BELOW THE ROOT COLLAR - THE KEY TO PLANTING SUCCESS

By

Peter P. Feret, Associate Professor
Department of Forestry
Virginia Polytechnic Institute and State University
Blackburg, VA 24061

Introduction

Site preparation and seedling planting are expensive operations. While their costs are usually justifiable when plantations are successfully established, reforestation is not financially attractive when low seedling survival leads to understocked forest lands. Understocking may result from poor overall seedling survival, or from a poor distribution of surviving seedlings. The biological and financial feasibility of interplanting or replanting have been repeatedly shown to be low.

Seedling death may be caused by an array of climatic factors beyond the control of the forester (i.e., excessive drought, wind, poor site quality, etc.). The probability is high, however, that seedling death may also be a function of events and practices which the forester is able to control: maintaining seedling moisture levels at the site, planting only when site conditions are favorable, planting at the proper time of year and planting high-quality seedling stock of proper genetic origin.

High seedling survival is essential for coupling efficient planting spacings to obtain adequate stocking at later ages. Good first year height growth is important for ensuring seedlings effectively compete with other vegetation for sunlight, water, and nutrients. Effective regeneration programs not only result in adequate stocking, but superior growth as well. However, good regeneration practices can be only as good as the growth potential of the seedlings used for planting.

A commercial product produced without quality control measures is a potential liability for the producer and user alike. Given the fact that all nurserymen spend their professional lives raising seedlings, it is an anomaly that a uniform code of seedling quality has not been established. The purpose of this article is to address one issue associated with the raising of bare-root seedlings and planting success: **seedling quality control.**

Seedling Quality— What is it?

Seedling quality may be measured by a variety of sophisticated (or not so sophisticated) laboratory techniques ranging from electrical conductance of plant tissues to the nutrient and carbohydrate status of the seedling (Durea 1985). Seedling quality may also be measured by qualitative or quantitative measures of seedling morphology including, but not limited to, root collar diameter, shoot/root ratio, shoot height or dry weight, root morphology and mass, or by just plain, ordinary "good looks" (Durea 1985). All nurserymen have favorite diagnostic tools for seedling evaluation. Some of these tools are documented in the forestry literature as scientifically sound, some are the result of "green thumb" experience (and may work as well as those in the literature!). Regardless of how seedling quality is measured, most people will agree that: **a high quality seedling is a seedling having a high probability of surviving the first year after planting, and once surviving, exhibiting good growth performance.**

The above definition of seedling quality is a functional one. The question of determining seedling quality quantitatively has entertained the research interests of scientists for many years. In the 1950's, Dr. E.C. Stone introduced the concept of Root Growth Capacity (RGC) as a way to measure the ability of a bare-root conifer seedling to rapidly grow new roots after transplanting (Stone 1955). While RGC is only one method for measuring seedling quality, it has particular merits allowing it to emerge as perhaps the single most reliable technique for quantifying bare-root seedling quality (Ritchie and Dunlap 1980).

There is general agreement that the probability of planting success is first and foremost a function of rapidly allowing the seedling to establish intimate contact with the soil (Smith 1986). If this is accomplished the seedling is able to take up water and nutrients, a process of critical importance in the early stages of seedling establishment. Once able to do this, it is free to grow and occupy its site. Suberized roots (brown older roots) are relatively inefficient at water uptake (figures vary but 10% - 75% efficiency compared to "new" white roots is a common range discussed by physiologists). Therefore, bare-root seedlings must generate new root growth to ensure efficient water and nutrient uptake. RGC is a measure of how successful the seedling is at growing those new roots.

For seedlings of **equal** physiological quality, morphological traits may be related to outplanting success (South et al. 1986). However, morphological traits are not useful for distinguishing differences in physiological quality among seedlots subjected to inappropriate post-harvest handling. Similarly, seedlings from different nurseries may have similar morphology but not be of the same physiological quality. This may be due to subtle differences in nursery culture, the time when seedlings are lifted, or different climatic and soil conditions at the nurseries. Therefore, any measure of seedling quality must reflect the **physiological condition** of the seedling. This concept is not new, going back at least as far as Dr. P.C. Wakeley's writings of the late 1940's (Wakeley 1949).

