A Review of the "Pull-up" and "Leave-down" Methods of Planting Loblolly Pine

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Two schools of thought exist regarding the planting of bare-root seedlings. One school favors the "pull-up" method where the seedling is pulled-up 3 to 10 cm after placing the roots in the planting hole. Although this action purportedly straightens the taproot, data are lacking to show this extra step actually improves field performance. Pulling the seedling up usually results in the root-collar 5 cm or less below the groundline (which could increase mortality on some sites). The "leave-down" school advocates making a deep planting hole, placing the roots near the bottom of the hole and no "pull-up." The "leave-down" technique results in planting the root-collar 3 to 10 cm deeper than the "pull-up" technique. Those from the "leave-down" school say that shallow holes kill seedlings; bent roots do not. Planting guidelines should be rewritten to: (1) emphasize the "proper" depth of planting to increase seedling survival; (2) de-emphasize intuitive beliefs that tap-roots and lateral roots must be oriented downward after planting; (3) not recommend unnecessary refinements in planting technique; (4) explain the advantages of machine planting; (5) explain the species/site/planting depth interaction for survival; and (6) cite references to support recommendations. Tree Planters' Notes xx:xxxxx

A high percentage of planted seedlings in the South (40% to 80%) can be classified as having deformed roots (Schultz 1973, Hay and Woods 1974a, Mexal and Burton 1978, Senior and Hassan 1983, Harrington and others 1989, Gatch and others 1999). However, just because a planted loblolly pine (*Pinus taeda* L.) seedling has a bent taproot or compressed lateral roots does not mean its performance will be less than seedlings that originate from direct seeding. In fact, on 4 sites in Arkansas (Harrington and others 1989), 32% percent of the trees originating from seed had bent taproots (likely due to rocks and compact soil layers). Therefore, bends in the taproot can be "natural" as well as "man-made." Even so, some claim that planting methods that result in J-roots or L-roots (Table 1) will kill seedlings and that utmost care should be exercised during planting to ensure the taproot is straight. Since planting the root-collar 15 cm below the surface (in a 25 cm hole) will bend the taproot, several planting guides indicate the "proper" planting depth is so the root-collar is slightly below the groundline.

Typically, survival and average diameter growth of transplanted 1+0 loblolly seedlings are greater than for trees in direct seeded fields (this may not hold for other species and stocktypes; Halter and others 1993). This partly explains why tree planting in slits (with flattened roots) is more common in the South than direct sowing. However, planting method can make a significant difference in survival (Muller 1983, Xydis 1983, Rowan 1987, Shriver and others 1990, Paterson 1993, Harrington and Howell 1998). For example, operational planting techniques can lower survival by 10% or more (Rowan 1987, Shriver and others 1990, Harrington and Howell 1998). The practice of stripping roots just before planting can reduce new root growth (South and Stumpff 1990) and lower survival (Marx and Hatchell 1986). On some sites, planting the roots just 8 cm deeper than the depth used by operational crews can increase survival by 15 percentage points (Blake and South 1991). In most years, machine planting provides better survival than hand planting (McNab and Brendemuehl 1983, Barber 1995, South and Mitchell 1999), probably because depth of planting is typically greater, the frequency of loose planting is lower, there is less root exposure, and there is less root pruning and root stripping by tree planters. Moderate root pruning can reduce seedling survival by 4% to 19% (Mexal and South 1991). When poor planting techniques are used the productivity of stands will be decreased (Mullin 1974, Rowan 1987, Paterson 1993).

Since planting technique affects survival, it is imperative that supervisors of tree planters know which techniques actually improves survival. If supervisors provide the wrong information to tree planters, they might encourage pruning of taproots and lateral roots. There is no doubt that root pruned seedlings are easier to plant and it is easier to get the roots straight in the hole without folding (Dierauf 1982). Although root pruning can make tree planting easier and can increase the percentage of straight taproots, it does not improve field performance. In fact, pruning roots after lifting often reduces seedling survival (Table 2). Despite this information, some recommend tree planters root prune seedlings when taproots longer than 18 cm. Dierauf (1982) believes that root pruning to a length not less than 13 cm is a good practice. In one study, 25-cm taproots were pruned to a length of 17 cm and lateral roots were pruned to a 5 cm length (Wilder-Ayers and Toliver 1987). At the end of the first growing season, the mean survival of these root-pruned seedlings was 39 percent.

In my opinion, most tree planting guides for loblolly pine exaggerate the dangers of both root deformation and deep planting (planting seedlings with the root-collar 7 to 18 cm below the groundline). Some planting guides emphasize the need for tree planters to prune long lateral roots and taproots in order to facilitate "proper" planting. These guides should be rewritten to stress the important aspects of planting and eliminate the unimportant.

This paper reviews the J-rooting and L-rooting studies that have been conducted with bare-root pines in the southern United States. It does not cover root-strangulation occasionally caused by growing seedlings in containers or when twisting bare-root seedlings during planting (Ursic 1963). It reviews data mainly from the compression method of planting where root systems are compressed into a vertical plane (also know as slit planting).

Two Schools of Thought

Two schools of thought exist regarding the planting of loblolly and slash pine (*Pinus elliottii* Englem.) seedlings. The difference planting recommendations between these schools are illustrated in figure 1. The older-school favors the "pull-up" technique where the seedling is placed deep into the planting hole and then pulled up 3 to 10 cm in order to straighten out the roots. Some from this school recommend pulling up the seedling so the root-collar is about 1 to 6 cm below the soil surface. This action purportedly improves field performance by straightening out the roots. Several planting guides recommend this technique when hand planting (Wakeley 1954, Balmer and Williston 1974, Anonymous 1981, Moorehead 1988, Anonymous 1989, Carlson and Miller 1990) or machine planting (Anonymous 1998). We do not know if pulling the seedling up 3 cm is really enough to straighten out the roots or if this technique makes any difference in survival or growth. To avoid ψ-roots, some members of this school recommend pruning of long fibrous roots by tree planters (Moorhead 1988, Anonymous 1989). Some recommend pruning roots with a sharp knife, machete, axe or hatchet when taproots exceed 18 cm in length. This school prefers straight taproots to planting bent roots 3 to 10 cm deeper. Some claim the "correct" planting depth is to have the root-collar 1 to 6 cm below the groundline (Martin et al. 1953, Wakeley 1954, Balmer and Williston 1974, Anonymous 1981, Anonymous 1989, Fancher et al. 1989, Carlson and Miller 1990). Others recommend a making planting holes that are 20 to 25 cm deep (Dierauf 1982) or less (Martin et al. 1953).

