Nursery Lifter Operation Affects Root Growth Potential of Pine Seedlings

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Abstract

Root damage to seedlings is inherent in a bareroot lifting operation. Full-bed lifters lift all seedling drills across a nursery bed at one time, whereas two-row lifters selectively lift any two seedling drills across a nursery bed but require multiple passes to lift all the seedlings. To determine the extent of root damage among lifting methods, we compared roots of seedlings lifted with a two-row or a full-bed lifter, each operated at the normal calibrated speed and a faster noncalibrated speed, to hand-lifted seedlings at three nurseries in the Southern United States. When root growth potential (RGP) and root morphology were used to evaluate lifter speed for the full-bed lifter, two of the three nurseries had greater RGP or root morphology measurements at a faster tractor speed. The use of two-row seedling lifters, which travel four to six times faster than full-bed lifters, resulted in significantly more root injury than hand-lifted seedlings. No difference existed in root biomass or root weight ratio measurements with nursery treatments. If nursery staff use ocular comparisons of seedling roots to evaluate lifter efficiency, careful attention needs to be given to the presence of fine root tips, mycorrhizae, and damage to root cortex on lateral roots that could cause a reduction in RGP.

Introduction

A priority for bareroot nursery managers during the lifting process is to minimize seedling damage caused by lifting equipment. Before 1934, all seedlings were lifted by hand using a shovel, but beginning in 1935, simple lifting blades were developed to cut the taproot and loosen the soil, thereby enabling crews to manually remove seedlings from nursery beds (May 1984). In 1958, the Agricultural Engineering Department at the University of Georgia developed the first mechanical harvester capable of loosening and lifting a full bed of eight seedling rows (Darby 1962). This machine became the prototype of other full-bed (eight-row) lifters as well as partial-bed lifters that are now used in the Southern United States (May 1984). Partial bed lifters (e.g., Mathis®) caught on in seedling production because they were less expensive (Sampson 1972) and operated at a higher ground speed than full-bed lifters, allowing for similar numbers of lifted seedlings per day (Sampson 1972, Black 1976). Unlike full-bed lifters, partial-bed lifters require multiple passes over the nursery bed to lift all seedlings.

Seedling lifters are pulled by a tractor and powered by a power take-off-driven hydraulic pump. As the lifter is pulled down the nursery bed, pairs of counter-running pickup belts are lowered to grab seedling stems at the ground line and gently lift individual rows (drills) of seedlings out of the soil. A full-bed lifter would typically have eight pairs of belts, one pair for each seedling drill. Before the belts lift the seedlings, the taproots are generally cut to approximately 6.0 in (15.2 cm) and the nursery bed loosened using either the lifter blade on the full-bed lifter or in a separate operation. One- and two-row lifters are not equipped with a lifter blade and require a separate operation to cut the taproot and loosen the soil nursery bed before lifting seedlings. Root shakers loosen excess soil as seedlings move up the belts. When the seedlings reach the end of the belts, they are directed either to seedling bins for shed packing operations or to personnel who place the seedlings directly into bags for field packing.

In contrast to mechanical lifters, some nurseries in the Southern United States continue to hand-lift their entire seedling crop. Nurseries use this method because mechanical lifters are more difficult to use in fine texture (heavy soils) and the cost of a mechanical lifter may not be economical based upon the number of seedlings grown. In this case, the seedling beds are undercut, the root systems are shaken and loosened by a tractor-pulled machine, and then the seedlings are hand-lifted and placed into either tubs or crates.

In the Southern United States, nearly all nurseries lateral-prune their seedlings within the nursery beds at least one time in early to middle fall. The lateral pruning severs the lateral roots between the seedling drills, which facilitates machine lifting. Nurseries also undercut the nursery beds at least one time before lifting regardless of whether the lifter blade on the full-bed lifter is used.

Nursery managers at bareroot nurseries take precautions to minimize seedling injury during the lifting and shipping process. At the beginning of the lifting season, nurseries generally follow a three-step calibration process. First, the lifter belts are adjusted so that their speed is slightly faster than the tractor ground speed. If the belt speed is too fast, seedlings are snatched from the ground causing root injury (figure 1) or injury to the root collar region. When the belt speed is too slow, seedlings are not separated coming up the belt, which leaves the roots susceptible to tearing during the packing process. The normal calibrated tractor speed used by a nursery is determined based on soil texture. Second, the root shakers are adjusted so as to leave some soil on the roots to prevent drying out. Too much soil can cause further root injury in handling. The third step in seedling lifter calibration involves comparing the root mass of seedlings lifted with a shovel from an adjacent area to seedlings from the lifter. Individual seedlings are examined for root biomass and the presence of fine root tips, mycorrhizae, or damage to lateral roots or to the root collar region. It is common for individual nurseries to make additional modifications to their seedling lifters based on their soil texture in an effort to maintain seedling quality.

