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SEEDLING MORPHOLOGICAL *EVALUATION* -- WHAT YOU CAN TELL BY LOOKING

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Durvea, M. L. (ed.). 1985. Proceedings: Evaluating *seedling* quality: principles, *procedures, and predictive* abilities *of* major tests. Workshop held October 16-18, 1984. Forest Research Laboratory, Oregon State University, Corvallis, ISBN 0-87437-000-0

ABSTRACT--Grading for height and root collar diameter is practiced by many nurseries as a basis for separating out stock of poor quality. Experiments relating seedling size to field performance are rather contradictory. In general, when seedling physiological status is equal, larger seedlings grow better but often do not survive as well as smaller stock. Diameter is the best single predictor of field survival and growth.

Seedling weights often correlate with field survival through their high correlation with stem diameter. Bud height can be used as a measure of potential field growth. Color indicates the nitrogen fertility regime used in the nursery but is only related to outplanting response under certain conditions. The presence of succulent shoots, foliage length, foliage density, multiple tops, and stem sweep is often included in grading standards, but

little is known about their subsequent effect on performance.

The desired morphology of the root is less defined than the shoot. Research supports the generalization that seedlings with more roots outperform those with less roots. No measure exists that determines how much root is sufficient. Shoot/root ratio has been used for this purpose, and it may be of substantial value when corrected for seedling size in predicting field survival. Other root morphological attributes such as stiff laterals, swept roots, root configuration, root damage, and the presence of mycorrhizae, may affect growth and survival, but little conclusive evidence exists.

Since one parameter seldom explains all the variability seen in the field, morphological indices have been developed that incorporate a number of measurements, such as height, diameter, and dry weights. Some of these show promise in predicting field performance.

Although physiological condition can override morphology, the size and shape of the plant does, in many instances, reflect its potential for field survival and growth. Nursery managers can be reassured that grading is beneficial.

6.1 INTRODUCTION

Morphology is defined as the form or structure of an organism or any of its parts. With a little thought, a long list of seedling physical attributes that could be measured can be generated. The list would range from the more obvious parameters of height, stem diameter, and weight; to the more obscure ones such as stomate number, bark thickness, and the number of root tips. The problem that the forester faces is which, if any, of these attributes serves as a good measure of seedling quality. In this paper, quality will be defined as fitness for purpose, which for a seedling is its ability to survive and then grow rapidly when planted in the field. Both morphological and physiological features are undoubtedly required to meet this objective.

The ease with which most morphological parameters can be measured makes them the most popular method for measuring seedling quality. For example, all nursery grading standards are based on morphology. In spite of general acceptance and widespread use, researchers have noted that morphology alone does not predict all the variability seen in field survival and growth (Wakeley 1954, Sutton 1979, Schmidt-Vogt 1981, Ritchie 1984, Hallet 1984). It can, however, be of great comparative value when the physiological status of the seedlings is equal (i.e., in a single lot of seedlings from a given nursery) or similar (i.e., different nurseries but similar lifting dates). Therefore, to clarify discussion about morphological features, this paper will assume seedlings being compared are of similar physiological status.

The purposes of this paper are to examine several parameters routinely used to grade seedlings, to evaluate the effect of grading on subsequent field performance, and to show that morphology is an important indicator of seedling survival and growth in the field.

6.2 HEIGHT

6.2.1 Measurement

One of the easiest morphological traits to observe is height. No instruments are necessary to visually determine that one tree is taller than another. If you wish a quantitative measurement, height is usually measured from the root collar to the base of the terminal bud. If no terminal bud is present as a result of injury or active growth, measurement is done either to the highest point (often the tip of a needle) or to the approximate growing point. The growing point method gives a more accurate measure and does not result in height fluctuations when sequential measurements are taken.

6.2.2 Standards

In the past, seedlings have been culled both for being too tall and too short. Exceedingly tall seedlings are difficult to plant, out of balance (poor shoot-root ratio) and susceptible to wind rock (Ritchie 1984). Tall seedlings may, however, be genetically superior (Nienstaedt 1981, Campbell and Sorenson 1984). Rather than culling these seedlings, top-mowing or clipping has been instituted in the nursery to reduce height and make these seedlings plantable (Duryea 1984). Top-mowing generally produces a more uniform crop with fewer culls due to extreme seedling size.

Minimum standards for height vary greatly by species, seed-zone, and age class. Standards are generally revised as more information on field performance becomes available from the field.

6.2.3 Quality Prediction

Height measures both the photosynthetic capacity of the seedlings and their transpirational area by being highly correlated to needle number (Armson and Sadreika 1974). This would suggest a good correlation of height with growth but an unpredictable relationship with survival, especially on droughty sites. Indeed, height has not been consistently correlated with survival (Pawsey 1972, Anstey 1971, Mullin and Svaton 1972).

In West Germany tall Norway spruce seedlings had poorer survival than smaller ones but had greater subsequent growth (Schmidt-Vogt 1981). Similarly, the tallest seedlings again showed the poorest survival for Douglas-fir (Hermann 1964) and Ponderosa pine (Lopushinsky and Beebe 1976). Other studies show little difference or increasing survival with height for Douglas-fir (Lopushinsky and Beebe 1976).

