"GROWTH OF FOUR CONIFER SPECIES DURING ESTABLISHMENT AND THE EFFECTS OF RECURRING SHORT-TERM DROUGHT ON GROWTH AND PHOTOSYNTHETIC CAPACITY"

by

JOSHUA ROY POOL

B.S., Kansas State University, 2002

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Horticulture, Forestry, and Recreation Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:

Major Professor
Dr. Jason Griffin

Copyright

Abstract

The Midwest and southern Great Plains regions of the United States are known for historic and severe droughts. However, short-term recurring drought events are more common and can limit tree survival in landscape and production settings. The pressure of environmental stress combined with numerous diseases and pests are decimating existing *Pinus* L. spp. (pine) plantings and driving the effort to identify alternative species. Four species of conifer were grown in a pine bark substrate and subjected to recurring moderate to severe drought in a controlled environment glass greenhouse as well as field planted to observe root and shoot growth during the initial 12 months after transplant. The species utilized were *Abies nordmanniana* (nordmann fir), *Cupressus arizonica* (Arizona cypress), *Picea engelmannii* (engelmann spruce), and *Thuja* x 'Green Giant' ('Green Giant' arborvitae). Results indicate that *C. arizonica* exhibited extraordinary growth after establishment and was able to maintain growth and photosynthesis following several drought cycles. *Thuja* x 'Green Giant' exhibited significant increase in root and shoot growth after transplant. Under conditions of moderate and severe drought, only minimal reductions in height and shoot dry weight were observed while root growth and photosynthesis were unchanged. *Abies nordmanniana* experienced minimal increases in root and shoot growth throughout the growing season and was unaffected by drought. In contrast, *P. engelmannii* had only modest increases in root dry weight after transplant, while shoot growth was non-existent. Under conditions of severe drought, photosynthesis was reduced. *Cupressus arizonica,* a known drought tolerant species, with its ability to establish quickly and endure drought may have an advantage when establishing in harsh climates such as the Midwest and southern Great Plains. *Thuja* x 'Green Giant' is known to be a rapid grower, however, it established slowly during the current study and may require additional time before resuming

rapid growth and maximum drought tolerance. Slow establishing species such as *A. nordmanniana* and *P. engelmannii* may require greater attention to season of planting to coincide with rapid root growth. However, *P. engelmannii* may not be a suitable choice for the Midwest due to the inability to maintain photosynthesis during periods of drought.

Table of Contents

List of Figures

List of Tables

Chapter 1 - Introduction

Conifers are an integral part of most landscapes, be it rural or urban. In an urban environment conifers anchor the landscape design and provide winter interest and color as well as wildlife habitat. Conifers are used widely for screening of unsightly structures. In rural locations, conifers have been used widely for windbreaks and dust abatement along gravel roads. After the dustbowl of the 1930s, windbreaks were promoted for their ability to slow winds in rural settings to control erosion on adjacent fields (Van Deusen, 1978). In Kansas, the primary conifers used for wind abatement, landscaping, and Christmas tree production are the native *Juniperus virginiana* L. (eastern redcedar), which can be weedy, as well as non-native *Pinus strobus* L. (eastern white pine), *Pinus sylvestris* L. (scots pine), and *Pinus nigra* Arnold (Austrian pine). Currently *Pinus* L. spp. (pine) are experiencing considerable pressure from numerous pests, diseases, and the sometimes harsh climate of the Midwest and southern Great Plains thus jeopardizing the health of current windbreaks and landscapes.

The most significant disease eliminating pine trees in Kansas is pine wilt. This disease complex consists of the pine wood nematode [*Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle] and members of the pine sawyer wood boring beetles (*Monochamus* spp.) (Kobayashi et al., 1984). The pine sawyer beetle vectors the nematode, which causes tree death. Young beetles then emerge the following spring from nematode infested trees; fly to healthy trees and begin feeding thus transferring the nematode to the new tree. The nematode was first reported in the United States in 1929 but was not recognized as a destructive pathogen until 1979 in Columbia, MO on *P. sylvestris* (Dropkin and Foudin, 1979; Steiner and Buhrer, 1934). The nematode kills the host by feeding and reproducing in the xylem and the phloem, which disrupts the flow of

carbohydrates and water throughout the tree. This disease is sometimes exacerbated by environmental stress. As a result of this disease and repeated environmental stress across the region, underutilized conifers that can withstand the environmental pressure of the Midwest and southern Great Plains and are resistant to pests and diseases are of utmost importance. However, a basic understanding of transplant success and ease of establishment will be required prior to widespread acceptance.

It has been said that no other resource on earth determines plant growth so much as water does (Castro et al, 2005; Kozlowski, 1968). Water stress is thought to be one of the main factors contributing to transplant failure (Gilman et al., 1998; Mathers et al., 2007). The Midwest and southern Great Plains regions are currently within a severe drought, with many counties being declared disaster areas (Brewer and Love-Brotak, 2012). In recent years, municipalities are turning to water restrictions more frequently during periods of extended drought, thereby limiting the ability of landowners and industry alike, to irrigate landscape plants. Therefore, there is a demand for drought tolerant conifer species in the Midwest and southern Great Plains that establish easily. Additionally, nursery professionals are always looking for new conifers to fill their plant palette. These plants should transplant easily, be drought tolerant, and withstand high and low temperatures that commonly occur throughout the region.

Plants have numerous mechanisms to cope with water deficit. Deciduous trees, for example, can reduce water loss through transpiration by reducing leaf size, changing stomata density, altering cuticle properties, and leaf senescence (Taiz and Zeiger, 2006). *Zea mays* L. and many *Poaceae* L. reduce water loss by implementing the strategy of leaf rolling, which reduces the leaf area available for transpiration. Conifers, on the other hand do not have the mechanisms to roll their leaves or the luxury of dropping foliage. Additionally, their needles need to survive

multiple growing seasons. Conifers cope with stress by having an efficient root system that can mine the soil profile for all available water, down regulating growth of above ground mass (going dormant), and maintaining an efficient photosystem (Blake and Li, 2003).

The growth periodicity of conifers can often be classified as determinate or indeterminate. Species with a determinate pattern produce one flush of above ground growth in the spring, then form a terminal bud. If conditions are right they can sometimes produce a secondary, smaller, flush of growth following a stressful event. Species with indeterminate growth habit will continue shoot extension throughout the growing season if the environment is favorable, thus having water available and a root system that can extract water throughout the growing season to continue shoot growth for indeterminate species is integral. Information regarding species growth habit can assist the landscape practitioner in selecting planting dates to maximize root growth prior to shoot growth initiating.

Root regeneration and elongation is one of the integral processes that must preclude shoot initiation to insure survivability of transplanted trees (Harris et al., 1996; Mattson, 1991; Richardson – Calfee et al., 2007). Initiation of shoot growth prior to root growth can lead to water and nutrient stress, thus jeopardizing the success of the new plant (Mattson, 1997; Richardson – Calfee and Harris., 2005). For many conifers, it is often the case that the shoot : root ratio declines during the first few years following transplant (Ledig et al., 1970; Mullin, 1963). In several studies, Drew and Ledig (1980) showed an inverse relationship between shoot and root biomass accumulation and that *Pinus taeda* L. (loblolly pine) exhibited greater root biomass accumulation during the first two years of growth as compared to total biomass. Ledig et al. (1970) also showed that *P. taeda* exhibited a tendency to increase aboveground biomass initially, when water and nutrients are abundant, to increase stored photosynthates and

outcompete neighboring plants. As biomass accumulates, a shift is then made to increase root biomass to gain balance between absorbing and transpiring surfaces. When water and nutrients are limiting, all energy is directed toward roots. Inversely, when a need for photosynthates for growth exists, all energy is directed toward shoot accumulation.

The Midwest and southern Great Plains typically has most of its precipitation in either spring or fall. Many plants exhibit a tendency to produce roots during one of these two seasons. This tendency can be linked to cooler soil temperatures and water availability. For some species, bud break can precede the onset of spring root growth. Timing of transplant has been widely documented for many species and recommendations vary significantly between and within genera. Richardson-Calfee et al. (2004) observed differences in trunk diameter, tree height, and root growth prior to spring bud break in northern red oak (*Quercus rubra* L.) and willow oak (*Quercus phellos* L.). *Quercus rubra* transplanted in fall had more roots prior to bud break than trees transplanted in spring. However, there was little difference in tree height and trunk diameter. Conversely, *Quercus phellos* transplanted in fall did have increased trunk diameter, with no difference in root growth. In other work, *Chionanthus virginicus* L. (fringe tree) failed to regenerate roots outside of the root ball until July, well after budbreak, for fall or spring transplanted trees (Harris et al., 1996). Even so, November transplanted *C. virginicus* accumulated the most total biomass compared to December or March transplanting. Several studies suggest that as long as water and nutrients are not limited, many genera can be transplanted nearly anytime during the year (Watson and Himelick, 1982; Watson et al., 1986). The research showed that twig and root growth was greatest when trees were transplanted in July. The authors attributed the results to warmer soil temperatures and available water and nutrients creating an environment conducive to root growth. When species were planted during

spring bud break the authors observed decreased root growth for a period (Watson and Himelick, 1982). Therefore, a better understanding of the root and shoot growth periodicity of a species prior to planting may aid transplant success in difficult environments. The objective of the current study was to investigate the root and shoot growth characteristics of selected conifer species for potential pine replacements.

Species were chosen based on potential for landscape use, Christmas tree production, and wind abatement. Trees must be able to survive in USDA hardiness zones 4-7 (USDA hardiness zone map, 2012) and AHS heat zone 7-8 (Cathey, 1997). Additionally, selected species must survive a wide range of annual precipitation. In Kansas, rainfall is divided with the western portion of the state averaging 381 mm (15 in.) per year and the eastern portion averaging 1143 mm (45 in.) per year (State of Kansas, 2012). *Juniperus virginiana* L. (eastern redcedar), which can be invasive in unmanaged pastureland, is the only conifer native to Kansas. Therefore, conifer species that can survive our climate and are pest resistant are of interest. Species chosen were *Cupressus arizonica* Greene (Arizona cypress), *Abies nordmanniana* (Steven) spach (nordmann fir), *Picea engelmannii* Parry ex Engelm. (engelmann spruce), *Thuja* L. x 'Green Giant' ('Green Giant' arborvitae).

Arizona cypress is known for its drought and heat tolerance (Aker, 1995). It is native in the southwest United States and is found on dry, sterile, rocky mountain slopes, and canyon walls (USDA, 2012). Though a slow grower on rocky, sterile sites, if given good soil and adequate irrigation it can attain 1 m (3.3 feet) of height growth in one growing season. It tolerates alkaline soils and shade, though not recommended for sites with high water tables (USDA, 2012). Canopy is considered dense with fine foliage texture. Prior work has shown that Arizona cypress is a good candidate for wind abatement, landscaping and Christmas tree

production (Fink and Ehrler, 1986; Maiers and Harrington, 1999). Mistletoes and rusts are the primary diseases that attack this species when humidity is high. Little water is required once established. It is an indeterminate growth species.

'Green Giant' arborvitae is a species known to be tolerant of a wide range of soil profiles, temperatures, flooding conditions, and is easily propagated by stem cuttings (Griffin et al., 1998; Holland et al., 2003;) 'Green Giant' arborvitae is a cross between *T. plicata* Donn ex D.Don (western arborvitae) and *T. standishii* (Gordon) Carr. (Japanese arborvitae), both of which are native to moist, cool, and humid climates (USDA, 2012). *Thuja plicata* is native to the northwest region of the United States and *T. standishii* is native to Japan. The cross is known to be hardy for USDA hardiness zones 5 to 7. Moist soils and full sun is the preferred environment. At this time drought tolerance has not been tested. The plant exhibits an upright growth habit reaching a mature height of 15.25 m. (50 ft.). The plant is a favorite among many landscapers for its ability to withstand a wide range of soil types, rapid growth rate, and remain upright in windy settings. In ideal settings, the species can attain 60 cm (2 ft.) of shoot growth in one growing season, which can be attributed to the indeterminate growth pattern that is exhibited by the species.

