Evaluation of Spectral Light Management on Growth of Container-Grown Willow Oak, Nuttall Oak and Summer Red Maple[1]

Donna C. Fare[2]
US National Arboretum, USDA-ARS
Tennessee State University Nursery Crop Research Station
472 Cadillac Lane, McMinnville, TN 37110

Abstract

Plant response to blue, red, gray or black shade cloth was evaluated with willow oak (*Quercus phellos* L.), Nuttall oak (*Quercus nuttallii* Palmer, Nuttall) and Summer Red maple (*Acer rubrum* L. 'Summer Red') liners. Light transmitted through the colored shade cloth had no influence on germination of willow oak acorns or height and caliper growth following germination. Tree height, trunk diameter, number of internodes, shoot and root dry weight were generally greater with the species tested when exposed to red or gray shade cloth, but were often similar to plants exposed to blue or black shade. Height increase of willow oak with red shade was similar to plants exposed to blue or gray; however, the average number of internodes was similar with oaks exposed to blue shade and 16% less with oaks exposed to gray shade. Summer Red maples exposed to black, blue or red shade cloth were similar in height, though plants with blue shade had 23% less dry weight. Nuttall oaks exposed to gray shade had the greatest height increase while the plants exposed to red shade had the largest trunk diameter. The growth parameters measured showed some increases with exposure to colored shade, but the morphology of the species tested was not significantly altered to recommend the use of colored shade during production.

Index words: light management.

Species used in the study: red maple (*Acer rubrum* L.), Nuttall oak (*Quercus nuttallii* Palmer), willow oak (*Quercus phellos* L.).

Significance to the Nursery Industry

Container grown tree liners are typically marketed by height. Often the trunk diameter (caliper) is too slender to support shoot growth; as a result the trunks are tied to a stake at the seedling stage and the stake is often required up to two years. However, trunk quality is often reduced due to scars on the trunk tissue made by the stakes. Colored shade products have successfully reduced plant height and resulted in stronger shoots with several herbaceous plants. This experiment evaluated the effect of colored shade cloth on germination of willow oak and the height and trunk diameter growth of willow oak, Nuttall oak and summer red maple. There were mixed results with respect to plant growth; however, none of the shade colors increased canopy development with more lateral shoots or increased trunk diameter to the point of eliminating staking. Overall, there was a lack of strong evidence to support the use of colored cloth for manipulating growth of woody ornamental tree liners.

Introduction

Research on container-grown tree liners (whips) has most often addressed nutrition, water use efficiency and container substrates (17, 18, 19, 20, 21, 22). Many studies conclude that nutrients can influence the growth in production of container-grown tree liners (4, 8, 20). While these tests indicate that maximum height growth can be obtained with many species by altering ambient temperature, substrate, and nutrition, the quality of liners including trunk diameter and lateral branching is not addressed.

Container-grown tree liners are typically marketed by height. Often there are only a few lateral branches in the canopy and the trunk diameter (caliper) is too slender to support shoot growth; as a result the trunks are tied to a stake at the seedling stage and staking is often required for up to two years. Staking has become a standard nursery practice to ensure straight trunks and provide support to tree liners that cannot support excessive shoot growth.

Chemical height control of nursery and greenhouse crops has been investigated and found to be beneficial in reducing height growth and in marketing compact plants (2, 9). As an alternative to chemical applications, mechanisms such as manipulating light quantity and quality have controlled the height of some greenhouse crops (14). Most light management regimes have evaluated red and far-red light and have resulted in plants with shorter stem internodes and leaf petioles, or produced mixed results depending upon species tested (11, 13, 14). With the use of photoselective films, height reduction of poinsettias was successful and eliminated the need for chemical growth regulators (5). Cerny-Koenig et al. (3) reported stem elongation is more strongly affected by light quality than light quantity. High red-to-far red ratios promote lateral branching, darker green leaf color and thicker leaves (3). Longer stems produced with red (R) light-absorbing films may prove beneficial to the cut flower industry while shorter stems produced with far-red (FR) light-absorbing films may be advantageous to the bedding plant industry (23). The potential commercial application of photoselective films has encouraged manufacturers to develop plastics with various spectral properties.

