The relevance of the costs presented in this study to other nurseries is questionable. Size of inventory, efficiency of operation, degree of indebtedness, among other things, would affect the overall cost per plant. However, a similar procedure could be developed to fit any nursery. The information this ongoing study gives Johnson Nursery is significant. We know our time limitations for growing plants. Discounts can easily be decided upon with regard to profitability. This study will also reveal production efficiency increases and decreases.

ROOT STRESS IN CONTAINERS

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Plants that are container-grown in artificial media are subjected to many stresses different from those encountered by a plant grown in soil. Containerized root systems are confined to a limited volume; thus, they rely on supplemental irrigation, supplemental nutrition, and are not buffered against temperature changes. Containers are left above ground during the winter, exposing the roots to temperature extremes. Roots are not as hardy as shoots; therefore, roots may be injured at temperatures lower than those that injure shoots (15). Summer container-media temperatures, in contrast, can easily exceed temperatures considered optimum for good root growth (14).

Container plant production of woody ornamentals has expanded rapidly in recent years and now represents more than 50 percent of all landscape plants sold in the United States (15). Technological advances have, and are, revolutionizing the nursery industry. However, as growers are keenly aware, temperature extremes and devastating winter freezes can destroy a crop unless some protection is provided. The objectives of this paper are to discuss high and low temperature stress of roots in containers and describe the physiology of root temperature stress.

LOW TEMPERATURE ROOT STRESS

Cold hardiness varies among species and often varies among cultivars and ecotypes (10). Marked differences are also observed among tissues on the same plant (15). Reproductive buds are less

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hardy than vegetative buds (10) and roots are less hardy than shoots (17). There are two forms of low temperature stress: freezing and chilling.

Freezing stress in containers. Freeze damage of roots occurs when ice forms within the tissues. Ice formation may be either extracellular or intracellular (11). When intracellular ice forms, crystals form within the protoplasm. Ice formation within the protoplasm tears membranes and is lethal (11). This type of ice formation occurs infrequently, and only when temperature falls very rapidly (15). Plants that are more resistant to intracellular freezing temperatures have protoplasts high in available water and few ice nucleators. This allows the protoplasm to *supercool* to temperatures as low as −30° to −47°C (−22° to −53°F) (10). Extracellular ice is ice that is formed between the cells and occurs during normal winters. Water that is within the cell moves outward towards the extracellular ice crystals in response to a vapor pressure gradient until an equilibrium exists (17). When too much water is removed by this means, damage may occur to the cells by desiccation (10).

Temperate woody plants acclimate, become hardy, to freezing temperatures in response to cooling temperatures and longer night periods (15). Freezing tissues for short periods also contributes to hardening (17). However, the hardening of roots is not as well understood as for shoots. Fall temperatures greater than 15°C (60°F) reduce root hardiness, thus cool temperatures contribute to root hardiness by slowing or stopping root growth (15). Variations in root hardiness do exist and the relative hardiness is known for many plants (Table 1).

Table 1. Average root killing temperatures (°F) of selected woody landscape plants [compiled by Smith and Beattie (15)].

	Studer[a]		Havis[b]
Taxon	Immature	Mature	All
Magnolia × *soulangeana*[c]			23
Buxus sempervirens	27		15
Cotoneaster microphyllus	25	9	
Ilex cornuta 'Dazzler'	25	18	
Pyracantha coccinea 'Lalandei'	25	18	18
Mahonia bealei	25	12	
Cotoneaster dammeri	23		
Euonymus fortunei var. *vegeta*	23	12	
Hypericum spp.	23	18	
Ilex crenata 'Helleri'	23		
Ilex 'Nellie Stevens'	23	14	
Ilex × *meserveae* 'Blue Boy'	23	9	
Ilex opaca	23	9	20
Cornus florida	21	11	20
Euonymus kiautschovica	21	16	
Ilex 'San Jose'	21	18	