In addition, nurseries try to minimize root exposure after lifting by spraying roots with acrylic-based gels, storing seedlings in a cooler, and shipping in refrigerated trucks. Examining the nursery bed behind any lifter today will reveal numerous fine roots remaining in the soil. Rowan (1987) reported that lifting bareroot seedlings from nursery beds can remove 35 to 77 percent of small roots from seedlings. South and Stumpff (1990) reported that a loss of 22 percent of the "short roots" and a few of the higher order "long lateral" roots reduced root growth potential (RGP) by 50 percent. The stripping of roots by machine lifters can increase seedling mortality after outplanting up to 50 percent (Langdon 1954; Wakeley 1965; Barnard and others 1980; Xydias 1982; Rowan 1987; Reynolds and others 2002). Summarizing these studies, South and Cary (2001) suggest that one- or two-row lifters had greater seedling mortality compared with full-bed lifters. Because the type and speed of lifter are two factors that can be adjusted, the purpose of this study was to compare RGP, root biomass, and root morphology of pine seedlings lifted with either a two-row or full-bed lifter operated at two different speeds.

Methods

Three bareroot nurseries located within the Coastal Plain region of the Southern United States were chosen for this study (figure 2, table 1). At Nursery A, slash pine (*Pinus elliottii* Engelm.) seedlings were lifted on December 15, 2010 using a Mathis® two-row lifter (figures 3 and 4) and a Love® full-bed lifter (figure 5). At Nurseries B and C, loblolly pine (*P. taeda* L.) seedlings were lifted on February 9 and February 23, 2011, respectively, using a Love® full-bed lifter. The Mathis® two-row lifter can be adjusted to lift any two seedling drills within a nursery bed (figure 6) whereas the Love® full-bed lifter removes all drills across the seedling bed (figure 7). The Love® full-bed lifter also has a seedling lifter blade that can be raised or lowered to assist in loosening soil and seedlings during operation (figure 8); this blade was used only at Nursery C. At each nursery, the lifter(s) were operated at two speeds: the normal speed at which the lifter was calibrated and a faster speed (table 2).

At each nursery, four sections (replications) of a bed row (approximately 80 ft [24 m]) were selected for the study. Within each 80 ft (24 m) section, the lifter(s) were operated at the

Figure 1. Example of seedling lifter damage to lateral roots. (Photo by Tom E. Starkey)

Figure 2. Example of southern coastal plain bareroot nursery. (Photo by Tom E. Starkey)

Table 1. Nursery, species, seedling density, date lifted, and nursery soil characteristics of the three nurseries included in this study.

Nursery	Pine species	Seedling density ft^2 (m^2)	Date lifted	Soil moisture (%)	Percent		
					Sand	Silt	Clay
A	Slash	21 (233)	12/15/2010	7.1	84	9	7
B	Loblolly	23 (255)	2/9/2011	10.1	83	9	8
C	Loblolly	21 (233)	2/23/2011	6.4	74	15	11

Figure 3. Mathis® two-row seedling lifter. (Photo by Tom E. Starkey)

Figure 5. Lifter belts for the Love® full-bed seedling lifter. Each of the two adjacent belts lifts one row of seedlings. (Photo by Tom E. Starkey)

Figure 4. One row of lifter belts for the Mathis® two-row lifter. (Photo by Tom E. Starkey)

Figure 6. Mathis® two-row lifter adjusted to lift seedling drills 3 and 6. (Photo by Tom E. Starkey)

two different speeds. This practice allowed for the collection of approximately 50 seedlings for each lifting speed in each replication. In addition, approximately 50 seedlings, designated as control seedlings, were hand lifted using a shovel from the third seedling drill in each 80-ft (24-m) plot at each nursery before any mechanical lifting. Hand-lifted seedlings were chosen as our control, because nurseries generally use these seedlings to evaluate the effectiveness of seedling lifter calibration.

