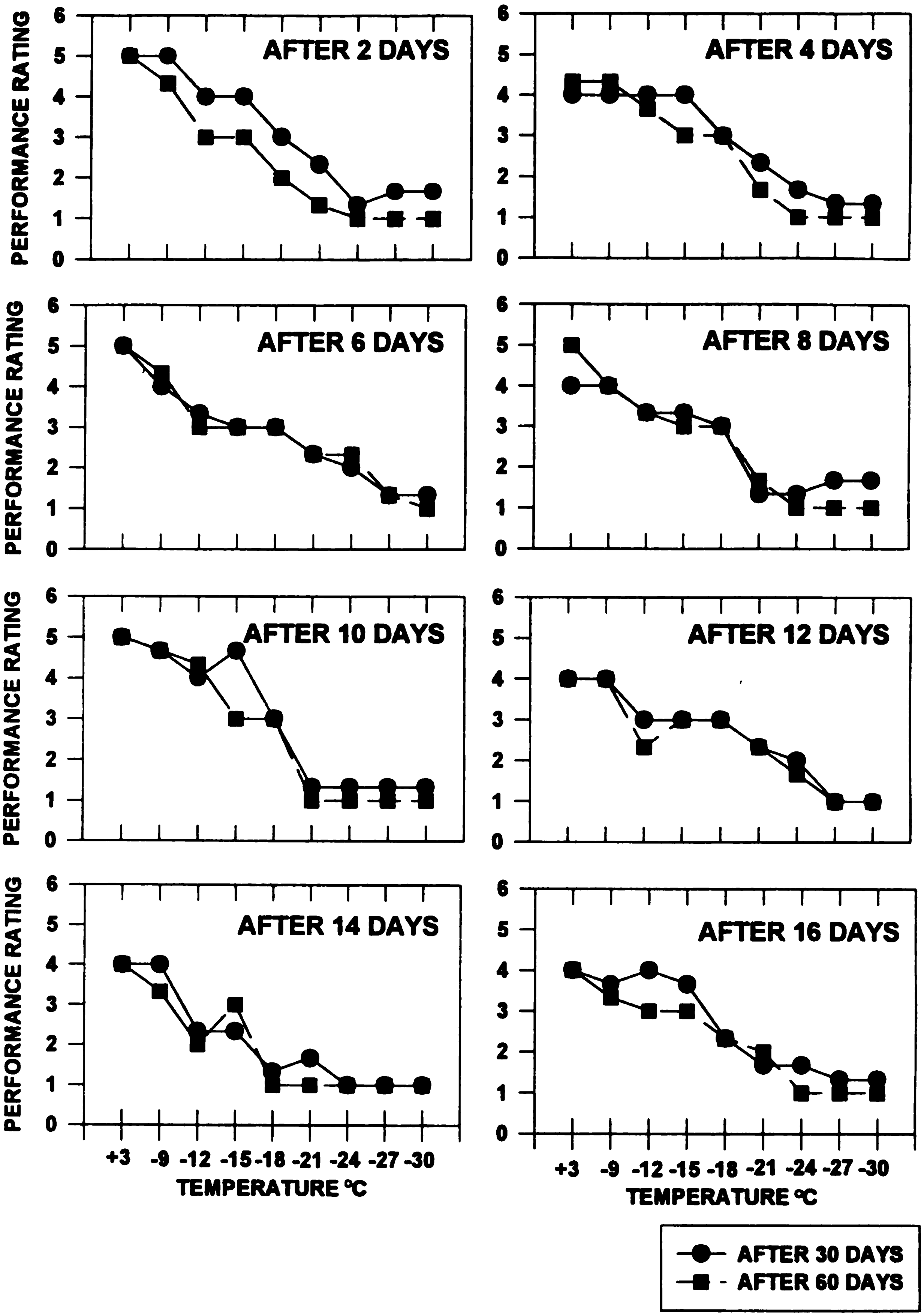

PERFORMANCE RATING
AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
0 1 2 3 4 5 6
+3 -9 -12 -15 -18 -21 -24 -27 -30
TEMPERATURE °C
AFTER 30 DAYS
AFTER 60 DAYS

Figure 2.12. Visual plant performance for *Forsythia X intermedia* 'Northern Gold', after exposure of two to 16 days of warming temperatures and controlled temperature freezing. Performance ratings were conducted 30 and 60 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per warming period per freezing temperature.