Picea engelmannii has a wide range of distribution across the western United States. The native range is the Rocky Mountains from British Columbia to Mexico and is the most widely distributed *Picea* spp. (spruce) in the region. In the Central Rocky Mountains, it is typically found from 2745 m (9006 ft.) up to tree line [3048 m (10000 ft.)]. Once established, the species has been noted for withstanding harsh winds, extreme temperatures, as well as drought and deep snow (USDA, 2012). Growth habit is to form a single leader with a conical shape, reaching a height of 60 m (197 ft.) in ideal conditions. Growth rate is slow but sustained for one hundred plus years. Shade tolerance is high for the species and prefers 40% to 80% shade during

establishment (Germino and Smith, 1999). Provenance of *P. engelmannii* is important in selecting for heat tolerance with the most heat tolerant selections originating from the southern range of the species (Burr et al., 1993). It has been used in landscapes with some success throughout the Midwest and southern Great Plains, but has yet to be tested for hardiness.

Abies nordmanniana is native to the Mediterranean Black sea region and is one of the most popular Christmas trees of Europe. It is often found associated in a mixed forest stand with Picea sp. at elevations ranging from 1200 m. to 1800 m. (3937 ft. to 5905 ft.) (Madsen, 1998) The species is gaining popularity in the United States for Christmas tree production. Needle retention rivals that of Frasier fir when kept in water for cut display but varies within provenance of the species (Chastagner and Riley, 2003; Nielsen and Chastagner, 2005). Growth habit is conical, reaching a height of 60 m (197 ft.) in ideal conditions (Oregon State University Landscape Plants, 2003). Plantings have been successful in the northern Great Plains and Pacific Northwest (Jones et al., 2004) but have yet to be tested in the Midwest and southern Great Plains due to perceived site limitations and drought intolerance (Guehl, 1991).

Chapter 2 - Short-term Recurring Drought Affects Growth and Photosynthetic Capacity of Four Conifer Species

Formatted for submission to HortScience

Short-term Recurring Drought Affects Growth and Photosynthetic Capacity of Four Conifer Species

Joshua R. Pool[2], Jason J. Griffin[3], Cheryl R. Boyer[3], and Stuart L. Warren[3]

Kansas State University, Department of Horticulture, Forestry and Recreation Resources, 2021 Throckmorton Plant Science Building, Manhattan, KS 66506

[1]Received for publication _____. This research was funded in part by K-State Agricultural Experiment Station and the Kansas Department of Agriculture. Assistance from the technical staff of the K-State John C. Pair Horticultural Center technical staff is greatly appreciated. From a thesis submitted by J. Pool in partial fulfillment of the requirements for the M.S. degree.

[2] Graduate teaching assistant. To whom reprint requests should be addressed. Email address: jrp0292@k-state.edu

[3]Associate Professor, Assistant Professor, Professor & Head (respectively).

Subject Category: Crop Production

Short-term Recurring Drought Affects Growth and Photosynthetic Capacity of Four Conifer Species

Additional Index words: environmental stress, landscape establishment, root growth, photosynthesis

Abstract: The Midwest and southern Great Plains are known for historic and severe droughts. However, short-term recurring drought events are more common and can limit tree survival. The pressure of environmental stress combined with numerous diseases and pests are decimating existing *Pinus* L. spp. (pine) plantings and driving the effort to identify alternative species. Four species of conifer were grown in a pine bark substrate and subjected to recurring moderate or severe drought to observe the effects on growth and photosynthesis. The species evaluated were: *Abies nordmanniana* (nordmann fir), *Cupressus arizonica* (Arizona cypress), *Picea engelmannii* (engelmann spruce), and *Thuja* x 'Green Giant' ('Green Giant' arborvitae). Height and growth index of *T.* x 'Green Giant' were reduced by recurring drought. However, *T.* x 'Green Giant' was able to maintain photosynthesis and root growth during all drought treatments. In contrast, only photosynthesis of *P. engelmannii* was affected by the drought treatments, while *A. nordmanniana* was not affected by drought. *Cupressus arizonica*, a known drought and heat tolerant species, reduced shoot dry weight, while maintaining P_{net} and root growth. Overall, *C. arizonica* was able to maintain growth of roots and shoots as well as maintain P_{net} which may be an advantage in the harsh climate of the Midwest and southern Great Plains.

It has been said that no other resource on earth determines plant growth so much as water does (Castro et al, 2005; Kozlowski, 1968). The Midwest and southern Great Plains regions are currently within a severe drought, with many counties declared disaster areas (USGS Drought Monitor, 2012). In recent years, municipalities are turning to water restrictions more frequently during periods of extended drought, thereby limiting the ability of homeowners to irrigate landscape plants. Therefore, there is a demand for drought tolerant conifer species in the Midwest and southern Great Plains that establish easily. Additionally, nursery professionals are always looking for new conifers to expand their plant palette. Ideally, these plants should transplant easily, be drought tolerant, and tolerant of extreme temperatures.

Water stress is one of the main factors contributing to transplant failure (Gilman et al., 1998; Mathers et al., 2007). In addition to annual drought cycles and municipal water use restrictions, species of *Pinus* L. (pine) in the Midwest and Great Plains are under pressure from a devastating disease known as pine wilt disease. This disease complex consists of the pine wood nematode [*Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle] and members of the pine sawyer wood boring beetles (*Monochamus* spp.) (Kobayashi et al., 1984). The nematode, which causes tree death, is vectored by the pine sawyer beetle. Young beetles emerge from nematode infested trees and fly to healthy trees to feed, thus infecting the healthy trees with the fatal nematode. A key component of this disease cycle leading to tree death is environmental stress. As a result of this disease and repeated environmental stress across the region, underutilized conifers that can withstand the environmental pressure of the Midwest and southern Great Plains are of utmost importance.

Plants have numerous mechanisms to cope with water deficit. Deciduous trees, for example, can reduce water loss through transpiration by reducing leaf size, changing stomata

density, altering cuticle properties, and leaf senescence (Taiz and Zeiger, 2006). *Zea mays* L. (Corn) and many *Poaceae* L. reduce water loss by implementing the strategy of leaf rolling, which reduces the leaf area available for transpiration. Conifers, on the other hand do not have the mechanisms to roll their leaves or the luxury of dropping foliage. Additionally, their needles need to survive multiple growing seasons. Conifers cope with stress through an efficient root system that can mine the soil profile for all the available water, down regulating growth of above ground mass (going dormant), and maintaining an efficient photosystem (Blake and Li, 2003). A plants' ability to photosynthesize, along with its energy reserves, is responsible for the resumption and expansion of root growth (Johnson-Flanagan and Owens, 1985; Phillipson, 1988). Rapid root expansion is responsible for a seedlings' ability to overcome water stress and in return, results in improved photosynthesis (Burdett, 1990).

Early selection for drought tolerance is ideal for slow growing species such as *Picea* Mill. sp. (spruce). Research has shown positive correlation between early growth rate and the resulting mature growth of *Picea mariana* [Mill.] B.S.P. (Black spruce), as well as other conifers, when grown under drought conditions (Gill, 1987; Tan et al., 1995). This suggests that early growth traits could be used as an indicator of drought tolerance for some conifers (Lambeth, 1980). When testing for drought tolerance, seedlings should be grown under a water-limiting situation (Johnson, 1980). Cannnell et al. (1978) found a correlation between seedling growth and biomass accumulation after 8 years of growth on a drought prone site when the seedlings were subjected to water stress. The investigators further suggested that early selection should be based on results from challenging the seedlings with the growth-limiting factor. Therefore, our objective was to observe growth and photosynthetic capacity of selected species under short-term recurring drought.

Conifers used in this research were: *Thuja* x 'Green Giant' L. ('Green Giant' arborvitae), *Cupressus arizonica* Greene (Arizona cypress), *Abies nordmanniana* (Steven) Spach (nordmann fir), and *Picea engelmannii* Parry ex Engelm. (engelmann spruce). *Thuja* x 'Green Giant' was selected because it is a fast growing conifer that is used widely throughout the country. However, its use in the Great Plains is in its infancy and there is little information available regarding its drought tolerance. *Abies nordmanniana* and *Picea engelmannii* were selected because they represent untested species of genera that are used in the landscape with some success throughout the region. *Cupressus arizonica* was selected for its known heat and drought tolerance. This species has potential to be used in much greater numbers than is currently used.

Materials and Methods

On 14 April 2010, 24 plants each of *T.* x 'Green Giant' (Botany Shop; Joplin, MO) rooted cuttings, *C. arizonica* (New Mexico State conservation seedling program; Santa Fe, NM) seedlings, *A. nordmanniana* (Lawyers Nursery; Plains, MT) seedlings, and *P. engelmannii* (Lawyers Nursery) seedlings were potted into containers filled with an amended pine bark substrate. The substrate consisted of pine bark:sand (8:1, v/v.) amended with 0.91 $kg \cdot m^{-3}$ micronutrient package (Micromax®, Scotts, Marysville, OH), 7.1 $kg \cdot m^{-3}$ controlled release fertilizer (Osmocote® 18N-2.6P-9.9K, Scotts, Marysville, OH), and 0.45 $kg \cdot m^{-3}$ dolomitic limestone. *Cupressus arizonica* seedlings were grown in 164 ml cone-tainers that were removed at potting and the roots manually teased out of the root ball. *Abies nordmanniana* and *P. engelmannii* seedlings were bare root liners whose root systems were trimmed to a consistent length of 18 cm prior to potting. *Thuja* x 'Green Giant' were rooted stem cuttings grown in peat pellets. Nylon stockings were removed from the *T.* x 'Green Giant' root balls prior to potting. Container size was selected based on the size of the plant's root system at potting. *Thuja* x

'Green Giant' were potted in 6.0 L containers (NSI, Chambersburg, PA), *C. arizonica*, 2.8 L containers (NSI), and *A. nordmanniana* and *P. engelmannii*, 10.8 L containers (NSI). Plants were grown under partial shade for 7-weeks at the John C. Pair Horticultural Research Center (Haysville, KS). On 4 June 2010, the plants were moved into a glass greenhouse at Throckmorton Plant Sciences Center, Kansas State University (Manhattan), and allowed to acclimate for 5-weeks. Plants were grown under natural photoperiod and irradiance and watered as needed to avoid moisture stress. Greenhouse temperatures were set to 27 °C day / 18 °C night. On the day of planting 10 plants of each species were selected at random for destructive analysis. The roots were separated from the top at the soil line and washed free of substrate. They were then placed in a forced air drying oven at 65 °C, dried to a constant weight, and subsequently weighed.

Initial substrate water holding capacity was determined by sub-irrigating individual containers in a large reservoir until water was observed glistening on the surface of the container substrate. Water was then allowed to drain slowly from the bottom of the reservoir and containers simultaneously. The containers were allowed to drain 2 hr and then weighed to obtain weight at container capacity (CC). Treatments were initiated on 7 July 2010 by withholding irrigation. Plants were weighed daily at 0600 hr. When they reached one of the three predetermined treatments: 90% CC (well watered control, WW), 80% CC (moderate drought, MD) or 70% CC (severe drought, SD), they were irrigated back to CC, using the sub-irrigation method. This repeated drought cycle was continued until the termination of data collection (31 August 2010).

