A Root-Bound Index for Container-Grown Pines

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Introduction

Root-bound seedlings have been a concern of nursery managers for more than four decades. When container-grown seedlings are root-bound (or pot-bound), survival, growth or stability might be reduced after outplanting (van Eerdin and Kinghorn 1978; Hulten 1982). In some cases, root-binding might not affect survival or early growth but it might adversely affect stability (Lindgren and Orlander 1976). Initially, the concern over root-binding was concentrated on root-spiraling which could result in "root-strangulation" and early toppling.

One source defines root-bound as: adj: of a potted plant; grown too large for its container resulting in matting or tangling of the roots. Our definition is broader and defines root-bound as: a plant grown too large for its container resulting in a reduction in field performance or root growth potential (RGP). The dictionary definition focuses on the appearance of the roots while our definition concentrates on plant performance. We contend field performance of pines will be reduced before the roots become tangled or matted and that nursery managers need a method to estimate when this begins to occur.

Only a few indexes have been proposed to evaluate root-binding in the nursery. Hiatt and Tinus (1974) proposed a "strangle-angle" index to evaluate the degree of root spiraling in container-grown seedlings. Due to concern over root spiraling, changes were made in container design and now most solid plastic containers have ridges which greatly reduce the amount of root spiral. For this reason, the "strangle-angle" index is rarely used as a predictor of seedling quality. However, there still is a need for a simple, easy-to-use "root-bound index" (RBI). A RBI would be useful when nursery managers and regeneration foresters evaluate stock quality prior to outplanting.

A RBI can be based either on a subjective score (based on the appearance of the root-plug) or on an objective value (such as root mass). In addition, the RBI could be determined with destructive or non-destructive measures. We wanted to develop a RBI that was both objective and non-destructive, therefore, root-collar diameter (RCD) was selected as the seedling attribute to measure (since it is often related to root mass). We calculated RBI as a ratio of either container diameter or volume. The objective of this study was to develop a RBI that would help nursery managers estimate the percentage of root-bound seedlings prior to shipping. We wanted to test the hypothesis that: (1) RBI was related to outplanting survival; and (2) independent of RCD, outplanting survival is related to the length of time stock is kept in the hardening phase.

Materials and Methods

Four separate studies were used to test the effects of RBI on survival in this paper. The first study was conducted in the United States on *Pinus palustris* (seedlings) whilst the other three studies were conducted in South Africa on *P. patula* (seedlings and cuttings) and the *P. elliottii* x *P. caribaea* hybrid (cuttings).

P. palustris

Seedlings from a southern Mississippi seed source were grown in six container types at the USDA Southern Forest Experiment Station research nursery in Pineville, Louisiana (31º 19' N, 92º 26' W). Container types included styroblock® (Beaver Plastics, 12150 - 160 Street, Edmonton, Alberta, Canada T5V 1H), Multipot® (Stuewe & Sons, Inc. 2290 SE Kiger Island Drive, Corvallis, Oregon 97333-9425) , Hiko® (BBC AB, Profilgatan 15, SE-261 35, Landskrona, Sweden) and Jiffy® (Jiffy Products of America, Inc., 600 Industrial Pkwy, Norwalk, Ohio 44857). The styroblock® tray was model 112/95 (112 cells per block and 95 cc/cell) and the cell walls were treated with SpinOut® (Griffin LLC, P.O. Box 847, Valdosta, GA 31603-1847). Although two types of Multipot® trays were used (M3 and M6), the cavity size was the same for both containers (Table 1). The difference was in number of cavities per m^2 (441 for M3 vs. 581 for M6). The Hiko® tray (H) had the widest cell diameter of any container type. The two Jiffy® Pellets included short (JPs) and standard (JP) versions.