The other school recommends the "leave-down" technique that does not involve the "pull-up" method. As a result, the roots are generally planted 3 to 10 cm deeper than when the "pull-up" method is used. The "leave-down" technique favors leaving the roots bent at the bottom of the planting hole over attempts to straighten taproots and laterals by pulling the root-collar closer to the soil surface). Due to an increase in probability of success, members of this school prefer machine planting to hand planting (average planting hole depth for machine planting is about 30 cm and the root-collar is typically about 15 cm below the soil surface; this sometimes results in a high percentage of L-roots). Planting on agricultural lands using machines that make slits that are only 15 to 20 cm deep will likely result in many L-roots (Gatch and others 1999). On sites where hand-planting is required, leaders in this school recommend making a wide (15 to 20 cm) and deep (27 to 34 cm) planting hole. The roots are placed at the bottom of the hole and there they remain. As a result, the root-collar ends up at least 5 to 10 cm deeper than usually recommended by the "pull-up" school. For many sites, the "correct" planting depth will result in the root-collar 15 cm below ground and the bottom of the roots will be 25 to 34 cm deep. They allow J-roots, L-roots and ψ-roots but prohibit shallow planting holes (less than 25 cm deep) as well as pruning or stripping of roots by tree planters. However, due to a three-way interaction between species, site, and planing depth, members of this school do not recommend the same planting depth for all pine species or for all sites. Deep planting on poorly drained sites (where the water table is near the soil surface) can decrease survival of loblolly pine (Switzer 1960). Therefore, the "correct" planting depth varies with site.

Because less time is required to make a narrow, shallow hole, hand planters prefer recommendations made by those who favor pruning roots (Dierauf 1982, Anonymous 1989). Making a deeper planting hole by hand increases planting costs. This is one reason those from the "leave-down" school favor machine planting. On many sites the cost of machine planting is similar or less than that for hand planting (Straka et al. 1992).

Definitions

Tree planting terminology can sometimes be confusing. For example, some planting guides say the seedling should not be planted deeper than the length of the dibble bar. Some from the "pull-up" school say the correct depth of planting should be 3 to 6 cm "below" the root-collar (Carlson and Miller 1990). Others define a seedling as being planted "deep" when the root-collar is just 3 cm below the soil surface (Brissette and Barnett 1989; Jones and Alm 1989). The "recommended" planting depth in Virginia is 3 to 5 cm deeper than the "normal depth" (Dierauf

1984). To improve the terminology of root classifications, I propose a new code system to define root shape, root-collar diameter, planting depth, rooting depth, and taproot length (Table 1). In addition, I offer the following definitions:

Root depth = distance between groundline and deepest point of the roots after planting.
Planting depth = distance between the root-collar and the groundline (negative values indicate the root-collar is aboveground).
Correct planting depth = depth where survival and early growth are reduced when planting the root-collar deeper or shallower.
Shallow planting = depth where survival is increased when planting the root-collar deeper.
Excessively deep planting = depth where survival or growth would be increased if the root-collar was planted closer to the groundline.
Shallow planting hole = hole less than 20 cm deep.
Deep planting hole = hole greater than 25 cm deep.

History of Transplanting Recommendations

The debate about proper planting techniques has been going on for more than a century. For example, Jarchow (1893) recommended planting the root-collar a little above ground and he could not comprehend how Hough (1882) could recommend "setting the seedlings deeper than they stood before." Jarchow said the "experts in this matter agree in accepting the reverse to be true." Likewise, those in the "pull-up" school today might not comprehend how those in the "leave-down" school could allow seedlings to be planted deep with J- and L-roots. Debates on proper planting techniques will likely continue since data from empirical studies contradicts intuition. But even Jarchow (1893) realized that pine seedlings were different. He said that on very poor soil, the "seedling should be buried so deep that only its top shows above the soil." So apparently, over a century ago he realized there existed a three-way interaction between species, site and planting depth. Many planting guides today do not mention this interaction and make recommendations as though the correct planting depth is the same for all species and for all sites.

According to Cheyney (1927), "The directions for the planting of a tree have become more or less stereotyped and have been copied for so many years that it is practically impossible now to say on what the directions are based…." The same can be said today. Some of the current recommendations regarding the "correct" planting depth can be traced back to 19th century Europe. For example, Toumey (1916) admitted that there was little information on deep planting in the United States (page 385) but said "… the investigations of many European foresters clearly prove that poor results are likely to follow the setting of plants too deep in the soil." He said that many investigators have recorded the bad effects from the deep planting of *Picea abies* (L.) Karst. The older the plants, the more disastrous the results." However, he did say that 1-year seedlings of *Pinus sylvestris* L.(in Prussia) can be safely set considerably deeper than their original position in the seedbed. Even though he said planting with the root-collar well below the soil surface will often enable trees to survive summer drought, he warned this would not be desirable even on dry sites "because of its effect upon later root development." Almost a century later, there is still a fear that deep planting of loblolly pine is undesirable because something bad might happen before the stand is 50 years-old. This fear is not supported by published studies (Hunter and Maki 1980) but has been passed down by word-of-mouth from forester to forester. Zon (1951) stated that one of forestry's early mistakes was the "Uncritical, almost slavish following of European patterns." For example, many loblolly pine planting guides today still have a figure to illustrate that planting the root-collar 10 cm (or more) below the soil surface is "incorrect" planting.

Three Types of Recommendations

Regardless of the century, tree planting recommendations can be placed into three types: (1) recommendations based on intuition; (2) recommendations based on observations; and (3) recommendations based on experiments designed to test a hypothesis. Little confidence should be placed on guidelines that rely on 19th century intuition. Likewise, guidelines that cite results from empirical experiments deserve more confidence than recommendations based solely on survey data.

Intuition. Recommendations based on intuition indicate that root distortion will: (1) kill seedlings; (2) reduce the seedling's ability to uptake water; (3) increase the susceptibility of disease; (4) slow growth of any surviving seedlings; and (5) cause seedlings to blow over. Some planting guides (Stephen 1928, Martin and others 1953) warn that J-rooting will kill seedlings but these guides cite no data or references. When data do not support intuition, the accuracy of these guesses can be questioned. For example, intuitive recommendations that longleaf pine (*Pinus palustris* Mill.) be planted with the root-collar above ground were made before 1940. However, after conducting an empirical test, Wakeley (1954) stated that this practice should be abandoned.

The "pull-up" method of tree planting is an "intuitive" recommendation. This technique (possibly started by Floyd Cossitt about 1939) can be found in several planting guides. As far as I know, there is no data to show this method of planting loblolly pine improves survival, growth, or field performance. Perhaps some researcher in the future will decide to test this "intuitive" method of tree planting. Seiler and others (1990) anticipate that this method of tree planting increases seedling mortality. My intuition says it could also increase the probability of toppling.

Root pruning after lifting is another example of an "intuitive" recommendation. Instead of improving the survival of loblolly pine (by planting a smaller I-root), root pruning can reduce root growth potential and seedling survival. Even so, some planting guidelines recommend that tree planters prune long roots before planting (Moorhead 1988, Anonymous 1989). Sometimes 44% of the roots are removed so the pruned roots will match the planting hole (Wilder-Ayers and Toliver 1987).

Observations. Operationally planted seedlings are sometimes excavated one or more years after planting and the root shape is reported. These observational reports do not involve an experiment laid out in a randomized complete block design. As a result, analyses often involve simple correlations or sometimes multiple regressions. After root systems are examined, a subjective root score is given to reflect the degree of distortion. In some cases, recommendations regarding the negative effects of root distortion are made without excavation of any direct seeded seedlings.

In a few cases, planted seedlings are compared with wildlings (Little and Somes 1964, Harrington and others 1989). These studies are useful for identifying the frequency of root abnormality of trees with "natural" root systems. Usually, differences in both location and genetics exist between the "natural" seedlings and the planted stock. Therefore, any observed differences are often confounded with site, genotype and sometimes there is a two-year difference in seedling age. However, such studies can illustrate what we think of as "abnormal" can occur to some extent in nature.

