Seedling Quality of Southern Pines: Influence of Plant Attributes

Steven C. Grossnickle and David B. South

Consultant, NurseryToForest Solutions, North Saanich, BC; Emeritus Professor, School of Forestry and Wildlife Sciences, Auburn University, AL

Abstract

Good seedling quality is a part of successful reforestation programs. Nursery managers use various cultural practices (e.g. seedbed density and root pruning for bareroot seedlings; cell density and volume for container seedlings; fertilization, irrigation, and top-pruning for all stock types) to produce southern pine seedlings with desired morphological and physiological attributes. Opinions vary on which of these attributes should be assessed in a seedling quality program. Growers generally agree that seedling height, root-collar diameter, root mass, nutrient status, and shoot/root balance are important, measurable plant attributes. Root growth, drought resistance, and freezing tolerance are also suggested as desirable plant attributes. Appropriate ranges of these attributes increase the probability for successful establishment of southern pine seedlings.

Introduction

The proper application of nursery practices to produce quality seedlings is a key component of successful restoration programs (Grossnickle 2000, Mexal and South 1991). Studies established in the 1930s (Wakeley 1954) were the first to define desirable morphological parameters with the goal of improving southern pine plantation establishment. By the mid-20th century, researchers began to critically examine plant morphological and physiological attributes that conferred improved survival and growth (i.e. performance) for bareroot (Duryea 1984; Stone 1955; Wakeley 1948, 1954) and container (Tinus 1974) seedlings. Defining appropriate morphological and physiological attributes is important to ensure successful seedling field performance (Dumroese et al. 2016, Grossnickle 2012, Grossnickle and Folk 1993), which can result in successful plantation establishment (figure 1).

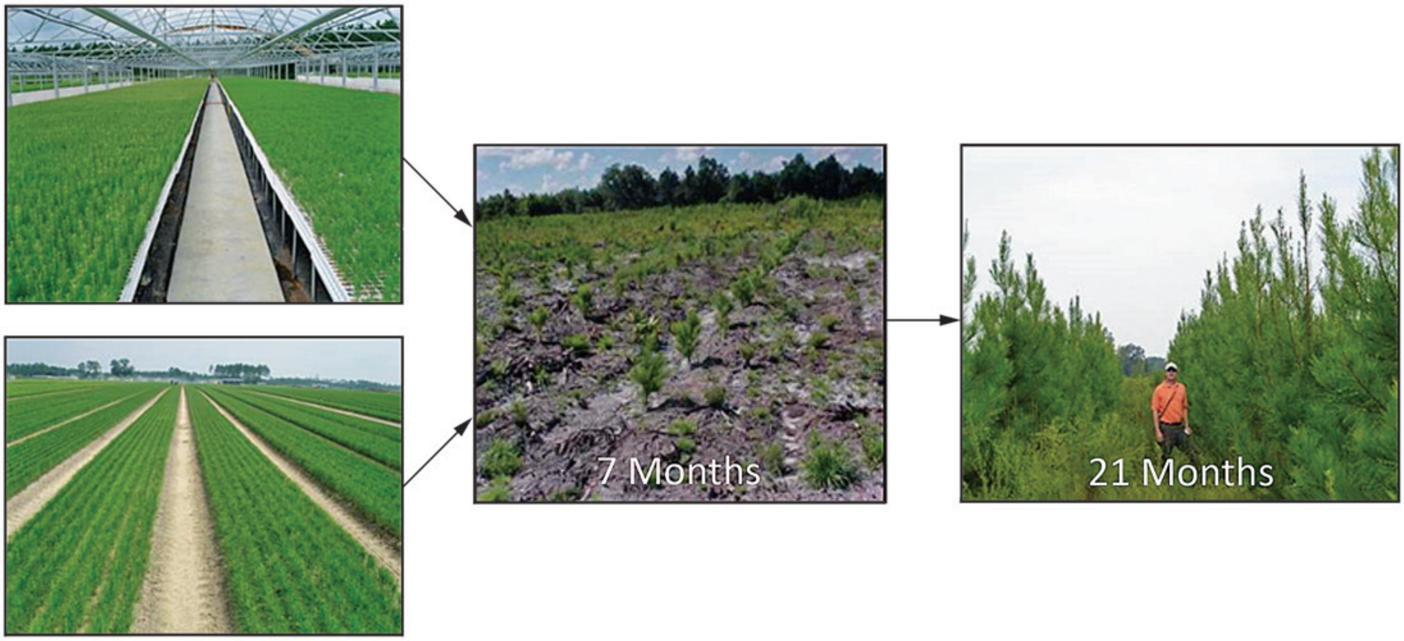

Figure 1. Container-grown and bareroot loblolly pine (*Pinus taeda* L.) stock grown with appropriate cultural practices and assessed to ensure they have desirable morphological and physiological attributes typically have good initial establishment and subsequent growth in forest plantations. (Adapted from Grossnickle 2011)