Containers were filled with a peat:vermiculite (V:V=1:1) medium that contained a slow-release fertilizer (Osmocote® 18-6-12; Scotts Company, Marysville, OH) at a rate of 3.56 kg/m^3. Seeds were sown on April 24, 2000 and seedlings were grown using procedures described by Barnett and McGilvary (1997). The containers were covered with a 10% shade cloth until seed germination was complete. About 3 weeks after sowing, the shade cloth was removed and seedlings were exposed to full sunlight. All of the containers received thiophanate-methyl and metalaxyl fungicides on an approximate 2-week interval during the growing phase. Times of fungicide application varied due to rainfall that delayed treatment. Irrigation was applied during dry periods

***Table 1.** The sizes and shapes of containers used to raise pines.Figure 1. The relationship between root-collar diameter, root bound index (diameter or volume) and seedling survival of P. palustris seedlings in Alabama. Numbers above each mean represent the number of seedlings in that class.*

Container type	Shape of top	Cavity volume (ml)	Cavity diameter (top section) (mm)	Density (#/m^3)
Unigro 128	Square	61	32	587
Unigro 98 side slits	Square	95	37	450
Unigro 98 solid	Square	95	37	450
Sappi 49	Round	80	39	423
Styroblock + Spinout	Round	93	35	530
Multipot-441	Round	98	38	441
Multipot-581	Round	98	38	581
Hico – V93	Round	93	41	526
Jiffy-pot-super	Round	120	38	588
Jiffy-pot-short	Round	60	33	735

to prevent medium from drying out. Seedlings were given additional applications of a water soluble fertilizer (Peters Professional 20-19-18 - Water Soluble Fertilizer, Scotts Company, Marysville, OH) late in the growing period to green-up the seedlings. Seedlings were extracted from containers on 6th November 2000 and culls and diseased seedlings were removed. The plantable seedlings were packed in boxes and placed in a cooler at 2°C.

P. elliottii x P. caribaea

The hybrid cuttings were set in four tray types (three Unigro containers plus the Sappi container) (Table 1). The Unigro 98 side-slit tray was the same dimension as the Unigro 98 solid tray but contained slits in the side walls to air prune lateral roots. All Unigro and Sappi container types contained internal ribs or ridges to prevent root spiralling. Cuttings were set on three different occasions (24/03/2000, 27/07/2000 and 28/09/2000) in order to produce plants of different ages at planting (13, 8 and 6 months). At each setting, cuttings were harvested from the same donor plants from four families. The cuttings were harvested from hedges that were growing in 10-litre black potting bags. Once set, the cuttings were left to root for a period of 3 months in a greenhouse where they received intermittent mist, before being placed on a raised bed underneath 30% shade cloth. Plants received water and fertilizer for the remainder of the nursery period. This trial was planted on the 17/05/2001 to determine the effect of raising cuttings in four different container types available for nursery use in South Africa.

P. patula

Cuttings were rooted from two elite families for this trial and seedlings were obtained from a mix of several elite families from a breeding seed orchard. The cuttings were raised in the nursery for a period of 9 months while seedlings were raised for a period of 7 months. These raising periods were considered optimal for each plant type and plants did not appear root-bound at planting. The *P. patula* cuttings were produced in the Unigro 98 solid tray whilst the seedlings were raised in the Sappi 49 tray.

The cuttings and seedlings were planted in separate but adjacent trials. The site chosen for the two trials can be described as cool temperate and suited to growing *P. patula*. Compared with other lower altitude *P. patula* sites, this site is expected to receive frost during the winter months and may experience insufficient rainfall in some years which can result in environmental stresses that can lead to increased field mortality. Cuttings were planted on the 6/06/2003 and seedlings were planted on the 8/06/2003. These two trials form part of a series of four trials. As with the case of the *P. elliottii x P. caribaea* trial, these trials were planted to test experimental factors not reported on in this paper but are being reported elsewhere (Mitchell and Jones 2005).