Increased height growth with increasing initial height is a more universal phenomenon. In red pine, initial seedling sizes of 7, 11, and 15 cm resulted in 299, 311, and 366 cm tall trees, respectively, after twelve years in the field

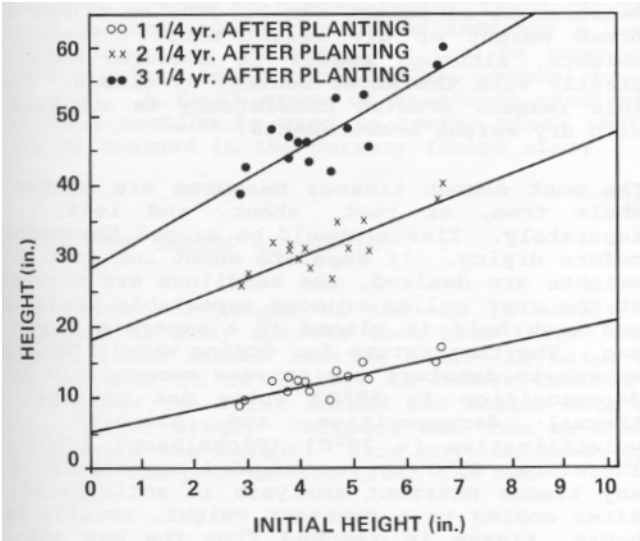

FIGURE 1. COMPARISON OF INITIAL HEIGHT OF CONTAINERIZED LOBLOLLY PINE SEEDLINGS TO HEIGHT AT 1¼, 2¼, AND 3¼ YEARS AFTER PLANTING. (From McGilvray and Barnett 1982)

(Curtis 1955). Loblolly pine shows even more striking growth differences based on initial height which result in larger total differences as the seedlings grow (Fig. 1) (McGilvray and Barnett 1982). The effect of initial height on subsequent height is seen to vary with stock-type for white spruce (Mullin and Christl 1981) (Fig. 2). Chavasse (1977) reports that

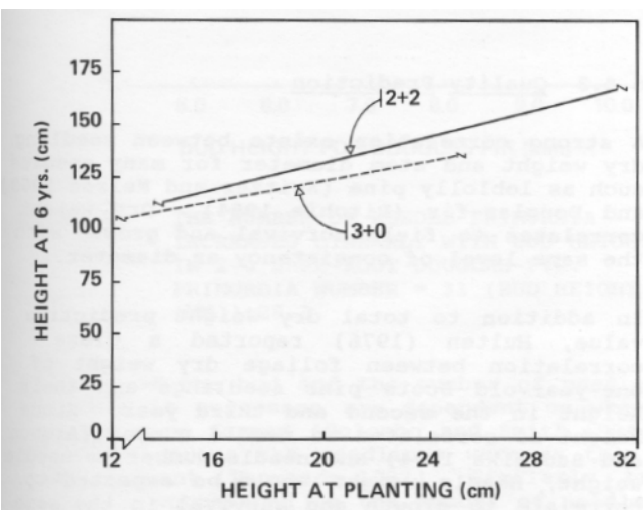

FIGURE 2. RELATIONSHIP OF HEIGHT AT SIX YRS. AFTER PLANTING TO THE HEIGHT AT TIME OF PLANTING FOR 3+0 (BROKEN LINE) AND 2+2 (SOLID LINE) WHITE SPRUCE. (From Mullkin and Christl (1981).

in radiata pine the initial height difference are maintained but not enlarged after one yea in the field.

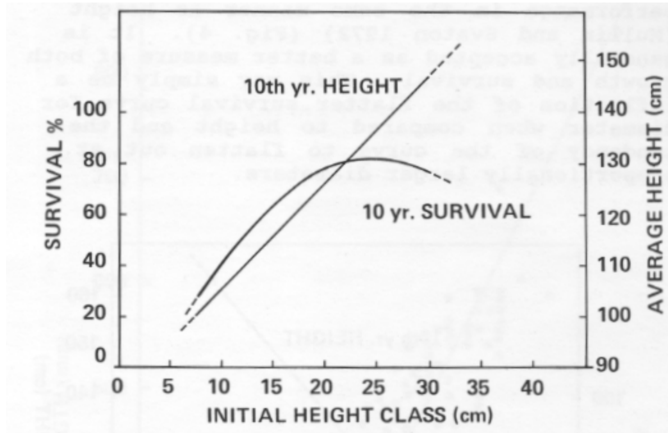

FIGURE 3. RELATIONSHIP OF THE TENTH-YEAR SURVIVAL AND HEIGHT TO THE ORIGINAL TOP-HEIGHT CLASSES AT THE TIME OF LIFTING AND PLANTING. (From Mullin and Svaton 1972)
SURVIVAL % = 31.50+9.21X-0.18X²
r = 0.889
HEIGHT (10 YR) = 84.46+2.06X
r = 0.964
X = INITIAL HEIGHT IN CM

The predictive power of height as a measure of field survival and growth is best summarized by Mullin and Svaton (1972) for white spruce (Fig. 3). As initial seedling height increases the height of the white spruce trees after ten years in the field increases, as does the total growth in the field. Survival is not linearly related to initial height but shows a definite maximum. The maximum is probably dependent on seedling root system size and site related. As the site becomes more droughty, the optimum height for survival probably decreases.

