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Growth and Physiology of Newly Planted Fraser Fir (*Abies fraseri*) and Colorado Blue Spruce (*Picea pungens*) Christmas Trees in Response to Mulch and Irrigation

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***Abstract*. We evaluated height growth, diameter growth, and survival of newly planted fraser fir and colorado blue spruce Christmas trees in southwest Michigan in response to mulch, weed control, and irrigation. Mulches included black polyethylene, white polyethylene, VisPore mulch mats, and wood chips. Seedlings were also established with or without raised beds and with or without complete weed control. Weed control (mulches or a combination of chemical weed control and hand weeding) improved survival and growth of both species after 2 years. Growth was similar for trees in irrigated plots or with wood chip mulch without irrigation. Polyethylene mulch increased growth compared with similar production systems with raised beds and bare ground. Among production systems, variation in growth and survival reflected patterns of predawn water potential and midday shoot gas exchange, suggesting that differences were largely related to plant moisture stress. White mulch improved growth relative to similar production systems with black mulch and wood chip mulch improved growth compared with similar production systems without irrigation. Overall, the ranking of magnitude of growth response effects were weed control > irrigation > mulch. These results underscore the importance of weed control for establishment and maintenance of high-quality Christmas tree plantations.**

Weed control is a major concern for Christmas tree growers in the midwestern United States. Controlling weeds improves initial conifer seedling survival and growth after establishment (Harper et al., 2005; Knowe and Stein, 1995; NeSmith and Lindstrom, 1996; Schneider et al., 1998). Weed control is also important to maintain Christmas tree quality by reducing shading of lower branches (Brown et al., 1991). Chemical weed control and mowing are the most common methods of weed control in current production systems and may comprise up to 18% of direct production costs for growers in the midwestern United States (Nzokou and Leefers, 2007). As production costs and environmental concerns related to chemical inputs increase, Christmas tree producers are interested in reducing chemical inputs and costs while maintaining crop quality and growth.

Plastic mulch—usually low-density polyethylene film—improves crop growth in a variety of horticultural production systems (Lamont, 2005). Plastic mulch or synthetic mulch mats have also been used to aid establishment of trees for afforestation and reforestation (Samyn and DeVos, 2002; Walker and McLaughlin, 1989). Plastic mulch typically improves early tree survival and growth, although Harper et al. (2005) found little effect of mulch mats on 10-year height and diameter of douglas fir [*Psuedotsuga menziesii* (Mirb.) Franco] trees. Plastic mulch reduced growth of Scots pine (*Pinus sylvestris* L.) Christmas trees compared with a bare-ground control (Lamont et al., 1993).

Plastic mulches affect plant growth by improving soil moisture availability through reduced surface evaporation, reduced water and nutrient loss to competing vegetation, reflected radiant energy, and increased length of effective growing season as a result of soil warming (Lamont, 2005). Organic mulches also improve growth by conserving soil moisture and improving soil physical properties (Chalker-Scott, 2007).

To determine the potential of plasticulture and other mulches as alternative weed control methods, we established a Christmas tree plasticulture study at Michigan State University's Southwest Michigan Research and Extension Center (SWMREC) near Benton Harbor, MI. The objective was to determine the effect of plasticulture technology and other weed control techniques on growth, photosynthetic gas exchange, water relations, and nutrition of newly planted seedlings of fraser fir [*Abies fraseri* (Pursh) Poir.] and colorado blue spruce (*Picea pungens* Engelm.), two major Christmas tree species in the upper midwestern United States. We also examined growth and physiological response of seedlings grown with mulch mats and wood chip mulch as alternatives for growers that do not have access to specialized equipment to form raised beds and install polyethylene mulch.

Specific objectives were to: 1) evaluate tree growth, photosynthetic gas exchange, water relations, and foliar nutrition of Christmas trees to irrigation and plastic and organic mulches; and 2) monitor changes in soil environment associated with mulch treatments.

