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Growth and development of Norway spruce and Scots pine seedlings under different light spectra

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ABSTRACT

The goal of this study was to examine how different light spectra affect growth and development of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) seedlings. The seedlings were grown in a darkened greenhouse under four light spectra consisting of different proportions of blue (B, 400–500 nm), red (R, 600–700 nm), and far-red (FR, 700–800 nm) light, with high-pressure sodium lamps (HPS) serving as controls. The light treatments (250 $\mu mol\ m^{-2}\ s^{-1}$ photosynthetically active radiation) were provided using light-emitting diodes (LEDs), and the treatments included the following: (1) 25% B + 70% R + 5% FR; (2) 25% B + 75% R; (3) 55% B + 45% R; and (4) HPS: 6% B + 44% green (500–600 nm) + 41% R + 9% FR. We measured germination, growth, morphology, gas exchange, N concentration in needles and stem, and terminal bud set of the seedlings after a 4-month growth period. Our results showed that the physiological and morphological responses of shade-intolerant Scots pine seedlings to light quality were more pronounced than those of the shade-tolerant Norway spruce seedlings. Growth under the FR-containing light treatments produced tall seedlings with larger needle dry mass. Removal of FR and addition of B in the growth light reduced the height growth, and it increased the sturdiness and altered the branching patterns in the seedlings. Growth under the treatment containing about 25% B and 75% R resulted in the highest root-to-shoot ratios in both species and highest root growth capacity and water-use efficiency in Scots pine. Timing of bud set was independent of growth light spectra. Our results show that it is possible to improve the seedling attributes that are contributing to good performance potential by using different wavelength combinations in growth light, particularly in Scots pine. However, the potential after-effects of growth under an incomplete light spectrum on seedling performance after planting to forest regeneration site are still unknown.

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1. Introduction

Plant growth and development are affected by light intensity, wavelength distribution, and photoperiod. Light provides energy to drive photosynthesis and also acts as a source of spatial and seasonal signals to plants. When a plant is growing below a vegetation canopy, it is experiencing a significant reduction in light quantity, in particular red (R) and blue (B) wavebands, which are absorbed by chlorophyll and used to drive photosynthesis, while the proportion of the lesser-absorbed regions of the spectrum, including green (G) and far-red (FR) wavebands, increases. These changes in spectral distribution of light trigger shade-avoidance responses in shade-intolerant plants, such as Scots pine (*Pinus sylvestris*). The shade-avoidance responses include rapid elongation of stems and leaves and reduced branching and chlorophyll content (Pierik and de Wit, 2014). In shade-tolerant species, such as Norway spruce (*Picea abies*), leaves display adaptations in photosynthetic structures, such as thinner leaves and higher chlorophyll content, to optimize photosynthetic efficiency at low light intensities (Franklin, 2008). On the other hand, plants that are

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developing under high light, rich in R and B, typically have thicker leaves, lower leaf area-to-dry mass ratios, higher rates of maximum net photosynthesis, stomatal conductance and transpiration, and higher chlorophyll contents (Poorter et al., 2009).

Wavelength distribution of light provides important seasonal information to species growing in boreal areas (Linkosalo and Lechowicz, 2006), where the photoperiod during the growing season is long and the twilight hours, characterized by low R:FR, are extended, particularly at northern latitudes. Northern populations use the length of the light period as a cue for growth control, whereas, for the southern populations, duration of darkness may be more important (Clapham et al., 1998; Mølmann et al., 2006). Consequently, there is a clinal increase in requirement for FR light with increasing latitude of origin for maintaining the growth in Norway spruce, and, for maintaining the development of secondary needles in Scots pine. The change in the requirement for FR occurs at latitudes of 60–64°N (Clapham et al., 1998; Mølmann et al., 2006).

The R:FR is perceived through phytochrome photoreceptors, which play a major role in plant photomorphogenesis, and exist in two photo-convertible isomers, a biologically inactive R-absorbing Pr form and a biologically active FR-absorbing Pfr form (Pierik and de Wit, 2014). Cryptochromes and phototropins are B and ultraviolet (UV)-A sensitive, but G also may affect plant processes via cryptochrome-dependent means (Folta and Maruhnich, 2007). Cryptochromes play a pivotal role in the generation and maintenance of circadian rhythms, and the phototropins are involved in regulating phototropism, chloroplast movements, and stomatal opening (Whitelam and Halliday, 2007). The different signaling pathways are likely to interact; G has been shown to counteract B effects (Folta and Maruhnich, 2007), and R and B may have interactive effects, since phytochromes also absorb B (Pierik and de Wit, 2014).