Replications for 25 seedlings per treatment were measured for root collar diameter (RCD), height, shoot and root biomass, and root weight ratio (RWR, defined as the root weight divided by total seedling weight). The roots from 10 of these seedlings per treatment replication were selected before drying for root morphology measurements using WinRhizo computer software using a flatbed scanner (Regents Instruments Inc., Quebec, Canada). Root morphology data included root volume, root length, number of root tips, and number of

Figure 7. Seedling bed after seedlings are removed using Love® full-bed lifter. (Photo by Tom E. Starkey)

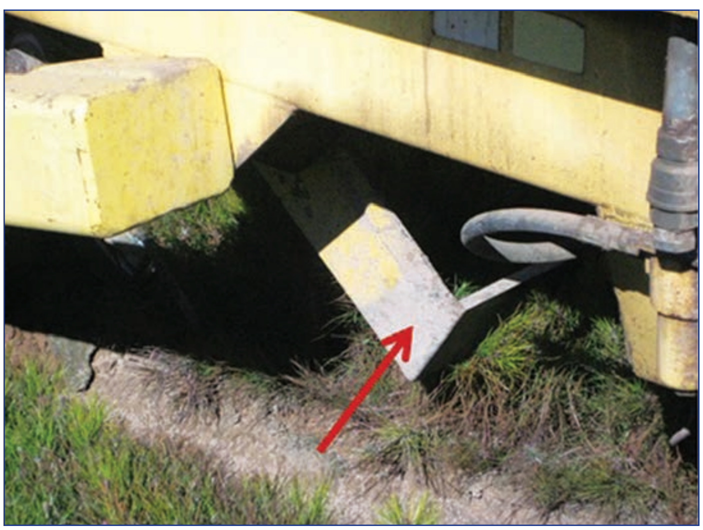

Figure 8. Love® full-bed lifter with seedling lifter bar in raised (unused) position (top) and in lowered (in use) position (bottom). (Photo by Tom E. Starkey [top] and Ben Whitaker, Auburn University [bottom])

Table 2. Lifter type and lifting speed used to remove seedlings from nursery beds.

Nursery	Lifter	Lifter blade used?	Normal speed mph (kph)	Fast speed mph (kph)
A	Mathis® two-row	NA	1.50 (2.4)	2.00 (3.22)
A	Love® full-bed	No	0.25 (0.40)	0.50 (0.81)
B	Love® full-bed	No	0.33 (0.53)	0.39 (0.63)
C	Love® full-bed	Yes	0.50 (0.81)	0.70 (1.13)

NA = not applicable

root forks (a rough estimate of mycorrhizae). Forty seedlings (five seedlings per treatment by eight replications) were placed in aquariums (figure 9) with aerated water for 30 days then evaluated for RGP by counting the number of white root tips that are greater than 0.5 cm (0.2 in) (Palmer and Holen 1986; figure 10). Analysis of variance was performed using the PROC GLM function to test for treatment differences at an alpha level of 0.05. Treatment means were separated using Duncan's Multiple Range Test (SAS Institute 2003).

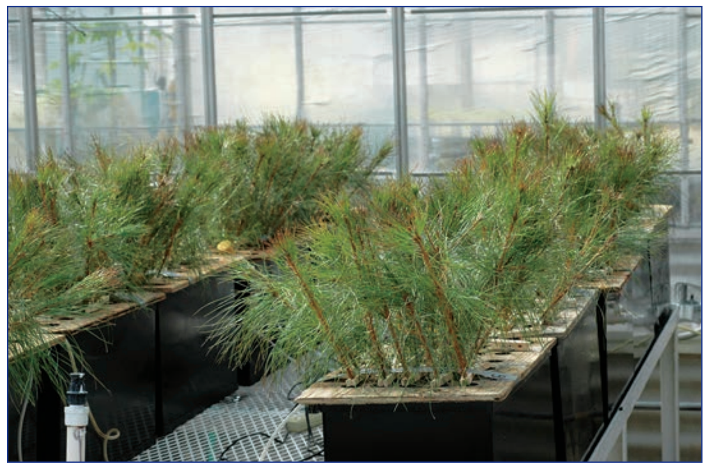

Figure 9. Aquariums used for root growth potential. (Photo by Tom E. Starkey)

Results

Nursery A

Lifter type or speed had no effect on seedling height, root biomass, or shoot biomass (data not shown). No significant difference existed for RWR between lifters or lifter speed (table 3). Seedlings lifted by the Love® full-bed lifter averaged 6 percent larger RCD than those collected from the Mathis® two-row lifter (data not shown). The full-bed lifter operated at the faster speed had 85 percent more white root tips than the normal speed. The speed of the two-row Mathis® lifter had no effect on RGP when comparing white root tips. The hand-lifted controls and the Love® full-bed fast speed

Figure 10. Slash pine roots ready to have root growth potential (RGP) white root tips counted (left) and white root tips being counted for RGP determination (right). (Photos by Paul Jackson, Louisiana Tech University [left] and Tom E. Starkey [right])

Table 3. A comparison of treatment means for root characteristics and root weight ratio at each nursery. Means within a column for each nursery followed by the same letter are not significantly different at alpha = 0.05.