ChromatiNets (Signature Supply, Lakeland, FL) are shade cloths developed to combine physical protection (shade) with specific light filtration from chromatic additives with the objective to promote desired plant responses by altering particular wavelengths (16). Black shade is often used to reduce temperature in plant production, and red films have

[1]Received for publication November 2, 2010; in revised form November 10, 2011.

[2]Donna.Fare@ars.usda.gov.

altered plant morphology with greenhouse crops (23). *Pittosporum tobira* 'Variegatum' resulted in dwarf plants when grown with nets that appear blue to the human eye, increased vegetative growth with red and yellow nets, and had smaller leaves and short branches when exposed to gray nets. Other species have shown increases in stem growth, length of flowering stems and delay of flowering (15).

It is the opinion of the author that quality of container-grown liners would increase if tree liners had more lateral branches and the trunk diameter was substantial enough to support shoot growth; thus, eliminating the need for staking. Therefore, the objective of this research was to evaluate morphological changes in container grown tree liners when exposed to colored shade as a spectral light management tool.

Materials and Methods

Experiment 1. On July 1, 2005, *Quercus phellos* L., willow oak, acorns were sown in tree bands [9.2 × 9.2 × 15.2 cm (3-5/8 × 3-5/8 × 6 in)] (Anderson Dye and Mfg. Co., Portland, OR) containing a pine bark substrate amended with 1.8 kg (3.0 lb) of 19-5-9 (19N-2.2P-7.5K) Osmocote Pro controlled-release fertilizer (The Scotts Co., Marysville, OH) and 0.6 kg (1.0 lb) per m^3 (per yd^3) of Micromax (The Scotts Co., Marysville, OH). Tree bands were placed in full sun on a gravel pad or under quonset-type shade structures 2.4 × 3.0 m (8 × 10 ft) in size, which were covered with black, blue, gray or red ChromatiNet colored shade cloth (Signature Supply, Lakeland, FL). Three shade structures of each color and a full sun plot were placed in a completely randomized pattern on an outdoor gravel pad at the TSU Nursery Research Center in McMinnville, TN. Each shade structure contained 3 flats of 16 tree bands for a total of 48 plants.

Photosynthetically active radiation (PAR) was measured with a quantum meter (Apogee Instruments, Inc., Logan, UT) at solar noon on August 16, 2006, and August 15, 2007. In addition, the spectral distribution of light transmitted through the shade coverings was measured 31 cm above gravel surface with a portable spectroradiometer (Apogee Instruments, Inc., Logan, UT).

Mist irrigation was applied several times daily to maintain substrate surface moisture. Weekly germination counts were recorded for 20 weeks (data shown for weeks 5, 10, 15, and 20). On November 29, 2005, height and trunk diameter [measured at 1 cm (0.4 in) above substrate] were recorded. Seedlings were placed in a plastic covered overwintering house until spring.

On April 6, 2006, 18 seedlings were selected from each original experimental unit (with the exception of the seedlings from full sun which were eliminated from experiment due to poor germination and growth) and potted into 11.3 liter (#3) nursery containers which contained a pine bark substrate amended with 5.3 kg (9.0 lb) of 19-5-9 (19N-2.2P-7.5K) Osmocote Pro controlled-release fertilizer and 0.9 kg (1.5 lb) of Micromax per m^3 (per yd^3). Seedlings were placed back into their respective shade color from the previous growing season. Irrigation was applied in a cyclic regime three times daily through spray stakes in each container unless rainfall exceeded 1.3 cm (0.5 in) within 12 hours of the next irrigation event. Height and trunk diameter [measured at 15.2 cm (6.0 in) above the container substrate] were measured at potting and at the end of the experiment. On August 16, 2006, the number of internodes per plant was counted from the substrate surface to within 15.2 cm (6.0 in) of the terminal bud. For shoot dry weight measurements, three plants from each experimental unit were oven dried at 56C.