RGP trial

A RGP study was initiated in January in a greenhouse at Auburn University's Pesticide Research facility. Five aquariums (37.8 liters per aquarium) equipped with aerators were double wrapped with black plastic and filled with tap-water. Plywood tops with thirty drilled holes about 2.5 cm in diameter were placed on the top of the aquariums. New, white roots were removed from the bareroot seedlings and from the outer edges of the root plugs for container-grown seedlings. Initial RCD was measured and recorded for each seedling. Each aquarium served as a replication and each contained four seedlings from each of the seven treatments (28 seedlings per aquarium). Each seedling was placed in a hole in the plywood at random and the root plugs were suspended in the water below the plywood top. Water temperature and air temperatures were recorded weekly during the study to ascertain laboratory growing conditions. Low temperatures were observed around 2300 hours and high temperatures were observed around 1300 hours. After five weeks, all new roots were excised and dried at 65° C for 36 hours, and then weighed.

RBI

All plants were measured for RCD using a digital calliper prior to planting. For each plant, a RBI was calculated. A total of 3376 *P. palustris* seedlings were evaluated. In the case of the hybrid trial, a total of 2304 plants were assessed. For *P. patula*, 3000 cuttings and 3000 seedlings were assessed.

RBI was determined using two techniques and expressed as a percentage. To avoid confusion, the RBIdia value is expressed as a percentage while RBIvol is expressed as a whole number.

(a) RBIdia = (RCD in mm ÷ Cavity diameter in mm) x 100
(b) RBIvol = (RCD in mm ÷ Cavity volume in cc) x 100

Field assessments

The effect of RBI on survival was assessed using the most recent survival count conducted in each of the four trials. The *P. palustris* study was last measured two years after planting, the pine hybrid trial three years after planting, and the two *P. patula* studies, one year after planting. In each case each tree planted in the field was recorded as being either dead or alive.

Statistical analyses

A General Linear Model was used for each analysis. For the *P. palustrius* study, the factors included site, replication and seedling class. For the remaining analyses, factors only included replication and class. Therefore, factors such as container type were not included in the model. Contrast statements were included in the model to determine if the relationship between class and survival was linear or quadratic. Survival data were not transposed prior to analysis.

An additional analysis was conducted to test the effect of age on survival of *P. elliottii x P. caribaea* cuttings (independent of differences in RCD). Therefore, stock with diameters larger than 3.5 mm or smaller than 3.1 mm were deleted prior to analysis.

Results

Survival of *P. palustris* seedlings was related to diameter class (P = 0.0001) and the relationship was similar to a bell-shaped curve (Fig. 1). There was a significant quadratic relationship (P=0.034). Seedlings with RCD values less than 7 mm or greater than 10 mm did not survive as well as seedlings with intermediate diameters. The lowest survival was observed for the seedlings with the largest diameter. Survival of *P. palustris* seedlings was also related to RBIdia (P = 0.0001) and RBIvol (P = 0.0001). In this case, the quadratic relationship was slightly stronger for RBIvol (P=0.0001) than for RBIdia (P=0.0017).

Survival of *P. elliottii x P. caribaea* cuttings was high (Fig. 2) but there still was a relationship between diameter class and survival (P=0.082). Contrast statements revealed a quadratic (P=0.034) relationship. The lowest survival was observed for stock with the largest diameter. In contrast, survival of hybrid cuttings was not related to either RBIdia (P=0.83) or RBIvol (P=0.55).

Seedlings of *P. patula* were also related to both diameter and RBIvol (P=0.0001) and the relationship was similar to the left half of a bell-shaped curve (Fig. 3).

There was a significant quadratic relationship (P=0.0001). Seedlings with RCD values less than 1.6 mm did not survive as well as seedlings with greater diameters.

Survival of *P. patula* cuttings was related to diameter class and RBIvol (P = 0.0001) and the relationship was generally positive (Fig. 3). There was a significant quadratic relationship (P=0.0014).

The RGP of container-grown *P. palustris* seedlings increased as average diameter increased from 5 mm to 9 mm. However, 10 mm seedlings produced 8 new roots per seedling while 9-mm seedlings produced 10 new roots.

