Understanding Forest Seedling Quality: Measurements and Interpretation

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Abstract

Assessment of forest seedling quality has many components beyond the usual height and stem-diameter specifications found in growing contracts. Various measurements can aid in making decisions about culturing, lifting, storing, and planting. Several common morphological and physiological measurements of forest seedlings and their interpretation are described.

Introduction

The demand for bigger, better, faster-growing seedlings has been ever-growing. As a result, forest seedling production is a continually evolving technology in reforestation. Evaluating seedling quality is crucial for understanding seedling development in the nursery, as well as subsequent field growth and survival. Stock quality, however, often is assessed inconsistently and on only a limited basis. Some nurseries and reforestation managers assess their stock thoroughly each year, while others do few assessments unless a problem arises.

Although seedlings are relatively pampered in the nursery, they can have a rather perilous journey from their safe growing environment to their outplanting destination. During lifting, grading, storing, handling, and planting, opportunities for seedlings to be subject to moisture stress, temperature stress, or physical stress are numerous. These stresses are cumulative and can lead to poor field performance. When this occurs, there can sometimes be a dispute between the nursery and the landowner over what caused the poor growth, survival, or both after outplanting. Seedling quality data can assist in determining whether seedling performance issues are due to something that occurred in the nursery, improper planting practices, or environmental conditions after outplant.

Seedling quality evaluation can be used to establish benchmarks at specific points, such as time of lift or delivery, so that the nursery and the customer have a quantitative appraisal of a particular seedling lot. In addition, seedling quality data can help seedling growers and users to better understand seasonal patterns among species, stocktypes, seed lots, and cultural treatments.

Seedling Quality Assessment

There are two categories of seedling quality assessment: morphological and physiological (Mattson 1997). Morphological quality is based on the physical attributes of the seedling (table 1), whereas physiological quality is based on the seedling's internal functions (table 2). Of course, the two categories are not mutually exclusive. A seedling's morphological characteristics can be considered a physical manifestation of its physiological activities.

Morphological Quality. Morphology is used far more often than physiology to evaluate seedling quality. Height and stem diameter are the two characteristics most commonly examined on forest seedling stock (figure 1). The growing contract usually specifies a target for these two parameters, along with acceptable minimum and maximum ranges. Oddly, height is usually designated in English inches (in) but stem diameter (also known as caliper or

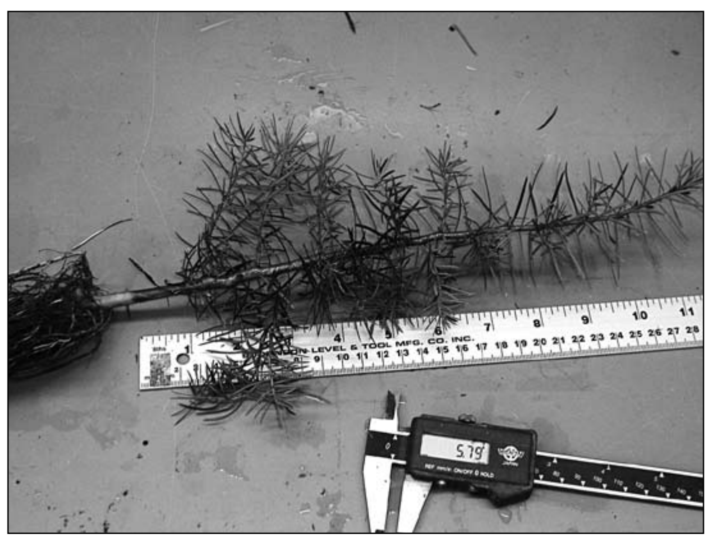

Figure 1. Measurement of height and stem diameter are the most common morphological assessments of seedling quality.