In summary, a quality seedling with respect to height is one that is as tall as possible while still possessing an acceptable level of survival potential for the designated site.

6.3 STEM DIAMETER

6.3.1 Measurement

Diameter is often included in the morphological grading done at the nursery. Diameter should be measured slightly above the root collar with either an accurate caliper for research purposes or a caliper gauge for nursery grading. For accurate measurements, care should be taken to compress the bark as little as possible and to exert a constant pressure.

6.3.2 Standards

Most nurseries employ only a lower limit for acceptable diameter. As with height standards, they vary greatly with species and stock-type.

6.3.3 Quality Prediction

Seedling diameter is related to field performance in the same manner as height (Mullin and Svaton 1972) (Fig. 4). It is generally accepted as a better measure of both growth and survival. This may simply be a reflection of the flatter survival curve for diameter when compared to height and the tendency of the curve to flatten out at proportionally larger diameters.

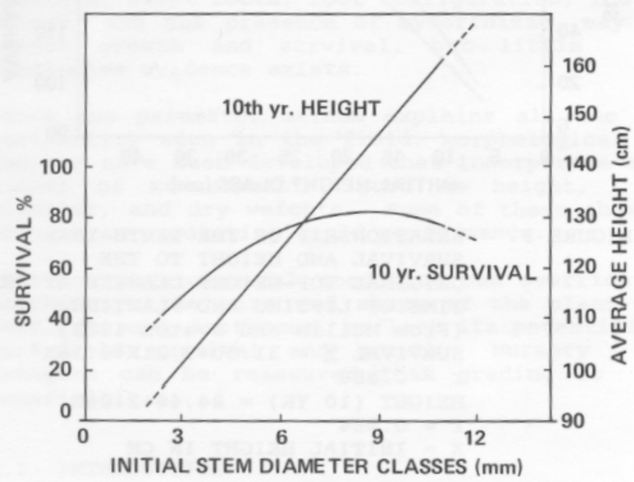

FIGURE 4. RELATIONSHIP OF THE TENTH YEAR SURVIVAL AND HEIGHT TO THE ORIGINAL STEM DIAMETER CLASSES AT THE TIME OF LIFTING AND PLANTING. (From Mullin and Svaton 1972)
SURVIVAL % = $4.26+180.73X-103.68X^2$
r = 0.744
HEIGHT (10 YR) = 78.90+74.57X
r = 0.982
X = STEM DIAMETER IN CM

As with height, diameter is not always correlated to field survival but is related to subsequent growth. For example, loblolly pine seedlings graded to Wakeley's standards (Wakeley 1954) in two separate studies had the best survival at the middle grade (Blair and Cech 1974, Venator 1983). After 13 years in the field, however, the seedlings in the Blair and Cech study had produced 6.5, 6.0, and 5.0 cu. ft. of wood per tree for grades 1, 2, and 3, respectively. The relationship between initial stem diameter and six-year height for two stock-types of spruce (Mullin and Christl 1981) and white pine was highly significant but differed by stocktype (Mullin and Christl 1982). Likewise, radiata pine field growth and survival after three years were well-correlated with initial stem diameter (Anstey 1971).

A quality seedling should possess the largest diameter that confers an acceptable level of survival potential on that seedling for a given site.

6.4 *WEIGHTS*

6.4.1 Measurement

Measurement of weight can be done on either a fresh weight or dry weight basis. Fresh weights, although easier to measure, vary greatly with the water content of tissue. For this reason, greater consistency is achieved with dry weight measurements.

The most common tissues measured are either whole tree, or root, shoot, and leaf, separately. Tissue should be washed thoroughly before drying. If separate shoot and root dry weights are desired, the seedlings are severed at the root collar or some repeatable position and each half is placed in a separate paper bag. The temperature for drying should be high enough to denature the enzymes responsible for decomposition (> 60°C) while not causing thermal decomposition and nitrogen volatilization (< 70°C) (Bickelhaupt 1980). Therefore, 65°C is recommended especially if any tissue nutrient analysis is anticipated. After coming to a constant weight, usually 24 hours, tissue is removed from the bag and weighed.

6.4.2 Standards

Dry weight is not used as a grading criterion because such measurement is both time-consuming and destructive. Weight measurements are generally used to evaluate the suitability of a lot of seedlings rather than individual seedlings. Additionally, weights are often used to calculate shoot-root ratios (see section 6.8.1) and a quality index (see section 6.8.3).

6.4.3 Quality Prediction

A strong correlation exists between seedling dry weight and stem diameter for many species such as loblolly pine (Switzer and Nelson 1963) and Douglas-fir (Ritchie 1984). Dry weight correlates to field survival and growth with the same level of consistency as diameter.

In addition to total dry weight predictive value, Hulten (1976) reported a close correlation between foliage dry weight of one-year-old Scots pine seedlings and their height in the second and third year. Since height is correlated to needle number (Armson and Sadreika 1974) and needle number to needle weight, needle weight would be expected to correlate to growth and survival in the same way as height.

