Successful Stock Production for Forest Regeneration: What Foresters Should Ask Nursery Managers About Their Crops

(and Vice Versa)

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Introduction

Forest regeneration is a cyclic operation. Seeds are collected from mature trees and planted in nurseries so that the resulting seedlings can be outplanted to the forest after the mature trees are harvested. Similarly, the process of deciding upon, and growing, the best seedlings for that site should be a cyclic process between foresters and nursery managers. The ideal seedling, suitable for all purposes, does not exist. Instead, the ultimate use of the nursery stock controls many aspects of the nursery program. In other words, nursery managers should grow the type of stock that is appropriate rather than the forester having to use whatever the nursery produces. Key to this process is good communication; this facilitates production of seedlings with ever increasing levels of quality for sites for which they are targeted. Thus, target seedlings, grown using the target seedling concept, are the result of foresters' observations and subsequent adjustments in cultural practices by nursery managers.

This is a departure from traditional reforestation seedling production. Nursery management and reforestation in North America have progressed tremendously since the first large scale forest nurseries were established in the early 1900s. In those days, the reforestation process was very simple and linear: nurseries produced seedlings that were then shipped for outplanting. Foresters took what was available and there was little choice. Tree planting was a mechanical process of getting seedlings in the ground in the quickest and least expensive manner. Not much thought was given to seedling quality or the possibility of using alternative stock types.

Since about 1975, however, more science has been infused into the reforestation process. New research into seedling physiology, along with better-educated customers has revolutionized traditional concepts of reforestation and restoration. We now understand much more about how seedlings function—both in the nursery and after outplanting. In particular, the advent of the container seedling showed the importance of nursery cultural practices and vividly demonstrated important concepts like hardiness and dormancy (Tinus and McDonald 1979). Today's seedling customers are very well educated and have high expectations; they know what they want; and they have many choices.

The target seedling concept is relatively new, but the basic idea can be traced back to the late 1970s and early 1980s when new insights into seedling physiology were radically changing nursery management. During this time, several books were published on seedling quality (e.g., Duryea and Brown 1984; Duryea 1985), and these served as precursors to the target seedling concept. In searching the literature, we found nothing published on target seedlings before 1990. In that year, however, a symposium to discuss all aspects of the target seedling was held and the resultant proceedings are still a major source of information on the subject (Rose et al. 1990).

Therefore, successful production of reforestation seedlings for outplanting sites requires that foresters and nursery managers agree on the biological and business parameters associated with seedling production. Although it sounds like these parameters are distinct, they truly overlap and influence each other, illustrating another reason why communication is essential to success.

In this paper, we discuss the business and biological parameters, posed as questions, that foresters and nursery managers must discuss candidly to ensure successful reforestation.

What is the Target Seedling?

A target seedling is a plant that has been cultured to survive and grow on a specific outplanting site. Defining a target seedling requires answers to six questions. Usually, the first five questions should be asked and answered by the forester and then relayed to the nursery manager. Together, the forester and manager can work out the answer to the sixth, and perhaps most important question: What is the ideal stocktype?

1. What is the outplanting objective?

The reason that seedlings are being outplanted will have a critical influence on the characteristics of the target seedling. In traditional reforestation, commercially valuable tree species that have been genetically improved to enhance yield are outplanted with the ultimate objective of producing saw logs or pulp. These objectives and resulting target seedlings should not be confused with seedlings targeted for other restoration projects dealing with riparian enhancement, conservation windbreaks, or ecosystem management purposes. Seedlings grown specifically for those types of projects may not have the characteristics needed on typical reforestation sites. Similarly, seedlings destined for fire restoration projects or for planting under shelterwoods or on obliterated roads may require additional characteristics or modifications not found on typical reforestation target seedlings (Landis 2002).

2. Should you use source-identified or genetically-improved seeds?

Before ordering nursery stock, several genetic concepts should be considered. All nursery managers and reforestation specialists are familiar with the idea of seed source. They know that plant species vary throughout their geographic range because they are adapted to local site conditions. Using a local seed source and collecting from enough individuals to maintain high genetic diversity are basic tenets of reforestation ecology. Proper seed source can be guaranteed through the use of seed zones, and so the location and elevation of seeds must always be recorded and included in the seed source identification code. For species without clearly defined seed zones, seeds should generally be collected as close to the outplanting site as possible.