Taxon	Studer[a]		Havis[b]
	Immature	Mature	All
Magnolia stellata	21	9	23
Daphne cneorum			20
Ilex crenata 'Convexa'			20
Ilex crenata 'Hetzii'			20
Ilex crenata 'Stokesii'			20
Leucothoe fontanesiana	19		5
Rhododendron prunifolium	19		
Viburnum plicatum forma *tomentosum*	19	7	
Rhododendron 'Hino-crimson'	19		
Cotoneaster dammeri 'Skogholmen'	19		
Euonymus alata 'Compacta'	19	7	
Cryptomeria japonica			16
Stephanandra incisa 'Crispa'	18	0	
Rhododendron (Exbury Hybrid)	18		
Taxus × *media* 'Hicksii'	18	−4	
Koelreuteria paniculata	16	−4	
Kalmia latifolia	16		
Pieris japonica	16		10
Rhododendron 'Purple Gem'	16		
Rhododendron schlippenbachii	16		
Cotoneaster horizontalis			15
Juniperus conferta	12	−10	
Juniperus horizontalis 'Plumosa'	12	−4	
Juniperus squamata 'Meyeri'	12		
Viburnum carlesii			15
Cytisus × *praecox*			15
Ilex glabra			15
Euonymus fortunei 'Carrierei'			15
Euonymus fortunei 'Graciles' [syn. E. *fortunei* 'Argenteo-marginata']			15
Hedera helix 'Baltica'			15
Pachysandra terminalis			15
Vinca minor			15
Pieris japonica 'Compacta'			15
Acer palmatum 'Atropurpureum'			14
Cotoneaster adpressa var. *praecox*			10
Taxus × *media* 'Nigra'			10
Rhododendron 'Gibraltar'			10
Rhododendron 'Hinodegiri'			10
Pieris floribunda			5
Euonymus fortunei 'Colorata'			5
Juniperus horizontalis			0
Juniperus horizontalis 'Douglasii'			0
Rhododendron carolinianum			0
Rhododendron catawbiense			0
Rhododendron (P. J. M. Hybrids)			−10
Potentilla fruticosa			−10
Picea glauca			−10
Picea omorika			−10

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[a] Studer, E. J. et *al.* 1978.

[b] Havis, H. R. 1976.

[c] Differences in root-killing temperatures for the same taxa were most likely due to variations in root maturity and experimental procedure.

Chilling stress in containers. Chilling injury of plants occurs at temperatures several degrees higher than freezing (10). Chilling-sensitive plants primarily include species of tropical origin. Chilling-sensitive species generally suffer damage indirectly through desiccation. Desiccation injury occurs when water is lost from the plant to the atmosphere faster than it can be replaced through the roots (15). Often leaf and air temperatures are high and the ambient air has a low relative humidity during midwinter through early spring. The vapor pressure deficit from the plant to the air is high, which results in excessive moisture loss. Further injury can occur if water cannot move within the plant to replenish desiccated leaf and stem tissues (15).

The restriction of water movement through root systems at chilling temperatures causes wilting (13). Increased water viscosity at low media temperatures is responsible in part for the decrease in water transport. Markhart, *et al.* (12) demonstrated that chilling reduces flux of water through chilling-sensitive plants and that the changes in hydraulic conductance were greater than those accounted for by the increase in viscosity of water. The rate-limiting site for water movement through a root is a membrane (12). The membrane most likely responsible is at the endodermis where all apoplastic water transport (extracellular water) must enter the symplast (intracellular water) for vascular water transport from the roots to the shoots.

Root systems have been demonstrated to acclimate to low temperatures, becoming more resistant to chilling stress. A major difference between chilling-acclimated root tissue and non-acclimated tissue is the degree of fatty acid saturation. Roots that are grown at low temperatures, 8° to 10°C (46° to 50°F) have a greater abundance of unsaturated fats in their membranes compared to roots grown at 20°C (68°F) (2). This increase in unsaturation correlates with increased water transport through acclimated root systems (3). During acclimation to low temperatures, phosphorus incorporation into membranes occurs more rapidly at low media temperatures compared to high media temperatures (2). Thus, phosphorus nutrition is important for root hardiness.