Photosynthetic measurements began on 31 August 2010. Photosynthetic capacity (P_{net}) of each plant was measured using a CIRAS-1 (PP Systems, Haverhill, MA) infrared gas analyzer

and a climate controlled cuvette supplying 2000 $\mu L \cdot L^{-1}$ CO_2, 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation (PAR), and a leaf temperature of 30 °C. All plants were irrigated 1-day prior to photosynthetic measurements to minimize stomata limitations. A terminal shoot containing current season's growth was placed in the cuvette and data recorded when carbon assimilation stabilized. Terminal shoot was then removed at the base of the cuvette and all photosynthetically active material was placed in a flatbed scanner to obtain area (Regents Instruments Inc. WinFolia leaf area meter; Quebec, Canada). Plants were then destructively harvested by separating the above and below ground portions of the plants. Roots were washed of substrate, and growth data was collected which included: height, shoot dry weight, and root dry weight. Growth Index (GI) was calculated as (plant height + maximum plant width + perpendicular plant width) ÷3. Dry weights were obtained by drying samples at 65 °C in a forced air drying oven until a constant weight was reached.

The experimental design was a randomized complete block design with eight single plant replicates. Data were subjected to ANOVA and means separation using Fisher's Protected LSD at $\alpha = 0.05$ (SAS Institute Inc., Cary, NC). No statistical comparisons were made between species.

Results and Discussion

At the time of planting, the root systems of the four species were different weight (Table 2.1). *Cupressus arizonica* had the smallest root system (0.7 g) followed by *T.* x 'Green Giant' (2.2 g). *A. nordmanniana* and *P. engelmannii* were (14.8 g) and (15.2 g), respectively. Due to this difference between species root systems at the time of planting and the inherent differences in growth rate of the root systems, each species filled the container volume at a different rate. As a result, each species reached the predetermined drought levels at a different rate. Throughout the

duration of the experiment plants subjected to the WW (90% CC) treatment were watered on alternating days. Species reached MD (80% CC) at different rates and with the following frequencies prior to photosynthesis measurement: *C. arizonica* (19 times), *T.* x 'Green Giant' (10 times), *A. nordmanniana* (4 times), and *P. engelmannii* (4 times). Species reached SD (70% CC) at different rates also and with even less frequency prior to photosynthesis measurement: *C. arizonica* (13 times), *T.* x 'Green Giant' (3 times), *A. nordmanniana* (2 times), and *P. engelmannii* (2 times).

Among the four species, *T.* x 'Green Giant' was the most responsive to recurring short-term drought. This was not surprising given that this species is known for its rapid shoot growth rate and that shoot growth is dependent upon adequate substrate moisture. Height and GI were reduced when the plants were exposed to repeated MD (Table 2.2). These two measures rely on shoot extension, which, in turn is dependent on soil moisture and cell turgidity. Repeated exposure to SD continued to suppress shoot growth to the extent that height was further reduced. Shoot growth suppression also resulted in reduced shoot dry weight (SDW). Growth index, however, was not further reduced under SD. Interestingly, root dry weight (RDW) was not affected by drought treatments. Under conditions of drought, plants commonly allocate available resources to root growth rather than shoot growth (Ledig et al., 1970). Apparently, drought treatments in this experiment were not severe enough to elicit a root response. There are various mechanisms that influence photosynthesis during a drought event, however, in the current study P_{net} of *T.* x 'Green Giant' was not affected on a per area basis. However, since plants under drought stress were considerably smaller there would likely be a reduction in whole plant carbon assimilation. Fortunately, this data suggests that under the drought conditions employed in this experiment there was little to no damage to the photosynthetic apparatus. The photosynthesis

data combined with the root growth data, suggests that plants may be able to recover quickly when soil moisture is improved by having a robust root system and the capability to continue photosynthesizing on the still active shoot growth.

In contrast, *P. engelmannii* was nearly unaffected by the drought treatments and *A. nordmanniana* was not affected by drought (Table 2.2). Although P_{net} of *P. engelmannii* was not affected by MD, P_{net} was greatly reduced under SD, which may lead to long-term survival difficulties. The inability to continue photosynthesizing under SD forces the seedlings to survive on stored energy while maintaining growth of a root system (Johnson-Flanagan and Owens, 1985). However, aboveground growth was unaffected for *P. engelmannii*. This was not entirely unexpected since these two species have determinate growth habits and seasonal growth had occurred prior to treatment initiation. Root dry weight of *A. nordmanniana* increased from potting (14.8 g) until termination (39.9 g, WW) of the experiment, with no difference between short-term drought treatments. Conversely, RDW for *P. engelmannii* did not increase from the time of potting to termination. Without a resumption of root growth after potting, the plants would be more susceptible to drought due to the inability to exploit available water. *Picea* Mill. spp. are known to experience severe and long lasting planting check (transplant shock), which is a period of prolonged reduced top growth, even when water and nutrients are not limiting (Mullin, 1963). It has been reported that *P. engelmannii* seedlings may be negatively affected by full and direct radiation and that planting preparation and care to avoid damaging of the root system will help alleviate the severity and duration of planting check (Mullin, 1963). Others attributed planting check to lifting date and storage of the seedlings prior to potting (Jiang et al., 1995; Zwiazek and Blake, 1989).

Cupressus arizonica, a known drought and heat tolerant species (Fink and Ehrler, 1986; Harrington et al., 2005), experienced minimal effects of the short-term recurring drought (Table 1). Shoot dry weight was the only growth variable affected. When subjected to MD there was a noticeable decrease in shoot dry weight, however, SD did not reduce growth any further. Height and GI were unaffected suggesting that the species compensated for moisture deficit by producing a less dense plant with less leaf area for transpiration, while maintaining shoot extension. Root growth was also unaffected by short-term recurring drought. The ability to maintain root growth afforded the shoots the ability to continually expand due to the continued flow of water from the still active root system and energy from the active photosystem. Many shade intolerant species, such as *C. arizonica*, exhibit the ability to produce enormous aboveground growth to outcompete any neighboring barriers to light (Grime, 1965; Wright et al., 2004).

Data herein indicates that *C. arizonica* has the ability to endure drought and continually grow to ensure that the species is not outcompeted for water or nutrients during times of drought. With the extraordinary ability to establish and quickly grow, coupled with the drought enduring capabilities, *C. arizonica* may be an exceptional replacement for *Pinus* spp. in the Midwest and southern Great Plains (Pool et al., M.S. Thesis, 2012). *Thuja* x 'Green Giant' was the most affected by the drought treatments which could be expected due to the rapid growth of the cultivar, which relies on adequate water supplies to maintain. Even so, *T.* x 'Green Giant was able to maintain root growth and an active photosystem. This leads us to believe that *T.* x 'Green Giant', contrary to popular belief, can avoid drought by reducing plant size while continually growing roots and photosynthesizing. Growth of *P. engelmannii* and *A. nordmanniana* were unaffected by drought, which was to be expected for determinate growth species. Unfortunately,

P. engelmannii failed to maintain an efficient photosystem and experienced minor losses for both MD (87.5% survival) and SD (75% survival). More research is needed on drought and establishment prior to recommending *P. engelmannii* and *A. nordmanniana* for use in the Midwest and southern Great Plains.

References

Blake, T. and J. Li. 2003. Hydraulic adjustment in jack pine and black spruce seedlings under controlled cycles of dehydration and rehydration. Physiol. Plant. 117:532-539.

Burdett, A.N. 1990. Physiological processes in plantation establishment and the development of specifications for forest planting stock. Can. J. For. Res. 20:415-427.

Cannell, M. G. R., F. E. Bridgewater, M.S. Greenwood, and P. Mitschke. 1978. Seedling growth rates, water stress responses and root – shoot relationships related to eight – year volumes among families of *Pinus taeda* L. Silvae Genetica 27:237-248.

Castro, J., R. Zamora, J.A. Hodar, and J.M. Gomez. 2005. Alleviation of summer drought boosts establishment success of *Pinus sylvestris* in a Mediterranean mountain: an experimental approach. Plant Ecol. 181:191-202.

Fink, D.H. and W.L. Ehrler. 1986. Christmas tree production using the runoff farming system. HortScience 21:459-461.

Gill, J. G. S. 1987 Juvenile – mature correlation and trends in genetic variances in Sitka spruce in Britain. Silvae Genetica. 36:189- 94.

Gilman, E., R. Black, and B. Dehgan. 1998. Irrigation volume and frequency and tree size affect establishment rate. J. of Arb. 24:1-9.

Grime, J.P. 1965. Comparative experiments as a key to the ecology of flowering plants. Ecology 46:513-515.

Harrington, J., M. Loveall, and R. Kirksey. 2005. Establishment and early growth of dryland plantings of Arizona cypress in New Mexico, USA. Agrofor. Syst. 63:183-192.

Jiang, Y., S.E. MacDonald, and J.J. Zwiazek. 1995. Effects of cold storage and water stress on water relations and gas exchange of white spruce (*Picea glauca*) seedlings. Tree Physiol. 15:267-273.

Johnson, D.A. 1980. Improvement of perennial herbaceous plants for drought-stressed western rangelands. In: Turner, N. C. and P.J. Kramer (eds.). Adaptation of plants to water and high temperature stress, Wiley, NY. pp. 419-433.

Johnson-Flanagen, A.M. and J.N. Owens. 1985. Root growth and root growth capacity of white spruce (*Picea glauca* (Moench) Voss) seedlings. Can. J. For. Res. 15:625-630.

Kobayashi, F., A. Yamane, and T. Ikeda. 1984. The Japanese pine sawyer beetle as the vector of pine wilt disease. Annu. Rev. Entomol. 29:115-135.

Kozlowski, T.T. 1968. Water deficit and plant growth. Vol. 1. Development, control and measurement. Academic press. Waltham, MA.

Lambeth, C. C. 1980. Juvenile – mature correlation in *Pinaceae* and implications for early selection. For. Sci. 26:571-580.

Ledig, F.T., F.H. Bormann, and K.F. Wenger. 1970. Distribution of dry matter growth between shoot and roots in loblolly pine. Bot. Gaz. 131:349-359.

Mathers, H.M., S.B. Lowe, C. Scagel, D.K. Struve, and L.T. Case. 2007. Abiotic factors influencing root growth of woody nursery plants in containers. HortTechnology. 17:151-162.

Mullin, R.E. 1963. Planting check in Spruce. The Forestry Chronicle 39:252-259.

Philipson, J.J. 1988 Root growth in Sitka spruce and Douglas fir transplant: dependence on the shoot and stored carbohydrates. Tree Physiol. 4:101-108.

Regents Instruments Inc. 2012. WinFolia leaf area meter. Quebec, Canada.

SAS Institute, Inc. 2004. SAS user's guide. Release 9.1. SAS Institute, Inc. Cary, NC.

Taiz, L. and E. Zeiger. 2006. Plant Physiology. 4th ed. pp 671-680. Sinauer Assoc. Sunderland, MA.

Tan, W., T. J. Blake, T. J. B. Boyle. 1995. Early selection for drought tolerance and relationship to dry weight partitioning in black spruce families. For. Sci. 41:168-180.

Wright, A.N., S.L. Warren, F.A. Blazich, and U. Blum. 2004. Root and shoot growth periodicity of *Kalmia latifolia* 'Sarah' and *Ilex crenata* 'Compacta'. HortScience 39:243-247.

Zwiazek, J. J. and T. J. Blake. 1989. Effects of preconditioning on subsequent water relations, stomatal sensitivity, and photosynthesis in osmotically stressed black spruce. Can. J. Bot. 67: 2240-2244.

Table 2.1 Initial height (Ht), shoot dry weight (SDW), root dry weight (RDW), and growth index (GI), of *Cupressus arizonica, Picea engelmannii, Thuja* x 'Green Giant' and *Abies nordmanniana* at potting.

	C. arizonica	*P. engelmannii*	*T.* x 'Green Giant'	*A.nordmanniana*
Ht (cm)	32.9	38.2	35.9	29.3
SDW (g)	2.0	52.5	7.7	32.5
RDW(g)	0.7	15.2	2.2	14.8
GI[z]	16.5	25.1	20.8	25.7

[z] (plant height + maximum plant width + perpendicular plant width) ÷3

Table 2.2 Height (Ht), shoot dry weight (SDW), root dry weight (RDW), growth index (GI), and net photosynthesis (P_{net}) of *Cupressus arizonica, Picea engelmannii, Thuja* x 'Green Giant' and *Abies nordmanniana* grown under recurring short-term drought cycles of 90%, 80%, or 70% container capacity.