The chief advantage of the RGC measure of seedling quality is that it measures the physiological condition of the seedling. It effectively integrates an array of physiological attributes affecting the probability of planting success into a single biologically meaningful measure—new root growth after planting. There are many instances where morphological grades correlate with outplanting success. This is likely due to the fact that all seedlings are usually treated similarly from the nursery to the planting site. Preharvest nursery conditions and postharvest handling conditions interact to result in a seedling of given quality. Morphological features can, at best, reflect preharvest conditions while RGC reflects both pre- and postharvest conditions. The bottom line is that a seedling of high physiological vigor, that can reproduce its root system after planting, is far superior to another that, even if of higher morphological grade, sits with its root system stagnant.

The effectiveness of RGC as a measure of seedling quality is well documented in the scientific literature (e.g., Ritchie and Dunlap 1980; Sutton 1980; Feret and Kreh 1985; Feret et al. 1985). Consistent regeneration success requires consistent supplies of high quality seedlings.

What Causes Root Growth Capacity to Vary?

Root growth capacity varies in seedlings listed at different times from a nursery (Jenkinson 1978). This has caused western nurserymen to utilize lifting windows (optimal weeks for lifting during the regular lifting season) for different species and seed sources. The literature also shows RGC varies by seed source (Jenkinson 1980; DeWald and Feret 1985), with some genetic strains possessing inherently greater or lesser "innate" amounts of RGC (suggesting that some improved genetic stock may show variability in planting success depending on origin of the seedlings). Different nurseries produce bare-root seedling stock with different RGC (Feret et al. 1985) and this can impact planting success. Even nurseries growing the same genotypes can produce seedlings with different RGC.

Nursery cultural practices can impact RGC, as can postharvest treatment of seedlings. In preliminary studies of nursery cultural practices RGC has been shown to vary with organic and nitrogen supplements (Feret et al. 1984), undercutting (Feret and Kreh 1986) and seedbed density (Freyman et al., in review). Stored seedlings exhibit changes in RGC and these are a function of storage temperature, moisture, lift-date and previous handling history (Feret et al. 1984, 1985). RGC has also been shown to be seriously eroded by the exposure of roots to air-drying (Feret et al. 1985).

How Much Root Growth is Enough?

There is no easy answer to the question of what constitutes enough root growth capacity to ensure planting success. There are reasons for this. First, different species probably have different

RGC requirements. That is, their ability to withstand moisture stress after planting varies, so what's good for one species may not be good for another (the same may hold for different genotypes). Second, for a given species RGC requirements will be less if planting is on a site well endowed with rich moist soil and soil moisture is well-maintained for several weeks after planting compared to a planting on a droughty site subject to continued drought for weeks after planting. The question cannot be answered in absolute terms, but from a philosophical point of view, RGC is sufficient if seedling survival and subsequent first year growth meet a pre-defined goal. This goal may be something like: 90% survival 90% of the time with seedlings increasing 100% in height the first year.

In practical terms, it appears from the literature that certainly having no new root growth after planting is simply asking for a plantation failure. This may or may not happen in any given year depending on site conditions at and after planting, the amount and type of mycorhizae on seedling roots (they likely enhance water and nutrient uptake in the absence of new root growth), and the efficiency of older suberized roots to uptake water. It appears that (for loblolly pine) after a seedling exhibits a RGC of 10-20 new roots (using a standard 21 day greenhouse test [Feret and Kreh 1986]) in a "good" planting year not much more will be gained by additional new root production. In a "poor" planting year perhaps an RGC of 30-40 new roots will continue to be of benefit. In short, there is no magic RGC threshold definable for a given species given our current state of knowledge.

An inability to define an aceptable level of RGC for a seedling is not a valid argument for discarding the RGC method for measuring seedling quality. Again, the issue is not one of defining the minimum level required, but of defining a generally acceptable RGC level to meet survival and growth goals. Ultimately it will be possible to define minimum RGC levels by species and planting region, but only after a large number of foresters use standardized RGC test as a measure of seedling quality and relate these measures to plantation performance in the "real world".