AFTER 2 DAYS
AFTER 4 DAYS
AFTER 6 DAYS
AFTER 8 DAYS
AFTER 10 DAYS
AFTER 12 DAYS
AFTER 14 DAYS
AFTER 16 DAYS
PERFORMANCE RATING
0
1
2
3
4
5
6
+3 -9 -12 -15 -18 -21 -24 -27 -30
TEMPERATURE °C
AFTER 30 DAYS
AFTER 60 DAYS

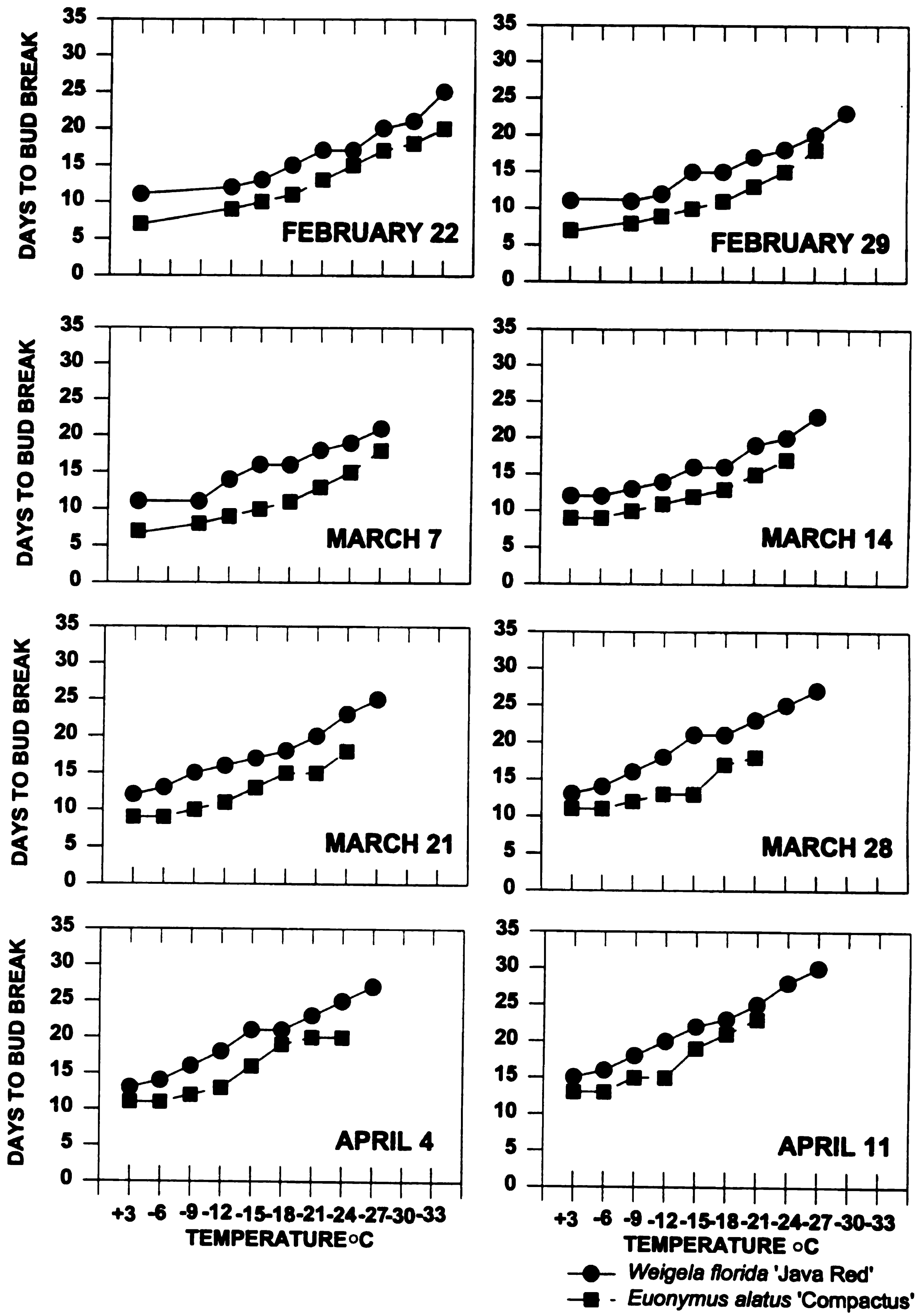
same day and was rated the same as the controls subjected to only two days of warming.

Freezing temperatures were used in this experiment which would not harm the stems of the plants, but would injure the tender root system. Warming accelerated deacclimation of shoots causing injury in response to freezing temperatures which resulted in delayed bud break. Growth of these buds were then dependent on a viable root system. Warming temperatures sensitized the roots which resulted in injury. The injured roots were not able to support an actively growing shoot system. The *Euonymus* root system had an impact on plant performance at -12.0°C (10.4°F), which was slightly warmer than the mature root killing temperature, -14.0°C (6.8°F), as discovered by Studer et al. (15). Davidson et al. (2) reported that roots could be injured at temperatures significantly higher than the average killing temperature if exposed to low temperatures following a period of fluctuating temperatures, which were conducive to growth.

The container substrate protects the root system from moisture loss as well as provides a buffer against temperature change. Root killing temperatures as determined by Studer et al. (15), and Havis (8), were evaluated by using severed roots. This leads to speculation that the cold hardiness results of severed roots may differ from those of undisturbed roots in containers. Future experiments should focus on the influence of cold and warm temperatures on whole plant performance.