The existing information on the effects of different wavelength combinations on plant physiology is mainly derived from experiments on horticultural species. These experiments have largely focused on R and B regions of the spectrum due to the high sensitivity of photosynthetic photoreceptors, such as chlorophyll and xanthophylls, to these spectral regions. It is clear that the growth and development of the plants can be manipulated by altering light spectra, although the responses are species-specific (Folta and Maruhnich, 2007; Li and Yang, 2007; Pierik and de Wit, 2014). Light-emitting diodes (LEDs) are of increasing interest to plant production and research due to their high energy efficiency, adjustable light intensity and spectrum, and low radiant heat load. The costs of LED lighting have been estimated to continue to decrease, which would facilitate the use of LEDs in horticultural applications (Pinho et al., 2013).

Earlier studies on wavelength distribution on Norway spruce and Scots pine mainly have focused on the responses of seedlings to different R:FR provided as a day-extension treatment (Clapham et al., 1998, 2002; Fløistad and Patil, 2002; Mølmann et al., 2006). In Norway spruce, a low R:FR has induced increased hypocotyl length (Ranade and García-Gil, 2013) and stem elongation, reduced shoot dry mass (Fløistad and Patil, 2002), and delayed bud formation (Clapham et al., 1998; Fløistad and Patil, 2002; Mølmann et al., 2006). In Scots pine, a low R:FR has increased stem elongation and shoot and root dry masses (de la Rosa et al., 1998), and FR was required for maintaining needle extension growth in northern populations (Clapham et al., 2002). The studies on the effects of B on Scots pine have revealed decrease in growth rate when B is exposed together with R (Fernbach and Mohr, 1990), with only minor effects on parameters other than height (Sarala et al., 2011). Less published information exists on the effects of B on Norway spruce growth and development. More knowledge is needed on the responses of conifer seedlings to different light spectra in order to develop commercial applications for producing high-quality seedlings for cost-efficient forest regeneration. Due to the short growing season and narrow transplanting window to forest sites in northern latitudes, it is essential that the timing of phenological events of the seedlings can be controlled. The seedlings must be sturdy and possess a well-developed root system to be able to grow in harsh conditions, compete with other vegetation, and withstand snow press. A high photosynthetic capacity and water use efficiency, which are highly depended on the light intensity and quality, contribute to the rapid establishment of a seedling to the forest site (Grossnickle, 2000).

Norway spruce and Scots pine are economically the most important forest tree species in Scandinavia, comprising more than 90% of the seedlings delivered for planting from the nurseries annually. There is a growing interest for year-round cultivation of seedlings in order to reduce cultivation costs and increase the cost-effectiveness of the expensive planting machinery and labor. The main objective of this research was to test whether seedlings with good performance potential can be grown using R, B, and FR radiation only. We grew Norway spruce and Scots pine seedlings originating from 62°N latitude in a greenhouse under three different LED light spectra that contained different proportions of R, FR, and B. High-pressure sodium lamps (HPS) served as controls. We studied germination, growth, morphology, gas exchange, N concentration in the needles and stem, and terminal bud set of the seedlings after a 4-month growth period under the light treatments. Our hypotheses were (1) seedlings with good performance potential can be produced without FR, under R and B only; (2) seedling sturdiness increases when the proportion of B in the growth light increases, while a reduction in R:FR decreases sturdiness in both species; (3) photosynthetic capacity may be higher under the LED treatments than under HPS that contain less R and B, while water use efficiency may be higher in the treatments with lower B proportion, since B is known to provoke stomatal opening; and (4) the responses to light treatments are more pronounced in shade-intolerant Scots pine compared to shade-tolerant Norway spruce.

Table 1
The proportion of different wavelength ranges in the light treatments. The values represent the percentage of each wavelength range of the total photon flux density from 400 nm to 800 nm.

Treatment	400–500 nm Blue	500–600 nm Green/yellow	600–700 nm Red	700–800 nm Far-red	650–670 nm/720–740 nm Red/far-red
$25B/R_{FR}$	25.4	0.9	69.0	4.7	19.2
25B/R	24.5	0.8	74.6	0.1	∞
55B/R	54.5	1.0	44.4	0.1	∞
HPS	6.1	43.9	40.8	9.2	2.9
HQI[a]	26.3	34.6	26.3	12.8	2.2

[a] HQI lamps were used during the germination instead of HPS to reduce the heat load.

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