In general, a quality seedling should be as heavy as possible to produce the best growth while still having the balance of shoot and root necessary to survive on a given site.

6.5 OTHER SHOOT PARAMETERS

In addition to the commonly measured parameters, a number of other factors can be examined. Some of these predict field growth (bud height), while others may indicate a lack of vigor (color, foliage density), or improper physiological condition (color, succulent shoots). A final group of standards examined in this section is used to remove stock that may be damaged in the nursery (swept stem).

6.5.1 Bud Height or Length

The height or length of the bud is easily measured in many species that have large- or medium-sized winter resting buds. To measure the height, it is easiest to remove the bud just below the first formed bud scales with a sharp razor blade. Calipers can then be used to measure the height. Care must be taken so that the calipers do not crush the bud.

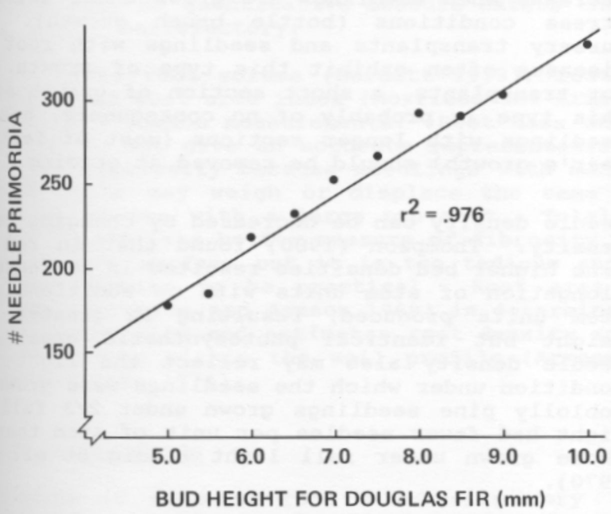

FIGURE 5. THE NUMBER OF NEEDLE PRIMORDIA INCREASES LINEARLY WITH BUD HEIGHT IN 2-0 BARE-ROOT DOUGLAS-FIR. PRIMORDIA NUMBER = 31 (BUD HEIGHT (MM))+28.3.

The size of the bud and the number of needle primordia it possesses are dependent on when the buds were formed (Colombo and Smith 1984) and how vigorous the seedlings were as they became dormant (Thompson 1982). Similarly, bud height is correlated to the number of needle primordia in Douglas-fir (Fig. 5) and to subsequent field growth in both determinant growth species, such as Ponderosa pine (Hanover 1963) and red pine (Kozlowski et al. 1973) (Fig. 6), and the multi-flushing species, loblolly pine (Boyer 1970) and slash pine (Bengtson et al. 1967).

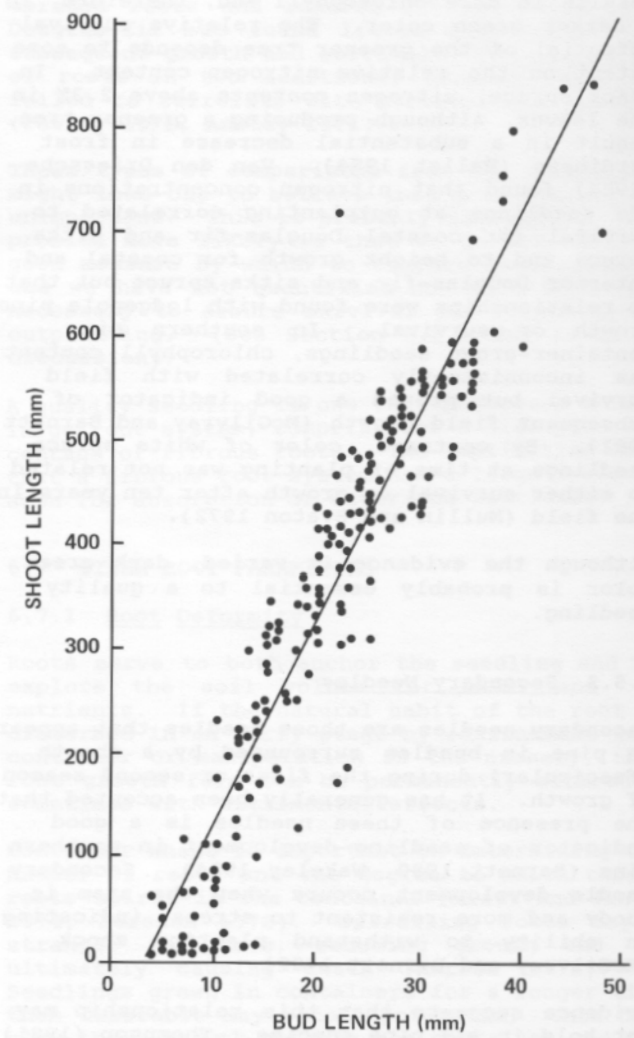

FIGURE 6. RELATIONSHIP OF BUD LENGTH ON SUBSEQUENT SHOOT LENGTH IN RED PINE. SHOOT LENGTH (MM) = 19.7 (BUD LENGTH [MM])-64.9 r = 0.92 (From Kozlowski et al. 1973)

Bud height may be an indicator that will probably be more useful for potential field growth comparisons between lots of seedlings rather than within a lot. It is an indirect method of measuring time of dormancy induction and seedling vigor. The strong correlations with field height make it an important morphological indicator of growth potential.