Experiment 2. On March 20, 2007, *Quercus nuttallii* Palmer, Nuttall oak, acorns were sown in tree bands as described in experiment 1. On June 20, 2007, 130 uniform seedlings were selected and potted into 11.3 liter (#3) nursery containers with a pine bark substrate amended with 6.5 kg (11 lb) 19-2-10 controlled-release fertilizer (Harrell's, Lakeland, FL) and 0.6 kg (1.0 lb) of Micromax (The Scotts Co., Marysville, OH) per m^3 (per yd^3). Ten seedlings were placed in each shade structure, as described in experiment 1.

On May 16, 2007, 78 rooted cuttings of *Acer rubrum* L. 'Summer Red', red maple, were selected from cuttings propagated in 8.2 × 8.2 × 7.6 cm (3.25 × 3.25 × 3.0 in) containers and potted as described above. Six seedlings were placed in each shade structure and grown as described in experiment 1. On October 2, 2007, the number of internodes per plant was counted from the substrate surface to within 15.2 cm (6.0 in) of the terminal bud. Three plants from each experimental unit were harvested for shoot and root dry weights by severing shoots from the roots at the substrate surface. Pine bark substrate was gently blown from the root mass using a compressed air system. Both roots and shoots were dried in a forced-air oven at 56C.

Data analysis. Plants in all experiments were arranged in a completely randomized design with single plant replications. Germination data in experiment one was subjected to analysis of variance following arcsine square root transformation.

All data were subjected to analysis of variance with the GLM procedure of SAS (Version 9.1, SAS Institute, Cary, NC) and differences among treatments were separated by a Fisher's least significant difference, $P \leq 0.05$.

Results and Discussion

Photosynthetically active radiation (PAR), the wavelengths of light between 440 and 660 nm used in photosynthesis, ranged from 1687 to 1693 (2006) and 1685 to 1691 (2007) $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively in full sun. ChromatiNets are shade cloths designed to combine physical protection (shade) with specific light filtration from chromatic additives with the objective to promote desired plant responses by altering particular wavelengths (16). Light transmission under black, blue, gray and red shade was 786 (785), 887 (885), 858 (849) and 814 (811) $\mu mol \cdot m^{-2} \cdot s^{-1}$ respectively, in 2006 (2007). Spectral distribution of light transmitted through the shade cloths was measured on August 15, 2007 (Fig. 1).

Experiment 1, germination. Five weeks after willow oak (*Quercus phellos* L.) acorns were sown, germination percent was similar with blue, black or gray shade (Table 1). Germination percent was less with red shade or in full sun than exposed to blue shade. From week 10 through week 20, acorn germination percentage was similar with all spectrums of shade, but lower compared to acorns in full sun. All seedlings received the same amount of irrigation. The substrate surface and acorns in the full sun treatment dried out during the day and caused a decrease in the germination percent and seedling growth compared to seedlings with colored shade treatments. These results agree with work

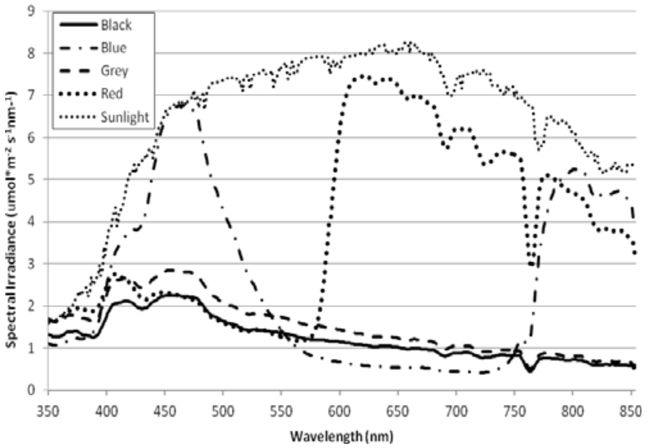

Fig. 1. Spectral transmission properties measured 31 cm above gravel surface under color shade structures at solar noon on August 15, 2007.

done by Ellingson et al. (7) in which marigold and tomato seed were not affected by photoselective films when sown in a soilless media. However, in contrast, Crawford (6) reported magnolias grown from seed were almost twice as large when exposed to red shade compared to plants grown under natural shade.

