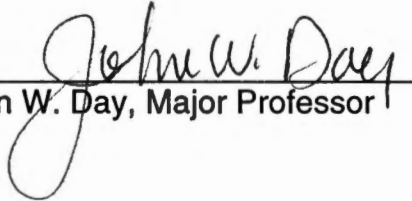
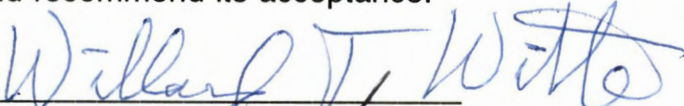
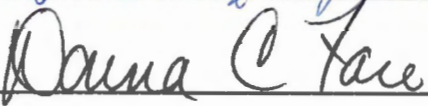


To the Graduate Council:

I am submitting herewith a thesis written by Lisa Richardson-Calfee entitled "Propagation and Container Production of *Carpinus caroliniana*, *Fagus grandifolia* and *Gymnocladus dioicus*." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ornamental Horticulture and Landscape Design.


John W. Day, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor and
Dean of The Graduate School

Propagation and Container Production of
Carpinus caroliniana, *Fagus grandifolia*
and *Gymnocladus dioica*

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Lisa E. Richardson-Calfee
May 1999

AG-VET-MED.

Thesis

99

.R55

Acknowledgments

First, I would like to thank my major professor, Dr. John Day, for his patience, encouragement, guidance and sense of humor. I would also like to thank my committee members Dr. Donna Fare and Dr. Willard Witte for their guidance, expertise, constructive suggestions and review of the manuscript. I thank Dr. Arnold Saxton for his invaluable assistance with the data analysis. I also thank Angie Berry, Joy Newvine, Kathy Johnson and Sandy Kitts for their assistance when it was needed. Thank you to Phil Flanagan who maintained the plants in my absence.

Thank you to the other graduate students (Linda Gombert, Joel Keebler, Dave Onan, Ted Murphy and Millie Williams) with whom I shared the graduate office. Thanks to Greg Miller for going through the graduate experience with me. I would like to thank my parents for their encouragement and especially my mom who I sent on endless errands.

Lastly, I thank my husband Earl F. Calfee III for his endless support and encouragement and Neshoba for her never ending patience.

Abstract

Recently there has been a growing interest and demand for alternative species. Native species are receiving much interest not only as alternative species but for their environmental value. Native species are usually better adapted to the soils, climate, rainfall, pests and soil microorganisms in their geographical range. They help in the retention of regional character, maintenance of biodiversity, prevention of exotic invasions and creation of more suitable habitat for native wildlife.

The purpose of this project was to determine optimum cultural practices for three native species thought to have considerable landscape merit - *Carpinus caroliniana* Walter (American hornbeam), *Fagus grandifolia* Ehrhart (American beech) and *Gymnocladus dioicus* (L.) K. Koch (Kentucky coffeetree). Research was conducted to determine the effects of: (1) seed stratification and scarification regimes, (2) light quality and photoperiod, (3) shade level, (4) fertilizer rate, (5) container size and (6) ectomycorrhizae on germination rate, stem height, stem caliper, dry weight of roots and shoots and quality of seedlings after one or two growing seasons.

Germination of *C. caroliniana* seeds was greater after 20 or 24 weeks of cold stratification compared to 4, 8, 12 or 16 weeks. Germination was further increased after 4 or 8 weeks of warm stratification compared to 0 or 2 weeks. Germination of *F. grandifolia* seeds was greater after 14 or 16 weeks of cold stratification compared to 12 weeks. No difference in germination of *G. dioicus* seeds was found between 2, 4 or 6 hours of scarification with concentrated sulfuric acid (86.5, 95 and 86.5% respectively).

After 12 weeks, *C. caroliniana* seedlings grown under 18 hour photoperiod and high pressure sodium lights (HPS) were taller than plants grown under 18 hour photoperiod and incandescent lights (INC) or natural light and daylength (NAT). *F. grandifolia* seedlings grown under the HPS and INC treatments were taller than plants in the NAT treatment after 14 weeks. No

growth differences of *F. grandifolia* were found between the HPS or INC treatments. After 12 weeks, *G. dioicus* seedlings grown under the HPS and INC treatments had greater growth in height and caliper and root and shoot dry weight than those under the NAT treatment. The HPS and INC treatments also caused a higher percent of *G. dioicus* seedlings to produce a second flush of growth.

There were no growth differences between *C. caroliniana* seedlings grown under different light intensities (full sun, 30% shade and 60% shade) after 21 weeks. *F. grandifolia* seedlings showed no growth response to light intensity after 22 weeks.

After 22 weeks, shoot dry weight of *C. caroliniana* seedlings grown in 3.8 L containers was greater than those grown in 5.7 L or 7.6 L containers. No differences were found in growth of height or caliper or root dry weight. Container size did not affect growth of *F. grandifolia* seedlings.

Increased rates of 18N-2.6P-10K fertilizer resulted in decreased height growth of *C. caroliniana* seedlings. Plants grew taller under the lowest fertilizer rate compared to the medium and high rates. Increased fertilizer rates (18N-2.6P-10K and 14N-6.1P-11.6K, respectively) did not affect growth of *F. grandifolia* or *G. dioicus* seedlings.

Ectomycorrhizae (*Pisolithus tinctorius*) did not increase growth of *C. caroliniana* or *F. grandifolia*.

Table of Contents

	Page
Part 1: Introduction and Literature Review	
Introduction	2
Literature Review.	3
Native Plants in the Landscape	3
<i>Carpinus caroliniana</i>	8
<i>Fagus grandifolia</i>	12
<i>Gymnocladus dioicus</i>	15
Stratification, Scarification and Seed Dormancy	18
Photoperiod and Light Quality	20
Container Production.	24
Light Intensity.	25
Container Size.	29
Fertilizer Rate.	31
Ectomycorrhizae.	33
Episodic Growth	39
Literature Cited	42
Part 2: The Effects of Various Warm and Cold Stratification Treatments on Germination of <i>Carpinus caroliniana</i> Seeds	
Abstract	53
Introduction.	53
Materials and Methods.	54
Results and Discussion	55
Literature Cited	56
Appendix.	58
Part 3: The Effects of Three Cold Stratification Treatments on Germination of <i>Fagus grandifolia</i> Seeds	
Abstract	61
Introduction.	61
Materials and Methods.	62
Results and Discussion	63
Literature Cited	63
Appendix.	64

Part 4: The Effects of Three Sulfuric Acid Scarification Treatments
on Germination of *Gymnocladus dioicus* Seeds

Abstract	66
Introduction	66
Materials and Methods.	66
Results and Discussion	67
Literature Cited	68
Appendix.	68

Part 5: The Effects of Extended Photoperiod and Light Quality
on Growth of *Carpinus caroliniana*, *Fagus grandifolia*
and *Gymnocladus dioicus* Seedlings

Abstract	70
Introduction.	70
Materials and Methods.	72
Results and Discussion	76
Literature Cited	77
Appendix.	80

Part 6: The Effects of Light Intensity on Growth of
Carpinus caroliniana and *Fagus grandifolia* Seedlings

Abstract	85
Introduction.	85
Materials and Methods.	86
Results and Discussion	89
Literature Cited	89
Appendix	91

Part 7: The Effects of Container Size on Growth of
Carpinus caroliniana and *Fagus grandifolia* Seedlings

Abstract	93
Introduction.	93
Materials and Methods.	94
Results and Discussion	97
Literature Cited	97
Appendix	99

Part 8: The Effects of Three Slow-Release Fertilizer Rates on
Growth of *Carpinus caroliniana*, *Fagus grandifolia* and
Gymnocladus dioica Seedlings

Abstract	101
Introduction.	101
Materials and Methods.	103
Results and Discussion	106
Literature Cited	107
Appendix.	109

Part 9: The Effects of Ectomycorrhizae (*Pisolithus tinctorius*) on
Growth of *Carpinus caroliniana* and *Fagus grandifolia* Seedlings

Abstract	112
Introduction.	112
Materials and Methods.	113
Results and Discussion	116
Literature Cited	117
Appendix.	118

Supplemental Appendix.	119
Vita	124

List of Tables

Table		Page
Part 2: The Effects of Various Warm and Cold Stratification Treatments on Germination of <i>Carpinus caroliniana</i> Seeds		
2-1	Warm and cold stratification treatments	58
2-2	Effect of various warm and cold stratification periods on germination of <i>Carpinus caroliniana</i> seeds.	58
Part 3: The Effects of Three Cold Stratification Treatments on Germination of <i>Fagus grandifolia</i> Seeds		
3-1	Effect of three cold stratification periods on germination of <i>Fagus grandifolia</i> seeds.	64
Part 4: The Effects of Three Sulfuric Acid Scarification Treatments on Germination of <i>Gymnocladus dioicus</i> Seeds		
4-1	Effect of three sulfuric acid scarification periods on germination of <i>Gymnocladus dioicus</i> seeds.	68
Part 5: The Effects of Extended Photoperiod and Light Quality on Growth of <i>Carpinus caroliniana</i>, <i>Fagus grandifolia</i> and <i>Gymnocladus dioicus</i> Seedlings		
5-1	Effect of 18 hour incandescent (INC) or high pressure sodium (HPS) light and natural light and daylength (NAT) on height and caliper of <i>Carpinus caroliniana</i> , <i>Fagus grandifolia</i> and <i>Gymnocladus dioicus</i> seedlings. . . .	80
5-2	Effect of 18 hour incandescent (INC) or high pressure sodium (HPS) light and natural light and daylength (NAT) on incremental height and caliper growth of <i>Gymnocladus dioicus</i> seedlings	81
5-3	Comparison of 18 hour incandescent (INC) or high pressure sodium (HPS) light and natural light and daylength (NAT) with traditional field planting method on height and caliper and root and shoot dry weight of <i>Gymnocladus dioicus</i> seedlings	81

- 5-4 Percent of total height of *Gymnocladus dioicus* seedlings grown under three light treatments that was completed in the first 4 weeks of a 33 week growing season. 82
- 5-5 Percent of *Gymnocladus dioicus* seedlings grown under three light treatments that produced a second flush of growth after 33 weeks 82

Part 6: The Effects of Light Intensity on Growth of
Carpinus caroliniana and *Fagus grandifolia* Seedlings

- 6-1 Effect of light intensity on height, caliper, quality rating, and branching of *Carpinus caroliniana* seedlings. 91
- 6-2 Effect of light intensity on height and caliper growth increment of *Fagus grandifolia* seedlings 91

Part 7: The Effects of Container Size on Growth of
Carpinus caroliniana and *Fagus grandifolia* Seedlings

- 7-1 Effect of container size on height and caliper growth increment and dry weight of shoots and roots of *Carpinus caroliniana* and *F. grandifolia* seedlings 99

Part 8: The Effects of Three Slow-Release Fertilizer Rates on
Growth of *Carpinus caroliniana*, *Fagus grandifolia* and
Gymnocladus dioicus Seedlings

- 8-1 Effect of three rates of slow release fertilizer on height and caliper growth increment and dry weight of shoots, stems and roots of *Carpinus caroliniana*, *Fagus grandifolia* and *Gymnocladus dioicus* seedlings. . . 109
- 8-2 Percent of total growth of *Gymnocladus dioicus* seedlings completed in the first 6 1/2 weeks of a 28 week growing season and subjected to three rates of slow release fertilizer (Osmocote 14-14-14). 110

Part 9: The Effects of Ectomycorrhizae (*Pisolithus tinctorius*) on
Growth of *Carpinus caroliniana* and *Fagus grandifolia* Seedlings

- 9-1 Effect of ectomycorrhizae (*Pisolithus tinctorius*) on height and caliper growth increment and dry weight of roots and shoots of *Carpinus caroliniana* and *Fagus grandifolia* seedlings 118

List of Figures

Figure	Page
Part 2: The Effects of Various Warm and Cold Stratification Treatments on Germination of <i>Carpinus caroliniana</i> Seeds	
2-1 Percent germination of <i>Carpinus caroliniana</i> seeds after several warm and cold stratification periods.	59
Part 5: The Effects of Extended Photoperiod and Light Quality on Growth of <i>Carpinus caroliniana</i> , <i>Fagus grandifolia</i> and <i>Gymnocladus dioicus</i> Seedlings	
5-1 Incremental growth of <i>Gymnocladus dioicus</i> seedlings under three light treatments.	83

Part 1

Introduction and Literature Review

Introduction

Most research on propagation and container production of ornamental trees has focused on traditional and popular taxa commonly used in commercial landscaping. These include native and exotic taxa such as *Acer rubrum* L. (red maple), *Cornus florida* L. (flowering dogwood), *Magnolia x soulangeana* Soul.-Bod. (saucer magnolia) and *Acer palmatum* Thunb. (Japanese maple). Recently there has been a growing interest and demand for alternative species. Native species such as *Aesculus flava* Solander (yellow buckeye), *Sassafras albidum* (Nutt.) Nees (common sassafras), *Oxydendron arboreum* (L.) DC. (sourwood), *Carpinus caroliniana* Walt. (American hornbeam) and *Gymnocladus dioica* (L.) K. Koch (Kentucky coffeetree) are receiving much interest. The gain in popularity of native species dates back to the passage of the federal Clean Water Act of 1977 (Knezick 1994). This act resulted in legislation that ordered the loss or disturbance of one wetland be 'mitigated' by the creation or enhancement of another wetland. This opened a new market for native species. Since that time many landscape architects have recognized the 'beauty and hardiness of indigenous species' and begun specifying native species for commercial and residential projects. Recently President Clinton issued a memorandum calling for the use of 'regionally native species' for federal facilities and federally funded projects (Eco-Watch 1994) but according to some city foresters the supply of many native trees has not kept up with the demand (Gamstetter and Gulick 1996).

Marketing, propagation and production practices greatly influence the availability of nursery crops. Although many native trees are in demand, many growers are reluctant to produce plants of landscape quality. There are many reasons why growers do not produce some of the desirable native tree species. Many species are considered difficult to grow and past experience may have proved disappointing. Other species may be difficult to propagate because of special stratification and/or scarification requirements of the seed. A few nurseries produce crops of native trees but often the seedlings are not grown to

the landscape size desired. Other nurseries may produce larger trees but the trees are not in the quantity nor of the quality that landscapers need.

In 1996, *C. caroliniana* was listed in an American Nurseryman article as being one of the least available trees on the market. This is due in part to the difficulty in propagation and extremely slow growth rate (Gamstetter and Gulick 1996). According to Dirr (1990), *Fagus grandifolia* Ehrh. (American beech) is reported to outgrow its European counterpart, *F. sylvatica* L., in the southeastern United States. *G. dioicus* was listed as one of the top ten urban trees of 1998 (Phillips 1999). In order for more native species to be readily available for use in the landscape, a fundamental knowledge of the propagation and production of these species is needed to overcome the cultural problems associated with these trees.

The purpose of this project was to determine optimum cultural practices for three native species thought to have considerable landscape merit - *Carpinus caroliniana* (American hornbeam), *Fagus grandifolia* (American beech) and *Gymnocladus dioicus* (Kentucky coffeetree). Studies were conducted to determine the effects of (1) seed stratification and scarification regimes, (2) light quality and photoperiod, (3) light intensity, (4) fertilizer rate, (5) container size and (6) mycorrhizae on germination rate, stem height, stem caliper, dry weight of roots and shoots, and quality of seedlings after one or two growing seasons. Comparative container and field studies were also performed. The information gained may be applied directly to the nursery industry and thus stimulate a greater interest in the production of native plant species for urban and suburban landscapes.

Literature Review

Native Plants in the Landscape

The term 'native' is commonly used to refer to species that existed in an area prior to European settlement. Guy Sternberg (1996) defined 'native' or indigenous as being a species that established over time in a particular area or

region. There are many valid reasons for the preferential selection of a 'native' over a 'non-native' species. These reasons include: the prevention of exotic invasions, retention of regional character, maintenance of biodiversity, reduction of demands on natural resources and creation of more suitable habitat for native wildlife.

A number of aesthetic and functional traits have been identified as desirable. Aesthetic characteristics include: flower, fragrance, form, foliage, fall color, fruit and bark color. Functional characteristics include: growth rate, vigor, drought tolerance, disease resistance and ease of culture (Sabuco 1990). While some native plants possess desirable aesthetic characteristics, others possess more functional characteristics thus making them especially valuable for 'difficult' landscape sites. Thus, landscape architects are specifying a greater number of native plants for commercial and residential projects (Knezick 1994).

With the passage of the Clean Water Act of 1977, there was a noticeable increase in landscape specifications calling for native species. The result of the act was that the loss or disturbance of wetlands in one area must be "mitigated" by the creation or enhancement of wetlands in another area. This piece of legislation created a market niche for native species (Knezick 1994).

In 1994, a partnership called the Native Plant Conservation Committee was created to conserve native plants and their habitat. The partnership includes: the Fish and Wildlife Service, the National Biological Survey, the Bureau of Land Management, the National Park Service, the Agricultural Resource Service, the U.S. Forest Service, the Soil Conservation Service, the Center for Plant Conservation, the National Association of Conservation Districts, the Soil and Water Conservation Society, the Society for Ecological Restoration, the Nature Conservancy and the Garden Club of America. The purpose of the Native Plant Conservation Committee is to identify key conservation needs for native plants and their habitats. The committee recognizes that the future of public lands depends on communities of native

plants and that plant biodiversity is the basis of a healthy ecosystem upon which all forms of life depend (Canfield 1994).

Due to environmental problems associated with numerous exotic species, environmental regulators have attempted to curb the use of non-native species by legislating against their use (Knezick 1994). President Clinton issued a memorandum calling for the use of "regionally native plants" and "environmentally and economically beneficial landscaping" in federally funded projects (Eco-Watch 1994).

As people move about the globe, they take with them plants, animals and microorganisms that did not exist in areas prior to man's movement. Some species introductions have been accidental while others have been deliberate. Introductions that have established viable populations without human intervention are termed biological invasions (Vitousek 1997). Biological invasions create a chain of reactions that affect not only human health but the functioning of ecosystems and the maintenance of biological diversity. Biological invasions are now considered by many scientists to be significant components of global environmental change (Vitousek 1997). According to Stanford University professor Peter Vitousek (1997), "biological invasions will be the most important factor shaping the composition and dynamics of the forests of the eastern United States in the foreseeable future".

Examples of a few biological invasions include: *Lythrum salicaria* L. (purple loosestrife) and *Acer platanoides* L. (Norway maple) in the northeast; *Trifolium incarnatum* L. (crimson clover), *Lonicera japonica* Thunb. (Japanese honeysuckle) and *Pueraria lobata* (Willd.) Ohwi (kudzu) in the southeast; and *Ailanthus altissima* (Miller) Swingle (tree of heaven), *Lonicera morrowii* Gray (bush honeysuckle), *Rosa multiflora* Thunb. (multiflora rose), *Cytisus scoparius* (L.) Link (Scotch broom), *Sorghum halepense* (L.) Pers. (Johnson grass) and *Polygonum cuspidatum* Siebold & Zucc. (Japanese knotweed) throughout the eastern United States (Sternberg 1996, U.S. Congress 1993).

In 1988, it was estimated that 17-21% of the vascular flora of the Great Smoky Mountains National Park were alien species (Vitousek 1988). Presently, over 4500 non-indigenous species have become "established" in the United States (U.S. Congress 1993). Dr. Susan Reichard of the University of Washington found 235 non-indigenous woody plant species to be invasive in North America. She went on to estimate that 76 of these are considered to be serious pests and 99% of these species were intentionally introduced, mostly for horticultural and conservation purposes (Sternberg 1996). In 1993, the U.S. Congress published a report which stated that 80% of introduced non-indigenous species eventually escape cultivation and 91% of these plant species have harmful effects (that is they are vectors for disease and insects or out compete and displace natives).

Introductions of non-indigenous species threaten biological diversity by breaking down the biogeographic barriers that led to and sustain the amount of biological diversity that currently exists. The Hawaiian islands are an example of the breakdown of a biogeographic barrier that has led to the extinction or endangerment of many species endemic to the islands (Vitousek 1997). In 1988, Peter Raven, of the Missouri Botanical Garden, predicted that 25,000 species of plants would disappear before the next century. He added that for every plant species that becomes extinct, 10 to 30 other species will follow. Raven (1988) stated in the book Biodiversity that "the diversity of plants is the underlying factor controlling the diversity of other organisms and thus the stability of the world ecosystem. On these grounds alone, the conservation of the plant world is ultimately a matter of survival for the human race".

Small disjunct populations of plants act essentially as islands and these 'islands' cannot be expected to act as 'arks of genetic diversity'. Paul Ehrlich (1981), a Stanford University ecologist, stated, "The theory of island biogeography reveals that a single reserve cannot be set aside and then continually stocked with species from elsewhere - even if the habitat seems perfectly suitable for the introduced species. Once the reserve's carrying

capacity is reached, extinctions will balance introductions". Thus, the use of native species could help bridge natural areas and thus allow for the genetic interactions necessary for the survival of a species.

The native flora of an area is a natural element that makes up much of the regional character of a landscape. The use of native plants in the urban and suburban landscape can help an area retain much of an area's 'character'. Regionally native species also contribute to the restoration of ecosystems and often place fewer demands on natural resources because they are often better adapted to the soils, climate, rainfall, pests and soil microorganisms. According to Guy Sternberg (1996), native trees often tolerate inclement weather better than non-indigenous species. For example, many homes in the midwestern states lost their *Acer palmatum* Thunb. (Japanese maple) and *Cercidiphyllum japonicum* Sieb. & Zucc. (katsura tree) trees during the drought of 1988 while few of the native oaks and hickories were harmed (Sternberg 1996).

Native trees provide alternative species for nurseries to offer their customers. In 1995, Gamstetter and Gulick composed a list of trees that municipalities desired but found were unavailable for use in the urban landscape. Of the 59 species listed, 31 of were native to the eastern United States. *Carpinus caroliniana* Walt., American hornbeam, one of the species that is of focus for this thesis, was said to be in "great" demand and was listed as the seventh least available tree (Gamstetter and Gulick 1996).

A 1991 study found that 'wooded' properties were considered more aesthetically pleasing and thus tended to have higher property values (King et al. 1991). A diversity of native species increases property values, improves quality of life, guards against the problems created by a monoculture and provides numerous environmental benefits. Native plants also provide critical habitat for wildlife and therefore help maintain biological diversity at all trophic levels. According to the National Wildlife Federation (1997), native plants can support up to 50 times as many species of native wildlife as non-indigenous plants.

The native flora is part of the complex web of biological diversity necessary to sustain a healthy ecosystem. As the public takes a greater interest in protecting wild lands and wildlife, they will eventually develop a greater interest in protecting and conserving the native flora that supports the wildlife and constitutes the natural areas they enjoy. One method of in-situ conservation that can be easily practiced by the public is by using native plants in the landscaping of their homes. This would help create more wildlife habitat and bridge fragmented natural areas.

Carpinus caroliniana

"...with its picturesque trunks and rich autumn hues, Hornbeam should be spared, if not planted, whenever a natural landscape effect is desired."

Donald Culross Peattie 1991

"This tree has a lot to offer our landscapes in subtle beauty."

Michael Dirr 1990

Carpinus caroliniana Walter belongs to the family Betulaceae. There are 26 species of *Carpinus* found worldwide (Rudolf and Phipps 1974). Common names for *C. caroliniana* include American hornbeam, musclewood, ironwood, blue beech and water beech (Dirr 1990). Most of the tree's names are derived from the characteristic wood or bark. The name hornbeam is derived from the German word 'horn' meaning tough and 'baum' meaning tree - the wood has a dry weight of 49 pounds per cubic foot (Peattie 1991). The smooth, light gray bark resembles that of *Fagus* (beech) and hence the name blue beech or water beech (Dirr 1990). The name musclewood is derived from the sinewy texture of the bark that resembles a twisted, flexed muscle (Peattie 1991). The density of the wood has allowed it to be used for tool handles and other hard wooden articles (Little 1986).

C. caroliniana is a small, deciduous tree native to eastern North America. The range of *C. caroliniana* extends from Nova Scotia, west to Minnesota and south to Texas and Florida (Dirr 1990). It is hardy in USDA zones 3 through 9 (Dirr 1990). *C. caroliniana* naturally occurs in rich, moist soils, along streams, in ravines and in the understory of hardwood forests (Little 1986). Hightshoe (1988) describes the habitat as lower, cool, northern and eastern slopes.

C. caroliniana typically grows 35 to 50 feet tall and 35 to 50 feet wide (Hightshoe 1988). The National Registry of Big Trees listed the largest *C. caroliniana* as having a 95 inch circumference at 4 1/2 feet, at being 69 feet tall and having a 56 foot horizontal spread (National Register of Big Trees 1996).

C. caroliniana is valued for several reasons. It produces food and habitat for wildlife such as deer who browse on twigs and foliage and grouse, pheasants and quail who eat the nutlets (Little 1986). It is valued for ornamental purposes in the naturalized landscape (Dirr 1990). Other uses include bonsai, hedging or screening, decks and patios, small shade tree and specimen or street trees (Gilman 1997). The fall color of the foliage ranges from yellow and orange to deep red or scarlet (Hightshoe 1988, Dirr 1990). Gilman (1997) reports the fall color of *C. caroliniana* as being "exceptionally showy". The winter form of this tree is considered by some horticulturists to be architecturally interesting with its characteristic bark. Paul Cappiello (1989) reports *C. caroliniana* as being smaller than its European relative and as having better fall leaf color.

Gamstetter and Gulick (1996) listed *C. caroliniana* to be the seventh least available tree among a list of 59 species that municipalities desired for street trees. The survey also found *C. caroliniana* to be one of the five most difficult species to propagate and one of the five species with the slowest growth rates. Hightshoe (1988) estimates growth to be about 8 inches per year in better sites.

According to Michael Dirr (1990), *C. caroliniana* seedlings can be somewhat difficult to transplant, especially when balled and burlapped, and should be transplanted in the spring. Cappiello (1989) reports that once

seedlings become established they grow very well. Gilman (1997) states that container grown trees of this species transplant better than field grown trees. They should be planted in sites that are rich, moist and slightly acidic (Dirr 1990). Hightshoe (1988) lists the soil pH preference as being 6.1-7.5. *C. caroliniana* is very tolerant of shade (Hightshoe 1988) and Dirr (1990) recommends planting seedlings in partial shade.

Hightshoe (1988) lists *C. caroliniana* as being sensitive to nitrogen oxides, lighting, drought, heat, soil compaction and mine spoils. It is also listed as being resistant to sulfur dioxide. Dirr (1990) reports *C. caroliniana* as being tolerant of periodic flooding. *C. caroliniana* is not reported to have any serious disease or insect problems (Hightshoe 1988, Dirr 1990).