Materials and Methods

Study design. In the spring of 2006, we initiated a Christmas tree plasticulture trial at SWMREC. The study area has less than 5% slope with a Selfridge loamy sand (USDA NRCS, 2008). Initial soil pH was 5.7. The trial was installed as a split plot in a randomized complete block design with four blocks. Each main plot treatment (combinations of weed control, bedding, irrigation) consisted of one 20-tree row (Table 1). Production systems were selected to examine a range of possible options for growers. A complete factorial design was not feasible or practical (e.g., growing trees with plastic mulch on a sandy soil without irrigation). Bedding was evaluated with and without plastic mulch because it may be useful in reducing problems associated with root rots (Bryla and Linderman, 2007; Heiberg, 1999). Within each main plot, 10-tree row plots of each species (fraser fir or blue spruce) were assigned at random to subplots.

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After site preparation, polyethylene mulch, bedding, and irrigation were installed before planting seedlings. Mulch mats (Vis-Pore® tree mats; Treesentials Company, St. Paul, MN) and wood chip mulch (coarse ground municipal wood chips) were applied after planting. Mulch mats provided a 3 ft × 3 fτ (0.9 × 0.9 m) weed-free zone around each tree. Uncomposted mixed hardwood wood mulch was applied at a depth of 3 inches to 4 inches (7.5– to 10 cm) to form a 2 ft (0.6 m) radius around each tree. One-mil thick polyethylene mulches (Mid-South Extrusion, Monroe, LA) were laid on raised beds using a combination bed-shaper plastic layer. Beds were 3 ft (0.9 m) wide and 3 inches (7.5 cm) high. We planted 320 fraser fir and 320 colorado blue spruce transplants (4-year-old, 2 + 2 transplants) provided by local nurseries in 10-tree row plots on 2.1 m × 2.1-m spacing. Mean (± SE) initial seedling heights were 41.4 (± 0.46) cm and 30.8 (± 0.35) cm for the fraser fir and colorado blue spruce, respectively. Initial mean stem diameters were 9.68 (± 0.08) mm and 9.61 (± 0.10) mm for the fir and spruce, respectively. Each block was surrounded by a border row of Serbian spruce [*Picea omorika* (Panèiæ) Purkyne] and/or white spruce [*Picea glauca* (Moench Voss.)] seedlings planted at the same time.

During the growing season, irrigation was supplied at 25 mm (1 inch) per week through a drip system. Weed control was maintained on the unmulched plots by a combination of hand weeding and postemergent herbicide (glyphosate). Irrigated plots were fertilized during the growing season every 2 weeks through the drip system with a water-soluble fertilizer (Peters Professional™ Conifer Grower 20-7-19; Scotts, Inc., Marysville, OH) at a rate of 67 kg of nitrogen (N) per ha in 2006 and 84 kg of N per ha in 2007. Nonirrigated plots were fertilized with a comparable amount of N with a slow-release polymer-encapsulated fertilizer (Scotts® field fertilizer 33-3-6; Scotts, Inc.) applied around the drip line of each tree in the spring of each year.

Measurements. Seedling heights and stem diameters were measured at the beginning and end of the 2006 and 2007 growing seasons. Stem diameter was measured ≈3 cm above the ground line using digital calipers. In June and July 2006 and July and Aug. 2007, we measured photosynthetic gas exchange on current-year shoots on two (2006) or three (2007) seedlings per plot using a portable photosynthetic system (LI-6400; LI-COR Inc., Lincoln, NE) equipped with a 0.2-L conifer shoot chamber (LI-6400-05; LI-COR Inc.). Gas exchange was measured between 1000 HR and 1600 HR on clear days with photosynthetic photon flux

Table 1. Weed control, irrigation, and bedding production systems for Christmas tree mulch study at MSU Southwest Michigan Research and Extension Center, Benton Harbor, MI.

Treatment number	Weed control	Irrigation	Bedding
1	Black polyethylene	Irrigated	Bedded
2	White polyethylene	Irrigated	Bedded
3	Chemical + hand weed[z]	Irrigated	Bedded
4	Chemical + hand weed	Irrigated	Flat
5	Mulch mats	Irrigated	Flat
6	Wood chips	Not irrigated	Flat
7	Chemical + hand weed	Not irrigated	Flat
8	None	Not irrigated	Flat

[z]Chemical + hand weed = weeds controlled monthly with combination of directed sprays of glyphosate and hand weeding.