NATURAL DEACCLIMATION Days to bud break for *Weigela* and *Euonymus* plants steadily increased during the deacclimation period as freezing temperatures decreased (Figure 2.13). Both cultivars showed significance for days to bud break at each freezing temperature with the exception of freezing temperatures of -30.0°C and -33.0°C (-22.0°F and -27.4°F), which the cultivars did not survive exposure to after the February 22 controlled

Figure 2.13. Bud break for two cultivars subjected to controlled temperature freezing during the deacclimation period, after being overwintered in a protective structure during the 1995/1996 test period. Data of bud break is expressed as date of first noticeable shoot elongation.


DAYS TO BUD BREAK
FEBRUARY 22
FEBRUARY 29
MARCH 7
MARCH 14
MARCH 21
MARCH 28
APRIL 4
APRIL 11
0 5 10 15 20 25 30 35
+3 -6 -9 -12 -15 -18 -21 -24 -27 -30 -33
TEMPERATURE °C
Weigela florida 'Java Red'
Euonymus alatus 'Compactus'

temperature freezer run (Table 2.4). Plants began to deacclimate and break bud in the polyhouse prior to controlled temperature freezing. Consequently the tender, new growth was mortally injured at gradually warmer freezing temperatures. None of the *Hibiscus* plants broke bud. Based on results from the previous experiment the Hibiscus root system was sensitive to temperatures of -9.0°C (15.8°F) and colder. Minimum polyhouse temperatures during the months of January and February were as low as -13.0°C (8.6°F), well below the temperature at which the *Hibiscus* root system may impact plant performance.

Visual plant performance ratings declined as the deacclimation period progressed and controlled freezing temperatures decreased (Figures 2.14-2.15). Ratings for both cultivars did not change from 30 to 60 days of growth. Therefore, during the deacclimation period, *Weigela* and *Euonymus* could possibly recover from injury before 30 days of growth. The temperature at which the root system impacted plant growth for *Weigela* was -15.0°C (5.0°F), while the temperature of impact for *Euonymus* was -12.0°C (10.4°F). Results form this experiment indicate that accelerated controlled warming created a similar response to natural deacclimation with whole plant performance.

Table 2.4. Influence of natural deacclimation on date of bud break after controlled temperature freezing for two cultivars during the 1995/1996 test period. Data analyzed by analysis of variance.

	FREEZING TEMPERATURE										
PLANT NAME	+3.0°C (37.4°F)	-6.0°C (21.2°F)	-9.0°C (15.8°F)	-12.0°C (10.4°F)	-15.0°C (5.0°F)	-18.0°C (-0.4°F)	-21.0°C (-5.8°F)	-24.0°C (-11.2°F)	-27.0°C (-16.6°F)	-30.0°C (-22.0°F)	-33.0°C (-27.4°F)
Weigela florida 'Java Red'	**	**	**	**	**	**	**	**	**	NA	NA
Euonymus alatus 'Compactus'	**	**	**	**	**	**	**	**	**	NA	NA

NS, *,** Not significant at P=0.05 or 0.01, respectively

Figure 2.14. Visual plant performance ratings for *Weigela florida* 'Java Red' subjected to controlled temperature freezing during the deacclimation period, after being overwintered in a protective structure during the 1995/1996 test period. Performance ratings were conducted 30 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per date of controlled temperature freezing per freezing temperature.