During 2014–2015, more than 1 billion seedlings were produced in the South, with approximately 80 percent being bareroot and 20 percent being container-grown seedlings (Hernández et al. 2016). In this article, seedling quality of both stock types is discussed based on material attributes of morphology, nutrition, drought resistance, and performance attributes of frost hardiness and root growth potential (attributes defined by Ritchie 1984). An understanding of how bareroot and container-grown southern pine seedlings respond to these attributes would enable practitioners to define their appropriate ranges to improve seedling field performance.

Morphological Attributes

Most morphological attributes are non-destructive, easy to measure, and considered to be reliable measures of seedling quality (Puttonen 1997) because they do not change appreciably from lifting to outplanting (Ritchie et al. 2010). Caution should be used in relying solely on morphological attributes because of interactions involving site factors, container size, handling, and environmental conditions. Morphological attributes measure only overall size and balance, not physiological quality, because they are only a subset of plant attributes required for defining successful seedling establishment of southern pines (Wakeley 1948, 1954). Southern pine seedlings must also have the optimum physiology and vigor for morphological attributes to forecast field performance (Mexal and Landis 1990; Pinto 2011; Wakeley 1948, 1954).

Height

Tall seedlings have been recommended for sites with little environmental stress but with the potential for excessive competition (Haase 2008). Large stock of southern pines will perform well on sites where competition is prevalent (South et al. 1993). This attribute is exhibited by taller bareroot loblolly pine (*Pinus taeda* L.) seedlings at planting, which have higher survival on sites with little environmental stress and extensive competition (figure 2). A height advantage is beneficial on sites with competing vegetation because they can capture more of the site environmental resources (Grossnickle 2005b), allowing them to outgrow competitors (South et al. 1985, 1989, 1993, 2001b, 2015).

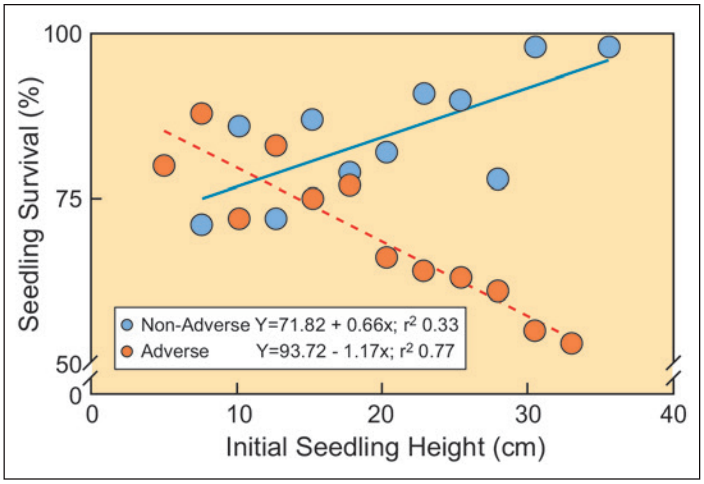

Figure 2. The relationship between survival (year 2) and initial seedling height for bareroot loblolly pine (*Pinus taeda* L.) seedlings differs greatly between adverse sites (i.e., greater temperature extremes and higher vapor pressure deficits) and non-adverse sites (i.e., little environmental stress and extensive competition). (Adapted from Tuttle et al. 1987)

Planting taller seedlings on stressful droughty sites can result in lower survival (Boyer and South 1987, Larsen et al. 1986, South et al. 2012, Tuttle et al. 1988). For example, shorter bareroot loblolly pine seedlings had higher survival on sites with limited soil water and greater environmental stress (i.e. greater temperature extremes and higher vapor pressure deficits) (figure 2). Tall seedlings are exposed to greater water stress than smaller seedlings under harsh conditions (Grossnickle 2005b) because root systems cannot supply enough water to transpiring foliage to maintain a proper water balance (Grossnickle 2005a). Thus, shorter seedlings can have an advantage on stressful sites (Grossnickle 2012, Mexal and Landis 1990, South et al. 2012).

