Light-Emitting Diode Lighting for Forest Nursery Seedling Production©

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INTRODUCTION

Crop lighting is an energy-intensive necessity for nursery production of high-quality native plants and forest tree seedlings. During the winter months (especially in northern USA latitudes) or overcast or cloudy days, the amount of solar radiation reaching greenhouse crops is insufficient resulting in growth cessation, early terminal bud formation, and failure of seedlings to reach target height for outplanting (Tinus, 1995; Lopez and Runkle, 2008). In light of this, nursery growers have added supplemental lighting to increase the daily light integral (DLI), defined as the photosynthetic light received over the course of the day for seedling production (Torres and Lopez, 2010). A wide range of supplemental light sources are used in nurseries to control plant development and manipulate plant quality (Tinus, 1995; Bourget, 2008). However, the problem with most lighting systems, such as high-pressure sodium (HPS) lamps, is that they do not provide the light spectrum that is most efficient for photosynthesis in plants. In addition, because of the huge amount of electrical energy required, using HPS as supplemental lighting, for most reforestation and native plant nurseries, is economically impractical.

The light-emitting diode (LED) is key to improving energy utilization for greenhouse lighting. Light-emitting diodes are solid-state, robust, very long-lived, and are designed to produce the exact light quality that plants can utilize for photosynthesis while using only a fraction of the electricity used by HPS, the current industry standard (Bourget, 2008). Thus, any new lighting technology that significantly reduces electricity consumption for crop lighting while producing top quality seedlings for ecological restoration and conservation efforts has significant benefits to society. The objective of the current study was to examine the effect of supplemental lighting provided by LED and HPS on growth and chlorophyll concentrations of Douglas fir (DF, *Pseudotsuga menziesii)* and Engelmann spruce (ES, *Picea engelmannii*) seedlings from British Columbia, Idaho, and New Mexico (northern, central, and southern populations, respectively).

MATERIALS AND METHODS

Plant Materials, Culture, and Growing Conditions

Pseudotsuga menziesii (Douglas fir, DF) and *Picea engelmannii* (Engelmann spruce, ES) seeds from three latitudinal sources: 1) British Columbia (BC), 2) Idaho (ID), and 3) New Mexico (NM), were sown in Ray Leach™ pine cells filled with a 1:1 (by volume) of sphagnum peat moss and vermiculite growing medium (40-50% peat, vermiculite, and bark, Sunshine Custom Blend #1, Sun Gro Horticulture, Bellevue, Washington, USA). Each tray held 200 cells and each cell measured 2.5×16 cm (66 cc). Osmocote (15N-9P-12K) 5-6 month controlled release fertilizer (The Scotts Company, Marysville, Ohio, USA) was incorporated into the media, with each seedling receiving 76.23 mg of N. Filled containers were placed onto greenhouse tables (8×3.5 ft) inside a fully-automated, thin-wall, polycarbonate greenhouse at the USDA Forest Service Rocky Mountain Research Station, Moscow, Idaho. The greenhouse air temperature set point was a constant 24°C and average relative humidity (RH) of 65±10%.

The seedlings were grown for 1.5 weeks prior to the supplemental lighting treatment. On 7 Feb. 2014, RL trays with germinated seedlings were assigned at random to eight tables and were comprised of four replications of 200 seedlings of each species growing under a 18-h photoperiod (0600 to 2400 HR) consisting of natural day lengths with

supplemental lighting from LED containing 15% B and 85% R (GreenPower DR/W LED 120-110V, Philips, Texas, USA) and HPS lamps (400 W, Sunlight Supply, Inc. Vancouver, Washington) that delivered a photosynthetic photon flux (PPF) of 70-80 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at plant height as measured with a quantum sensor (LI-COR Biosciences, Lincoln, Nebraska). To avoid light pollution between lighting treatments, one layer of 6-mil-thick black polyethylene plastic (Hummert International, Topeka, Kansas), between two layers of white plastic (curtains) were hung from the upper frame of the greenhouse structure. Irrigation scheduling was determined by gravimetric water content (GWC) and seedlings were irrigated when GWC reached 75% of field capacity.

