

A Review of Tree Seedling Undercutting

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INTRODUCTION

Historically, many bare-root tree nurseries have been plagued with paltry survivorship of their transplanted seedlings. One method employed by some nurseries to try to remedy poor survivorship is to physically manipulate the seedling's roots. Root pruning often times leads to the regeneration of healthy, fibrous root system. A well developed seedling root system is pivotal to survivorship, establishment, and growth of transplanted trees (Harmer and Walder, 1994).

The term root undercutting is generally used to describe a form of root manipulation. In general, root pruning is an umbrella term which refers to the above ground root trimming while undercutting is best applied to the severance of the plants roots *in situ* in the nursery seedbed (Sutton, 1967; Sutton and Tinus, 1983). The undercutting of roots is accomplished by drawing a horizontally mounted, thin, sharpened blade through the nursery bed, severing roots along the way (Hobbs *et al*, 1986).

The primary objectives of undercutting are to restrict seedling shoot growth, improve overall root fibrosity, decrease shoot-root ratio and precondition seedlings for out-planting (Hobbs *et al*, 1986). In addition, root undercutting is used to aerate the soil, improve infiltration and improve the ease in lifting.

HISTORY OF ROOT UNDERCUTTING

Undercutting was first used to improve bare-root seedling stock at about the turn of this century. As early as the 1920's, the objectives of undercutting were to improve bare-root seedling quality and increase seedling production.

The *in situ* manipulation of roots and the culling of inferior seedlings was a method of early nursery practice used with some measure of success. Early nursery managers desired the production of high class nursery stock in adequate quantities and at prices within the reach of every land owner. It was evident that the price of seedlings had a decided effect upon the number of trees planted. To increase planting, nursery stock prices had to be lowered. The byproduct of this early root manipulation was a seedling considered superior to transplants because of a well defined sturdy root system and a sturdy form (Racey and Racey, 1988).

By the 1930's, root undercutting was identified as the principal means of altering root form. Some thought that underground pruning alone was not an adequate substitute for the more expensive operation of transplanting. Others felt the undercut seedlings were fundamentally better trees than transplants (Racey and Racey, 1988).

The practice of root manipulation was continued by nursery managers with marked success. By the early 1970's, many Federal, State, and private forest tree nurseries used some form of a fixed bottom root pruner in their operations (Hallman and Lott, 1974).

It wasn't until the 1950's in southern nurseries that the practice of root pruning was being discussed as a possible method of "conditioning" seedlings for outplanting. In 1981, a questionnaire was sent to southeastern nurseries to document the practices currently employed to produce southern pine species. Some of the changes over the past 50 years of nursery management included root manipulation. In 1980, root-pruning was used in several nurseries throughout the south (Boyer and South, 1984).

ROOT UNDERCUTTING RESEARCH

Most research on root undercutting has focused on the effect of physical root manipulation on tree morphology (Stein, 1984; Tanaka *et al*, 1976; Rook; 1972). Others have tried to address the physiological mechanisms of seedling response to undercutting.

EQUIPMENT AND OPERATIONS

The techniques and equipment used by nurseries for undercutting have changed over time with advances in technology and management objectives. Every nursery has different specific management objectives for their tree species. Therefore, there is no general cookbook to follow in root undercutting. To effectively utilize undercutting equipment and operations to meet specific objectives, nursery managers must familiarize themselves with the literature.

Certain equipment may be designed specifically for root undercutting or be a modification of an existing piece of equipment.

The undercutting blade mechanism is pulled by the use of a tractor.

The tractor used should contain enough torque and horsepower to maintain a consistent speed and power. Many modern tractors are equipped with direct drive. The benefits of direct drive over the torque converters of older model tractors is that a constant speed and tow can be sustained without an increased risk of the engine overheating.

Today, most southern, bare-root, pine nurseries utilize a flat cutting blade set to undercut at a depth of 6 to 7 inches. The undercutting blade should be adjustable (up to 8 inches) and be able to cut an absolutely horizontal position in the soil. The blade needs to be thin yet rigid, and sharp. Periodically, the blade must be sharpened to ensure an adequate cutting surface. The objective should be to cut roots cleanly and quickly with minor disturbances to the soil.