Table 1. Morphological characteristics of seedling quality

Seedling attribute	Measurement method	Units	Interpretation
Height	Measured with a yardstick or meter stick from the cotyledon scar to the base or tip of the terminal bud (or end of growing tip if no bud formed)	Centimeters (cm) or inches (in)	Shoot height is correlated to the number of needles on the seedling and therefore provides an estimate of photosynthetic capacity and transpirational area. Taller seedlings may have an advantage against severe weed competition and may indicate superior genetics. However, the greater transpirational area of taller seedlings may result in moisture stress on drier sites, especially before root establishment. Very tall seedlings may be difficult to plant, out of balance, and subject to wind damage.
Stem diameter (caliper)	Measured with a calipers just below the cotyledon scar; it's important to ensure that the calipers are perpendicular to the stem during measurement	Millimeters (mm)	In general, the bigger the better. Stem diameter has been considered the best predictor of field survival and growth. A larger diameter also indicates a larger root system and a larger stem volume.
Height: diameter	Calculation of height ÷ diameter (must use same units for each, e.g., mm/mm)	Unitless ratio	Height:diameter is a sturdiness ratio. A high ratio indicates a relatively spindly seedling while a lower ratio indicates a stouter seedling. Seedlings with high ratios can be susceptible to damage from handling, wind, drought, and frost.
Bud length	Measured with a ruler or a calipers from the base of the bud to the tip of the bud	Millimeters (mm)	Bud length is correlated with the number of needle primordia in many species and therefore gives an indication of seedling vigor and shoot growth potential.
Shoot mass	Measured as volume via water displacement (Harrington and others 1994) to include all shoot mass above the cotyledon scar or as dry weight following oven drying at 68 °C for 48 h	Volume in cubic centimeters (cm^3), or dry weight in grams (g)	Seedlings with a larger shoot mass have a greater photosynthetic capacity and potential for growth. However, a greater transpirational area may lead to moisture stress on dry sites prior to root establishment. Shoot mass must be in balance with root mass for optimum seedling quality.
Root mass	Measured as volume via water displacement to include all root mass below the cotyledon scar or as dry weight following oven drying at 68 °C for 48 h	Volume in cubic centimeters (cm^3), or dry weight in grams (g)	Seedlings with larger root mass tend to grow more and survive better than those with smaller root mass. Root mass, however, does not always reflect root fibrosity since a seedling with many fine roots can have the same mass as a seedling with a large tap root.
Shoot:root	Calculation of shoot ÷ root (must use same units for each, e.g. cm^3/cm^3)	Unitless ratio	Shoot:root measures the balance between the transpirational area (shoot) and the water absorbing area (root) of the seedlings. Generally, quality bareroot seedlings have shoot:root of 3:1 or less and quality container seedlings have shoot:root of 2:1 or less.
Color	Visual observation, or comparison with color charts	None, or color chart value	Foliar color can vary by species and time of season. Yellow, brown, or pale-green foliage can indicate lower vigor and/or chlorophyll content than dark green foliage.
Form	Visual observation	None	Existence of multiple or forked shoots, stem sweep, root deformity, stiff lateral roots, and physical damage are undesirable and can negatively affect seedling field performance.