Measurements and Data Analysis

Seedling growth (height and root collar diameter, RCD), shoot and root dry mass (DM) were measured 17 weeks (n=12) after supplemental lighting treatment began. Tissue dry mass was obtained after oven-drying at 70°C for 72 h. Total chlorophyll (chl) content (n= 12) was measured according to the methods described by Islam et al. (2008). Power use for both HPS lamps and LED lights was measured using a plug power meter (P440Kill A Watt; P3 International, New York, New York). Analysis of variance (ANOVA) was used to examine the effects of light source and seed sources on the measured response variables for each species separately (α=0.05) (SAS 9.1 Institute Inc., Cary, North Carolina).

RESULTS AND DISCUSSION

Significant differences in seedling height ($P<0.001$), RCD ($P<0.001$), shoot ($P<0.001$) and root ($P<0.001$) DM between supplemental light sources were observed at the end of the experimental period (17 weeks). Seedlings grown under LED had significantly greater growth compared to HPS (Fig. 1). The magnitude of increase in seedling growth and tissue DM to LED was greater in ES compared to DF (Fig. 1).

As expected, the northern (BC) and southern (NM) seed sources of DF and ES were the most and least sensitive to supplemental lighting, respectively. The DF from BC showed the highest growth among the seed sources after the final, 17th week of supplemental lighting. For example, LED lighting caused 15.4, 15.0, and 3.2% increase in height compared with HPS in BC, ID, and NM, respectively at the end of the supplemental lighting period.

Of the studied seed sources (Fig. 1), overall LED-grown seedlings from BC had the greatest growth and tissue DM followed by ID and NM populations. At the end of the experiment, light-emitting diode-grown ES showed 31-35% increase in height for both BC and ID and 15% increase in height for NM than was observed in HPS-grown seedlings. Within the DF and ES, seedling growth and tissue DM decreased latitudinally from BC, through ID, and NM seed sources. Our study reveals the presence of seed sources variation for seedling growth and physiology in response to supplemental light source, which could be interpreted as an adaptive response to the length of the growing season (Clapham et al., 1998).

By the end of the treatment period (Week 17), total chlorophyll (chl, $P<0.0001$) was significantly affected by light source. Light-emitting diode-grown DF and ES seedlings from NM had 28 and 30% increase in total chl compared with DF seedlings grown under HPS, respectively (Fig. 1).

In forest nurseries, provision of light during natural short photoperiods is a common practice for several conifers to prevent seedling dormancy and maintain growth rates to meet target size specifications for outplanting (Landis et al., 1992; Tinus, 1995). The greater growth measures and DM production of the LED-grown plants compared with the HPS-grown seedlings observed in our study correlates with enhanced gas exchange measures (data not shown) and chlorophyll contents. This is in accordance with the findings of Currey and Lopez (2013), where LED treatments containing 85:15 red:blue (similar to the spectral ratio we used in our present study) led to a significantly higher accumulation of DM in *Petunia* compared with HPS lamps.

