WHICH LOBLOLLY PINE SEEDLING HAS A HIGHER SURVIVAL POTENTIAL – A DEEP PLANTED J-ROOT OR A SHALLOW PLANTED I-ROOT?

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Abstract--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 up the seedling usually results in "shallow" planting (which could increase mortality on some sites). The "push-down" school advocates making a deep planting hole and placing the roots near the bottom of the hole. They 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 roots should look "normal" after planting; (3) eliminate 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.

INTRODUCTION

In the South, many planted seedlings (40% to 80%) can be classified as having deformed roots (Gruschow 1959, Schultz 1973, Hay and Woods 1974a, Mexal and Burton 1978, Harrington and others 1989). However, just because a planted pine seedling has a bent taproot, this does not mean the performance will be less than seedlings that originate from direct seeding. In fact, sometimes 32% percent of loblolly pines (*Pinus taeda* L.) originating from seed have bent taproots (Harrington and others 1989). Therefore, bends in the taproot can be "natural" as well as "man-made." Even so, some claim that J-roots (Table 1) will kill seedlings and that utmost care should be exercised during planting to ensure the taproot is straight. They claim that planting seedling roots deeply will bend the roots and, therefore, they say the "proper" planting depth is so the root-collar is slightly below groundline.

In my opinion, tree planting guidelines for loblolly pine overemphasize the dangers of both J-rooting and deep planting. Planting guidelines should be rewritten to eliminate the unimportant aspects of planting and to stress the important. Most data with loblolly pine indicate that bent roots, *per se*, do not affect early seedling survival or growth. On many sites, planting loblolly pine or slash pine (*Pinus elliottii* Englem.) deep in the hole increases survival (Slocum and Maki 1956, Malac and Johnson 1957, Malac 1965, Blake and South 1989).

This paper reviews the J-rooting 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. It reviews data mainly from the compression method planting where root systems are compressed into a vertical plane (also know as slit planting).

TWO SCHOOLS OF THOUGHT REGARDING THE PROPER PLANTING TECHNIQUE

Two schools of thought exist regarding the planting of loblolly and slash pine seedlings. The older-school favors the "pull-up" technique where the seedling is placed into the planting hole and then pulled up 3 to 10 cm (and the root-collar is about 1 to 5 cm below the soil surface). This action purportedly improves field performance by straightening out the roots. Several tree planting guides recommend this technique even though empirical trials by Wakeley (1954) show no advantage of this technique when compared to planting with a mattock. We even do not know if pulling the seedling up 3 cm is really enough to straighten out the roots. To avoid ψ-roots, members of this school allow some pruning of long fibrous roots by tree planters. "Graduates" of this school prefer straight taproots to deep planting. They claim the "correct" planting depth is to have the root-collar at or slightly below the groundline.

The other school recommends the "push-down" technique (which favors deep planting over straight taproots). 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). On sites where hand-planting is required, leaders in this school recommend making a wide (15 to 18 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 recommended by the "pull-up" school. For many sites, the "correct" planting depth for loblolly pine 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 sites where the water table is near the surface can decrease survival of loblolly pine (Switzer 1960). Therefore, the "correct" planting depth varies with site.

Because less time is required to make narrow, shallow holes, hand planters prefer recommendations from the "pull-up" school. Making a deeper planting hole by hand increases planting costs which is one reason those from the "push-down" school favor machine planting.

DEFINITONS

Tree planting terminology can sometimes be confusing. For example, 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). I offer the following definitions.

Root depth = distance between groundline and bottom of 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.

Deep planting = planting seedlings with the root-collar 7 to 18 cm below the groundline.

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 PLANTING RECOMMENDATIONS

The debate about proper planting techniques has been going on for more than a century. For example, Jarchow (1893) recommended shallow planting (a little higher than they stood in the nursery) and 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 probably can not comprehend how those in the "push-down" school can allow seedlings to be planted deeply (which results in J- and L-rooting). Debates on proper planting techniques will likely continue when data from empirical studies contradict intuition.

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. Observational studies are good for formulating a hypothesis but are not good for testing one. Experiments carefully designed to minimize confounding are good for testing hypotheses. Little confidence should be placed in guidelines that rely only on 19th century intuition. Tree planting guides that cite only observational studies should also be viewed with caution. The greatest confidence should be placed on guidelines that cite results from actual planting method experiments.

SHALLOW PLANTING KILLS SEEDLINGS

Several tree planting guides state that root deformation will kill seedlings (Stephen 1928, Martin and others 1953). However, for loblolly pine or slash pine, there are no data proving this is true. Not only do most J-rooting trials show no significant effect on survival, but almost all these trials confound root depth with root form. Therefore, the real cause of mortality in such trials could simply be due to shallow planting. Apparently, the idea that J-rooting can kill seedlings may have originated from a misinterpretation of a photo in a book by Toumey (1916). His figure 106 shows two L-rooted seedlings (one dead and one alive). Apparently some readers assumed the tree died because of the L-root as opposed to the shallow planting. However, 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. All seedlings 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 1). In fact, when compared to the survival of I-roots (15-0) placed in a very shallow planting hole (only 13 cm deep), J-roots (15-5) increased survival by 18% to 27%! Extrapolating the equations in figure 1 suggest that 90% survival could have been obtained if roots had been planted 22 cm to 28 cm below the groundline. Unfortunately, the researchers made no holes this deep. Perhaps they were following recommendations that holes only be 15 cm to 20 cm deep (Martin and others 1953). In Virginia, planting holes using a OST bar are typically only 17 cm to 20 cm deep (Dierauf 1992).