Root-Collar Diameter and Root Mass

Seedling root-collar diameter (RCD) is a general measure of seedling sturdiness, root system size, and protection against drought and heat damage (Mexal and Landis 1990). RCD indirectly describes a number of desirable plant attributes (i.e., water absorption—roots, water transport—stem) considered important for ensuring seedling survival during drought (Mexal and Landis 1990). RCD is considered to be the single most useful morphological measure of seedling quality to forecast outplanting performance of southern pines (Johnson and Cline 1991, VanderSchaaf and South 2008). RCD is easily measured at the time of lifting and should be assessed in any southern pine seedling quality program.

RCD is important because it correlates well with root mass (Mexal and South 1991, Rodriguez-Trejo and Duryea 2003, South and Mitchell 1999, South et al. 2015). For example, RCD was related to root volume of both bareroot and container-grown loblolly pine stock types grown in operational nurseries (figure 3a). Studies show that, as root mass increases, seedling survival can increase (Boyer and South 1987, Larsen et al. 1986, South and Mitchell 1999). Greater root system size means a seedling has a greater root absorptive surface for water uptake, providing southern pines seedlings (Carlson and Miller 1990) with the capacity to overcome planting stress (Grossnickle 2005a).

Southern pine seedlings with large RCD have higher survival, e.g. bareroot (Kabrick et al. 2011; Lauer 1987; McGrath and Duryea 1994; South 1993; South and Mexal 1984; South and Mitchell 1999; South et al. 1985, 2001a, 2005b, 2015) and container-grown (Barnett 1988, Haywood et al. 2012, South et al. 2005a) (figure 3b). One should also consider root fibrosity (i.e., fibrous root system with many growing tips) to ensure the reliability of RCD to forecast survival (Hatchell and Muse 1990). Greater root system size also confers greater root growth potential (RGP) in southern pines (South and Mitchell 1999; South et al. 2005b, Sword Sayer 2009). A positive relationship between initial RCD and field growth has been reported for southern pines (McGrath and Duryea 1994, South and Mitchell 1999, South et al. 1989, 2015) (figure 3c and figure 4).