Davis Sydnor from Ohio State University summed up his thoughts on the response of several trees to construction activity. *C. caroliniana* was listed as having relatively fair tolerance. Comments were, "This plant's service life in its natural range is short due to the presence of hornbeam borer. Increased stress will result in more frequent and more severe attacks. This plant can persist as a forest understory plant if minimum disturbance has been experienced. Excellent follow up care is required for this plant to persist following construction activity. Once the plant is reestablished it is stable" (Sydnor 1998).

Companion species of *C. caroliniana*, which grow in similar site conditions and are of the same plant community, include: *Acer saccharum* Marsh. (sugar maple), *Fagus grandifolia* Ehrh. (American beech), *Tilia americana* L. (American linden), *Hamamelis virginiana* L. (common witch-hazel), *Quercus rubra* L. (northern red oak), *Cornus alternifolia* L. f. (alternate-leaf dogwood), *Amelanchier arborea* (Michx. f.) Fern. (downy serviceberry), *Euonymus atropurpureus* Jacq. (eastern burningbush) and *Ostrya virginiana* (Mill.) K. Koch (American hophornbeam) (Hightshoe 1988).

Seeds of *C. caroliniana* require a period of cold stratification prior to germination. The U.S. Forest Service's book Seeds of Woody Plants in the U.S. recommends a warm stratification (15/30C) period of 60 days followed by a

cold stratification (5C) period of 60 days (Rudolf and Phipps 1974). Following this method 10% germination can be expected (Bretzloff and Pellett 1979). Bretzloff and Pellett (1979) found that by lengthening cold stratification to 18 weeks they were able to increase germination to 58%. They also concluded that warm stratification did not increase germination and that germination could be slightly increased by soaking stratified seeds in 100 ppm giberrellic acid (GA_3). Seeds germinated when scarified (by cutting the seed coat) and exposed to GA_3 . Bretzloff and Pellett (1979) suggested that GA_3 cannot penetrate the seed coat of *C. caroliniana* and thus the embryo of this species cannot expand until scarified or stratified. Seed flotation was reported to be a useful method to separate viable seeds from the nonviable seeds (Bretzloff and Pellett 1979). Viable seeds sank after a 17 hour soak in tap water. This was confirmed by testing with tetrazolium. Germination capacity of seeds is extremely variable within this species. Often sheltered branches of seed bearing trees produce viable seed while exposed branches produce nonviable seed (Browse 1979). Winstead et al. (1977) found a general pattern of decreasing fruit weight with decreasing latitude for *C. caroliniana*.

In standard nursery practice, seeds are sown in moist, rich, loamy soil that is protected from extreme fluctuations in temperature. Germination occurs the second spring after planting. Seeds which are collected green can be put immediately into cold stratification or sown outdoors for germination the following spring. Seeds should be sown at a rate of 30 to 40 seedlings per square foot and covered with 1/4 to 1/2 inch of soil. Beds should be mulched until the last frost and lightly shaded for the first year. Transplant first year seedlings in mineral-rich, silty soils or on warm limestone slopes which contain a good layer of humus (Rudolf and Phipps 1974).

Fagus grandifolia

*"Taken in all seasons and judged by all that makes a tree noble-strength
combined with grace, balance, longevity, hardiness, health -
the Beech is all that we want a tree to be."*

Donald Culross Peattie 1991

Fagus grandifolia Ehrhart (American beech) belongs within the family Fagaceae. There are 10 species of *Fagus* in the Northern Hemisphere (Rudolf and Leak 1974). The range of *F. grandifolia* extends from Southern Ontario/Michigan, east to Cape Breton Island, south to Florida and west to Texas (Little 1986). It is hardy in zones 3 through 9 (Dirr 1990). Michael Dirr (1990) reported *F. grandifolia* as being "more amenable to culture in zones 7 through 9 than the European" species. *F. grandifolia* naturally occurs in rich, moist soils of uplands and well drained soils of lowlands (Little 1986). It prefers soils that have a soil pH in the range of 5.5 to 6.5 and is tolerant of flooding and shady conditions (Hightshoe 1988).

F. grandifolia typically reaches heights of 75 to 100 feet and diameters of 1 to 2 1/2 feet (Little 1986, Hightshoe 1988). The largest tree is 115 feet tall, has a 279 inch circumference (at 4 1/2 feet) and has a 138 foot spread (National Register of Big Trees 1996). This species is slow growing (9 to 12 feet in 10 years) but according to Dirr (1990), *F. grandifolia* outgrows and out performs the smaller European beech, *F. sylvatica*, in the southeast. According to Kozlowski (1971), *F. grandifolia* has one of the longest life spans of the eastern North American angiosperms. The average life span is 300 to 400 years.

F. grandifolia is fairly resistant to urban pollutants such as sulfur dioxide and ozone. However, it is sensitive to excess light, salt, drought and soil compaction. It is reported to not have any serious disease problems (Dirr 1990, Gilman 1997, Hightshoe 1988), but in recent years many trees are becoming threatened with beech bark disease (Klein 1997).

Beech bark disease is a destructive complex of beech scale, *Cryptococcus fagisuga* Lind., and one of the two species of the fungus *Nectaria* Fries. The disease is initiated upon the infestation of beech scale which mechanically and enzymatically weakens the tree. This weakening leaves the tree susceptible to the invasion of the cambium killing fungus. Symptoms of the disease include large, peeling strips of dead bark, dieback of the crown and cankers (Klein 1997). Trees of all sizes are susceptible but most disease caused mortality occurs in trees that have a diameter at breast height (dbh) greater than 25 cm (Mize and Lea 1979). Mortality is greater than 50% and thus reduces the stability of the forest. The disease complex is thought to have originated in Europe. It has been recorded and is on the rise in the Great Smoky Mountains National Park (Klein 1997).

F. grandifolia is of value for its beautiful, yet sturdy and imposing growth habit. Its large, rounded crown casts a dense shade (Dirr 1990). Beechnuts are edible and valued as a major source of food for wildlife (Hightshoe 1988, Peattie 1991). Fall color of *F. grandifolia* is copper with leaves often being retained late into winter (Gilman 1997, Dirr 1990). Landscape uses for *F. grandifolia* include shade or specimen trees at estates, parks, campuses, golf courses or large commercial properties (Gilman 1997, Dirr 1990).

Davis Sydnor from Ohio State University summed up his thoughts on the response of several trees to construction activity. *F. grandifolia* was listed as having low relative tolerance. Comments were as follows, "Protect the tree from construction activity under the dripline of the tree. Mulch over the root zone following construction in highly desirable. Tree is sensitive to increased light following removal of surrounding forest. Major branches are sensitive to sunscald following loss of surrounding trees. Thin bark makes this tree sensitive to wounding. A poor wound response makes this tree vulnerable to decay" (Sydnor 1998).

Companion species of *F. grandifolia* include: *Acer saccharum* Marsh. (sugar maple), *Acer pennsylvanicum* L. (striped maple), *Acer spicatum* Lam.

(mountain maple), *Acer rubrum* L. (red maple), *Picea rubens* Sarg. (red spruce), *Pinus strobus* L. (eastern white pine), *Betula lutea* Michx. f. (yellow birch), *Quercus rubra* L. (northern red oak), *Tilia americana* L. (American linden), *Magnolia acuminata* L. (cucumber magnolia), *Tsuga canadensis* (L.) Carr. (Canadian hemlock) and *Fraxinus americana* L. (white ash) (Hightshoe 1988).

F. grandifolia seeds require a cold stratification (5C) period of 90 days in order to break dormancy (Rudolf and Leak 1974). Germinative capacity of seeds is extremely variable within this species. Heavy crops of seed are produced periodically, generally every 2 to 3 years (Dirr 1990). Germination percent will be high in some years and low in other years.

In standard nursery practice, seeds are sown as soon as possible after collection in the fall. Stratified seed can be sown in the spring. Seeds should be sown at a rate to produce 25 two-year-old seedlings or 45 one-year-old seedlings per square foot. Seed beds should be covered with 1/2 inch of soil and mulched until midsummer. Seedbeds require half-shade until past midsummer of the first year (Rudolf and Leak 1974). Beech nuts are food for many animals. Therefore it is necessary to take precautions to ensure that seedbeds are protected (Browse 1979). Lamb et al. (1975) recommended transplanting seedlings at regular intervals to prevent the formation of a large tap root.

F. grandifolia should be transplanted balled and burlapped during the spring into moist, well drained, acidic (pH 5.0 to 6.5) soil (Hightshoe 1988, Dirr 1990). Full sun is preferable but shade is tolerated by this species (Dirr 1990). However, it will not tolerate wet or compacted soils and grass can be difficult to grow beneath the trees (Dirr 1990).

F. grandifolia is monoecious. The small, insignificant flowers emerge in early spring after the leaves expand (Rudolf and Leak 1974). Fruits consist of a three-sided nut which is enclosed in a prickly bur (developed from the floral involucre). Beech trees exhibit periodic seed production (Dix and Skrentny 1965). *F. sylvatica* produces heavy crops every 5 to 7 years and lighter crops in

years between (Lamb et al. 1975). During 'off' years fruits are produced but are void of seeds (Browse 1979). Possible reasons for poor viability are: poor pollination, self sterility and frost (Stalter 1982). Stalter determined seed viability to be highly variable - ranging from 0% in Knoxville, TN to 20% in East Lansing, MI and 70% in Cayce, SC. He concluded that little evidence exists to support the good year bad year seed production theory of beech. Data from this study suggested that beech seed production is variable throughout the range and that in certain years in certain localities a large number of seeds may be potentially viable. Sain and Blum (1981) also reported finding hollow nuts. They determined germinative capacity of high elevation nuts (that were subjectively selected) to be 72.26% compared to 71.12% for low land nuts.

Gymnocladus dioicus

Gymnocladus dioicus (L.) K. Koch belongs in the family Fabaceae, subfamily Caesalpinioideae. Its generic name in Greek means 'naked branch' (Little 1986). It received its common name, Kentucky coffeetree, from settlers who may have used its roasted seed as a coffee substitute (Sander 1974). However, Little (1986) reported that the raw seeds are poisonous. Dirr (1990) speculated that roasting the seeds may destroy the toxic principles.

The natural range of *G. dioicus* extends from New York and Pennsylvania, west to Minnesota, south to Oklahoma and east to Kentucky and Tennessee (Sander 1974). In the wild, populations are scattered and rare (Little 1986). Small populations exist in New York, Pennsylvania, West Virginia, Maryland, Virginia, Tennessee, Wisconsin and Minnesota. Large populations exist in Michigan, Ohio, Illinois, Indiana, Missouri, Iowa, Oklahoma, Arkansas, Kentucky and Kansas (Hightshoe 1988). *G. dioicus* prefers deep, rich soils of bottomlands, ravines and moist slopes. It is hardy in zones 3 through 8 (Dirr 1990).

G. dioicus is a medium to large sized deciduous tree. It can reach heights of 100 feet but is more commonly 70 feet (Hightshoe 1988, Dirr 1990).

Diameters can reach 2 feet (Little 1986). According to the National Register of Big Trees, the largest *G. dioicus* tree measured 222 inches in circumference (at 4 1/2 feet), 90 feet in height and has an 89 foot horizontal spread (National Register of Big Trees 1996). This species is reported to be a slow to medium grower, 12 to 14 feet in 10 years (Dirr 1990). The bark has narrow furrowed ridges which curve outward along a vertical margin (Hightshoe 1988). The wood has been primarily used for timber and fence posts (Sander 1974).

G. dioicus is tolerant of drought and heat, mine spoils and salt (Hightshoe 1988, Gilman 1997). It is also listed as having moderate tolerance to soil compaction and is not reported to have any serious disease or insect problems (Hightshoe 1988, Gilman 1997).

Potential landscape usage for *G. dioicus* includes buffer strips, highways, reclamation sites and shade or specimen trees. The thin, open canopy allows light to penetrate to the ground thus allowing lawns to be kept beneath. The leaves are showy yellow in the fall. It is well adapted to a wide range of soil conditions, tolerates drought and performs well in the urban environment (Gilman 1997). *G. dioicus* was listed as one of the top ten urban trees of 1998 (Phillips 1999).

G. dioicus seedlings can be somewhat difficult to transplant and should be transplanted balled and burlapped (B&B) in the spring (Hightshoe 1988). Gilman (1997) reported that the tree recovers slowly from transplanting and using root pruning containers in the nursery could help produce trees that can be more readily transplanted. Dirr (1990) recommended transplanting B&B trees into deep, rich, moist soils but notes that they are adaptable to a wide range of conditions such as limestone sites. Hightshoe (1988) listed the soil pH preference as being 6.6 to 7.5. *G. dioicus* grows best in full sun and is tolerant of most soil textures (Gilman 1997).

Recently, Davis Sydnor (1998) from Ohio State University summed up his thoughts on the response of several trees to construction activity. *G. dioicus* was listed as having good relative tolerance. Comments were, "Plants adapt to

high light and urban situations. Tough bark is resistant to mechanical injury. Tolerates disturbance".

Companion species of *G. dioicus* include: *Fraxinus pennsylvanica* Marsh. (green ash), *Gleditsia triacanthos* L. (common honeylocust), *Acer saccharinum* L. (silver maple), *Juglans nigra* L. (black walnut), *Celtis occidentalis* L. (common hackberry), *Carya cordiformis* (Wang.) K. Koch (bitternut hickory), *Ulmus americana* L. (American elm), *Morus rubra* (red mulberry), *Crataegus crus-galli* L. (cockspur hawthorn), *Euonymus atropurpureus* Jacq. (eastern burningbush) and *Juglans cinerea* L. (butternut) (Hightshoe 1988).

G. dioicus is polygamo-dioecious (primarily dioecious but on occasion having both pistillate and staminate flowers on the same tree). Dirr (1990) reported the fragrance to be similar to a rose. Gilman (1997) described the flowers as greenish-white, having a pleasant fragrance and being somewhat showy. Fruits of *G. dioicus* are brown leathery pods, 5 to 10 inches long. Dirr (1990) reported good seed crops to be produced alternately or on 3 year cycles. Seeds are very hard and bony and remain in the pod until it is broken up by the decay process which may take 2 or more years (Sander 1974).

The seeds of *G. dioicus* have a hard, impermeable seedcoat that prevents or delays germination and must be scarified. Scarification can be achieved by soaking seeds in room temperature water for 24 hours and then soaking in concentrated sulfuric acid (H_2SO_4) for another 2 hours (Sander 1974). In a study conducted by Liu et al. (1981), it was found that 30, 60, 90, 120 and 150 minutes of soaking in H_2SO_4 produced 53, 84, 93, 95 and 99% germination. Liu et al. also determined that with no pregerminative treatment 4% germinated while 1 and 3% germinated when treated with boiling water or liquid nitrogen. It was concluded that 120 or 150 minutes of soaking in H_2SO_4 was optimum. Frett and Dirr (1979) reported that 0, 2, 4, 8, 16 and 32 hours of acid scarification resulted in 7, 93, 100, 95, 83 and 87% germination. Browse

(1979) reported that fresh seed will germinate readily if sown prior to the hardening of the seedcoat.

Standard nursery practice for *G. dioicus* involves planting pretreated seeds during the spring in rows spaced 18 to 30 inches apart. The sowing rate should be 12 to 18 seeds per lineal foot row. Seeds should be covered with 1" of firmed soil. Sixty to 75% of seeds produce plantable seedlings. Seedlings should be field planted after one year (Sander 1974).

In a study by Geneve et al. (1990), in vitro shoot initiation of *G. dioicus* was found to be possible using seedling explants. In a later study, Smith and Obeidy (1991) developed a method for clonally producing plants of the male genotype of *G. dioicus*. *G. dioicus* seeds were used in an experiment conducted by Henderson and Hensley (1987) who concluded that hydrophilic gels used as seed coatings did not consistently nor significantly improve seed emergence or seedling vigor.

Stratification, Scarification and Seed Dormancy

A viable seed which does not germinate under favorable conditions (adequate water, sufficient oxygen and suitable temperatures) is considered to be dormant (Berrie 1987). Dormancy refers to the delay in germination that occurs after a seed has matured. This mechanism helps protect the seed from germinating in late summer or fall as temperatures are decreasing (Goss 1973). Most woody plants in temperate regions have evolved such natural defense mechanisms to help ensure the survival of the species by delaying germination until favorable conditions arise and by spreading germination over a period of years (Bonner et al. 1974). Seed behavior is closely related to the ecology of the species. The conditions required to overcome dormancy are often the normal climatic conditions that prevail in the growth range of the species (Berrie 1987).

There are several types of dormancy (i.e., seedcoat dormancy and dormancy due to inhibitors, immature embryos, chemical deficiencies and soil

inhibitors) (Goss 1973). Browse (1979) divides dormancy types into three groups: (1) those which physically impede germination by preventing uptake of water, restricting gaseous exchange or limiting embryo expansion, (2) those which prevent germination due to an immature embryo and (3) those that are chemical in their mode of action and prevent germination by inhibition of an essential reaction necessary to promote germination.

For the purposes of this thesis, the only types of dormancy that will be addressed are seedcoat dormancy (*G. dioicus*) or physiological dormancy that requires a period of cold stratification (*C. caroliniana* and *F. grandifolia*). Stratification of *C. caroliniana* and *F. grandifolia* and scarification of *G. dioicus* were previously covered in the sections pertaining to the individual species.

A hard seedcoat prevents germination by limiting the uptake of water, diffusion of gases or expansion of the embryo (Browse 1979). In this type of dormancy the enzymatic activity associated with germination cannot occur as long as these processes cannot occur. Therefore the impermeable seedcoat must be damaged. Scarification is the process by which the seedcoat is damaged (Goss 1973). This type of dormancy is common of plants in the Fabaceae family (Browse 1979). Under natural conditions, scarification would be accomplished by passage through an animal's digestive tract, exposure to alternating temperatures, microbial action, fire or mechanical abrasion (Salisbury and Ross 1978). In the laboratory, seedcoats are broken by soaking in a strong acid, hot water or alcohol or by putting the seed through a series of freezing and warming (Goss 1973). Seedcoats can also be broken by rubbing with sandpaper, filing or chipping (Browse 1979).

The use of acids to digest seedcoats is one of the most reliable and accurate methods of breaking seedcoat dormancy (Browse 1979). Normally, concentrated sulfuric acid (95% H_2SO_4) is used to digest the seedcoat. The temperature at which digestion takes place should be 18 to 20°C. Seeds should be stirred gently and regularly to ensure uniform digestion. At the end of the digestion period, the acid should be drained off and the sample plunged into a

large volume of cold water. Seeds can be left to soak in water for 24 hours to determine the number which imbibed (Browse 1979).

Cold stratification is required by many species to break physiological dormancy and subjects seeds to cool, moist conditions (between 0 and 10C) for a period of time (7 to 180 days) (Berrie 1987). Seeds of many plants in temperate climates exhibit this type of dormancy. Conditions necessary to overcome this type of dormancy are: imbibed seeds, adequate aeration, cold temperatures and a period of time (Browse 1979). In nature, stratification occurs when seeds are left over winter among the leaf matter on the forest floor. If temperatures do not drop to necessary levels and remain so for a sufficient period of time, dormancy will not be broken (Goss 1973). Stratification usually refers to a period of cold moist conditions, but may also indicate moist, warm conditions. Warm temperatures allow immature embryos to enlarge and further differentiate (Krugman et al. 1974).

Photoperiod and Light Quality

The growth and development of trees is affected by light intensity, photoperiod and light quality (Kozlowski 1971). Before the 1930's, it was assumed that low temperatures were responsible for the cessation of growth (Jester and Kramer 1939). In 1918, Garner and Allard (1920) discovered that photoperiodism was a control in flowering. Soon after, the effect of photoperiod on the vegetative growth of woody plants was recognized (Garner and Allard 1923).

Numerous studies have since been conducted to determine the effects of photoperiod on plants. In an experiment designed to test the effects of extended photoperiod, Kramer (1936) exposed plants to continuous (24 hours) light, 14.5 hours light, natural photoperiod (9.5 to 14.5 hours) or shortened photoperiod (8.5 hours). Results showed that woody plants continued to produce vegetative growth and may be induced to break dormancy with daylengths longer than a critical number of hours (approximately 14.5). When

daylength was shorter than a critical number of hours (approximately 8.5), plants had reduced growth or become dormant (Kramer 1936).

Downs and Borthwick (1956) concluded that in many woody plants long days increase the rate and duration of vegetative elongation while short days decrease the rate of growth and hasten bud formation. Most of the plants Downs and Borthwick tested required 4 weeks of 8 hour days to induce dormancy. *Catalpa bignonioides* Walt. (catalpa), *Ulmus americana* L. (American elm), *Betula mandshurica* (Regel) Nakai. (Asian white birch), *Acer rubrum* L. (red maple) and *Cornus florida* L. (flowering dogwood) grew continuously under 16 hour days while *Liquidambar styraciflua* L. (sweetgum) and *Aesculus hippocastanum* L. (horsechestnut) did not. Some species, such as *C. bignonioides*, require a period of cold to break bud dormancy while in other species, such as *C. florida*, the necessary cold period can be replaced by continuous light.

Nitsch (1957b) divided the growth habits of woody plants into several categories: (1) long days promote continuous growth, (2) long days promote periodic growth, (3) short days do not promote dormancy and (4) long days do not prevent onset of dormancy. In groups (1) and (2), short days promote dormancy while long days delay dormancy.

In *Rhus typhina* L. (staghorn sumac), short photoperiods do not inhibit seedling growth until the first pair of true leaves is fully expanded (Nitsch 1957a). This is due to the lack of photoperiodically controlled mechanisms in the cotyledons. According to Nitsch (1957a), cessation of growth is accompanied by a reduction of growth promoter and an increase in growth inhibitor.

Many species from high elevations or latitudes have developed sensitivities to small annual variations in photoperiod (Daubenmire 1974). These species often have stronger reactions to photoperiod and require longer daylengths to prevent dormancy (Junttila 1980). Ecologically, it is desirable for

plants to respond to daylength rather than temperature in order to prevent early emergence and subsequent frost damage (Daubenmire 1974).

Numerous studies demonstrate that the period of vegetative growth can be extended by increasing daylength, especially in young seedlings. Read and Bagley (1967) compared the growth of several species of seedlings grown under extended and continuous photoperiod with those grown in seedbeds. All species tested grew faster when photoperiod was lengthened. In another study, several tree species (*Koelreuteria paniculata* Laxm. (flametree), *Magnolia x soulangeana* Soul.-Bod. (saucer magnolia), *Quercus palustris* Muenchh. (pin oak) and *Prunus caroliniana* (Mill.) Ait. (Carolina cherry) grew taller under continuous light (Cope 1981). However, not all species responded similarly. Extended photoperiod had no effect on growth of *Betula pendula* Roth (European birch) or *Liquidambar styraciflua* L. (sweetgum) (Cope 1981). Blazich et al. (1994) found that *Oxydendrum arboreum* (L.) DC. (sourwood) seedlings grown under long days had significantly greater shoot dry weights than those grown under short days.

Cathey and Campbell (1979) reported the effectiveness of high and low pressure sodium lights (HPS and LPS) and incandescent lights (INC) in increasing vegetative growth for numerous species. For several woody species, HPS and LPS lighting increased shoot growth compared to INC or natural daylength and light. According to Cathey and Campbell (1977), an extended photoperiod serves two primary purposes. Continuous, high intensity light causes an increase in photosynthesis and thus an increase in growth while intermittent, low intensity light can be used to delay dormancy (Cathey and Campbell 1977).

Day et al. found that tissue culture maples (*Acer rubrum* L. 'Autumn Flame' and *Acer x freemanii* 'Autumn Fantasy') grown for 2 months under HPS light and 18 hour photoperiod grew taller and had greater dry weights than plants grown under 18 hour photoperiod with INC light or natural light and

daylength (1994). Plants grown under INC light had greater height and caliper growth and dry weights than those under natural light and daylength.

Growth is controlled by light and the measurement of night length through reversible reactions of phytochrome (Borthwick and Hendricks 1960). The active form of phytochrome (P_{730}) changes in darkness to the inactive form of phytochrome (P_{660}). The rates of change between the two forms are essential factors in the plant's measurement of night length.

Light quality is another factor which can alter photosynthesis. Visible light is between the wavelengths 380 and 780 nm. Ultraviolet light (UV) is less than 380 nm and infra red is above 780 nm (Biddle 1993). Far red light, 700 and 800 nm, causes an increase in height through the elongation of internodes and is absorbed by the far red form of phytochrome (P_{730}) (Noggle and Fritz 1976). Red light has wavelengths between 610 and 700 nm and is absorbed by the red form of phytochrome (P_{660}). At these wavelengths photosynthetic activity is at a peak. Yellow-green light has wavelengths between 510 and 610 nm and has little effect on plant growth. Blue light is absorbed by phytochrome, carotenoids and flavo proteins and has wavelengths between 400 and 510 nm. UV light has wavelengths between 280 and 400 nm and causes leaf thickening and compact growth habit. Light with wavelengths less than 280 nm, called short UV, is lethal to most forms of life (Noggle and Fritz 1976).

A good source of light for the purposes of photosynthesis should have a spectral composition of peaks of emission at 400 to 500 nm and 600 to 700 nm (Noggle and Fritz 1976). Generally, incandescent lights are not used for supplemental photosynthetic lighting because of excessive heat, poor light quality and low efficiency. They convert only 7% of electrical energy into visible light (Nelson 1991). The light emission spectrum extends from 500 to 1000 nm (Campbell et al. 1975). Incandescent lights are valuable for photoperiodic lighting, where a low intensity light (10 fc, 108 lux) is applied during the middle of the night (Nelson 1991).

High pressure sodium lights are currently the most popular type of artificial light source for supplemental photosynthetic lighting. The light emission spectrum peaks at 589 nm (yellow) (Campbell et al. 1975) but extends into the far-red spectrum (700 to 850 nm) (Nelson 1991). These lights are very efficient, converting 25% of the electrical input into visible radiation. Lights are available in 250, 400 and 1000 W sizes and life expectancy is as high as 24,000 hours (Nelson 1991).

Container Production

After World War II, a new production method of woody plants began to emerge in southern California (Whitcomb 1984). The warm climate allowed nurserymen to grow woody plants outdoors in containers. By the 1960's container production of woody plants had spread throughout the southern United States (Whitcomb 1984). The main advantages that container production offered were: individual control over seedling growth, mechanization of operations, absence of planting shock, extended seasons for outplanting and greater control in tree improvement programs (Spencer 1981). One problem associated with containerized plants is the limited time that a plant can be grown or held in a container due to root growth (Whitcomb 1984). According to Walker and Johnson, plug-type container stock has a better chance of survival than bareroot stock, especially during the hot summer months of July and August (Walker and Johnson 1980).