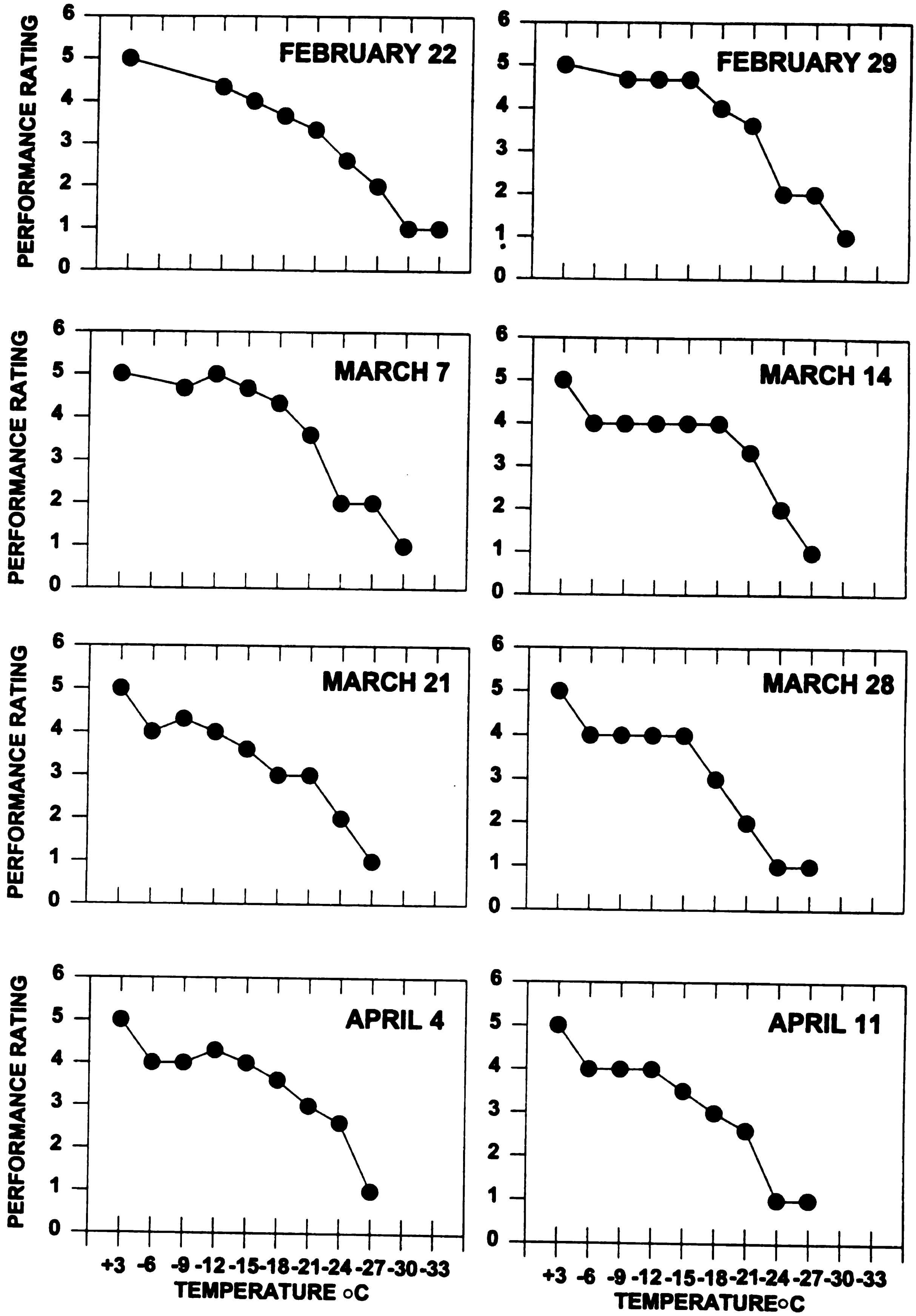
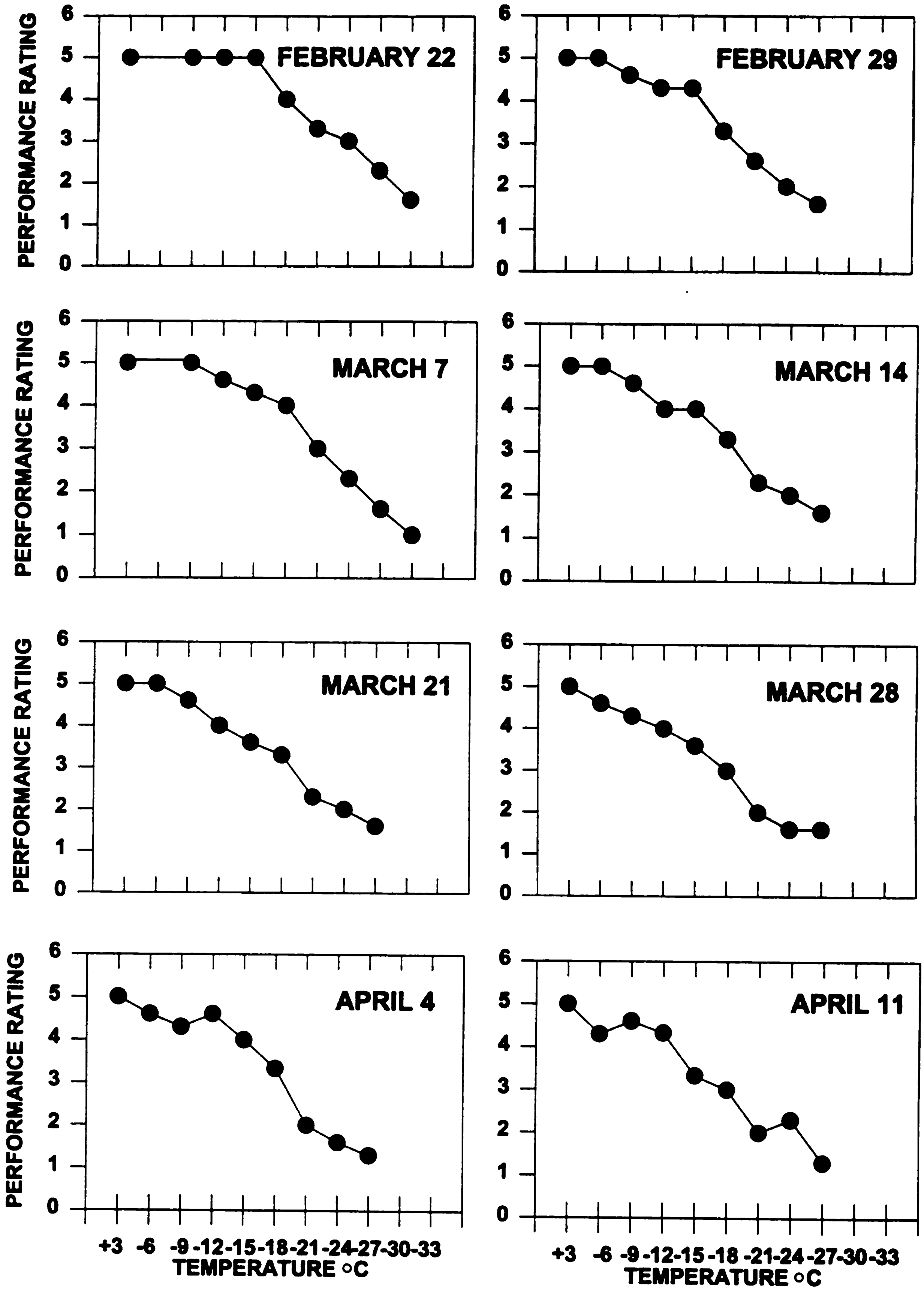