Measuring Root Growth Capacity

There are a number of systems used for measuring RGC, and most are similar in concept. Each method requires the placement of bare-root seedlings into a controlled growth environment, roots are allowed to grow for a specified period of time, then seedlings are harvested and new roots (easily distinguished by their white color) counted and/or measured.

Many of the RGC testing systems for scientific investigation are expensive (i.e., growth chambers coupled with controlled temperature baths for ensuring a constant root environment). For instance, a moderately expensive system in use at Virginia Tech (Feret and Kreh 1986) utilized acrylic trays measuring approximately 16"I x 4"w x 16" deep. The trays are filled with a commercially available potting medium into which are planted bare-root seedlings to be tested. The planted trays are then watered to field capacity, stoppered to make them watertight, then dropped into water baths. The water baths are constructed of heavy duty galvanized steel filled with water. The water temperature is controlled using immersible heaters, 5000 BTU/hr. coolers with pumps to circulate the water within and among tanks. While the system is expensive (ca. $3500/tank), it is not as expensive as some but works well.

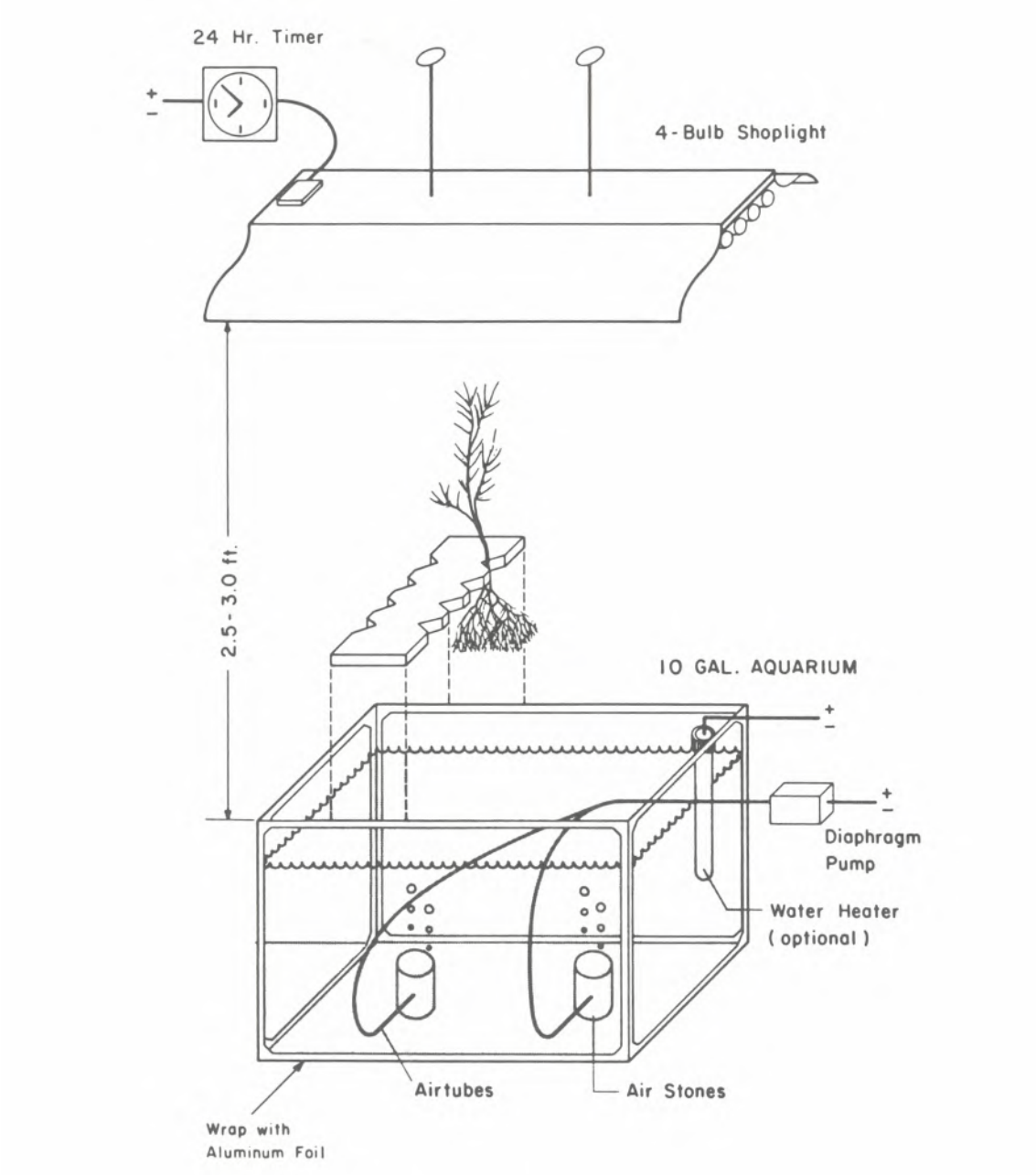
In contrast to the above test system, over the past several years my graduate students and I have gained experience with a hydroponic system suitable for practical field application (DeWald et al. 1985). The test system is inexpensive to build and operate, is constructed from materials available from the local pet shop and building supply store and takes up little space.