Containerized plants are preferred by the public because: (1) plants are often in full leaf (and sometimes flower) and the stigma of buying a "dead" (dormant) plant is removed, (2) containers provide a neat package that is easy to display and leaves little mess in the homeowners vehicle, (3) container plants can usually be planted anytime during the growing season and (4) for most of the public, container-grown plants provide a greater chance of success (Whitcomb 1984).

Light Intensity

Light intensity is a major factor governing the rate of photosynthesis. Different species reach maximum photosynthetic rate at different light intensities (Goss 1973). Daubenmire (1974) used the term 'heliophytes' in reference to plants that grow best in full sunlight and 'sciophytes' for plants that grow best in partial shade. The compensation point (where photosynthesis equals respiration) for many heliophytes may be as high as 4200 lux while the compensation point for shade plants may be as low as 27 lux (Daubenmire 1974). Typically, plants that naturally occur in shady areas reach their maximum rate of photosynthesis at lower light levels than plants that occur in open areas (Goss 1973). Håbjørg (1972) found that northern plant populations required higher light intensities than southern populations.

Light intensity affects shoot growth by effecting photosynthesis, stomatal opening, chlorophyll synthesis, cell enlargement and differentiation, hormone synthesis, and leaf desiccation as a result of excessive transpiration (Kozlowski 1971). Some of the morphologic and physiologic features of plants grown under full sun include: (1) thicker stems with well developed xylem and supporting tissues, (2) shorter internodes, (3) increased branching, (4) decreased leaf area, (5) smaller but thicker leaves, (6) more deeply lobed leaves, (7) fewer and smaller chloroplasts, (8) greater root growth and root/shoot ratio, (9) increased fresh and dry weight of roots and shoots, (10) decrease in chlorophyll content thus making carotenoids more apparent, (11) high respiration rate thus an increased compensation point, (12) increased transpiration, (13) higher optimum fertility level, (14) high carbohydrate/N ratio, (15) low K, Ca and P content and (16) greater vigor of flowering and fruiting (Daubenmire 1974). Because sunlight continuously decomposes chlorophyll, plants in full sun will be at a disadvantage unless they can manufacture chlorophyll at a rapid rate (Daubenmire 1974).

In many plants light intensity is directly correlated with anthocyanin (red pigment) formation (Daubenmire 1974). Anthocyanins are located in the

superficial layers of the cells and act as a reflective screen (primarily of red rays). This retards the penetration of light into underlying tissues. Since red light waves generate more heat, the chances of overheating are reduced (Daubenmire 1974). According to Bleasdale (1984), plants will more efficiently use light when leaves are evenly illuminated at low intensities versus when some leaves are over-saturated by high intensities and others in deep shade (cast by leaves above).

Trees vary greatly in their capacity to tolerate shade. Thus, light intensity is an important factor controlling species composition of tree communities. According to Kozlowski (1971), the response of shoot growth to shading often correlates with the effects of light intensity on photosynthesis. Some species increase photosynthesis under high light intensities while other species achieve maximum rates of photosynthesis at lower light intensities. Photosynthesis of *Pinus taeda* L. (loblolly pine) increased with increasing light intensity but photosynthesis of *Quercus rubra* L. (northern red oak), *Q. alba* L. (white oak) and *Cornus florida* L. (flowering dogwood) reached a maximum at approximately 1/3 full sunlight and showed a slight decrease in photosynthesis at higher light intensities (Kozlowski 1971). These results indicate that lack of light is an important factor in the inability of pine seedlings to compete with more tolerant angiosperm seedlings in dense forest stands.

Many woody plants benefit from shading, particularly in the warmer regions of the United States (Brand 1997). Shading not only influences light intensity but also relative humidity and air temperature (Andersson and Skov 1991). Shoot and root dry weight and leaf area of *Euonymus japonica* Hand. - Mazz. 'Aureo-marginata' increased under 53% shade in Mississippi (Newman and Follett 1988). Growth of *Cornus stolonifera* Michx. (red-osier dogwood) was optimized at 25% shade and reduced with additional shade (Sheppard and Pellett 1976). Shoot dry weight and leaf area of *Rhododendron* x 'Pink Ruffles' increased under shade (Anderson et al. 1991b).

Whitcomb (1984) tested the effect of different levels of shade on several species. Juniper, pyracantha, elaeagnus and euonymus grew best under full sun and were termed 'sun requiring' plants. Azalea, barberry, boxwood, abelia and holly grew best under shade and were termed 'shade preferring' plants. Shoot and root weight of the 'shade preferring' plants was greatest under 25, 30 or 47% shade. Aucuba was listed as being 'shade requiring' (Whitcomb 1984). Anderson et al. (1991a) determined that *Aucuba japonica* Thunb. 'Variegata' is an obligate shade species and should be grown in 47% full sunlight.

Over an extended period of time, K. T. Logan grew 22 native tree seedlings under full sunlight (100%), 45%, 25% or 13% light for 4 to 7 years to determine optimum light requirements for regeneration. *Ulmus americana* L. (white elm) increased height and stem weight at 45% light (Logan 1966). *Betula papyrifera* Marsh. (paper birch), *B. alleghaniensis* Britt. (yellow birch), *Acer saccharinum* L. (silver maple) and *A. saccharum* Marsh. (sugar maple) reached maximum heights under 45% light (Logan 1965). *Fraxinus americana* L. (white ash), *Tsuga canadensis* (L.) Carr. (Canadian hemlock) and *Fagus grandifolia* Ehrh. (American beech) had the greatest amount of growth under 45% light (Logan 1973).

Historically, *Sequoia sempervirens* Endl. (redwood) has been considered a facultative shade species that can thrive in high light. Boldenow (1996) determined that increased light intensity resulted in increased height, caliper, number of branches/cm of stem, branch length, leaf area, specific leaf area, leaf mass, root mass, total mass, root/shoot ratio, stomatal density and needle thickness of redwood seedlings and thus suggested that redwood should instead be considered a facultative sun species.

Drew (1983) determined that *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) seedlings grown for one season under 71% of full sun had greater total weight compared to those grown under full sun. When shade was removed the following season, plants began to allocate more energy for root development. By the end of the second season, root/shoot ratios were similar

between the two treatments. However, previously shaded plants had greater dry weights.

According to Bir and Bilderback (1989), in the southeastern United States, container grown *Kalmia latifolia* L. (mountain laurel) seedlings require shade from high pine trees or 50% shade cloth. Brand (1997) studied the effect of shading during production on *K. latifolia* in the northeastern United States. Plants were grown under 40%, 60% or full sun for 2 years. No differences in growth were found between light levels the first year but plants under shade had darker leaves with a higher chlorophyll content. The second year, similar results were obtained for leaf color and chlorophyll content but plant size, branch number, leaf area, leaf dry mass and stem dry mass decreased under higher shade levels. It was concluded that although shading improves foliage color, it should not be used in northern areas because of reduction in growth (Brand 1997).

Kozlowski (1971) reported *F. grandifolia* to be very shade tolerant. Rushmore (1961) reported that *F. grandifolia* seedlings grew better under moderate shade compared to open areas. However, Dirr (1990) stated that it "does best in full sun although withstands shade". Logan (1973) found that *F. grandifolia* seedlings grown under shade were taller than those grown in full light. Leaf area was greater when grown under 25% or 45% full sun. Dry weight of roots and shoots was greatest in the 45% light treatment.

Shading not only influences shoot primordia formation and extension but also induces the death of lower branches on trees. Some species readily lose the lower branches in shade. A common response to a sudden increase in light intensity as a result of natural pruning is the stimulation of epicormic shoots (Kozlowski 1971).

Several factors affect light intensity. High temperatures and elevations increase light intensity while water vapor (high relative humidity), fog, smog and dust decrease light intensity. Light intensity is also affected by the angle of the sun, being strongest when the sun is directly overhead. Proper spacing of

plants, removing competing plants and removing leaves that no longer efficiently photosynthesize will help to increase light intensity (Goss 1973).

Container Size

Research has shown reductions in tree growth as container size or planting hole size decreased (Murray et al. 1996). According to Milbocker (1992), "plant size is very much dependent on container size yet very little information is available to help nurserymen choose container sizes for growing larger nursery stock". Previously it was thought that seedlings should be started in small containers and potted into larger containers as they grew. According to Whitcomb (1984), this causes several problems: (1) additional labor is required, (2) progressively deformed root systems develop and (3) potting up is not usually done at the appropriate time thus causing plants to become stressed and causing a slow in growth.

Most research shows that plant growth increases as container size increases. In a study on the relationship between container size (1, 1 1/2 and 3 gallons), fertilization and plant growth, Milbocker (1992) found that each additional gallon of container volume resulted in a 25 gram increase in weight (12% of total weight) of azalea liners (*Rhododendron obtusum* Planch. 'Hershey's Red'). Weights of holly liners (*Ilex crenata* Thunb. 'Helleri') also increased (5% of total weight) for each gallon of container volume.

Tilt et al. (1991) determined that *Quercus virginiana* Mill. (live oak) and *Q. shumardii* Buckl. (shumard oak) trees had greater height and caliper growth when grown in 30 gallon containers compared to 15 gallon containers. Using the pot-in-pot production method, *Betula pendula* Roth (European birch), *Gleditsia triacanthos* L. (thornless honey locust) and *Fraxinus pennsylvanica* Marsh. (green ash) responded to larger containers (76 liter compared to 38 liter) with increased growth (Murray et al. 1996). Top dry weight and trunk diameter were greater when grown in 76 liter versus 38 liter containers. It was also

reported that root restriction appeared to have a stronger effect on tree growth than fertility.

In a study designed to compare the effects of container size (1 1/2, 3, 6 and 12 gallons) and fertilizer rate, fresh weight of *Rhododendron* 'Formosa' and *Ilex* x 'Nellie R. Stevens' increased as container size increased (Laiche and Newman 1990). It was concluded that growth was restricted by smaller container size at high fertilizer rates (10.6 lb/yd³ of 17N-7P-12K fertilizer). Similar results occurred when rooted cuttings of *Ficus benjamina* L. (weeping fig) were planted in 4, 6 and 8 inch diameter containers. According to McConnell (1988), cuttings grew fastest in 8 inch containers and slowest in the 4 inch containers. In the same study, 1, 2 and 3 gallon containers were used to grow *Eriobotrya japonica* (Thunb.) Lindl. (loquat) liners. Plants in the 3 gallon containers grew faster than those in the 1 gallon containers.

In a study comparing the effects of particle and container size (3.8, 5.7 and 11.4 liter) on *Ilex* x 'Nellie R. Stevens', *Cupressocyparis leylandii* (Dallim. & A. B. Jackson) Dallim. 'Haggerston Grey' (Leyland cypress) and *Rhododendron* 'Sunglow', a 2-fold increase in top dry weight resulted as container volume increased from 3.8 to 11.4 liters (Tilt et al. 1987).

Container shape and size affected *Quercus rubra* L. (northern red oak) seedling growth (Hanson et al. 1987). Shoot and root dry weights increased as container size increased up to 6 x 14 inch. However, growth did not increase in the 6 x 43 inch containers. South et al. (1994) determined that growth of stem height and diameter of *Pinus taeda* L. (loblolly pine) seedlings was greater in larger cells compared to smaller cells. In another study conducted to determine the effects of container size and fertilizer level, it was found that schefflera plants increased markedly in growth and quality as container size increased (Poole and Conover 1979).

Although many plants respond to larger containers with increased growth, some respond with decreased growth. Goodale and Whitcomb (1980) observed that growth of juniper and pyracantha increased with increasing

container size, but growth of barberry decreased with increasing container size. No differences were observed with elaeagnus, dwarf burford holly and aucuba. In another experiment designed to compare the effects of container size and fertility levels, Gibson and Whitcomb (1978) concluded that *Pinus thunbergii* Parl. (Japanese black pine) seedlings grew best in smaller sized containers while *Pistacia chinensis* Bunge. (Chinese pistache) and *Quercus rubra* L. (northern red oak) seedlings grew best in larger containers.

Fertilizer Rate

There are thirteen inorganic elements which are considered to be essential in the life cycle of a plant. The six macronutrients are: nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), and calcium (Ca). The seven micronutrients are: iron (Fe), copper (Cu), zinc (Zn), boron (B), manganese (Mn), molybdenum (Mo) and chlorine (Cl) (Goss 1973). Each element has a specific role in plant metabolism. The quantity available to the plant must be adequate and in balance with the other mineral nutrients. Deficiencies or excesses of nutrients can cause an imbalance, resulting in abnormal growth of the plant. The pH of a soil or media affects minor element availability. At about pH 6.5, all minerals are available to plants (in mineral soils) (Daubenmire 1974). In a soil-less media, a pH of 5.0 to 5.5 is desirable (Peterson 1982). As the pH deviates in either direction, certain nutrients become unavailable to most plants. At the extremes of pH, certain elements are excessively soluble and become toxic.

Soluble and controlled release fertilizers are often used to fertilize container-grown nursery crops. Soluble fertilizers may be injected into the watering system while controlled release fertilizers can be incorporated into growing medium, spread on the medium or applied in a dibble hole (Laiche and Newman 1990). Controlled release fertilizers are useful in areas where rain makes it difficult to control nutrient levels with soluble fertilizers. Osmocote (Scotts-Sierra Horticultural Product Co., Marysville, OH), one type of controlled

release fertilizer, is a mixture of nitrogen, phosphorous and potassium encased by a semi-permeable resinous coat. The rate of release is temperature and moisture dependent. High temperatures and ample moisture promote increased release by osmosis. Osmocote does not begin releasing nutrients until 2 or 3 weeks after application. This allows young plants sufficient time to develop root systems without risk of root burn (Edmonds 1980).

Numerous studies have been conducted on the effects of fertilizer rate on plant growth. Not all species exhibit growth increases with increasing fertilization. In a container fertility study, Gibson and Whitcomb (1978) determined that *Pinus thunbergii* Parl. (Japanese black pine) and *Quercus rubra* L. (northern red oak) seedlings grew best in fertilizer levels of 12 or 16 lb/yd³ compared to 20 lb/yd³ but no response was found in *Pistacia chinensis* Bunge. (Chinese pistache). In a study intended to determine the effects of container size and fertilizer level, fertilizer had little effect on growth of schefflera plants (Poole and Conover 1979). More recently, research conducted on *Juniperus conferta* Parl. (shore juniper) 'Blue Pacific' resulted in evidence that shoot and root dry weights decreased as nitrogen rate increased when fertilizer was dibble applied (Eakes et al. 1990).

In many cases plant growth increases as fertilizer rates increase. According to Goodale and Whitcomb (1980), elaeagnus, juniper and pyracantha size increased as fertilizer rates increased but growth of dwarf burford holly and aucuba showed no response. As fertilizer rate increased, root ratings for *Rhododendron* x 'Coral Bells' (Eakes et al. 1990) and fresh weight of *Rhododendron* 'Formosa' (Laiche and Newman 1990) increased. Growth response of *Kalmia latifolia* L. (mountain laurel) 'Elf', 'Freckles' and 'Goodrich' to fertilizer rate (0.5, 1.0 or 2.0 lb/yd³) was determined to be cultivar dependent (Hummel and Privett 1991). As fertilizer rates increased, dry weights of 'Elf' and 'Freckles' increased, growth index of 'Elf' increased but root density and length of 'Goodrich' decreased. Fertilizer rate had no effect on pH using the VTEM

(pour-through) method and only the 2.0 lb/yd³ rate had significantly greater soluble salt levels.

Eakes et al. (1990) found that as fertilizer rate increased, electrical conductivity (EC) measurements increased. Similarly, Milbocker (1991) reported that nutrients were released at the same rate per gram of fertilizer. For example, 16 gram applications released twice as much as 8 gram applications. Nutrient absorption was highly dependent on frequency of irrigation, and decreased from 25 to 50% at less than daily irrigation. It was concluded that high application rates were useful for accumulating nutrients for use during later periods of growth.

Ectomycorrhizae

The literal translation of the term mycorrhiza means "fungus-root" (Went and Stark 1968). In 1885 A. B. Frank, a German botanist, coined the term to refer to the fungus-tree association that he observed (Hacskeylo 1972). Mycorrhizae are symbiotic associations between fungi and the roots of plants. In the symbiotic relationship, both plant and fungi are benefited - the plant supplies the fungus with sugars, amino acids and vitamins while the fungus aides the plant with uptake of water and minerals such as phosphorus and zinc (Galea and Poli 1994). Estimates indicate that 90% of all higher plant species normally form mycorrhizal associations (Kendrick 1992).

There are three major types of mycorrhizae - endomycorrhizae, ectomycorrhizae and ectendomycorrhizae. Ectomycorrhizal fungi characteristically grow intercellularly (between the cortical root cells), endomycorrhizae grow intracellularly (penetrate the cells) and ectendomycorrhizae grow both inter- and intracellularly (Hacskeylo 1972). The type of mycorrhizae employed in this study was ectomycorrhizae.

Ectomycorrhizal fungi are prevalent in temperate climates. Of the coniferous plants, all of the Pinaceae family (*Pseudotsuga*, *Tsuga*, *Picea*, *Larix* and *Pinus*) are ectomycorrhizal. Within the angiosperms, ectomycorrhizae are

usually limited to the dicotyledonous, amentiferous families (Salicaceae, Juglandaceae and Fagaceae) and the Myrtaceae, Tiliaceae and Betulaceae families (Hacskeylo 1972, Linderman 1981). While most ectomycorrhizal fungi are basidiomycetes (over 4,000 species), a few are ascomycetes. Many mushrooms found on the forest floor are the fruiting bodies of the ectomycorrhizal fungi associated with the forest trees (Sylvia 1998). While some ectomycorrhizal fungi have broad host ranges, others have narrow host ranges. For example, *Pisolithus arhizus* (*P. tinctorius*) forms ectomycorrhizal associations with more than 46 tree species belonging to at least eight genera while *Boletus betulicola* is specific to the *Betula* genera (Sylvia 1998).

Ectomycorrhizal fungi benefit plants in several ways. Advantages of the symbiotic relationship are: (1) increased root surface area and therefore increased availability of nutrients and improved competitiveness for water and nutrients, (2) improved absorption of PO_4^{--} , Ca^{++} , K^+ , Rb^+ , Cl^- , SO_4^{--} , Na^+ , NO_3^- , NH_4^{++} , Mg^+ , Fe^{++} and Zn^{++} , (3) metabolic-provisioning of growth regulating substances such as vitamins and hormones to the plant, (4) excretion of toxic substances which select for more suitable microflora, (5) production of pathogen suppressing antibiotics which creates a more selective soil environment, (6) presence of a fungal sheath which acts as a protective barrier against pathogenic infection, (7) detoxification of phytotoxins often present in soils and (8) decrease in the detrimental effects of soil nematodes and other root pathogens (Langlois and Fortin 1981).

The matrix of fungal hyphae that forms between the cortical root cells is termed the Hartig net and is characteristic of ectomycorrhizae (Sylvia 1998). Also characteristic of ectomycorrhizae is a sheath of fungal tissue that covers much of the plants absorbing roots. The function of the sheath is to increase the surface area of the absorbing roots. Surface area is the critical root parameter controlling the uptake of nutrients. It is increased by hyphal strands which extend from the sheath into the soil. Hyphal strands absorb and translocate inorganic nutrients and water. When hyphae penetrate soil, surface area is

increased considerably and a much larger soil volume can be utilized (Sylvia 1998). Rousseau et al. (1994) reported that aggregates of hyphae accounted for less than 20% of the total nutrient absorbing surface mass but contributed almost 80% of the absorbing surface area of pine seedlings.

Mycorrhizal roots can be recognized by the numerous thick, short, lateral roots, abundant branching and sheaths of hyphae (Went and Stark 1968). Ectomycorrhizal fungi induce root branching which increases areas for absorption and additional sites for hyphal attachment (HacsKaylo 1972). Clusters of hyphal strands, called rhizomorphs, may sometimes be seen without the aid of magnification. Rhizomorphs function as long distance transport tunnels for water and nutrients (Sylvia 1998).

When a plant removes nutrients from the soil solution quicker than the nutrients can be replaced, an area of low nutrient concentration is created. Mycorrhizae distribute hyphae beyond the nutrient poor area thus aiding the plant in nutrient uptake. Some ions such as phosphate have limited mobility but hyphal extensions "reach" through deficient zones to areas higher in phosphate thus supplying the plant with needed phosphorus. Another factor that contributes to hyphal strand absorption is the narrow diameter of the hyphal strand compared to the diameter of plant roots. The thin hyphal strands are capable of penetrating tiny soil pores that are inaccessible to roots and root hairs (Sylvia 1998).

Hatch (1937) determined that ectomycorrhizal fungi aide plants in the absorption of nutrients from the soil. He demonstrated an 86% increase in nitrogen, 234% increase in phosphorous and 75% increase in potassium in ectomycorrhizal *Pinus* seedlings when compared to nonmycorrhizal seedlings. Using P³², Kramer and Wilbur (1949) confirmed that greater quantities of phosphorous accumulated in the roots of ectomycorrhizal pines compared to nonmycorrhizal pines. Melin et al. (1958) found greater absorption of radioactive nitrogen, phosphorus, calcium and sodium from the substrate by mycorrhizal roots of pines compared to nonmycorrhizal roots. These studies

confirmed that ectomycorrhizal fungi play a very active role in nutrient uptake in trees.

The exchange of nutrients between plant and fungus goes both directions. Melin and Nilsson (1957) confirmed this when they exposed needles of aseptically grown pine seedlings to C^{14} which allowed them to trace the movement of C^{14} from the tree's needles to the fungal mycelium. Recently, Sylvia (1998) reported that up to 20% of the total carbon assimilated by plants may be transferred to the fungal partner. Although this may appear stressful to the plant, the plant may increase photosynthetic activity due to mycorrhizal colonization. This compensates the plant for lost carbon. Growth suppression has only been attributed to mycorrhizal colonization in low light or high phosphorus conditions (Sylvia 1998).

Mycorrhizal fungi secrete substances that increase the solubility of ions bound in soils (Hacskeylo 1972). Hyphal strands mineralize organic matter by producing enzymes that break down leaf litter. This mineralization releases nutrients and ions that are absorbed by hyphae and translocated to the host plant in exchange for carbohydrates. The flow of carbon to the soil by way of mycorrhizae serves several important functions. The extramatrical hyphae improve soil aggregation by binding soil particles. Recently, it has been determined that soil aggregation due to carbon flow to the soil is critical in the maintenance of a healthy plant-soil system (Sylvia 1998). Went and Stark (1968) also reported that fungi contribute much to the cohesiveness of soils.

There are several methods by which mycorrhizal fungi protect plant roots against pathogens. The dense mat of hyphal material serves as a mechanical barrier against some pathogenic organisms (Marx 1970). Certain ectomycorrhizal fungi produce antibiotics that restrict growth of other types of fungi. Marx (1969) was able to isolate an antibiotic that restricted growth of several types of fungi and bacteria. Trappe et al. (1967) found that the ectomycorrhizal fungi associated with *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) also produced antibiotics. Sylvia (1998) suggested that

mycorrhizal fungi also reduce the incidence and severity of root diseases by competing with pathogenic organisms for nutrients and inducing generalized host defense mechanisms.

Several examples demonstrate the effects of growing specific plants in environments devoid of the plant's native mycorrhizal fungi. In prairie and grassland soils, growth of tree seedlings was suppressed after the first whorl of leaves appeared (White 1941). These plants eventually showed signs of malnutrition and died. This occurred despite the abundance of available nutrients. When the fungal symbionts were introduced, vigorous growth resumed.

When attempts were made to establish a North American species of pine, *Pinus elliottii* Engelm. (slash pine), in Puerto Rico, a drastic example of the close association between pines and mycorrhizal fungi resulted. Seedlings grew to heights of 3 to 12 inches, became chlorotic, showed symptoms of phosphorous deficiency and died. Phosphorous fertilizers did not improve plant vigor. It was not until inoculated soil from a stand of pines in the southeastern United States was introduced that the pines were able to flourish. Within 3 years dramatic results were seen. Inoculated plants grew up to 8 feet in height while uninoculated plants grew less than 12 inches and died. Further research showed that inoculated seedlings were consistently more vigorous and larger than their uninoculated counterparts (Vozzo and HacsKaylo 1971).

According to Sylvia (1998), plants respond differently to the colonization of their roots by mycorrhizal fungi. Some plants exhibit dramatic increases in growth while others exhibit growth depressions. Many factors effect the response of a plant to the colonization of its roots. Some of these factors include the mycorrhizal dependency of the host crop, the nutrient status of the soil and the inoculum potential of the mycorrhizal fungi (Sylvia 1998). Typically coarse rooted plants benefit more from mycorrhizal infection that fine rooted plants. Plants in nutrient poor or moisture deficient soils benefit more than those in nutrient rich or moist soils. The inoculum potential of mycorrhizal fungi

can be diminished by pesticide use, fertilization, crop rotation, fallowing, tillage and topsoil removal (Sylvia 1998).

Several factors effect the establishment of mycorrhizal fungi. It has been shown that less than 50% daylight will affect mycorrhizal formation of most species negatively (Langlois and Fortin 1981). Björkman (1944) found mycorrhizal formation to be reduced at light levels below 23% of full sunlight and completely inhibited at light levels below 6% of full sunlight. Availability of inorganic ions also affects mycorrhizal establishment (HacsKaylo 1972). Research results have shown that mycorrhizae is more abundant in soils that contain low amounts of nitrogen and phosphorus. In conditions of increased availability of nitrogen and phosphorus, mycorrhizal formation is suppressed or eliminated (HacsKaylo and Snow 1959). Most mycorrhizal fungi prefer a soil pH between 4 and 5 and soil temperatures between 15 and 30C (Langlois and Fortin 1981). Another factor affecting mycorrhizae establishment is the availability of soluble carbohydrates. Björkman (1944) found that ectomycorrhizal formation slowed or stopped when carbohydrate formation and translocation were impeded. An excess of soluble carbohydrates within the plant's roots is essential for mycorrhizal formation (HacsKaylo 1972).

Containerized plants often produce roots of the second and third order (first order being the root originating from the seed). These roots differ morphologically and physiologically from roots grown under natural conditions (Smith 1980). There are many pathogenic microorganisms present in soils that can retard the establishment of seedlings (Langlois and Fortin 1981). Therefore it is important that seedlings intended for forest planting be inoculated with mycorrhizal fungi. Mycorrhizal fungi will help protect the fine roots from some of the stresses of transplanting. In nutrient-poor or moisture deficient soils, mycorrhizal plants are often more competitive and tolerate environmental stresses better than nonmycorrhizal plants (Sylvia 1998). Thus, inoculation of nursery crops may prove worthwhile to nursery growers in the future.

