Seedling Size and Reforestation Success
How Big is Big Enough?

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Introduction

Foresters are frequently confronted with the option of planting seedlings that have a range of sizes. Most practitioners assume that larger planting stock has greater inherent performance capability to grow larger and faster, compete with vegetation for site resources under field site conditions and shorten the time to reach a desired size; thus meet management objectives (e.g., free to grow plantation status). For example, there are many reported historic (e.g., Dobbs 1976, McMinn 1978, Vyse 1982, Hines and Long 1986, Payandeh and Wood 1988, Sutherland and Newsome 1988) and current (e.g., Jobidon et al. 1997, 2003) studies that have shown larger spruce seedlings result in improved plantation performance. However, in some situations planting of larger seedlings might not make biological sense. This review examines available work on spruce seedlings size in relation to stock quality and stocktype size versus field performance from a biological perspective. The subsequent discussion tries to determine 'how big is big enough' when it comes to seedling size and reforestation success.

Stock Quality and Seedlings of Various Sizes

Stock quality characterization provides information on similarities and differences between stocktypes. This characterization allows one to have a better understanding of performance capabilities of nursery-grown seedlings and thus a better capability to forecast their field performance. Stock quality is a seedling's "fitness for purpose" as it relates to achieving specific silvicultural objectives (Lavender et al. 1980). In this instance, examples show variation in stock quality of seedlings from across a range of container cavity sizes and variation that can occur within a single container cavity size.

Seedling material attributes versus seedling size

In this first example, spruce seedlings grown in a range of container cavity sizes are compared for their stock quality material attributes. Material attributes are single-point measures of individual parameters that represent specific seedling subsystems (Ritchie 1984). Spruce seedlings grown in large-volume containers have greater shoot and root size, but maintain fairly comparable balance within their shoot system (i.e., height to diameter ratios), and between their shoot and root system (i.e., shoot to root ratios) (Table 1). Even though large-volume containers produced larger seedlings, all of these stocktypes met target specifications for 'plantable' container-grown spruce seedlings. Other work has also found that spruce seedlings grown in large-volume containers are taller, have larger root collar diameters, and greater total shoot and root dry weights (Lamhamedi et al. 1997; Paterson 1997). In addition to having a taller shoot, seedlings grown in large-volume containers have a greater number of branches and buds, but no greater potential for predetermined shoot growth (i.e., number of needle primordia found in the terminal bud) (Table 1). Nurseries can use large-volume containers to produce larger seedlings that can occupy a greater area within the planting spot, without compromising structural balance.

Spruce seedlings of all sizes have comparable physiological stock quality attributes (Table 1). This is reflected in the similar drought tolerance and avoidance for spruce seedlings grown over a range of container volumes. Photosynthetic capability was also comparable between seedlings of various container sizes. This indicates that producing a morphologically larger seedling does not confer any additional physiological stock quality attributes to enhance performance under optimum or limiting environmental conditions. If there is a benefit of a larger seedling in relation to physiological performance, it is that its greater foliar mass allows for greater seedling photosynthetic capacity. This capability could be critical in enhancing the ability of larger seedlings to grow quickly and occupy site resources during establishment (Grossnickle 2000).

Seedling performance attributes versus seedling size

In this second example, spruce seedlings grown in a similar container cavity size are compared for their stock quality performance attributes in relation to seedling size variation. Performance attributes reflect an integrated effect of many material attributes, are environmentally

Table 1. *Stock type material attribute characterization (mean + SE) of interior spruce seedlings (2+0 stock from the same seedlot) produced in three container Styroblock™ formats for the summer planting program (adapted from Grossnickle 2000).*

Attribute	415B†	415D†	615A†
Height	24.2 + 0.8 cm*	29.7 + 0.7 cm*	33.3 + 0.8 cm*
Diameter	4.4 + 0.1 mm*	5.0 + 0.1 mm	6.8 + 0.2 mm
Height to diameter ratio	5.6 + 0.2*	6.0 + 0.2*	5.0 + 0.2*
Shoot dry weight	2.8 + 0.1 g	4.5 + 0.2 g	6.4 + 0.3 g
Root dry weight	1.1 + 0.1 g	1.4 + 0.1 g	2.1 + 0.1 g
Shoot to root ratio	2.84 + 0.1	3.4 + 0.1	3.3 + 0.1
Number of branches	18 + 1	24 + 2	33 + 12
Number of buds	50 + 2	67 + 3	86 + 3
Number of needle primordia	193 + 35	164 + 36	147 + 38
Net photosynthesis (µmol m-2 s-1)	2.72 + 0.24	2.68 + 0.27	2.39 + 0.32
Drought tolerance Osmotic potential at turgor loss point (MPa)	-1.60 + 0.15	-1.64 + 0.09	-1.49 + 0.11
Drought Avoidance Cuticular transpiration (mg H2O $(g\ DW)^{-1}\ h^{-1}$)	435 + 72	364 + 42	415 + 60

† All stocktypes were grown in format 600 Styroblock® containers (Beaver Plastics Ltd.) in the following individual cavity volumes: 415B at 105 mL, 415D at 170 ml, and 615A at 340 mL.