Empirical trials. The scientific method involves: (1) identification of a problem; (2) researching the known literature; (3) formulating a hypothesis; (4) deciding on a procedure to test the hypothesis; (5) collecting data and conducting a proper analysis to test the hypothesis; (6) deriving a conclusion; (7) publishing the results; (8) reevaluating the hypothesis. Observational studies are good for formulating a hypothesis but planned experiments must be conducted in order to test a hypothesis. Carefully designed experiments (designed to minimize confounding) may require years before adequate growth data are obtained (which may explain why some researchers only report observational data). However, there are several examples of empirical studies in the literature (e.g. Deleporte 1982). Results from these trials are more reliable than those where root form at planting is not known. However, not all empirical studies are designed properly (e.g. Cheyney 1927).

J-rooting *per se* does not kill seedlings: shallow planting kills seedlings

Some tree planting guides state that root deformation will kill seedlings (Stephen 1928, Martin and others 1953). However, for both loblolly pine and slash pine, there is no proof to show this is true. Not only do most J-rooting trials show no significant effect on survival (Table 3), but almost all these trials confound root depth with treatment. Therefore, the real cause of mortality in such trials could simply be due to shallow planting. Apparently, the idea that L-rooting can kill seedlings might have originated from a misinterpretation of a photo in a book by Toumey (1916). He shows two L-rooted seedlings: one alive and one dead (Figure 2). Apparently some authors of tree planting guides assumed the tree died because of the L-root. But the photo clearly shows the deeper planted L-root seedling in good condition. The cause of mortality was a shallow planting hole.

Brissette and Barnett (1989) established an empirical study where both root depth and J-roots were tested. Roots were pruned to a length of 15 cm and were placed into shallow holes (8 cm to 18 cm deep). A close examination of their data suggests that root depth (not J-rooting) was the primary factor affecting survival (Figure 3). In fact, when planting in a very shallow hole (13-cm root depth) J-roots had 18% to 27% greater survival than I-roots! Extrapolating the equations in figure 3 suggest that 90% survival could have been obtained if rooting depth was 22 cm to 28 cm. However, the researchers planted no roots this deep.

A new OST planting bar (Council Tool Co. Lake Waccamaw, North Carolina 28450) can be used to make a 25 cm deep hole and a Whitfield planting bar (R.A. Whitfield Manufacturing Co., P.O. Box 188, Mableton, Georgia 30126) can help make a 34 cm deep hole. Ursic (1963) and Bilan (1987) planted trees deep using a 45 cm bar. Malac (1965) recommends using a dibble with a 30 to 35 cm blade when planting Grade 1 seedlings but his recommendation is rarely followed. In contrast, one planting guide recommends that planting holes be 15 cm to 20 cm deep (Martin and others 1953). Therefore, when planting pruned roots in holes only 8 to 19 cm deep, tree planters should expect some mortality (even under well-watered conditions in a greenhouse).

I agree with those who say a shallow planting hole is the main reason for increased mortality and not root deformation *per se*. Toumey (1916) states that "One of the most frequent defects in planting arises from crowding trees with large roots into shallow holes." Wakeley (1954) concluded that U-rooting "usually has a negligible effect on initial survival." He said that setting depth probably reduces survival more often and more seriously than any and all other errors in planting depth combined. After evaluating the performance of many operational plantings throughout the South, Xydias and others (1983) stated "Probably root deformation, per se, has no effect on survival. A too shallow planting slit results in root deformation, but the real cause of mortality is shallow planting." Seiler and others (1990) said "instructing planters to avoid J-roots by pulling back up on the seedlings when they are planted in the bottom of the planting hole may do more harm than good since the end result could be shallower root placement."

Twenty studies that compared I-roots with bent roots of southern pines are listed in Table 3. On average, survival of bent roots was about 0.6% less than I-roots. However, in all cases, bent roots had less root depth than I-roots. Therefore, confounding exists between root depth and root form.

Effect of Planting Depth on Survival

Wakeley (1954) conducted several planting depth studies and found that planting the root-collar of longleaf pine seedlings 1.3 cm above the groundline reduced the survival by 25 to 29%. In contrast, planting the seedlings with root-collars 1.3 cm below the groundline increased the survival 7 or 8%. Similar results were reported by Smith (1954).

Planting loblolly pine or slash pine with root-collars 5 to 28 cm below the groundline (on drained sites) tends to increase outplanting survival (Table 4). On average, the increase is about 4 percentage points. Unfortunately, several studies during the 1950's and 1960's dealt with cull seedlings. Although the data are limited, there appears to be a site by planting depth interaction for loblolly pine. Deep planting is not recommended on poorly drained sites (Switzer 1960).

Although data by Koshi (1960) suggest a detrimental effect of deep planting loblolly pine during a wet year, he made a math error. Apparently, he reported percentages as survival data instead of mortality data. Overall survival for four loblolly pine seedling grades was 67% (not 33%).

Sutton (1969) reviewed the research on planting and stated that "deep planting has been damned by many… as a common cause of plantation failure…" However, he said that the evidence indicated that deep planting is beneficial on many sites. Our data (Blake and South 1991) support his 30-year-old conclusion.

Effect of Bent Roots on Short-term Growth

According to Toumey (1916), Möller (1910) conducted a series of experiments with *Pinus sylvestris* on sandy soil in Prussia and concluded “that it does not matter apparently whether roots are bent to one side, tied together, or crowded into the planting hole. He found that if roots were not permitted to dry out, the above manner of treatment was not likely to kill the trees or even appreciably to check their growth." Toumey (1916) concluded that unnecessary refinements in the planting technique should be avoided.

Ursic (1963) excavated 13 seedlings that had been planted with U-roots. Examinations showed that roots had either elongated and turned to grow downward or that new roots had developed along the U-root (Figure 4). Ursic indicated that the dangers attributed to U-roots “have been exaggerated.”

Hay and Woods (1974a) excavated 348 saplings and found a positive correlation between root deformation and size of loblolly pine seedlings 4 to 6 years after planting. On one site, seedlings with the most root deformation were more than twice as heavy as seedlings with I-roots. However, this apparent correlation may be simply due to more root deformation when planting seedlings with larger roots. Seedlings with larger roots and a larger root-collar diameter at time of planting tend to grow more than seedlings with small roots (South 1993).

Mexal and Burton (1978) excavated 100 seedlings 2 to 4 years after planting. As one might expect, they found a positive relationship between initial seedling size and early growth on all 4 sites but found no correlation between taproot deformation and height growth. However, on one site, they found a positive relationship between taproot deformation and volume growth ($r^2 = 0.10$). On a bedded site, they found a positive relationship between planting depth and height ($r^2 = 0.14$).

Mexal and others (1978) excavated trees from 30 stands across the South. Five trees were excavated per plot (for a total of 150 excavated trees). A strong positive relationship ($r^2 = 0.14$; n=30) was reported between the number of seedlings per plot with good roots and seedling height. Average height (4 to 9 years after planting) was 20 cm taller for plots with 4 "good" roots compared to plots with just 3 "good" roots. A root system was judged to be "poor" if it had less than 6 lateral roots, or had a deformed taproot, or was encircled by lateral roots. Although some trees had missing taproots (or twisted laterals resulted in strangulation), it is possible that tree height in this study was correlated with the number of large seedlings (those containing six or more first-order lateral roots at time of planting).