Episodic Growth

Most woody plants in temperate regions alternate between periods of rapid shoot growth during warm seasons and cessation of shoot growth during cold seasons. Episodic growth is a term used to describe this alternation of growth episodes (Kuehny and Decoteau 1994). As days shorten, buds decrease their metabolic activity and enter a dormant state before low winter temperatures arrive (Berrie 1987). Buds come out of rest and resume growth once a sum of temperature deficits is achieved and environmental conditions are favorable. These mechanisms enable plants to better survive adverse conditions. According to Borchert (1991), a "true" episodic flush consists of: (1) expansion of the resting bud, (2) expansion and maturation of new stem and leaves, (3) formation of a new resting bud and (4) a rest period in which no new leaf or stem elongation takes place.

There are over 50 terms used to describe dormant conditions (Martin 1991). Therefore a brief summary of some useful terminology associated with dormancy follows: (1) dormancy - general term for all instances in which a tissue predisposed to elongate does not do so, (2) quiescence - dormancy which is triggered by the external environment (aitonomic dormancy), (3) correlated inhibition - physiological dormancy which is maintained by internal conditions in the plant but not the dormant organ itself (summer dormancy) and (4) rest - physiological dormancy which is maintained by conditions within the dormant organ itself (winter dormancy or autonomic dormancy). These plants will not come out of dormancy even under favorable environmental conditions. Quiescent plants will activate growth once the environmental stress has disappeared. Lang et al. (1987) simplified the terminology and defined dormancy as "any temporary suspension of growth of any structure containing a meristem". He listed three types of dormancy as: ecodormancy - regulated by environmental factors (temperature extremes, nutrient deficiency and water stress), paradormancy - regulated by physiological factors outside the affected structure (apical dominance and photoperiodic responses) (correlated inhibition

or summer dormancy) and endodormancy - regulated by physiological factors inside the affected structure (chilling responses and photoperiodic responses) (rest or winter dormancy) (Lang et al. 1987).

Some species produce individual leaves at regular intervals throughout the growing season. This is referred to as an indeterminate growth habit (Dickson 1994). Other species have recurrent or multiple flushes per year. This usually occurs in regions with little seasonal variation. These species are referred to as semi-determinate or sympodial species (Dickson 1994, Kozlowski and Pallardy 1997). In regions where climates have more marked seasons there is a tendency for the flushing cycles to become locked to seasonal changes. Many North American trees follow this pattern of flushing. These species are referred to as determinate or monopodial. In these plants only one bud will expand on a shoot per year (Kozlowski and Pallardy 1997). In all cases, the first flush consists of the expansion of preformed stem units (primordia-node-internode) contained in the winter bud (Dickson 1994). Late season temperatures influence the number of leaf primordia laid down in the winter bud and therefore determine the following years flush of shoot growth (Kozlowski 1971). Late summer droughts are thought to restrict the number of primordia that are laid down in the new bud. Therefore the stress that a plant endures may not show until the following year when shoots expand in an amount which reflects the number of primordia contained in the winter bud (Kozlowski 1971).

Shoot growth is largely determined by genetic factors but environmental factors also play a role. The contributions of several environmental factors are interacting and interdependent. Therefore, it is difficult to approximate the specific contributions of each environmental factor to shoot growth. Some of the environmental factors which affect shoot growth are light, water, temperature, mineral supply, composition of the atmosphere above and below ground, physical and chemical soil properties, insects, other plants and various animals (Kozlowski 1971).

Many hypotheses have been suggested to explain the control mechanisms that regulate leaf and internode expansion and primordia initiation. According to Kozlowski (1971), the growth of shoots is a response to the climatic and biotic factors which influence internal physiological processes and thus effect the formation and expansion of shoot primordia. Borchert (1991) suggested that water stress was responsible for inducing bud rest and episodic growth. Others have suggested that abscisic acid or cytokinins are responsible. Dickson (1994) suggested that "during a flush, photosynthate movement to roots decreases, water stress and abscisic acid concentrations increase, cytokinin concentrations and/or translocation decrease, primordia development decreases, leaf growth decreases and buds are set". According to Reid et al. (1991), resting bud formation is a developmental change influenced by photoperiod and generally promoted by short days. Downs and Borthwick (1956) previously stated that the primary factor for inducing bud dormancy is daylength. They summarized that short days induced dormancy while long days prolonged growth. As days shorten, buds enter the dormant state. Growth resumes as days lengthen and grow warmer. Other factors, such as nutrition, water status, temperature and irradiance also play a role in inducing bud dormancy (Perry 1971).

According to Goss (1973), the breaking of bud dormancy is thought to be due to an increase in the ratio of abscisic acid to gibberellin. Buds are dormant when this ratio is high and dormancy is broken when the ratio decreases. In some species, dormancy can be broken by applying gibberellic acid to the apical buds (Goss 1973). Taylor and Dumbroff (1975) found an increase in cytokinin activity at bud break. Abeles (1973) determined that bud dormancy can be broken by ethylene or ethylene-generating chemicals. Growth promoters such as gibberellic acid and cytokinin have been reported to accelerate bud growth once dormancy is broken (Berrie 1987). In *Acer saccharum* Marsh. (sugar maple), 2000 hours of 5C was necessary to break dormancy (Berrie 1987). Most years this is achieved by mid February or March.

Recent research indicates that episodes of shoot and root growth are strongly influenced by the distribution of carbohydrates and nitrogen. According to Kuehny and Decoteau (1994), nitrogen is the primary element absorbed and utilized during root growth. When nitrogen is scarce, plants respond by reducing shoot growth and increasing root growth. Excess nitrogen may prolong dormancy until first frost but this puts the plants at risk of being damaged or killed (Perry 1971).

Kienholz (1941) reported that *Fagus grandifolia* Ehrh. (American beech) shoots grew rapidly to a late May climax and then ceased completely before the end of June. The entire period of growth lasted approximately 60 days and 90% of annual shoot growth was completed in a four week period which began 1 or 2 weeks after growth started. Kienholz also found preformed shoots in the winter buds.

An understanding of episodic flushing could lead to improved nursery and silvicultural practices for the production and establishment of species which exhibit similar growth habits.

Literature Cited

Abeles, F. B. 1973. Ethylene in plant biology. Academic Press, New York.

Anderson, P. C., G. W. Knox and J. G. Norcini. 1991a. Light intensity influences growth and leaf physiology of *Aucuba japonica* 'Variegata'. HortScience 26:1485-1488.

Anderson, P. C., J. G. Norcini and G. W. Knox. 1991b. Influence of irradiance on leaf physiology and plant growth characteristics of *Rhododendron* x 'Pink Ruffles'. J. Amer. Soc. Hort. Sci. 116:881-887.

Andersson, N. E. and O. Skov. 1991. The influence of permeability and shade factor of the shading screen material on air and canopy temperature. Gartenbauwissenschaft 56:180-184.

Berrie, A. M. M. 1987. Germination and dormancy. In Wilkins, Malcolm B. (ed.), Advanced plant physiology. John Wiley and Sons, Inc., New York.

- Biddle, Gordon. 1993. Using artificial light in plant propagation. Comb. Proc. Int. Plant Prop. Soc. 43:95-96.
- Bir, R. E. and T. E. Bilderback. 1989. Growing better mountain laurel in containers. Comb. Proc. Int. Plant Prop. Soc. 39:442-447.
- Björkman, E. 1944. The effect of strangulation on the formation of mycorrhiza in pine. Svensk Bot. Tidskr. 38:1-14.
- Blazich, Frank A., Stuart L. Warren and Mack Thetford. 1994. Growth response of sourwood as influenced by temperature, photoperiod and media. SNA Research Conf. 39:137.
- Bleasdale, J. K. A. 1984. Plant physiology in relation to horticulture. MacMillan Press Ltd., London.
- Boldenow, Ronald W. 1996. Physiological and morphological responses of redwood (*Sequoia sempervirens*) seedlings to light intensity and light pattern (shade tolerance). University of California, Berkeley. Ph.D. Dissertation.
- Bonner, F. T., B. F. McLemore and J. P. Barnett. 1974. Presowing treatment of seed to speed germination. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.
- Borchert, R. 1991. Growth periodicity and dormancy. In Raghavendra, A. S. (ed.), Physiology of trees. John Wiley and Sons, New York, NY.
- Borthwick, H. A. and S. B. Hendricks. 1960. Photoperiodism in plants. Science 132:1223-1228.
- Brand, Mark H. 1997. Shade influences plant growth, leaf color and chlorophyll content of *Kalmia latifolia* L. cultivars. HortScience 32(2):206-208.
- Bretzlöff, L.V. and N. E. Pellett. 1979. Effect of stratification and gibberellic acid on the germination of *Carpinus caroliniana*. HortScience 14(5):621-622.
- Browse, P. D. A. McMillan. 1979. Hardy woody plants from seed. Grower Books, London.
- Campbell, L. E., R. W. Thimijan and H. M. Cathey. 1975. Spectral radiant power of lamps used in horticulture. Trans. Amer. Soc. Agr. Engineers 18(5):952-956.
- Canfield, Joan E. 1994. Plant conservation blossoms with the creation of the Native Plant Conservation Committee. Endang. Species Tech. Bull. 19(4):9-10.
- Cappiello, Paul E. 1989. Think small! Noteworthy shade trees for today's smaller landscapes. Am. Nurseryman 170(5):83-89.

Cathey, H. M. and L. E. Campbell. 1977. Light frequency and color aid plant growth regulation. *Am. Nurseryman*, CLXLVI (10):16-18, 108-114.

Cathey, Henry M and Lowell E. Campbell. 1979. Relative efficiency of high- and low-pressure sodium and incandescent filament lamps used to supplement natural winter light in greenhouses. *J. Amer. Soc. Hort. Sci.* 104(6):812-825.

Cope, P. A. 1981. The propagation of tree seedlings under continuous light in square, bottomless containers. University of Tennessee, Knoxville. M.S. Thesis.

Daubenmire, R. F. 1974. *Plants and environment: a textbook of autecology* (3rd ed.). John Wiley and Sons, Inc., New York.

Davidson, Harold, Roy Mecklenburg and Curtis Peterson. 1994. *Nursery management: administration and culture* (3rd ed.). Prentice Hall Career and Technology, Englewood Cliffs, NJ.

Day, John, Willard T. Witte and Hermon Dickerson. 1994. Response of tissue cultured red maple plantlets to high pressure sodium, incandescent and ambient light. *SNA Research Conf.* 39:279-282.

Dickson, Richard E. 1994. Height growth and episodic flushing in northern red oak. *Biology and silviculture of northern red oak in the north central region, a synopsis*. U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station.

Dirr, Michael A. 1990. *Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation, and uses*. 4th ed. Stipes Publishing Co., Champaign, IL.

Dix, R. L. and R. F. Skrentny Jr. 1965. Reproduction of *Fagus grandifolia* Ehrh. by seed in Wisconsin. *Can. J. Bot.* 43:757-763.

Downs, R. J. and H. A. Borthwick. 1956. Effect of photoperiod on growth of trees. *Bot. Gaz.* 117:310-326.

Drew, A. P. 1983. Optimizing growth and development of 2-0 Douglas fir seedlings by altering light intensity. *Can. J. Forest Research.* 13(3):425-428.

Eakes, D. J., W. J. Foster, C. H. Gilliam and J. W. Olive. 1990. Effects of method of application and rate of three slow release fertilizers. *SNA Research Conf.* 35:55-56.

Eco-Watch. 1994. Clinton gives nod to natives. *Am. Nurseryman* 180(2):130.

Edmonds, John. 1980. *Container plant manual*. Grower Books, London.

- Ehrlich, Paul R. 1988. The loss of diversity; causes and consequences. *In* Wilson, E. O. (ed.), *BioDiversity*. National Academy Press, Washington DC.
- Frett, J. L. and M. A. Dirr. 1979. Scarification and stratification requirements for seeds of *Cercis canadensis* L. (redbud), *Cladrastis lutea* (Michx. F.) C. Koch (yellowwood) and *Gymnocladus dioica* (L.) C. Koch (Kentucky coffeetree). *Plant Propagator* 25(2):4-6.
- Galea, Victor J. and Richard C. D. Poli. 1994. The potential for the use of VA mycorrhizae in nursery crop production. *Comb. Proc. Int. Plant Prop. Soc.* 44:52-58.
- Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. *Am. Nurseryman* 184(4):47-55.
- Garner, W. W. and H. A. Allard. 1920. Effect of the relative length of day and night and other factors of the environment on growth and reproduction in plants. *J. Agric. Research* 18:553-606.
- Garner, W. W. and H. A. Allard. 1923. Further studies in photoperiodism, the response of the plant to relative length of day and night. *J. Agric. Research* 23:871-920.
- Geneve, R. L., S. T. Kester and S. El-Shall. 1990. In vitro shoot initiation in Kentucky coffeetree. *HortScience* 25(5):578.
- Gibson, J. and C. E. Whitcomb. 1978. Effects of container size and fertility levels on the growth of tree seedlings in square bottomless containers. Oklahoma State University Agric. Exp. Station Research Report No.P-777.
- Gilman, Edward F. 1997. *Trees for urban and suburban landscapes*. Delmar Publishers, Albany, NY.
- Goodale, T. W. and C. E. Whitcomb. 1980. Producing woody ornamental shrubs in containers, influence of fertility level and container size. *Ornamentals South* 2(3):10-13.
- Goss, James A. 1973. *Physiology of plants and their cells*. Pergamon Press Inc., Elmsford, NY.
- Håbjørg, A. 1972. Effects of light quality, light intensity and night temperature on growth and development of three latitudinal populations of *Betula pubescens* Ehrh. *Inst. Den. and Nursery Manage., Agric. Univ. Norway, Rep.* No. 47.
- HacsKaylo, Edward. 1972. Mycorrhiza: the ultimate in reciprocal parasitism? *BioScience* 22(10):577-583.

- Hacsckaylo, E. and A. G. Snow. 1959. Relation of soil nutrients and light to prevalence of mycorrhizae. USDA Sta. Paper No. 125, North Eastern For. Serv.
- Hanson, P. J., R. K. Dixon and R. E. Dickson. 1987. Effect of container size and shape on the growth of northern red oak seedlings. *HortScience*. 22(6):1293-1295.
- Hatch, A. B. 1937. The physical basis of mycotrophy in the genus *Pinus*. Black Rock For. Bull. vol. 6.
- Henderson, Janet C. and David L. Hensley. 1987. Effect of a hydrophilic gel on seed germination of three tree species. *HortScience* 22(3):450-452.
- Hightshoe, Gary L. 1988. Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers. Van Nostrand Reinhold, New York.
- Hummel, Rita L. and Diane W. Privett. 1991. Effect of slow-release fertilizer rate on root and shoot growth of container-grown *Kalmia latifolia* 'Elf', 'Freckles' and 'Goodrich'. *Comb. Proc. Int. Plant Prop. Soc.* 41:278-282.
- Jester, J. R. and P. J. Kramer. 1939. The effect of the length of day on the height growth of certain forest tree seedlings. *J. Forestry* 37:797-803.
- Junttila, Olavi. 1980. Effects of photoperiod and temperature on apical growth cessation in *Salix* and *Betula*. *Physiol. Plant* 48:347-352.
- Kendrick, B. 1992. The fifth kingdom (2nd ed.). Focus Texts, Focus Information Group, Inc. Newburyport, MA.
- Kienholz, R. 1941. Seasonal course of height growth in some hardwoods in Connecticut. *Ecology* 22:249-258.
- King, D. A., J. L. White and W. W. Shaw. 1991. Influence of urban wildlife habitats on the value of residential properties. In Adams, L. W. and D. L. Leedy (eds.), *Wildlife Conservation in Metropolitan Environments*. National Institute for Urban Wildlife, Columbia, MD.
- Klein Jr., Robert Nicholas. 1997. Influence of biotic and abiotic factors on the epidemiology of beech bark disease in the Great Smoky Mountain National Park. University of Tennessee, Knoxville. M.S. Thesis.
- Knezick, Donald R. 1994. Responding to the increased demand for native plants. *Comb. Proc. Int. Plant Prop. Soc.* 44:559-561.
- Kozlowski, Theodore T. 1971. Growth and development of trees. Academic Press, Inc. New York.

- Kozlowski, Theodore T. and Stephen G. Pallardy. 1997. Physiology of woody plants. Academic Press, Inc., San Diego, CA.
- Kramer, P. J. 1936. Effect of variation in length of day on growth and dormancy in trees. *Plant Physiology* 11:127-137.
- Kramer, P. J. and K. M. Wilbur. 1949. Absorption of radioactive phosphorous by mycorrhizal roots of pine. *Science* 110:8-9.
- Krugman, Stanley L., William I. Stein and Daniel M. Schmitt. 1974. Seed biology. *In* U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.
- Kuehny, Jeff S. and D. R. Decoteau. 1994. Interrelationship of nitrogen and light on episodic growth of *Ligustrum japonicum*. *J. Environ. Hort.* 12(1):43-46.
- Laiche Jr., A. J. and S. E. Newman. 1990. Effects of container size and fertilizer rate on growth of *Rhododendron* 'Formosa' and *Ilex* 'Nellie R. Stevens' plants. *Comb. Proc. Int. Plant Prop. Soc.* 39:354-360.
- Lamb, J. G. D., J. C. Kelley and P. Bowbrick. 1975. Nursery stock manual. Grower Books, London.
- Lang, G. A., J. D. Early, G. C. Martin and R. L. Darnell. 1987. Endo-, para- and ecodormancy: Physiological terminology and classifications for dormancy research. *HortScience* 22:371-377.
- Langlois, C. Gilles and J. Andre Fortin. 1981. Mycorrhizal development on containerized tree seedlings. *In* Scarratt, J. B., C. Glerum and C. A. Plexman. Proceedings of the Canadian containerized tree seedling symposium. Dept. of the Environment, Canadian Forest Service, Ontario, Canada.
- Linderman, R. G. 1981. Mycorrhizae in relation to container plant production. *Comb. Proc. Int. Plant Prop. Soc.* 32:434-442.
- Little, Elbert L. 1986. The Audubon Society field guide to North American trees: eastern region. Alfred A. Knopf, Inc. New York.
- Liu, N. Y., H. Khatamian, and T. A. Fretz. 1981. Seed coat structure of three woody legume species after chemical and physical treatments to increase seed germination. *J. Amer. Soc. Hort. Sci.* 106(5):691-694.
- Logan, K. T. 1965. Growth of tree seedlings as affected by light intensity. I. white birch, yellow birch, sugar maple and silver maple. *Can. Dep. Forest. Publication* 1121.
- Logan, K. T. 1966. Growth of tree seedlings as affected by light intensity. III. basswood and white elm. *Can. Dep. Forest. Publication* 1176.

Logan, K. T. 1973. Growth of tree seedlings as affected by light intensity. V. white ash, beech, eastern hemlock and general conclusions. Can. Forest. Serv. Publication 1323.

Martin, George C. 1991. Bud dormancy in deciduous fruit trees. In Steward, F. C. and R. G. S. Bidwell (eds.). Plant physiology: a treatise vol. X: growth and development. Academic Press, Inc. San Diego, CA.

Marx, D. H. 1969. The influence of ectotrophic mycorrhizal fungi on the resistance of pine roots to pathogenic infections II. Production, identification and biological activity of antibiotics produced by *Leucopaxillus cerealis* var. *Piceina*. Phytopath. 59:144-417.

Marx, D. H. 1970. The influence of ectotrophic mycorrhizal fungi on the resistance of pine roots to pathogenic infections V. Resistance of mycorrhizae to infection by vegetative mycelium of *Phytophthora cinnamomi*. Phytopath. 60:1472-1473.

McConnell, D. B. 1988. Container size and potting medium affect growth rate of weeping fig and loquat. Proc. of the Florida State Hort. Soc. 100:337-339.

Melin, E. and H. Nilsson. 1957. Transport of C¹⁴ labeled photosynthate to the fungal associate of pine mycorrhiza. Svensk Bot. Tidskr. 51:166-186.

Melin, E., H. Nilsson and E. Hacskeylo. 1958. Translocation of cations to seedlings of *Pinus virginiana* throughout mycorrhizal mycelia. Bot. Gaz. 119:241-246.

Milbocker, Dan. 1991. Efficiency of nutrient uptake for slow-release fertilization. SNA Research Conf. 36:77-78.

Milbocker, Daniel C. 1992. The relationship between container size, fertilization and plant growth. SNA Research Conf. 37:81-83.

Mize, C. W. and R. V. Lea. 1979. The effect of beech bark disease on the growth and survival of beech in northern hardwoods. European. J. For. Pathol. 9:243-248.

Murray, C. L., G. P. Lumis and Calvin Chong. 1996. Fertilizer method and container size effects on shade trees grown in in-ground containers. Can. J. Plant Sci. 76(3):507-513.

National Register of Big Trees. 1996. The 1996-97 National Register of Big Trees. Am. Forests 102(1):20-46.

National Wildlife Federation. 1997.
<http://www.nwf.org/nwf/habitats/greener/natives/index.html>

Nelson, Paul V. 1991. Greenhouse operation and management. Prentice Hall, Englewood Cliffs, NJ.

Newman, S. E. and M. W. Follett. 1988. Irrigation frequency and shading influences on water relations and growth of container-grown *Euonymus japonica* 'Aureo-marginata'. J. Environ. Hort. 6:96-100.

Nitsch, J. P. 1957a. Growth responses of woody plants to photoperiodic stimuli. Amer. Soc. Hort. Sci. Proc. 70:512-525.

Nitsch, J. P. 1957b. Photoperiodism in woody plants. Amer. Soc. Hort. Sci. Proc. 70:526-544.

Noggle, Ray G. and George J. Fritz. 1976. Introductory plant physiology. Prentice Hall, Inc., Englewood Cliffs, NJ.

Peattie, Donald Culross. 1991. A natural history of trees of eastern and central North America. Houghton Mifflin Co., Boston, MA.

Perry, T. O. 1971. Dormancy of trees in winter. Science 171:29-36.

Peterson, J. C. 1982. Effects of pH upon nutrient availability in a commercial soilless root medium utilized for floral crop production. Ohio Agr. Res. and Devel. Center Res. Cir. 268, pp16-19.

Phillips, Leonard E. 1999. Top ten urban trees of '98. Arbor Age 19(3):8-12.

Poole, R. T. and C. A. Conover. 1979. Influence of container size, fertilizer level and area or volume rate basis on schefflera growth. Soil and Crop Science Soc. of Florida Proc. 38:4-5.

Raven, Peter H. 1988. Our diminishing tropical forests. In Wilson, E. O. (ed.), BioDiversity. National Academy Press, Washington DC.

Read, R. A. and W. T. Bagley. 1967. Response of tree seedlings to extended photoperiod. USDA Forest Service Research Paper RM-30.

Reid, David M., Frederick D. Beall and Richard P. Pharis. 1991. Environmental cues in plant growth and development. In Steward, F. C. and R. G. S. Bidwell (eds.). Plant physiology: a treatise vol. X: growth and development. Academic Press, Inc. San Diego, CA.

Rousseau, J. V. D., D. M. Sylvia and A. J. Fox. 1994. Contribution of ectomycorrhiza to the potential nutrient-absorbing surface of pine. New Phytol. 128:639-644.

Rudolf, P. O. and W. B. Leak. 1974. *Fagus* Ehr. Beech. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.

Rudolf, P. O. and H. Phipps. 1974. *Carpinus* L. Hornbeam. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.

Rushmore, F. M. 1961. Silvical characteristics of beech. U.S. Forest Service, NE Forest Exp. Station., Sta. Paper 161.

Sabuco, John J. 1990. Exploring the native range: part 1. Am. Nurseryman 172:10, 28-30, 32-37.

Sain, R. E. and K. E. Blum. 1981. Seedling production in the high-elevation beech (*Fagus grandifolia* Ehrh.) forests of the Great Smoky Mountains National Park Tennessee. Castanea 46(3):217-224.

Salisbury, Frank B. and Cleon W. Ross. 1978. Plant physiology. Wadsworth Publishing Company, Inc. Belmont, CA.

Sander, Ivan L. 1974. *Gymnocladus dioica* (L.) K. Koch Kentucky coffeetree. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.

Sheppard III, R. and H. Pellett. 1976. Light intensity effects on red osier dogwood. HortScience 11:200-202.

Smith, M. A. L. and A. A. Obeidy. 1991. Micropropagation of a mature, male Kentucky coffeetree. HortScience 26(11):1426.

Smith, S. E. 1980. Mycorrhizas of autotrophic higher plants. Biol. Rev. 55:475-510.

South, David B., Janusz B. Zwolinski and John B. McRae. 1994. Influence of container size and spacing on first-year field performance of *Pinus taeda*. SNA Research Conf. 39:104-105.

Spencer, Henry A. 1981. Opportunities for improvement in containerized reforestation-an independent view. In Scarratt, J. B., C. Glerum and C. A. Plexman. Proceedings of the Canadian containerized tree seedling symposium. Dept. of the Environment, Canadian Forest Service, Ontario, Canada.

Stalter, Richard. 1982. Production of viable seed by the American beech (*Fagus grandifolia*). Bull. Torrey Bot. Club 109(4):542-544.

Sternberg, Guy. 1996. Getting friendly with the natives. Am. Nurseryman 184(6):36-47.

Sydnor, T. Davis. 1998. The response of Ohio's native and naturalized trees to construction activity. Landscape Plant News 9(1).

- Sylvia, David M. 1998. Mycorrhizal symbioses. *In* Sylvia, D. M., Jeffry J. Fuhrmann, Peter G. Hartel and David Zuberer (eds.), Principles and applications of soil microbiology. Prentice Hall, Upper Saddle River, NJ. www.ifas.ufl.edu/~dmsa/refram.htm
- Taylor, J. S. and E. B. Dumbroff. 1975. Bud, root and growth regulator activity in *Acer saccharum*. *Planta* 104:110-114.
- Tilt, K. M., T. E. Bilderback and W. C. Fonteno. 1987. Particle size and container size effects on growth of three ornamental species. *J. Amer. Soc. Hort. Sci.* 112(6):981-984.
- Tilt, Ken, Ronald Shumack and John Olive. 1991. Effects of container size and sub-irrigation on growth of two tree species. *SNA Research Conf.* 36:93-95.
- Trappe, J. M., J. F. Franklin, R. F. Tarrant and G. M. Hansen (eds.). 1967. Biology of Alder. Proc. of a Symposium held at N. W. Sci. Assoc., 40th Ann. Meeting, Pullman, Washington.
- U. S. Congress Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. U.S. Government Printing Office. Washington D. C. OTA-F565.
- Vitousek, Peter M. 1988. Diversity and biological invasions of oceanic islands. *In* Wilson, E. O. (ed.), BioDiversity. National Academy Press, Washington DC.
- Vitousek, Peter M. 1997. Stopping biological invasions before they do lasting damage. *The Chronicle of Higher Education*, Inc. 01/17/97. <http://chronicle.com>
- Vozzo, J. A. and E. Hacskeylo. 1971. Inoculation of *Pinus caribaea* with ectomycorrhizal fungi in Puerto Rico. *For. Sci.* 17:239-245.
- Walker, N. R. and H. J. Johnson. 1980. Containerized conifer seedling field performance in Alberta and the Northwest Territories. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-218.
- Went, F. W. and N. Stark. 1968. Mycorrhiza. *BioScience* 18(11):1035-1039.
- Whitcomb, Carl E. 1984. Plant production in containers. Lacebark Publications, Stillwater, OK.
- White, D. P. 1941. Prairie soil as a medium for tree growth. *Ecology* 22: 398-407.
- Winstead, J. E., Smith, B. J. and G. I. Wardell. 1977. Fruit weight clines in populations of ash, ironwood, cherry, dogwood and maple. *Castanea* 42(1): 56-60.