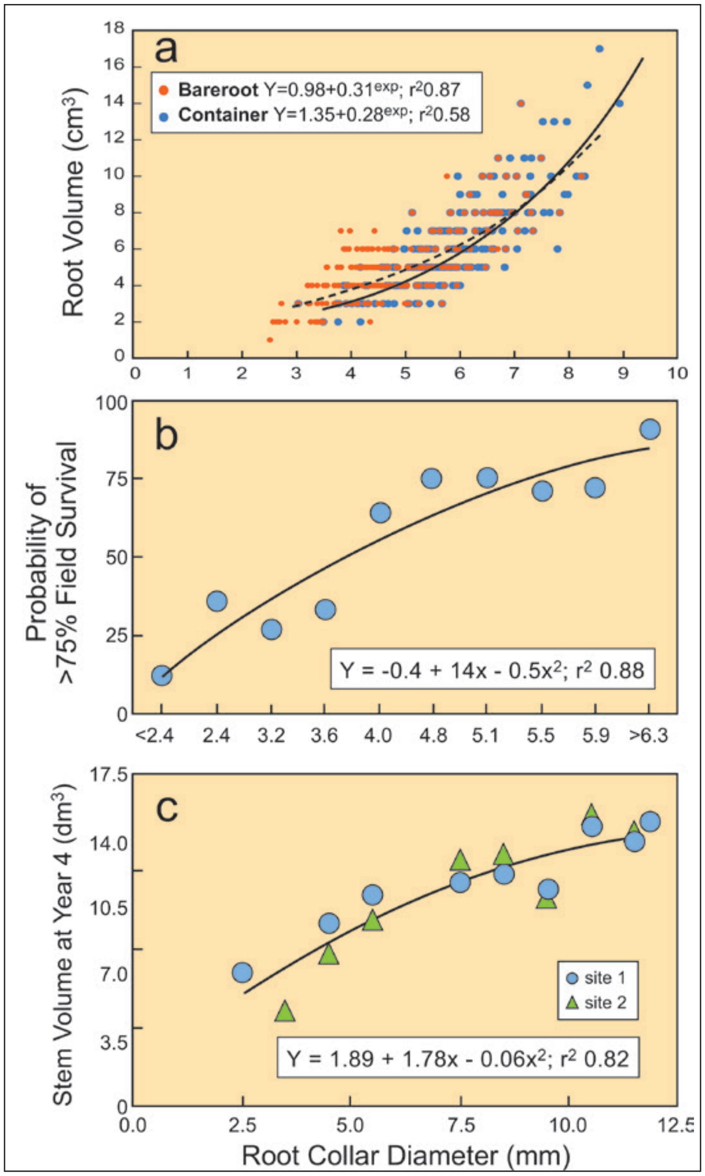

Figure 3. Root-collar diameter affects southern pine field performance including (a) root volume at lift for loblolly pine (*Pinus taeda* L.) in bareroot (----) and container (- - -) nurseries (Grossnickle unpublished); (b) the probability of seedling field survival (>75 percent) for bareroot loblolly pine and slash pine (*Pinus elliottii* Engelm.) seedlings graded into stem-diameter classes (adapted from South et al. 1985); and (c) bareroot loblolly pine stem volume after 4 years on two intensively managed field sites. (Adapted from South et al. 2001a)

Seedling Ratios

A balance between the shoot and root system is considered a desirable attribute for seedling survival (Grossnickle 2012, Grossnickle and Folk 1993, Mexal and South 1991, Puttonen 1997, Ritchie 1984). Views on this attribute's influence on seedling growth are mixed, since some believe that this ratio is not related to field growth (Thompson 1985), whereas others (Close et al. 2005) believe that low shoot-to-root ratio, along with high RGP, are important for maximizing seedling growth. Nonetheless, proper proportionality between shoot and root systems has long been recognized as a desirable plant attribute (Toumey 1916) because water status is directly tied to the shoot-to-root ratio of bareroot (Baldwin and Barney 1976) and container-grown (Grossnickle and Reid 1984) seedlings. Another definition of seedling balance that defines field performance is the root-weight ratio (root dry weight divided by total seedling dry weight) (South 2016). Studies have found that southern pine seedling survival increases as the shoot-to-root ratio decreases (Mexal and Dougherty 1983) or root-weight ratio increases (Larsen et al. 1986, Boyer and South 1987, South and Mitchell 1999). Having a desirable root-weight ratio is one reason managers apply undercutting for bareroot pine seedlings

Figure 4. Slash pine (*Pinus elliottii* Englm.) seedlings were sorted into nine groups (50 seedlings each) by root-collar diameter (RCD). From left to right, the seedling RCD groups are: 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, 8.5, 9.5, and 10.5 mm. Three years after planting, groups to the right of the vertical stick (7.5 to 10.5 mm RCD) had greater survival and grew taller than those to the left of the stick (2.5 to 6.5 mm RCD). (Photo by David South, 1991)

(South and Donald 2002) and top pruning for all stock types (South 1998, South et al. 2011).

Morphological Ideotypes

Morphological standards for southern pine bareroot and container seedling ideotypes have been proposed (table 1). Bareroot ideotype A has all of the morphological attributes that, on average, confer higher survival and growth (Mexal and South 1991). Bareroot ideotype B is preferred by hand planters since seedlings with small roots are relatively easy to transplant, even though subsequent field performance is less than ideotype A. The proposed ideotypes for container-grown seedlings of varying cell volumes are not based on performance trials, but instead were developed from measuring typical seedlings. Stock type standards for shoot development and height-to-diameter ratios are similar for both bareroot and container-grown seedlings. For a given diameter, root volume is typically greater for container-grown stock compared with bareroot stock (South et al. 2016). Greater root mass and fibrosity help explain why survival is usually greater for container-grown seedlings of similar shoot size (Grossnickle and El-Kassaby 2016). The ideotypes listed in table 1 and their associated field performance can be verified with well-designed field tests. Field performance, however, is also dictated by seedling physiology, handling practices, and site environmental conditions.

Physiological Attributes

Field performance is determined, in part, by the ability of seedlings to withstand potentially stressful environmental conditions affecting the establishment

Table 1. Morphological attributes and expected field performance of two bareroot southern pine seedling ideotypes (adapted from Mexal and South 1991) and three container-grown seedling ideotypes (Wayne Bell personal communication and Grossnickle unpublished).