At the end of week 20, height and trunk diameter was similar among seedlings grown with colored shade, but was significantly different from seedlings grown in full sun (Table 1). Typically, acorns are germinated in early spring and grown for eight to nine months prior to repotting in larger nursery containers. However, this often results in plants with overgrown root systems with large circling roots. Initiating the experiment during mid season ensured that shoot development was not influenced by a restricted overgrown root system in the tree band containers.

Experiment 1, year 2. Plant growth of willow oak responded with mixed results to light spectrum management. Height increase of oaks grown with red shade was similar to plants exposed to blue or gray and had greater increases in height than plants grown with black shade (Table 2). Trunk diameter increase was similar with all plants regardless of shade color. However, the average number of internodes was 16 to 25% less with oaks grown with gray or black shade cloth compared to plants exposed to blue or red. Shoot dry weight was greater with red shade compared to plants exposed to blue or black. Overall, willow oaks grown with red shade cloth produced the largest plants in 4 out of the 4 parameters measured, whereas plants exposed to blue or gray shade had the largest plants in 3 out of the 4 parameters. Oaks grown with black shade produced the largest plants in 1 category. Seedlings germinated in full sun were not included in year 2 due to the low germination percentage and poor growth during year 1.

Experiment 2. 'Summer Red' maples exhibited varied growth responses from light spectrum management (Table 3). Maples grown with black, blue or red shade cloth were similar in height; however, plants grown in full sun were about 16% shorter than maples exposed to gray shade and had about 13% fewer internodes per plant. Trunk diameter was similar with all maples regardless of shade treatment. Maples grown with red shade or in full sun had about 20% greater shoot dry weight than plants exposed to black or blue shade cloth, and were similar to plants grown with gray shade. Plants grown in full sun had more root mass than plants grown with blue or black shade but had similar root dry weight to plants exposed to red or gray shade. All plants had a root mass that completely filled the #3 nursery containers, and extensive circling of the roots on the perimeter of the root ball was evident. Overall, maples grown with red or gray shade cloth produced the largest plants in all 5 parameters measured, whereas plants grown in full sun or with black shade had the largest plants in 3 out of the 5 categories.

Nuttall oak responded with mixed results to the light spectrum management. Oaks grown with gray shade had the largest height increase but were similar to plants exposed to black or red shade and had about 11% increase in height than plants with blue shade or in full sun. Trunk diameter growth was greater with plants with red shade cloth compared to other shade colors, but was similar to plants grown in full sun. Oaks grown with gray or red shade had about 20% more internodes than plants grown in full sun or with blue shade. Shoot dry weight was greater with plants grown in full sun or with red shade compared to plants exposed to black or blue shade, and was similar to plants grown with gray shade. In contrast, Brant et al. (1) reported colored nets increased dry biomass of lemon balm compared to plants grown in full sun. Root dry weight was greater with plants grown in full sun compared to plants in the shade treatments. The roots of all plants completely filled the #3 nursery containers and as with red maple, extensive circling of the roots was evident on the

Table 1. Effect of light spectrum management on percent germination and growth of *Quercus phellos* L., willow oak acorns, experiment 1.

Light treatment	Percent light transmission	Percent germination Week 5	Week 10	Week 15	Week 21	Height, cm Week 21	Trunk diameter[z], mm Week 21
Black shade cloth	54	9.7ab[y]	29.9a	36.8a	41.0a	11.7a	3.1a
Blue ChromatiNet	48	13.9a	36.8a	49.3a	53.5a	11.4a	3.1a
Gray ChromatiNet	49	10.4ab	35.4a	50.0a	52.1a	10.2a	2.9a
Red ChromatiNet	52	4.9bc	29.2a	45.1a	45.1a	11.1a	3.0a
Full sun	100	1.4c	4.2b	12.5b	16.0b	6.0b	2.1b
LSD		7.7	15.3	17.8	20.5	2.6	0.5

[y]Mean within columns followed by the same letter are not significantly different (LSD, α = 0.05).

[z]Trunk diameter measured at 1 cm (0.4 in) above container substrate surface.

Table 2. Effect of light spectrum management on height growth and trunk diameter increase of container-grown *Quercus phellos* L., willow oak liners, experiment 1, year 2.