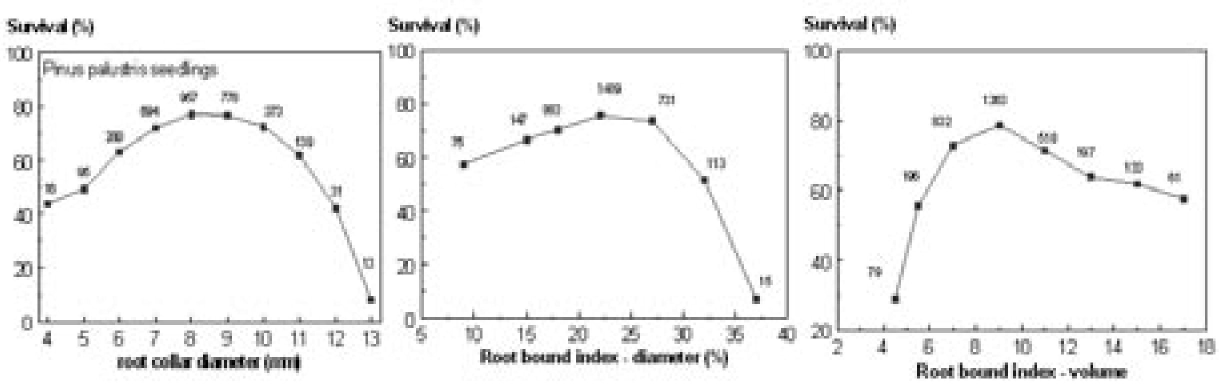

Figure 1. *The relationship between root-collar diameter, root bound index (diameter or volume) and seedling survival of* P. palustris *seedlings in Alabama. Numbers above each mean represent the number of seedlings in that class.*

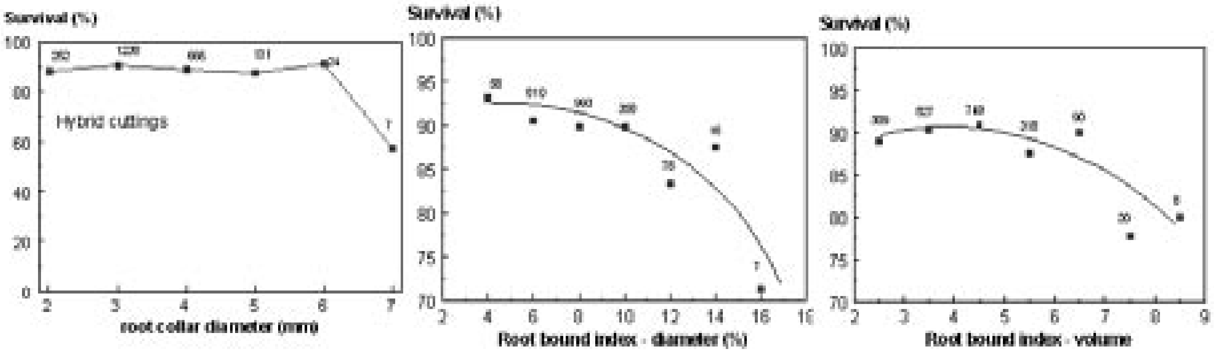

Figure 2. *The relationship between root collar-diameter and survival of* P. elliottii x caribaea *cuttings. Numbers above each mean represent the number of cuttings in that class.*