Morphological attributes	Bareroot		Container size (Cell volume)		
	Ideotype A	Ideotype B	94 cm^3	122 cm^3	152 cm^3
Species	*P. taeda* *P. elliottii* *P. echinata*	*P. taeda* *P. elliottii* *P. echinata*	*P. taeda* *P. elliottii*	*P. taeda* *P. elliottii*	*P. palustris*
Median height (mm) or needle length (bold, mm)	150–250	150–300	175–300	200–350	**200–250**
Median root-collar diameter (mm)	> 5.0	> 4.0	3.0–5.5	3.5–6.5	5.0–6.5
Median root volume (cm^3)	> 4.0	> 2.0	2.9–5.7	3.4–7.3	4.9–7.3
Height-diameter ratio	< 50	> 50	50–60	50–60	< 8
Expected field 2-year survival (%)	> 90	> 80	> 90	>90	> 80
Expected 4-year field height (m)	> 3	< 3	> 3	> 3	> 1

m = meter. cm = centimeter. mm = millimeter. P. = *Pinus.*

Note: Container cell densities for pines typically range from 525 to 570 $m^{-2.}$

of forest stands, such as site fertility, water balance, and heat exchange processes (Grossnickle 2000). The following discussion focuses on seedling physiological attributes related to nutrient status, drought resistance, and freezing tolerance of southern pines.

Nutrient Status

Nutrition is considered an important attribute in recent seedling quality discussions (Hawkins 2011, Ritchie et al. 2010); therefore, foliar nutrition standards (Boyer and South 1985) are important for determining southern pine seedling quality. Accumulating seedling nutrient reserves is a significant component of conifer nursery culture (Benzian et al. 1974, Brix and van den Driessche 1974). Some of these nutrient reserves can then be remobilized to improve seedling establishment after planting (Irwin et al. 1998). Increasing nutrient reserves through nursery fertilization is considered efficient, compared with nutrient acquisition on the planting site (Binkley 1986, Tinus 1974). The practice of late-season nitrogen fertilization has been successfully applied in southern nurseries (Irwin 1995; South et al. 2016). According to Dumroese (2003), an ideal fertilization program will achieve a target foliar nitrogen-concentration range of 1.5 to 2.5 percent for adequate nutrient reserves.

Field trials with southern pines found that increased nutrient reserves prior to planting resulted in higher survival rates (Hinesley and Maki 1980, Irwin et al. 1998, South and Donald 2002). van den Driessche (1991) cautioned, however, that increased nutrient reserves do not increase survival under all field situations. For example, when field conditions are such that the survival rate of non-fertilized seedlings is high, one should not expect extra nitrogen to increase survival (Switzer and Nelson 1967). In addition, fertilization might stimulate the growth of *Pythium* in cool storage. These factors could explain why high nitrogen levels reduced the survival rate of bareroot seedlings of various southern pine species that were stored for 6 weeks prior to planting (Rodriguez-Trejo and Duryea 2003, South and Donald 2002).

Seedlings outplanted with increased nutrient reserves typically have greater shoot and root growth (Grossnickle 2012). Longleaf pine (*Pinus palustris* Mill.) with additional nitrogen reserves exhibited increased diameter (Jackson et al. 2007) and shoot (Jackson et al. 2012) growth in the field. Nursery fertilization with additional nitrogen can also increase shoot growth of loblolly pine seedlings after planting (Switzer and Nelson 1967, VanderSchaaf and McNabb 2004). For example, loblolly pine seedlings with a higher nitrogen content at planting were taller after 3 years in the field than those with a lower nitrogen content at planting (figure 5a). Some have postulated that nitrogen content is more useful than nitrogen concentration in forecasting seedling field performance, as it is a measure of both initial seedling size and nutrient status (Cuesta et al. 2010).

The lack of a consistent positive response to additional nutrient reserves has been attributed to sufficient internal seedling nutrient status prior to nutrient enrichment (Hawkins 2011), nutrient availability on the planting site (Andivia et al. 2011), or other site factors limiting growth (e.g., water stress) (Wang et al. 2015). For example, growth of loblolly pine on a sandy site was not improved with fall fertilization in the nursery (South and Donald 2002). Thus, a beneficial response to increased nutrient reserves may not occur for southern pines under all field conditions.

