CHARACTERISTICS OF SEEDLINGS WITH HIGH SURVIVAL POTENTIAL 1/

Richard W. Tinus 2/

Abstract.--To survive, (1) species and seed source must be adapted to the site, (2) the seedlings must be in the proper physiological state to meet the new environment, and (3) root contact with the soil must be quickly established. In contrast to outdoor-grown bare-root seedlings, the physiological state of greenhouse seedlings can be more precisely controlled, and containerized seedlings do not lose root contact with the soil.

REQUIREMENTS FOR SURVIVAL

Genetically Adapted

The first requirement for survival is that the species and seed source be adapted to the site on which the seedling is planted (Hawley and Smith 1954). This is one of the basic tenets of forest genetics and is part of every forester's education. Yet planting the the wrong species or the wrong seed source has probably been responsible for as many failures as any other factor. Following either of these two simple rules would prevent many such problems:

(1) Use a good local seed source. This assures that the next generation will be genetically as good as the last. In the Southeast where climate is uniform over a wide area, "local" may be interpreted very broadly. But in the West where climate may vary dramatically within short distances, exact location of seed source may be very important (Hite 1974).

(2) Use seed that has been tested and proven better than the local source. Seed collection zones are guides to suitable wild seed. Select seed production areas and seed orchards are sources of superior seed.

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2/Principal Plant Physiologist, Shelterbelt Laboratory, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Bottineau, North Dakota 58318.

Match Seedling Condition to Season

After growth in the nursery, our genetically adapted seedling must be placed in proper physiological condition for outplanting. This is necessary because the planting site climate is likely to be different from that of the nursery. There will be no irrigation, microsite soil conditions will be less uniform and probably less fertile, and there will be little or no protection from competition, diseases, or predators beyond the original site preparation. Furthermore, site climate is not static. Most planting is done in the spring or fall when the season is changing most rapidly. The seedling must be ready and able to respond to these changes.

Being moved from nursery to planting site stresses the seedling. It is best able to withstand stress when it is well watered, well nourished (both mineral nutrient and food reserves are high), uninjured, and dormant (no shoot growth).

Growth Response Needed

After it is outplanted, the seedling must quickly extend new roots into the surrounding soil (Sutton 1974). Failure to do so is fatal. After root establishment, the seedling must flush and grow in height to dominate competing vegetation. Finally, planted seedlings frequently have misshapen root systems. There is increasing evidence that the nurseryman and planter must exercise some control over root system configuration so that the tree will live long enough and grow fast enough to do its assigned job. This is a long term problem; rarely will a tangled, coiled, J-rooted root system kill a seedling quickly.

For the seedling to become established the environment must be favorable. Initially, moisture and temperature are the most important. Tree moisture stress of 4 to 12 bars, depending on species, stops root growth (Leshem 1970, Stone and Jenkinson 1970). Low soil temperature also stops root growth (Sutton 1974, Bilan 1967). Although there have been reports of root growth at freezing temperatures, roots of most species do not grow much below 5 to 7 degrees C (Hoffman 1971). High temperature accelerates desiccation and raises respiration rates. At high temperature respiration may exceed photosynthesis even in bright light, and food reserves will be depleted (Eliasson 1968, Kreuger and Trappe 1967, Ronco 1973). Without food reserves no growth can occur.

Light can be intense enough to cause solarization (Ronco 1970), but more often it is too low because of shade from competing vegetation. In addition, the whole host of environmental factors that affect seedling growth will also affect survival.

HOW TO MAKE IT HAPPEN

So far I have said nothing about container seedlings. That is because the requirements for survival in the field are the same whether the seedling is container grown or bare-root. The difference between the two is in the way they are equipped to meet the new environment.

Root System

The bare-root seedling has lost all contact with soil and has lost a portion of its fine roots. Loss of roots can be minimized by root pruning, undercutting, and wrenching (Sweet and Rook 1972) in the nursery. This promotes the development of a fibrous root system close to the surface which will not be severed when the tree is lifted. Stressing the tree also retards height growth and helps balance evaporating area against water-absorbing capability. Care in lifting, grading, packing, and planting also help retain fine roots.