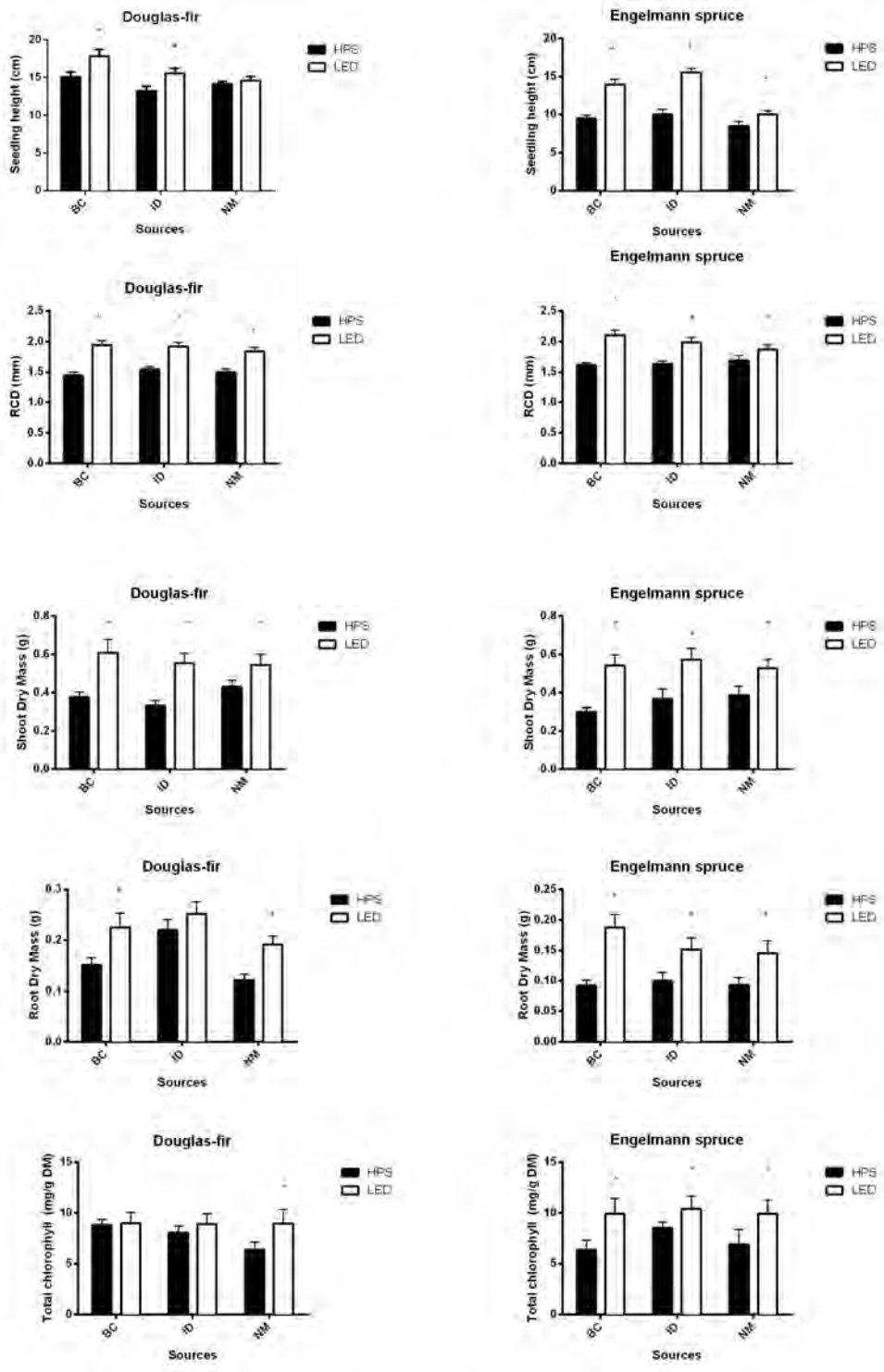

Fig. 1. Seedling height, root collar diameter, tissue DM and total chlorophyll content of LED and HPS-grown DF and ES seedlings from three latitudinal sources. Each data point represents mean (n=12) ± SE. LED bars marked with an asterisk above indicate a significant difference from the HPS at P<0.05. Only pairs of means (HPS and LED) at each source are being compared with each other.

In our study, the energy consumption metrics indicated 70% energy savings using LED supplemental lighting technology relative to HPS lamps. Currey and Lopez (2013) demonstrated a 35-40% reduction for LED-grown annual bedding plants (*Impatiens*, *Pelargonium*, and *Petunia*) compared with HPS lamps whereas, Gomez et al. (2013) reported 75% energy savings for tomato (*Solanum lycopersicum*) crops grown under LED lighting.

The significant increase in seedling growth and chlorophyll measures and energy savings in LED compared with HPS highlights the promise of using LED for container seedling production in the northern latitudes particularly during light-limited times of year.

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QUESTIONS AND ANSWERS

Dharma Sharma: What was the distance from the lights to the crop?

Kent Apostol: Since we had to match the light intensity to the HPS, we kept the lights about 2 ft above the canopy of the crop.

Robert Boada: Was the light bar we saw in the pictures a traveling boom? What is your experience with it?

Kent Apostol: Actually, the growers don't really like the travelling boom. When installed

they work well, but over time they are not very reliable.

Katarzyna Gradowsky: Do you think there is a demand for the design of customized light systems for crops?

Kent Apostol: Yes. When you talk to manufacturers they'll ask you about what kind of quality you want to achieve for your crops and the light intensity you'll want. There are many ways you can customize the light system.

Diego Martinez: How do you determine relative amount of red and blue wavelengths?

Kent Apostol: When we planned this study we found in the literature that 10% of the blue wavelengths are needed for stomatal opening with the rest being used for photosynthesis which is in the red region. There is some flexibility with the relative amounts of red and blue wavelengths needed and this depends on the plant in question.