FEBRUARY 22
FEBRUARY 29
MARCH 7
MARCH 14
MARCH 21
MARCH 28
APRIL 4
APRIL 11
PERFORMANCE RATING
0
1
2
3
4
5
6
+3 -6 -9 -12 -15 -18 -21 -24 -27 -30 -33
TEMPERATURE oC

Figure 2.15. Visual plant performance ratings for *Euonymus alatus* 'Compactus' subjected to controlled temperature freezing during the deacclimation period, after being overwintered in a protective structure during the 1995/1996 test period. Performance ratings were conducted 30 days after they were placed in a greenhouse. Observations were based on three plants per cultivar per date of controlled temperature freezing per freezing temperature.


PERFORMANCE RATING
FEBRUARY 22
FEBRUARY 29
MARCH 7
MARCH 14
MARCH 21
MARCH 28
APRIL 4
APRIL 11
0
1
2
3
4
5
6
+3 -6 -9 -12 -15 -18 -21 -24 -27 -30 -33
TEMPERATURE °C

CONCLUSION

The root system is the least hardy part of a plant and the root systems of container-grown nursery stock are especially vulnerable to fluctuating warming and cooling temperatures. During this period temperatures in a polyhouse are higher than ambient field temperatures. Plant roots can deharden in 24 hours and be killed when temperatures suddenly drop below freezing. Temperature fluctuations usually occur in Michigan during the months of January and February and last from a few days to a few weeks. Growers need to be concerned with a lengthy 'midwinter thaw' period. As seen in the previous experiments, as the warming period progressed, days to bud break increased and plant vigor declined. Future experiments should focus on root cold hardiness and whole plant performance after exposure to fluctuating periods aside from the 12 hours of 21.0°C (69.8°F) and 12 hours of 0°C (32.0°F) used in this thesis. Other experiments could study conditions of a shorter period of 21.0°C (69.8°F) and a longer period of 0°C (32.0°F). Perhaps days to bud break would not increase as rapidly for two to 16 days and plant vigor would not decline at such a fast rate. Lastly, other cultivars, both more cold tolerant and cold tender, could be subjected to the conditions of the Controlled Warming and Natural Deacclimation experiments.

LITERATURE CITED

1. Clark, W.S. 1988. Overwintering container-grown ornamentals. Long Island Horticulture News, pp. 4-6.

2. Davidson, H., R. Mecklenburg, and C. Peterson. 1994. Nursery Management: Administration and Culture. Prentice Hall, Inc. pp. 24 & 422.

3. Gartner, J.B. 1981. Container plants require special fertilization and overwintering systems. Amer. Nurs. 104(5):655-658.

4. Good, G.L., P.L. Steponkus, S.C. Wiest, and E.J. Studer. 1977. Overwintering container-grown ornamentals. New York's Food and Life Science. 10(2):15-17.

5. Green, J.L., and L.H. Fuchigami. 1985. Principles: Protecting container-grown plants during the winter months. Ornamental Northwest Newsletter. 9(2):10-22.

6. Gouin, F.R., and C.B. Link. 1979. Temperature measurement, survival, and growth of container-grown ornamentals, overwintered unprotected, in nursery shelters, and under microfoam thermoblankets. J. Amer. Soc. Hort. Sci. 104:655-658.

7. Havis, J.R. 1974. Tolerance of plant roots in winter storage. Amer. Nurs. 139(1):10.

8. Havis, J.R. 1976. Root hardiness of woody ornamentals. HortScience. 11(4):385-386.

9. McHugh, E., J. Robbins, and D. Hensley. 1988. Overwintering ornamental plants. Kansas Nursery Notes. 20:1-3.

10. McNamara, S., and H. Pellett. 1993. Flower bud hardiness of *Forsythia* cultivars. J. Environ. Hort. 11(1):35-38.

11. Mityga, H.G., and F.O. Lanphear. 1971. Factors influencing the cold hardiness of *Taxus cuspidata* roots. J. Amer. Soc. Hort. Sci. 96(1):83-86.

12. Pellett, H. 1971. Comparison of cold hardiness levels of root and stem tissue. Can. J. Plant. Sci. 51:193-195.

13. Pellett, N.E., D. Dippre, and A. Hazelrigg. 1985. Coverings for overwintering container-grown plants in northern regions. J. Environ. Hort. 3(1):4-7.