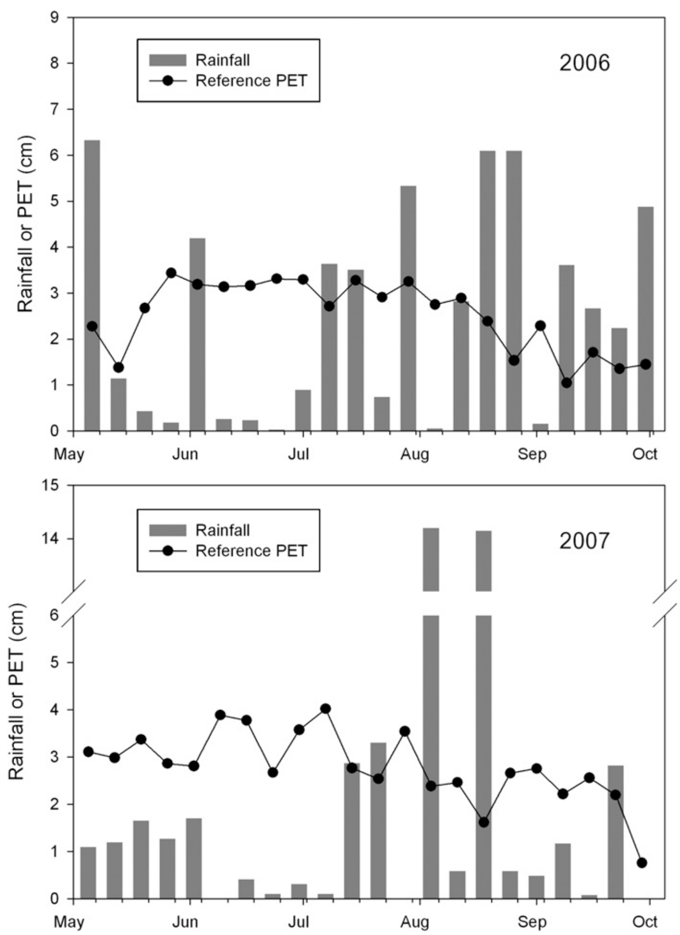

Fig. 1. Rainfall and reference potential evapotranspiration (PET) from the weather station at Michigan State University Southwest Michigan Research and Extension Center, 2006 to 2007.

Table 2. Diameter and height growth and survival of fraser fir and colorado blue spruce Christmas trees after 2 years under various combinations of weed control, irrigation, and bedding at MSU Southwest Michigan Research and Extension Center, Benton Harbor, MI, 2007.

Production system			Fraser fir			Colorado blue spruce		
Weed control	Irrigation	Bedding	Diam growth (mm)	Ht growth (cm)	Survival (%)	Diam growth (mm)	Ht growth (cm)	Survival (%)
1 Black plastic	Irrigated	Bedded	12.4 bc[y]	17.3 bc	95 a	15.5 ab	21.6 a	98 a
2 White plastic	Irrigated	Bedded	17.9 a	21.1 ab	100 a	16.5 a	23.2 a	98 a
3 Chemical + hand weed[z]	Irrigated	Bedded	12.5 bc	22.6 ab	100 a	11.8 bc	21.0 a	95 ab
4 Chemical + hand weed	Irrigated	Flat	13.4 b	20.4 ab	100 a	14.6 ab	23.2 a	100 a
5 Mulch mats	Irrigated	Flat	15.7 ab	22.9 ab	100 a	15.2 ab	20.8 a	100 a
6 Wood chips	Not irrigated	Flat	13.6 b	26.2 a	100 a	12.7 abc	23.5 a	95 ab
7 Chemical + hand weed	Not irrigated	Flat	8.8 c	13.8 cd	95 a	9.4 c	17.5 ab	88 ab
8 None	Not irrigated	Flat	1.9 d	9.4 d	67 b	1.4 d	10.2 b	71 b

[z]Chemical + hand weed = weeds controlled with combination of directed sprays of glyphosate and hand weeding.
[y]Means within a column followed by the same letter are not different at $P \leq 0.05$ significance level according to the Tukey-Kramer multiple comparison test.

density greater than 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Shoots used for gas exchange measurements were flagged with plastic tags and harvested at the end of the growing season. Projected shoot area was determined for each shoot using a leaf area meter (LI-3100; LI-COR Inc.) and all gas exchange measurements were adjusted for projected shoot area. In Aug. 2007, we evaluated plant moisture stress on the same trees used for gas exchange measurements by measuring predawn shoot water potential with a pressure chamber (Model 600; PMS Instruments Company, Albany, OR).