Other literature recommends that a suitable depth to undercut seedlings is 3 to 4 inches. In this case, cutting below 4 inches would result in little root growth stimulation. Also, care must be taken not to cut above a depth of 2 inches. Reducing the depth of cutting increases the risk of seedling mortality through drought susceptibility and cutting off of stems at ground level (Aldhous, 1972).

If the nursery objectives are to control seedling height and root growth, then the timing of the undercut is crucial. In general, timing should be dictated by the developmental stage of the seedling. Most root is should carried out in the autumn when seedlings reach a desired height. The idea behind cutting in the fall (i.e., late August to October) is that new root and shoot growth will be able to adjust to the meet their restricted water intake capacity (Davidson and Mecklenburg, 1981).

One pruning per growing season is usually not adequate to significantly increase the uniformity of the stock at the time of lifting. To obtain optimum shoot and shoot growth, two or more root undercuttings are used (May, 1984).

For loblolly pine, the time for the first root undercutting should be done when the majority of the seedling crop has some fascicle bundles and are showing signs of additional height growth. Another sign used to determine when to undercut is the amount of new,

elongating roots. The presence of a "root halo" of new root growth is a strong indication that new shoot growth will occur soon (Chapman, 1997 ; Simms, 1983).

The MBI Nursery performs the initial undercutting of loblolly pine around mid-August. The number of undercuttings per season is three. However, if there is a late wet fall, then seedlings may start to put on additional height. In such cases, an additional undercutting is required (Chapman, 1997).

The Columbia Nursery (Columbia, Louisiana) does their initial undercuttings when seedlings average 6 ½ to 7 inches in height. The idea behind this time-frame is to allow for some growth to occur during the mid-season while still obtaining the goal of seedlings 8 to 11 inches in height (Simms, 1986).

In northern hardwood nurseries, there is an lack of research dealing with the routine practice of undercutting (Walder, 1994). However, root undercutting is widely used on broad-leaved species (Aldhous, 1972). Like southern nurseries, root pruning is utilized to prepare field-grown nursery stock for transplanting.

Long or curled and twisted roots are cut back to a few inches of the crown of the seedling by the use of a U-blade cutter. The U-blade cutter is used the first and second year to cut the roots 1 to 2 ft. below the soil surface. A vibrating "lifter" behind the blade helps to move the cutting surface through the soil (Hartmann and Kester, 1975).

A compact fibrous root system is desired on the transplants. Not only is a compact root system easy to pack in burlap root covers but it is easier to plant.

OTHER METHODOLOGY IN ROOT PRUNING

In addition to root undercutting the term root pruning has been used to describe four other separate types of root manipulation methods. Some of these pruning methods have been used in combination with undercutting to try and achieve specific management objectives (Racey and Racey, 1988).

- 1) Box pruning is the *in situ* cutting of lateral roots and the tap root (May, 1984). The benefits of box pruning are superior stress resistance, reduced malformation of roots after planting and a reduced number of handling steps after lifting (Racey and Racey, 1988).
- 2) The trimming of lateral roots and the tap root can also be performed after the seedling is removed from the bed. This method is employed for more efficient packing and planting (May, 1984).
- 3) Root wrenching is a modified form of undercutting. Specifically, the seedling taproot is periodically undercut at different depths during the growing season. Either a fixed or reciprocating tilted blade is used. The objectives of root wrenching are to hasten seedling dormancy and develop a short fibrous root mass. Wrenching may create a physiological shock from which the seedling may not recover for several weeks or months (May, 1984).
- 4) Lateral root pruning is the cutting of seedling lateral roots *in situ* by the use of a rolling coulter or knife blade. Lateral root pruning cuts roots from adjacent drills and allows tree lifting without stripping roots (May, 1984).