* Meets or exceeds the accepted BC MoF target (Scagel et al. 1993).

sensitive seedling properties, and are measured under specific testing conditions (Ritchie 1984). Seedling root growth is the most commonly measured performance attribute used in operational programs throughout the world to define stock quality (Ritchie 1985, Sutton 1990, Simpson and Ritchie 1997). That is because root growth capacity (RGC) is a direct indicator of a seedlings ability to grow roots and is a general indicator that all systems in the seedling are functioning properly and thus provides a measure of seedling performance potential (Ritchie 1984, Burdett 1987). Shoot growth is also critical for recently planted spruce seedlings. New shoot growth allows the seedling to occupy the site and become dominant within the reforestation site vegetation complex. The shoot growth potential test defines the ability of seedlings to break bud and grow new shoots under defined environmental conditions (Folk and Grossnickle 2000, Grossnickle and Folk 2005). This assessment approach complements results of the RGC test and the combination of these tests provides a means of defining overall seedling growth performance.

Seedling size affected spruce seedlings ability to grow roots. Seedlings with greater initial root weight, in general, had greater root growth (Fig. 1A). Studies have shown that greater initial root mass is related to greater RGC in pine (Johnsen et al 1988, Williams et al. 1988) and spruce (Grossnickle and Major 1994) seedlings. Container-grown spruce seedlings have a high field survival potential when seedlings average at least ten new roots (>1.0 cm in length) per plant (Burdett et al. 1984, Simpson 1990). On the other hand, spruce seedlings with low RGC (<10 new roots) have the potential for poor field survival (Burdett et al. 1984, Simpson 1990). This is why the RGC threshold of at least 10 new roots is used as a batch culling guideline in British Columbia for container-grown seedlings (Simpson et. al. 1988). There is also a minimum accepted root weight (target root weight = 0.7 g) for container-grown spruce seedlings (Scagel et al. 1993). In general, as long as spruce seedlings root systems size exceeds this target root weight they have a sturdy root plug that can grow enough roots to ensure good seedling establishment within reforestation programs, though seedlings with greater root weight, in general, grow a greater number of roots.

Seedling size affected spruce seedlings ability to grow additional new shoot system. Seedlings with greater initial shoot size, in general, had greater total seedling new shoot growth (Fig. 1B). This occurs because larger spruce seedlings have a greater number of branches and buds (Table 1). Thus, when all of these buds break and the shoot system elongates larger seedlings put on proportionally greater amounts of shoot biomass. This allows larger seedlings to occupy a greater area within the planting spot and capture more of the site resources (i.e., incoming solar radiation).

