Forest Ecology and Management 318 (2014) 294–303

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Growth and root development of black and white spruce planted after deep planting

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ARTICLE INFO

Article history:
Received 23 October 2013
Received in revised form 21 January 2014
Accepted 23 January 2014
Available online 14 February 2014

Keywords:
Adventitious root
Stem burial
Tree plantation
Black spruce
White spruce

ABSTRACT

The capacity of trees to produce new roots is essential for rapid early growth of planted seedlings. Black and white spruce trees (*Picea mariana* and *Picea glauca*) are widely planted in the eastern boreal forest of Canada and are known to develop substantial adventitious root systems. In this study, we compared root development and growth of 17-year-old trees that had been planted at two different depths (ground level vs 10–12 cm) to see if partial stem burial would hasten adventitious root development, and in turn, growth. Root number (total and adventitious), root total area, rooting depth, year of root formation, tree height and basal diameter were measured in black and white spruce trees. Both species developed adventitious root systems, and adventitious roots size and area were greater for deeply planted trees than for trees planted at ground level. The number of adventitious roots and the speed of adventitious root development were greater for deeply planted black spruce but not for deeply planted white spruce, compared with trees planted at ground level. For the latter, site conditions could explain the absence of a planting depth response. Deep planting increased tree height and basal diameter of white spruce, but only height for black spruce trees. However, tree growth was related to total root cross-sectional area (not just adventitious roots), underscoring the importance of both types of roots for tree growth.

1. Introduction

Rapid establishment and early growth of trees is crucial for maximising plantation productivity and avoiding seedlings being quickly overtopped by competing vegetation (Ritchie and Dunlap, 1980; Trottier, 1998; Prévost and Dumais, 2003; Johansson et al., 2007; Thiffault et al., 2012). The capacity of trees to absorb water is one of the most important factors that affect the speed of establishment of planted seedlings, and drought stress is often the main reason for mortality or growth stagnation of conifer seedlings (Burdett, 1990). Planted trees access water by producing new roots (Carlson, 1986; Johnsen et al., 1988; Grossnickle, 2005). Therefore, the capacity to produce new roots is a selection criterion in nurseries and also has been suggested as a predicted relative measure of performance in plantations (Ritchie and Dunlap, 1980; Sutton, 1980; Burdett et al., 1983; Feret and Kreh, 1985; Johansson et al., 2007). The initial period of stagnant growth in planted seedlings, which is called plantation shock, corresponds to the length of time that is required for seedlings to produce new roots to comprise an adequate root system (Rietveld, 1989). Plantation shock is especially damaging for forest productivity when its effects are still noticeable long after seedlings have developed good root systems (Grossnickle, 2005). Consequently, plantation productivity can suffer from plantation shock over multiple years.

Each year, about 100–150 million seedlings are planted in Quebec (Parent et al., 2012). The most frequently planted species is black spruce (*Picea mariana* (Miller) BSP) with 60 million seedlings per year (58%), but white spruce (*Picea glauca* (Moench) Voss; 11% of planted trees) and jack pine (*Pinus banksiana* Lambert; 23%) are also commonly used (Parent, 2010). The root system of mature black spruce trees is almost exclusively adventitious, i.e., the majority of roots have developed directly on the stem (DesRochers and Gagnon, 1997; Krause and Morin, 2005). White spruce is also known to develop adventitious roots (Peters et al., 2002), but does so to a lesser extent than black spruce. This indicates that the primary root system does not develop for these two species, even for mesic sites, without large surface accumulations of organic matter (DesRochers and Gagnon, 1997). For the successful development of adventitious roots, the base of the stem must experience humid conditions (Aubin, 1996). This condition might explain, at least for black spruce, why seedlings tend to bend at the base when they are produced in nurseries (Béland and Lapierre, 1992), thereby placing their stems in contact with the soil and promoting the formation of adventitious roots.

Preliminary studies have shown that burying the bases of the seedling stems, either in the greenhouse or in the field, allowed

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http://dx.doi.org/10.1016/j.foreco.2014.01.032

for faster development of adventitious roots compared to seedlings planted at the root collar (Aubin, 1996; Gagnon, 2002). Sutton (1991) also recommended deeper nursery planting of black spruce seedlings, i.e., below root-collar level, to accelerate the development of adventitious roots. Whether faster development of adventitious roots would accelerate establishment and early growth of white and black spruce seedlings is unclear (Schwan, 1994; Whaley et al., 1995; Beyeler, 1996; Gagnon, 2002). Most studies on burial of trees took place on coastal or desert sand dunes, and these studies show generally a positive effects of partial sand burial on tree height, biomass (shoot and root), and photosynthetic rate (Zhang and Maun, 1992; Brown, 1997; Shi et al., 2004; Dech and Maun, 2006). However, a recent study in the boreal forest of Canada showed no effect of deep planting on growth or survival of black and white spruce seedlings (Paquette et al., 2011), but any differences in root development were not addressed. As stem burial in sand dunes or in the boreal forest offer very different conditions (e.g. soil type, water availability and soil temperature), tree responses to burial may vary. The lack of an overall consensus emphasises the need for further studies of tree response to partial stem burial under boreal conditions.

