Short-term Recurring Drought Affects Growth and Photosynthetic Capacity of Four Conifer Species[1]

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Abstract

The Midwest and southern Great Plains are known for historic and severe droughts. More common, however, are short-term recurring drought events that 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 subjected to recurring moderate or severe drought to observe the effects on growth and photosynthesis. Species evaluated were: *Abies nordmanniana* (Nordmann fir), *Cupressus arizonica* (Arizona cypress), *Picea engelmannii* (Engelmann spruce), and *Thuja* × 'Green Giant' ('Green Giant' arborvitae). Recurring drought reduced height and growth index of *T.* × 'Green Giant'. However, photosynthesis and root growth were unaffected by drought treatments. In contrast, reduced P_{net} was the only detectable effect of recurring drought in *P. engelmannii*. Growth of *A. nordmanniana* was not affected by drought. When subjected to drought, *C. arizonica* reduced shoot dry weight, while maintaining photosynthesis and root growth. Overall, *C. arizonica* was able to maintain growth of roots and shoots as well as maintain photosynthesis which may be an advantage in the harsh climate of the Midwest and southern Great Plains.

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

Species used in this study: Arizona cypress (*Cupressus arizonica* Greene); Engelmann spruce (*Picea engelmannii* Perry ex Engelm.); 'Green Giant' arborvitae (*Thuja* L. × 'Green Giant'); Nordmann fir [*Abies nordmanniana* (Steven) Spach.].

Significance to the Nursery Industry

Containerized 'Green Giant' arborvitae, Arizona cypress, Nordmann fir, and Engelmann spruce were subjected to recurring short-term, moderate, or severe drought in a greenhouse environment. Results suggest 'Green Giant' arborvitae and Arizona cypress reduce shoot growth under drought conditions, however, they maintained root growth and photosynthesis. Nordmann fir grew very little, however, growth was unaffected by drought. Engelmann spruce, however, lacked the ability to recover photosynthetic capacity following two drought events. The data herein suggests that 'Green Giant' arborvitae, Arizona cypress, and Nordmann fir have potential as evergreen landscape ornamentals for the Great Plains.

Introduction

It has been said that no other resource on earth determines plant growth so much as water does (4, 14). The Midwest and southern Great Plains are regions known for frequent and sometimes extreme drought. Often, municipalities turn to water restrictions during periods of extended drought to conserve water resources, and therefore limit the ability of homeowners to irrigate landscape plants. As a result, 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 a primary factor contributing to transplant failure (7, 17). In addition to annual drought cycles, 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.) (13). 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 (22). *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 available water, down regulating growth of above ground mass (going dormant), and maintaining an efficient photosystem (1). A plant's ability to photosynthesize and replenish its energy reserves, is responsible for continued root growth (12, 19). Rapid root expansion is responsible for

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a seedling's ability to overcome water stress and in return, results in improved photosynthesis (2).

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 (6, 23). This suggests that early growth traits could be used as an indicator of drought tolerance for some conifers (15). When testing for drought tolerance, seedlings should be grown under a water-limiting situation (11). Cannell et al. (3) 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* × '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* × '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 April 14, 2010, 24 plants each of *T.* × '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 by vol) amended with 0.91 $kg{\cdot}m^{-3}$ (1.5 $lbs{\cdot}yd^{-3}$) micronutrient package (Micromax®, Scotts, Marysville, OH), 7.1 $kg{\cdot}m^{-3}$ (12 $lbs{\cdot}yd^{-3}$) controlled release fertilizer (Osmocote® 18N-2.6P-9.9K, Scotts, Marysville, OH), and 0.45 $kg{\cdot}m^{-3}$ (1.0 $lb{\cdot}yd^{-3}$) dolomitic limestone. *Cupressus arizonica* seedlings were grown in 164 ml (10.0 in^3) 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 (7 in) prior to potting. *Thuja* × 'Green Giant' were rooted stem cuttings grown in peat pellets. Nylon stockings were removed from the *T.* × 'Green Giant' root balls prior to potting. Container size was selected based on the size of the plant's root system at potting. *Thuja* × 'Green Giant' were potted in 6.0 liter (1.6 gal) containers (NSI, Chambersburg, PA), *C. arizonica*, 2.8 liter (0.75 gal) containers (NSI), and *A. nordmanniana* and *P. engelmannii*, 10.8 liter (2.9 gal) containers (NSI). Plants were grown under partial shade for 7 weeks at the John C. Pair Horticultural Research Center (Haysville, KS). On June 4, 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 27/18C (80/65F) day/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 65C (149F), 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 July 7, 2010, by withholding irrigation. Plants were weighed daily at 6:00 AM. 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 (August 31, 2010).