Part 2

The Effects of Various Warm and Cold Stratification Treatments on Germination of *Carpinus caroliniana* Seeds

Abstract

Carpinus caroliniana Walter (American hornbeam) seeds were subjected to 0, 2, 4 or 8 weeks of warm stratification and 4, 8, 12, 16, 20 or 24 weeks of cold stratification. Results indicated that germination was greater after 20 or 24 weeks of cold stratification (57 to 61%, respectively) compared to 4, 8, 12 or 16 weeks. Germination was further increased after 4 or 8 weeks of warm stratification compared to 0 or 2 weeks. An interaction was found to exist between length of warm stratification and length of cold stratification. Increased period of warm stratification decreased the amount of cold stratification required to maintain a certain level of germination.

Introduction

C. caroliniana is a small, deciduous tree indigenous to much of the eastern United States. The sinewy texture of its smooth, gray bark resembles the bark of *Fagus* (beech) or a twisted, flexed muscle. *C. caroliniana* is valued for ornamental purposes in the naturalized landscape. Its fall color is reported as being "exceptionally showy burnt-orange or red to yellow" (Gilman 1997). Recently, *C. caroliniana* was listed as one of the seventh least available trees and one of the five species with the slowest growth rates among a list of 59 species that municipalities desired for street trees (Gamstetter and Gulick 1996). It was also listed as being one of the most difficult species to propagate.

The U.S. Forest Service's book Seeds of Woody Plants in the U.S. recommends warm (15/30C) stratification for 60 days followed by cold (5C) stratification for 60 days (Rudolf and Phipps 1974). Following this method, Bretzloff and Pellett (1979) reported 10% germination. They determined that lengthening the cold stratification period to 18 weeks increased germination to 58% and warm stratification (prior to cold stratification) had no effect on germination. The objective of this study was to determine the effect of various warm and cold stratification periods on germination.

Materials and Methods

Plant Materials

170 grams (6 ounces) or approximately 11,000 *C. caroliniana* seeds were obtained from F. W. Schumacher Co., Inc. (Sandwich, MA) in October 1996. Seeds were kept in cold, dry storage (4C) until initiation of the experiment. Prior to the experiment, seeds were soaked in room temperature tap water for 17 hours to separate viable seeds from nonviable seeds (Bretzlöff and Pellett 1979). Floating seeds were assumed to be nonviable. Viable seeds were dusted with Hi-Yield Captan Fungicide - 50%WP (Voluntary Purchasing Groups, Inc., Bonham, TX) at a rate of 5.3 grams per kilogram of seed (1/2 teaspoon per 1 lb.) to decrease risk of fungal contamination.

Treatments and Experimental Design

Seeds were divided into groups of 10 and placed in sterile labeled petri plates with approximately 1 cm of moistened, sterile sand. On 1 November 1996 seed treatments (Table 2-1)¹ were initiated. The experimental design was a split plot design with main plots consisting of 4 warm stratification periods (0, 2, 4 or 8 weeks) and subplots consisting of 6 cold stratification periods (4, 8, 12, 16, 20 or 24 weeks). There were 5 replications of each treatment with 10 seeds per experimental unit. The experiment was conducted at the Racheff Research Building at the University of Tennessee, Knoxville, TN.

Cultural Practices

During the warm stratification periods, petri plates were kept in a cloth covered plastic tray in a greenhouse where temperatures were maintained between 22 and 26C. During the cold stratification period, seeds were stored in a refrigerator at 1 to 4C. Seeds were checked weekly. When additional moisture was required, seeds were sprayed with sterile, deionized water.

¹ All tables and figures may be found in the Appendix.

Sampling and Analysis

Upon completion of cold stratification, petri plates were placed on a greenhouse bench where temperatures were maintained between 22 to 26C. High pressure sodium lights were used to extend the photoperiod to 16 hours. Petri plates were checked daily for newly germinated seeds. To minimize error, germinated seeds were removed from the germination area.

On 17 February 1997, a white-footed mouse (*Peromyscus leucopus*) opened several petri plates and ate many seeds in the germination area. Thus the petri plates were moved to a higher bench and the mouse hole was sealed. After 12 weeks, it was assumed that the seeds would not germinate.

Data was subjected to an analysis of variance (ANOVA) to determine the significance of the stratification treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

Germination increased as the cold stratification period increased and was greatest after 20 or 24 weeks of cold stratification (57 and 61%, respectively) (Table 2-2). Germination after 16 weeks of cold stratification (38%) was greater compared to 8 or 12 weeks of cold stratification (13 and 22%, respectively). Eight or 12 weeks cold stratification increased germination compared to 4 weeks of cold stratification (3% germination). There appeared to be no advantage for seed germination to extend cold stratification to 24 weeks. Germination of *C. caroliniana* seeds was further increased after 4 or 8 weeks warm stratification (prior cold stratification) compared to 0 or 2 weeks warm stratification (Table 2-2).

An interaction occurred between length of warm stratification period and length of cold stratification period. Increased length of warm stratification, decreased the amount of cold stratification required to maintain a certain level of germination.

The results from this research are consistent with the U.S. Forest Service's book Seeds of Woody Plants in the U.S. which recommended a 60-day warm (15/30C) stratification period prior to a 60-day cold (5C) stratification period (Rudolf and Phipps 1974). Bretzloff and Pellett (1979) reported 10% germination under these conditions. Following this schedule, our research resulted in 40% germination. Bretzloff and Pellett also determined that lengthening the cold stratification period to 18 weeks increased germination to 58%. After 16 and 20 weeks of cold stratification, our research resulted in 38 and 57% germination, respectively. Bretzloff and Pellett concluded that 2 weeks of warm stratification (prior to cold stratification) did not increase germination. Our work showed similar results with 2 weeks of warm stratification. However, our findings concluded that 4 or 8 weeks of warm stratification resulted in increased germination.

A similar experiment was repeated in 1998 but only 3 seeds (of 2000 seeds) germinated. Gamstetter and Gulick (1996) listed *C. caroliniana* as being one of the most difficult species to propagate. According to Browse (1979), "hornbeam is erratic in its seedbearing habits, producing good crops of sound viable seed every 2 to 4 years". Therefore, a good source of viable seed is a crucial factor in the production of *C. caroliniana*. In conclusion, the best germination in this experiment resulted from 4 weeks warm stratification followed by 20 or 24 weeks cold stratification (66 and 72% germination, respectively).

Literature Cited

- Bretzloff, L.V. and N. E. Pellett. 1979. Effect of stratification and gibberellic acid on the germination of *Carpinus caroliniana*. HortScience 14(5):621-622.
- Browse, P. D. A. McMillan. 1979. Hardy woody plants from seed. Grower Books, London.
- Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. Am. Nurseryman 184:47-55.

Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.

Rudolf, P. O. and H. Phipps. 1974. *Carpinus* L. Hornbeam. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.

Appendix

Table 2-1. Warm and cold stratification treatments.

treatment	weeks in warm stratification	weeks in cold stratification
1	0	4
2	0	8
3	0	12
4	0	16
5	0	20
6	0	24
7	2	4
8	2	8
9	2	12
10	2	16
11	2	20
12	2	24
13	4	4
14	4	8
15	4	12
16	4	16
17	4	20
18	4	24
19	8	4
20	8	8
21	8	12
22	8	16
23	8	20
24	8	24

Table 2-2. Effect of various warm and cold stratification periods on germination of *Carpinus caroliniana* seeds.

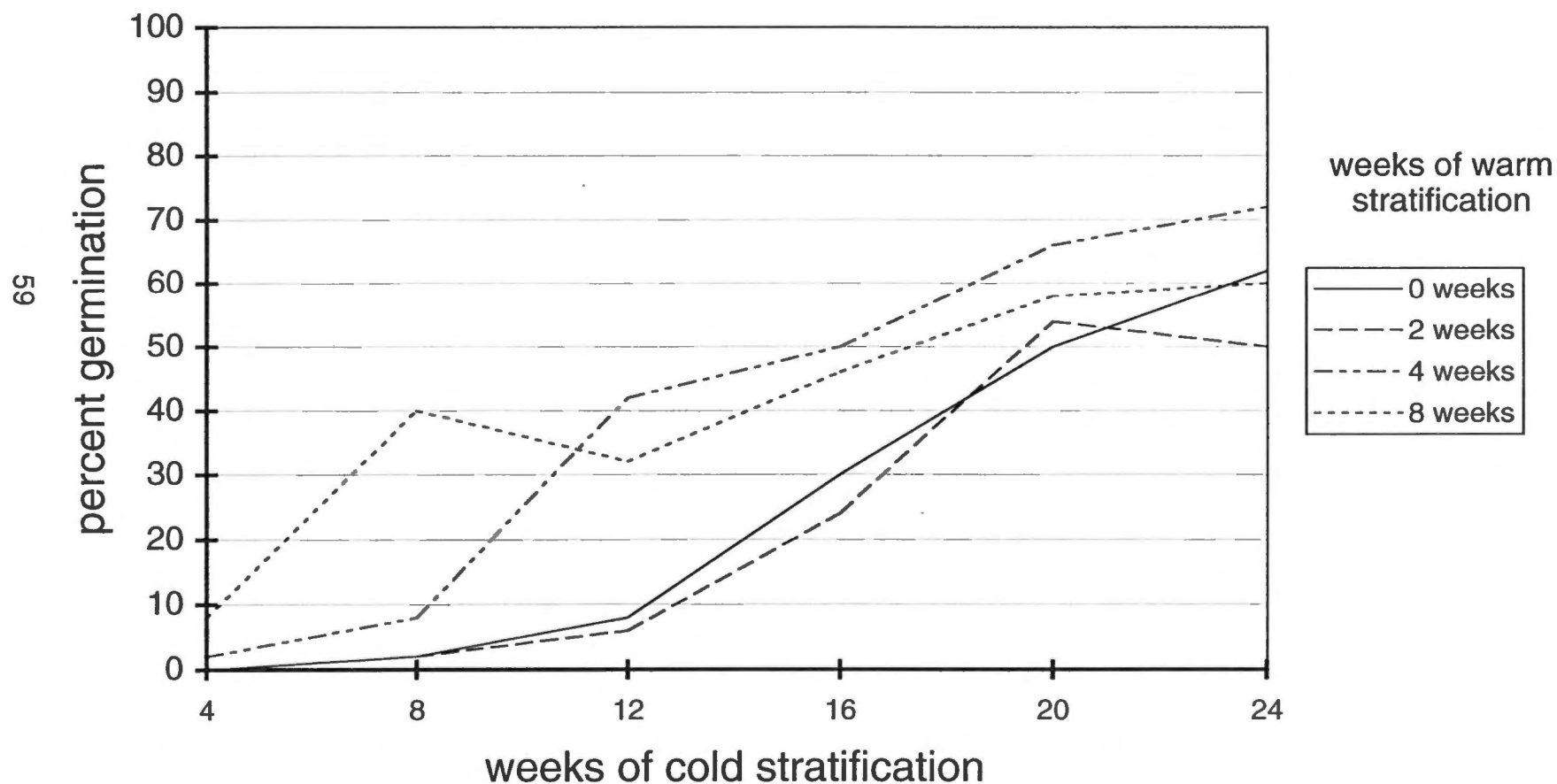
weeks in warm stratification	percent ^z germinated	weeks in cold stratification	percent ^y germinated
0	25b ^x	4	3d
2	23b	8	13c
4	40a	12	22c
8	41a	16	38b
		20	57a
		24	61a

^z 300 seeds per replication and 10 seeds per experimental unit

^y 200 seeds per replication and 10 seeds per experimental unit

^x Means within a column followed by the same letter are not significantly different by LSD at $p=0.05$.

Figure 2-1. Percent germination of *Carpinus caroliniana* seeds after several warm and cold stratification periods.



Part 3

The Effects of Three Cold Stratification Treatments on Germination of *Fagus grandifolia* Seeds

Abstract

Fagus grandifolia Ehrhart (American beech) seeds were subjected to 12, 14 or 16 weeks cold stratification. Results indicated that germination was greater after 14 or 16 weeks cold stratification. The critical factor in working with *F. grandifolia* is finding a reliable source of viable seed. During the years 1996 and 1997, *F. grandifolia* seed could not be found at any of the major seed companies. Therefore seeds were collected locally. A cut test revealed that less than 33% of the seeds contained endosperm.

Introduction

F. grandifolia is indigenous to much of the eastern United States. It is highly regarded as being a major source of food for wildlife (Hightshoe 1988, Peattie 1991) and has one of the longest lifespans (300 to 400 years) of angiosperms in the eastern United States (Kozlowski 1971). *F. grandifolia* is well suited for landscape use at estates, parks, campuses, golf courses or along drives of large commercial properties (Gilman 1997, Dirr 1990). According to Dirr (1990), *F. grandifolia* outgrows and outperforms the smaller European beech, *F. sylvatica*, in the southeastern United States.

F. grandifolia seeds require cold (5C) stratification for 90 days to break dormancy (Rudolf and Leak 1974, Dirr 1990) but seed viability can be highly variable. Generally, heavy seed crops are produced every 2 to 3 years (Dirr 1990). During 'off' years, fruits are produced but the seeds are void (Browse 1979). Possible reasons for the poor viability are poor pollination, self sterility and frost (Stalter 1982). In 1970, Stalter determined seed viability to be highly variable, ranging from 0% in Knoxville, TN to 20% in East Lansing, MI and 70% in Cayce, SC.

Although *F. grandifolia* is reported to have considerable landscape merit, little research has been conducted on its cultural requirements. Therefore, the purpose of this germination study was to determine the germination capacity of seeds from available seed sources after different periods of cold stratification.

Materials and Methods

Plant Materials and Cultural Practices

In September 1998, approximately 3000 *F. grandifolia* seeds were collected in middle Tennessee at the General Motors Saturn Corporation factory near Spring Hill, TN. Seeds were also collected in east Tennessee at a residence in Blount Co. All seeds were cleaned, dried and kept in cold storage (4C) until the initiation of the experiment, when they were soaked in tap water at room temperature for 18 hours to separate viable seeds. Floating seeds were assumed to be nonviable (Browse 1979). Viable seeds were sterilized with 10% bleach (5.25% sodium hypochlorite) and dusted with Hi-Yield Captan Fungicide - 50%WP (Voluntary Purchasing Groups, Inc., Bonham, TX) at a rate of 5.3 grams per kilogram of seed (1/2 teaspoon per 1 lb.) to decrease risk of fungal contamination.

Treatments and Experimental Design

Seeds were divided into groups of 195 and mixed with moist peat and placed inside sterile, plastic jars. Three cold stratification periods were tested: (1) 12 weeks cold stratification - initiated 27 November 1997, (2) 14 weeks cold stratification - initiated 13 November 1997 and (3) 16 weeks cold stratification - initiated 30 October 1997. During the cold stratification period, seeds were kept in a refrigerator at 1 to 4C. Seeds were checked weekly and sprayed with sterile, deionized water when additional moisture was required.

The experiment was arranged in a randomized complete block design. There were 3 replications of each treatment with 195 seeds in each experimental unit. The experiment was conducted at the Racheff Research Building at the University of Tennessee, Knoxville, TN.

Sampling and Analysis

Upon completion of cold stratification, plastic jars were moved to a greenhouse bench where temperatures were maintained between 22 and 26C.

High pressure sodium lights were used to extend the photoperiod to 16 hours. Plastic jars are checked daily for newly germinated seeds which were removed from the germination area.

Data was subjected to an analysis of variance (ANOVA) to determine the significance of the stratification treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

Germination of *F. grandifolia* seeds increased after 14 or 16 weeks of cold stratification compared to 12 weeks of cold stratification (Table 3-1)¹. However, germination was poor among all treatments (ranging between 0.7 to 4.4%). A cut test revealed that none of the seeds collected at the residence in Blount Co., TN had endosperm while 33.3% of the seeds collected at the General Motors Saturn Corporation factory in Spring Hill, TN had endosperm. When seeds were separated by flotation, 90% of the seeds that sank had endosperm while over 90% of the seeds that floated lacked endosperm (were hollow).

During 1996 and 1997, *F. grandifolia* seeds could not be found at any of the major seed companies. In 1997, we were able to obtain previously stratified seed from Darrell Kronne of Reeseville Ridge Nursery, Reeseville, WI (920 927 3291). Of the donated seed, 73 germinated while 140 failed to germinate (34% germination). Beech trees exhibit periodic seed production (Dix and Skrentny 1965, Browse 1979). According to Lamb et al. (1975), *F. sylvatica* produces heavy seed crops every 5 to 7 years. Thus, a critical factor in working with *F. grandifolia* is locating a source of viable seed.

Literature Cited

Browse, P.D.A. McMillan. 1979. Hardy woody plants from seed. Grower Books, London.

¹ All tables and figures may be found in the Appendix.

- Dirr, Michael A. 1990. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. 4th ed. Stipes Publishing Co., Champaign, IL.
- Dix, R. L. and R. F. Skrentny Jr. 1965. Reproduction of *Fagus grandifolia* Ehrh. by seed in Wisconsin. Can. J. Bot. 43:757-763.
- Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.
- Hightshoe, Gary L. 1988. Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers. Van Nostrand Reinhold, New York.
- Kozlowski, Theodore T. 1971. Growth and development of trees. Academic Press, Inc. New York.
- Lamb, J. G. D., J. C. Kelley and P. Bowbrick. 1975. Nursery stock manual. Grower Books, London.
- Peattie, Donald Culross. 1991. A natural history of trees of eastern and central North America. Houghton Mifflin Co., Boston, MA.
- Rudolf, P. O. and W. B. Leak. 1974. *Fagus* Ehr. Beech. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.
- Stalter, Richard. 1982. Production of viable seed by the American beech (*Fagus grandifolia*). Bull. Torrey Bot. Club 109(4):542-544.

Appendix

Table 3-1. Effect of three cold stratification periods on germination of *Fagus grandifolia* seeds^z.

weeks in cold stratification	percent germinated
12	0.68b ^y
14	3.76a
16	4.44a

^z 585 seeds per replication and 195 seeds per experimental unit

^y Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Part 4

The Effects of Three Sulfuric Acid Scarification Treatments on Germination of *Gymnocladus dioicus* Seeds

Abstract

Gymnocladus dioicus (L.) K. Koch (Kentucky coffeetree) seeds were scarified with concentrated sulfuric acid (95% H₂SO₄) for 2, 4 or 8 hours. There was no effect of scarification time on germination which ranged between 87 and 95%.

Introduction

G. dioicus is a medium to large sized, deciduous native tree. Its natural range extends from New York and Pennsylvania, west to Minnesota, south to Oklahoma and east to Kentucky and Tennessee (Sander 1974). In the wild, populations are scattered and rare (Little 1986). The leaves are showy yellow in the fall and Gilman (1997) reports that it is well adapted to a wide range of soil conditions, tolerates drought and performs well in the urban environment. *G. dioicus* is considered by many plantsmen to be a choice tree for large areas such as parks and golf courses (Dirr 1990). In 1998, *G. dioicus* was listed to be one of the top ten urban trees (Phillips 1999).

The seeds of *G. dioicus* have a hard, impermeable seedcoat that prevents or delays germination. Seeds should be scarified by soaking in concentrated sulfuric acid for 2 hours (Sander 1974). Liu et al. (1981) reported that 120 or 150 minutes of soaking in sulfuric acid was optimum. Frett and Dirr (1979) reported that 0, 2, 4, 8, 16 and 32 hours of acid scarification resulted in 7, 93, 100, 95, 83 and 87%. The purpose of this study was to determine the effects of three sulfuric acid scarification treatments on germination of *G. dioicus* seeds.

Materials and Methods

Thirteen pounds or approximately 3000 *G. dioicus* seeds were obtained from F. W. Schumacher Co., Inc. (Sandwich, MA) in October 1996. Seeds were kept in a cool storage cabinet (17C) until the initiation of the experiment. On 3 February 1997, seeds were divided into groups of 20 and placed in glass beakers. Treatments were: (1) 2 hour soak in concentrated sulfuric acid, (2) 4

hour soak in concentrated sulfuric acid and (3) 6 hour soak in concentrated sulfuric acid. Acid scarification was performed under a fume hood and seeds were stirred every 30 minutes to ensure uniform digestion. After the scarification period, seeds were thoroughly rinsed in cool tap water and soaked in deionized water for 24 hours. Seeds were planted immediately after removal from the deionized water in 11.5 x 11.5 x 35 cm (4.5 x 4.5 x 14 inch) Zarn tree containers (Zarn Inc., Reidsville, NC) using Fafard no. 4 (Conrad Fafard Inc., Agawan, MA), a commercially available mix of sphagnum peat, bark and vermiculite, as the growing medium. Seeds were placed on a greenhouse bench where temperatures were maintained between 20 and 29C. High pressure sodium lights were used to extend the photoperiod to 16 hours (4:30 pm to 12:30 am). Seeds were checked daily for germination.

The experiment was arranged in a randomized complete block design with three replications of each treatment and 20 seeds in each experimental unit. Acid scarification took place in the Plant Molecular Genetics laboratory at the University of Tennessee, Knoxville, TN.

Data was subjected to an analysis of variance (ANOVA) to determine the significance of the scarification treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

No differences were found between the acid scarification treatments (Table 4-1)¹. Results obtained from this research were similar to those reported by Frett and Dirr (1979). They reported 0, 2, 4, 8, 16 and 32 hours of acid scarification resulted in 7, 93, 100, 95, 83 and 87% germination. Our research resulted in 87, 95 and 87% germination for 2, 4 or 6 hours of acid scarification.

¹ All tables and figures may be found in the Appendix.

Literature Cited

- Dirr, Michael A. 1990. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. 4th ed. Stipes Publishing Co., Champaign, IL.
- Frett, J. L. and M. A. Dirr. 1979. Scarification and stratification requirements for seeds of *Cercis canadensis* L. (redbud), *Cladrastis lutea* (Michx. F.) C. Koch (yellowwood) and *Gymnocladus dioicus* (L.) C. Koch (Kentucky coffeetree). Plant Propagator 25(2):4-6.
- Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.
- Little, Elbert L. 1986. The Audubon Society field guide to North American trees: eastern region. Alfred A. Knopf, Inc. New York.
- Liu, N. Y., H. Khatamian and T. A. Fretz. 1981. Seed coat structure of three woody legume species after chemical and physical treatments to increase seed germination. J. Amer. Soc. Hort. Sci. 106(5):691-694.
- Phillips, Leonard E. 1999. Top ten urban trees of '98. Arbor Age 19(3):8-12.
- Sander, Ivan L. 1974. *Gymnocladus dioicus* (L.) K. Koch Kentucky coffeetree. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.

Appendix

Table 4-1. Effect of three sulfuric acid scarification periods on germination of *Gymnocladus dioicus* seeds^z.

hours scarified	percent germinated
2	86.5a ^y
4	95.0a
6	86.5a

^z 60 seeds per replication and 20 seeds per experimental unit

^y Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Part 5

The Effects of Extended Photoperiod and Light Quality
on Growth of *Carpinus caroliniana*, *Fagus grandifolia*
and *Gymnocladus dioica* Seedlings

Abstract

Carpinus caroliniana Walter (American hornbeam), *Fagus grandifolia* Ehrhart (American beech) and *Gymnocladus dioicus* (L.) K. Koch (Kentucky coffeetree) seedlings were planted into 4 x 4 x 10 cm (2 x 2 x 4 inch) cardboard bands, 5.3 x 5.3 x 20.5 cm (2 x 2 x 8 inch) cardboard bands and 11.5 x 11.5 x 35 cm (4.5 x 4.5 x 14 inch) plastic tree containers, respectively, using a commercially available media consisting of sphagnum peat, bark and vermiculite. Plants were subjected to three light treatments: 18 hour photoperiod using high pressure sodium lights (HPS), 18 hour photoperiod using incandescent lights (INC) and natural light and daylength (NAT).

Stem height of *C. caroliniana* seedlings was greater when grown under HPS light as compared with NAT light (7.4 and 5.5 cm, respectively). However, there was no difference in stem height of seedlings grown under INC light (6.7 cm) compared to HPS or NAT light. Stem height of *F. grandifolia* was greater for the HPS and INC light treatments (11.5 and 9.9 cm, respectively) compared with the NAT light treatment (7.5 cm).

In 1997, stem height and caliper of *G. dioicus* was different for each of the light treatments with HPS light resulting in the greatest growth (22.6 cm). In 1998, stem height and caliper and shoot and root dry weight was greatest under the HPS and INC light treatments compared with the NAT light treatment. This difference in growth was likely a result of the percent of seedlings that produced a second flush of growth.

Introduction

C. caroliniana and *F. grandifolia* are deciduous trees indigenous to much of the eastern United States. *C. caroliniana* is valued for ornamental purposes in the naturalized landscape. Its fall color is reported as being "exceptionally showy burnt-orange or red to yellow" (Gilman 1997). Recently, it was listed as one of the seventh least available trees and one of the five species with the

slowest growth rates among a list of 59 species that municipalities desired for street trees (Gamstetter and Gulick 1996).

F. grandifolia is highly regarded as a major source of food for wildlife (Hightshoe 1988, Peattie 1991) and has one of the longest life spans (300 to 400 years) of angiosperms in the eastern United States (Kozlowski 1971). This species is well suited for planting at estates, parks, campuses, golf courses or along drives of large commercial properties (Gilman 1997, Dirr 1990). According to Dirr (1990), *F. grandifolia* outgrows and outperforms the smaller European beech, *F. sylvatica*, in the southeastern United States.