6.5.2 Color

Seedling color is often used as a subjeccive measure of seedling quality. In a gross sense, it probably has value. Yellow, brown, or light green seedlings are less vigorous than dark green ones. Within the range of dark green color, however, the evidence for correlations with field growth and survival is less convincing (Linder 1980).

During a given season, more foliar nitrogen results in more chlorophyll and, therefore, in a darker green color. The relative survival potential of the greener tree depends to some extent on the relative nitrogen content. In black spruce, nitrogen contents above 2.2% in the leaves, although producing a greener tree, result in a substantial decrease in frost hardiness (Hallet 1984). Van den Driessche (1984) found that nitrogen concentrations in the seedlings at outplanting correlated to survival for coastal Douglas-fir and sitka spruce and to height growth for coastal and interior Douglas-fir and sitka spruce but that no relationships were found with lodgepole pine growth or survival. In southern pine container-grown seedlings, chlorophyll content was inconsistently correlated with field survival but proved a good indicator of subsequent field growth (McGilvray and Barnett 1982). By contrast, color of white spruce seedlings at time of planting was not related to either survival or growth after ten years in the field (Mullin and Svaton 1972).

Although the evidence is varied, dark green color is probably essential to a quality seedling.

6.5.3 <u>Secondary</u> <u>Needles</u>

Secondary needles are those needles that appear in pine in bundles surrounded by a sheath (fascicular) during the first or second season of growth. It has generally been accepted that the presence of these needles is a good indicator of seedling development in southern pine (Barnett 1980, Wakeley 1954). Secondary needle development occurs when the stem is woody and more resistant to stress, indicating an ability to withstand planting shock (McGilvray and Barnett 1982).

Evidence suggests that this relationship may not hold in all pine species. Thompson (1981) compared two types of 1-0 container-grown Scots pine seedlings; one group with normal 1-0 field morphology (very few secondary needles and a terminal rosette of needles surrounding the bud) and a second group resembling 2-0 Scots pine (many secondary needles and a terminal bud with surrounding lateral buds). The findings indicate that seedlings with the "normal" 1-0 morphology start growth slightly later in the spring but consistently produce larger seedlings in the field even with similar initial heights and calipers. Thompson concludes that seedlings with the 1-0 type morphology in the greenhouse are more desirable because of their greater growth potential.

Presence of secondary needles on container--grown pine seedlings must be evaluated on each species before its value as a morphological measure of quality can be determined.

6.5.4 <u>Succulent</u> <u>Shoots</u> vs. <u>Dormant</u> <u>Buds</u>

Lemmas or late season growth often produces shoots that remain succulent at lifting. In Douglas-fir, survival of seedlings with succulent shoots was lower than for those without, but the difference was not significant (Hermann 1964). Although the succulent shoots increase seedling height, late season growth delays budset and delays the normal sequence of fall dormancy induction. This, in turn, delays spring bud break. Seedlings demonstrating delayed bud burst generally have decreased growth and survival in the field (Lavender and Cleary 1974, Ritchie 1984).

In Northeast species, actively growing stock is easily broken and dies or wilts when outplanted under water stress (McNeish and Heinstein 1982, Bacon et al. 1977).

Seedlings without active growth at the time of lifting may be one universally acceptable grading criterion for improved seedling growth and survival in the field.

6.5.5 <u>Needle</u> <u>Size</u> and <u>Density</u>

Needle length and the distance between needles decrease when seedlings are grown under water stress conditions (bottle brush growth). Nursery transplants and seedlings with root diseases often exhibit this type of growth. For transplants, a short section of growth of this type is probably of no consequence, but seedlings with longer sections (most of last year's growth) should be removed at grading.

Needle density can be decreased by changing bed density. Thompson (1980) found that in red pine higher bed densities resulted in increased elongation of stem units with no additional stem units produced, resulting in greater height but identical photosynthetic area. Needle density also may reflect the light condition under which the seedlings were grown. Loblolly pine seedlings grown under 2/3 full light had fewer needles per unit of stem than those grown under full light (Ledig et al. 1970).

An optimum foliage density presumably exists for various species. Extremely high foliage density or short needle lengths should probably be avoided for quality seedlings.

6.5.6.1 Multiple shoots

Multiple shoots can either be genetic in nature or result from cultural practices (top-mowing),, disease, or insects. Many Northwest nurseries cull for multiple tops that split within a given distance from the ground line. This is intended to eliminate genetically determined multiple tops. When multiple tops result from damage or insects in the nursery, the seedlings - usually recover rapidly in the field and produce a single terminal *(Lanquist* 1966, McLemore 1982). Some reduction in growth may occur during the first year while side shoots compete for dominance.

6.5.6.2 Stem sweep

Stem sweep often occurs when seedlings are transplanted incorrectly and grow to right themselves. How much sweep is too much and what effect, if any, it has on field survival and growth are unknown. Sweep, however, is often used as a grading criterion for transplants.