Drought Resistance

Nursery cultural practices that develop drought resistance in southern pines can mitigate planting stress and maintain a desirable seedling-water balance, thereby improving survival and growth after outplanting. Drought resistance is considered important for the establishment of southern pine seedlings (Wakeley 1954). Drought-hardening cultural practices, in some cases, have beneficial effects on seedling field survival (Grossnickle 2012), especially under harsh site conditions (Villar-Salvador et al. 2004).

Drought resistance takes many forms (e.g. drought tolerance as osmotic adjustment and drought avoidance as cuticular development). The application of water stress results in “physiological adjustments in plants” (Kozlowski and Pallardy 2002). Loblolly pine seedlings develop drought resistant in response to drought (Bongarten and Teskey 1986) and during hardening nursery cultural practices where watering is restricted (Hennessey and Dougherty 1984, Seiler and Johnson 1985) (figure 5b). Nursery managers use reduced irrigation to slow shoot growth and develop drought resistance in years with a dry fall

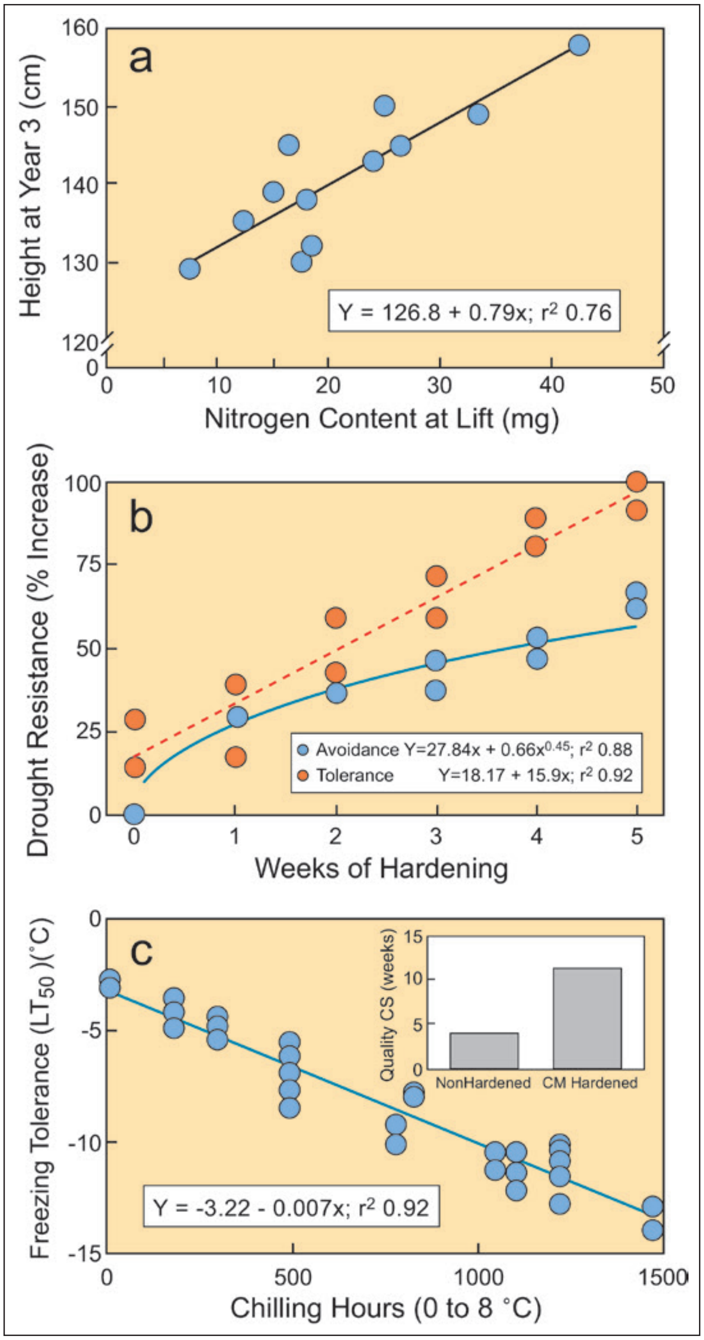

Figure 5. The performance of loblolly pine (*Pinus taeda* L.) is affected by various seedling quality attributes. (a) Third-year field height was influenced by nitrogen content at lift (adapted from Larsen et al. 1988). (b) The shift in drought resistance as measured by drought avoidance (cuticular transpiration that declined from 3.8 to 2.3 percent water loss h-1 after stomatal closure) and drought tolerance (osmotic potential at turgor loss point that declined from -1.0 to -2.0 MPa) during nursery hardening (i.e. reduced fertilization and watering) (Grossnickle unpublished). (c) As photoperiod decreases, seedling freezing tolerance (FT; temperature causing 50 percent electrolyte leakage from needles) responds to chilling hours (0 to 8 °C) and (c-insert) weeks of quality cooler storage (CS at 2–4 °C) for nonhardened miniplug clones or those seedlings exposed to 750 chilling hours (CH-hardened) in the fall. (Adapted from Grossnickle and South 2014)

(Duryea 1984, Lantz 1985, Mexal and South 1991). Southern pine seedlings are typically grown outdoors, which improves various drought avoidance attributes (e.g. cuticular development, secondary needles, increased RCD, reduced height-diameter ratio) (Barnett 1988, Boyer and South 1984, Mexal et al. 1979).

Drought resistance of southern pine seedlings is also achieved by manipulating the shoot and root systems. Root culturing practices (e.g., ripping soil to increase soil porosity, properly timed root pruning) are sometimes applied to increase root system fibrosity of bareroot seedlings (Duryea 1984, Lantz 1985, Mexal and South 1991). Root wrenching also creates stress and hardens bareroot seedlings during latter stages of seedling development (Duryea 1984, Kainer and Duryea 1990). Finally, careful mechanical lifting of bareroot seedlings minimizes root damage and maintains a fibrous root system, thereby resulting in higher root growth (Starkey and Enebak 2013). These desirable attributes are important because they can increase survival of loblolly pine (South and Donald 2002) and longleaf