G. dioicus is a medium to large sized, deciduous native species. The natural range of *G. dioicus* extends from New York and Pennsylvania, west to Minnesota, south to Oklahoma and east to Kentucky and Tennessee (Sander 1974). In the wild, populations are scattered and rare (Little 1986). The leaves are showy yellow in the fall and Gilman (1997) reports that it is well adapted to a wide range of soil conditions, tolerates drought and performs well in the urban environment. *G. dioicus* is considered by many plantsmen to be a choice tree for large areas such as parks and golf courses (Dirr 1990). In 1998, *G. dioicus* was listed to be one of the top ten urban trees (Phillips 1999).

Numerous studies have demonstrated that the period of vegetative growth of trees can be extended by increasing daylength, especially in young seedlings. For example, Read and Bagley (1967) found that several species of seedlings grew faster under extended and continuous photoperiod versus those grown in standard practice (seedbed). In another study, it was concluded that several species (*Koelreuteria paniculata* Laxm. (flametree), *Magnolia x soulangeana* Soul.-Bod. (saucer magnolia), *Quercus palustris* Muenchh. (pin oak) and *Prunus caroliniana* (Mill.) Ait. (Carolina cherry) grew taller under continuous, incandescent light (Cope 1981). Blazich et al. (1994) determined that *Oxydendrum arboreum* (L.) DC. (sourwood) seedlings grown under long days had significantly greater shoot dry weights than those grown under short days.

Cathey and Campbell (1979) reported the effectiveness of high and low pressure sodium lights (HPS and LPS) and incandescent lights (INC) in increasing vegetative growth for numerous species. Sixteen hour photoperiod (0800-2400) using HPS and LPS lighting significantly increased shoot growth of several species when compared to 16 hour photoperiod (2000-0400 night interruption) using INC lighting or natural light and daylength. According to Cathey and Campbell (1977), continuous, high intensity light causes delayed dormancy and an increase in photosynthesis, thus an increase in growth. Low energy, intermittent light causes only a delay in dormancy.

Day et al. (1994) determined that after two months, tissue culture maples (*Acer rubrum* L. 'Autumn Flame' and *Acer x freemanii* 'Autumn Fantasy') grown under an 18 hour photoperiod using HPS lights grew significantly taller and had greater dry weights than plants grown under an 18 hour photoperiod with INC or plants grown under natural light and daylength. Plants grown under INC lights had significantly greater height and caliper growth and dry weights than those under natural light and daylength. However, not all species respond similarly. Extended photoperiod was found to have no effect on growth of *Betula pendula* Roth (European birch) or *Liquidambar styraciflua* L. (sweetgum) (Cope 1981).

Although *C. caroliniana*, *F. grandifolia* and *G. dioicus* have considerable landscape merit, they are not grown in landscape sizes by most nurseries and are difficult to locate in garden centers. Little research has been conducted on the cultural preferences of these species. Therefore, the objective of this research was to determine the effects of extended photoperiod and light quality on seedling growth of *C. caroliniana*, *F. grandifolia* and *G. dioicus*.

Materials and Methods

Plant Materials

170 grams (6 ounces) or approximately 11,000 *C. caroliniana* seeds were obtained from F. W. Schumacher Co., Inc. (Sandwich, MA) in October

1996 and stratified over winter in a 1 to 4C refrigerator. Viable *F. grandifolia* seeds were donated by Darrell Kronne of Reeseville Ridge Nursery, Reeseville, WI (920 927 3291) on 11 February 1997. These seeds were stratified prior to their arrival. *G. dioicus* seeds were also obtained from F. W. Schumacher Co., Inc. in October 1996. These seeds were kept in a cool storage cabinet (17C) until the initiation of the experiment at which time they were scarified in concentrated sulfuric acid (95% H₂SO₄) for 4 hours and then soaked in tap water for 24 hours.

C. caroliniana, *F. grandifolia* and *G. dioicus* seedlings were potted into 4 x 4 x 10 cm (2 x 2 x 4 inch) cardboard bands (Monarch Manufacturing, Salida, CA), 5.3 x 5.3 x 20.5 cm (2 x 2 x 8 inch) cardboard bands and 11.5 x 11.5 x 35 cm (4.5 x 4.5 x 14 inch) plastic Zarn tree containers (Zarn Inc., Reidsville, NC), respectively. Fafard no. 4 (Conrad Fafard Inc., Agawan, MA), a commercially available mix of sphagnum peat, bark and vermiculite, was used as the growth medium for all plants.

Due to difficulty obtaining viable *F. grandifolia* and *C. caroliniana* seed, experiments on these species were only conducted in 1997. Experiments on *G. dioicus* were conducted in 1997 and 1998. The 1997 light studies were conducted on raised benches in a greenhouse using burlap cloth to shield adjacent treatments. In 1998, black plastic was utilized instead of burlap.

The *F. grandifolia* and *C. caroliniana* experiments were initiated on 11 and 24 February 1997, respectively. A second planting on 24 March was utilized for *C. caroliniana* due to erratic seed germination. The *G. dioicus* experiments were initiated on 5 February 1997 and 24 February 1998. For purposes of comparison, *G. dioicus* seeds were planted in a raised nursery seed bed on 21 March 1997 and 6 April 1998. Seeds were sown approximately 3.8 cm (1 1/2 inches) apart and 2.5 cm (1 inch) deep with 25.5 cm (10 inches) between rows (Sander 1974).

Treatments and Experimental Design

Treatments used in this experiment were: (1) natural light and daylength (NAT), (2) 18 hour photoperiod using 100 watt incandescent lights (INC) ($130 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$), (3) 18 hour photoperiod using 400 watt high pressure sodium lights (HPS) ($350 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$) and (4) raised seed bed (*G. dioicus* only). Lamps were kept approximately 30.5 cm (12 inches) above the plants.

The *G. dioicus* and *F. grandifolia* experiments were arranged in a randomized complete block design, keeping species separate. There were 3 replications of each light treatment. In 1997, there were 20 *G. dioicus* seedlings and 6 to 8 *F. grandifolia* seedlings per experimental unit. In 1998, there were 10 *G. dioicus* seedlings per experimental unit. The 1997 *C. caroliniana* experiment was arranged as a split plot design with the main plot being planting date (24 February or 24 March) and subplots being light treatments. This was done because of erratic seed germination. The experiment was replicated 3 times with 3 to 6 seedlings per experimental unit. All experiments took place in a greenhouse at the University of Tennessee, Knoxville, TN.

Cultural Practices

Plants were fertilized once a week for the first 3 weeks of growth with 50 ppm 20N-8.7P-16.6K (Peters 20-20-20) (Scotts-Sierra Horticultural Products Co., Marysville, OH) and watered approximately twice a week. After 3 weeks, concentration was increased to 100 ppm. Greenhouse temperatures ranged between 16 and 30C. All plants were treated with 1% granular Marathon (1% imidocloprid) (Olympic Horticultural Products, Mainland, PA).

The Virginia Tech Extraction Method was used to obtain extracts of the medium (Wright 1987, Yeager et al. 1983). Leachate samples were collected and analyzed for soluble salts and pH. Soluble salts were measured as electrical conductivity (EC) using a Myron L Agri-meter AG-5 (Myron L Co., Carlsbad, CA). pH was measured using a SA720 model Orion pH meter. EC

readings and pH measurements remained within an acceptable range (0.2 to 0.75 mmhos/cm and 5.5 to 6.9) throughout the duration of the experiment.

Sampling and Analysis

In 1997, stem height of *G. dioicus* was measured after 2, 4, 8 and 13 weeks of growth. Caliper was measured after 13 weeks. Stem heights of *C. caroliniana* and *F. grandifolia* were measured after 8 and 12 weeks of growth for *C. caroliniana* and 14 weeks of growth for *F. grandifolia*.

In 1998, stem height, caliper and root and shoot dry weight were measured for all *G. dioicus* plants on 13 October 1998. Additionally incremental growth of stem height of *G. dioicus* was measured after 4, 8 and 12 weeks of growth to determine the duration of the first flush of growth. Stem caliper was measured after 14 weeks. Dry weights of shoots and roots were collected for *G. dioicus*. Height, caliper and dry weights of seedlings grown in the seed bed were measured only at the conclusion of the experiment on 13 October 1998 (after 27 weeks).

Stem height was recorded to the nearest 0.1 cm. Stem caliper was measured 5 cm above the soil line using a Digimatic Caliper meter (Mitutoyo Corp., Tokyo, Japan). Shoots were severed from the roots at the soil line, cut into approximately 2 cm pieces and placed along with the leaves into cotton bags. Roots were rinsed free of media, cut into 4 cm pieces and placed into bags. Shoots and roots were dried at the University of Tennessee Knoxville Experiment Station, Plant Sciences Unit in a 50C drying oven. After 5 days, bags were removed from the drying oven, emptied into plastic dishes and weighed to the nearest gram.

Data was subjected to an analysis of variance (ANOVA) to determine the significance of the treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

Stem height of *C. caroliniana* seedlings was greater under HPS lighting (7.4 cm) compared to NAT lighting (5.5 cm) (Table 5-1)¹. However, there was no difference in height of seedlings grown under INC lighting (6.7 cm) compared to HPS or NAT lighting. After 14 weeks, stem height of *F. grandifolia* was greater for the HPS and INC light treatments (11.5 and 9.9 cm, respectively) when compared with the NAT light treatment (7.5 cm) (Table 5-1). There was no significant difference in stem height of *F. grandifolia* seedlings grown under INC or HPS lighting.

In 1997, stem height and caliper of *G. dioicus* were different for each of the light treatments (Table 5-1). Seedlings grown under HPS lighting had greatest height and caliper growth (22.6 cm/5.1 mm, respectively), followed by those grown under INC lighting (19.5 cm/4.4 mm) and those grown under NAT lighting (15.7 cm/3.8 mm). In 1998, stem height, caliper and shoot and root dry weight of *G. dioicus* was greatest under the HPS and INC light treatments when compared with the NAT light treatment (Tables 5-1, 5-2 and 5-3). However, there were no differences in growth of *G. dioicus* seedlings grown under INC and HPS lighting. The reason for this difference is unknown but may have been due to the effects of decreased light, temperature and other environmental effects in the rear of the greenhouse in 1998.

Under all light conditions, a major portion of the total height growth was completed within the first 4 weeks of growth (58 to 89% of the total growth) (Table 5-4). This is particularly true for the plants grown under NAT lighting. Table 5-2 shows the growth of *G. dioicus* seedlings at 4 week intervals. After 33 weeks, plants grown under INC and HPS lighting had greater growth of height and caliper (27.2 cm/4.8 mm and 25.4 cm/4.9 mm, respectively) than those grown under NAT lighting (14.7 cm/3.5 mm). These results were similar to the 12 week measurements. While seedlings under NAT light grew 4.3 cm in

¹ All tables and figures may be found in the Appendix.

height between the 12th and 33rd week, the INC and HPS seedlings grew 9.7 and 8.9 cm, respectively.

For purposes of comparison, measurements of *G. dioicus* seedlings grown in a raised nursery bed were included. These seedlings were grown for 27 weeks as frost did not permit earlier planting. Results show that these seedlings grew to heights and calipers (13.3 cm/3.5 mm) similar to seedlings grown under NAT lighting in the greenhouse (Table 5-3).

More *G. dioicus* seedlings grown under INC and HPS lighting produced a second flush of growth (77 and 73%, respectively) compared to those under NAT lighting (23%) (Table 5-5). The increase in height growth of *G. dioicus* seedlings under the INC and HPS lighting can be attributed to this second flush.

Table 5-4 shows the percent of total height growth (for the duration of the 33 week experiment) that was completed within the first 4 weeks of growth. Seedlings grown under NAT lighting completed approximately 89% of their total growth within the first 4 weeks, while seedlings under INC or HPS lighting completed approximately 58%. This indicates how critical the first 4 weeks of growth is for this species and shows how INC and HPS light can be used to stimulate the continued growth of this species.

This study demonstrates that *C. caroliniana*, *F. grandifolia* and *G. dioicus* can be produced during late winter in a greenhouse environment with supplemental lighting. Extended photoperiod can be used to produce a second flush of growth in species which typically produce one flush, thus increasing stem height and caliper and root and shoot dry weight. In most cases, INC produced results as good as HPS lighting.

Literature Cited

Blazich, Frank A., Stuart L. Warren and Mack Thetford. 1994. Growth response of sourwood as influenced by temperature, photoperiod and media. SNA Research Conf. 39:137.

- Cathey, H. M. and L. E. Campbell. 1977. Light frequency and color aid plant growth regulation. *Am. Nurseryman*, CLXLVI (10):16-18, 108-114.
- Cathey, Henry M and Lowell E. Campbell. 1979. Relative efficiency of high- and low-pressure sodium and incandescent filament lamps used to supplement natural winter light in greenhouses. *J. Amer. Soc. Hort. Sci.* 104(6):812-825.
- Cope, P. A. 1981. The propagation of tree seedlings under continuous light in square, bottomless containers. University of Tennessee, Knoxville. M.S. Thesis.
- Day, John, Willard T. Witte and Hermon Dickerson. 1994. Response of tissue cultured red maple plantlets to high pressure sodium, incandescent and ambient light. *SNA Research Conf.* 39:279-282.
- Dirr, Michael A. 1990. *Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses.* 4th ed. Stipes Publishing Co., Champaign, IL.
- Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. *Am. Nurseryman* 184:47-55.
- Gilman, Edward F. 1997. *Trees for urban and suburban landscapes.* Delmar Publishers, Albany, NY.
- Hightshoe, Gary L. 1988. *Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers.* Van Nostrand Reinhold, New York.
- Kozlowski, Theodore T. 1971. *Growth and development of trees.* Academic Press, Inc. New York.
- Little, Elbert L. 1986. *The Audubon Society field guide to North American trees: eastern region.* Alfred A. Knopf, Inc. New York.
- Peattie, Donald Culross. 1991. *A natural history of trees of eastern and central North America.* Houghton Mifflin Co., Boston, MA.
- Phillips, Leonard E. 1999. Top ten urban trees of '98. *Arbor Age* 19(3):8-12.
- Read, R. A. and W. T. Bagley. 1967. Response of tree seedlings to extended photoperiod. U. S. Dept. of Agri. Forest Service Research Paper RM-30.
- Sander, Ivan L. 1974. *Gymnocladus dioicus* (L.) K. Koch Kentucky coffeetree. *In* U.S. Forest Service, *Seeds of woody plants.* USDA, Agric. Handbook 450. Washington, DC.

Wright, R. D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

Yeager, T. H., R. D. Wright and S. S. Donohue. 1983. Comparisons of pour-through and saturated pine bark extract on N, P, K and pH levels. J. Amer. Soc. Hort. Sci. 108:112-114.

Appendix

Table 5-1. Effect of 18 hour incandescent (INC) or high pressure sodium (HPS) light and natural light and daylength (NAT) on height and caliper of *Carpinus caroliniana*, *Fagus grandifolia* and *Gymnocladus dioica* seedlings.

light treatment	height cm	caliper mm
<u><i>Carpinus caroliniana</i></u> ^z (1997)		
18 hr high pressure sodium (HPS)	7.4a ^y	-
18 hr incandescent (INC)	6.7ab	-
natural light and daylength (NAT)	5.5b	-
<u><i>Fagus grandifolia</i></u> ^x (1997)		
18 hr high pressure sodium	11.5a	-
18 hr incandescent	9.9a	-
natural light and daylength	7.5b	-
<u><i>Gymnocladus dioica</i></u> ^w (1997)		
18 hr high pressure sodium	22.6a	5.1a
18 hr incandescent	19.5b	4.4b
natural light and daylength	15.7c	3.8c
<u><i>Gymnocladus dioica</i></u> ^v (1998)		
18 hr high pressure sodium	16.5a	3.9a
18 hr incandescent	17.5a	3.6a
natural light and daylength	10.4b	2.8b

^z Grown for 8 and 12 weeks (data from 2 planting dates was pooled)

^y Means within a column of an individual species and year followed by the same letter are not significantly different by LSD at p=0.05.

^x Grown for 14 weeks

^w Grown for 13 weeks

^v Grown for 12 weeks, caliper was measured after 14 weeks

- Not applicable

Table 5-2. Effect of 18 hour incandescent (INC) or high pressure sodium (HPS) light and natural light and daylength (NAT) on incremental height and caliper growth of *Gymnocladus dioicus* seedlings.

light treatment	height, cm				caliper, mm	
	4 wks	8 wks	12 wks	33 wks	12 wks	33 wks
18 hr HPS	8.7a ^z	9.6a	16.5a	25.4a	3.9a	4.9a
18 hr INC	9.4a	10.2a	17.5a	27.2a	3.6a	4.8a
NAT	8.7a	9.1a	10.4b	14.7b	2.8b	3.5b

^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Table 5-3. Comparison of 18 hour incandescent (INC) or high pressure sodium (HPS) light and natural light and daylength (NAT) with traditional field planting method on height and caliper and root and shoot dry weight of *Gymnocladus dioicus* seedlings.

light treatment	height cm	caliper mm	shoot dry weight g	root dry weight g
18 hr HPS ^z	25.4a ^y	4.9a	8.9a	31.3a
18 hr INC ^z	27.2a	4.8a	9.9a	37.1a
NAT ^z	14.7b	3.5b	4.7b	19.4b
field ^x	13.3b	3.5b	3.3b	16.2b

^z Grown for 33 weeks

^y Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

^x Grown for 27 weeks

Table 5-4. Percent of total height of *Gymnocladus dioicus* seedlings grown under three light treatments that was completed in the first 4 weeks of a 33 week growing season.

light treatment	height in 4 weeks %
18 hr high pressure sodium (HPS)	58.4b ^z
18 hr incandescent (INC)	58.3b
natural light and daylength (NAT)	88.5a

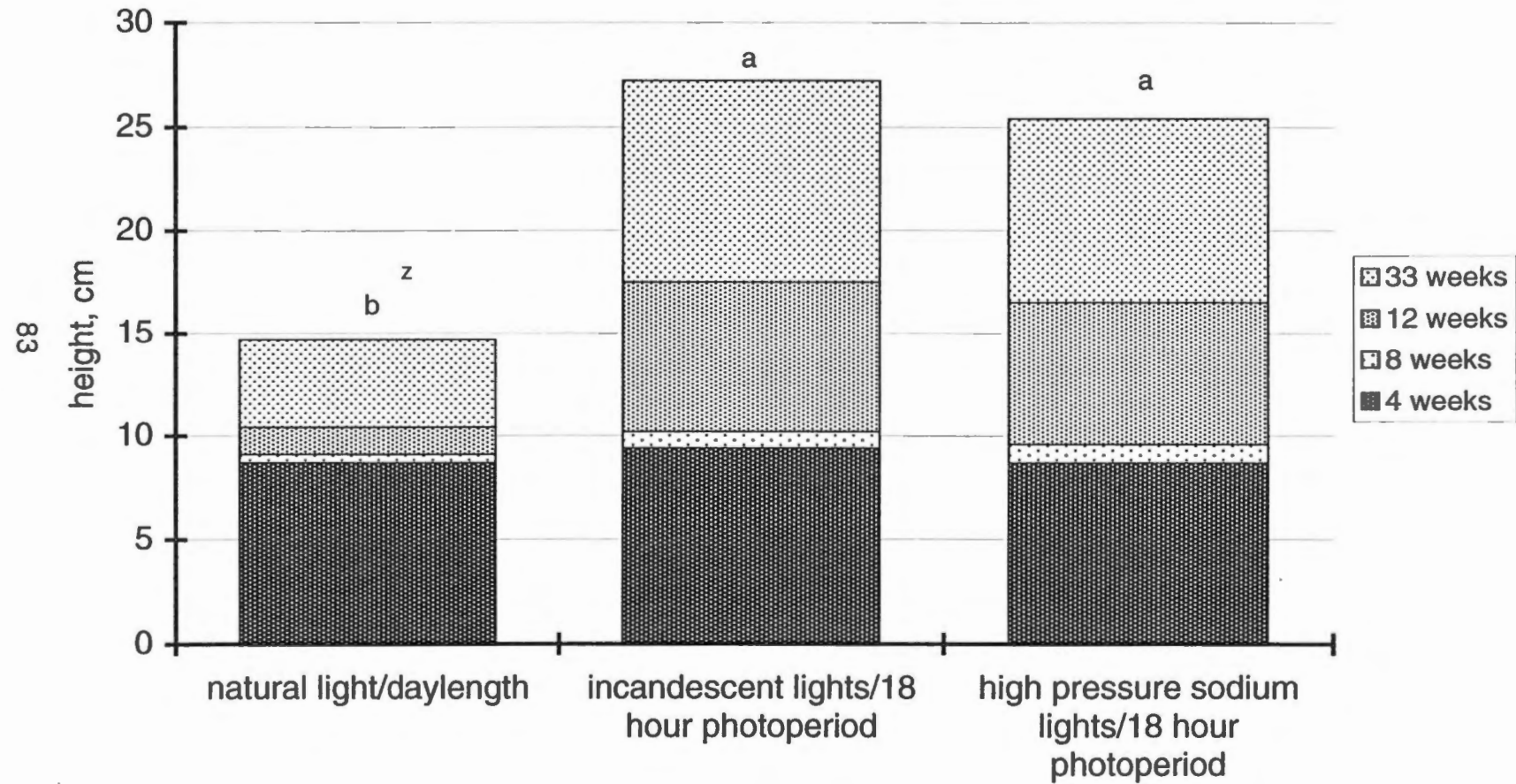
^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Table 5-5. Percent of *Gymnocladus dioicus* seedlings grown under three light treatments that produced a second flush of growth after 33 weeks.

light treatment	second flush %
18 hr high pressure sodium (HPS)	73b ^z
18 hr incandescent (INC)	77b
natural light and daylength (NAT)	23a

^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Figure 5-1. Incremental growth of *Gymnocladus dioicus* seedlings under three light treatments.



^z Means followed by the same letter are not significantly different by LSD at $p=0.05$.

Part 6

The Effects of Light Intensity on Growth of
Carpinus caroliniana and *Fagus grandifolia* Seedlings

Abstract

Carpinus caroliniana Walter (American hornbeam) seedlings were transplanted into 15 x 9.5 cm (6 x 3 5/8 inch) bottomless containers using a pine bark growing medium. *Fagus grandifolia* Ehrhart (American beech) seedlings were transplanted into 5.7 L (1 1/2 gallon, no. 600) containers, using a using a 5 pine bark: 4 sphagnum growing medium. Plants were subjected to three light intensities: full sun, 30% shade and 60% shade. Light intensity had no effect on stem height, caliper, quality rating and branching of *C. caroliniana* or height and caliper growth increment of *F. grandifolia*.

Introduction

C. caroliniana and *F. grandifolia* are deciduous trees indigenous to much of the eastern United States. *C. caroliniana* is valued for ornamental purposes in the naturalized landscape. Its fall color is reported as being "exceptionally showy burnt-orange or red to yellow" (Gilman 1997). Recently, *C. caroliniana* was listed as one of the seventh least available trees and one of the five species with the slowest growth rates among a list of 59 species that municipalities desired for street trees (Gamstetter and Gulick 1996).

F. grandifolia is highly regarded as being a major source of food for wildlife (Hightshoe 1988, Peattie 1991) and has one of the longest life spans (300 to 400 years) of angiosperms in the eastern United States (Kozlowski 1971). It is well suited for planting at estates, parks, campuses, golf courses or along drives of large commercial properties (Gilman 1997, Dirr 1990). According to Dirr (1990), *F. grandifolia* outgrows and outperforms the smaller European beech, *F. sylvatica*, in the southeastern United States.

Research has shown that light intensity affects growth of various species in different ways. While some species have increased growth at high light intensities, other species have increased growth in lower light intensities (Anderson et al. 1991a & b, Logan 1966, Newman and Follett 1988, Sheppard and Pellett 1976). Young and Young (1992) reported that *C. caroliniana* and *F.*

grandifolia seedlings require shade for the first year of growth. Dirr (1990) reported that *F. grandifolia* 'does best in full sun although withstands shade'.

Although *C. caroliniana* and *F. grandifolia* have considerable landscape merit, they are not grown in landscape sizes by most nurseries and are difficult to locate in garden centers. The objective of this study was to determine the effect of light intensity on root and shoot growth of container grown *C. caroliniana* and *F. grandifolia* seedlings.

Materials and Methods

Plant Materials

170 grams (6 ounces) or approximately 11,000 *C. caroliniana* seeds were obtained from F. W. Schumacher Co., Inc. (Sandwich, MA) in October 1996 and stratified over winter in a 1 to 4C refrigerator. Four hundred bareroot *F. grandifolia* seedlings were obtained from Little River Nursery in McMinnville, TN. On 22 May 1997, *C. caroliniana* seedlings were transplanted into 15 x 9.5 cm (6 x 3 5/8 inch) bottomless containers using the UT standard bark mix. Amendments for 1 m³ of standard bark mix are as follows: 4.1 kg dolomitic limestone, 1.2 kg treble superphosphate (0-46-0), 1.2 kg 18N-2.6P-10K (18-6-12) slow release fertilizer, 1.3 kg gypsum (CaSO₄) and 0.9 kg Micromax (Sierra Chemical Company, Milipitas, CA). For purposes of comparison, *C. caroliniana* seedlings were also planted in a raised nursery bed. On 22 April 1997, seedlings were planted 2.5 cm (1 inch) apart with 28 cm (11 inches) between rows.

On 4 May 1998, 72 *F. grandifolia* seedlings of uniform height (52.6 to 52.8 cm) were transplanted into 5.7 L (1 1/2 gallon, no. 600) containers. The growing medium consisted of 0.424 m³ UT standard bark mix combined with 0.34 m³ of Promix BX (Premier Horticulture Inc., Red Hill, PA).

Treatments and Experimental Design

Shade structures consisted of shade hoops and wooden structures covered with Dewitt knitted shade cloth (Hummert International, Earth City, MO). The *C. caroliniana* and *F. grandifolia* experiments were initiated on 22 May 1997 and 10 May 1998, respectively. Both species were subjected to the following treatments: (1) full sunlight, (2) 30% shade cloth and (3) 60% shade cloth.

The experiments were arranged in a randomized complete block design. In 1997, there were 3 replications of each treatment and 2 to 6 *C. caroliniana* seedlings per experimental unit. In 1998, there were 6 replications of each treatment with each experimental unit consisting of 4 *F. grandifolia* seedlings. *F. grandifolia* plants were blocked by size (height) to reduce variation observed in seedling lots. The experiment was conducted at the Nursery Compound at the University of Tennessee, Knoxville, TN.