A new OST planting bar can be used to make a 25 cm deep hole and a Whitfield planting bar 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. Therefore, when planting roots in holes only 8 to 19 cm deep, tree planters should expect some mortality (even under well-watered conditions in a greenhouse).

Results from U-root and depth of planting trials caused Wakeley (1954) to conclude that in ordinarily well-conducted planting operations, plnating depth probably reduces survival more often and more seriously than any and all other errors in planting combined. He said that U-rooting “usually has a negligible effect on initial survival.” I have to assume those that claim U-roots reduce survival do not realize that shallow root depths kill seedlings, root form does not.

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.” 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 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 2. On average, survival of seedlings with bent roots was about 0.6% less than seedlings with I-roots. However, in almost all cases, bent roots had less root depth than I-roots. Therefore, confounding exists between root depth and root form.

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 planting technique should be avoided.

Gruschow (1959) excavated 2,005 loblolly pine seedlings three years after planting. He said it “was impossible to predict the condition of the roots from the above-ground development and appearance of the seedlings. The early growth did not seem to be related to the root classes.” After excavating 163 slash pine seedlings, Schultz (1973) concluded that root deformation did not appear to be detrimental to tree growth. Hay and Woods (1974a) excavated 348 saplings and found a positive correlation between root deformation and size of seedlings four to six years after planting. On one site, loblolly seedlings with the most root deformation were more than twice as heavy as seedlings with I-roots. This apparent correlation may be simply due to more root deformation when planting seedlings with larger roots. However, Harrington and Gatch (1999) reported a growth benefit when size at planting was not confounded with root form.

Mexal and Burton (1978) excavated 100 seedlings two to four years after planting. As one might expect, they found a positive relationship between initial seedling size and early growth on all four 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). Harrington and others (1987) excavated 192 loblolly pine seedlings (ages varied from three to nine years old). Half of the trees were from natural or artificial seeding. 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 four plots in Arkansas, they found a total of 3 planted trees that still had roots shaped like an L- or J- (root class #2). These 3 trees averaged 24 cm less growth than 14 planted trees with single taproots (root class #1). Likewise, in the Gulf Coastal Plain, they found a

12 cm difference in growth between I-roots (22 trees) and J-roots (7 trees). They conclude 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. In contrast, Harrington and Gatch (1999) found better height growth for seedlings that were J-rooted.

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, observations from Europe suggest this might have occurred with pine and spruce in Germany and Austria (Toumey 1916). Since scientists cannot prove a null hypothesis, advocates of the "push-down" technique cannot prove that something bad will not happen in the future. They can only say that in one study, 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 but it is a problem on planted trees in some countries, especially on sites with high water tables. However, even in areas with hurricanes, toppling of bare-root southern pines is rare. In a recent review, none of the 125 cited references dealt with the southern pines (Rosvall 1994). Infrequent toppling has occurred 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. Older loblolly pine trees tend to snap as opposed to lean (Fredericksen and others 1993). However, intuition suggests to some (Gruschow 1959) that when shallow planted seedlings are so cramped that they defy classification, high winds might cause toppling.

There are some who say that slit planting affects toppling more than J-rooting. For example, Schultz (1973) excavated five slash pine seedlings that had blown over. Although all five 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).

Intuition suggests that toppling might be negatively related to planting depth. Klawitter (1969) believed that toppling increased when roots were planted parallel to the surface (and on wet soils). 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. There is word from New Zealand that the “pull-up” method of tree planting results in more toppling than planting the seedlings deep. If toppling becomes a problem in the South when using intensive methods on old-field sites, 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 old-field sites with high fertility (Birk 1991, Touvey and others 1993).

Some believe that crooked stems can result from toppling. Some pines that have a 50° lean at age 2 will recover to a 5° lean by 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 (Harris 1977).

If shallow planting results in toppling, this can cause crooked stems. Gatch and Harrington (1999) excavated 144 trees and observed stem sinuosity on trees with and without straight taproots. The amount of sinuosity on trees with bent taproots was about twice as great as trees with straight taproots. If a "ball-and-socket" results in toppling, then this might explain the apparent correlation between bent roots and sinuosity. Also, if fast-growing seedlings are planted on a lean, this might also result in the formation of compression wood and sinuosity. 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 but is planted deeply (on a drained soil) will have a higher probability of survival than a shallow planted seedling 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.

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

Code	Orientation
I-root	A taproot pointed straight down (0-20°)
D-root	A bent taproot (1 cm or more) pointed down (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 ((0-20°) 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 planting depth, rooting depth, and taproot length. For example, an L-root (3:13:15) is planted 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 (8:15:16) would have 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 (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 (-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 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
*** Planted with hoedad – roots lightly pruned

Figure 1—The effects of 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). Each equation was derived using five means.