	C. arizonica			*P. engelmannii*			*T.* x 'Green Giant'			*A. nordmanniana*		
	90%	80% (19)[z]	70% (13)	90%	80% (4)	70% (2)	90%	80% (10)	70% (3)	90%	80% (4)	70% (2)
Ht (cm)	65.4[NS]	60.3	59.4	42.0[NS]	42.3	43.0	58.6[**]a[y]	49.5b	43.1c	35.5[NS]	34.3	32.6
SDW (g)	43.4[**]a	35.4b	33.9b	40.3[NS]	39.0	33.4	52.5[**]a	46.3a	33.1b	55.8[NS]	53.0	50.9
RDW (g)	9.2[NS]	6.7	7.3	19.2[NS]	21.2	15.6	8.2[NS]	7.4	5.3	39.9[NS]	37.6	31.8
GI[x]	45.1[NS]	42.5	43.2	29.9[NS]	29.2	30.6	49.2[**]a	42.5b	42.4b	39.0[NS]	36.4	35.8
P_{net}[w]	5.4[NS]	6.2	8.6	6.2[**]a	5.6a	1.4b	2.3[NS]	3.2	3.2	3.4[NS]	3.0	2.8

[z] Numbers in parentheses refers to number of short-term drought cycles.

[NS,*,**] Not significant, significant at $P \leq 0.05$, or significant at $P \leq 0.01$ within a species and within a row.

[y] Means followed by a different letter within a species and within a row are significantly different, Fishers Protected LSD ($\alpha = 0.05$), n=8.

[x] (plant height + maximum plant width + perpendicular plant width) ÷3

[w] Net photosynthesis (P_{net}) measured in µmol $CO_2 \bullet m^{-2} \bullet s^{-1}$

Chapter 3 - Establishment and Growth of Transplanted Conifers in the Southern Great Plains

Formatted for submission to HortScience

Establishment and Growth of Transplanted Conifers in the Southern Great Plains

Joshua R. Pool[2], Jason J. Griffin[3], Cheryl R. Boyer[3], and Stuart L. Warren[3]

Kansas State University, Department of Horticulture, Forestry and Recreation Resources, 2021 Throckmorton Plant Science Building, Manhattan, KS 66506

[1]Received for publication _____. This research was funded in part by K-State Agricultural Experiment Station and the Kansas Department of Agriculture. Assistance from the technical staff of the K-State John C. Pair Horticultural Center technical staff is greatly appreciated. From a thesis submitted by J. Pool in partial fulfillment of the requirements for the M.S. degree.

[2]Graduate teaching assistant. To whom reprint requests should be addressed. Email address: jrp0292@k-state.edu

[3]Associate Professor, Assistant Professor, Professor & Head (respectively).

Subject Category: Crop production

Establishment and Growth of Transplanted Conifers in the Southern Great Plains

Additional Index words: field production, landscape establishment, root growth, shoot growth, bare root

Abstract: Currently *Pinus* L. spp. (pine) are experiencing considerable pressure from numerous pests, diseases, and the sometimes harsh climate of the Midwest and Great Plains thus jeopardizing the health of current windbreaks and landscapes. Four species of conifers, *Abies nordmanniana* (nordmann fir), *Cupressus arizonica* (Arizona cypress), *Picea engelmannii* (engelmann spruce), and *Thuja* x 'Green Giant' ('Green Giant' arborvitae) were planted in a sandy loam soil to observe root and shoot growth during the initial 12 months following transplant. Whole plant (roots and shoots) harvests occurred monthly for examination and collection of growth data. Results indicate that *C. arizonica* exhibited extraordinary root and shoot growth throughout the growing season with increases in dry weight of 4800% and 6300%, respectively. In contrast, *P. engelmannii* exhibited a modest increase in root dry weight of 82% throughout the growing season while shoot growth was essentially non-existent. *Thuja* x 'Green Giant' exhibited significant increases in shoot (230%) and root (350%) growth throughout the growing season. *Abies nordmanniana* exhibited minimal yet significant shoot and root growth during the study, with dry weight increases of 13% and 55%, respectively. The data herein suggests that *C. arizonica* easily establishes following transplant because it rapidly establishes new root and shoot growth. *Thuja* x 'Green Giant' may require a year to establish before rapid

growth is observed. Attention to season of planting may be important for slow establishing species such as *A. nordmanniana* and *P. engelmannii*.

Conifers are an integral component of most landscapes, be it rural or urban. In an urban environment conifers anchor the landscape design and provide winter interest and color as well as wildlife habitat. Conifers are used widely for screening of unsightly structures. In the rural environment, conifers have been used for windbreaks and dust abatement along gravel roads. After the dustbowl of the 1930s, windbreaks were promoted for their ability to slow winds in rural settings and to control erosion on adjacent fields (Van Deusen, 1978). In Kansas, the primary conifer used for wind abatement, landscaping, and Christmas tree production is native *Juniperus virginiana* L. (eastern redcedar), which can be weedy, as well as non-native *Pinus strobus* L. (eastern white pine), *Pinus sylvestris* L. (scots pine), and *Pinus nigra* Arnold (Austrian pine). Currently *Pinus* L. spp. (pine) are experiencing considerable pressure from numerous pests, diseases, and the sometimes harsh climate of the Midwest and Great Plains thus jeopardizing the health of current windbreaks and landscapes. The most significant disease eliminating pine trees in Kansas is pine wilt. This disease complex consists of the pine wood nematode [*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle] and members of the pine sawyer wood boring beetles (*Monochamus* spp.) (Kobayashi et al., 1984). The nematode, which causes tree death, is vectored by the pine sawyer beetle as young beetles emerge from nematode infested trees and fly to healthy trees to feed. The nematode was first reported in the United States in 1929 but was not recognized as a destructive pathogen until 1979 in Columbia, MO on Scots pine (Dropkin and Foudin, 1979; Steiner and Buhrer, 1934). The nematode kills the host by feeding and reproducing in the xylem and the phloem, which disrupts the flow of carbohydrates and water throughout the tree. This disease is sometimes exacerbated by environmental stress. As a result of this disease and repeated environmental stress across the

region, underutilized conifers that can withstand the environmental pressure of the Midwest and Great Plains and are resistant to pests and diseases are of utmost importance. However, a basic understanding of transplant success and ease of establishment will be required prior to widespread acceptance.

Root regeneration and elongation is one of the integral processes that must preclude shoot initiation to ensure survivability of transplanted trees (Harris et al., 1996; Mattson, 1991; Richardson – Calfee et al., 2007). Initiation of shoot growth prior to root growth can lead to water and nutrient stress, thereby jeopardizing the success of the new plant (Mattson, 1997; Richardson – Calfee and Harris, 2005). For many conifers, it is often the case that the shoot : root ratio (shoot dry weight ÷ root dry weight) declines during the first few years following transplant (Ledig et al., 1970; Mullin, 1963). Drew and Ledig (1980) showed an inverse relationship between shoot and root biomass accumulation and that *Pinus taeda* L. (loblolly pine) exhibited greater root biomass accumulation during the first two years of growth as compared to total biomass. Ledig et al. (1970) also showed that *P. taeda* exhibited a tendency to increase aboveground biomass initially when water and nutrients are abundant to increase stored photosynthates. As biomass accumulates, a shift is then made to increase root biomass to gain balance between absorbing and transpiring surfaces. When water and nutrients are limiting, all energy is directed toward roots. Inversely, when a need for photosynthates for growth exists, all energy is directed toward shoot accumulation.

Timing of transplant has been widely documented for many species and recommendations vary significantly between and within genera. Richardson-Calfee et al. (2004) observed differences in trunk diameter, tree height, and root growth prior to spring bud break in *Quercus rubra* L. (northern red oak) and *Quercus phellos* L. (willow oak). *Quercus rubra*

transplanted in fall had more roots prior to bud break than trees transplanted in spring. However, there was little difference in tree height and trunk diameter. Conversely, *Q. phellos* transplanted in fall did have increased trunk diameter, with no difference in root growth. In other work, *Chionanthus virginicus* L. (fringe tree) failed to regenerate roots outside of the root ball until July, well after budbreak, for fall or spring transplanted trees (Harris et al., 1996). Even so, November transplanted *C. virginicus* accumulated the most total biomass compared to December or March transplanting. One study suggests that as long as water and nutrients are not limited, many genera can be transplanted nearly anytime during the year (Watson and Himelick, 1982; Watson et al., 1986). These studies also showed that twig and root growth was greatest when trees were transplanted in July with a tree spade. The authors attributed the results to warmer soil temperatures and available water and nutrients creating an environment conducive to root growth. When *Acer platanoides* L. (Norway maple) were planted during spring bud break the authors observed decreased root growth compared to later planting dates (May), yet resumed root growth similar to May transplants after one year of growth (Watson and Himelick, 1982). Therefore, a better understanding of root and shoot growth periodicity of a species prior to planting may aid transplant success in difficult environments. Our objective was to investigate the root and shoot growth characteristics of selected conifer species for potential pine replacements for the southern Great Plains.

Materials and Methods

On 7 April 2010, 96 plants each of *Thuja* x ‘Green Giant’ L. (‘Green Giant’ arborvitae) (Botany Shop; Joplin, MO), *Cupressus arizonica* Greene (Arizona cypress) (New Mexico state conservation seedling program, Santa Fe, NM), *Abies nordmanniana* (Steven) Spach (nordmann fir) (Lawyer Nursery; Plains, MT), and *Picea engelmannii* Parry ex Engelm. (engelmann spruce)

(Lawyer Nursery) were planted into a Canadian-Waldeck fine sandy loam soil at the Kansas State University John C. Pair Horticulture Center (Haysville, KS). Prior to planting, the site was cultivated, leveled and nitrogen (Urea 46N-0P-0K) was incorporated following a soil test recommendation (Servi-Tech Laboratories; Dodge City, KS) at a rate of 39 kg· ha^{-1} and cultivated to a depth of 7.6 cm. *Cupressus arizonica* seedlings were grown in 164 ml cone-tainers which were removed at planting and the roots manually teased out of the root ball. *Abies nordmanniana* and *P. engelmannii* seedlings were bare root liners whose root systems were trimmed to a consistent length of 17.8 cm prior to planting. *Thuja* x 'Green Giant' were rooted stem cuttings grown in peat pellets. The nylon stockings were removed from the root ball prior to planting. The seedlings were planted in six rows with 1.0 m in-row spacing and 3.0 m between-row spacing. All planting was done by hand and plants were watered immediately following planting. Freezing temperatures occurred the night following planting and slight freeze damage was observed on all species. *Cupressus arizonica* and *T.* x 'Green Giant' were staked with 1.2 m bamboo stakes to provide additional support. Drip irrigation was utilized to maintain adequate soil moisture [Robert's RO-Drip 300 LPH•100 m^{-1}; San Marcos, CA]. Watering occurred weekly for 6 hr to achieve 18.0 L•m^{-1} of water when precipitation was insufficient. Weed control was accomplished using oryzalin (United Phosphorous Inc., Trenton, NJ) applied after planting at a rate of 9.45 L•ha^{-1} and directed applications of glyphosate (2%) as needed. On the day of planting 10 plants of each species were harvested and measured for initial growth data utilizing the procedures mentioned below.