The hydroponic RGC test unit is built with 10 gal. fish aquarium (Figure 1). After sterilization with a bleach solution (1 cup/10 gal.) for 24 hrs., the tank is rinsed and filled to 2" to the top with tap water. In cases where tap water has high concentrations of iron, calcium or other impurities that might be detrimental to plant growth, bottled water or deionized water should be used. If chlorine

is an additive to the water supply, filled aquaria should be allowed to stand 24 hrs. before using. Each aquarium should be equipped with two air stones operated by a standard diaphragm fish aquarium pump.

Over each tank, at a height of approximately 2.5 to 3 ft., a fluorescent workshop light is hung and set with a timer to provide a constant 16 hr. photoperiod. The tanks themselves should be placed in a room (or greenhouse if available) where temperature can be held at a constant 70°(± 2°) (F) temperature. A standard fish tank water heater set to maintain a constant water temperature is a useful addition to the system where water temperature cannot be maintained at 70°F.

Figure 1. Diagram of a hydroponic system for the measurement of root growth capacity.



Since seedlings will not support themselves in the water bath, it is necessary to construct Styrofoam blocks to hold seedlings upright in the aquarium and to prevent them from becoming

immersed in the water above the root collar. These blocks may be constructed from styrofoam building sheathing. Block size and configuration are depicted in Figure 1.

Seedlings should be root pruned to operational lengths prior to being placed into the styrofoam blocks. Excessively long root systems are difficult to handle, and the primary concern is to evaluate seedlings as they are to be planted. Complete cleansing of the roots with a hose is also recommended to avoid the introduction of undue amounts of soil into the water bath which can result in algae blooms during the test. Any white roots on the seedlings should also be removed.

Finally, after placing the seedlings in the tanks, the sides of each tank should be wrapped with aluminum foil to reduce incident light reaching the hydroponic solution. This is to delay the growth of algae during the test and to aid in maintaining constant water temperatures.

Seedlings should be left to grow for 15-24 days before new roots are measured. Test duration is an individual matter but 15-24 days work well for loblolly pine seedlings. For red, scotch and white pines 21 days are preferred. When removing the seedlings to measure roots, carefully lift them from the styrofoam blocks to avoid breaking roots. Each seedling is then scored for the number of new white roots greater than 1/4" in length. While root lengths may also be measured, this is a tedious procedure and adds little to the analysis since number and length of new roots generally correlate extremely well ($r > 0.85$). After experience is gained with the system it becomes very easy to "grade" seedlings into 3-5 groups (i.e., (a) 0-1 new roots; (b) 2-10 new roots; (c) 10-20 new roots; (d) 20-50 new roots; (e)>50 new roots).