Genetically improved seeds should be used if the project objective is rapid growth and uniform stand structure, or if disease resistance is needed for restoration. For example, Weyerhaeuser Company grows many of their seedling by genetic family as a way to minimize growth variation in the nursery and obtain faster growth rates in the resulting plantation (Carlson 2003).

3. What factors may limit seedling growth on the outplanting site?

The specifications of the target seedling should be developed by identifying environmental factors that will be most limiting to survival and growth on each particular site. For example, a fire restoration site in eastern Oregon USA might have shallow soils and competition from grasses for moisture and nutrients. In the mountains of northern British Columbia, Canada, however, cold soil temperatures are a limiting factor. In the mountains of Arizona and New Mexico USA, it might be lack of the summer monsoon rains. Other limiting factors might include herbivory, shallow or rocky soil, early or late-season frosts, flooding, vegetative competition (including other trees in a shelterwood), soils with physical properties modified by wildfire, and known root disease pockets.

4. When will seedlings be outplanted?

The outplanting window is the period of time in which environmental conditions on the project site are most favorable for survival and growth. As mentioned in the previous section, soil moisture and soil temperature are the usual constraints. In the Pacific Northwest USA, seedlings are usually outplanted during the rains of winter or early spring. In the mountainous portions of the western USA, stock is normally outplanted as soon as the snow melts; however, a summer outplanting window with specially conditioned “hot planted” nursery stock is recommended on some high-elevation or high latitude sites. In the interior portions of the western USA that are affected by monsoonal moisture, late summer outplanting may be desired. In the southeastern USA, seedlings are planted from late fall through winter. It is important to assure that plants of optimal quality (see below) are timed to be available during the limited outplanting window.

5. How will seedlings be outplanted?

Each outplanting site has an ideal planting tool. All too often, foresters develop a preference for a particular implement because it has worked well in the past. No single tool, however, will work under all site conditions. Special planting hoes called hoedads are popular in the steep terrain of the Pacific Northwest USA, but the level terrain on the Kenai peninsula in Alaska USA or afforestation sites in the Midwest and southeastern USA allow machine planting.

6. What is the ideal stocktype?

Using all of the answers to the first five questions, the nursery manager and forester should candidly discuss stocktype options. Ideally, they decide on the general “look” of the seedling needed. That is, short and stocky for tough sites; small volume containers or 2+0 seedlings for typical, high-quality, low competition sites; tall, stocky, large volume containers or 2+2 seedlings for use under shelterwoods; etc. If only a bareroot facility nursery is nearby, then stocktypes are limited to seedlings (1+0, 2+0, 3+0) or transplants (1+1, 1+2, 2+1, 2+2, etc.). Perhaps 10 or so stocktypes are possible. If only a container nursery is nearby, the potential number of stocktypes is several magnitudes higher. A myriad of containers is available, from 8 ml to 3200 ml, with or with copper coatings, with or without air slits in the sides. Within these choices cavity density is another variable, as is the type of material used: Styrofoam® or polyethylene. If both types of nurseries are nearby, then foresters also have the option of outplanting bareroot–container hybrids, commonly referred to as “plug plus” seedlings. These seedlings usually take advantage of the quick and uniform growth possible in the greenhouse, and then the plug seedlings are transplanted into bareroot beds where extensive, fibrous root systems and large stem diameters are possible. Again, a gamut of stocktypes are possible because plugs can range from a month or two in age to a year, and they can be grown in bareroot beds for a month or two to a year or two. A seedling grown one year in the container and one year in a transplant bed would be a “plug + 1" or more commonly, “P+1.”

Once the general morphology of the target seedling is decided, and a stocktype selected that will yield that target, the next step is determining production time.

How Long Will it Take to Produce the Target Seedling?

Crop schedules help foresters understand the time required by nurseries to produce crops. In a contract, these schedules can help both entities plan their work and ensure that planting stock are produced as needed. The best approach for determining crop schedules, or propagation protocols, is to “work backward,” starting at when the seedlings need to be on the outplanting site and then working backward to when the process needs to be initiated (Landis and Dumroese 2000). Although generally only showing the nursery production phase, foresters could include the time needed to harvest cones and scout seed crops from select trees. Schedules will vary by species and stock type (Table 1).

In Production, Who is Responsible For What?