EVOLUTION OF EQUIPMENT (Racey and Racey, 1988)

Year Species Equipment Frequency (wks) Time of year Depth

1923 ? draw knife ? fall 5-6"
1925 yellow and white pine ? ? close to first season 4-5"
1927 yellow and jack pine sharp blade ? beginning of second year 9"
1942 ? horizontal blade ? year 3 (?) 4-5"
1952 ? 25 angle blade ? early spring ?
1957 white spruce square spades 2 June and Sept. 3"
1957 2-0 jack pine Barton root pruner 1 spring 3-5" 3-0 red & white pine
1958 longleaf pine lifters 1 July 7-8"
1958 pines and eucalyptus pruner wire every 1-3 weeks seedling 5-6" ?until outplanting
1959 longleaf pine tractor drawn blade 1 2-3 months before lifting 7"
1959 longleaf pine tractor drawn blade 1 late season 7"
1961 all species (UK) Gunn lifting bar 1 March or September 3-4" Blair Atholl and Ledmore undercutter
1961 all species (Kenya) piano wire 3 week cycle 9-11 weeks after sowing 5-7"
1961 all species (Uganda) piano wire weekly 2-3 month prior to lifting 4-5"
1961 all species (Trinidad) cutlass monthly 3 months prior to lifting ?
1962 Australian pine lifting bar ? before bud break ?
1963 longleaf, tractor mounted blade 1 1month before lifting 5-8" slash, and loblolly
1965 jack pine center mounted blade 1 before year 2 4"
1968 Douglas fir ? 1 spring 5"
1969 Monterey pine piano wire 1 February ?
1970 Monterey pine tractor drawn blade 1 seedling height 10-12" 5-8"
1974 Douglas fir ? ? late November for fall sown ?late Feb. for spring sown
1978 Caribbean pine ? ? seedlings 10-15 cm tall 13-15 cm
1984 red pine ? 1 July 10 5-8 cm
1984 ? sharp, flat blade 1 seedlings 15 cm tall 15 cm
1997 loblolly pine sharp, flat horizontal blade 3 August to October 6-7"

MOISTURE CONTROL DURING UNDERCUTTING

The control of water (e.g. irrigation and rainwater) is important prior to and following root undercutting. Nursery seedbeds should have low soil moisture prior to root pruning. In soils that have become satiated with water, the under cutting blade ends up pushing the root

ends forward rather than cleanly cutting them. The outcome of trying to undercut in soil too wet is creating severe physiological shock from which seedling may not recover from for weeks or months (May, 1984). For loblolly pine, as much as 1.5 inches of water may be applied to freshly undercut roots (Chapman, 1997). Surface water is allowed to meet the lower strata ground moisture. At this point, the soil moisture is allowed to recede to the undercutting blade's shear (approximately 6 inches below the surface). Once moisture reaches this level, irrigate heavily until the surface water meets the sub-surface water. This ruse is performed to try to stress the plant into reacting to its perceived death, thus reducing height and increasing root production.

By limiting irrigation inputs following an undercutting, some New Zealand nurseries are pushing the stress level limits which their seedlings can tolerate. Although there has been no research on the consequences of this practice, some feel that overall survival and establishment will diminish (Racey and Racey, 1988).

COSTS OF UNDERCUTTING

The costs of undercutting can be significant and must be taken into account by the nursery. The purchase price, or the construction costs, of an undercutting machine are usually high (Simms, 1986). Since undercutting machinery is not a fully automated, labor costs must also be addressed.

As long as the revenues from seedling sales outweighs the actual and potential costs of undercutting than it will continue to be an important part of nursery management.

OBJECTIVES FOR ROOT UNDERCUTTING

Root undercutting may meet several objectives for the nursery owner (May, 1984; Duryea, 1984):

- confine the growth of larger seedlings
- sever long tap roots, decrease shoot-root ratio (i.e. a better balanced tree).
- stimulate growth of smaller seedlings by improving root fibrosity
- loosen the soil to stimulate aeration
- loosen the soil to increase infiltration

Often times root undercutting is combined with root wrenching to achieve the same the desired results.

BIOLOGY OF SHOOT GROWTH

The shoot system of a tree consists of its stems and needles (or leaves). The function of this system is to provide the tree with sugars and other organic nutrients produced from photosynthesis (Campbell, 1989).

Shoot growth is controlled by meristematic tissue activity. Shoots elongate because of bud openings and expansions along the apical meristems distributed along the tree. Specifically, the process of elongation involves continued cell divisions followed by the subsequent expansion of cells (Kozłowski and Pallardy, 1997). Ultimately, the growth of the shoot is regulated by endogenous hormones.