Two whole plants per species (roots and shoots) were harvested every 28 days utilizing a skid-steer mounted U-blade [Bobcat Digger 91.4 cm ; West Fargo, ND] to obtain a standard size root ball. Once lifted, free soil was shaken loose and plants were placed in a polyethylene bag

and transported to Throckmorton Plant Sciences Center, Kansas State University, Manhattan. Plants were held in a cooler at 6.7 °C with all data collection occurring within 21 days after harvest. Data included plant height, width 1 (at the widest point), width 2 (90° to width 1), and stem caliper at the soil line were measured. Roots were then separated from the shoots and washed with dry weights of both obtained following drying to a constant weight at 65.0°C in a forced air drying oven. A growth index (GI) was calculated as (plant height + maximum plant width + perpendicular plant width) ÷ 3. The experiment was a randomized complete block design with a split-plot arrangement of treatments. Whole plots consisted of time (harvest) and species were the sub-plot. There were two sub-samples per species per harvest and the experiment was replicated four times (blocks) resulting in eight plants per species per harvest. Data were subjected to ANOVA and regression lines were fit where appropriate using SAS v. 9.1 (SAS Institute, Inc. 2004; Cary, NC).

Results and Discussion

Percent survival for *C. arizonica*, *T.* x 'Green Giant', *P. engelmannii*, and *A. nordmanniana* were, 99%, 92%, 65%, and 82%, respectively. All of which would be considered acceptable for many growers. There was a significant interaction between the main effects of species and harvest date for all measured variables. In addition, species height and shoot dry weight (SDW) responded similarly throughout the growing season (Figs. 1 and 2). Height of *C. arizonica* seedlings increased 165% from 34.3 cm at planting to a maximum of 91.1 cm by 36 weeks after planting (WAP). Height increase of *T.* x 'Green Giant' was less dramatic (51% increase); however, substantial growth did occur from 30.4 cm at planting to 45.9 cm by 48 WAP. Shoot height of *P. engelmannii* (40.0 cm) and *A. nordmanniana* (33.3 cm) were unchanged throughout the year.

As expected, SDW followed a similar pattern as shoot height (Fig. 2). *Cupressus arizonica* exhibited an exceptional increase in SDW, from 2.7 g at planting to 201.1 g at 32 WAP (7300% increase) (Fig. 2). Shoot dry weight of *T.* x 'Green Giant' also increased from 8.9 g to a maximum of 30.6 g at 40 WAP (230% increase). Shoot dry weight of *P. engelmannii* (46.0 g) and *A. nordmanniana* (37.8 g) were unchanged throughout the year. These results were not entirely surprising given the inherent growth pattern of *C. arizonica* and *T.* x 'Green Giant'. So long as resources (soil moisture and fertility) are available and the temperature is acceptable for growth, the two species will continue growing throughout the season. *Picea engelmannii* and *A. nordmanniana*, however, are species that have determinate growth habits, which typically occurs shortly after budbreak.

Growth index (GI) of *C. arizonica* and *T.* x 'Green Giant' increased (145% and 36.0%, respectively) throughout the growing season (Fig. 3) which was expected based on height and SDW increases. However, GI of *A. nordmanniana* was unchanged and that of *P. engelmannii* decreased. The decrease in GI of *P. engelmannii* is likely an artifact of increased variability due to fewer samples per harvest from plant death. The rapid increase of *C. arizonica* shoot growth may be associated with an inherent trait to assist in avoiding competition while producing an abundant root system to exploit soil resources (Grime, 1965; Wright et al., 2004). In a study by Grimes (1965), *Ailanthus altissima* (Mill.) Swingle (tree of heaven) exhibited rapid shoot growth that allowed the plant to avoid shading by competitors. *Cupressus arizonica* is native to, and well adapted to, drought prone regions. In the current study, this species was not subjected to prolonged drought conditions and therefore efficiently utilized its resources for rapid growth.

Root growth of *C. arizonica* initiated prior to the first harvest (4 WAP) and by the final harvest (48 WAP) had reached a depth greater than 1.0 m. It has been documented that the time

to initiation of new root growth is an excellent predictor of a species ability to successfully transplant (Harris et al., 1996; Richardson-Calfee et al., 2007; Wright et al., 2004). Root dry weight (RDW) of *C. arizonica* increased by 5300%, from 0.51 g at planting to 27.3 g at 36 WAP (Fig. 4). The ability of *C. arizonica* to exploit favorable conditions and rapidly increase root mass may explain some of its known drought tolerance. New root growth of *T.* x 'Green Giant' was not observed until 16 WAP with a total increase of 375% at 44 WAP. *Abies nordmanniana* and *P. engelmannii* had similar patterns of root regeneration with new root growth beginning by 8 WAP and ceasing by 24 WAP resulting in increases of 90% and 135%, respectively. Overall, each of the species substantially increased their root mass throughout the growing season. However, in the case of *A. nordmanniana* and *P. engelmannii* roughly doubling the root mass may not be sufficient in a stressful environment.

Shoot to root ratio (SDW : RDW) of *C. arizonica* increased rapidly (268%) after planting due to rapid shoot expansion relative to root growth in early spring (4 to 12 WAP) but decreased with increasing root growth throughout the summer and into fall resulting in a decrease of 68% from 12 WAP to 48 WAP (Fig. 5). Above ground biomass was approximately 90% of total plant dry weight throughout the entire study (data not shown). Similar research by Ledig et al. (1970) on *P. taeda* (loblolly pine), a similar semi-determinant growth species, showed that shoot growth was active during the spring when soil moisture was adequate and temperatures were ideal, then root growth resumed a more dominant role as water became limiting. *Thuja* x 'Green Giant' followed a similar pattern to *C. arizonica* with an initial increase of 56% at 12 WAP followed by a decline in SDW : RDW (54%) at 48 WAP. *Picea engelmannii* and *A. nordmanniana* both had declines in SDW : RDW (46% and 28%, respectively), which is expected for a species with one flush of shoot growth in the spring followed by several weeks of root growth.

Stem caliper is often positively correlated with root growth (Ammer and Wagner, 2005; Drexhage and Gruber, 1999; Santantonio et al., 1977). In the current study, caliper and RDW followed similar trends. As with the other growth measurements, caliper of *C. arizonica* increased rapidly (380 %) from 3.1 mm at planting to 14.9 mm at 48 WAP (Fig. 6). *Picea engelmannii* and *T.* x 'Green Giant' caliper increased similarly to RDW with maximum increases of 24% and 72%, respectively. However, *A. nordmanniana* failed to increase stem diameter during the study (10.1 mm).

Data herein suggests that *C. arizonica* rapidly establishes a robust root system and produces considerable shoot growth in a single season. These traits along with its known drought and heat tolerance make this species an ideal candidate for the lower Midwest and Great Plains regions. *Thuja* x 'Green Giant' is known for its rapid growth and local plantings have been successful. However, in the current study growth of this species was less than anticipated. Although many growth parameters increased throughout the season, the magnitude of increase failed to meet expectations. Perhaps this species requires a season to establish prior to assuming a rapid growth habit. *Picea engelmannii* and *A. nordmanniana* did not produce any shoot growth and root growth was minimal. In many instances, these species did not acclimate to the summer heat and the root system was insufficient to sustain the plant. Planting check (transplant shock) has been observed in numerous species of *Picea* sp. Mill.(spruce) with severity lasting from one up to 15 years (Mullin, 1963). Laing (1932) attributed this to damage to the root system at planting which inhibits the absorption of water and nutrients. Both of these species (*P. engelmannii, A. nordmanniana)* can be successfully grown in the southern Great Plains region, however, more research regarding planting and establishment may be needed.

References

Ammer, C. and S. Wagner. 2005. An approach for modeling the mean fine-root biomass of Norway spruce stands. Trees 19:145-153.

Drew, A. and F. Ledig. 1980. Episodic growth and relative shoot -root balance in loblolly-pine seedlings. Annals of Bot. 45:143 - 148.

Drexhage, M. and F. Gruber. 1999. Above- and below-stem relationships for *Picea abies*: estimating root system biomass from breast-height diameters. Scand. J. For. Res. 14: 328-333.

Dropkin, V.H. and A.S. Foudin. 1979. Report of the occurrence of *Bursaphelenchus lignicolus*-induced pine wilt disease in Missouri. Plant Dis. Rep. 63: 904-905.

Grime, J.P. 1965. Comparative experiments as a key to the ecology of flowering plants. Ecology 46: 513-515.

Harris, J.R., P. Knight, and J. Fanelli. 1996. Fall transplanting improves establishment of balled and burlapped fringe tree (*Chionanthus virginicus* L.). HortScience 31: 1143-1145.

Kobayashi, F., A. Yamane, and T. Ikeda. 1984. The Japanese pine sawyer beetle as the vector of pine wilt disease. Annu. Rev. Entomol. 29: 115-135.

Laing, E.V. 1932. Studies on tree roots. For. Comm. Bull. London. 13:1 – 73.

Ledig, F.T., F.H. Bormann, and K.F. Wenger. 1970. Distribution of dry matter growth between shoot and roots in loblolly pine. Bot. Gaz. 131: 349 -359.

Mullin, R.E. 1963. Planting check in Spruce. The Forestry Chronicle 39(3): 252-259.

Richardson-Calfee, L.E., J.R. Harris, and J.K. Fanelli. 2004. Seasonal effects of transplanting on northern red oak and willow oak. J. Environ. Hort. 22: 75- 79.

Richardson-Calfee, L.E. and J.R. Harris. 2005. A review of the effects of transplant timing on landscape establishment of field-grown deciduous trees in temperate climates. HortTechnology 15:132-135.

Richardson-Calfee, L.E., J.R. Harris, and J.K. Fanelli. 2007. Post-transplant root and shoot growth periodicity of sugar maple. J. Amer. Soc. Hort. Sci. 132: 147-157.

Santantonio, D., R.K. Herrmann; W.S. Overton. 1977. Root biomass studies in forest ecosystems. Pedobiologia 17: 1 – 31.

SAS Institute, Inc. 2004. SAS user's guide. Release 9.1. SAS Institute, Inc. Cary, NC.

Steincr, G. and E.M. Buhrer. 1934 *Aphelenchoides xylophilus* n. sp. a nematode associated with bluestain and other fungi in timber. J.Agric. Res. 48: 949-951.

Van Deusen, J.L. 1978. Shelterbelts on the Great Plains: what's happening? J. of For. 76: 160-161.

Watson, G.W. and E.B. Himelick. 1982. Root distribution of nursery trees and its relationship to transplanting success. J. of Arb. 8:225-229.

Watson, G.W., E.B. Himelick, and E.T. Smiley. 1986. Twig growth of eight species of shade trees following transplanting. J. of Arb. 12: 241-245.

Wright, A.N., S.L. Warren, F.A. Blazich, and U. Blum. 2004. Root and shoot growth periodicity of *Kalmia latifolia* 'Sarah' and *Ilex crenata* 'Compacta'. HortScience 39: 243-247.

Figure Captions

Fig. 1 Height (cm) of Arizona cypress (AC) ($y = -0.05x^2 + 3.5x + 13.6$; $R^2 = 0.89$), engelmann spruce (ES), nordmann fir (NF), and 'Green Giant' arborvitae (GG) ($y = 0.2x + 31.2$; $R^2 = 0.48$) throughout 48 weeks after planting (WAP).

Fig. 2 Shoot dry weight (SDW) of Arizona cypress (AC) ($y = -0.10x^2 + 10.30x - 73.88$; $R^2 = 0.86$), engelmann spruce (ES), nordmann fir (NF), and 'Green Giant' arborvitae (GG) ($y = 0.53x + 4.58$; $R^2 = 0.76$) throughout 48 weeks after planting (WAP).

Fig. 3 Growth index [(width + perpendicular width + height) ÷ 3] of Arizona cypress (AC) ($y = -0.03x^2 + 2.25x + 6.26$; $R^2 = 0.88$), engelmann spruce (ES) ($y= -0.10x + 29.32$; $R^2 = 0.69$), nordmann fir (NF), and 'Green Giant' arborvitae (GG) ($y = 0.16x + 21.33$; $R^2 = 0.68$) throughout 48 weeks after planting (WAP).