Light treatment	Height increase, cm[z]	Trunk diameter[y] increase, mm[x]	Internodes/plant	Shoot dry weight, g
Black shade cloth	123.7b[w]	9.1a	32.6b	108.8c
Blue ChromatiNet	125.8ab	9.0a	43.5a	130.1bc
Gray ChromatiNet	130.3ab	9.1a	36.1b	141.6ab
Red ChromatiNet	143.4a	9.5a	43.1a	165.2a
LSD	17.7	0.9	6.5	27.9

[z]Height increase calculated by subtracting initial height from height at termination.

[y]Trunk diameter measure at 15.2 cm (6 in) above container substrate surface.

[x]Trunk diameter increase calculated by subtracting initial trunk diameter from trunk diameter at termination of the experiment.

[w]Mean within columns followed by the same letter are not significantly different (LSD, α = 0.05).

perimeter of the root ball. Overall, Nuttall oaks grown with red shade cloth produced the largest plants in 4 out of the 5 parameters measured.

Previous work has demonstrated the use of blue shade resulted in reduced plant height and internode length of container-grown *Pittosporum tobira* 'Variegatum' Ait. (12, 15) and cyclamen grown under blue shade compared to black shade had reduced height growth (10). However in the present test, the morphology of 'Summer Red' maple and Nuttall oak was not influenced enough by the blue shade to eliminate the use of staking. The trunk diameter was not strong enough to support the shoot growth and within six weeks of potting into #3 nursery containers all plants in the experiment required staking.

In summary, the use of color shade did not significantly increase germination percentage of acorns, though germination was higher and growth was significantly greater with seedlings grown under shade than in full sun. The substrate in the full sun treatments often dried out between irrigation applications; thus, optimal germination conditions were reduced. The use of colored shade did influence some growth parameters of the species tested. Plants grown with red shade often had the largest increase in height growth, but were similar to other shade treatments. Plants exposed to blue shade did not response with the same results as reported with herbaceous plants. The trunk diameter did not increase nor was internode length remarkably reduced. The growth increases that are attributed to spectral light management were not of significance to recommend their use during production of container grown trees.

Literature Cited

1. Brant, R., J. Pinto, L. Rosa, C. Albuquerque, P. Ferri and R. Correa. 2009. Growth, content and composition of lemon balm essential oil cultivated under color shading nets. Ciencia Rural 39:1401–1407.

2. Burnett, S.E., G.J. Keever, J.R., Kessler, and C.H. Gilliam. 2000. Growth regulation of Mexican sage and 'Homestead Purple' verbena during greenhouse and nursery production. J. Environ. Hort. 18:166–170.

Table 3. Effect of light spectrum management on height growth and trunk diameter increase of container-grown *Acer rubrum* L. 'Summer Red' red maple and *Quercus nuttallii*, Nuttall oak liners, experiment 2.

Light treatment	Height increase, cm[z]	Trunk diameter[y] increase, mm[x]	Internodes/plant	Shoot dry weight, g	Root dry weight, g
			Summer Red maple		
Black shade cloth	130.2ab[w]	15.8a	35.9ab	103.7b	24.0b
Blue ChromatiNet	127.2ab	11.1a	35.8ab	101.1b	25.4b
Gray ChromatiNet	132.0a	16.4a	38.5a	119.2ab	30.2ab
Red ChromatiNet	124.0ab	11.1a	36.0ab	132.6a	33.2ab
Full sun	111.2b	11.1a	33.1b	128.3a	37.2a
LSD	19.2	5.5	3.5	22.8	9.4
			Nuttall oak		
Black shade cloth	112.3ab	7.9cd	49.2ab	73.7c	22.6c
Blue ChromatiNet	108.9b	7.6d	42.7b	79.2bc	22.9c
Gray ChromatiNet	122.0a	8.5bc	55.7a	88.5ab	28.7b
Red ChromatiNet	119.8ab	9.3a	52.0a	92.8a	27.3bc
Full sun	110.2b	8.9ab	43.3b	101.2a	34.6a
LSD	11.6	0.6	7.0	12.8	5.2

[z]Height increase calculated by subtracting initial height from height at termination.

[y]Trunk diameter measure at 15.2 cm (6 in) above container substrate surface.

[x]Trunk diameter increase calculated by subtracting initial trunk diameter from trunk diameter at termination of the experiment.