UNDERCUTTING EFFECTS ON SHOOT GROWTH

The goal of the nurseryman should be to produce an well proportioned tree. Therefore, the control of shoot growth is a major objective of root undercutting. Studies have shown that a balanced seedling will have higher survival rates once transplanted. In general, root undercutting is effective in height growth reductions and creating a more balanced tree.

Height control is especially important for those nurseries in temperate climates with fast growing, coniferous tree species (Racey and Racey, 1988).

Loblolly pine seedling height is particularly effected by multiple undercuttings (Feret and Kreh, 1986). The largest reductions in height have been shown by treatments which are more severe or frequent (Rook, 1971).

Some studies have not been able to achieve reductions in height growth (Bunting and McLeod, 1984). More than likely the studies that could not retard height growth were undercutting too late in the season or with not enough frequency.

BIOLOGY OF ROOT GROWTH

A plant's root system functions to conduct water and nutrients, move water and minerals and store food (Campbell, 1989).

Most trees have a taproot system, consisting of one large, vertical root (taproot) which produces many smaller secondary roots (lateral roots). The first taproot develops directly from the root meristem of the seed embryo. Lateral roots on the other hand, develop from the deep-seated outer layer of the stele, also known as the pericycle. Three branches of lateral roots may develop off of the tap root. The new branch is usually a long root that becomes a part of the permanent woody root system. The second type of lateral roots are short roots. The final type of lateral roots are developed when short roots convert to long roots. Following an injury to the woody long root tip, a branch results and usually two more long root tips follows. Injury can also occur to the non-woody lateral roots. Forking of replacement lateral roots follow (Kozłowski and Pallardy, 1997). Severed roots decompose and the ends will form calluses. Bud-like root primordia may develop near these callous tips (May, 1984). In general, injury to the root system (such as that from root pruning) leads to the formation of additional lateral roots and an a well developed root system.

Root fibrosity is a term used by nursery managers to refer to the extensive, multi-branched tree roots spread out under the soil surface. The attributes of a fibrous root system are important to a young, transplanted seedling's establishment and survival. Root fibrosity gives the tree extensive exposure to soil water and minerals and also helps to anchor it in place (Campbell, 1989). In addition, trees with a fibrous root system are able to withstand drought better than shallow, sparsely branched root systems (Kozłowski and Pallardy, 1997).

UNDERCUTTING EFFECTS ON ROOTS

The regeneration of roots following an undercutting is important to transplanted tree's survival, establishment and growth. Numerous studies have shown that a compact, fibrous root system result from undercutting (Racey and Racey, 1988). In addition, the denser, more fibrous root system results in a better balanced tree at the time of lifting.

Root pruning has been shown to increase both the amount of root surface area and the percentage of the total root system. A heavily branched root system in trees can be produced by multiple undercuts the tap root (Racey and Racey, 1988). Close examination of undercut roots reveals that many small roots will regenerate from each severed one. Such trees, because of their greater compactness of the root system, are easier to lift and transplant (Stoeckeler and Jones, 1957). Over time, however, some of the small replacement roots may begin to deteriorate. Lifting the trees when the number of replacement roots is the highest will maximize the total root surface area and hence survival (Watson and Sydnor, 1987).

Root quality and vigor were shown to increase with undercutting of loblolly pine (Wisniewski *et al*, 1991). New lateral root production was shown to occur in red oak after multiple undercuts (Harmer and Walder, 1994).

Undercutting was shown to be very effective in fine root production of black walnut (Williams, 1972), Douglas fir (Tanaka *et al*, 1974), and yellow poplar (Thor, 1965).

Not all researchers have been able to show that undercutting is effective in fine root production. Ponderosa pine responded to undercutting with decreased root mass and lateral root production (Hobb *et al*, 1987). Another study with loblolly pine showed that the mean number of roots did not increase with undercutting (Venator and Mexal, 1981).