It Starts with Seeds

Both the forester and nursery manager should consult the propagation protocol described above to agree on when seeds need to enter the production timeline. This is necessary so that seeds are supplied, treated (i.e., disinfesting, cold stratification, upgrading), tested (germination, purity, seeds per weight), and sown to meet the outplanting deadline. Although nursery managers are careful with maintaining seedlot integrity, foresters may wish to ask how quality assurance is achieved to ensure they receive the correct seedlings after nursery production.

Planning Along the Way

To ensure that proper resources are committed and scheduled for outplanting the seedlings, foresters need to know the progress of their crop as it grows in the nursery. Usually, it is helpful if the nursery managers provide inventory numbers at logical times throughout the production cycle. Often, the first inventory is “occupancy,” indicating what percentage of containers have a seedling, or “emergence,” an estimate of seedlings per square area of bareroot bed. Usually completed about a month after sowing, this inventory can alert foresters if a large deficit or overage may be occurring in the crop. A second inventory at about the time of bud initiation refines the number of expected plants. A third inventory in the fall can further distill the number of seedlings expected, but the final inventory at harvest provides the definitive number. The forester can use these values as the outplanting time draws nearer to adjust planting contracts and crew logistics. The timing of inventories should be described in the contract. A contract proviso should also address what to do when more seedlings than needed by the forester are produced, and conversely, what penalties should be imposed when inventories fall short.

Assessing Seedling Quality

This is the prickliest portion of the contract for the forester and nursery manager to agree upon—therefore ongoing communication is essential. “Seedling quality” is a euphemism we use to describe how well a seedling is expected to survive and grow after outplanting (Duryea 1985; Mattsson 1997). Another way to describe seedling quality is whether or not the nursery stock meets management objectives—quality then is “fitness for purpose” (Ritchie 1984). Therefore, seedling quality can only really be evaluated after outplanting. So, as you can see, foresters and nursery managers need not only agree on a definition of quality but on how to measure it (Wilson and Jacobs *in press*). [Colombo et al. (2001) segregate seedling characteristics into four categories: physical, physiological, chemical, and pest status, but for brevity in this paper we consider physical and pest status to be morphological and physiological, respectively, and chemical to be physiological.] Fortunately, morphological quality can be easily discerned as seedlings are being harvested from the nursery, but physiological quality is often more difficult, or time consuming, to assess. Therefore, foresters and nursery managers have traditionally focused on morphology (Ritchie 1984),

Table 1. *Hypothetical timeline (shown in reverse order) for production of container pine seedlings in the western USA, beginning with the forester checking trees for cones through outplanting. This scenario requires 36 months (three years).*

Month	Activity	Responsibility
1 - Mar	Outplanting	Forester
2 - Feb	Thaw crop / pick up crop	Manager / Forester
5 - Nov	Harvest crop & put into storage; provide final inventory to forester	Manager
6 - Oct	Test cold hardiness prior to harvest	Specified in contract
7 - Sep	Inspect crop & agree on acceptable seedling specifications — preharvest inventory	Manager & Forester
9 - Jul	Initiate hardening	Manager
11 - May	Inventory and provide to forester	Manager
13 - Mar	Sow crop	Manager
16 - Dec	Stratify seeds based on seed tests	Specified in contract
19 - Sep	Begin testing seeds	Specified in contract
20 - Aug	Harvest & process seeds	Forester
21 - Jul	Sign contract	Manager & Forester
22 - Jun	Meet and discuss target seedling specifications	Manager & Forester
23 - May	Confirm cone collection	Forester
31 - Sep	Confirm cone collection	Forester
35 - May	Look for developing female cones	Forester
36 - Apr	Select “plus” trees for cone harvest	Forester

but, ideally, all parties should be concerned about both because these seedling quality assessments can be intricately related (Grossnickle et al. 1991; Colombo et al. 2001).