Treatment	# White root tips	Root volume cm^3 (in^3)	Root length cm (in)	# Root tips	# Root forks	Root weight ratio
Nursery A (slash pine)						
Hand-lifted (control)	78.1 a	2.30 (0.140) a	293 (115) a	814 a	1,488 a	0.16 a
Mathis® two-row—normal speed	51.0 b	1.68 (0.103) b	215 (85) bc	746 ab	894 b	0.14 a
Mathis® two-row—fast speed	53.8 b	1.66 (0.101) b	202 (80) bc	582 b	886 b	0.15 a
Love® full-bed—normal speed	47.5 b	1.96 (0.120) ab	240 (94) bc	593 b	945 b	0.15 a
Love® full-bed—fast speed	88.0 a	2.04 (0.124) ab	254 (100) ab	585 b	1,101 b	0.15 a
Nursery B (loblolly pine)						
Hand-lifted (control)	63.5 a	3.81 (0.232) a	353 (139) a	742 a	1,916 a	0.24 a
Love® full-bed—normal speed	61.1 a	2.20 (0.134) c	206 (81) c	466 c	907 c	0.23 a
Love® full-bed—fast speed	74.1 a	2.75 (0.165) b	255 (100) b	580 b	1,204 b	0.23 a
Nursery C (loblolly pine)						
Hand-lifted (control)	34.1 b	3.72 (0.227) a	441 (174) a	847 a	2,402 a	0.23 a
Love® full-bed—normal speed	45.1 a	3.79 (0.231) a	383 (151) a	727 a	1,845 a	0.25 a
Love® full-bed—fast speed	26.5 c	3.78 (0.231) a	431 (170) a	776 a	2,058 a	0.24 a

treatments had greater RGP than either speed used on the Mathis® two-row lifter and the slow speed on the Love® full-bed lifer (table 3). Seedling root volume, root length, and number of root forks were significantly less for the Mathis® two-row lifter compared with the hand-lifted controls. No difference existed between the root volume from the hand-lifted controls and the Love® full-bed lifter (table 3).

Nursery B

Lifter speed had no effect on number of white root tips, RWR (table 3), RCD, height, root biomass, or shoot biomass (data not shown). In contrast, root volume, root length, number of root tips, and number of root forks were significantly greater on seedlings lifted at the fast speed compared with those lifted at the slower (normal) speed (table 3). Hand lifting seedlings at this nursery resulted in greater root volumes, root lengths, number of roots tips and forks when compared with either speeds of the full-bed lifter (table 3).

Nursery C

The lifting speed had no effect on root volume, root length, number of root tips, number of root forks, or RWR (table 3). In addition, RCD, height, root biomass, and shoot biomass were similar between lifting speeds and the hand-lifted controls (data not shown]. In contrast, the full-bed lifter operated at the normal speed had more white root tips than either the full-bed lifter operated at fast speed or the hand-lifted controls (table 3).

Discussion

Personnel operating forest-seedling nurseries routinely calibrate their seedling lifter before the lifting and packing season. Comparing the root mass of seedlings lifted with a shovel from an adjacent area with those from the seedling lifter is the most common method for evaluating seedling lifter efficiency (Langdon 1954). The goal is to have a fibrous root system equal or better than hand lifted (Darby 1962). This method is very subjective, and detecting root loss, especially of fine and mycorrhizal roots, may be difficult. In our study, no differences were observed among treatments for root biomass or RWR at any nursery; however, treatment differences were observed for RGP and other root morphology characteristics. South and Stumpff (1990) showed that even a small loss of fine roots, not reflected in root weight, can result in up to a 50-percent reduction in RGP.

One of the more interesting results was that seedlings lifted by the Love® full-bed lifter had larger RCD compared with those lifted by the partial-bed Mathis® lifter. This larger RCD is likely because of the difference in seedling size within the seedling drills and the seedlings sampled by each lifter. In a typical nursery bed, the two outside drills (drills 1 and 8) have larger RCD than the inside drills (drills 2 to 7). Thus, the Love® lifter sampled the entire nursery bed, whereas the Mathis® two-row lifter lifted seedlings from the interior rows, using drills 3 and 6, which tend to be smaller (figure 4). Although the difference was statistically significant, a 6-percent difference would not be biologically significant.