ROOT GROWTH POTENTIAL (RGP)

A newly planted bare-root seedling has access to only a limited volume of underground resources. This makes the tree prone to both desiccation and nutrient deficiency. It follows that the ability of a planted seedling to become established often depends on the speed at which it can develop a new fibrous rooting system (Burdett *et al*, 1983). The rate of new root growth is referred to as the root growth potential (RGP). Increased RGP is important in seedling establishment and is promoted by root disturbances (Hobbs *et al*, 1987).

RESULT OF UNDERCUTTING ON RGP

The parameter of RGP is not necessarily increased or decreased by undercutting (Racey and Racey, 1988). Studies of loblolly pine have shown that there was no significant increase in RGP following undercutting (Feret and Kreh, 1986). The same conclusions were reached for Douglas fir RGP (Racey and Racey, 1988). One possible explanation for these observations is that RGP is affected by physiological factors not modified by undercutting (Feret and Kreh, 1986).

SHOOT/ROOT RATIO

The shoot/root ratio is defined as the ratio of transpiring (leaf) surface area to the absorbing (root) surface area. If root absorption begins to lag behind leaf transpiration, a water deficit will develop and desiccation follows (Kozlowski and Pallardy, 1997). When transplanting tree seedlings, water conservation is generally more important than the amount of photosynthetic surface area (i.e. a low shoot/root ratio). This concept is especially important during the lifting process of nursery seedlings, since it has been calculated that less than 5 percent of the root system survives with a typical nursery lifting (Watson and Sydnor, 1987).

UNDERCUTTING EFFECTS ON SHOOT/ROOT RATIO

Evidence suggests that shoot/root ratio can be effectively controlled by undercutting (Racey and Racey, 1988). By decreasing the shoot/root ratio the nursery manager would be helping to increase transplant survival. Specifically a decreased shoot/root ratio relates to a reduction in shoot height, stem diameter and weight with an increase in the size of the root system.

Survival of undercut Douglas fir and ponderosa pine was improved with a low shoot/root ratio (Lopushinsky and Beebe, 1976). Other studies have shown similar responses of Douglas fir shoot/root ratio to undercutting (Tanaka *et al*, 1974; Koon and O'Dell, 1977).

Undercut longleaf pine also had an increased survival at a low shoot/root ratio (Shoulder, 1963). Similar reductions to shoot/root ratio from undercutting were observed in Caribbean pine (Bacon and Hawkins, 1977), Australian pine (Gingerich and Hertel, 1962), and western hemlock (Morris, 1979).

There has been a few studies which have shown that root undercutting can increase shoot/root ratio. Douglas fir undercut early in the growing season showed an increase in shoot/root ratio (Stein, 1985). In these cases, root regeneration was probably not sufficient enough to compensate for lost, pruned roots.

Some research has not been able to conclusively show any change in the shoot/root ratio from undercutting. The reason for null results may be because of flaws in the research methodology. For example, undercutting too deep may not cut any roots while undercutting too shallow will remove too many roots (Racey and Racey, 1988).

BIOLOGY OF PLANT HORMONES

The timing of cellular elongation (and hence growth) in tree roots and stems is regulated by five major endogenous growth hormones located within the tree. These hormones are auxins, gibberellins, cytokinins, abscisic acid (ABA), and ethylene (Davies, 1990). Cytokinins are produced in actively growing tissues, particularly roots. Transport of this hormone is facilitated by xylem sap. The amount of cytokinin in the xylem sap and plant tissue changes with stage of plant development, environmental conditions and season. Cytokinins are linked to the control of cell division (and hence growth) of meristematic tissues (Kozlowski and Pallardy, 1997). Alone, cytokinins have no effect on plant growth.

ABA inhibits cell division in the vascular cambium. In addition, ABA slows growth and directs leaf primordia to develop into the scales that will protect the dormant bud during winter (harden the tree). ABA has acts as a stress hormone, helping the tree to cope with adverse environmental conditions, such as water stress (Kozlowski and Pallardy, 1997).

The apical meristem of a shoot is the origin of auxin synthesis. Auxin is responsible for a wide range of physiological functions related

to tree growth. These functions include cell enlargement, cell division, differentiation of vascular tissues and apical dominance (Davies, 1990).

Roots and young leaves near the shoot apex are major sites of gibberellin production. Gibberellins stimulate growth in both the leaves and the stem, but have little effect on root growth (Kozłowski and Pallardy, 1997).