14. Regan, R.P., R.L. Ticknor, D.D. Hemphill, Jr., T.H.H. Chen, P. Murakami, and L.H. Fuchigami. 1985. Influence of winter protection covers on survival and hardiness of container grown *Ilex crenata* Thunb. 'Green Island' and *Euonymus fortunei (*Turcz.) 'Emerald 'n Gold'. J. Environ. Hort. 8(3):142-146.

15. Studer, E.J., P.L. Steponkus, G.L. Good, and S.C. Wiest. 1978. Root hardiness of container-grown ornamentals. HortScience. 13(2):172-174.

16. Wildung, D.K., C.J. Weiser, and H.M. Pellett. 1973. Temperature and moisture effects on hardening of apple roots. HortScience. 8(1):53-55.

17. Wynstra, J.A., and E.M. Smith. 1970. A comparison of white vs. aluminum poly for overwintering woody ornamental landscape plants. pp. 16-19.

APPENDIX A

Figure A.1. Killing temperature (T_{50}, °C), of three *Forsythia X intermedia* cultivars during the 1996/1997 test period as influenced by time of placement in a protective structure (early-10/15/96). The T_{50} values are separated by ±SE.

HARDINESS DATA FOR THE 96-97 TEST PERIOD

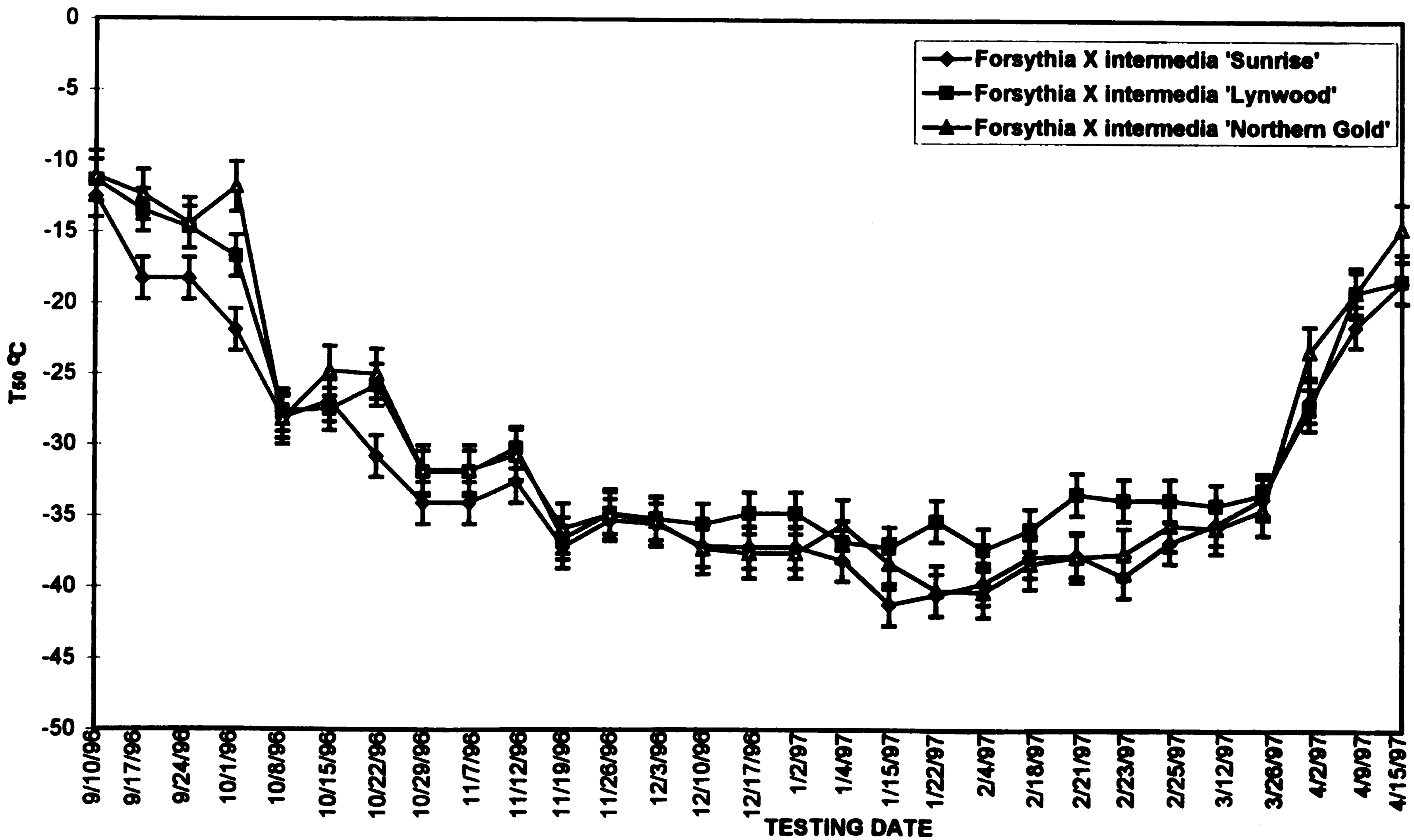


Figure A.2. Killing temperature (T_{50}, °C), of three *Forsythia X intermedia* cultivars during the 1996/1997 test period as influenced by time of placement in a protective structure (late-12/5/96). The T_{50} values are separated by ±SE.