6.5.6.3 Disease deformities

Disease can produce some pronounced stem deformities. Phomopsis canker can girdle Douglas-fir stems, producing a large bulge above the girdle. Fusiform rust in southern pine also produces a characteristic stem deformity. All diseased seedlings should be removed in grading.

6.6 ROOT SIZE 6.6.1

Measurement

Although the root is at least as important as the shoot in determining survival and growth of the plant, no quantitative measure exists that is wholly satisfactory.

Root mass, root volume (Burdett 1979), root length and root area index (Morrison and Armson 1968) are common measurements. Root mass and volume do not give an accurate representation of root fibrosity because seedlings with many fine roots may weigh or displace the same amount as one with a large tap root. Total root length is a better measure of fibrosity or absorptive surface but it is too tedious and time-consuming to be practical. Root area index (Morrison and Armson 1968) is determined photometrically and estimates root density and distribution within the soil profile (Armson and Sadreika 1974).

6.6.2 Standards

Grading is done on root size using very subjective standards of sufficient root for the height and visual density.

6.6.3 Quality Prediction

Root weight is often correlated to seedling diameter (Ritchie 1984, Mullin and Christl 1981) and thereby to survival and growth. Although root weight correlated to growth and survival of container loblolly pine seedlings, height, diameter and stem weight were all better predictors (McGilvray and Barnett 1982).

In studies where fibrosity was intentionally reduced, or seedlings visually graded before planting, field results differ. In lodgepole pine (Burdett 1976) and Douglas-fir (Hermann 1964), root fibrosity correlated well with field survival. Loblolly pine seedlings had large increases in mortality when 50 to 75% of the feeder roots were removed (Rowan 1983). Lavender and Wareing (1972), on the other hand, abraded roots and removed fibrous roots of Douglas-fir but found little difference in subsequent growth and survival. Visual grading of roots in two additional studies, also, failed to correlate with survival and growth (Pawsey 1972, Anstey 1971).

These types of comparisons from the literature might lead one to believe that root quality is unimportant. This is probably misleading. The problem more likely is that we do not have a good measure by which to compare root systems and we have not quantified how much root is necessary to assure survival and growth upon outplanting. (See Section 6.8.1 for further discussion).

A quality seedling is one that possesses a large root system, comprised of a high percentage of fibrous roots. The implication is that a fibrous root system has a large surface area for absorption of water and nutrients.

6.7 OTHER ROOT PARAMETERS

6.7.1 Root Deformity

Roots serve to both anchor the seedling and to explore the soil volume for water and nutrients. If the natural habit of the root is disturbed in an early stage by confinement in a container or manipulation in the nursery, the root growth form can be permanently altered, sometimes with detrimental effects.

Container shape is important in determining the number of roots and the degree to which those roots spiral in the container (Hiatt and Tinus 1974, Persson 1978). Spiralling roots may strangle the tree, reducing growth and ultimately causing death (Harris 1978). Seedlings grown in containers for a longer time than desirable may become pot-bound; this can slow their growth both in the container and the field. Seedlings may, also, only have active root tips at egress holes at the bottom of the container. When outplanted, few if any new roots originate in the top 10 cm of the plug. These seedlings may not be wind-firm and may be damaged or uprooted by strong winds. A new method of treating containers with cupric carbonate may reduce this problem (Burdett 1978).

In bare-root nurseries, undercutting by running a sharp blade under the seedlings in the bed is a common practice. Schmidt-Vogt (1981) reports that undercutting can affect older fir seedlings by inhibiting their subsequent tap root development. He reports 10-year-old trees toppling in the wind and believes more attention should be paid to this area in the future.

Root sweep in transplants, although avoidable, is nevertheless common. How much sweep is permissible and its effect on growth and survival are debatable. In general, Northwest seedlings are culled if the main axis of the root system is greater than 45° from that of the stem. In outplanting trials, root sweep was associated with reduced growth of Norway spruce (Grene 1978). Loblolly pine root systems, deformed to simulate planting problems, accumulated carbohydrates at the bend, which resulted in more roots developing at that point (Hay and Wood 1975). This would probably be desirable on mesic sites but detrimental on droughty sites.

For a more complete coverage of root deformity, the reader is referred to The Symposium on Root Form of Planted Trees held in Victoria, B.C. in 1978.

After several years in the field, a quality seedling root system should resemble, as much as possible, that of a field-grown tree. How the root system should look at planting to achieve this goal is not fully known.

6.7.2 Stiff Lateral Roots

Stiff lateral roots that originate near the root collar and extend over 10 cm in any direction are difficult to plant in the field. To alleviate this problem, seedlings in the nursery beds are root-pruned between the seedling rows. Some seedlings with stiff laterals still remain; these are generally culled.

6.7.3 Mycorrhizae

Mycorrhizae is the association of the seedling root with a symbiotic fungus. In conifers, it is often visible as a fuzzy mantle on the roots. Characteristic bifurcate roots (branching) are also formed. The author knows of no grading system that uses mycorrhizae as a criterion.

Some mycorrhizal associations have been shown to confer superior growth and survival potential to seedlings under certain conditions. For example, *Pisolithus tinctorius* on loblolly pine roots has resulted in up to a 25% increase in both growth and survival when the seedlings were planted on poor sites (Cordell and Marx 1980). Less dramatic results are seen on better sites.