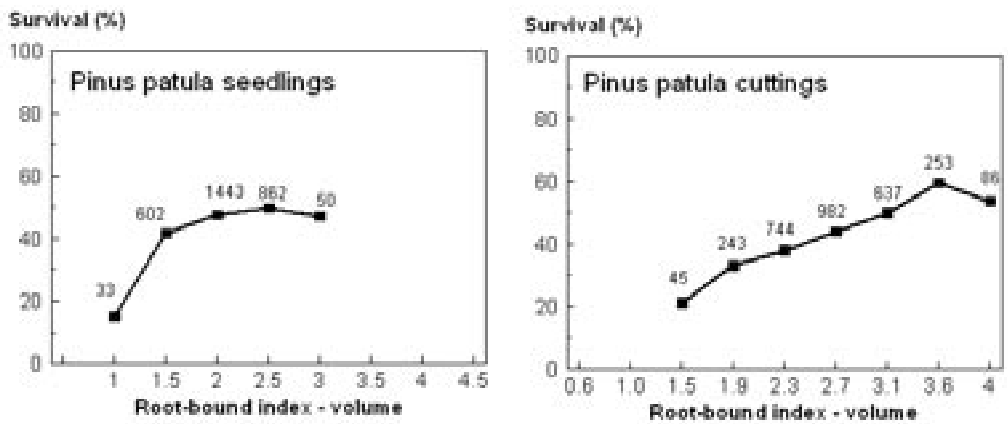

Figure 3. *The relationship between root-bound index (volume) and survival of container-grown P. patula in South Africa. Numbers*
x-axis values will change.

Discussion

Overall, the largest-diameter stock in the *P. palustris* and *P. elliottii* x *P. caribaea* study did not survive as well as pines that were closer to the median size. These findings suggest that a small proportion of operationally produced container stock may suffer symptoms of root-binding. For example, survival of the large container-grown *P. palustris* seedlings (RCD of 12-13 mm) exhibited much lower survival than seedlings with a RCD of 8-9 mm (Fig. 1). These findings cast doubt on the belief that only small diameter container-seedling need to be culled.

A bell-shaped curve was apparent for *P. palustris* seedlings and the curve for *P. patula* seedlings could be considered to be a truncated bell-shaped curve. This study may be the first to demonstrate this bell-shaped, survival-response curve for container-grown pine seedlings. Previous authors have warned against root-binding of seedlings but data showing the relationship between root-binding and field performance are rare. In some cases planting date and plant age are confounded, which casts some doubt on the conclusions.

Age or size?

Some warn against growing seedlings too long in the container (Dickerson 1974, Zwolinski and Bayley 2001, Salonius et al. 2002). For example, 6-month old pine seedlings grown in paper-pots survived better than 18-month old seedlings (Alm et al. 1982). Brisette and others (1991) say that “Adverse root forms increase rapidly with the length of time seedlings are grown in containers.” They suggest that if *P. palustris* seedlings are kept in containers only 3 to 4 months, there should be no problem if the containers are properly designed. Others say the optimum seedling age in South Africa is between 5 and 7 months (Zwolinski and Bayley 2001). However, stock size and stock age are confounded. As a result, RBI increases as seedling age increases (Fig. 4).

Since root-binding is a function of both seedling size and container size, then plant age should not be the sole

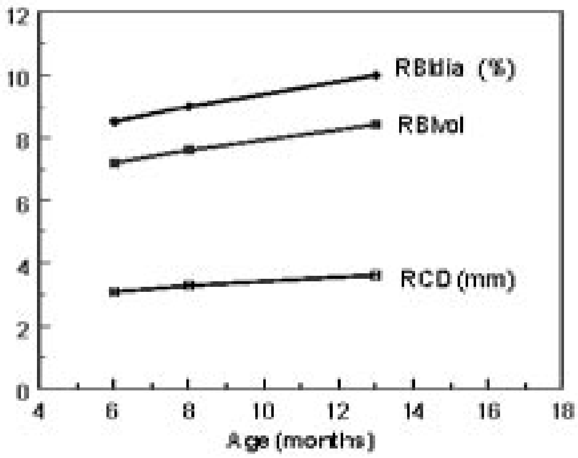

Figure 4. *The relationship between age and RBI values for cuttings of* P. elliottii x P. caribaea. *RBIdia = RCD/cell diameter. RBIvol = RCD/cell volume.*

criterion for determining stock quality (Barnett 1974a). The *P. palustris* data suggest that 26-week-old seedlings may perform satisfactorily in >90 ml containers if the RBIvol is within the 8 to 10 range (Fig. 1). Of course young, 1-month-old *P. palustris* seedling do not survive in the field as well as 2-month-old seedlings (Barnett 1974b).