Fig. 4 Root dry weight (RDW) of Arizona cypress (AC) ($y = 0.70x - 4.85$; $R^2 = 0.84$), engelmann spruce (ES) ($y = -0.01x^2 + 0.92x + 9.25$; $R^2 = 0.54$), nordmann fir (NF) ($y = 0.21x + 15.74$; $R^2 = 0.40$), and 'Green Giant' arborvitae (GG) ($y = 0.00x^2 + 0.10x + 0.60$; $R^2 = 0.89$) throughout 48 weeks after planting (WAP).

Fig. 5 Shoot dry weight (SDW) : root dry weight (RDW) of Arizona cypress (AC) ($y = -0.14x + 13.64$; $R^2 = 0.15$), engelmann spruce (ES) ($y = 0.00x^2 - 0.11x + 4.16$; $R^2 = 0.91$), nordmann fir

(NF) ($y = -0.02x + 2.41$; $R^2 = 0.78$), and ‘Green Giant’ arborvitae (GG) ($y = -0.10x + 8.16$; $R^2 = 0.63$) throughout 48 weeks after planting (WAP).

Fig. 6 Caliper of Arizona cypress (AC) ($y = -0.01x^2 + 0.78x - 1.92$; $R^2 = 0.90$), engelmann spruce (ES) ($y = -0.00x^2 + 0.16x + 9.57$; $R^2 = 0.50$), nordmann fir (NF), and ‘Green Giant’ arborvitae (GG) ($y = 0.06x + 3.20$; $R^2 = 0.69$) throughout 48 weeks after planting (WAP).

Figure 3.1

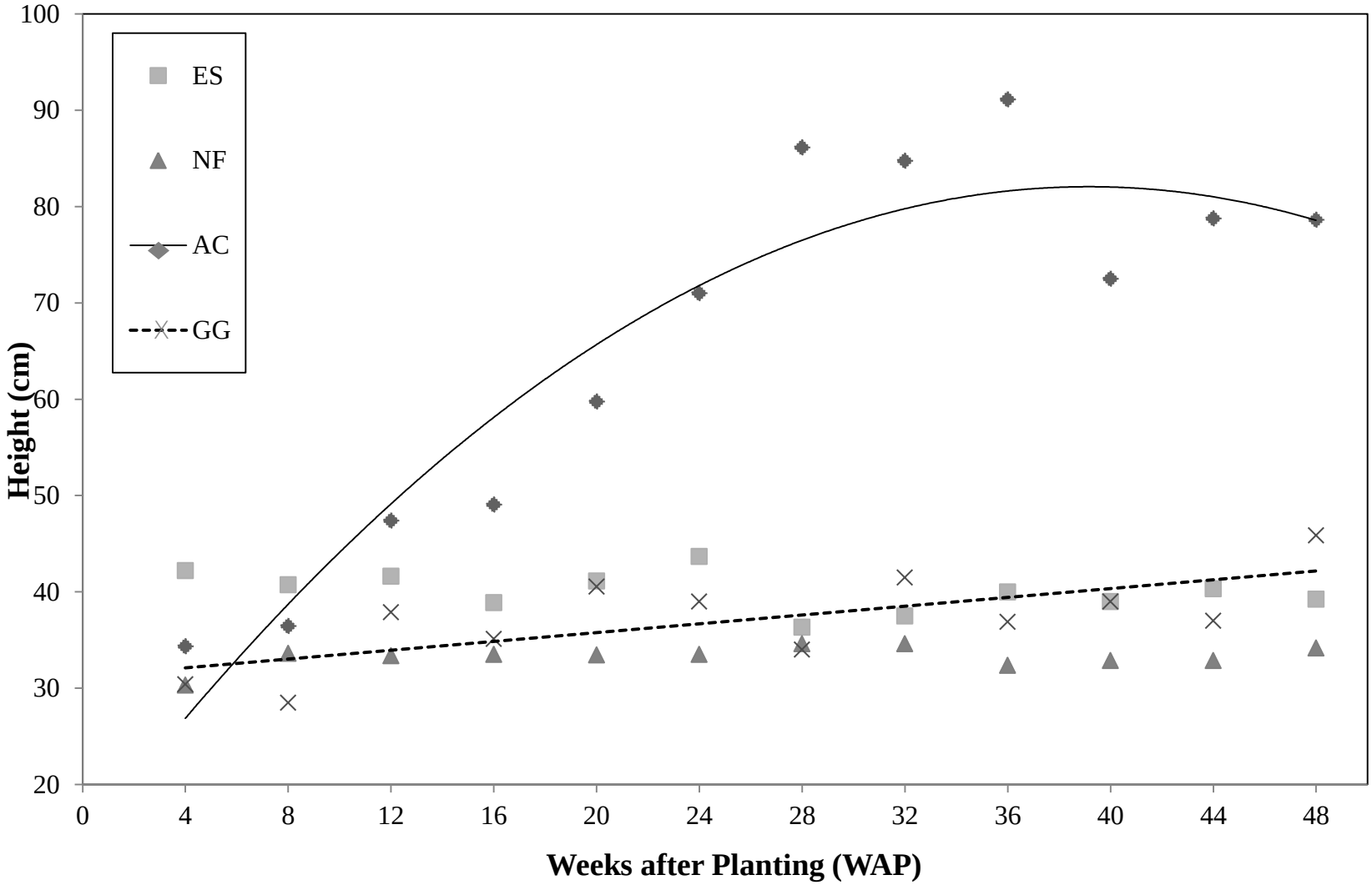

ES
NF
AC
GG
Height (cm)
100
90
80
70
60
50
40
30
20
0
4
8
12
16
20
24
28
32
36
40
44
48
Weeks after Planting (WAP)

Figure 3.2

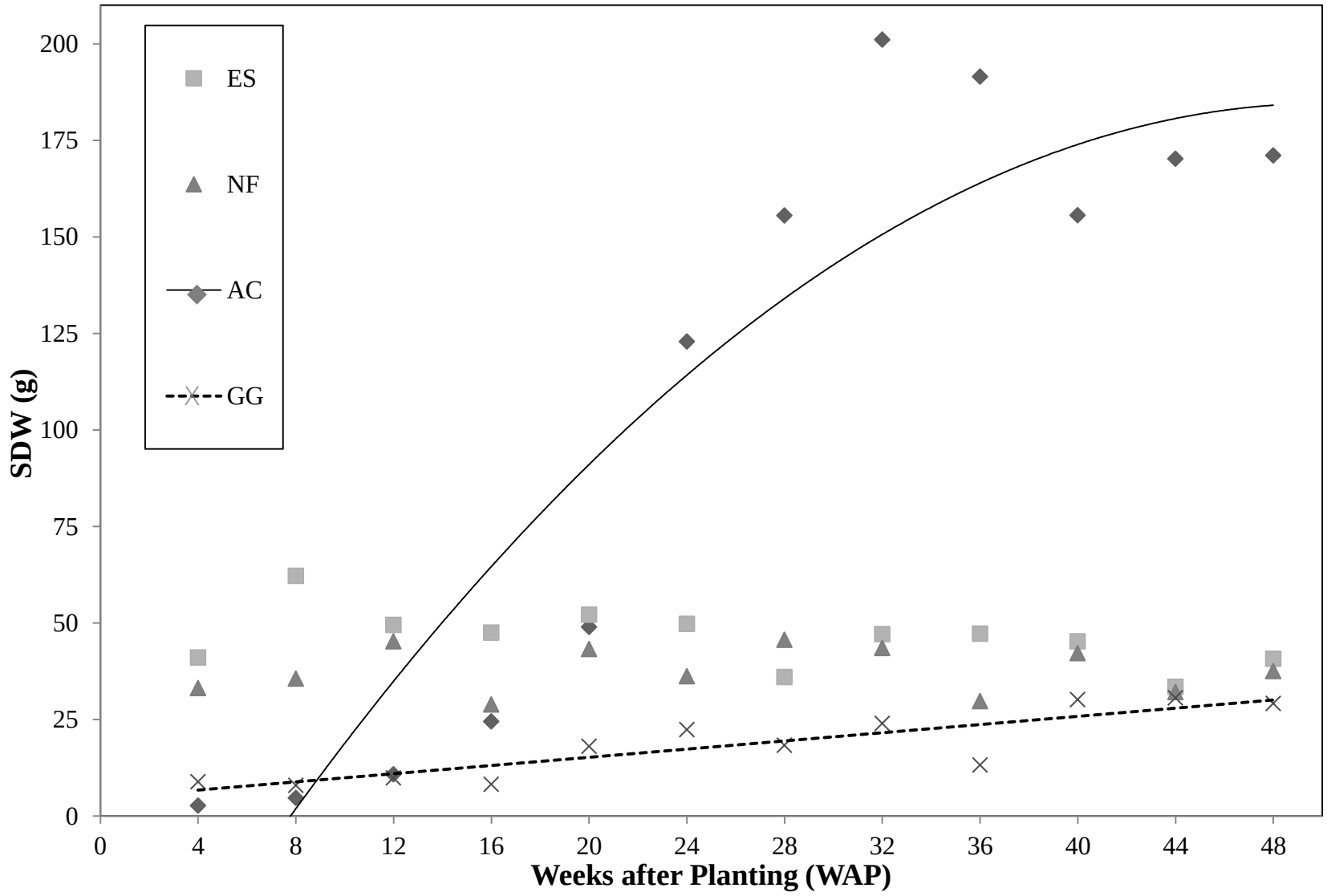

ES
NF
AC
GG
SDW (g)
0
25
50
75
100
125
150
175
200
0
4
8
12
16
20
24
28
32
36
40
44
48
Weeks after Planting (WAP)

Figure 3.3

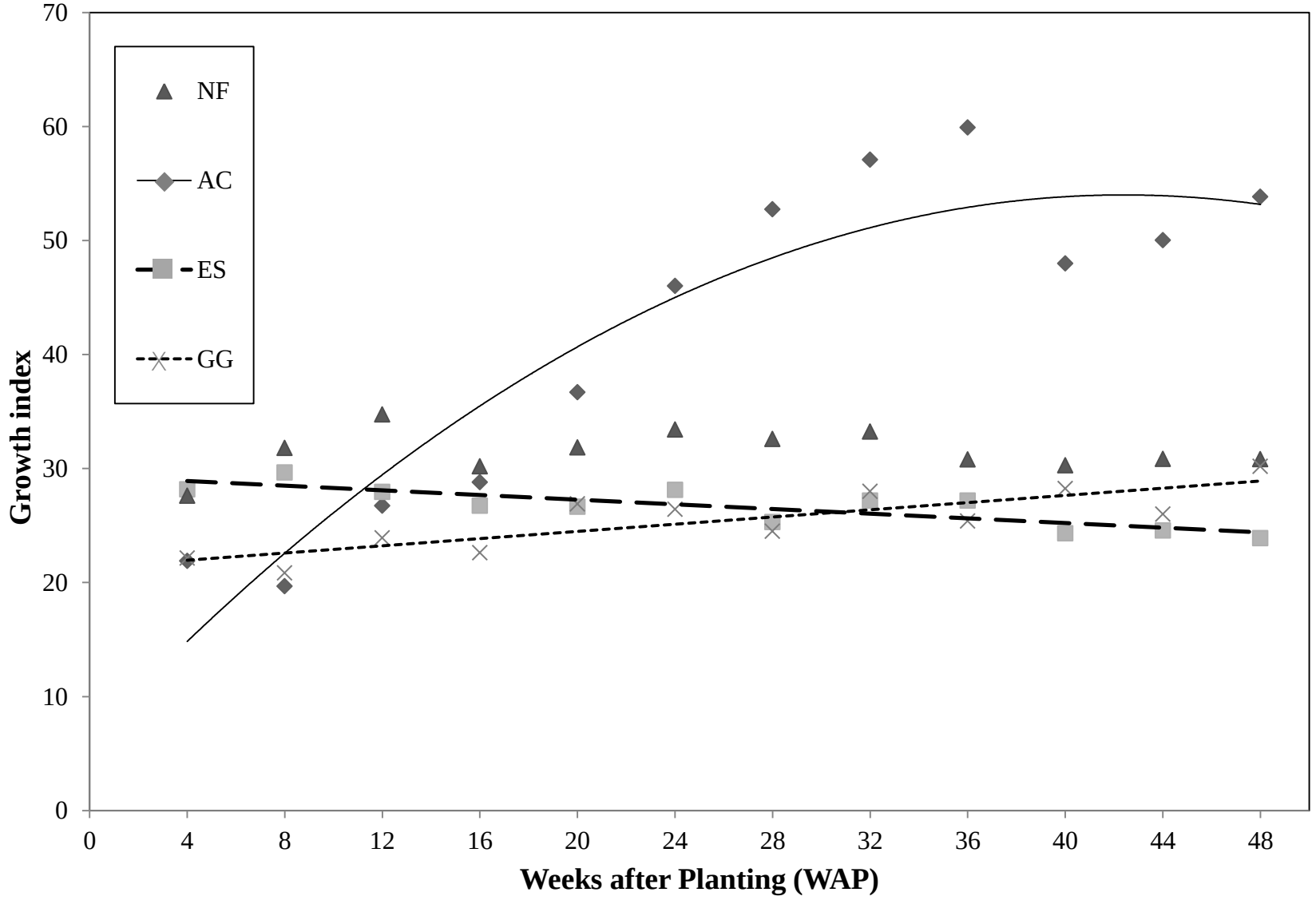

70
60
50
40
30
20
10
0
Growth index
NF
AC
ES
GG
0
4
8
12
16
20
24
28
32
36
40
44
48
Weeks after Planting (WAP)