Some Thoughts for the Nurseryman

Morphological Traits: Seedbed density, soil amendments and cultural practices all have strong and predictable effects on the morphological traits of seedlings. So the question is: how do the morphological traits relate to seedling quality as measured by RGC? Our research suggests that for loblolly pine, most morphological features of a seedling are not related to RGC. The only exception appears to be the number of fine secondary and tertiary lateral roots. At least during some times of the lifting season, there is a strong positive relationship (DeWald 1986).

This relationship between RGC and root morphology is a good example of the inherent conflicts between "traditional" measures of seedling quality and physiological quality. For instance, root/shoot ratio is supposed to estimate the relative balance between the shoot and the root, good balance indicating a high quality seedling. But, root weight is composed of both tap root and lateral roots. A seedling with most of its root mass in the tap root will likely have low RGC while a root system with most of its root mass in secondary and tertiary roots is more capable of having a high RGC. Root/shoot ratio analysis will draw no distinction between the two types of seedlings while the measure of "physiological quality", RGC, will integrate these factors and yield useful and pertinent information. It has even been suggested that a ratio of shoot biomass to RGC might be a useful substitute for the root/shoot ratio indicator of seedling quality (Feret and Kreh 1986).

Lifting Dates: The date on which a seedling is lifted from the nursery is predicated by soil conditions, seedling demand, availability of seedling storage facilities and other constraints well known to most nurserymen. A potential problem not widely realized is that seedling lift-date has a major impact on seedling physiological quality which can be directly translated into transplant success. RGC varies over the "dormant" season in every temperate pine species in which it has been investigated. What this means is that a dormant seedling is not the same from December to April, that seedling roots are more or less capable of root regeneration without concomitant visual changes in the seedling above-ground plant elements.

For northern species such as white pine, scotch pine and red pine we have found that RGP is low throughout the dormant season, but rises in March for 2-3 weeks, falling again in late March. Thus, in Virginia our data suggests that the strictly biological lifting window for these species is narrow and that lifting prior to March or later than the last week of March will cause decreases in the probability of planting success. These data illustrate for us the necessity of not only paying

heed to the logistical constraints associated with spring lifting, but also to some previously undefined biological considerations.

Seedling Storage: Most nurserymen find it necessary to store bare-root seedlings for varying periods of time to balance inventory with demand. Generally seedlings are held in cold storage (ca. 35-38°F) for periods of up to 2 months. We have routinely stored hand-lifted loblolly pine seedlings for periods in excess of 3 months at these temperatures with no apparent decline in RGC.

Seedling storage is not a straightforward process, however. Seedlings handled operationally often exhibit varying responses to storage (Feret et al. 1985) and may exhibit temperature x length of storage interactions which are not easily explained. In my lab we have been conducting carefully controlled experiments in an attempt to define those factors leading to seedling quality declines in storage. One factor we have recently isolated has to do with the moisture content of stored loblolly pine seedlings. Our findings to date indicate that moisture content inside seedling storage containers is a critical factor, with too much water apparently detrimental to the seedling storage process.

Field Handling: Recently published research has shown that if roots of seedling are allowed to dry during the planting operation, RGC is diminished and this is followed by declines in survival and height growth (Feret and Kreh 1985). No matter what the quality of a seedling is when it is shipped from the nursery, if it is not handled correctly during the planting operation the physiological quality may be harmed (Cleary and DeYoe 1986).

In the Final Analysis...

The credit for the success or blame for the failure of a reforestation program often falls to the nurseryman. This is primarily because he is a convenient scapegoat for the reforestation process. The credits for success may be graciously accepted; the blame for failures routinely denied. Nurserymen should quantify seedling quality. Measures of quality should not just be made when seedlings are shipped from the nursery to forestall blame of failure, but also to gauge the success or failure of cultural practices, lifting procedures and post-harvest handling techniques. Measuring RGC is one quantitative technique well worth considering for this purpose. If the nurseryman can show that seedlings shipped were fully capable of growing new roots when they left the nursery, then planting failure will not be his responsibility. In the absence of better methods for quanitfying physiological quality, RGC should become a routine method of quality testing in forest tree bare-root nurseries.