A quality seedling should have a beneficial mycorrhizal association to insure the greatest likelihood of superior survival and growth. This requirement is probably more important when seedlings are destined for harsh sites.

6.7.4 Root Damage

In addition to seedlings culled for insufficient roots, seedlings with sufficient but damaged roots are also culled. Root damage can be caused by insects such as weevils or cranberry girdlers that eat the bark at or below the root collar or by diseases such as *Phytophora* and Black root rot which are seen as black, soft roots. The most common form of damage is created during the lifting process, when roots are ripped off leaving gashes or severely abraded roots. Seedlings with damaged roots are seen as poor risks in the field and should be removed.

6.8 MORPHOLOGICAL INDICES

A morphological index is a combination of two or more morphological measurements. They are generally designed to serve one of two purposes. The first is to describe an abstract attribute of a seedling, such as balance and sturdiness. The second is to determine the relative importance of the morphological measurements by combining them into an index that more closely corresponds to field performance than any individual parameter.

6.8.1 Shoot-root Ratio

6.8.1.1 Measurement

The shoot-root ratio (S/R) was devised as a measure of balance between the transpirational area (shoot) and the water absorbing area (root) of a seedling. Racey et al. (1983) gave a thorough account of the methods of measuring S/R and how they compare for various populations. In general, either dry weight or volume displacement of the shoot and root are used to obtain the ratio. As the S/R ratio increases, the volumetric measure increasingly over-estimates the dry weight ratio. The error is of little concern, however, for the S/R range generally encountered in seedlings.

6.8.1.2 Quality prediction

Much controversy exists over the value of S/R in determining seedling quality. When seedlings were first graded into height classes, Hermann (1964) (using Douglas-fir) and Lopushinsky and Beebe (1976) (with both Douglas-fir and ponderosa pine) found that seedlings with lower S/R within a height class had better survival. It has been demonstrated that S/R changes with seedling size (Ledig et al. 1970, Carlson and Preisig 1981). Therefore to determine if treatments affect S/R or to find an acceptable S/R for a seedling, the effect of size must be removed. To do this, S/R for the Douglas-fir seedlings in the two studies mentioned above were plotted against total seedling height (Fig. 7). This exercise demonstrates that as seedling height increases, the "acceptable" S/R also increases.

Wrenching studies in which the S/R was altered have shown mixed results; in some cases, large changes in survival were reported (Tanaka et al. 1976, Koon and O'Dell 1977) while in other cases the influence on survival was small (Van den Driessche 1983). Bed density was found to significantly change seedling S/R but to have little effect on survival (Van den Driessche 1982).

In an attempt to explain the contradictory results found when S/R is used to predict survival, the results from the comparable wrenching and bed density studies mentioned above were plotted versus seedling height (Fig. 7). The survival of the seedlings from each study was then considered. If the survival was greater than 80% or more than 5% greater than the mean for the study it was considered good; otherwise, poor. Thus arrayed, the data segregated into two lines. The seedlings with better S/R had 29% better survival on average. The strength of this relationship is impressive when you consider that although all the five studies used 2-0 bare-root Douglas-fir, growing regimes, seed-zones, planting site, planting year, and a whole host of other factors differ among the studies.

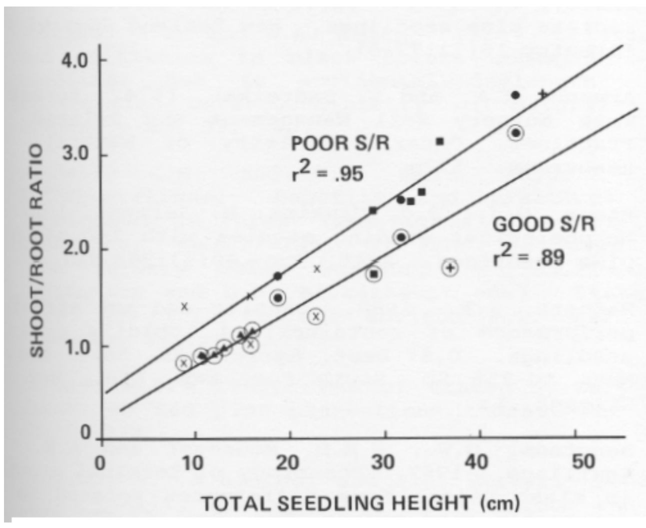

FIGURE 7. RELATIONSHIP BETWEEN SHOOT/ROOT RATIO AND SEEDLING HEIGHT FOR 2-0 DOUGLAS-FIR SEEDLINGS WITH GOOD AND POOR SURVIVAL. DATA FROM LOPUSHINSKY AND BEEBE (1976)X, HERMANN (1964)., VAN DEN DRIESSCHE (1983)., VAN DEN DRIESSCHE (1982)x, AND KOON AND O'DELL (1977)+. CIRCLED POINTS HAD HIGH SURVIVAL OR 5% GREATER THAN MEAN FOR THE STUDY. FOR POOR S/R, S/R = 0.51-0.065 (HEIGHT), AVERAGE SURVIVAL=50.9% FOR GOOD S/R, S/R = 0.21-0.057 (HEIGHT), AVERAGE SURVIVAL=79.7%