[w]Mean within columns followed by the same letter are not significantly different (LSD, α = 0.05).

3. Cerny-Koenig, T.A., J.E. Faust, and N.C. Rajapakse. 2005. Role of gibberellin A4 and gibberellin biosynthesis inhibitors on flowering and stem elongation in Petunia under modified light environments. HortScience 40:134–137.

4. Chong, C. 2000. Response of little-leaf linden and honey locust to rates of organic and mineral nitrogen. HortScience 35:144.

5. Clifford, S.C., E.S. Runkie, F.A. Langton, A. Mead, S.A. Foster, S. Pearson, and R.D. Heins. 2004. Height control of poinsettia using photoselective filters. HortScience 39:383–387.

6. Crawford, M. 2005. Methods and techniques to improve root initiation of cuttings. Intern. Plant Prop. Soc. 55:581–584.

7. Ellingson, K.A., T.A. Cerny and N.C. Rajapakse. 2001. Seed germination and seedling growth under photoselective films. Proc. Southern Nursery Assoc. Res. Conf. 46:342–344.

8. Larimer, J. and D. Struve. 2002. Growth, dry weight and nitrogen distribution of red oak and 'Autumn Flame' red maple under different fertility levels. J. Environ. Hort. 20:28–35.

9. March, H.W., T.J. Banko, and J.G. Latimer. 2002. Response of spaced and unspaced woody shrubs to growth regulators. Proc. Southern Nursery Assoc. Res. Conf. 47:290–294.

10. Mascarini, L., A. Landini, L. Botin, A. Mascarini, S. Orden, and F. Vilella. 2005. Influence of light quality on the morphology of *Cyclamen persicum* cultivated under photoselective shade screens. Phyton Buenos Aires 2005:161–169.

11. McMahon, M.J. and J.K. Kelly. 1989. The effects of light quality on growth of potted roses and exacum. Proc. Southern Nursery Assoc. Res. Conf. 34:38–40.

12. Oren-Shamir, M., E.E. Gussakovsky, E. Shpiegel, E. Matan, I. Dory, and Y. Shahak. 2000. Colored shade nets can manipulate the vegetative growth and flowering behavior of ornamental plants. HortScience 35:503.

13. Poole, R.T., R.H. Henley, and K. Steinkamp. 1992. Growth of *Gardenia jasminoides* 'Veitchii' under red or black shadecloth. Southern Nursery Digest 26(10):13–14.

14. Rajapakse, N.C., R.E. Young, M.J. McMahon, and R. Oi. 1999. Plant height control by photoselective filters: Current status and future prospects. HortTechnology 9:618–624.

15. Shahak, Y. 2001. Colored shade nets-A new agro-technology. www.polysak.com. Accessed September 15, 2009.

16. Shahak, Y., E.E. Gussakovsky, E.Gal, and R. Ganelevin. 2004. ColorNets: Crop protection and light-quality manipulation in one technology. Acta Hort. 659:143–151.

17. Stoven, A.A., H.M. Mathers, and D.K. Struve. 2006. Fertilizer application method affects growth, nutrient and water use efficiency of container-grown shade tree whips. HortScience 41:1206–1212.

18. Struve, D.K. 1995. Nitrogen, phosphorus and potassium recovery of container-grown red oak and blackgum seedlings under different fertilizer application methods. J. Environ. Hort. 13:169–175.

19. Struve, D.K. 1996. Bare root shade tree whip production in containers. J. Environ. Hort. 14:13–17.

20. Struve, D.K. 2002. Growth of several tree spp. in containers in response to N loading, fertilizer type and substrate. J. Environ. Hort. 20:133–137.

21. Struve, D.K. and E.L. McCoy. 1996. Physical and chemical properties of media suitable for containerized bare root whip production. J. Environ. Hort. 14:137–141.

22. Struve, D.K., M.A. Arnold, and D.H. Chinery. 1987. Red oak whip production in containers. Proc. Intl. Plant Prop. Soc. 344:415–420.

23. Wilson, S.B. and N.C. Rajapakse. 2001. Growth control of lisianthus by photoselective plastic films. HortTechnology 11:581–584.