In Sept. 2007, we collected current-year shoots from the mid- to upper-crown position on each tree (10 shoots per plot) to determine foliar N concentration. Shoots were pooled by plot and foliar N determined on a composite sample at Waters Agricultural Laboratories, Camilla, GA.

Soil samples were collected at 0- to 15-cm depth in Sept. 2007. Samples were collected near the drip line on every other tree (five samples per plot) using a soil push probe and composited in a clean bucket. Soil pH was determined on each composite sample using a 1:1 (v:v) mix of soil and deionized water with a pH meter (Model AB15; Fisher Scientific, Pittsburgh, PA).

In Summer 2007, we installed an automatic data logging system (Model CR-10x; Campbell Scientific, Logan, UT) with thermocouple burial probes (Model 105T; Campbell Scientific) to measure soil temperature under the mulches. Temperature thermocouples were installed to a depth of 5 cm on five treatments: white polyethylene, black polyethylene, mulch mats, wood chip mulch, and nonirrigated + weed control. Probes were replicated four times in each production system.

Table 3. Summary of F-values for linear contrast of production system effects on diameter and height growth of fraser fir and colorado blue spruce seedlings.

		Fraser fir		Colorado blue spruce	
Contrast[z]	Treatments[y]	Ht growth	Diam growth	Ht growth	Diam growth
Weed control versus none	7 versus 8	4.83*[x]	26.73**	7.97*	37.31**
Irrigation versus none	4 versus 7	12.18**	14.97**	5.77*	20.47**
Polyethylene versus none	1 and 2 versus 3	4.27	6.82*	0.06	17.85**
White polyethylene versus black polyethylene	1 versus 2	4.06	21.10**	0.01	0.77
Flat versus bedded	3 versus 4	1.47	0.52	0.74	5.98*
Mulch mats versus polyethylene	1 and 2 versus 5	4.98*	0.28	0.25	0.65

[z]Contrast effect with higher mean diameter or height growth listed first.
[y]As listed in Table 1.
[x]Probability of greater F-value: * ≤ 0.05, ** ≤ 0.01.