HARDINESS DATA FOR THE 96-97 TEST PERIOD

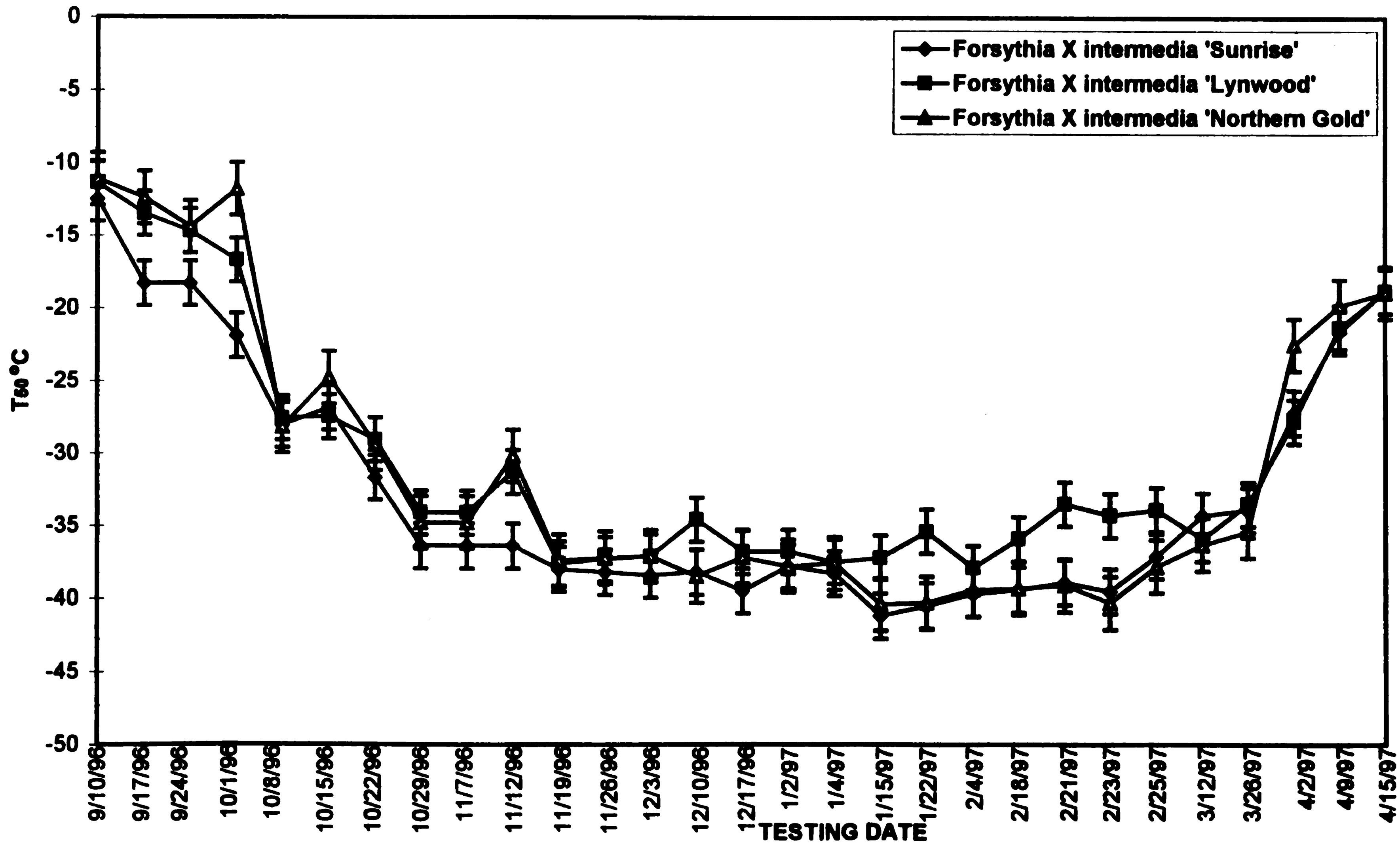
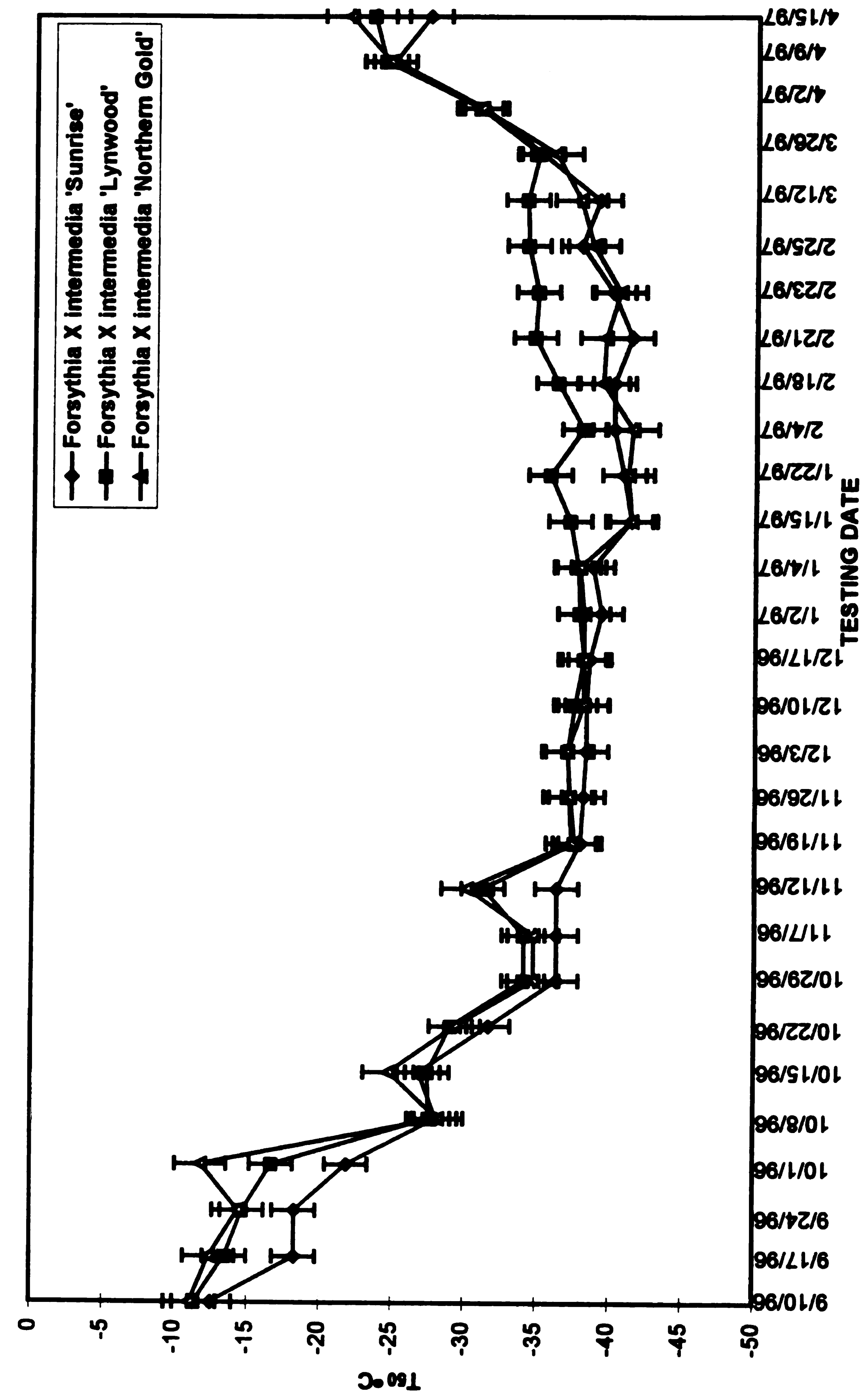