pine (Hatchell and Muse 1990). In contrast, container-grown seedlings are typically extracted from hard-walled containers in a manner resulting in minimal root damage, which aids in improving their field performance compared with bareroot seedlings (Grossnickle and El-Kassaby 2016, South et al. 2005b). Shoot pruning of seedlings is a standard practice used to develop drought avoidance by reducing the amount of transpiring foliage and improving the shoot-to-root balance (South 1998, South et al. 2011, 2016). Shoot pruning controls the height growth of southern pine seedling stock types and increases the probability of higher survival after outplanting (South and Blake 1994, South 1998, South et al. 2011).

Freezing Tolerance

Temperate-zone tree species undergo many changes during the annual phenological cycle in response to seasonal environmental conditions; freezing tolerance is at its highest level in the winter (Burr 1990). Freeze tolerance in loblolly pine has been related to the cessation of shoot growth and seasonal shifts in temperature (Grossnickle and South 2014, Mexal et al. 1979, South 2007) and top pruning (South 1998). Nitrogen status in longleaf pine has been positively related to freezing tolerance (Davis et al. 2011).

North of the southern pine range, many programs measure freezing tolerance to determine the level of stress resistance, and thus how long conifer seedlings can be stored frozen for extended periods (i.e., up to 4-6 months) while maintaining seedling quality (Colombo et al. 2001). Freezing tolerance is considered important when northern conifers are fall-lifted and stored before planting (Glerum 1985, Ritchie 1984). Since southern pine seedlings are not freezer-stored (Grossnickle and South 2014), nurseries in the South do not test for freeze tolerance prior to lifting seedlings.

Measurable seedling attributes for determining when seedlings may be stored for 4 weeks in a cooler (2 to 3°C) are not readily apparent for southern pines. For example, the development of a well-formed bud is required for storage of northern latitude conifers (Colombo et al. 2001), whereas southern pines can undergo long-term storage without the presence of a “winter” bud (with bud scales) (South 2013). Since the planting season of southern pines typically runs from late November through early March, and seedlings are lifted throughout the fall and winter, the lifting for cooler storage is typically dictated by calendar date (Dumroese and Barnett 2004) or operational planting schedules. The timing of when to extract container-grown seedlings is also determined by plug integrity. Typically, short-term storage of bareroot stock is practiced prior to December 21; thereafter, seedlings may be stored for up to 4 weeks (Grossnickle and South 2014). In contrast, container seedlings can tolerate 4 weeks of cooler storage more than bareroot seedlings (Grossnickle and South 2014). Research shows that loblolly pine seedlings develop freezing tolerance as chilling hours accumulate and photoperiod decreases. This capability to develop freezing tolerance (figure 5c) was used as an operational practice for extended cool storage of southern pine miniplug clones at a Canadian nursery (Grossnickle unpublished).