Harrington and others (1987) excavated 192 loblolly pine seedlings (ages varied from 3 to 9 years old). Half of the 16 plots were from natural or artificial seedling. Distance between sites within each of the 8 pairs was less than 15 km. Although planted trees exhibited more root deformation, there was no difference in growth (i.e. past 3 years height growth) between planted and seeded trees. However, on 4 plots in Arkansas, they found a total of 3 planted trees with L- or J-roots (root class #2) that grew 58 cm during the year prior to excavation while 14 trees with single taproots averaged 70 cm of height growth (a difference of 12 cm). Likewise, in the Gulf Coastal Plain, they found a 24 cm difference in growth between I-roots (22 trees: 127 cm height growth) and J-roots (7 trees: 103 cm height growth). Although the trees may not have been the same age, they concluded that root system deformation and orientation are factors in the long-term performance of loblolly pine plantations.

Seiler and others (1990) found no difference in third-year height growth between J-roots and I-roots. Likewise, Dierauf (1992) found no difference in height growth between I-roots and ψ-roots. On an agricultural site, Harrington and Gatch (1999) found better height growth for J-roots than for I-roots.

Effect of Bent Roots on Long-term Growth

An argument against bent taproots planted deeply is that something bad might happen to the stand after it reaches an age of 20 or 30 years. Stated another way, deep planting and the associated root deformation might be bad even if we cannot prove it to be so today. Indeed, reports from Europe suggest this might have occurred with pine and spruce in Germany and Austria (Toumey 1916). Since scientists cannot prove a null hypothesis, followers of the "leave-down" school cannot prove that something bad will not happen in the future. They can only say that in three stands, nothing bad happened for 10 years (Harms 1969) and in another stand nothing bad happened for 24 years (Hunter and Maki 1980).

Effect of Bent Roots on Toppling

"Toppling" occurs when high winds blow over young (1 to 6 year-old) seedlings. Toppling is almost non-existent for slow-growing wildlings (Burdett and others 1986). Toppling of fast growing pines is a problem in some windy countries such as South Africa and New Zealand (Mason 1985, Zwolinski and others 1993). For *Pinus radiata*, researchers believe that bent roots will give poor anchorage to the seedling and it will result in toppling at a later date (Maclaren 1993). However, even in areas with hurricanes, toppling of bare-root loblolly pine is rare in the United States. Infrequent toppling has occurred when planting bare-root stock on good sites between the ages of 3 and 5 (Klawitter 1969, Hunter and Maki 1980; Harrington and others 1989), especially when the foliage is loaded with ice or snow (Dierauf 1982). Older bare-root loblolly pine trees tend to snap as opposed to lean (Fredericksen and others 1993). However, some guess that that if shallow planted seedlings are so cramped that the root systems defy classification by form, high winds might cause toppling of bare-root loblolly pine (Gruschow 1959). In the southern United States, I have observed more cases of toppling of container-grown stock than I have observed from bare-root stock.

Slit planting might affect toppling more than J-rooting. For example, Schultz (1973) excavated 5 slash pine seedlings that had blown over by a high wind. Although all 5 had deformed taproots, he concluded the primary reason for toppling was compression of the lateral root system as a result of slit planting (there was only one or no lateral roots on the windward side of the tree). After excavating 163 trees, he concluded that root deformation did not appear to be detrimental to tree growth.

My intuition suggests that toppling might be negatively related to planting depth. The “ball-and-socket” effect that precedes toppling might be reduced when the stem above the root-collar is supported by 15 to 18 cm of firm soil. Instead of preventing toppling, the "pull-up" method of tree planting might result in more toppling than planting loblolly pine seedlings deep. If toppling becomes a problem in the South, this would be an interesting hypothesis to test.

Effect of Bent Roots on Sinuosity

For pines, sinuosity of the stem (also known as speed-wobble) is related to genetics and growth rate. Slow growing provenances of loblolly pine have less sinuosity than fast growing provenances (Anonymous 1993). The heritability for bole sinuosity can range from 0.2 to 0.35 for loblolly pine and 0.2 to 0.55 for *Pinus radiata* D. Don (Bail and Pederick 1989, Anonymous 1993). If the bole is sinuous, the branches will also be sinuous (genetic correlation = 0.93 or greater). In Australia, sinuosity occurs on soils with high fertility (Birk 1991, Turvey and others 1993).

Crooked stems can result from toppling. Some pines that have a 50° lean at age 2 will recover and only have a 5° lean at age 6 (Harris 1977). As seedlings gradually recover, compression wood forms on the underside of the lean. Although this enables the seedlings to recover, some of the seedlings develop a crook in the stem (Dierauf 1982, Harris 1977).

If shallow planting results in toppling, this can cause sinuosity. Harrington and others (1999) excavated 144 trees and observed stem sinuosity on trees with and without straight taproots. However, the amount of sinuosity on trees with bent taproots was about twice as great as trees with straight taproots. If root deformation causes seedlings to form a "ball-and-socket" and this results in toppling, then this might explain the apparent correlation between bent roots and sinuosity. Also, if seedlings are machine-planted with a lean (Klawitter 1969) or result in a lean after hand-planting (Gleason 1981), this might also result in the formation of compression wood and butt sweep. Examination of empirical trials (e.g. Harrington and Howell 1998) will confirm or fail to confirm the hypothesis that L-roots cause sinuosity.

Conclusion

For bare-root loblolly pine or slash pine, shallow planting regardless of taproot form can kill seedlings. Therefore, a loblolly pine seedling that has a bent taproot (J:5:15:25:15) but is planted deeply (on a drained soil) will have a higher probability of survival than a shallow planted seedling (I:5:0:15:15) with a straight taproot. Research needs to be conducted to determine if planting seedlings deep will reduce the frequency of toppling and subsequent butt-sweep.

References

Anonymous. 1981. The Yazoo-Little Tallahatchie flood prevention project: reforestation procedures for erosion control. Forestry Report SA-FR-16. Atlanta, GA: USDA Forest Service, Southeastern Area. 20 pp.

Anonymous. 1989. Reforestation Standards. Alabama Forestry Commission. Montgomery, AL. 27 pp.

Anonymous. 1993. Growth and stem sinuosity of diverse provenances of three-year-old loblolly pine. In: The 37th Annual Report of the North Carolina State University Industry Cooperative Tree Improvement Program. 7 p.

Anonymous. 1998. Pocket Guide to Seedling Care and Planting Standards. North Carolina Division of Forest Resources, Raleigh, NC. 52 pp.

Bail IR, Pederick LA. 1989. Stem deformity in *Pinus radiata* on highly fertile sites: expression and genetic variation. Australian Forestry 52:309-320.

Balmer WE, Williston HL. 1974. Guide for planting southern pines. Southeastern Area State and Private Forestry-7. Atlanta, GA: USDA Forest Services, State and Private Forestry. 17 p.

Barber BL. 1995. Reforestation on non-industrial private forestland in East Texas from 1983-1993: factors associated with first-year seedling survival. In: Edwards MB.comp. Proceedings of the Eighth Biennial Silvicultural Research Conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SR-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 381-388.