There is no way to replant a bare-root seedling as well as it was planted in the nursery. Usually the roots are pressed into a two dimensional spray. Even dead roots can function for a while to absorb moisture, but the volume of soil to which they have access is very limited, especially at soil moisture levels below field capacity (Good and Tukey 1969). Therefore, new roots must grow into the surrounding soil, and to do so the seedling needs a high root regenerating potential (RRP). Stone and coworkers (Stone 1955, Stone and Schubert 1959b, Stone et al. 1962) in California found that root regenerating potential of ponderosa pine and Douglas-fir varied considerably with the season. The timing of maximum RRP also varied from one year to the next (Stone and Schubert 1959a, Stone and Bensler 1962), and from one nursery to the next (Stone et al. 1963). Cold nights promoted RRP, but more cold nights were required than were required for bud break (Krugman and Stone 1966).

Therefore, nurseries should test their stock for RRP and lift only when it is high. It is apparently better to lift at high RRP and store than to lift without regard to RRP and ship without storage (Stone and Bensler 1962).

The container-grown seedling, on the other hand, should lose practically none of its roots during removal from the nursery, shipping, and planting. Furthermore, container seedlings are outplanted with little or no change in the intimate contact between soil and root. More than anything else, it is the intact and undisturbed root system that accounts for the superior initial survival and growth of container over bare root seedlings, and this is demonstrated by the following experiment.

In 1972 and 1973 we grew several thousand seedlings in large book planters and outplanted them along with bare root stock at 33 sites in North and South Dakota. Planting procedure was to grasp the tree by the stem, pull it from the container, and place it in the planting shoe. Most often the rootball would be withdrawn intact, but sometimes part or all of it would be lost. The man on the tree planter spoke into a tape recorder giving an estimate of the percent rootball remaining on each tree as it was planted. The following fall when survival and height growth measurements were taken, the trees could be grouped according to percent rootball when planted. Table 1 shows that both survival and growth decreased as rootball was lost.

Table 1.--Effect of percent rootball on survival and growth of ponderosa pine

Rootball	1st year survival 1972	1st year survival 1973	1st year growth 1972
Percent	Percent		cm
100	95a	92a	4.2a
75	90ab	72b	3.7b
50	85b	78b	3.0c
25	87b	40c	3.0c
0	79c	15e	2.6c
Bare-root	89b	26d	3.0c

Numbers within columns followed by the same letter are not significantly different.(p=.05)

Complete loss of rootball was worse for the tree than if it had been grown outdoors and lifted as a bare-root seedling. The 1972 plantings were made as early as possbble in the spring. The weather was cool and moist; 1973 plantings were made in late spring and early summer when the weather was hotter and drier. It is apparent that loss of rootball is most serious under adverse conditions.

Does root damage have any beneficial effects at all? Destruction or injury of growing terminals does promote root branching (Horsley 1971, Wilson 1970). Good horticultural practice for planting containerized shade trees involves slicing the sides of the rootball and removing the twist of roots at the very bottom (Harris et al. 1967). This procedure stimulates root growth, but it is usually severe enough to retard top growth even under irrigation, and it is not the way to plant trees in the forest by the millions.

Planting Season

The most desirable physiological condition of the seedling is determined by the season in which it is planted (table 2).

Winter plantings are possible only in climates where the ground does not freeze. Day temperatures must be warm enough to avoid damage to exposed roots of the seedlings.

Early spring plantings are probably the most widely practiced and universally successful. As the season advances and the weather becomes hotter, and in many areas drier, planting success declines. There are many valid reasons for late plantings, including logistic (couldn't plant sooner) as well as site problems such as cold soil in the boreal forest or snow in the mountains.

Summer plantings are reserved for those areas with adequate summer rainfall. Bare-root success has generally been poor, but prospects for success of container stock are much better. One reason for poor success is that higher temperatures desiccate the seedling faster and do not allow time for enough root growth to replenish the loss. Early summer is when the shoot is flushing (Lathrop and Mecklenburg 1971), and root growth is usually minimal. To plant bare root stock during active flushing is to court disaster. I have successfully planted container grown ponderosa pine during active flushing, but I can't recommend it until we gain more experience.

By late summer most trees have stopped top growth and set buds. At this time there may be a renewed surge of root growth which continues into the fall. In many areas fall is a favorable time to plant, but the most frequent problem with bare root stock is that the season at the planting site is more advanced than it is at the nursery. The stock is not ready to be lifted at the nursery until winter almost closes the planting site.