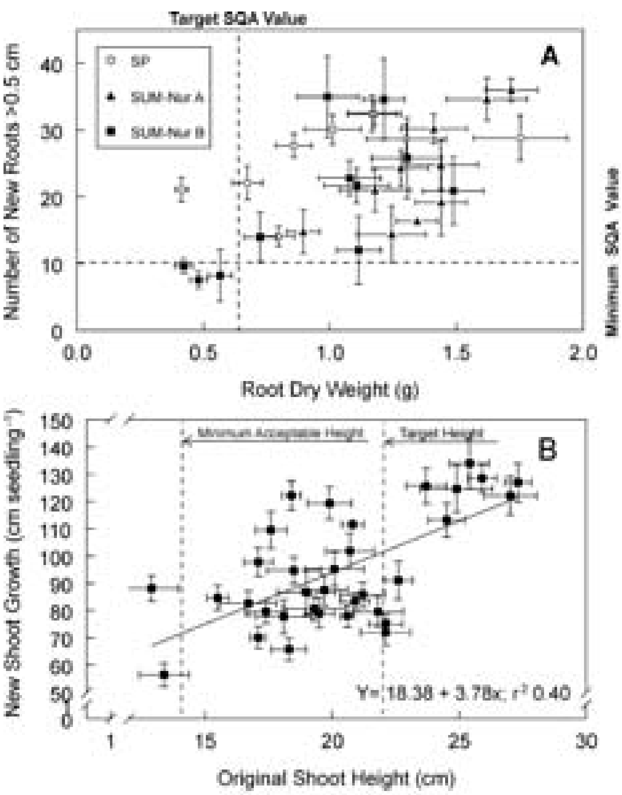

Figure 1. *Stock quality performance (mean ± SE) of interior spruce seedlings (1+0 stock from genetic sources within the same seedlot) produced in the 415B container Styroblock™ format (105 ml cavity volume) showing: A) root growth capacity in relation to the original root weight grown at three different nurseries for either spring (SP) or summer (SUM) planting programs, and B) shoot growth potential (i.e., a measure of total seedling shoot growth over a predetermined time, eight weeks, under optimum environmental conditions) in relation to the original shoot height for the spring planting program (Grossnickle, unpublished data). Dashed lines represent accepted BC MoF targets (Scagel et al. 1993).*

Field Performance Related to Initial Seedling Size

Trials have been conducted to determine whether there is a benefit to planting larger seedlings to ensure good plantation establishment on reforestation sites. These field trials have found that planting larger seedlings can be beneficial to seedling establishment and better growth up to 15 years after planting (Smith 1975, Chavasse 1977, Overton and Ching 1978, Balneaves 1989; Newton et al. 1993; South et al. 1993; South et al. 1995; Zwolinski et al. 1996, Mason 2001). This pattern was also evident in field trials with various spruce species; Sitka (South and Mason 1993), white (Mullin and Svaton 1972, Mullin and Christl 1981, McMinn 1982, Jobidon et al. 2003), interior (Dobbs 1976, Vyse 1982, Hines and Long 1986, Sutherland and Newsome 1988) and black (Jobidon et al. 1998, Jobidon et al. 2003).

So what is the major benefit of planting larger seedlings within many reforestation programs? Intuitively one would assume that seedlings with larger root and shoot systems have greater potential for rapid site occupation and access of site resources during the establishment phase. This section reviews published work on seedling size in relation to ecophysiological performance and seedling establishment.

Response to competition

Competition for light between planted seedlings and the site vegetation complex is one of the main limiting environmental factors that affect the performance of seedlings in the transitional phase of plantation development (Grossnickle 2000). Jobidon and co-workers (1997, 2003) found that shoot systems of larger stock had a greater exposure to the growing season available light, which resulted in greater shoot growth. The degree of this benefit of available light was directly related to the level of competition and silvicultural practices. So what is happening to these seedlings from an ecophysiological perspective? On sites with low levels of competition seedlings of all sizes received enough light to ensure a high level of photosynthetic capability (Fig. 2A). However, on sites with high levels of competition larger seedlings had access to greater levels of incoming light and thus greater photosynthetic capability (Fig. 2B). If seedlings on sites with high levels of competition were released from competitive vegetation, larger seedlings had much greater photosynthetic capability than smaller seedlings. In addition, the greater foliar mass of a larger seedling allows for greater seedling photosynthetic capacity. The combination of access to greater levels of incoming solar radiation and greater photosynthetic capacity could be critical in enhancing the ability of larger seedlings to grow quickly and occupy site resources during establishment. This is why large seedlings have been found to have a higher intrinsic growth potential than small seedlings on sites where competition is a silvicultural concern (Jobidon et al. 2003). The use of larger seedlings may be a good silvicultural strategy if vegetation competition is a major factor limiting plantation establishment (Thiffault 2004).