Cultural Practices

Plants were grown on a raised nursery bed covered with geotextile ground cloth. Plants were irrigated by hand based on visual inspection and weeded as needed by hand. *F. grandifolia* seedlings were topdressed with 18N-2.6P-10K (Osmocote 18-6-12) (Scotts-Sierra Horticultural Products Co., Marysville, OH) at the following rate: 5.7 L (1 1/2 gallon) - 14 grams. *C. caroliniana* seedlings were topdressed with 2 grams of Osmocote 14N-6.1P-11.6K (Osmocote 14-14-14) (Scotts-Sierra Horticultural Products Co., Marysville, OH). *C. caroliniana* seedlings were also fertilized with 100 ppm 20N-8.7P-16.6K (Peters 20-20-20) (Scotts-Sierra Horticultural Products Co., Marysville, OH) to maintain an appropriate soluble salt reading.

The Virginia Tech Extraction Method was used to obtain extracts of the medium (Wright 1987, Yeager et al. 1983). *F. grandifolia* leachate samples were collected on 29 May and 7 August 1998 and analyzed for electrical conductivity (EC) and pH. Electrical conductivity of the *C. caroliniana* seedlings

was measured biweekly. Electrical conductivity was measured using a Myron L Agri-meter AG-5 (Myron L Co., Carlsbad, CA). pH was measured using a SA720 model Orion pH meter. EC readings and pH measurements remained within an acceptable range (0.21 to 0.55 mmhos/cm and 5.1 to 6.7) throughout the duration of the experiment.

Sampling and Analysis

Stem height and caliper of *F. grandifolia* seedlings were measured at the initiation of the experiment (10 May 1998) and at the conclusion of the experiment (13 October 1998). Stem height, caliper, quality rating and branch number of the *C. caroliniana* seedlings were measured 15 October 1997. Stem height of *C. caroliniana* was also measured on 21 August 1997. Stem height was recorded to the nearest 0.1 cm. Stem caliper was measured 5 cm above the soil line using a Digimatic Caliper meter (Mitutoyo Corp., Tokyo, Japan). Quality of the seedlings was assessed visually by 4 independent evaluators. Plants were assigned a number between 0 and 5 based on visual appearance where 0 = dead, 1 = 0-3", highly branched, burnt, small leaves, 2 = 3-7", moderately branched, mild burning, 3 = 7-9", average branching, minimal burning, 4 = 9-12", little branching and burning, good leaf color, and 5 = +12", minimal branching, no burning, good leaf color.

Light intensities were recorded at the top of the plant canopy with a handheld quantum sensor (LI-COR, Glen Spectra Ltd., Lincoln, NE). At 12 pm on 15 August 1997 with sunny conditions, the light reading for full sun was 1605 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, 1224 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for 30% shade and 405 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for 60% shade. Data was subjected to an analysis of variance (ANOVA) to determine the significance of the treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

Young and Young (1992) reported that *C. caroliniana* and *F. grandifolia* seedlings need to be partially shaded for the first year of growth. However, results from this research indicate that light intensity had no effect on stem height, caliper and quality rating of *C. caroliniana* seedlings after 21 weeks (Table 6-1)¹. Height and caliper ranged between 19.4 cm/3.3 mm in full sun to 22.2 cm/2.9 mm in 60% shade. Seedlings grown under 60% shade had fewer branches (1.5) than those grown in full sun or 30% shade (4.6 and 4.0, respectively).

Dirr (1990) reported that *F. grandifolia* 'does best in full sun although withstands shade'. This research does not support that claim. Although light intensity was found to have no effect on growth of *F. grandifolia* (Table 6-2), this may have been influenced by several factors including limited roots at delivery, a lack of uniformity of seedlings, transplant shock and rapid vegetative growth prior to the initiation of the experiment (10 May 1998). Height and caliper growth increment of *F. grandifolia* ranged between 2.8 cm/1.7mm in full sun to 2.0 cm/1.7 mm in 60% shade.

Literature Cited

Anderson, P. C., G. W. Knox and J. G. Norcini. 1991a. Light intensity influences growth and leaf physiology of *Aucuba japonica* 'Variegata'. HortScience 26:12, 1485-1488.

Anderson, P. C., J. G. Norcini and G. W. Knox. 1991b. Influence of irradiance on leaf physiology and plant growth characteristics of *Rhododendron* x 'Pink Ruffles'. J. Amer. Soc. Hort. Sci. 116:881-887.

Dirr, Michael A. 1990. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. 4th ed. Stipes Publishing Co., Champaign, IL.

Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. Am. Nurseryman 184:47-55.

¹ All tables and figures may be found in the Appendix.

- Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.
- Hightshoe, Gary L. 1988. Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers. Van Nostrand Reinhold, New York.
- Kozlowski, Theodore T. 1971. Growth and development of trees. Academic Press, Inc. New York.
- Logan, K. T. 1966. Growth of tree seedlings as affected by light intensity. III. basswood and white elm. Can. Dep. Forest. Publication 1176.
- Newman, S. E. and M. W. Follett. 1988. Irrigation frequency and shading influences on water relations and growth of container-grown *Euonymus japonica* 'Aureo-marginata'. J. Environ. Hort. 6:96-100.
- Peattie, Donald Culross. 1991. A natural history of trees of eastern and central North America. Houghton Mifflin Co., Boston, MA.
- Sheppard III, R. and H. Pellett. 1976. Light intensity effects on red osier dogwood. HortScience 11:200-202.
- Wright, R. D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.
- Yeager, T. H., R. D. Wright and S. S. Donohue. 1983. Comparisons of pour-through and saturated pine bark extract on N, P, K and pH levels. J. Amer. Soc. Hort. Sci. 108:112-114.
- Young, James and Cheryl Young. 1992. Seeds of woody plants in North America. Dioscorides Press, Portland, OR.

Appendix

Table 6-1. Effect of light intensity on height, caliper, quality rating^z, and branching^y of *Carpinus caroliniana* seedlings.

shade treatment	height cm	caliper mm	quality rating 0-5	branch number #
full sun	19.4a ^x	3.3a	1.8a	4.6a
30% shade	20.7a	3.0a	2.0a	4.0a
60% shade	22.2a	2.9a	2.3a	1.5b

^z Quality rating (0 = dead, 5 = healthy and vigorous).

^y Number of branches above the soil line.

^x Means within a column followed by the same letter are not significantly different by LSD at $p=0.05$.

Table 6-2. Effect of light intensity on height and caliper growth increment of *Fagus grandifolia* seedlings.

shade treatment	height cm	caliper mm
full sun	2.8a ^z	1.7a
30% shade	2.5a	1.9a
60% shade	2.0a	1.7a

^z Means within a column followed by the same letter are not significantly different by LSD at $p=0.05$.

Part 7

The Effects of Container Size on Growth of
Carpinus caroliniana and *Fagus grandifolia* Seedlings

Abstract

Carpinus caroliniana Walter (American hornbeam) and *Fagus grandifolia* Ehrhart (American beech) seedlings were transplanted into 3.8 L (1 gallon, no. 400), 5.7 L (1 1/2 gallon, no. 600) and 7.6 L (2 gallon, no. 800) containers using a 5 pine bark: 4 sphagnum growing medium. Plants were topdressed with 18N-2.6P-10K (Osmocote 18-6-12) at the following rates: 3.8 L - 9 grams, 5.7 L - 14 grams and 7.6 L - 19 grams and grown for 22 weeks. There was no effect of container size on stem height and caliper growth and shoot and root dry weight of *C. caroliniana* and *F. grandifolia*.

Seedlings of both species were also grown in a raised nursery bed to compare growth of container and field grown trees. *C. caroliniana* plants grown in containers had significantly greater stem caliper growth than those grown in the field. There was no significant difference in growth between container or field grown *F. grandifolia* plants.

Introduction

C. caroliniana and *F. grandifolia* are deciduous trees indigenous to much of the eastern United States. *C. caroliniana* is valued for ornamental purposes in the naturalized landscape. Its fall color is reported as being "exceptionally showy burnt-orange or red to yellow" (Gilman 1997). Recently, *C. caroliniana* was listed as one of the seventh least available trees and one of the five species with the slowest growth rates among a list of 59 species that municipalities desired for street trees (Gamstetter and Gulick 1996).

F. grandifolia is highly regarded as being a major source of food for wildlife (Hightshoe 1988, Peattie 1991) and has one of the longest life spans (300 to 400 years) of angiosperms in the eastern United States (Kozlowski 1971). This species is well suited for planting at estates, parks, campuses, golf courses or along drives of large commercial properties (Gilman 1997, Dirr 1990). According to Dirr (1990), *F. grandifolia* outgrows and outperforms the smaller European beech, *F. sylvatica*, in the southeastern United States.

Research on multiple species has shown that container size has an effect on plant growth. Most research shows that plant growth increases as container size increases (Laiche and Newman 1990, McConnell 1988, Milbocker 1992, Murray et al. 1996). However, some plants are not affected by container size (Goodale and Whitcomb 1980) and in a few cases growth is decreased in larger containers (Gibson and Whitcomb 1978).

Although *C. caroliniana* and *F. grandifolia* have considerable landscape merit, they are not grown in landscape sizes by most nurseries and are difficult to locate in garden centers. Little research has been conducted on the production practices of these species. Therefore, the objective of this study was to determine the effect of container size on root and shoot growth of container grown *C. caroliniana* and *F. grandifolia* seedlings.

Materials and Methods

Plant and Fungal Materials

C. caroliniana seedlings were grown at the University of Tennessee Nursery Compound the year prior to the experiment. Four hundred bareroot *F. grandifolia* seedlings were obtained from Little River Nursery in McMinnville, TN. On 5 May 1998, 54 *C. caroliniana* seedlings of uniform height (23.5 to 25.2 cm) and 90 *F. grandifolia* seedlings of uniform height (42.3 to 43.5 cm) were selected for use in this experiment. The growing medium consisted of 0.424 m³ UT standard bark mix combined with 0.34 m³ of Promix BX (Premier Horticulture Inc., Red Hill, PA). Amendments for 1 m³ of standard bark mix are: 4.1 kg dolomitic limestone, 1.2 kg treble superphosphate (0-46-0), 1.2 kg 18N-2.6P-10K (18-6-12) slow release fertilizer, 1.3 kg gypsum (CaSO₄) and 0.9 kg Micromax (Sierra Chemical Company, Milipitas, CA).

Treatments and Experimental Design

For purposes of comparison, 10 to 14 *C. caroliniana* and 9 *F. grandifolia* seedlings were planted in a raised nursery bed. On 6 May 1998, *C. caroliniana*

and *F. grandifolia* seedlings were transplanted into a raised nursery bed and on 10 May 1998, *C. caroliniana* and *F. grandifolia* seedlings were transplanted into three container sizes. Four treatments included: (1) 3.8 L (1 gallon, no. 400) containers, (2) 5.7 L (1 1/2 gallon, no. 600), (3) 7.6 L (2 gallon, no. 800) and (4) raised nursery bed.

The experiments were arranged by species in a completely randomized design with 6 replications of *C. caroliniana* and 10 replications of *F. grandifolia* for each container size. Each experimental unit consisted of 3 *C. caroliniana* and *F. grandifolia* plants. There were 3 replications of the raised nursery bed treatment with 10 to 14 *C. caroliniana* and 9 *F. grandifolia* plants per experimental unit. Plants were blocked by size (height) to reduce variation observed in seedling lots. The experiments were conducted at the Nursery Compound at the University of Tennessee, Knoxville, TN.

Cultural Practices

Container plants were grown under 30% shade on a gravel bed and irrigated based on visual inspection with an overhead sprinkler. Plants in the nursery bed were grown under 30% shade and irrigated by hand based on visual inspection. Lateral branches on the *C. caroliniana* seedlings were pinched at the initiation of the experiment to stimulate the growth of the primary leader. All container plants were staked and tied to promote straight leaders and reduce wind damage.

Fertilization was proportional to container size therefore each plant received the same amount of fertilizer per unit volume of potting medium. 18N-2.6P-10K (Osmocote 18-6-12) was top dressed at the following rates: 3.8 L - 9 grams, 5.7 L - 14 grams and 7.6 L - 19 grams. The Virginia Tech Extraction Method was used to obtain extracts of the medium (Wright 1987, Yeager et al. 1983). Leachate samples were collected on 29 May and 7 August 1998 and analyzed for electrical conductivity (EC) and pH. Electrical conductivity was measured using a Myron L Agri-meter AG-5 (Myron L Co., Carlsbad, CA). pH

was measured using a SA720 model Orion pH meter. May pH and EC readings for *C. caroliniana* were 5.02/5.08 and 2.6/3.0 mmhos/cm, respectively. May pH and EC readings for *F. grandifolia* were 6.0 and 0.55 mmhos/cm, respectively. August pH and EC readings for *C. caroliniana* were 6.74 and 0.22 mmhos/cm, respectively. August pH and EC readings for *F. grandifolia* were 6.78 and 0.48 mmhos/cm, respectively.

Sampling and Analysis

Height and caliper of all plants were measured at the initiation of the experiment (10 May 1998) and at the conclusion of the experiment (13 October 1998). Stem height was measured and recorded to the nearest 0.1 cm. Stem caliper was measured 5 cm above the soil line using a Digimatic Caliper meter (Mitutoyo Corp., Tokyo, Japan).

Shoots and roots were collected for *C. caroliniana* on 16 October 1998. Two *C. caroliniana* plants of average height were selected from each experimental unit. Shoots were severed from the roots at the soil line, cut into approximately 1.5 cm pieces and placed along with the leaves into cotton bags. Roots were rinsed free of media, cut into 1.5 cm pieces and placed in individual bags. Shoots and roots were dried at the University of Tennessee Knoxville Experiment Station, Plant Sciences Unit in a 50C drying oven until 21 October 1998. After 5 days, bags were removed from the drying oven, emptied into plastic dishes and weighed to the nearest gram. Dry weights were not taken for *F. grandifolia* because upon completion of the experiment and analysis of the stem heights and calipers it was concluded that dry weights would not provide any additional information. Dry weights were also not taken for the field planted *C. caroliniana* plants because root systems were too extensive. Data was subjected to an analysis of variance (ANOVA) to determine the significance of the treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

Most research has shown that plant growth increases as container size increases (Laiche and Newman 1990, McConnell 1988, Milbocker 1992, Murray et al. 1996), but some plants are not affected by container size (Goodale and Whitcomb 1980). Although container size was found to have no effect on growth of *F. grandifolia* (Table 7-1)¹, this may have been influenced by several factors including limited roots at delivery, a lack of uniformity of seedlings, transplant shock and rapid vegetative growth prior to the initiation of the experiment (10 May 1998). There was no effect of container size on stem height or caliper growth increment of *C. caroliniana* (Table 7-1). However, shoot dry weight of *C. caroliniana* plants grown in 5.7 L gallon containers was greater (35.2 g) than those in 3.8 L containers (20.8 g). Shoot dry weight of *C. caroliniana* plants grown in 7.6 L containers (27.4 g) was no different than those in the 3.8 L or 5.7 L containers. Container grown *C. caroliniana* seedlings had greater caliper growth (5.3 to 6.3 mm) than those in the nursery bed (3.8 mm). *C. caroliniana* plants grown in 5.7 L gallon containers had greater shoot dry weight (35.2 g) than those grown in the nursery seed bed (19.0 g).

Literature Cited

- Dirr, Michael A. 1990. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. 4th ed. Stipes Publishing Co., Champaign, IL.
- Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. Am. Nurseryman 184:47-55.
- Gibson, J. and C. E. Whitcomb. 1978. Effects of container size and fertility levels on the growth of tree seedlings in square bottomless containers. Oklahoma State University Agric. Exp. Station Research Report No.P-777.
- Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.

¹ All tables and figures may be found in the Appendix.

Goodale, T. W. and C. E. Whitcomb. 1980. Producing woody ornamental shrubs in containers, influence of fertility level and container size. *Ornamentals South* 2(3):10-13.

Hightshoe, Gary L. 1988. Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers. Van Nostrand Reinhold, New York.

Kozlowski, Theodore T. 1971. Growth and development of trees. Academic Press, Inc. New York.

Laiche Jr., A. J. and S. E. Newman. 1990. Effects of container size and fertilizer rate on growth of *Rhododendron* 'Formosa' and *Ilex* 'Nellie R. Stevens' plants. *Comb. Proc. Int. Plant Prop. Soc.* 39:354-360.

McConnell, D. B. 1988. Container size and potting medium affect growth rate of weeping fig and loquat. *Proc. of the Florida State Hort. Soc.* 100:337-339.

Milbocker, Daniel C. 1992. The relationship between container size, fertilization and plant growth. *SNA Research Conf.* 37:81-83.

Murray, C. L., G. P. Lumis and Calvin Chong. 1996. Fertilizer method and container size effects on shade trees grown in in-ground containers. *Canadian Journal of Plant Science* 76(3):507-513.

Peattie, Donald Culross. 1991. A natural history of trees of eastern and central North America. Houghton Mifflin Co., Boston, MA.

Wright, R. D. 1986. The pour-through nutrient extraction procedure. *HortScience* 21:227-229.

Yeager, T. H., R. D. Wright and S. S. Donohue. 1983. Comparisons of pour-through and saturated pine bark extract on N, P, K and pH levels. *J. Amer. Soc. Hort. Sci.* 108:112-114.

Appendix

Table 7-1. Effect of container size on height and caliper growth increment and dry weight of shoots and roots of *Carpinus caroliniana* and *F. grandifolia* seedlings.

container size	height incrmnt cm	caliper incrmnt mm	shoot dry wt g	root dry wt g
<i>Carpinus caroliniana</i>				
3.8 L	56.9a ^z	5.3a	20.8b	20.0a
5.7 L	78.5a	6.3a	35.2a	27.8a
7.6 L	71.6a	5.7a	27.4ab	28.5a
field ^y	62.9a	3.8b	19.0b	-
<i>Fagus grandifolia</i>				
3.8 L	1.3a	0.8a	-	-
5.7 L	1.3a	0.8a	-	-
7.6 L	1.0a	0.7a	-	-
field ^y	1.2a	1.1a	-	-

^z Means within a column of an individual species followed by the same letter are not significantly different by LSD at p=0.05.

^y Field plants were measured for comparison purposes.

- Not applicable

Part 8

The Effects of Three Slow-Release Fertilizer Rates on
Growth of *Carpinus caroliniana*, *Fagus grandifolia* and
Gymnocladus dioica Seedlings

Abstract

Carpinus caroliniana Walter (American hornbeam) and *Fagus grandifolia* Ehrhart (American beech) seedlings were transplanted into 3.8 L (1 gallon, no. 400) and 8.6 L (2 1/4 gallon, no. 900) containers, respectively, using a 5 pine bark: 4 sphagnum growing medium. *C. caroliniana* and *F. grandifolia* seedlings were topdressed with 18N-2.6P-10K (Osmocote 18-6-12) at the following rates: 3.8 L - 9, 14 or 18 grams, 8.6 L - 23, 35 or 46 grams. *Gymnocladus dioicus* (L.) K. Koch (Kentucky coffeetree) seedlings were grown in 15.2 L (4 gallon, no. 1600) containers in a pine bark medium and were top dressed with 14N-6.1P-11.6K (Osmocote 14-14-14) at 23, 40 or 85 grams per container. Fertilizer was applied to the *G. dioicus* seedlings in a split application with 1/2 applied at the first growth flush (2 April 1998) and the other half applied later in the season (7 August 1998). Thus, a total of 46, 80 or 170 grams was applied.

Results for *C. caroliniana* indicated that stem growth was inversely proportional to fertilizer rate. Stem height growth increment was greater at the lowest fertilizer rate (65.9 cm) when compared with the highest rate (36.9 cm). Although caliper and shoot dry weight increased at lower fertilizer levels, there were no significant differences. There was no effect of fertilizer rate on root dry weight.

No differences were found between fertilizer rates for *G. dioicus*. Seedlings were also grown in a raised nursery bed to compare growth of container and field grown *G. dioicus* trees. Plants grown in containers had a greater stem height and caliper growth increment (35.5 cm/6.5 mm, respectively) than those grown in a raised nursery bed (22.1 cm/2.1 mm). There was no effect of fertilizer rate on growth of *F. grandifolia*.

Introduction

C. caroliniana and *F. grandifolia* are deciduous trees indigenous to much of the eastern United States. *C. caroliniana* is valued for ornamental purposes in the naturalized landscape. Its fall color is reported as being "exceptionally

showy burnt-orange or red to yellow" (Gilman 1997). Recently, *C. caroliniana* was listed as one of the seventh least available trees and one of the five species with the slowest growth rates among a list of 59 species that municipalities desired for street trees (Gamstetter and Gulick 1996).

F. grandifolia is highly regarded as being a major source of food for wildlife (Hightshoe 1988, Peattie 1991) and has one of the longest life spans (300 to 400 years) of angiosperms in the eastern United States (Kozlowski 1971). This species is well suited for planting at estates, parks, campuses, golf courses or along drives of large commercial properties (Gilman 1997, Dirr 1990). According to Dirr (1990), *F. grandifolia* outgrows and outperforms the smaller European beech, *F. sylvatica*, in the southeastern United States.

G. dioicus is a medium to large sized, deciduous native species. The natural range of *G. dioicus* extends from New York and Pennsylvania west to Minnesota, south to Oklahoma and east to Kentucky and Tennessee (Sander 1974). In the wild, populations are scattered and rare (Little 1986). The leaves are showy yellow in the fall and Gilman (1997) reports that it is well adapted to a wide range of soil conditions, tolerates drought and performs well in the urban environment. *G. dioicus* is considered by many plantsmen to be a choice tree for large areas such as parks and golf courses (Dirr 1990). In 1998, *G. dioicus* was listed to be one of the top ten urban trees (Phillips 1999).

Numerous studies on the effects of fertilizer rates on plant growth have been conducted on container and field grown nursery crops. Research results have shown a variety of growth effects. Some species exhibit increased growth (Goodale and Whitcomb 1980, Hummel and Privett 1991, Laiche and Newman 1990) while others exhibit decreased growth (Eakes et al. 1990, Gibson and Whitcomb 1978). In general, plant growth increases as fertilizer rate increases but will decrease when fertilizer salt concentrations become too high.

Although *C. caroliniana*, *F. grandifolia* and *G. dioicus* have considerable landscape merit, they are not grown in landscape sizes by most nurseries and are difficult to locate in garden centers. Furthermore, there are few reported

cultural studies on these species. Therefore, the purpose of this study was to determine the effects of three slow-release fertilizer rates on shoot and root growth of *C. caroliniana*, *F. grandifolia* and *G. dioicus*.

Materials and Methods

Plant Materials

C. caroliniana and *G. dioicus* seedlings were grown at the University of Tennessee Nursery Compound. Four hundred bareroot *F. grandifolia* seedlings were obtained from Little River Nursery in McMinnville, TN. On 4 and 5 May 1998, 54 *C. caroliniana* seedlings of uniform height (14.3 to 14.7 cm) were potted into 3.8 L (1 gallon, no. 400) containers and 72 *F. grandifolia* seedlings of uniform height (49.0 to 52.3 cm) were potted into 8.6 L (2 1/4 gallon, no. 900) containers. The growing medium consisted of 0.424 m³ UT standard bark mix combined with 0.34 m³ of Promix BX (Premier Horticulture Inc., Red Hill, PA). Amendments for 1 m³ of standard bark mix are as follows: 4.1 kg dolomitic limestone, 1.2 kg treble superphosphate (0-46-0), 1.2 kg 18N-2.6P-10K (18-6-12) slow release fertilizer, 1.3 kg gypsum (CaSO₄) and 0.9 kg Micromax (Sierra Chemical Company, Milipitas, CA). *G. dioicus* seedlings remained in the 15.2 L (4 gallon, no. 1600) containers and the UT standard bark mix in which they were planted the previous summer.

Treatments and Experimental Design

On 10 May 1998, *C. caroliniana* and *F. grandifolia* seedlings were top dressed with 18N-2.6P-10K (Osmocote 18-6-12) (Scotts-Sierra Horticultural Products Co., Marysville, OH) at the low, medium and high rates specified by the company. *G. dioicus* seedlings were top dressed with a split application of 14N-6.1P-11.6K (Osmocote 14-14-14) (Scotts-Sierra Horticultural Products Co., Marysville, OH) at the low, medium, and high rates specified by the company. The first application was at the first growth flush on 2 April 1998 and the second application was on 7 August.

Treatments were as follows: (1) High - *G. dioicus* seedlings (15.2 L) were top dressed with 85 g + 85 g each (total 170 g), *C. caroliniana* seedlings (3.8 L) received 18 g and *F. grandifolia* seedlings (8.6 L) received 46 g, (2) Medium - *G. dioicus* seedlings were top dressed 40g + 40 g (total 80 g), *C. caroliniana* seedlings received 14 g and *F. grandifolia* seedlings received 35 g and (3) Low - *G. dioicus* seedlings were top dressed 23 + 23 grams each. *C. caroliniana* seedlings received 9 grams and *F. grandifolia* seedlings received 23 g.

The *C. caroliniana* and *F. grandifolia* experiments were arranged in a randomized complete block design by species. There were 6 replications of each fertilizer rate. Each experimental unit consisted of 3 *C. caroliniana* and 4 *F. grandifolia* seedlings. *C. caroliniana* and *F. grandifolia* plants were blocked by size (height) to reduce variation observed in seedling lots. The *G. dioicus* experiment was arranged in a completely randomized design with 3 replications of each fertilizer rate and 19 or 20 plants per experimental unit. The experiments were conducted at the Nursery Compound at the University of Tennessee, Knoxville, TN.

Cultural Practices

All plants were grown under 30% shade on a gravel bed and irrigated based on visual inspection with an overhead sprinkler. Lateral branches on *C. caroliniana* and *G. dioicus* seedlings were pinched at the initiation of the experiment to stimulate the growth of the primary leader. All plants were staked and tied to promote straight leaders and reduce wind damage.

The Virginia Tech Extraction Method was used to obtain extracts of the medium (Wright 1987, Yeager et al. 1983). Leachate samples were collected on 29 May and 7 August 1998 and analyzed for soluble salts and pH. Soluble salts were measured as electrical conductivity (EC) using a Myron L Agri-meter AG-5 (Myron L Co., Carlsbad, CA). pH was measured using a SA720 model Orion pH meter. May pH and EC readings for *C. caroliniana* were 5.00/4.92/4.92 (Hi/Med/Lo) and 2.8/3.4/2.2 mmhos/cm, respectively. May pH

and EC readings for *F. grandifolia* were 5.96/5.65/6.55 (Hi/Med/Lo) and 1.0/1.6/0.35 mmhos/cm, respectively. May pH and EC readings for *G. dioicus* were 5.18 and 5.59/6.47 and 6.36/6.21 and 5.87 (Hi/Med/Lo) and 1.75 and 1.6/0.38 and 0.30/0.56 and 0.39 mmhos/cm, respectively. August pH and EC readings for *C. caroliniana* were 6.76/6.83 (Hi/Med/Lo) and 0.31/0.22 mmhos/cm, respectively. August pH and EC readings for *F. grandifolia* were 6.34/6.68/6.89 and 0.5/0.4/0.24 mmhos/cm, respectively. August pH and EC readings for *G. dioicus* were 5.26 and 6.22/6.53 and 6.61/6.03 and 5.91 (Hi/Med/Lo) and 1.35 and 0.78/0.48 and 0.48/0.36 and 0.25 mmhos/cm, respectively.