Morphological quality

In contracts, and depending on the target seedling, morphological characteristics such as minimum and maximum acceptable heights and stem diameters, sturdiness quotient (height:diameter), incidence of forking, bud set, plug firmness, presence of mycorrhizae, and incidence of pests or disease are commonly used. Other morphological metrics might include first-order lateral roots (especially for bareroot hardwoods), shoot-to-root ratio, and root volume. They can be straight forward and definitive; for example, container seedlings must be 10 to 15 cm tall with a stem diameter > 2.7 mm, no forks, firm rootplug, and disease free. From the forester’s perspective, these quality specifications may sounds good. From a nursery manager’s perspective, they may seem precarious. A manager might be concerned that a forester who didn’t get the outplanting site properly prepared might refuse the seedling crop because *Fusarium*, a potential pathogen, is present on 80% of the crop, even though the seedlings look healthy and the strain of *Fusarium* might have little or no virulence. Or, perhaps the seedlings are all 20 cm tall with stem diameters > 4 mm. They could be rejected by the aforementioned forester for being too tall even though the sturdiness coefficient is 5 (or 50:1), a potentially better value than the 15 cm tall – 2.7 mm diameter seedling (5.6 [56:1]). Or, how exactly do we define a “firm” rootplug, knowing that we need sufficient roots to maintain plug integrity but that too many roots, and root binding, might lead to toppling in plantations? Clearly, the forester and nursery manager must agree on some flexibility in interpretation of the morphological specifications, and resolve how, and when, and by whom the final decision on acceptance or decline of stock is made. Morphological assessments are usually made immediately prior to crop harvest, often synchronized with a pre-harvest inventory. But, this is only half of the story—seedlings of high morphological quality might have low physiological quality (Stone and Jenkinson 1971), or, may even be dead!

Physiological quality

A variety of physiological quality tests are available to evaluate seedlings for reforestation, including root growth potential (or capacity); electrolyte leakage from fine roots, taproots, shoots, needles, and buds; water potential; root moisture content; root carbohydrate levels; mineral nutrition; chlorophyll fluorescence; stress-induced volatile emissions; photosynthesis; and bud dormancy status. Colombo et al. (2001) compare most of the popular tests and provide estimates on ease of assessment, equipment costs, and time required to obtain results. Although most seedling physiological assessments have been developed for conifers, some have applicability to hardwood crops, whereas others do not (Wilson and Jacobs *in press*). For example, chlorophyll fluorescence, a rapid nondestructive test is often done on conifer foliage during the winter dormant period to monitor physiological changes related to harvesting and storage, but is less useful on hardwood seedlings without leaves (Wilson and Jacobs *in press*). So, it is important for foresters and managers to realize that no single test can predict outplanting performance (a “silver bullet” does not exist as per Puttonen 1997), and that physiological tests are mere “snapshots” of seedling viability at the time of the test. Whereas a seedling measured before and after storage will have the same height and stem diameter, cold hardiness values will be different before and after storage, and perhaps vary greatly if the storage conditions were severely affected by a prolonged mechanical disruption.

Therefore, foresters and managers, reviewing their description of the target seedling, should determine which factors are most limiting on the outplanting site and focus physiological tests toward those factors. For example, if the site has low nutrient availability, then perhaps a target calls for loading the seedlings via exponential fertilization (Timmer 1997); an appropriate physiological test would be to measure foliar nitrogen content to ensure the values are optimal. Conversely, if severe browsing is expected on a south-facing clearcut in the mountains of the western US, the same test might be advised to ensure a lower nitrogen concentration to discourage browse (Bergquist and Örlander 1998). Or, if the site is harsh in terms of temperature extremes and low moisture availability, a test of frost hardiness might be appropriate—seedlings with high resistance to cold temperatures may better tolerate other stresses as well. Thus, maximizing cold hardiness may infer advantage over seedlings with low cold hardiness.

Seedling quality assessments are also helpful if it is believed the stock has been damaged during production, storage, or shipping. For example, a freak cold event killed the roots of a container crop just days before harvest. The manager had a root growth potential test and a plant moisture stress test completed before harvesting the crop—the tests confirmed that the seedlings were dead, even though they still “looked” fine, saving the manager the expense of harvesting and storing while also providing the forester sufficient lead time to secure seedlings from other sources.

Because physiological tests are “snapshots,” no single test is definitive, conducting tests can be costly, and results are open to interpretation, it is imperative that foresters and managers agree on basic tests to conduct on crops, who pays for the testing, and who interprets results. A minimum testing regime might include a cold hardiness test to ensure the stock is ready to be stored and a post-storage root growth potential test to ensure the seedlings are alive and able to produce new roots.

Storage and Shipping

Seedlings may spend 30 to 50% of the nursery production cycle in storage, or, in the case of container seedlings in the southeastern US or Intermountain areas of the western US, they may be “hot planted” with little or no storage. Traditionally, seedlings destined for spring outplanting are stored overwinter, either in cooler storage for short terms (0^0 to 2^0 C; 1 to 2 months) or cold (freezer) storage for longer terms (-2^0 to -4^0 C; 2 to 6 months). These storage temperatures promote dormancy release (van den Driessche 1977) but at suboptimum rates (Anderson and Seeley 1993) so that stored stock retain higher levels of dormancy and stress resistance than non-stored stock when removed for outplanting. Freezer-stored stock maintains food reserves better than cooler-stored seedlings (Ritchie 2004) and substantially reduces growth of storage molds (Sutherland et al. 1989).