Bilan MV. 1987. Effect of time and depth of planting on survival and growth of loblolly pine (*Pinus taeda* L.) Seedlings in Texas. In: Phillips DR.comp. Proceedings of the Fourth Biennial Silvicultural Research Conference; 1994 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 67-72.

Birk EM. 1991. Stem and branch form of 20-year-old radiata pine in relation to previous land use. Australian Forestry 54:30-39.

Blake JI, South DB. 1991. Planting morphologically improved seedlings with shovels. Alabama Agricultural Experiment station. School of Forestry Series No. 13. 7 p.

Brissette JC, Barnett JP. 1989. Depth of planting and J-rooting affect loblolly pine seedlings under stress conditions. In: Miller JH. comp. Proceedings of the Fifth Biennial Silvicultural Research Conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-71. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 168-176.

Burdett AN, Coates H, Eremko R, Martin PAF. 1986. Toppling in British Columbia's lodgepole pine plantations: significance, cause and prevention. The Forestry Chronicle 62:433-439

Carlson WC, Miller DE. 1990. Target seedling root system size, hydraulic conductivity, and water use during seedling establishment. In: Rose R, Campbell SJ, Landis TD, eds. Proceedings of the Combined Meeting of the Western Forest Nursery Associations; 1990 August 13-17; Roseburg, OR. Gen. Tech. Rep. RM-200 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 53-65.

Cheyney EG. 1927. The effect of position of roots upon the growth of planted trees. Journal of Forestry 25:1013-1015.

Deleporte P. 1982. Premiers resultats de trois essais de deformjations racinaires. Annales de Recherches Sylvicoles, AFOCEL, France: 164-239.

Dierauf TA. 1984a. A comparison of "normal depth" with "deep planting" of loblolly pine seedlings. Virginia Division of Forestry. Occasional Report 63. 3p.

Dierauf TA. 1984b. Survival of root pruned loblolly after long-term storage. Virginia Division of Forestry. Occasional Report 64. 2p.

Dierauf TA. 1982. Planting loblolly pine. In: Kellison RC, Gingrich S. eds. Symposium on the loblolly pine ecosystem. East Region; 1982 December 8-10; Raleigh, NC. N.C. State University, School of Forest Resources. 124-135.

Dierauf TA. 1992. Lateral roots extending from the planting hole – how serious? Virginia Department of Forestry. Occasional Report 104: 3.

Dierauf TA, Garner, JW. 1978. Root pruning loblolly pine seedlings effect on survival and growth. Virginia Division of Forestry. Occasional Report 52. 4p.

Donald, DGM. 1970. The effect of planting depth on the survival of *Pinus radiata*, *Pinus pinaster* and *Pinus taeda*. South African Forestry Journal 74:17-19.

Fancher GA, Mexal GJ, Fisher JT. 1989. Planting and Handling Conifer Seedlings in New Mexico. New Mexico State University, Cooperative Extension Service. Las Cruces, NM. Circular 526. 9 pp.

Fredericksen TS, Hedden RL, Williams SA. 1993. Testing loblolly pine wind firmness with simulated wind stress. Canadian Journal of Forest Research 23:1760-1765.

Gatch, JA, Harrington, TB, Price, TS, Edwards, MB. 1999. Influence of bent taproots on stem sinuosity and tree size of machine-planted loblolly and slash pines in Georgia. Georgia Forestry Commission. 13 p.

Gleason GD. 1981. Monterey vs loblolly. Southern Journal of Applied Forestry 5(3):169.

Gruschow FF. 1959. Observations on root systems of planted loblolly pine. Journal of Forestry 57:894-896.

Halter MR, Chanway CP, Harper GJ. 1993. Growth reduction and root deformation of containerized lodgepole pine saplings 11 years after planting. Forest Ecology and Management 56:131-146.

Harms, WR. 1969. Deep planting of slash pine in the Carolina sandhills. Journal of Forestry 67:160.

Harrington CA, Carlson WC, Brissette JC. 1987. Relationship between height growth and root system orientation in planted and seeded loblolly and shortleaf pine. In: Phillips DR. comp. Proceedings of the Fourth Biennial Silvicultural Research Conference; 1994 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 53-60.

Harrington CA, Brissette JC, Carlson WC. 1989. Root system structure in planted and seeded loblolly and shortleaf pine. Forest Science 35:469-480.

Harrington TB, Gatch JA. 1999. Second-year responses of loblolly pine seedlings to combined herbaceous weed control and fertilization: influence of taproot configuration. In: Reynolds DB, ed. Proceedings, Southern Weed Science Society; 1999 January 25-27; Greensboro, NC: 140-141.

Harrington TB, Gatch, JA, Price, TS. 1999. Stem sinuosity, tree size and pest injury of machine-planted loblolly pine with bent versus straight taproots. Southern Journal of Applied Forestry 23:197-202.

Harrington TB, Howell KD. 1998. Planting cost, survival, and growth one to three years after establishing loblolly pine seedlings with straight, deformed, or pruned taproots. New Forests 15:193-204.

Harris JM. 1977. Shrinkage and density of *radiata pine* compression wood in relation to its anatomy and mode of formation. N.Z.J. Forest Sci. 7:91-106.

Hay RL, Woods FW. 1968. Distribution of available carbohydrates in planted loblolly pine root systems. Forest Science 14:301-303.

Hay RL, Woods FW. 1974a. Root deformation correlated with sapling size for loblolly pine. Journal of Forestry 72:143-145.

Hay RL, Woods FW. 1974b. Shape of root systems influences survival and growth of loblolly seedlings. Tree Planters' Notes 25:1-3.

Hough FB. 1882. Elements of Forestry. Cincinnati: R.Clark and Co. 381 p.

Hunter SC, Maki TE. 1980. The effects of root-curling on loblolly pine. Southern Journal of Applied Forestry 4:45-49.

Jarchow HN. 1893. Forest Planting. New York: Orange Jude Co.237 p.

Jones B, Alm AA. 1989. Comparison of planting tools for containerized seedlings: two-year results. Tree Planters' Notes 40(2): 22-24.

Klawitter RA. 1969. Wind damages improperly planted slash pine. Southern Lumberman 218(2709): 24.

Koshi, PT. 1960. Deep planting has little effect in a wet year. Tree Planters' Notes 40:7.

Little S. 1973. Survival, growth of loblolly, pitch, and shortleaf pines established by different methods in New Jersey. Tree Planters' Notes 24:1-5.

Little S, Somes H. 1964. Root systems of direct seeded and variously planted loblolly, shortleaf, and pitch pines. USDA Forest Service, N.E. Expt. Sta. NE 26: 13 pp.

Maclaren, JP. 1993. Radiata Pine Growers' Manual. FRI Bulletin No. 184. Rotorua, NZ: New Zealand Forest Research Institute Limited. 140 pp.

Malac BF, Johnson JW. 1957. Deep planting increases survival of slash pine on sandy site. Union Bag & Paper Corporation, Woodlands Research Note no. 5: 2 p.

Malac B. 1965. Planting and direct seeding. In: A guide to loblolly and slash pine plantation management in southeastern USA. Georgia Forest Research Council Report No. 14.

Martin IR, Prout CT, DeVall WB. 1953. Forestry Handbook. The Alabama Forestry Council. 78 p.