Table 2. Physiological characteristics of seedling quality

Seedling attribute	Measurement method	Units	Interpretation
Cold hardiness	Whole plant freeze testing (WPFT) is used to evaluate tissue damage 6 d after freezing to specific temperatures. Another method, freeze-induced electrolyte leakage (FIEL), is based on the ratio of electrolytes leaked from frozen tissue to total electrolytes of killed tissue.	LT_{50}—lethal temperature for 50% of the sample; less common is the LT_{10}	Cold hardiness develops in an annual pattern similar to dormancy, with roots being much less hardy than shoots. Cold hardiness is related to stress resistance and is influenced by seed source, nursery practices, and environment.
Root growth potential (RGP)	Seedlings are potted in soil or peat media, or placed in a hydroponic tank. After 21 d in an environment optimal for root growth, the quantity and length of new roots are evaluated.	Typically divided into classes: 0=no new roots; 1=some roots, all less than 1 cm long; 2=1–3 new roots over 1 cm long; 3=4–0 new roots over 1 cm long; 4=11–30 new roots over 1 cm long; 5=more than 30 new roots over 1 cm long	RGP is influenced by stocktype, species, seedlot, and physiology and is related to field performance when trees are dead or when water uptake is dependent on new growth. However, RGP may not necessarily be expressed when under field conditions since outplanting usually occurs when soil temperatures are below optimal for root growth.
Bud dormancy	Three methods: 1) Seedlings are placed under favorable growth conditions and the number of days to budbreak (DBB) are recorded. 2) Mitotic index (MI) is assessed by placing buds in a fixative, then squashing and staining on a microscope slide. Using a microscope, the percentage of actively dividing cells is determined. 3) The bud is dissected and the number of primordia are estimated by multiplying the number of rows and columns.	Number of days (DBB); percentage of dividing cells (MI); number of primordia	Bud activity is an indicator or dormancy and stress resistance. The days to budbreak is dependent on the number of chilling hours (≤5 °C) a seedling is exposed to after budset. Mitotic index (MI) is another measure of bud dormancy and unlike days to budbreak, it does not require a long period of time to assess. MI is defined as the percentage of cells in mitosis at a given time. Owens and Molder (1973) termed Douglas-fir buds to be dormant when mitotic activity in the bud cells is zero, a condition which generally occurs from December through February.
Plant moisture stress (PMS)	A pressure chamber is the most common method for determining plant moisture stress (Cleary and Zaerr 1980).	Bars; 10 bars of PMS is equivalent to -1.0 MPa of xylem water potential	PMS indicates seedling water potential and reflects interactions among water supply, water demand, and plant regulation. PMS can be affected by time of day, species, plant age, level of dormancy and stress resistance, and environment. PMS increases with increasing moisture stress. Moderate stress can cause stomatal closure, decreased photosynthesis, and growth reductions. Severe stress can permanently damage the photosynthetic system and lead to decreased growth and survival.
Nutrients	A variety of laboratory techniques are used to determine tissue macronutrient and micronutrient concentrations. To determine content, the concentration is multiplied by the biomass of the sample.	Commonly expressed as a concentration in percent (%) or parts per million (ppm); also expressed as content in grams (g) or milligrams (mg)	Nutrient balance is important for optimal physiological processes and outplanting performance.
Chlorophyll fluorescence	The seedling's photosystem can be evaluated with pulses of saturating light by using a fluorometer.	F_{var}/F_{max} (dark-adapted foliar tissue), or quantum yield (not dark-adapted)	Fluorescence is a noninvasive, nondestructive method to evaluate plant physiology. It can provide information about the photosynthetic activity of the plant and its responses to disturbances.

root collar diameter) is referred to metrically in millimeters (mm). The contract specifications for height and stem diameter are then used to grade seedlings as packable or cull. Workers on the grading line should be trained to also cull seedlings with physical deformities, mechanical damage, and signs of disease (e.g., dead tops or blackened roots).

Height and stem diameter are easy and quick to measure and can be a good estimate of seedling quality and subsequent field performance (Omi and others 1986; South and others 1988; Mexal and Landis 1990; Rose and Ketchum 2003). These two shoot measures alone, however, are inadequate to assess the seedling condition fully. Although stem diameter is well correlated with root system size, root development usually is not directly assessed other than by a cursory observation on the grading line. Unfortunately, measures of root quality are not as quick and simple as those for shoot quality and require a subsample evaluation separate from the grading line in order to assess root size and form accurately (table 1, figure 2). The root system should not be overlooked, however, since it can profoundly affect seedling growth and survival after outplanting (Rose and others 1997; Jacobs and others 2005). Another morphological aspect that should not be overlooked is seedling balance. Even if height and stem diameter are on target, the seedling could be very unbalanced. It is important that the shoot not be too tall relative to the stem diameter (figure 3) and that the shoot mass not be too large relative to the roots (figure 4).

Physiological Assessment. Simple height and diameter assessments are also ineffective in estimating seedling physiology (table 2), especially when there has been a stress that can seriously compromise seedling quality. The most common inquiries I receive regarding conifer seedling quality are after an early fall freeze (such as the severe Halloween freezes in 2002 and 2003, which significantly damaged many Pacific Northwest crops). Because seedling shoots are not actively growing in the fall, freeze damage can be difficult to discern; as long as conditions are cool, seedlings can remain green for quite some time despite significant damage. As a result, dead or damaged seedlings can make it through the grading line and be shipped for outplanting. A simple option to evaluate damage following a freeze is to collect a representative sample of 15–20 seedlings from each lot in question and pot them. Keep the potting medium moist and place the pots in a warm environment. After 6–7 days, using a razor blade, examine the cambium

Figure 2. Seedling root and shoot volume can be measured via the water displacement method; these data can be valuable for determining root development and overall seedling balance.