Many nurseries still rely on natural, outdoor storage in the hope being that snowfall will blanket seedlings and insulate them through winter. Using snow-making machines reduces the risk factor. Additionally, many nurseries only have access to cooler storage. Both of these methods can provide satisfactory overwintering of stock. Prudent foresters should ask nursery managers how, and how often, the stock is evaluated during storage to ensure that temperatures are suitable for storage and that storage molds, which can spread rapidly at temperatures just above freezing, are not a problem.

If the stock is frozen, the most critical phase is thawing. Foresters and managers need to agree on the thawing technique and post-thawing handling procedures. Ideally, stock should be thawed very rapidly because several detrimental things can happen during thawing. Uneven thawing between seedlings on the outsides of pallets and boxes and seedlings deep in interiors can result in vast differences in loss of stress resistance, depletion of food reserves, and perhaps even desiccation (Ritchie 2004). And, storage molds can proliferate rapidly. Ideally, pallets should be widely spaced and boxes within pallets rotated to facilitate air movement and promote uniform thawing.

For container stock, it may be possible to outplant seedlings with frozen plugs, avoiding the need for thawing. Recent work by Kooistra and Bakker (2002) demonstrates the applicability of this technique. If foresters wish to use this technique, they must ask managers how the seedlings will be packaged—the seedlings must be wrapped so that root plugs don't touch and freeze together, which would necessitate thawing on site and delays in planting.

One final thought on "hot planting"—if this technique is used, it is essential that the forester ask the manager how the crop will be hardened before outplanting. Even though the seedlings may still be actively growing, the manager can condition the seedlings for the rigors of outplanting by manipulating irrigation frequency and perhaps moving the stock outside if they were growing indoors to acclimate to the ambient exterior environment. Seedlings with succulent growth will perform poorly if hot planted.

It may be a good idea to pack small temperature recorders, such as I-Buttons® or Hobo® recorders, into several boxes during harvesting so that storage and thawing temperatures and durations can be evaluated and critiqued toward improving the entire process. Again, the contract should indicate who is responsible for obtaining, placing, and retrieving monitoring devices and how the data will be interpreted. It may also be prudent to include these during shipment from the nursery to the field, even for hot planted seedlings, to ensure proper temperatures were maintained.

What About Follow-Up?

Often, foresters use "stake lines" or "regen circles" to assess outplanting performance, particularly survival and often growth (Neumann and Landis 1995). These types of survey points should be placed in areas representative of the overall outplanting site. Seedlings should be outplanted by a variety of planters to ensure the incompetence of one planter does not invalidate all of the data. It is also a good idea for the nursery manager to retain a few seedlings—these should be randomly removed from boxes at the moment the seedlings leave the nursery and either transplanted into a nursery bed or into some pots to see how well they perform under optimal conditions. This simple practice will help with diagnosis if an outplanting failure occurs.

For those wanting to make empirical comparisons of stock type performance on outplanting sites for their own purposes, the general physiological condition and morphology of the stock should be measured or, at least, described. A recurring problem is growing seedlings in several different types of containers or as different bareroot stock types but only using one fertility and irrigation regime—this can cause broad discrepancies in seedling quality and invalidate any conclusions on the outplanting site. It is the combination of physiological and morphological characteristics and their interactions with the environment rather than stock type, per se, that will largely determine how the stock performs. Keep in mind that large stock generally grows larger faster than small stock, so measuring growth increments may be more insightful than total growth. Also factor in the additional costs of larger stock, both in production and planting costs, and seedling survival. It may be that planting fewer seedlings from "higher quality" stock on a site is more economical than planting more "acceptable quality" seedlings (South et al. 2005). Another caution about stock type comparisons is to not draw conclusions about survival and growth too soon. Monitoring should be done at the end of the first growing season, but it might take five or more years to be reasonably sure about survival and growth differences. We recommend that test plots be examined at least every second year.

Completing the Cycle

As the forester collects and analyzes data from the field, ideally that information is shared with the nursery manager. Hopefully, this stimulates an eagerness by the manager to periodically manipulate the propagation protocol to further enhance outplanting performance.

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