Ethylene is unique among plant hormones because it is a gas. Ethylene functions primarily as a growth inhibitor. In addition, ethylene has been associated with a variety of aging processes in plants (Kozłowski and Pallardy, 1997).

HORMONAL RESPONSES TO UNDERCUTTING

Root undercutting has been shown to have significant effects on hormonal expression (Rook, 1972). These physiological hormone changes translate into morphological changes for the undercut seedling.

To date, studies dealing with hormone responses to root undercutting have focused on the short term patterns rather than long term ones (Fraser, 1976). Most agree that more research needs to be done in long term hormonal responses to undercutting.

Following the undercutting of western hemlock seedling roots, an absence of cytokinin activity in the xylem sap was observed (Morris, 1979). Loblolly pine was shown to have a reduced supply of cytokinins to the shoot after undercutting, possibly the result of fewer roots (Wisniewski *et al*, 1991). Similar studies with red oak have shown an initial increase in cytokinin activity for the first 24 hours after root pruning, followed by a drop in activity levels (Carlson and Larson, 1977). Forsyth and Van Staden (1981) also found that cytokinin content was increased by root pruning. In general, increased levels of cytokinin are probably the result of increased lateral root production.

Decreased levels of ABA were shown in root undercutting studies of loblolly pine (Sweet and Rook, 1972). Similar results were achieved on root pruning studies on Caribbean pine (Bacon and Bachelard, 1972).

Studies which addressed the levels of auxin following root pruning are inconsistent, possibly the result of experimental differences. Red oak has been shown to have short term decreases in auxin (Carlson and Larson, 1977). On the contrary, no change in auxin levels were observed with Caribbean pine (Bacon and Bachelard, 1979).

Root pruning has been shown to reduce the activities of gibberellins in Caribbean pine (Bacon and Bachelard, 1979).

No research has been done to date which addresses the response of ethylene to root undercutting. However, we know that undercutting decreases auxin and cytokinin activity. Since the synthesis of ethylene is an amalgam of auxin and cytokinins, we can assume that ethylene activity would also decrease (Kozłowski and Pallardy, 1997).

Much more research remains to be discovered on how undercutting effects the precise mechanisms of tree physiology.

EFFECTS OF UNDERCUTTING ON NURSERY SOILS

One negative byproduct of nursery practices (i.e. irrigation and heavy equipment) is soil compaction and hence, increased soil bulk density. Increases in the soils bulk density decreases favorable conditions for nursery seedlings.

Undercutting reverses the effects of soil compaction by breaking up the soil surface and aerating it. In aerated soils, permeability to air, water, fertilizer, and herbicide increases. Most importantly, the space available for root growth and water storage increases as the undercutting blade moves through the soil.

Often a compact layer of dirt (called a pan) can form at the interface between the undercutting blade and the soil. The pan forms an impervious barrier to water and air movement through the soil horizons. In addition, this pan may become a prime niche for soil pathogens. The effect on nursery bare-root stock is mortality of tap and lateral roots and disappearance of second and third order lateral roots. Fine-textured soils are the most susceptible to this problem.

DISEASES

It has been postulated that root undercutting can increase seedling susceptibility to disease through increased stress levels in the plant. In addition, cut roots may facilitate the entrance of root disease organisms into the tree. However, there is a paucity of research to conclusively determine what the interaction between undercutting and disease (Racey and Racey, 1988).

FIELD PERFORMANCE

There has been an increase in research of nursery root manipulation practices aimed to improve seedling field performance (Hobbs *et al*, 1986). The current thinking is that root undercutting increases the establishment and survival of transplanted seedlings (Racey and Racey, 1988). In fact, survival of undercut seedlings is significantly better (for first few years) than non-undercut seedlings (Edgren, 1981).

STORAGE

The cold storage of bare-root nursery stock is a fairly recent procedure. To date, there has been a lack of research addressing the effects of cold storage on undercut bare-root stock. Of the studies that have been performed thus far, a common ground has yet to be reached by researchers (Racey and Racey, 1988). Specifically, some researchers conclusions are in direct conflict with others.

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