Table 2.--Physiological condition and growth response required as a function of planting season

Time of year	Usual planting success	Seedling condition needed	Growth response needed after planting
winter	good in climates that permit	deep dormancy fully cold hardy	1. active root growth 2. top remain dormant until spring 3. break bud and flush
early spring	best	post dormant cold hardy	1. active root growth 2. break bud and flush
late spring early summer	good to poor	post dormant, but not flushing	1. active root growth 2. flush
late summer	poor	non-dormant, flush completed buds set	1. active root growth 2. may or may not flush that year
fall	good	flush completed buds set dormant cold hardiness developing	1. active root growth 2. enter deep dormancy 3. develop full cold hardiness

Conditioning the Trees

The nurseryman has much more control over the environment, and therefore, the physiological condition, of greenhouse grown containerized trees than he does outdoor grown bare-root seedlings. By manipulating the environment he may cause the seedlings to be in the correct state for outplanting at times when outdoor grown seedlings would not be. How does he do this?

The nurseryman has much more control over the environment, and therefore, the physiological condition of greenhouse-container grown than he does outdoor grown bare-root seedlings. By manipulating the environment he may cause the seedlings to be in the correct state for outplanting at times when outdoor grown seedlings would not be. How do you do this?

During growth of the seedling the objective is to prevent dormancy. This is done with extended photoperiod, warm temperatures, adequate watering, high nitrogen diet, and high CO_2 atmosphere.

When the seedling reaches desired size, these factors are modified to cause dormancy. Trees rarely change their growth patterns suddenly in nature, but they must in the greenhouse, because time is money. Growth can be stopped quickly by applying moisture stress. This stress in combination with shortened photoperiod and low N, high PK fertilization induces shoot dormancy in many species. For some species lower temperatures may also be necessary.

Moisture stress is just a shock treatment, however, and should not be maintained any longer than necessary. The natural photoperiod may be short enough to induce dormancy between October 1 and March 15, but in the summer and especially at high latitudes, it will probably be necessary to shorten the photoperiod artificially by covering the seedlings (Tanaka 1974). As soon as a bud has formed and the upper stem has lignified, seedlings are ready to be outplanted, provided they will not encounter freezing conditions.

There may be situations where dormancy is not required. We have found that seedlings can be shipped from the greenhouse with no conditioning at all. The trees may be very young seedlings that are still producing juvenile foliage; a seedling has to reach a certain stage of growth before it is possible to become dormant. Another case would be that the difference between greenhouse climate and planting site climate is minimal. This may occur in the Southeast in the summer.

Trees that grow in distinct flushes have the cells for the next flush laid down in the bud. The bud must be well developed for the tree to flush vigorously (Kozlowski et al. 1973, Curtis and Popham 1972, Sucoff 1971). Therefore, if the seedling is expected to flush after outplanting, enough tine under short photoperiod and moderate temperature must be allowed, not just to enter dormancy, but to fully develop the buds.

If the seedling will encounter subfreezing temperatures, it must also be cold hardy. Shoot dormancy is necessary before cold hardiness can develop, but dormancy and hardiness are not the same (Weiser 1970, Mityga and Lanphear 1971). While photoperiod controls dormancy in many species, full cold hardiness develops only at low temperature (Steponkus and Lanphear 1969). A good greenhouse regime is a night temperature of 1 to 3°C and a maximum day temperature of 10°C. Our experience at Bottineau has been that 5 weeks of the above regime will fully harden quite a range of conifer species. If it is not possible to hold greenhouse temperatures that low, the trees can be moved to a cooler, but they will not harden properly in the dark (Hurst et al. 1967, van den Driessche 1970, Zehnder and Lanphear 1966). We have successfully hardened ponderosa pine and blue spruce in a cooler by adding about 1000 lux of fluorescent light 10 hours per day.

Low temperature and short photoperiod have several effects. Cold hardiness develops, and the chilling requirements for bud break and development of RRP are met. These are apparently three independent processes which proceed simultaneously but may take different lengths of time. For fall planting only enough cold hardiness is needed to put the seedling in phase with the season at the planting site. Winter will take care of the rest. For early spring planting full cold hardiness is needed. The chilling requirements must be met, otherwise the bud will not break properly.