Photosynthetic measurements began on August 31, 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 $\mu L{\cdot}liter^{-1}$ CO_2, 1000 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ photosynthetically active radiation (PAR), and a leaf temperature of 30C (86F). 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 severed from the plant at the base of the cuvette and all photosynthetically active material was placed in a flatbed scanner to obtain area (20). 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 65C (149F) 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 $\alpha = 0.05$ (21). No statistical comparisons were made between species.

Results and Discussion

At the time of potting, the root systems of the four species were of considerably different size (Table 1). *Cupressus arizonica* had the smallest root system [0.66 g (0.02 oz)] followed by *T.* × 'Green Giant' [2.16 g (0.08 oz)]. *A. nordmanniana* and *P. engelmannii* were 14.77 and 15.24 g (0.52 and 0.54 oz), respectively. Due to the size difference between species root systems at the time of potting and the inherent differences in root growth rate, each species filled the container volume at a different rate. As a result, each species reached the predetermined drought levels at a different rate.

Table 1. **Initial height (Ht), shoot dry weight (SDW), root dry weight (RDW), and growth index (GI), of *Cupressus arizonica*, *Picea engelmannii*, *Thuja* × 'Green Giant' and *Abies nordmanniana* at potting.**

	C. arizonica	*P. engelmannii*	*T.* × 'Green Giant'	*A. nordmanniana*
Ht (cm)	32.9[z]	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[y]	16.5	25.1	20.8	25.7

[z]n = 10.

[y]GI = (plant height + maximum plant width + perpendicular plant width) ÷ 3.

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.* × '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.* × 'Green Giant' (3 times), *A. nordmanniana* (2 times), and *P. engelmannii* (2 times).

Among the four species, *T.* × 'Green Giant' was the most responsive to recurring short-term drought. This was not surprising given that this species is known for its rapid rate of shoot growth 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). 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, further reducing height. Suppression of shoot growth 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 (16). There are various mechanisms that influence photosynthesis during a drought event, however, in the current study P_{net} of *T.* × '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. Photosynthesis data combined with the root growth data suggests that plants may be able to recover quickly when soil moisture improves by maintaining 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). 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 (12). 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 (0.52 oz)] until termination [39.9 g (1.41 oz) 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. Species of *Picea* Mill. 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 (18). It has

Table 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* × 'Green Giant' and *Abies nordmanniana* grown under recurring short-term drought cycles of 90, 80, or 70% container capacity.**

	C. arizonica			*P. engelmannii*			*T.* × 'Green Giant'			*A. nordmanniana*		
	90%	80%	70%	90%	80%	70%	90%	80%	70%	90%	80%	70%
Ht (cm)	65.4[NS]	60.3	59.4	42.0[NS]	42.3	43.0	58.6**a[z]	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[y]	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}[x]	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
Drought[w]	Daily	19	13	Daily	4	2	Daily	10	3	Daily	4	2

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

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

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

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

[w]Indicates the number of times a specified container capacity was achieved.

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 (18). Others attributed planting check to lifting date and storage of the seedlings prior to potting (10, 25).

Cupressus arizonica, a known drought and heat tolerant species (5, 9), experienced minimal effects of the short-term recurring drought (Table 2). 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 (8, 24).

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 ability to quickly establish and grow, coupled with the drought enduring capabilities, *C. arizonica* may be an exceptional replacement for *Pinus* spp. in the Midwest and southern Great Plains. *Thuja* × '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.* × 'Green Giant was able to maintain root growth and an active photosystem. This leads us to believe that *T.* × '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 several 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.

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