The goals of this study were (1) to evaluate the effects of planting depth on adventitious root production and (2) to examine the relationship between adventitious root development and tree growth. Overall, we hypothesised that burial would increase both the quantity of adventitious roots and their speed of formation, and in turn increase growth of deeply planted trees. As black spruce generally produce more adventitious roots than white spruce trees (Schwan, 1994), we assumed that black spruce would better respond to deep planting.

2. Materials and methods

2.1. Study sites

In June 1993, 26,000 bare-root seedlings of black (BS) and white spruce (WS) were planted by Quebec's Ministry of Natural Resources at eight study sites that were between 49°12′N and 49°14′N, and between 72°38′W and 72°40′W. The sites were located in boreal forest of the Lac-Saint-Jean region (Quebec, Canada), within the western balsam fir-paper birch (*Abies balsamea* (L.) Mill. – *Betula papyrifera* Marsh.) bioclimatic domain (Grondin, 1996). The provincial nursery at Normandin supplied two-year-old (2 + 0) bare-root stock. Soil scarification was done prior to planting using a Wadell disk-trencher. The field trial design was simple, with 4 sites per species (Fig. 1). For each species, two sites (replicates) were planted at ground level and the other two at 10–12 cm deep (deep planting, Fig. 1). Spacing in plantation was around 2 × 2 m (2200 trees per hectare) and between 2900 and 3400 trees were planted per site. Minister of natural resources recorded tree mortality during the two years following plantation, and no differences were recorded between planted sites. From 1971 to 2000, precipitation was recorded at the closest Environment Canada weather station (Albanel), averaging 887 mm annually (639 mm as rainfall, 248 mm as snowfall). Average annual temperature (±standard deviation, SD) was 1.7 ± 4.9 °C (Environnement Canada, 2011). Slope was generally low (4–8%). Soils were constituted with glacial deposits of undifferentiated till with moderate drainage (mesic). The ground cover included ericaceous shrubs and a dense mat of fruticose lichen, feather moss, or sphagnum (Table 1).

2.2. Field measurements

Sampling was done in September 2010. Height (m), basal diameter (cm, at soil level) and diameter at breast height (cm; DBH, 1.3 m, when possible) were measured for 30–50 trees that were located in a randomly established 20 × 20 m quadrat within each site (Table 2). Tree height was measured using a measuring pole and basal diameter with a digital calliper. Average tree height and basal diameter was first calculated for each site, and 5 trees that were close to these averages or higher (codominant or dominant trees) were then selected for excavation. Soil level was identified on each tree using tape. The five selected trees were cut and their root system excavated by hand with shovels. In the field, soil was removed from around the root mass by shaking the trees and the remaining soil was removed in laboratory by washing roots under water. Tree boles, stumps and all roots within a 50–60 cm radius of the stem were brought to the laboratory for further analysis. For each tree, we estimated mean crown radius (by measuring the length of three largest branches) to determine competition radius. Competition radius is the estimated crown radius of canopy trees multiplied by 3.5 (Hegyi, 1974). If a tree was located in the competition radius, it was recorded as a competitor. However, we found that only one black spruce tree had competition, thus this variable was dropped from further analysis.

2.3. Dendrochronological analysis

Each root was identified and cross-sectional area of the root was measured at the stump. To minimise bias due to root eccentricity, average root diameter was determined as the average between the longest and a second measurement made at about 90° from the first. Root cross-sectional area at the stump was calculated, as π multiplied by the longest and radius at 90°. A cross-section of about 1 cm thick was cut at the base of the stump for each root with a diameter greater than 2 mm. The cross-sections were air-dried for several months and then sanded with coarse to fine papers (up to 600 grit). Where necessary, the visibility of very narrow rings was increased by using a razor blade and white chalk. The ages of trees and roots were determined by counting the number of annual growth rings under a binocular microscope. To avoid mistakes related to missing or partial rings, cross-dating was done using skeleton plots and pointer years such as frost marks, light rings, compression wood, and narrow or wide rings (Schweingruber, 1988). For the 17 years, we found 7 pointer years (essentially frost marks).

To determine the location of the root collar (root/shoot interface), stumps were cut into very thin cross-sections (2–3 mm thick), using a band saw. The root collar was identified as the shift from the presence of a pith to a central vascular cylinder (DesRochers and Gagnon, 1997). The distance between the root collar and soil level (identified in the field with tape) was defined as organic matter accumulation since the year of planting, 1993. For deeply planted trees, this value thus also included 10–12 cm of mineral soil. Roots that were located above the root collar were labelled as adventitious roots, while roots that were located below the root collar were labelled as initial roots. Some of the trees that were excavated were older or younger than the plantation age; these individuals were probably of natural origin and were thus excluded from the analysis. A total of 16 black (9 planted at ground level and 7 deeply planted) and 19 white (10 planted at ground level and 9 deeply planted) spruces were used for statistical analysis.

2.4. Statistical analysis

Statistical analyses were performed in R v. 2.7.2 (R Development Core Team, 2008), and a significance level of $\alpha = 0.05$ was chosen for all response variables. Data from excavated trees ($N = 35$) were first used to determine the effects of planting depth