Healthy Trees Needed

Besides proper state of dormancy or growth, the seedling should be shipped in the best possible health, uninjured and unstressed. According to Winjum (1969)3/ bare-root Douglas-fir lifted when under low internal moisture stress (10 pounds as measured with a pressure bomb) arrived at the planting site with low internal moisture stress. If lifted under high (350 psi) stress, recovery was only partial (to 150 psi) even though water was added to

3/Winjum, John. 1969. Forest Regeneration Manager, Weyerhaeuser Co., Centralia, Wash. Personal communication.

the plastic lined bag in which the seedlings were enclosed. This would indicate that lifting should begin very early in the morning and cease when stress becomes high. Perhaps if seedlings had to be lifted in the afternoon, they could be treated with an antitranspirant or spray irrigated to maintain low internal stress. Container seedlings probably would recover from moisture stress more quickly because of their undisturbed root system, but they, too, should be well watered before leaving the nursery.

Large healthy buds, especially the apical bud, are important to the survival of the tree. Damage to the apical bud is serious, because loss of apical dominance can delay height growth several years which increases the chance that the tree will succumb to competition. The damage may occur in several ways. If proper rearing procedure is not followed in the nursery, the buds may be small, immature, or not capable of breaking. Buds may be damaged by careless handling in the nursery, in shipment, and in planting, but this, too should be largely preventable. High moisture stress after planting may kill the bud or at least prevent it from breaking. The latter may be just as serious as an outright kill, because buds that do not break on schedule may degenerate.

Seedlings should leave the nursery with adequate internal mineral nutrient and food reserves, because until they become well established, they will have limited ability to extract these from their new environment. In this regard container seedlings have an immense advantage over bare-root stock. Not only can their internal supply be adequate, but they have access to an external supply several times larger than possessed by the seedling internally (Day and Skoupy 1971). Food reserves are required for root growth. High temperatures and moisture stress may cause respiration to be greater than photosynthesis. The larger the initial food reserve, the longer a seedling can tolerate a net loss.

One last point deserves mention. Initial survival and growth are of no value, if they are gained at the expense of creating a defect that will kill the tree or slow its growth before the tree has accomplished its purpose. One such shadow is the possibility of serious root deformities produced by the container in which the seedlings are grown (Ben Salem 1971, Donald 1968). Some species seem to recover from a balled up root system after outplanting and others don't. Some containers produce less root deformity than others (Hiatt and Tinus 1974). Unfortunately, we do not know how much deformity a tree can tolerate and still perform the way we want it to.

SUMMARY

Let me summarize. A seedling must (1) be genetically adapted to the site, (2) be in the proper state of dormancy and hardiness to match the season, and (3) be healthy, uninjured, and unstressed when planted. Its first and most important growth response must be to establish root contact with the soil. After that, it must grow in height.

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Question: Is top pruning recommended if the seedling shoot is too tall in relation to the root system?

Tinus: There must be a better way to control the shoot:root ratio than to cut off the terminal. I don't like to see top pruning for two reasons: (1) The larger seedlings are probably genetically better seedlings that should be favored. Once top pruned, you don't know which they are. (2) If a tree loses its terminal bud, another has to take over before the tree resumes height growth. For some species in some situations terminal replacement can happen very quickly; in such cases, loss of the terminal is not serious. For the conifers in our areas, loss of the terminal bud means the tree remains a cabbage for as long as 3-5 years.

Question: How do you determine highest root regenerating potential before seedling delivery to the planting site?

Tinus: See papers by Stone and coworkers. They lifted seedling samples, put them into a controlled environment under good growing conditions, waited for a period of weeks, then pulled them up and counted the new white root tips. Presumably, once you've gone through this procedure for your nursery and your conditions, you should know when peak root regenerating potential occurs, with allowance for weather conditions. For instance, 90 days with a night temperature below a certain level were required for development of high root regenerating potential at one nursery. Once this relation is established, you don't have to test each batch before shipment.

Question: Since you advocate planting dormant stock, how can you hope to obtain either effective moisture supply, nutrition, or anchorage in the new field environment?

Tinus: We want the shoot to be dormant. It is possible for the roots to grow at their maximum, when the shoot is dormant. When the shoot is actively flushing, it generally has first call on the food reserves of the tree, and that means root growth is minimal.