The use of RGC in quality testing is not the final solution to the day-to-day questions of quality as they pertain to an individual seedling lot. The RGC test takes from 15-21 days and by its completion, the answers it gives are usually too late to be of immediate use. This means that if the RGC test is to make significant contributions to the enhancement of nursery practices, the nurseryman must make the commitment to perform the tests on a routine basis over a period of several years. Primary areas to investigate include the following:

1. Defining RGC changes during the lifting season to allow maximization of RGC by manipulating lifting schedules.
2. Defining the patterns of RGC changes in storage.
3. Estimating the effects of nursery cultural practices on RGC.
4. Establishment of **FIELD TRIALS** in order to obtain data relating RGC to field performance.

Literature Cited

Cleary, B.D. and D. R. DeYoe. 1986. Seedling care and handling. Nat. Woodlands 9(2):15-17.

DeWald, L.E. 1986. Changes in loblolly pine seedling root growth potential over time, during cold storage, and among half-sib families. Ph.D. Dissertation, Dept. of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. 147pp.

DeWald, L.E., and P.P. Feret. 1985. Genetic variation in loblolly pine root growth potential. In: Proc. 18th. Southern Forest Tree Imp. Conf., May, 1985, Long Beach, MS. pp.155-162. Sponsored Pub. No. 40 of the Southern Forest Tree Improvement Committee.

DeWald, L.E., P.P. Feret and R.E. Kreh. 1985. A 15-day hydroponic system for measuring root growth potential of stored loblolly pine seedlings. In: Proc. Southern Biennial Silvicultural Res. Conf., Atlanta, GA. Nov. 7-8, 1984. USDA-USFS Southern Forest Experiment Station. General Tech. Rpt. SO-54, April, 1985. pp.18-24.

Durea, M.L. (ed.) 1985. Evaluating seedling quality: principles, procedures and predictive abilities of major tests. Forest Res. Laboratory, Oregon State Univ., Corvallis, OR. 143pp.

Feret, P.P., R.E. Kreh and L.E. DeWald. 1984. Root growth potential-one tool for evaluating loblolly pine seedling quality. In: Proc. Southern Nurserymans Conference, Ashville, NC. pp. 129-137.

Feret, P.P. and R.E. Kreh. 1985. Seedling root growth potential as an indicator of loblolly pine field performance. For. Sci. 31:1005-1011.

Feret, P.P., R.C. Freyman and R.E. Kreh. 1985. Variation in root growth potential of loblolly pine from seven nurseries. In: Proc. I.U.F.R.O. -Auburn Univ. Symp. on Nursery Management Practices for the Southern Pines. Aug. 4-7, 1985. Birmingham, AL. pp. 317-328.

Feret, P.P., R.E. Kreh and C. Mulligan. 1985. Effects of air drying on survival, height, and root growth potential of loblolly pine seedlings. Si. Appl. For. 9:125-128.

Feret, P.P. and R.E. Kreh. 1986. Effect of undercutting on loblolly pine seedling size and its relation to root growth potential. S.J. Appl. For. 10:24-27.

Jenkinson, J.L. 1980. Improving plantation establishment by optimizing growth capacity and planting time of western yellow pines. USDA-USFS Research Paper PSW-154.

Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: its development and expression in forest tree seedlings. New Zea. J. For. Sci. 10:218-248.

Stone, E.C. 1955. Poor survival and the physiological condition of planting stock. For. Sci. 1:90-94.

Smith, D.M. 1986. The practice of silviculture, 8th ed.; John Wiley & Sons, New York. 527p.

South, D.B., J.N. Boyer, and L. Bosch. 1985. Survival and growth of loblolly pine as influenced by seedling grade-13 year results. S.J. Appl. For. 9:76-81.

Sutton, R.F. 1980. Planting stock quality, root growth capacity, and field performance of three boreal conifers. New Zea. J. For. Sci. 10:54-71.

Wakeley, P.C. 1949. Physiological grades of southern pine nursery stock. In: Proc. Soc. Am. For. Meeting, Dec. 16-18, 1948. Boston, MA, p. 311-322.