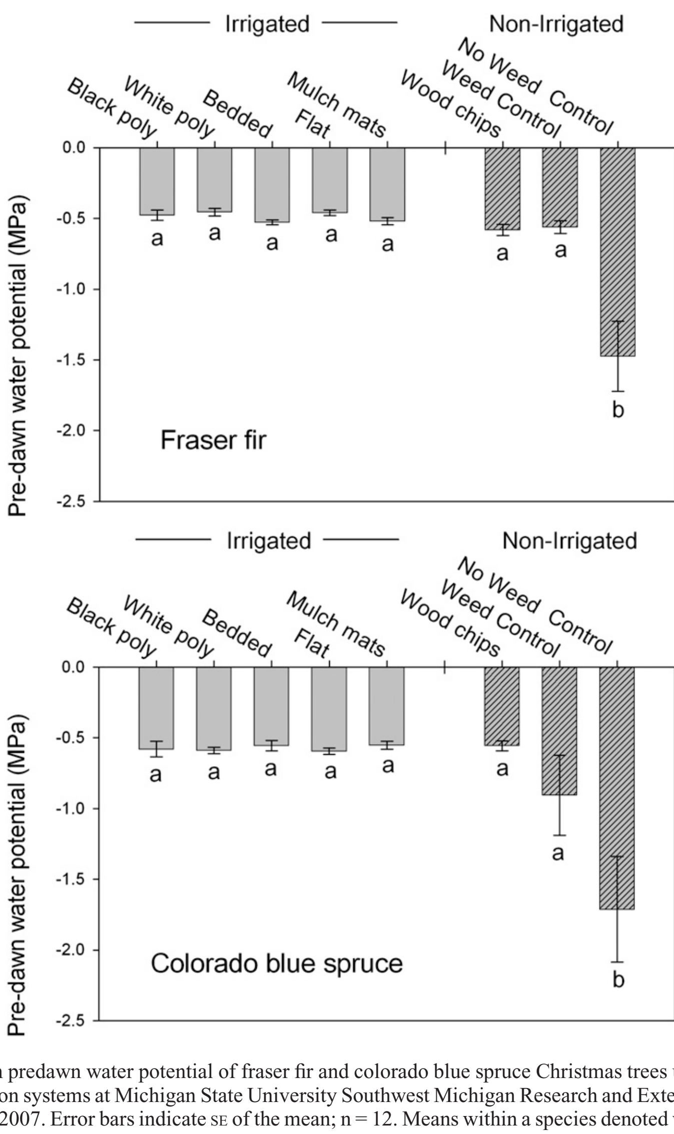

Fig. 2. Mean predawn water potential of fraser fir and colorado blue spruce Christmas trees under various production systems at Michigan State University Southwest Michigan Research and Extension Center, 15 Aug. 2007. Error bars indicate SE of the mean; n = 12. Means within a species denoted with the same letter are not different at $P \leq 0.05$ based on Tukey's Studentized range test.

Analysis. Overall growth and survival data were analyzed by analysis of variance based on a split plot in a randomized complete block with production system as the main plot and species as the subplot using the model $y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \gamma_k + \alpha\gamma_{ik} + \varepsilon_{ijk}$ where: μ = the overall mean, α_i = production system, β_j = block effect, $\alpha\beta_{ij}$ = main plot error term (Error A), γ_k = species effect, $\alpha\gamma_{ik}$ = production system × species interaction, and ε_{ijk} = subplot error (Error B).

Where significant ($P < 0.05$) production system effects were indicated, means were separated by Tukey's Studentized range test. To further evaluate component effects, we constructed a priori linear contrasts to compare specific weed control, irrigation, and mulch effects.

Results

Weather. Rainfall patterns differed widely between the 2 study years (Fig. 1). In 2006, two large [greater than 4 cm (1.5 inches)] rainfall events occurred in early May and early June followed by a month-long dry period. In contrast, reference potential evapotranspiration in 2007 exceeded rainfall for 11 consecutive weeks from May through mid-July, including a 5-week period in June and July during which less than 1.2 cm (half inch) of rain fell. The latter part of the 2007 growing season was marked by two extremely heavy [greater than 14 cm (5.5 inches)] rainfall events.

Weed control. During the 2 years of the study, plastic mulches, mulch mats, and wood chips provided close to 100% weed control around the study trees. Some weeds came through tears (likely caused by animal traffic) in the plastic mulch. By mid-Summer 2007, weed cover in the no mulch + no weed control plots was nearly 100%. Common weeds observed in the plots were wild buckwheat (*Polygonum convolvulus* L.), Quackgrass [*Elymus repens* (L.) Gould], black nightshade (*Solanum ptycanthum* Dun.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and common lambsquarter [*Chenopodium album* (L.)].

Survival and growth. In Fall 2007 (2 years after planting), seedling survival was 88% or