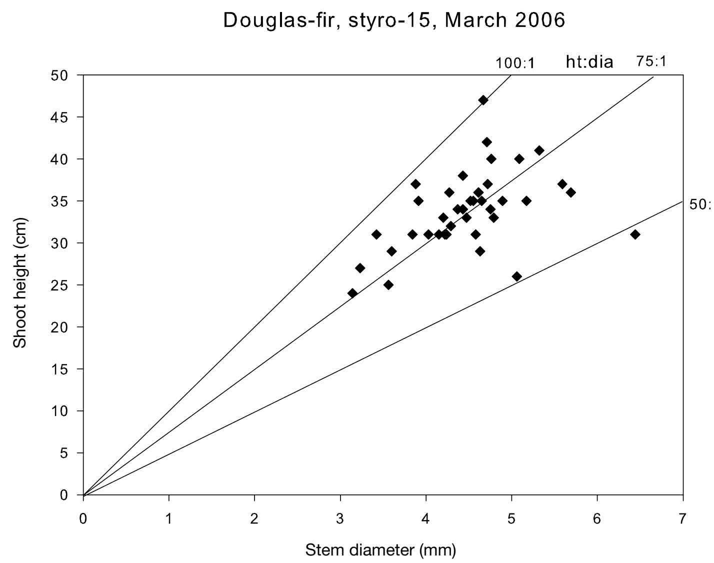

Figure 3. The ratio of height to stem diameter provides information about the seedling's sturdiness.

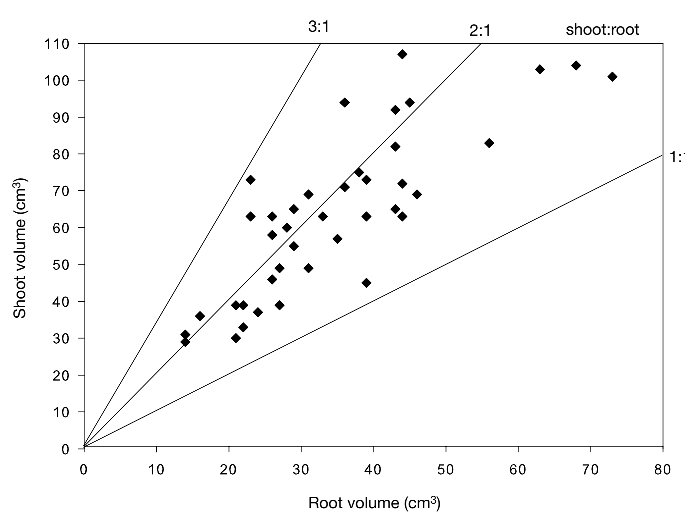

Figure 4. The balance between the seedling shoot and root is often critical to subsequent outplanting performance.

and buds. Any browning in either tissue indicates freezing damage. From there, the nursery manager or customer can decide whether or not to keep the crop. If damage is minimal and the crop is kept, lifting could be delayed to allow recovery, seedlings could be outplanted to a site with low stress conditions, or both.

Cold hardiness is likely the most useful physiological quality test available. Cold hardiness testing can provide a good estimate of stress resistance for a given seed lot (Faulconer 1988, Burr 1990). To test for hardiness, groups of seedlings are placed in a programmable freezer. The temperature in the freezer is decreased gradually from room temperature to a target subfreezing temperature and held for 2 h. Four target temperatures are selected on the basis of their expected ability to create a given range of damage. Similar to the procedure described for assessing damage after a fall freeze, seedlings are then placed in a greenhouse with adequate moisture and warm temperatures for 6 d, after which damage to foliage, cambium, and buds is evaluated (figure 5). If the cambium is dead in the mid- to lower section of the main stem or if more than 50 percent of the buds are damaged, the seedling is considered nonviable (Tanaka and others 1997). From these data, the lethal temperature to 50 percent of the seedlings is estimated (figure 6).