Marx DH, Hatchell GE. 1986. Root stripping of ectomycorrhizae decreases field performance of loblolly and longleaf pine seedlings. Southern Journal of Applied Forestry 10:173-179.

Mason EG.1985. Causes of juvenile instability of *Pinus radiata* in New Zealand. New Zealand Journal of Forestry Science 15:263-280.

McGee CE, Hatcher JB. 1963. Deep-planting small slash pine on old field sites in the Carolina sandhills. Journal of Forestry 61: 382-383.

McNab WH, Brendemuehl RH. 1983. Choctawhatchee sand pine survival, height, and biomass in South Carolina: third-year results. In: Jones EP. Ed. Proceedings of the Second Biennial Silvicultural Research Conference; 1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 96-100.

Mexal J, Burton S. 1978. Root development of planted loblolly pine seedlings. In: Van Eerden E, Kinghorn JM. eds. Proceedings, Root Form of Planted Trees. Joint Report 8. Victoria, BC. British Columbia Ministry of Forests and Canadian Forest Service. 85-90.

Mexal JG, Moser RL, Bryant JR, Lane, TL. 1978. Root quality in plantations affects growth of loblolly pine. Weyerhaeuser Forestry Research Technical Report 042-2008/78/53. 16 p.

Mexal JG, South, DB. 1991. Bareroot seedling culture. In: Duryea, ML, Dougherty, PM, eds. Forest Regeneration manual. Dordrecht, The Netherlands: Kluwer Academic Publishers; 89-116.

Möller A. 1910. Versuch zur Betwertung von Kiefernpflanzmethoden. Ztschr. Forst u. Jagdw.42: 629-633.

Moorhead DJ. 1988. Selecting and planting pine seedlings. Univeristy of Georgia College of Agriculture Cooperative Extension Bulletin 983: 22 p.

Muller, C. 1983. Loblolly pine seedling survival study. In: Brissette J, Lantz, C. Comp. Proceedings, 1982 Southern Nursery Conferences; 1982, July 112-15; Savannah, GA. Tech. Pub. R8-TP4 Atlanta, GA: U.S. Department of Agriculture, Forest Service: 27-39.

Mullin RE. 1974. Some planting effects still significant after 20 years. Forest Chronicle 50:191-193.

Paterson JM. 1993. Handling and planting methods influence field performance of red pine ten years after planting. The Forestry Chronicle 69:589-593.

Preisig CL, Carlson WC, Promnitz LC. 1978. Comparative root system morphologies of seed-in-place bareroot, and containerized Douglas-fir seedlings after outplanting. Canadian Journal of Forest Research 9:399-405.

Rischbieter NO. 1978. Root egress from dibble planted containerized Douglas-fir seedlings. M.S. Thesis, Univ. Wash. 96 p.

Rowan SJ. 1987. Nursery seedling quality affects growth and survival in outplantings. Georgia Forestry Commission. Georgia Forest Research Paper No. 70: 15 p.

Rudolf PO. 1939. Why forest plantations fail. Journal Forestry 37:377-383.

Rudolf PO. 1940. Further comments on “why forest plantations fail.” Journal of Forestry 38:442-443.

Schantz-Hansen T. 1945. The effect of planting methods on root development. Journal of Forestry 43:447-448.

Schultz RP. 1973. Site treatment and planting method alter root development of slash pine. U.S.D.A. Forest Service Research Paper SE 109.

Seiler JR, Paganellli DJ, Cazell BH. 1990. Growth and water potential of J-rooted loblolly and eastern white pine seedlings over three growing seasons. New Forests 4:147-153.

Senior MT, Hassan AE. 1983. Field evaluation of tree transplanting methods. American Society of Agricultural Engineers Paper No. 83-1606: 19 p.

Shoulders, E. 1962. Deep-planted seedlings survive and grow well. Sth. For. Notes Sth. For. Exp. Sta. No. 140. [2].

Shriver BD, Borders BE, Page HH Jr, Raper SM. 1990. Effect of some seedling morphology and planting quality variables on seedling survival in the Georgia Piedmont. Southern Journal of Applied Forestry 14:109-114.

Slocum GK. 1951. Survival of loblolly pine as influenced by depth of planting. Journal of Forestry 49:500.

Slocum GK, Maki TE. 1956. Some effects of depth of planting upon loblolly pine in the North Carolina Piedmont. Journal of Forestry 54:21-25.

Smith, MB. 1954. Longleaf pine seedling survival affected by depth of planting. Tree Planters’ Notes 17:13-14

South, DB. 1993. Rationale for growing southern pine seedlings at low seedbed densities. New Forests 7:63-92.

South, DB, Mitchell RJ. 1999. Survival of the fittest - pine seedling survival increased by machine planting large seedlings. Ala. Agr. Exp. Sta. Highlights Agr. Res. 46(3):16-18.

South DB, Stumpff NJ. 1990. Root stripping reduces root growth potential of loblolly pine seedlings. Southern Journal of Applied Forestry 14:196-199.

Straka, TJ, Dubois MR, Watson, WF. 1992. Costs and cost component trends of hand and machine tree planting in the southern United States (1952 to 1990) Tree Planters' Notes 43(2):89-92.

Stephen JW. 1928. Making best use of idle lands in New York. New York State College of Forestry. Bulletin No.17: 55 p.

Sutton RF. 1969. Form and development of conifer root systems. Commonwealth Forestry Bureau, Oxford. Tech. Bulletin No. 7: 131 p.

Swearingen, JW. 1963. Effects of seedling size and depth of panting on early survival and growth of slash pine. Tree Planters' Notes 58:16-17.

Switzer GL. 1960. Exposure and planting depth effects on loblolly pine planting stock on poorly drained sites. Journal of Forestry 58:390-391.

Toumey JW. 1916. Seeding and Planting. New York: John Wiley and Sons. 455 pp.

Turvey ND, Downes GM, Hopmans P, Stark N, Tomkins B, Rogers H. 1993. Stem deformation in fast grown *Pinus radiata*: an investigation of causes. Forest Ecology and Management 62:189-209.

Ursic SJ. 1963. Modifications of planting technique not recommended for loblolly on eroded soils. Tree Planters' Notes 57:13-17.

Wakeley PC. 1954. Planting the southern pines. Agriculture Monograph 18. Washington, DC: U.S. Department of Agriculture, Forest Service. 233 pp.

Wilder-Ayers, JA, Toliver, JR. 1987. Relationships of morphological root and shoot characteristics to the performance of outplanted bareroot and containerized seedlings of loblolly pine. In: Phillips DR. comp. Proceedings of the Fourth Biennial Silvicultural Research Conference; 1994 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 206-211.

Woods FW. 1980. Growth of loblolly pine with roots planted in five configurations. Southern Journal of Applied Forestry 4:70-73.

Xydias GK, Sage RD, Hodges JD, Moehring DM. 1983. Establishment, survival, and tending of slash pine. In: Stone EL. ed. Proceedings of the Managed Slash Pine Ecosystem; 1981 June 9-11; Gainesville, FL. School of Forest Resources and Conservation University of Florida. 165-193.

Xydias GK. 1983. Factors influencing survival and early stocking trends in plantation of loblolly pine. In: Jones EP. Ed. Proceedings of the Second Biennial Silvicultural Research Conference;

1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 101-108.