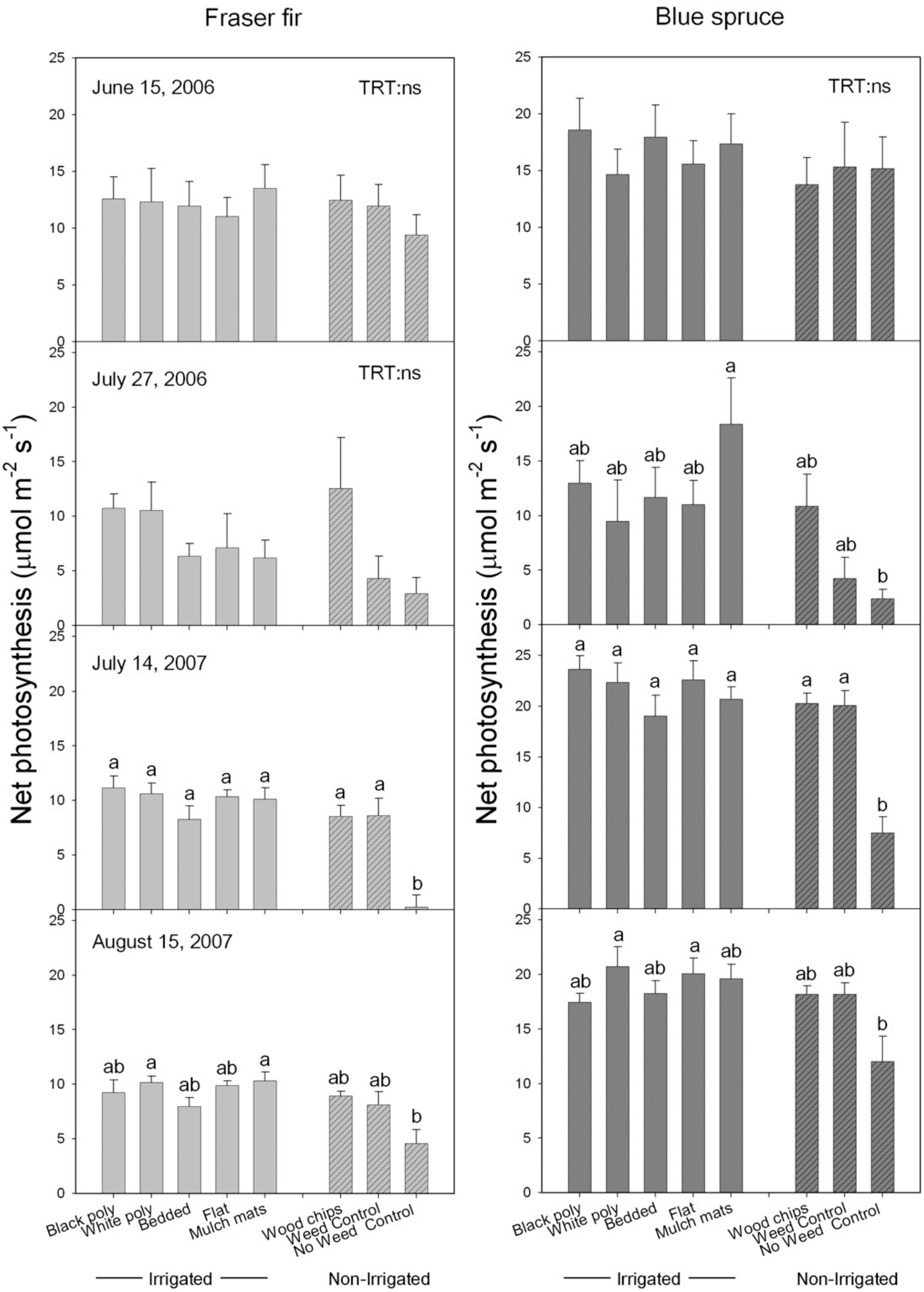

Fig. 3. Mean net photosynthesis of fraser fir and blue spruce Christmas trees under various production systems at Michigan State University Southwest Michigan Research and Extension Center, 2006 to 2007. Error bars indicate SE of the mean; n = 8 in 2006, n = 12 in 2007. Means within a species denoted with the same letter are not different at $P \leq 0.05$ based on Tukey's Studentized range test. TRT: NS indicates no significant effect of treatment for a given species and date.

greater for all production systems except nonirrigated + no weed control (Table 2) Survival did not vary ($P > 0.05$) between species. Production system, species, and interaction of production system and species affected ($P \leq 0.05$) seedling diameter and height growth. Production system effects on seedling growth were related to weed control, irrigation, and mulch effects (Tables 2 and 3). Weed control provided the single greatest improvement in diameter growth for both species. Irrigation increased diameter and height growth for both species and was particularly effective in increasing height growth of fraser fir trees. Mulch color (white versus black) did not affect growth of blue spruce trees. However, diameter growth of fraser fir trees increased with white mulch relative to black. Among the nonirrigated production systems, wood chip mulch increased height and diameter of fraser fir trees compared with the no weed control or weed control-only systems. Wood chip mulch without irrigation resulted in survival and growth comparable to most irrigated production systems for both species.