In Southern pine, the value of S/R in predicting quality may be more difficult to assess. Seedlings grown in warmer climates can continue to grow roots as long as the soil temperature allows. The S/R ratio, in turn, changes rapidly and dramatically during the lifting season. one study with seedlings grown in Virginia reports a change in S/R for loblolly pine from 5.5 in October to 3.8 in January and finally to 2.8 in March (Garner and Dierauf 1976). This reflects an actual change in *S/R* due to root dry weight increase at the expense of shoot dry weight with little change in total dry weight. In another study with loblolly pine in southern Georgia, the seedlings accumulated dry weight during the winter and the S/R ratio changed from approximately 1.0 in October to 0.5 in March (Jeff Melkonian, personal communication). These study results do not correspond to allometric relationships proposed for loblolly pine (Ledig and Perry 1965).

In the past several years, the usefulness of S/R has been questioned by many nursery managers. In light of the previous discussion, S/R should be re-evaluated against height or dry weight, especially for species that do not reallocate their dry weight or grow substantially during the winter. Within limits, it appears that S/R can be a useful index for predicting field survival but probably has little value in predicting field growth (Mullin and Christl 1981, 1982).

A quality seedling should have as low a shoot/root ratio as possible to insure the best survival.

6.8.2 Sturdiness quotient

The sturdiness quotient is the height (h) in centimeters divided by the stem diameter (d) in millimeters (h/d). It reflects the stocky or spindly nature of the seedlings. Although a good indicator of the ability to withstand physical damage in all stock-types, it is of particular importance in container-grown seedlings where the sturdiness quotient can get very high on undesirable spindly stock.

Roller (1977) found that black spruce seedlings with sturdiness quotients greater than six were seriously damaged when exposed to wind, drought, and frost.

In general, sturdiness quotient should closely parallel diameter in predicting survival and growth in the field.

6.8.3 Dickson Quality Index

$$\text{Quality Index} = \frac{\text{Total Seedling Dry wt (g)}}{\dfrac{\text{Height (cm)}}{\text{Diameter (mm)}} + \dfrac{\text{Shoot wt (g)}}{\text{Root wt (g)}}}$$

The quality index was devised by evaluating how well a number of possible combinations of morphological parameters predicted field performance of white spruce and white pine seedlings and selecting the best combination (Dickson et al. 1960[a]). In a subsequent test, this index was able to predict quality based on the nutrient environment (soil fertility) in which the seedlings were grown (Dickson et al. 1960[b]). The index was successfully used by Roller (1976) to differentiate between plantable and non-plantable containerized seedlings. In Douglas-fir, the index may reflect the outplanting success of various stock-types (Ritchie 1984).

6.8.4 Iyer and Wilde Quality Index

The index proposed by Iyer and Wilde (1982) combines diameter-height ratio, root-shoot ratio, specific gravity of the stem, catalytic capacity of the feeder roots, and the coefficient of variability of the height into a single number. The determination of this number is somewhat complex, but the authors claim success in correctly determining the quality of stock from four nurseries. The method needs further testing to assess its reliability.

6.9 RELATIVE PREDICTIVE VALUE OF MORPHOLOGICAL PARAMETERS

Diameter is probably the best and easiest-to-measure overall predictor of subsequent growth and survival. It must be remembered that past a certain size, survival begins to decline as diameter increases. This may reflect a lack of balance in the larger tree.

Shoot-root ratio corrected for seedling size is another good indicator of survival potential. It may be of particular importance on droughty sites. The index may have value in determining when seedlings become too large and out of balance.

When seedling heights or diameters are equal for two lots of trees but their bud heights are different, those with the larger buds have the greatest field growth potential. In this way, bud height can be used to refine predictions of field growth.

Further evaluation of the predictive value of the Dickson Quality Index is warranted. From the data available, it has promise and is relatively easy to measure.

Many of the parameters discussed in this paper are highly correlated to diameter but are either harder-to-measure (dry weight) or more variable (height). The remaining morphological features may have value as grading criteria to remove damaged or poorly-grown trees, but their usefulness as predictors of field performance is either unproven or unlikely.

The amount of genetic selection that results from morphological grading is beyond the scope of this paper but nevertheless warrants brief mention. Some grading procedures, such as height or diameter segregation, put a directional genetic selection pressure on the seedling population, while other grading standards exert little genetic influence. Campbell and Sorenson (1984) give thorough coverage to the genetic implications of grading.

A large part of this workshop deals with physiological attributes of the seedling. This is not because it is inherently more interesting to read about frost-hardiness than height. It is because no matter how well you meet some proven superior morphological targets, if the seedling is not frost-hardy and is subjected to a frost your seedling will die. If lifted too early, mishandled, or improperly stored, your beautifully-balanced, sturdy, tall, green seedlings may die or at least suffer transplant shock. One consolation to nursery managers who spend a great deal of money each year to grade seedlings is that given the same physiological state at lifting and the same lifting and handling practices, your big beautiful seedling will outperform the one that should have been left on the grading room floor.

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