Figure 3.4

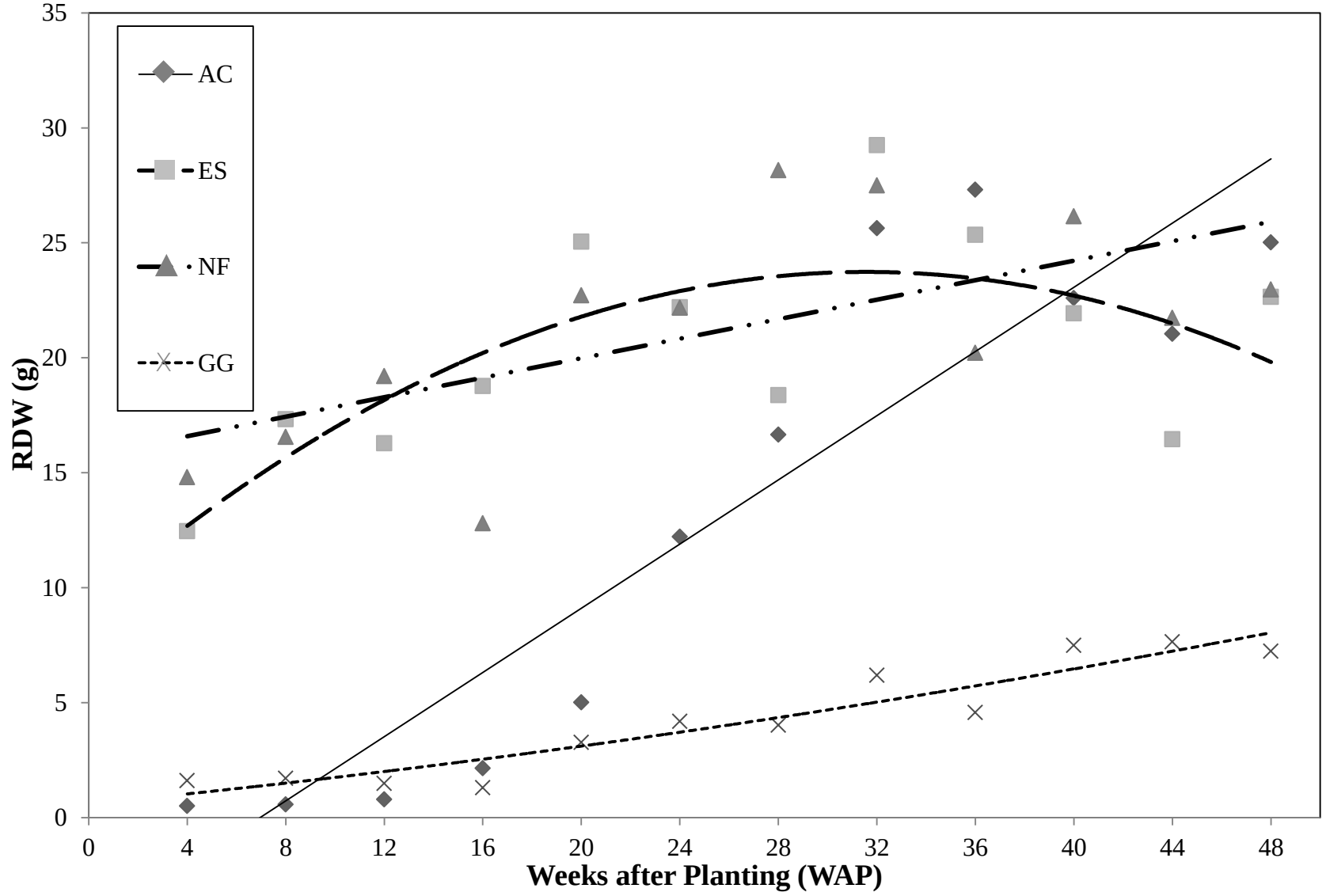

AC
ES
NF
GG
RDW (g)
Weeks after Planting (WAP)
0
5
10
15
20
25
30
35
0
4
8
12
16
20
24
28
32
36
40
44
48

Figure 3.5

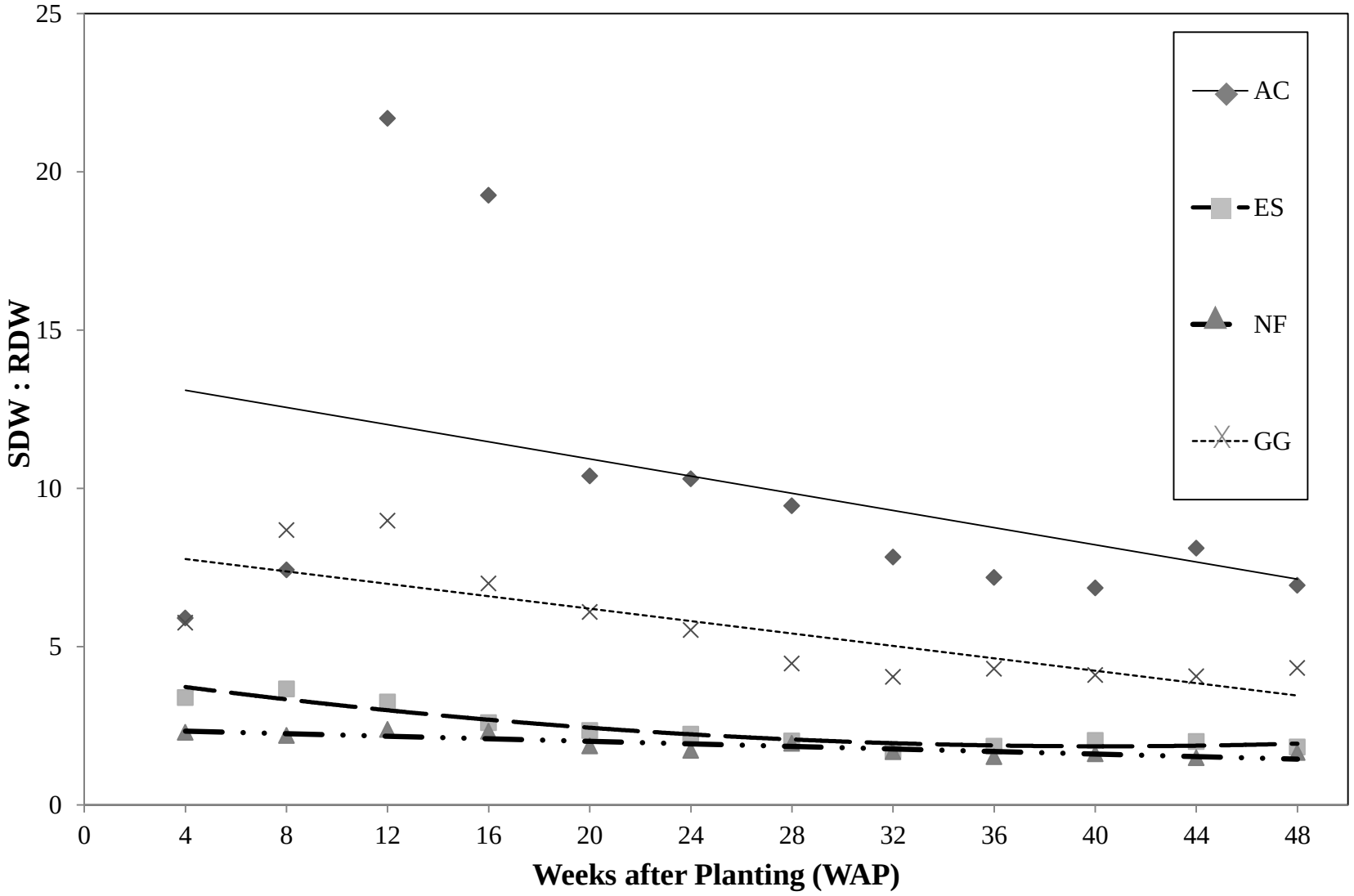
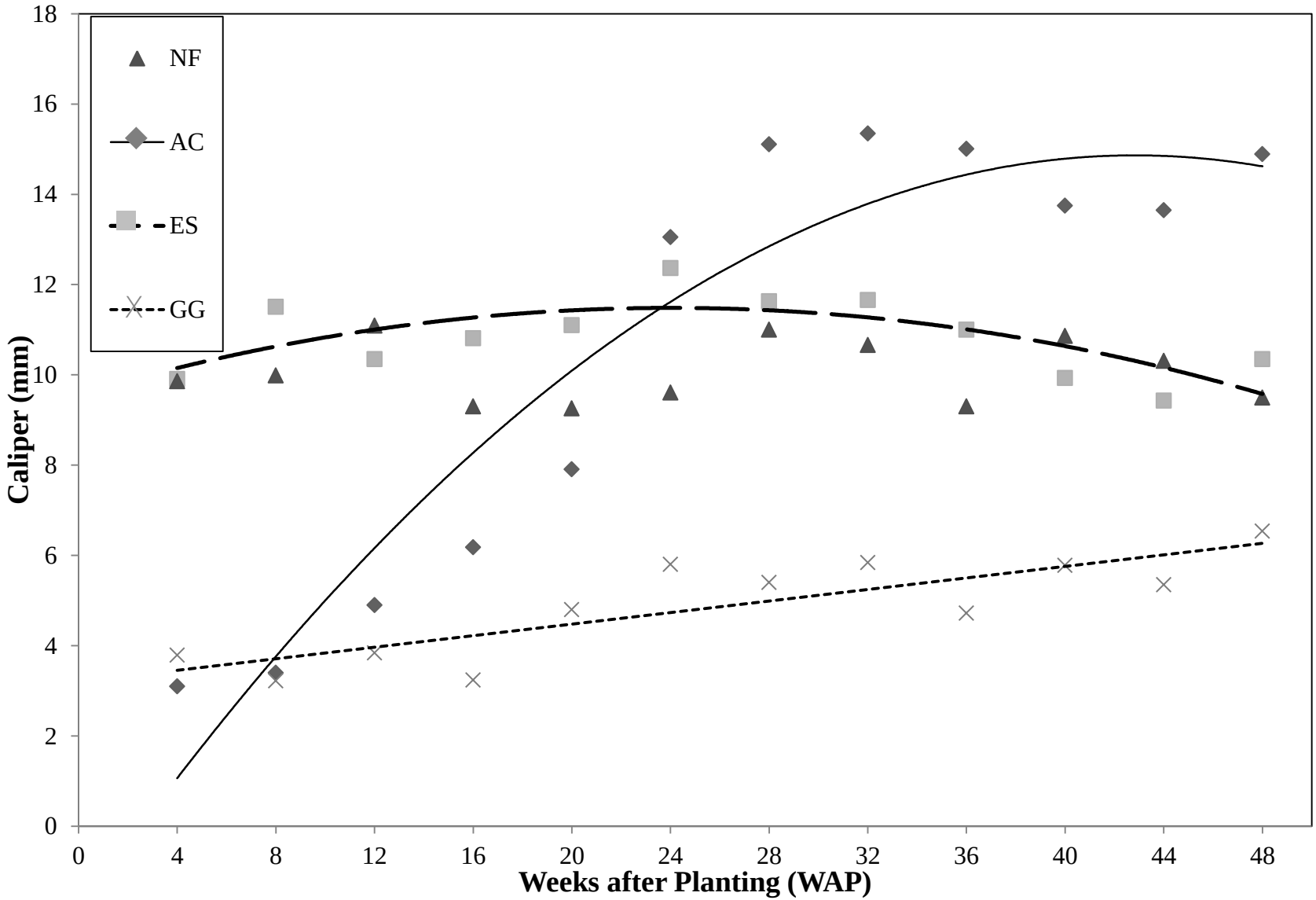