Predawn water potential and gas exchange. Irrigation and weed control increased predawn water potential of fir and spruce trees in Aug. 2007 indicating

Table 4. Soil pH and foliar nitrogen of fraser fir and colorado blue spruce Christmas trees after 2 years of production systems in southwest Michigan.

				Foliar N (%)	
Weed control	Irrigation	Bedding	Soil pH	Fraser fir	Blue spruce
Black polyethylene	Irrigated	Bedded	6.37 ab[y]	2.41 a	3.30 a
White polyethylene	Irrigated	Bedded	6.80 a	2.61 a	3.65 a
Chemical + hand weed[z]	Irrigated	Bedded	6.42 ab	2.47 a	3.08 a
Chemical + hand weed	Irrigated	Flat	5.76 ab	2.41 a	3.35 a
Mulch mats	Irrigated	Flat	6.76 a	2.49 a	3.63 a
Wood chips	Not irrigated	Flat	6.00 ab	2.64 a	3.41 a
Chemical + hand weed	Not irrigated	Flat	5.57 b	2.24 a	2.89 a
None	Not irrigated	Flat	5.97 ab	2.72 a	3.08 a

[z]Chemical + hand weed = weeds controlled with combination of directed sprays of glyphosate and hand weeding.
[y]Means within a column followed by the same letter are not different at $P \leq 0.05$ significance level according to the Tukey's Studentized range test.

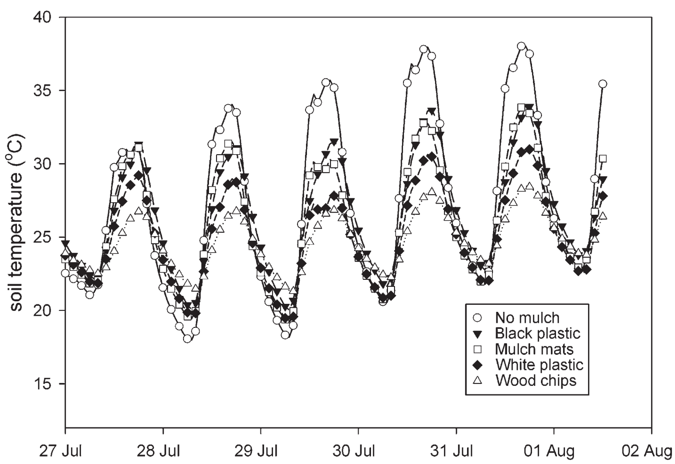

Fig. 4. Mean hourly soil temperatures at 2 inches (5 cm) soil depth in a Christmas tree trial at Michigan State University Southwest Michigan Research and Extension Center, Benton Harbor, MI, 27 July through 2 Aug. 2007.

increased moisture stress for trees in nonirrigated, no weed control plots (Fig. 2).

Variation in photosynthetic gas exchange reflected variation in moisture availability among production systems and seasonal variation in rainfall (Fig. 3). Differences in net photosynthesis (*Pnet*) among production systems receiving irrigation were generally small and not significant. After rainfall in early June 2006, there was no difference in *Pnet* among any production system. As conditions became drier in July 2006, however, differences in gas exchange between seedlings on the nonirrigated wood chip mulch and the other nonirrigated plots became apparent, especially for blue spruce seedlings. In 2007, differences in gas exchange among production systems were relatively small except for nonirrigated + no weed control treatments, which had significantly lower levels of gas exchange than other production systems in July. Gas exchange rates of blue spruce seedlings were higher ($P < 0.05$) than fraser fir seedlings for all measurement dates.

Soil pH and foliar nitrogen. Soil pH varied among production systems after 2 years (Table 4). Within the irrigation production systems, there was no discernible pattern of variation in soil pH. A linear contrast of irrigated versus nonirrigated treatments indicated soil pH was significantly ($P < 0.01$) higher for irrigated than nonirrigated plots (pH = 6.4 versus 5.8). The increase in pH is likely associated with the quality of the well water used for irrigation (pH = 8.0, alkalinity = 164 $mg \cdot L^{-1}$). Foliar N sampled in Aug. 2007 was higher ($P < 0.01$) for blue spruce trees than for fraser fir trees (3.3% versus 2.5%). Within species, foliar N did not vary ($P > 0.05$) among production systems (Table 3).