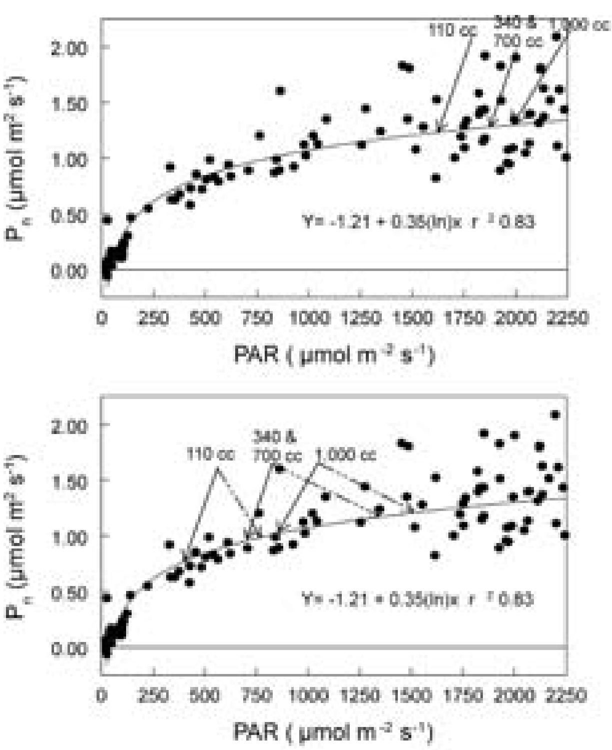

Figure 2. *Spruce seedlings hypothetical photosynthetic response pattern to a range of reforestation site light conditions. The photosynthetic pattern is for spruce seedlings measured on a field site under optimal soil water conditions (Grossnickle, unpublished data). The light levels are defined as the mean quantity of light reaching the mid-upper crown of four spruce seedling stock sizes (Stock height (cm) at planting: 110cc = 22.2 ± 3.3, 340cc = 35.7 ± 6.8, 700cc = 42.8 ± 9.3, 1,000cc = 47.3 ± 8.5) during the fifth growing season after being planted on reforestation sites (adapted from Jobidon et al. 2003). Figure A represents light levels in relation to their shoot system size on a reforestation site with a low level of competition. Figure B represents light levels in relation to their shoot system size on a reforestation site with a high level of competition with no vegetation release treatment (solid arrows) and two years after a vegetation release treatment (dashed arrows).*

Planting stress

Planting seedlings of larger size can also create risks in establishing a forest plantation. This may occur where limiting environmental conditions can put seedlings with a large shoot to root balance under physiological stress. The ability of a seedling to take up water is affected by its root system size and distribution, root-soil contact, and root hydraulic conductivity. The seedling shoot system, which is exposed to the atmospheric demand for water, has transpirational water loss from needles which is determined by the degree of stomatal opening and needle area. Typically, newly planted seedlings have restricted root placement, low root system permeability and/or poor root-soil contact, which can limit water uptake from the soil (Kozlowski and Davies 1975, Rietveld 1989, Burdett 1990). As a result, seedlings can be exposed to stress just after planting (i.e., planting stress) because they are not fully coupled into the hydrologic cycle whereby water flows from the soil to plant roots, through the plant and into the atmosphere. Stress occurs when a newly planted seedling's root system can not supply enough water to transpiring needles to maintain a proper water balance and ensure survival (Grossnickle 2005).

Under dry soil conditions, larger conifer seedlings are reported to have greater water stress (Rose et al. 1993; Stewart and Bernier 1995) or reduced growth (Baer et al. 1977; Hahn and Smith 1983) than smaller seedlings. Under dry conditions, black spruce seedlings with very large shoot systems (i.e., six times the foliar mass of small seedlings) had greater water stress and reduced photosynthesis compared to seedlings with smaller shoot systems (Lamhamedi et al. 1997). As the seedling shoot system reaches a certain size, the increased foliar mass can increase the seedling's susceptibility to water stress. This can be a problem in newly planted seedlings that have restricted root development. The susceptibility of larger seedlings to be exposed to water stress at planting is mitigated if seedlings have the capability to quickly develop new roots. Large container-grown Engelmann spruce seedlings had increased first-year survival compared to smaller seedlings (Hines and Long 1986) on sites that dry out as the growing season progresses. Hines and Long (1986) found that increased survival in larger seedlings was related to greater root growth over the initial four-week period after planting, which reduced seedling water stress. In most instances, spruce seedlings show a general trend of greater new root growth with a greater original root system size (Fig. 1B). This allows larger seedlings to generate enough roots, which supply enough water to transpiring needles, thereby maintaining a proper water balance and avoid planting stress conditions. However, increased root growth does not always occur in larger seedlings having bigger root systems, and this variability can be related to stock type, nursery cultural practices, and genetic source (Grossnickle 2000). In addition, restricted root development of newly planted seedlings can be limited by field site edaphic (i.e., low water and temperature) conditions (Grossnickle 2000). Caution should be used when considering whether to plant large stock on potentially dry sites that can limit initial root growth and subsequent seedling establishment.

Conclusions

What is the answer to the question "How big is big enough?" when it comes to seedling size and reforestation success? The answer is it depends. On sites where there is vegetative competition for light resources, larger seedlings that can put on proportionally greater amounts of shoot biomass can have a competitive advantage over smaller seedlings. On sites where limiting environmental conditions (i.e., drought, high evaporative demand or cold soils) can put seedlings with a large shoot to root balance under physiological stress and limit root development just after planting, seedlings with smaller shoot systems can have a competitive advantage over larger seedlings. Foresters need to recognize the strengths and weaknesses of all stocktypes. This is why stocktype selection in relation to site conditions should be part of an effective silvicultural strategy.

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