Zon B. 1951. Forestry mistakes and what they have taught us. Journal of Forestry 49:179-183.

Zwolinski JB, Donald DGM, Groenewald WH. 1993. Impact of site preparation on wind resistance of young *Pinus radiata*. South African Forestry Journal 164: 27-34.

Table 1. Definitions of various root shapes at time of transplanting.

Code	Orientation
I-root	A taproot pointed straight down (0-20°)
D-root	1 cm or more of the taproot pointed down at an angle (21°-69°)
L-root	1 cm or more of the taproot pointed horizontally (70° –110°)
J-root	Less than half of the taproot in a J-shape pointed up (>110°)
N-root	Two bends in the taproot with the tip pointed down
P-root	A loop in the taproot with the tip pointed down
U-root	Half or more of the taproot pointed up (>110°)
ψ-root	A taproot pointed straight down ((0-10°) but with two or more first-order lateral roots pointed up (>110°)

In addition to the letter code, a number code can be added to provide more information on the root-collar diameter, planting depth, rooting depth, and taproot length. For example, seedling with an L-root and a code of (L:5:3:13:15) has a 5 mm root-collar with the root-collar 3 cm below the surface, it has a root depth of 13 cm, and the taproot is 15 cm long. A U-root with a 6 mm root-collar diameter (U:5:8:15:16) would the root-collar 8 cm below the groundline, the roots are up to 15 cm below ground, and the taproot is 16 cm long. A N-root with a 4 mm root-collar diameter (N:4:0:7:18) would have the root-collar at groundline, the roots would only extend to 7 cm below the surface, and the bent taproot (if extended) would measure 18 cm long. An I-root with a 5 mm root-collar diameter (I:5:-1:18:15) would have the root-collar 1 cm above the groundline, the lateral roots would extend to 18 cm below the surface, and the taproot is 15 cm long.

Table 2. Effect of root pruning after lifting on survival (%) of pine seedlings (Wakeley 1954, Dierauf and Garner 1978, Dierauf 1984, Dierauf 1992, Harrington and Howell 1998).

Year	Species	No prune	Pruned	Heavily pruned
1954	Slash	77	36	6
1954	Slash	40	24	1
1954	Longleaf	81	80	42
1954	Longleaf	61	39	11
1978	Loblolly	95	94	90
1978	Loblolly	95	95	87
1978	Loblolly	93	90	92
1978	Loblolly	93	85	87
1978	Loblolly	100	93	82
1984	Loblolly	94	98	--
1984	Loblolly	90	93	--
1984	Loblolly	90	91	--
1992	Loblolly	82	80	--
1992	Loblolly	100	95	--
1992	Loblolly	97	95	--
1998	Loblolly	80	76	74

Table 3.--Effect of root distortion on outplanting survival (%) of bare-root pines in the southern United States (Wakeley 1954, Ursic 1963, Little 1973, Hay and Woods 1974b, Hunter and Maki 1980, Woods 1980, Dierauf 1992, Harrington and Howell 1998). In no case was a statistically significant difference reported.

Year	Species	Straight roots	Bent-roots	Root form	Difference
1954	Longleaf	86	86	U	0
1954	Longleaf	42	42	U	0
1954	Longleaf	82	88	U	+6
1954	Slash	62	69	U	+7
1954	Slash	71	56	U	-15
1954	Slash	96	94	U	-2
1963	Loblolly	87	75	U	-12
1963	Loblolly	89?	89?	U	?
1963	Loblolly	94?	94?	U	?
1973	Loblolly	89	86	L+J	-3
1973	Loblolly	60	67	L+J	+7
1974	Loblolly	90	90	J	0
1980	Loblolly	89	91	Curl	+2
1980	Loblolly	70	78	L	+8
1980	loblolly	55	51	L	-4
1992	Loblolly	80 ***	82	ψ	+2
1992	loblolly	95 ***	100	ψ	+5
1992	Loblolly	95 ***	97	ψ	+2
1998	Loblolly	87 *	80 **	J	-7
1998	Loblolly	76 ***	80 **	J	+4

* Planted with shovel – roots not pruned
** Planted with hoedad – roots not pruned
*** roots pruned

Table 4. Effect of planting depth on survival (%) of southern pine seedlings (Slocum 1951, Smith 1954, Wakeley 1954, Malac and Johnson 1957, Slocum and Maki 1956, Switzer 1960, Shoulders 1962, McGee and Hatcher 1963; Swearingen 1963, Ursic 1963, Donald 1970, Dierauf 1984, Bilan 1987, Blake and South 1991). Where reported, numbers in parentheses indicate the distance in cm between the root-collar and the soil surface.

Year	Species	Root-collar near surface	Deeper	Difference
1954	Longleaf	73 (0)	83 (1.3)	+10
1954	Longleaf	74 (0)	90 (1.3)	+16
1954	Longleaf	68 (0)	76 (1.3)	+8
1954	Slash	83 (0)	83 (5)	0
1954	Slash	92 (0)	95 (5)	+3
1957	Slash	40	61	+21
1963	Slash	80 (0)	90 (15)	+10
1963	Slash	80 (0)	95 (28)	+15
1963	Slash	86	89	+3
1963	Slash	71	70	-1
1951	Loblolly	97 (0)	97 (5.7)	0
1956	Loblolly	97	97	0
1956	Loblolly	97	91	-6
1956	Loblolly	99 (2)	94 (9.3)	-5
1956	Loblolly	85 (1.5)	98 (5.5)	+13
1960*	Loblolly	59	66	+7
1963	Loblolly	87	76	-11
1970	Loblolly	72 (0)	82 (6)	+10
1984	Loblolly	79 (2.5)	86 (7.5)	+7
1984	Loblolly	84 (2.5)	86 (7.5)	+2
1984	Loblolly	84 (2.5)	90 (7.5)	+6
1987	Loblolly	90 (0)	87	-3
1991	Loblolly	70 (4.8)	85 (11.9)	+15
1991	Loblolly	69 (1.3)	84 (9.4)	+15
Poorly drained soil				
1960	Loblolly	90	73	-17
1960	Loblolly	90	32	-58

* Data from Koshi (1960) assumes he made an error and reported data as survival instead of mortality.

Figure 1 – A comparison of hand planting recommendations from members of the "pull-up" school (Anonymous 1981) with hand planting recommendations from members of the "leave-down" school.