HIGH-TEMPERATURE ROOT STRESS

High temperature root stress is an important concern of nursery growers, especially when the air temperature exceeds 35°C (95°F). It is at this temperature that summer dormancy of nursery plants occurs, and plants will not grow until the temperature is reduced (4). High media temperatures, a principal cause of summer dormancy, contributes to plant stress. This is termed high-temperature root stress.

Root damage occurs in a container nursery during midsummer, with the southern and western exposures of containers and plots being most severe (5, 8, 14, 18, 19, 21). Temperatures as high as 50°C (122°F) have been reported (5, 14, 18, 19, 21). Roots either die or become weak on the exposed surfaces. The plant then becomes less thrifty and possibly dies (20). This is confounded after scheduled spacing if the original orientation of the container is not maintained.

Polyethylene containers are widely used because they are rigid and light enough for shipping, durable enough to withstand field handling, and fairly inexpensive (4). Black is the preferred color because it is cheaper to manufacture, causes media temperatures to increase rapidly stimulating earlier spring growth, and prevents algae growth and root greening.

Growing surfaces also contribute to root damage (14). For example, many nursery growers place their containers on either crushed limestone rock or white shells. These lightly colored materials are highly reflective and the resulting albedo increases the heat gain of a dark container (14, 19).

White containers have been shown to reduce media temperatures but such containers allow light transmission, contributing to root greening and algae growth (18). White polybags with black liners significantly reduce media temperatures and reduce light transmission (8, 18, 19). However, white polybags are not acceptable containers for a large scale container nursery because they are difficult to handle in the field and are difficult to ship with conventional equipment and techniques (8).

High temperature stress is defined as the retardation or cessation of metabolic functions in response to high temperatures. Temperature susceptibility varies among species and the vital metabolic process concerned (10). Alexandrov (1) described the first symptom to appear in response to heating was the cessation of protoplasmic streaming. Next, the rate of photosynthesis was decreased with subsequent damage to the chloroplasts. In the terminal stage, semipermeability of cell membranes was disrupted. Ingram (8) reported lethal temperatures for thermostability of root cells of several species from 45° to 50°C (113° to 112°F).

Little research has been devoted to root water uptake at high media temperatures. Kramer (9), using heat-killed root systems, demonstrated that plants remained alive and unwilted for several days after root death. Transpiration decreased after root death due to leaf injury and gum deposits released from dead cells.

Predawn shoot water potential of *Berberis thunbergii* 'Atropurpurea' and *Pittosporum tobira* 'Wheeler's Dwarf' increased when exposed to media temperatures greater than 40°C (104°F) (14). Predawn shoot water potential of *Buxus microphylla* var. *japonica* increased when exposed to media temperatures greater than 45°C (113°F) (14). These data correlated with increased hydraulic conductance data, where hydraulic conductance of *B. microphylla* increased linearly from 25° to 45°C (77° to 113°F) and *B. thunbergii* increased quadratically over the same temperature range (14). Even though water was not limiting, stomatal conductance was decreased sharply due to toxic substances released into the transpiration stream.