Root Growth Potential

The view that root growth is important for seedling survival and successful field establishment is why RGP is used to evaluate seedling quality (Simpson and Ritchie 1997). RGP is determined through a testing procedure that records the number of new roots after a defined period of time. Numerous reviews have discussed the merits of measuring RGP within a seedling quality assessment program (Burdett 1987, Ritchie and Dunlap 1980, Ritchie and Tanaka 1990). RGP is considered an indicator of a seedling’s ability to grow roots, which generally suggests that all physiological systems are functioning properly (Burdett 1987, Ritchie 1984). These indications are why root growth in newly planted seedlings has long been recognized for its importance to ensuring successful field performance (Stone 1955, Tinus 1974, Toumey 1916, Wakeley 1954). Southern pine seedlings with greater RGP exhibit greater survival (Larsen et al. 1986, South and Loewenstein 1994, Feret and Kreh 1985) (figure 6) and early growth (Feret and Kreh 1985, South and Mitchell 1999, Williams and South 1995).

A number of reviews found RGP forecasted seedling survival 70 to 80 percent of the time (Ritchie and Dunlap 1980, Ritchie and Tanaka 1990, Joustra et al. 2000). The lack of a consistent relationship between RGP (measured before seedlings were lifted) and field performance of southern pines led to questions about the usefulness of this test to determine when to lift seedlings (South and Hallgren 1997). Simpson and Ritchie (1997) maintained that RGP was strongly related to field performance when seedlings have an inherently low level of stress resistance and/or when site environmental conditions become more severe. Root egress into the surrounding soil (i.e. good RGP) establishes

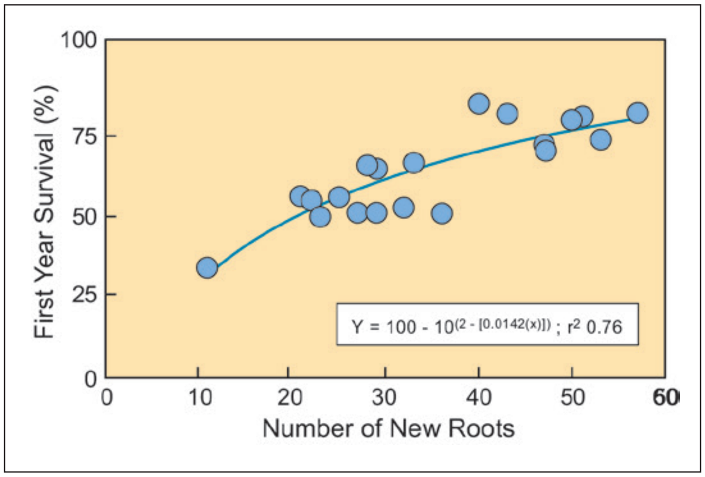

Figure 6. Relationship between root growth potential (number of new roots >0.5 cm) and seedling survival 11 months after planting for bareroot loblolly pine (*Pinus taeda* L.) seedlings. (Larsen et al. 1988)

a favorable morphological balance for water and nutrient uptake, which reduces planting stress (Grossnickle 2005a). If seedlings are not exposed to planting stress, then initial root growth is not essential for good field performance (Simpson and Ritchie 1997). This view is illustrated by Stone et al. (2003), where critical RGP (i.e., minimum root growth required for seedling survival on a given planting site) was twice as high for harsh sites compared with low-stress sites. Thus, site conditions dictate the amount of root growth required to overcome planting stress and ensure good seedling performance. Site conditions must be taken into account when using RGP to forecast seedling survival.

Conclusion

Nursery cultural practices used to produce southern pine seedlings affect seedling morphological and physiological attributes and—along with handling, weather, and field site conditions—affect their field performance. An adequate understanding of the previously discussed material and performance attributes helps managers produce good quality seedlings. When nursery cultural practices that improve seedling quality are applied, chances are good that these practices can optimize seedling field performance after outplanting.

Address correspondence to—

Steven C. Grossnickle, NurseryToForest Solutions, 1325 Readings Drive, Sidney, BC, V8L 5K7, Canada

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