Figure A.3. Killing temperature (T_{50}, °C), of three *Forsythia X intermedia* cultivars during the 1996/1997 test period as influenced by time of placement in a pot-in-pot overwintering treatment under natural conditions. The T_{50} values are separated by ±SE.

HARDINESS DATA FOR THE 1996/1997 TEST PERIOD



APPENDIX B

APPENDIX B

Origins of plant material used in this thesis:

The species of *Euonymus alatus* 'Compactus', was introduced to the United States in 1860. Its native habitat is from Northeastern Asia to central China (1).

The parentage of *Forsythia X intermedia* is *F. suspensa and F. viridissima* (N. Pellett, personal communication). The cultivar 'Sunrise' was introduced by Dr. Wiegle, Professor Emeritus, of Iowa State University and was a cross between *F. ovata* Nakai and a plant purchased as *F. ovata* from a nursery (2). *Forsythia X intermedia* 'Northern Gold' was released by the Ottawa Research Station in 1979 and is a result of a cross between *F. ovata* 'Ottawa' and *F. europaea* (N. Pellett, personal communication). 'Lynwood' was introduced by the Slieve Donard Nursery of Newcastle in Northern Ireland in 1935 (1).

The species of *Hibiscus syriacus* 'Jeanne d' Arc' and 'Paeonyflorus' were introduced to the United States prior to the 1600s. The species native habitat is China and India (1).

The species of *Weigela florida* 'Java Red' is native to Japan and was introduced in 1860 (1).

LITERATURE CITED

1. Dirr, M.A. 1990. Manual of woody landscape plants. 4th Ed. Stipes Publishing Company. Champaign, IL. pp 312-313, 336-337, 337-378, and 924-926.

2. Weigle, J.L. 1982. 'Sunrise' *Forsythia*. HortScience. 17(2):261.