LITERATURE CITED

1. Alexandrov, V. Y. 1964. Cytophysical and cytoecological investigations of heat resistance of plant cells toward the action of high and low temperature. *Quart. Rev. Biol.* 39:35–77.
2. Clarkson, D. T. 1976. The influence of temperature on the exudation of xylem sap from detached root systems of rye *(Secale cereale)* and barley *(Hordeum vulgare)*. *Planta.* 132:297–304.
3. Clarkson, D. T., K. C. Hall, and J. K. M. Roberts. 1980. Phospholipid composition and fatty acid desaturation in the roots of rye during acclimatization to low temperature. *Planta.* 149:464–471.
4. Davidson, H. and R. Mecklenburg. 1981. *Nursery Management: Administration and Culture.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
5. Fretz, T. A. 1971. Influence of physical conditions on summer temperatures in nursery containers. *HortScience.* 6:400–401.
6. Havis, J. R. 1976. Root hardiness of woody ornamentals. *HortScience.* 11:385–386.
7. Ingram, D. L. 1985. Modeling high temperature exposure and time interactions on *Pittosporum tobira* root cell membrane thermostability. *Jour. Amer. Soc. Hort. Sci.* 110:470–473.
8. Ingram, D. L. 1981. *characterization of temperature fluctuations and woody plant growth in white polybags and conventional black containers. HortScience.* 16:762–763.
9. Kramer, P. J. 1933. The intake of water through dead root systems and its relation to the problem of absorption by transpiring plants. *Amer. Jour. Bot.* 20:481–492.
10. Larcher, W. 1980. *Physiological plant ecology,* 2nd edition. Springer-Verlag, Inc. Heidelberg.
11. Levitt, J. 1980. *Responses of plants to environmental stress,* 2nd ed. Academic Press, Inc., New York.
12. Markhart, A. H. 1984. Amelioration of chilling-induced water stress by abscisic acid-induced changes in root hydraulic conductance. *Plant Physiol.* 74:81–85.
13. McWilliam, J. R., P. J. Kramer, and R. L. Musser. 1982. Temperature-induced water stress in chilling sensitive plants. *Austral. Jour. Plant Physiol.* 9:343–352.
14. Newman, S. E. 1985. *Effects of mycorrhizal fungi on high temperature root stress of container grown nursery crops.* Ph.D. Dissertation. Texas A&M University.
15. Smith, E. M. and D. J. Beattie. 1986. Principles, practices, and comparative costs of overwintering container-grown landscape plants, D. J. Beattie, Ed. Southern Coop. Ser. Bull. 313, May 1986.
16. Studer, E. J., P. L. Steponkus, G. L. Good, and S. C. Weist. 1978. Root hardiness of container-grown ornamentals. *HortScience* 13:172–174.
17. Weiser, C. J. 1970. Cold resistance and injury in woody plants. *Science.* 169:1269–1278.

18. Whitcomb, C. E. 1981. Controlling the temperatures in containers, in: Nursery research field day. Research Report p-818, Agric. Exp. Sta. Okla. State Univ.

19. Whitcomb, C. E. 1980. The effects of containers and production bed color on root temperatures. *Amer. Nurs.* 151:11, 65–67.

20. Wong, T. L., R. W. Harris, and R. E. Fissell. 1971. Influence of high soil temperatures on woody plant species. *Jour. Amer. Soc. Hort. Sci.* 96:80–82.

21. Young, K. and K. R. W. Hammett. 1980. Temperature patterns in exposed black polyethylene containers. *Agric. Meteorol.* 21:165–172.

PRODUCTION TECHNIQUES TO MINIMIZE STRESS

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This paper summarizes the production techniques used at Greenleaf Nursery Company's Oklahoma Division to reduce plant stress from both high and low temperatures. The nursery is located in hardiness zone 6, based on average minimum temperature, and zone 4, based on extreme minimum temperature. We have had temperatures from −18°F to 112°F. We are constantly forced to deal with a wide range of temperatures. It is from this experience that we have developed these techniques.

COLD WEATHER STRESS REDUCTION

Many of our ideas regarding cold weather changed after the winter of 1983–84. The effects of those observations are included in this current list.

Proper hardening of plant material prior to the onset of cold weather. This factor is quite possibly the single most important factor in reducing plant stress and subsequent damage or death due to cold weather. We establish dates for different broad groups of plant materials, at which time we reduce the nitrogen level in the container and the amount of water applied to the plant. We also never wash off frost that accumulates on the plants in the fall in order to help harden the growth.

Structures. We currently use several types of poly houses for winter production.

1. Portable wooden 'A' frame structures.
2. Permanent welded pipe frame houses.
3. Commercial gutter-connected greenhouses.
4. Quonset-type structures.