Sampling and Analysis

All plants were measured before the initiation of the experiments for an initial height and caliper (2 April 1998 for *G. dioicus* and 10 May 1998 for *C. caroliniana* and *F. grandifolia*). Additionally, stem height and caliper of *G. dioicus* were measured 18 May 1998 (6 1/2 weeks after the initiation of the experiment) to determine the length of the first flush of growth. Height and caliper of all plants were measured again at the conclusion of the experiment (13 October 1998). Stem height was measured and recorded to the nearest 0.1 cm. Stem caliper was measured 5 cm above the soil line using a Digimatic Caliper meter (Mitutoyo Corp., Tokyo, Japan).

Shoot and roots for dry weights were collected from container and field grown *C. caroliniana* and *G. dioicus* plants on 16 October 1998. Three *G. dioicus* and 2 *C. caroliniana* plants of average height were selected from each experimental unit. Shoots were severed from the roots at the soil line, cut into 2 cm pieces and placed along with the leaves into individual cotton bags. Roots were rinsed free of media, cut into pieces and placed in bags. Shoots and roots were dried at the University of Tennessee Knoxville Experiment Station, Plant Sciences Unit in a 50C drying oven. On 21 October 1998 bags were removed from the drying oven, poured into plastic dishes and weighed to the nearest

gram. Weights of *G. dioicus* were measured as total shoot weight and stem weight because most of the field grown plants had already lost their leaves. Dry weights were not taken for *F. grandifolia* because upon completion of the experiment and analysis of the stem heights and calipers it was concluded that dry weights would not provide any additional information.

Data was subjected to an analysis of variance (ANOVA) to determine the significance of the fertilization treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

Results for *C. caroliniana* indicated that growth of stem height was inversely proportional to fertilizer rate. Stem height was significantly greater at the lowest fertilizer rate (65.6 cm) when compared with the highest rate (36.9 cm) (Table 8-1)¹. Although caliper and shoot dry weight increased at lower fertilizer levels, the difference was not significant. There was no effect of fertilizer rate on root dry weight of *C. caroliniana*. Although the EC readings in May were much higher than expected, plants did not show any indication of leaf burn or toxicity. It is speculated that the elevated EC readings may have been a result of soluble salt accumulation. Upon obtaining the elevated EC readings, plants were promptly leached. August EC readings were in an acceptable range.

Although fertilizer rate was found to have no effect on growth of *F. grandifolia* (Table 8-1), this may have been influenced by several factors including limited roots at delivery, a lack of uniformity of seedlings, transplant shock and rapid vegetative growth prior to the initiation of the experiment (10 May 1998).

No significant differences were found between fertilizer rates for *G. dioicus* (Table 8-1). Although insignificant, shoot dry weight of *G. dioicus* increased with higher fertilizer rates and root dry weight was inversely

¹ All tables and figures may be found in the Appendix.

proportional to fertilizer rate. *G. dioicus* was also grown in a raised nursery bed to compare growth of container and field grown trees. Plants grown in containers had significantly greater height and caliper growth and stem and root dry weights than those grown in the field. The root dry weight of *G. dioicus* was less than expected and probably suppressed due to the development of a large taproot which was difficult to remove intact.

In 1997, a similar fertilizer rate experiment on *G. dioicus* was attempted where there was no response to fertilizer treatment. However, only 25% of the plants initiated new growth which suggested that *G. dioicus* is a species which exhibits episodic growth patterns. A second fertilizer experiment was conducted the following year (1998) and stem heights were measured at the beginning of the experiment and after 6 1/2 weeks of growth. The percent of total height completed in the first 6 1/2 weeks of the 28 week growth period is shown in Table 8-2. Although there was no effect of fertilizer treatment, 67 to 75% of the total growth for the season was completed within the first 6 1/2 weeks thus indicating how critical this period is for this species.

Literature Cited

Dirr, Michael A. 1990. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. 4th ed. Stipes Publishing Co., Champaign, IL.

Eakes, D. J., W. J. Foster, C. H. Gilliam and J. W. Olive. 1990. Effects of method of application and rate of three slow release fertilizers. SNA Research Conf. 35:55-56.

Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. American Nurseryman 184:47-55.

Gibson, J. and C. E. Whitcomb. 1978. Effects of container size and fertility levels on the growth of tree seedlings in square bottomless containers. Oklahoma State University Agric. Exp. Station Research Report No.P-777, 40-41.

Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.

Goodale, T. W. and C. E. Whitcomb. 1980. Producing woody ornamental shrubs in containers, influence of fertility level and container size. *Ornamentals South* 2(3):10-13.

Hightshoe, Gary L. 1988. Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers. Van Nostrand Reinhold, New York.

Hummel, Rita L. and Diane W. Privett. 1991. Effect of slow-release fertilizer rate on root and shoot growth of container-grown *Kalmia latifolia* 'Elf', 'Freckles', and 'Goodrich'.

Kozlowski, Theodore T. 1971. Growth and development of trees. Academic Press, Inc. New York.

Laiche Jr., A. J. and S. E. Newman. 1990. Effects of container size and fertilizer rate on growth of *Rhododendron* 'Formosa' and *Ilex* 'Nellie R. Stevens' plants. *Comb. Proc. Int. Plant Prop. Soc.* 39:354-360.

Little, Elbert L. 1986. The Audubon Society field guide to North American trees: eastern region. Alfred A. Knopf, Inc. New York.

Peattie, Donald Culross. 1991. A natural history of trees of eastern and central North America. Houghton Mifflin Co., Boston, MA.

Phillips, Leonard E. 1999. Top ten urban trees of '98. *Arbor Age* 19(3):8-12.

Sander, Ivan L. 1974. *Gymnocladus dioica* (L.) K. Koch Kentucky coffeetree. In U.S. Forest Service, Seeds of woody plants. USDA, Agric. Handbook 450. Washington, DC.

Wright, R. D. 1986. The pour-through nutrient extraction procedure. *HortScience* 21:227-229.

Yeager, T. H., R. D. Wright and S. S. Donohue. 1983. Comparisons of pour-through and saturated pine bark extract on N, P, K and pH levels. *J. Amer. Soc. Hort. Sci.* 108:112-114.

Appendix

Table 8-1. Effect of three rates of slow release fertilizer on height and caliper growth increment and dry weight of shoots, stems and roots of *Carpinus caroliniana*, *Fagus grandifolia* and *Gymnocladus dioicus* seedlings.

fertilizer rate	height increment cm	caliper increment mm	shoot dry weight g	stem dry weight g	root dry weight g
<i>Carpinus caroliniana</i> ^z					
18g (high)	36.9b ^y	4.4a	11.3a	-	12.0a
14g (medium)	45.2b	5.4a	11.8a	-	13.8a
9g (low)	65.6a	5.4a	13.9a	-	13.3a
<i>Fagus grandifolia</i> ^x					
46g (high)	3.5a	1.9a	-	-	-
35g (medium)	4.1a	1.9a	-	-	-
23g (low)	3.8a	1.5a	-	-	-
<i>Gymnocladus dioicus</i> ^w					
85 + 85g (high)	40.6a	6.1a	103.7a	42.3a	189.0ab
40 + 40g (medium)	42.2a	6.8a	91.7a	42.3a	228.7a
23 + 23g (low)	35.5ab	6.5a	84.0a	41.0a	260.7a
23 + 23g (field)	22.1b	2.1b	-	8.0b	25.2b

^z Fertilized with Osmocote 18-6-12 and grown in 3.8 L containers for 22 weeks.

^y Means within a column of an individual species and year followed by the same letter are not significantly different by LSD at p=0.05.

^x Fertilized with Osmocote 18-6-12 and grown in 8.6 L containers for 22 weeks.

^w Fertilized with Osmocote 14-14-14 and grown in 15.2 L containers for 28 weeks.

- Not applicable

Table 8-2. Percent of total growth of *Gymnocladus dioicus* seedlings completed in the first 6 1/2 weeks of a 28 week growing season and subjected to three rates of slow release fertilizer (Osmocote 14-14-14).

fertilizer rate	height in 6 1/2 weeks
	%
85 + 85g (high)	70.1a ^z
40 + 40g (medium)	74.9a
23 + 23g (low)	67.3a

^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Part 9

The Effects of Ectomycorrhizae (*Pisolithus tinctorius*)
on Growth of *Carpinus caroliniana* and
Fagus grandifolia Seedlings

Abstract

Carpinus caroliniana Walter (American hornbeam) and *Fagus grandifolia* Ehrhart (American beech) seedlings were transplanted into 3.8 L (1 gallon, no. 400) and 2.9 L (3/4 gallon, no. 300) containers, respectively, using a 5 pine bark: 4 sphagnum growing medium. Plants were inoculated with MycorTree™ *Pisolithus tinctorius* Marx Superstrain using the 'container seedling banding' method - approximately one teaspoon (5 ml) of inoculum was placed 4 to 5 cm (1 1/2 to 2 inches) deep in the proximity of the primary lateral roots. Plants were topdressed with 18N-2.6P-10K (Osmocote 18-6-12) at the following rates: 3.8 L - 9 grams, 2.9 L - 7 grams and grown for 22 weeks. There was no significant effect of application of the ectomycorrhizal fungi (*P. tinctorius*) on height and caliper growth and shoot and root dry weight of *C. caroliniana* and *F. grandifolia*.

Introduction

C. caroliniana and *F. grandifolia* are deciduous trees indigenous to much of the eastern United States. *C. caroliniana* is valued for ornamental purposes in the naturalized landscape. Its fall color is reported as being "exceptionally showy burnt-orange or red to yellow" (Gilman 1997). Recently, *C. caroliniana* was listed as one of the seventh least available trees and one of the five species with the slowest growth rates among a list of 59 species that municipalities desired for street trees (Gamstetter and Gulick 1996).

F. grandifolia is highly regarded as being a major source of food for wildlife (Hightshoe 1988, Peattie 1991) and has one of the longest life spans (300 to 400 years) of angiosperms in the eastern United States (Kozlowski 1971). This species is well suited for planting at estates, parks, campuses, golf courses or along drives of large commercial properties (Gilman 1997, Dirr 1990). According to Dirr (1990), *F. grandifolia* outgrows and outperforms the smaller European beech, *F. sylvatica*, in the southeastern United States.

Ectomycorrhizal fungi benefit plants in several ways. Some advantages of the symbiotic relationship are: (1) increased root surface area and therefore increased availability of nutrients and improved competitiveness for water and nutrients, (2) improved absorption of PO_4^{3-} , Ca^{++} , K^+ , Rb^+ , Cl^- , SO_4^{--} , Na^+ , NO_3^- , NH_4^{++} , Mg^+ , Fe^{++} and Zn^{++} , (3) metabolic-provisioning of growth regulating substances such as vitamins and hormones to the plant, (4) excretion of toxic substances which select for more suitable microflora, (5) production of pathogen suppressing antibiotics which creates a more selective soil environment, (6) presence of a fungal sheath which acts as a protective barrier against pathogenic infection, (7) detoxification of phytotoxins often present in soils and (8) decrease in the detrimental effects of soil nematodes and other root pathogens (Langlois and Fortin 1981).

Containerized plants often produce roots of the second and third order. These roots differ morphologically and physiologically from roots grown under natural conditions (Smith 1980). Therefore it is particularly desirable for seedlings deemed to go into a forest to be inoculated with mycorrhizal fungi to help protect the fine roots. In nutrient-poor or moisture deficient soils, mycorrhizal plants are often more competitive and tolerate environmental stresses better than nonmycorrhizal plants (Sylvia 1998). Thus, inoculation of nursery crops may prove worthwhile to nursery growers in the future. The purpose of this study was to determine the effect of ectomycorrhizae (*P. tinctorius*) on root and shoot growth of container grown *C. caroliniana* and *F. grandifolia* seedlings.

Materials and Methods

Plant and Fungal Materials

C. caroliniana seedlings were grown at the University of Tennessee Nursery Compound the previous year. Four hundred bareroot *F. grandifolia* seedlings were obtained from Little River Nursery in McMinnville, TN. On 4 and 5 May 1998, 36 *C. caroliniana* seedlings of uniform height (37.7 to 37.8 cm)

were potted into 3.8 L (1 gallon, no. 400) containers and 60 *F. grandifolia* seedlings of uniform height (38.5 to 39.7 cm) were potted into 2.9 L (3/4 gallon, no. 300) containers. The growing medium consisted of 0.424 m³ UT standard bark mix combined with 0.34 m³ of Promix BX (Premier Horticulture Inc., Red Hill, PA). Amendments for 1 m³ of standard bark mix are as follows: 4.1 kg dolomitic limestone, 1.2 kg treble superphosphate (0-46-0), 1.2 kg 18N-2.6P-10K (18-6-12) slow release fertilizer, 1.3 kg gypsum (CaSO₄) and 0.9 kg Micromax (Sierra Chemical Company, Milipitas, CA).

A ten liter bag of vegetative MycorTree™ *P. tinctorius* Marx Superstrain was obtained from Plant Health Care, Inc. (Pittsburgh, PA). This species is intended for use with many indigenous forest tree species, such as *F. grandifolia*.

Treatments and Experimental Design

On 10 May 1998, the following treatments were initiated: (1) seedlings were inoculated with the ectomycorrhizal fungi *P. tinctorius* using the 'container seedling banding' method where approximately 5 ml (1 teaspoon) of inoculum was placed 4 to 5 cm (1 1/2 to 2 inches) deep in the proximity of the primary lateral roots and (2) seedlings were not inoculated.

The experiments were arranged in a randomized complete block design, keeping species separate. There were 6 replications of *C. caroliniana* and 10 replications of *F. grandifolia* for each treatment. Each experimental unit consisted of 3 plants. Plants were blocked by size (height) to reduce variation observed in seedling lots. The experiments were conducted at the Nursery Compound at the University of Tennessee, Knoxville, TN.

Cultural Practices

All plants were grown under 30% shade on a gravel bed and irrigated based on visual inspection with an overhead sprinkler. Lateral branches on the *C. caroliniana* seedlings were pinched at the initiation of the experiment to

stimulate the growth of the primary leader. All plants were staked and tied to promote straight leaders and reduce wind damage.

18N-2.6P-10K (Osmocote 18-6-12) (Scotts-Sierra Horticultural Products Co., Marysville, OH) was top dressed at the following rates: 3.8 L (1 gallon) - 9 grams, 2.9 L (3/4 gallon) - 7 grams. The Virginia Tech Extraction Method was used to obtain extracts of the medium (Wright 1987, Yeager et al. 1983). Leachate samples were collected on 29 May and 7 August 1998 and analyzed for electrical conductivity (EC) and pH. Electrical conductivity was measured using a Myron L Agri-meter AG-5 (Myron L Co., Carlsbad, CA). pH was measured using a SA720 model Orion pH meter. May pH and EC readings for *C. caroliniana* were 5.07/5.23 and 3.5/3.8 mmhos/cm, respectively. May pH and EC readings for *F. grandifolia* were 5.71 and 0.69 mmhos/cm, respectively. August pH and EC readings for *C. caroliniana* were 6.76/6.83 and 0.31/0.22 mmhos/cm, respectively. August pH and EC readings for *F. grandifolia* were 6.47/6.81 and 0.28/0.44 mmhos/cm, respectively.

Sampling and Analysis

Height and caliper of all plants were measured at the initiation of the experiment (10 May 1998) and at the conclusion of the experiment (13 October 1998). Stem height was measured and recorded to the nearest 0.1 cm. Stem caliper was measured 5 cm above the soil line using a Digimatic Caliper meter (Mitutoyo Corp., Tokyo, Japan).

Shoot and roots were collected for *C. caroliniana* on 16 October 1998. Two *C. caroliniana* and *F. grandifolia* plants of average height were selected from each experimental unit. Shoots were severed from the roots at the soil line, cut into approximately 1.5 cm pieces and placed along with the leaves into cotton bags. Roots were rinsed free of media, cut into 1.5 cm pieces and placed in individual bags. Shoots and roots were dried at the University of Tennessee Knoxville Experiment Station, Plant Sciences Unit in a 50C drying oven. After 5

days, bags were removed from the drying oven, emptied into plastic dishes and weighed to the nearest gram.

Data was subjected to an analysis of variance (ANOVA) to determine the significance of the treatments (SAS Institute, Cary, NC). Means were separated by the Least Significant Difference (LSD) test at the 0.05 level.

Results and Discussion

There was no effect of application of the ectomycorrhizal fungi (*P. tinctorius*) on height and caliper growth and shoot and root dry weight of *C. caroliniana* and *F. grandifolia* (Table 9-1)¹. Although the results from this research indicate that mycorrhizal fungi had no effect on growth, results may have been influenced by the episodic nature of *F. grandifolia* and the possibility of transplant shock. When the bareroot *F. grandifolia* plants arrived, they had very few roots. Other possibilities may have to do with the time of inoculation and the time needed for the inoculum to become established. Results may show significant increases in growth in the long term growth of these plants. *P. tinctorius* has a broad host range including: *Quercus*, *Fagus*, *Betula*, *Carya*, *Castanea*, *Salix*, *Tilia*, *Pinus*, *Picea*, *Tsuga*, *Abies*, *Larix*, *Juniperus* and *Taxodium* (Plant Health Care, Inc. 1995) and forms ectomycorrhizal associations with more than 46 tree species belonging to at least eight genera (Sylvia 1998). While this fungi is listed to have a broad host range, it is may not be the appropriate mycorrhizal symbiont of *C. caroliniana*.

Many factors affect the result of mycorrhizal fungi application. Some of these include: (1) mycorrhizal dependency of the host crop, (2) inoculum potential to colonize the host plant and (3) the nutrient status of the soil (Sylvia 1998). Although the plants in these experiments were fertilized at a low rate, it may have not been low enough to benefit the mycorrhizal plants more than the nonmycorrhizal plants. One of the major benefits of the mycorrhizal symbiosis is improved phosphorus uptake (Sylvia 1998). If phosphorus is readily

¹ All tables and figures may be found in the Appendix.

available to the plant, the result of mycorrhizal infection will be less dramatic. Not all plants benefit equally from mycorrhizal infection. As a rule, coarse-rooted plants benefit more than fine-rooted plants and plants in nutrient poor or moisture deficient soils benefit more than those in nutrient rich or moist soils (Sylvia 1998).

Literature Cited

Dirr, Michael A. 1990. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. 4th ed. Stipes Publishing Co., Champaign, IL.

Gamstetter, D. and J. Gulick. 1996. Urban dwellers only need apply. *Am. Nurseryman* 184:47-55.

Gilman, Edward F. 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, NY.

Hightshoe, Gary L. 1988. Native trees, shrubs and vines for urban and rural America: a planting design manual for environmental designers. Van Nostrand Reinhold, New York.

Kozlowski, Theodore T. 1971. Growth and development of trees. Academic Press, Inc. New York.

Langlois, C. Gilles and J. Andre Fortin. 1981. Mycorrhizal development on containerized tree seedlings. *In* Scarratt, J. B., C. Glerum and C. A. Plexman. Proceedings of the Canadian containerized tree seedling symposium. Dept. of the Environment, Canadian Forest Service, Ontario, Canada.

Peattie, Donald Culross. 1991. A natural history of trees of eastern and central North America. Houghton Mifflin Co., Boston, MA.

Plant Health Care, Inc. 1995. MycorTree™ PT. Plant Health Car, Inc. Data Sheet #3.

Smith, S. E. 1980. Mycorrhizas of autotrophic higher plants. *Biol. Rev.* 55:475-510.

Sylvia, David M. 1998. Mycorrhizal symbioses. *In* Sylvia, D. M., Jeffry J. Fuhrmann, Peter G. Hartel and David Zuberer (eds.), Principles and Applications of Soil Microbiology. Prentice Hall, Upper Saddle River, NJ. www.ifas.ufl.edu/~dmsa/refram.htm

Wright, R. D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

Yeager, T. H., R. D. Wright and S. S. Donohue. 1983. Comparisons of pour-through and saturated pine bark extract on N, P, K and pH levels. J. Amer. Soc. Hort. Sci. 108:112-114.

Appendix

Table 9-1. Effect of ectomycorrhizae (*Pisolithus tinctorius*^z) on height and caliper growth increment and dry weight of roots and shoots of *Carpinus caroliniana* and *Fagus grandifolia* seedlings.

mycorrhizae treatment	height incrmnt cm	caliper incrmnt mm	shoot dry wt g	root dry wt g
<i>Carpinus caroliniana</i>				
inoculated	53.9a ^y	4.3a	24.0a	24.3a
uninoculated	62.1a	4.5a	25.7a	23.1a
<i>Fagus grandifolia</i>				
inoculated	1.8a	0.9a	3.1a	1.8a
uninoculated	1.9a	0.8a	3.2a	2.2a

^z Marx Superstrain

^y Means within a column of an individual species followed by the same letter are not significantly different by LSD at p=0.05.

Supplemental Appendix

Supplement to Part 1

Effect of warm and cold stratification periods on germination of *Carpinus caroliniana* seeds^z.

weeks of warm stratification	weeks of cold stratification	number germinated	percent germinated
0	4	0.0	0
0	8	0.2	2
0	12	0.8 ^y	8 ^y
0	16	3.0	30
0	20	5.0	50
0	24	6.2	62
2	4	0.0	0
2	8	0.2	2
2	12	0.6 ^y	6 ^y
2	16	2.4	24
2	20	5.4	54
2	24	5.0	50
4	4	0.2	2
4	8	0.8 ^y	8 ^y
4	12	4.2	42
4	16	5.0	50
4	20	6.6	66
4	24	7.2	72
8	4	0.8 ^y	8 ^y
8	8	4.0	40
8	12	3.2	32
8	16	4.6	46
8	20	5.8	58
8	24	6.0	60

^z 10 seeds per experimental unit

^y Treatments which were affected by the white-footed mouse

Supplement to Part 6

Effect of light intensity on height and caliper growth of *Fagus grandifolia* seedlings.

shade treatment	height, cm			caliper, mm	
	March	May	October	May	October
full sun	48.2a ^z	52.6a	55.4a	4.4a	6.1a
30% shade	48.3a	52.8a	55.3a	4.8a	6.7a
60% shade	49.5a	52.7a	54.8a	4.5a	6.2a

^z Means within a column followed by the same letter are not significantly different by LSD at $p=0.05$.

Supplement to Part 7

Effect of container size on height and caliper growth of *Carpinus caroliniana* seedlings.

container size	height, cm		caliper, mm	
	May	October	May	October
400	25.2a ^z	82.1a	3.2b	8.5ab
600	25.0a	103.4a	3.5ab	9.7a
800	25.2a	96.6a	3.8ab	9.5a
field	23.5a	86.6a	3.9a	7.3b

^z Means within a column followed by the same letter are not significantly different by LSD at $p=0.05$.

Effect of container size on height and caliper growth of *Fagus grandifolia* seedlings.

container size	height, cm			caliper, mm	
	March	May	October	May	October
400	39.7a ^z	42.3a	43.7a	3.8a	4.6a
600	39.6a	43.5a	44.8a	3.8a	4.6a
800	39.2a	42.6a	43.6a	3.7a	4.4a
field	38.4a	42.6a	43.7a	3.6a	4.7a

^z Means within a column followed by the same letter are not significantly different by LSD at $p=0.05$.

Supplement to Part 8

Effect of three rates of Osmocote 18-6-12 on height and caliper growth of *Carpinus caroliniana* seedlings.

fertilizer rate	height, cm		caliper, mm	
	May	October	May	October
18g (high)	14.6a ^z	51.4b	2.5a	7.0a
14g (medium)	14.7a	59.9b	2.2a	7.6a
9g (low)	14.3a	79.9a	2.3a	7.7a

^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Effect of three rates of Osmocote 18-6-12 on height and caliper growth of *Fagus grandifolia* seedlings.

fertilizer rate	height, cm			caliper, mm	
	March	May	October	May	October
46g (high)	48.9a ^z	52.3a	55.8a	4.7a	6.5a
35g (medium)	46.0ab	49.1ab	53.3a	4.3a	6.2a
23g (low)	44.5b	49.0b	52.8a	4.6a	6.1a

^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Effect of three rates of Osmocote 14-14-14 on height and caliper growth of *Gymnocladus dioica* seedlings grown in containers or field grown.

fertilizer rate	height, cm			caliper, mm	
	March	May	October	May	October
85 + 85g (high)	18.2a ^z	47.1a	58.9ab	5.8ab	11.9a
40 + 40g (medium)	22.3a	54.0a	64.5a	6.4a	13.3a
23 + 23g (low)	20.1a	44.8a	55.8ab	6.0ab	12.5a
23 + 23g (field)	18.1a	18.1b	40.4b	4.4b	6.5b

^z Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Supplement to Part 9

Effect of ectomycorrhizae (*Pisolithus tinctorius*^z) on height and caliper growth of *Carpinus caroliniana* seedlings.

mycorrhizae treatment	height, cm		caliper, mm	
	May	October	May	October
inoculated	37.7a ^y	91.6a	4.6a	8.9a
uninoculated	37.8a	100.0a	4.4a	8.9a

^z Marx Superstrain

^y Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Effect of ectomycorrhizae (*Pisolithus tinctorius*^z) on height and caliper growth of *Fagus grandifolia* seedlings.

mycorrhizae treatment	height, cm			caliper, mm	
	March	May	October	May	October
inoculated	35.2a ^y	38.5a	40.3a	3.1a	4.0a
uninoculated	36.3a	39.7a	41.6a	3.5a	4.3a

^z Marx Superstrain

^y Means within a column followed by the same letter are not significantly different by LSD at p=0.05.

Vita

Lisa E. Richardson-Calfee was born in Forest, Mississippi on July 19, 1970. She graduated from Nürnberg American High School in June 1988. The following August she entered University of Tennessee, Knoxville and in December 1992 received a Bachelor of Science degree in Biology and Zoology. In August 1996, Lisa reentered University of Tennessee, Knoxville and in May 1999 received a Master of Science degree in Ornamental Horticulture and Landscape Design.

In August 1999, she will begin a Doctor of Philosophy degree in Horticulture at Virginia Polytechnic Institute and State University.

Lisa is married to Earl F. Calfee III of Cleveland, TN.

8233 3339 35
10-21-99
MRB
ICI
INFORMATION
CONSERVATION, INC.