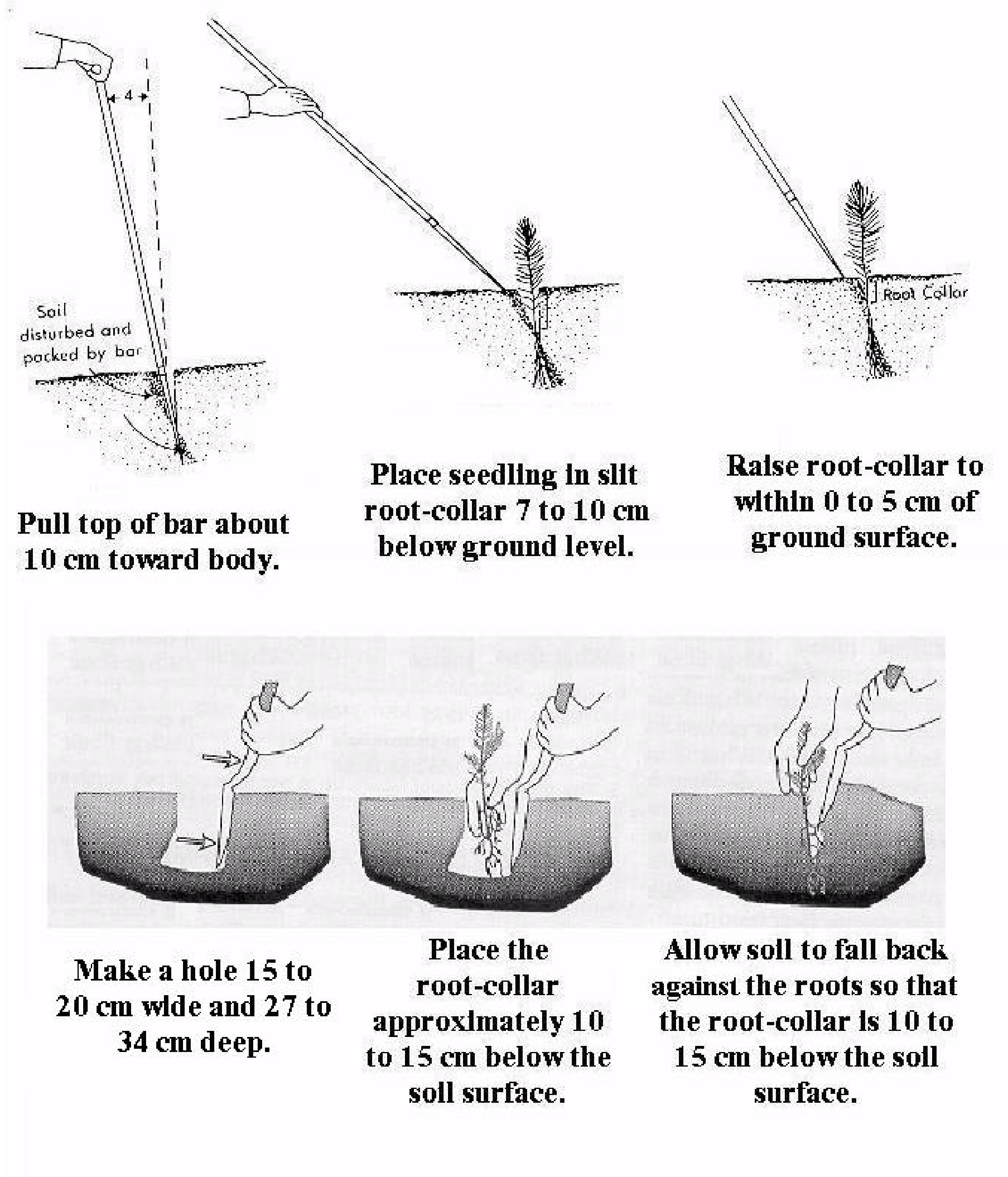

Figure 2—Yellow pine killed from crowding its roots into a shallow planting hole (A). Yellow pine in the same plantation in good condition and tap-root re-established (B). L-root planted in a deeper hole.

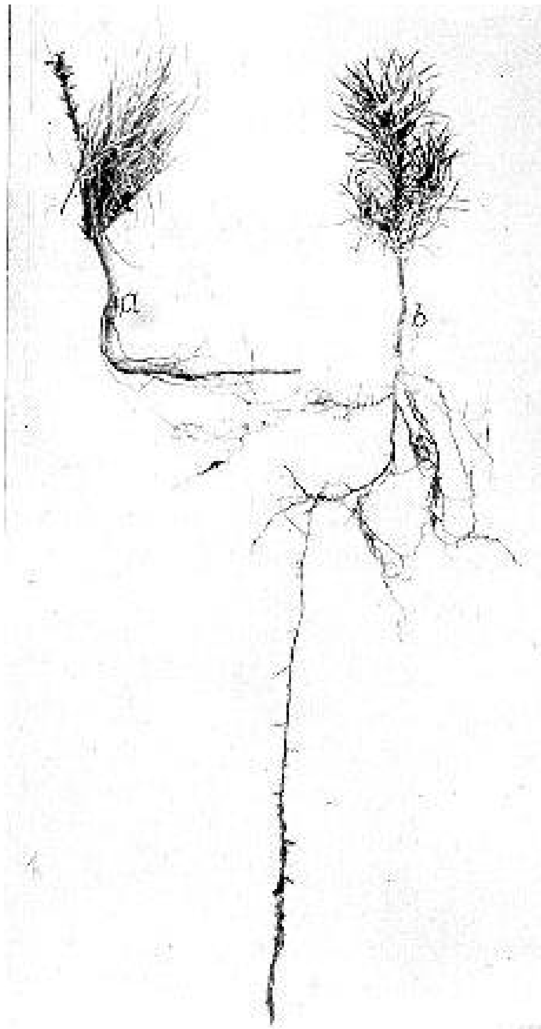

Figure 3—The effect root depth, water stress and root form on the survival of loblolly pine seedlings 12 weeks after planting in shallow holes (8 to 18 cm deep) in a greenhouse (adapted from Brissette and Barnett 1989).

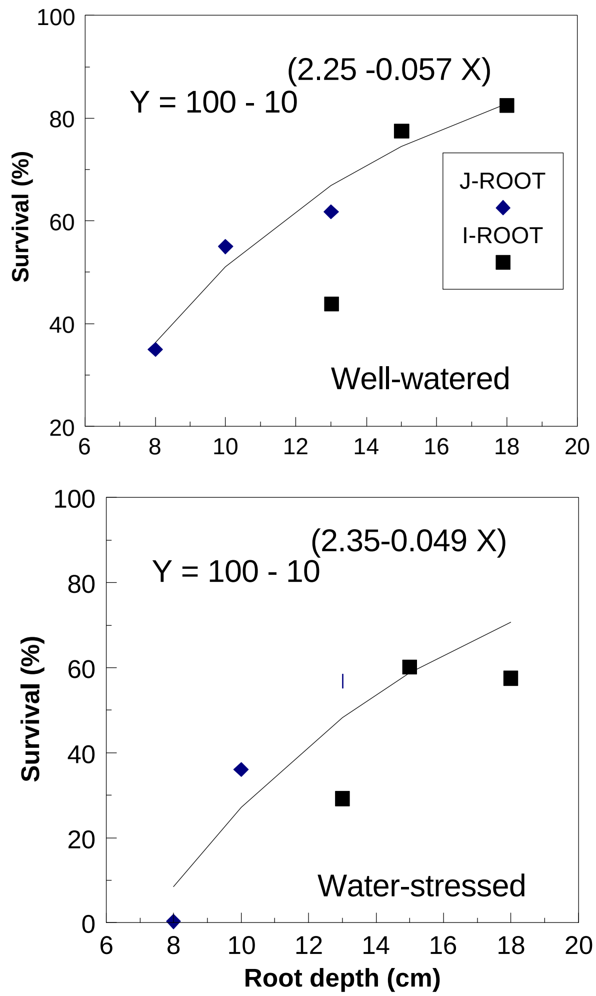

Figure 4—New growth of U-roots of loblolly pine often turn downward. This seedling was excavated from a sandy textured soil in April of the third growing season (from Ursic 1963).