Root growth potential (RGP) is another popular physiological test to evaluate seedling vigor (figure 7). It is useful for determining the percentage of live or dead seedlings in a particular lot, but there is some debate regarding its usefulness in predicting subsequent field performance (Simpson and Ritchie 1997). RGP is determined after 3 wk under ideal environmental conditions. Seedlings are rarely outplanted to optimum temperature and moisture conditions, however, and therefore will likely have a lower expression of root growth in the field.

Other physiological tests include the following:

- Plant moisture stress (PMS), which is an indicator of xylem water potential and is often used to schedule irrigation and monitor water stress during lift and pack operations (Lopushinsky 1990) (figure 8);
- Bud development, which is related to seedling dormancy and shoot growth potential for the following season (figure 9);

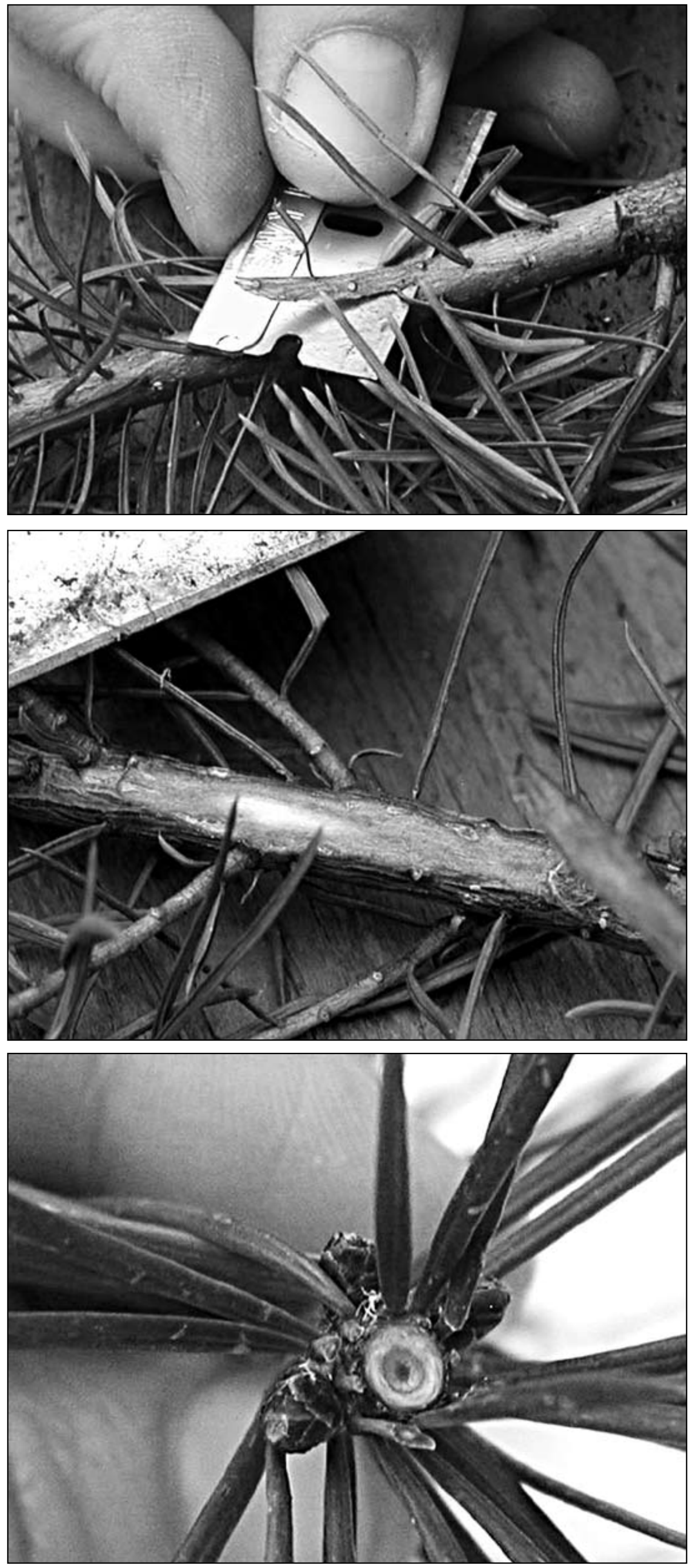

Figure 5. Examination of damage to bud and cambium tissue following freezing at specific temperatures determines the seedling's viability.