25
20
15
10
5
0
SDW : RDW
0
4
8
12
16
20
24
28
32
36
40
44
48
Weeks after Planting (WAP)
AC
ES
NF
GG

Figure 3.6


NF
AC
ES
GG
Caliper (mm)
Weeks after Planting (WAP)
0
2
4
6
8
10
12
14
16
18
0
4
8
12
16
20
24
28
32
36
40
44
48

Combined References

Aker, S. 1995. *Cupressus glabra* 'Blue Ice'. Am. Nurseryman 181:106.

Ammer, C. and S. Wagner. 2005. An approach for modeling the mean fine-root biomass of Norway spruce stands. Trees 19:145-153.

Blake, T. and J. Li. 2003. Hydraulic adjustment in jack pine and black spruce seedlings under controlled cycles of dehydration and rehydration. Physiol Plant. 117:532-539.

Brewer, M. and L. Love-Brotak. 2012. USGS Drought Monitor. 6 March 2012. http://droughtmonitor.unl.edu/

Burdett, A.N. 1990. Physiological processes in plantation establishment and the development of specifications for forest planting stock. Can. J. For. Res. 20:415-427.

Burr, K.E., S.J. Wallner, and R.W. Tinus. 1993. Heat Tolerance, Cold hardiness, and bud dormancy relationships in seedlings of selected conifers. J. Amer. Soc. Hort. Sci. 118:840-844.

Cannell, M. G. R., F. E. Bridgewater, M.S. Greenwood, and P. Mitschke. 1978. Seedling growth rates, water stress responses and root – shoot relationships related to eight – year volumes among families of *Pinus taeda* L. Silvae Genetica 27:237-248.

Castro, J., R. Zamora, J.A. Hodar, and J.M. Gomez. 2005. Alleviation of summer drought boosts establishment success of *Pinus sylvestris* in a Mediterranean mountain: an experimental approach. Plant Ecol. 181:191-202.

Cathey, H.M. 1997. American Horticultural Society plant heat zone map. http://www.ahs.org/pdfs/05_heat_map.pdf

Chastagner, G. and K. Riley. 2003. Postharvest quality of noble and Nordmann fir Christmas trees. HortScience 38:419-421.

Drew, A. and F. Ledig. 1980. Episodic growth and relative shoot -root balance in loblolly-pine seedlings. Annals of Bot. 45:143-148.

Drexhage, M. and F. Gruber. 1999. Above- and below-stem relationships for *Picea abies*: estimating root system biomass from breast-height diameters. Scand. J. For. Res. 14:328-333.

Dropkin, V.H. and A.S. Foudin. 1979. Report of the occurrence of *Bursaphelenchus lignicolus*-induced pine wilt disease in Missouri. Plant Dis. Rep. 63:904-905.

Fink, D.H. and W.L. Ehrler. 1986. Christmas tree production using the runoff farming system. HortScience 21:459-461.

Germino, M. and W. Smith. 1999. Sky exposure, crown architecture, and low-temperature photoinhibition in conifer seedlings at alpine treeline. Plant, Cell Environment 22:407-415.

Gill, J. G. S. 1987 Juvenile – mature correlation and trends in genetic variances in Sitka spruce in Britain. Silvae Genetica. 36:189-194.

Gilman, E., R. Black, and B. Dehgan. 1998. Irrigation volume and frequency and tree size affect establishment rate. J. of Arb. 24:1-9.

Griffin, J.G, F.A. Blazich, and T.G. Ranney. 1998. Propagation of *Thuja* x 'Green Giant' by stem cuttings: Effects of growth stage, type of cutting, and IBA treatment. J.Environ. Horticulture. 16:212-214.

Grime, J.P. 1965. Comparative experiments as a key to the ecology of flowering plants. Ecology 46:513-515.

Guehl, J.M., G. Aussenac, J. Bouachrine, R. Zimmerman, J.M. Pennes, A. Ferhi, and P. Grieu. 1991. Sensitivity of leaf gas exchange to atmospheric drought, soil drought, and water-use efficiency in some Mediterranean *Abies* species. Can.J. For. Res. 21:1507-1515.

Harrington, J., M. Loveall, and R. Kirksey. 2005. Establishment and early growth of dryland plantings of Arizona cypress in New Mexico, USA. Agrofor. Syst. 63:183-192.

Harris, J.R., P. Knight, and J. Fanelli. 1996. Fall transplanting improves establishment of balled and burlapped fringe tree (*Chionanthus virginicus* L.). HortScience 31:1143-1145.

Holland, B.T., S.L. Warren, and T.G. Ranney. 2003. Evaluating the recovery of Cupressaceae taxa after flooding at contrasting temperatures. J. Environ. Hort. 21:51-55.

Jiang, Y., S. E. MacDonald, and J. J. Zwiazek. 1995. Effects of cold storage and water stress on water relations and gas exchange of white spruce (*Picea glauca*) seedlings. Tree Physiol. 15:267-273.

Johnson, D.A. 1980. Improvement of perennial herbaceous plants for drought – stressed western rangelands. In: Turner, N. C. and P.J. Kramer (eds.). Adaptation of plants to water and high temperature stress, Wiley, NY. pp. 419-433.

Johnson-Flanagen, A.M. and J.N. Owens. 1985. Root growth and root growth capacity of white spruce (*Picea glauca* (Moench) Voss) seedlings. Can. J. For. Res. 15:625-630.

Jones, G., B. Cregg, and K. Schneller. 2004. True Firs (*Abies* sp.): New conifers for the Midwestern landscape. HortScience 39:897.

Kobayashi, F., A. Yamane, and T. Ikeda. 1984. The Japanese pine sawyer beetle as the vector of pine wilt disease. Annu. Rev. Entomol. 29:115-135.

Kozlowski, T.T. 1968. Water deficit and plant growth. Vol. 1. Development, control and measurement. Academic press. Waltham, MA.

Laing, E. V. 1932. Studies on tree roots. For. Comm. Bull. London. 13:1-73.

Lambeth, C. C. 1980. Juvenile – mature correlation in *Pinaceae* and implications for early selection. For. Sci. 26:571-580.

Ledig, F.T., F.H. Bormann, and K.F. Wenger. 1970. Distribution of dry matter growth between shoot and roots in loblolly pine. Bot. Gaz. 131:349-359.

Madsen, S. 1998. Christmas trees of Bornmuller fir and Nordmann fir in a North Sealand field experiment, Denmark. Forskningsserien - Forskningscentret for Skov Landskab 22:91-112.

Maiers, R.P. and J.T. Harrington. 1999. Windbreak establishment in semi – arid agricultural regions of New Mexico. New Mexico Journal of Science 214. Academic One File. Web. 4 Feb. 2011.

Mathers, H.M., S.B. Lowe, C. Scagel, D.K. Struve, and L.T. Case. 2007. Abiotic factors influencing root growth of woody nursery plants in containers. HortTechnology.17:151-162.

Mattson, A. 1991. Root growth capacity and field performance of *Pinus sylvestris* and *Picea abies* seedlings. Scand. J. For. Res. 6:105-112.

Mattsson, A. 1997. Predicting field performance using seedling quality assessment. New Forests 13:227-252.

Mullin, R.E. 1963. Planting check in Spruce. The Forestry Chronicle 39:252-259.

Nielsen, U. and G. Chastagner. 2005. Genetic variation in postharvest needle retention among Nordmann fir families and grafted clones. Scand. J. For. Res. 20:304-312.

Philipson, J.J. 1988 Root growth in Sitka spruce and Douglas fir transplant: Dependence on the shoot and stored carbohydrates. Tree Physiol. 4:101-108.

Richardson-Calfee, L.E., J.R. Harris, and J.K. Fanelli. 2004. Seasonal effects of transplanting on northern red oak and willow oak. J. Environ. Hort. 22:75-79.

Richardson-Calfee, L.E. and J.R. Harris. 2005. A review of the effects of transplant timing on landscape establishment of field-grown deciduous trees in temperate climates. HortTechnology 15:132-135.

Richardson-Calfee, L.E., J.R. Harris, and J.K. Fanelli. 2007. Post-transplant root and shoot growth periodicity of sugar maple. J. Amer. Soc. Hort. Sci. 132:147-157.

Santantonio, D., R.K. Herrmann; W.S. Overton. 1977. Root biomass studies in forest ecosystems. Pedobiologia 17:1-31.

Regents Instruments Inc. 2012. WinFolia leaf area meter. Quebec, Canada

SAS Institute, Inc. 2004. SAS user's guide. Release 9.1. SAS Institute, Inc. Cary, NC.

State of Kansas. 2012. Kansas Fast Facts. Kansas Department of Wildlife, Parks, and Tourism. http://www.travelks.com/s/index.cfm?aid=25

Steincr, G. and Buhrer, E.M. 1934 *Aphelenchoides xylophilus* n. sp. a nematode associated with bluestain and other fungi in timber. J.Agric. Res. 48:949-951.

Taiz, L. and E. Zeiger. 2006. Plant Physiology. 4th ed. pp 671-680. Sinauer Assoc. Sunderland, MA.

Tan, W., T. J. Blake, T. J. B. Boyle. 1995. Early selection for drought tolerance and relationship to dry weight partitioning in black spruce families. For. Sci. 41:168-180.

USDA Plant Hardiness Zone Map, 2012. Agricultural Research Service, U.S. Department of Agriculture. Accessed from http://planthardiness.ars.usda.gov.

USDA. 2012. Plants Database. Natural Resources Conservation Services. http://plants.usda.gov/java/

Van Deusen, J.L. 1978. Shelterbelts on the Great Plains: what's happening? J. of For. 76:160-161.

Watson, G.W. and E.B. Himelick. 1982. Root distribution of nursery trees and its relationship to transplanting success. J. of Arb. 8:225-229.

Watson, G.W., E.B. Himelick, and E.T. Smiley. 1986. Twig growth of eight species of shade trees following transplanting. J. of Arb. 12:241-245.

Woodhams, D. and T.T. Kozlowski. 1954. Effects of soil moisture stress on carbohydrate development and growth in plants. Am. J. Bot. 41:316-330.

Wright, A.N., S.L. Warren, F.A. Blazich, and U. Blum. 2004. Root and shoot growth periodicity of *Kalmia latifolia* 'Sarah' and *Ilex crenata* 'Compacta'. HortScience 39: 243-247.

Zwiazek, J. J. and T. J. Blake. 1989. Effects of preconditioning on subsequent water relations, stomatal sensitivity, and photosynthesis in osmotically stressed black spruce. Can. J. Bot. 67:2240-2244.