Soil temperature. All mulches moderated soil temperature at 5 cm (2 inches) depth compared with bare-ground plots (Fig. 4). During a warm period in late July 2007 when daily high air temperatures were ≈31 °C (88 °F), mean soil temperatures at midday reached 38 °C (100.4 °F) on the bare-ground plots. Wood chip mulch had the largest effect on moderating peak soil temperature compared with bare ground [10 °C (18 °F cooler)] followed by white plastic mulch [7 °C (12.6 °F cooler)]. Black plastic and black mulch mats had similar effects on soil temperature and were cooler than bare ground during the day.

Discussion

Plastic mulch increases plant growth and crop yield in a wide array of horticultural applications (Lamont, 2005). Increased growth associated with mulch can be related to weed control, moisture conservation, soil temperature modification, and changes in spectral reflectance. In this study, weed control and effects on plant moisture stress were the overriding factors driving seedling growth, especially stem diameter growth. Effects of weed competition were evident in water potential measurements and shoot gas exchange. Weed control without irrigation (Treatment 7 versus Treatment 8) increased stem diameter growth of fraser fir and colorado blue spruce by 7 and 8 mm, respectively (Table 3). By comparison, irrigation only (Treatment 4 versus Treatment 7) increased diameter growth by 4.6 to 5.3 mm. Estimates of irrigation effects on growth and survival in this study should be considered conservative given the favorable weather conditions immediately after plantation establishment in 2006. Overall, both species responded similarly to production systems, except fraser fir trees were more responsive to white than black mulch compared with colorado blue spruce trees. It is unclear whether this response is related to soil temperature or increased reflected radiation from the mulch surface. Soil temperatures under the black mulch were up to 2.5 °C warmer than under the white mulch, although larger differences have been reported (Tarara, 2000). High root zone temperatures can result in excess root respiration and reduced water and mineral nutrient uptake (Cooper, 1973; Dodd et al., 2000). Moreover, white mulch can reflect up to six times the amount of photosynthetically active radiation as black mulch (Decoteau et al., 1989).

During the dry period in 2007, soil temperatures were warmer on the bare-ground plots than under black polyethylene or black mulch mats (Fig. 4). This result contrasts with several studies that indicate black mulch significantly increases soil temperature relative to bare ground (Díaz-Pérez and Batal, 2002; Díaz-Pérez et al., 2005). The lack of soil warming under black mulch in the current study could be the result of air insulation because soil temperatures were measured in the second year after mulch installation. The reduced warming effect of black mulch in the second year after mulch installation may be tthe result of loss of tight contact between the mulch and soil surface needed for conductive heat transfer (Ngouajio and Ernest, 2005; Tarara, 2000). In addition, soils on the bare-ground plots could have warmed excessively during the dry period as a result of lack of evaporative cooling (Tarara, 2000).

The significant improvement in tree growth and water relations associated with the wood chip mulch could provide growers with a relatively low-cost, sustainable method of weed control. Wood chips also provide additional long-term benefits to soil physical and chemical properties and do not require removal and disposal. For all production systems, values of foliar N for both species were above established standards for healthy Christmas tree plantations (Slesak and Briggs, 2007). This indicates fertilizer regimes, including granular applications, provided adequate nutrition. Moreover, foliar N levels of trees in the wood chip treatment did not show any evidence of nutrient "tie-up," which is sometimes cited as a concern with mulches with a high C:N ratio (Chalker-Scott, 2007). Arthur and Wang (1999) noted that sawdust mulch improved soil organic mater, moisture content, and total N compared with bare-ground controls in a Christmas tree plantation of Scot pine (*Pinus sylvestris* L.) and Eastern white pine (*Pinus strobus* L.) trees.

Results of this study highlight the overriding importance of controlling weeds to ensure survival and improved early growth of newly planted Christmas trees. Polyethylene mulch improved diameter growth, but response was small relative to effects of weed control or irrigation. Response of trees to mulch color was species-dependent with fraser fir trees growing better with white mulch than with black. Mulch mats performed as well as polyethylene mulch and could be a suitable option where specialized mulch-laying equipment is not available. Similarly, wood chip mulch may offer a low-cost alternative to plastic mulches.

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