Although no differences were observed in RWR at any of the nurseries with respect to lifting speed, a difference in the magnitude of RWR was observed among nurseries. A RWR of more than 27 percent is equivalent to a shoot-to-root ratio of 2.5:1.0, an optimum ratio for outplanting survival (USDA Forest Service 1989). While none of the lifting speeds or lifters examined in these trials resulted in the optimum RWR at the time of lifting, a number of factors may have influenced the RWR. For example, the time of lifting, the seeding density, the time of root pruning (lateral and undercutting), the irrigation regime, and the time since fertilization can all affect the RWR. At Nursery A, when the seedlings were lifted in December, the average RWR was 15 percent whereas at the other two nurseries, where seedlings were lifted in February, the average RWR was 24 percent. Sung and others (1997) showed that typical southern pine RWRs from September to February can range from 11 to 28 percent and can increase up to 25 percent per month. Because of the various cultural practices conducted within a nursery, it is difficult for nurseries that lift seedlings in October or November to obtain RWRs near 27 percent. Because RWR is correlated with survival after outplanting (South 1998), the loss of roots or damage to the root system in nurseries with low RWR (low root biomass) may have the potential for poor outplanting performance compared with seedlings with a greater RWR (greater root biomass).

Most nurseries in the Southern United States no longer use a two-row lifter because of the amount of fine roots remaining in the soil after lifting. In addition, four passes must be made over the same bed to lift all seedlings, resulting in even more root damage. In this study, the use of the Mathis® two-row lifter at both speeds resulted in lower RGP, root volume, root length, and root forks when compared with hand-lifted controls. Similar reductions in root morphology as well as decreased outplanting survival, 1-year volume, height, and diameter were reported by Reynolds and others (2002) when loblolly pine seedlings lifted with a Mathis® two-row lifter were compared with hand-lifted seedlings. In another study, second-year survival, height increment, and volume index were significantly less with a Mathis® two-row lifter compared with hand-lifted controls (Greene and Danley 2001). South and Cary (2001) reported outplanting survival of loblolly pine from a two-row lifter was reduced by 40 percent compared with the hand-lifted controls.

In this study, the normal speed used for each lifter was not always the most efficient as measured by RGP and/or root morphology characteristics. At Nursery A, the full-bed lifter at the faster speed had greater RGP than seedlings lifted at their normal, operational speed. At Nursery B, all root morphology characteristics were greater on seedlings lifted at the faster speed than seedlings lifted at the normal, operational speed. Based on these seedling root characteristics, better seedling quality may have been achieved at Nurseries A and B if the lifter had been calibrated at a faster tractor speed before the onset of the lifting season. Care should be taken to ensure the belt speed and tractor speed result in the greatest amount of roots per seedling to ensure seedling survival after outplanting. The best RGP and root morphology data would be expected when the belt speed properly matches the tractor speed. This observation was made at Nursery C, where the RGP at the normal (calibrated) speed was greater than at the faster speed with no other detectable difference in root morphology measurements.

Of the lifters examined in these trials, Nursery C was the only nursery to use the lifter blade during operation. This particular nursery has a finer textured soil than the other two nurseries (table 1) and was the only nursery where the hand-lifted seedlings resulted in a lower RGP than the machine-lifted seedlings. Lower RGP on hand-lifted seedlings is counterintuitive and one explanation may be the lateral and undercutting process at this nursery. When we hand-lifted the control seedlings, only vertical shovel cuts were made, and, although the seedling beds had been undercut several months earlier, the roots in the fine-textured soil continued to grow and were difficult to remove from the soil with a shovel without root damage. In addition, when the fast speed was used with the lifter blade, the seedling belts did not pick up individual seedling but rather, large clumps of seedlings were lifted at a time. Running the tractor at the faster speed caused the seedlings to jam the seedling belt as described by Darby (1962). Making a corresponding adjustment to the seedling belts would have compensated for the faster tractor speed. The lifter at this nursery was calibrated for the normal speed using the lifter blade, which may explain the lack of differences in the root morphology characteristics.

Conclusions

Calibrating the belt speed on a seedling lifter so that seedlings are individually removed from the nursery bed without injury is critical. When using ocular comparisons to evaluate seedling lifter efficiency, nursery staff need to give careful attention to the presence or absence of fine root tips, mycorrhizae, damage to the root collar region, and any possible breaks in root cortex on lateral roots. Even minor root damage can reduce RGP and negatively affect outplanting performance. The use of the lifter blade on the full-bed lifter may help to increase seedling quality on other soil types by reducing the loss of fine roots but tractor speed must be matched to the belt speed to minimize root damage.

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