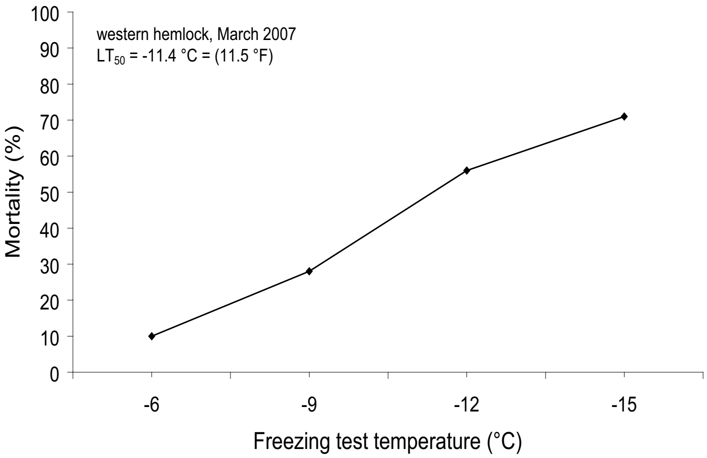

Figure 6. Cold hardiness (LT_{50}) is estimated by assessing the level of seedling mortality across a range of freezing temperatures.

Figure 7. The length and quantity of new roots generated during a 3-wk period under optimum growing conditions is used to assess RGP.

Figure 8. A pressure chamber is used to determine the xylem water potential of a seedling branch sample.

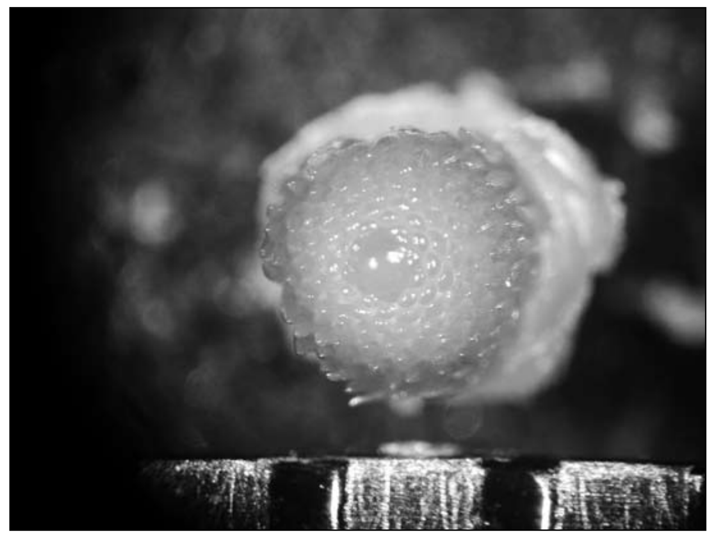

Figure 9. The number of bud primordia present in a seedling bud determines the number of new needles that will form in the following growing season.

- Chlorophyll fluorescence, which indicates a seedling's photosynthetic activity (Mohammed and others 1995); and
- Nutrient status, which governs many metabolic processes in the seedling.

Seedling Quality Testing Facilities. At the very least, nearly all nurseries evaluate height and stem diameter of their stock. Some nurseries also conduct more intensive in-house seedling quality evaluations on a portion of their seed lots. With the exception of several laboratories that offer nutrient testing on plant tissue samples, there are very few third-party seedling quality testing facilities in the country. The Nursery Technology Cooperative (NTC) established a regional forest seedling quality testing facility at Oregon State University (Corvallis) in 2000. Those who use the service are pleased to have an objective resource available to provide the requested data in a timely manner. Currently, services available through the NTC program include morphological evaluation (height, stem diameter, height:diameter, root and shoot volume, shoot:root) and cold hardiness determination (whole plant freeze test). Further information can be found at http://www.cof.orst.edu/coops/sqes.htm.

Conclusions

Many morphological and physiological variables can be monitored in order to track and assess seedling quality. A comprehensive evaluation regime provides useful data for aiding management decisions and understanding effects of culturing, handling, or environmental stress events. Through inhouse programs or third-party services, seedling quality evaluation is a valuable tool for both nurseries and reforestation personnel.

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