McCubbin and Smith (1991) examined the relationship between age and growth of *Eucalyptus grandis* seedlings. Older seedlings did not grow as well as 13-week-old seedlings. However, it was not clear if this was a function of age or was a function of size. The data from the hybrid pine trial suggest that age may have an effect on survival. Young seedlings had higher survival than 13-week-old seedlings. For bareroot *P. palustris* seedlings (where root-binding is not a factor), seedling performance was reduced if the seedlings were a year older than normal (Lyle et al. 1958).

Reduced RGP

The mechanism which explains why root-bound seedlings have lower survival is not known. Lower survival from root-bound seedlings might result due to a reduced RGP and a lower root-weight ratio. Our data along with data by others suggest the older root-bound seedlings have lower RGP than smaller non-bound planting stock. Smith and McCubbin (1992) found RGP of *E. grandis* seedlings was cut in half as seedlings increased in age from 16 weeks to 21 weeks. We observed a 20% reduction in RGP when comparing 10-mm diameter *P. palustrius* seedlings with 9-mm seedlings. When hybrid cuttings with a limited RCD (3.1 to 3.5 mm) were selected, age still had a significant effect on seedling survival. In this analysis, six-month-old cuttings had 94% survival while 13- week-old cuttings only had 84% survival. This suggests a decline in RGP may occur after hardening practices are initiated to slow root development.

When top-pruning is not employed, seedlings held too long in the nursery will sometimes produce an unbalanced seedling. Even when hardening techniques are employed, the growth in root mass is sometimes limited by the container while shoot mass continues to increase (McCubbin and Smith 1991). Therefore, the root-weight ratio will sometimes decline over time.

RCD, RBIdia or RBIvol?

If a single container type is used in the nursery, there will be no need to calculate a RBI index that has only one value in the denominator. RBI will be directly related to RCD (Fig. 1). However, if several types of containers are used, then a single RBI value might be useful. Otherwise separate RCD limits would need to be developed for each container type.

The size of the container determines how long the plants can remain in the nursery without being root-bound. Therefore, stock grown in a 600 ml container can remain in the nursery for a longer time than seedlings grown in a 60 ml container.

Which RBI method is preferred? For *P. palustris*, survival of seedlings in the 60-ml Jiffy-pot was less than the 120-ml Jiffy-pot (South et al. 2005). The reduced survival might be a result of either use of smaller seedlings or might be a result of root-binding. To address this question, an analysis was conducted using trees within a limited diameter range (RCD 6.8-7.8 mm). This analysis indicated that survival of similar-sized seedlings in the 60-mm container was 18 percentage points lower than trees in the 120-mm container. In this case there was only a slight change in container diameter but the rooting volume was doubled. The RBIdia was 19% for the 120-ml pot and 22% for the smaller 60-ml pot. Likewise, the RBIvol was 6 for the large pot and 12 for the small pot. According to the curves in Fig. 1, a RBIdia of 22% should not have reduced survival. Therefore, these findings favor the use of RBIvol over that of RBIdia. A decline in survival would be expected for a RBIvol of 12 but survival should have been high for a RBIdia of 22% (Fig. 1).

Operational considerations

In South Africa, one company uses a subjective ranking of root-binding (values of 1 to 5) which are based on the visual appearance of roots on the outside of the seedling plug. Until now, there has been no objective definition of root-binding. In the past, many container nursery managers have used plant age as a surrogate for root-binding. Now managers can use RCD or RBIvol as an indicator of plant quality.

The RBIvol values will vary with species. For example, the performance limit for *P. palustris* seedlings might be 11 while the value for *P. patula* seedlings is about 3. To effectively determine the value may require researchers to conduct RGP tests on plants that cover a range of diameters. Only a few RGP over container size studies exist (e.g. South et al. 2005). Stock could also be planted in sand and subjected to moisture stress to obtain a robust survival-over-RBI curve (e.g. Fig. 1). Favorable environmental conditions might mask potential differences in survival if tests are conducted on sites where adequate rainfall is likely.

Once researchers have determined a RBIvol value for a given species, then the nursery manager can, at lifting, determine the percentage of plants that exceed this value. For example, 6% of *P. palustris* stock exceeded a RBIvol value of 11. By culling these root-bound seedlings, the average survival on one site would have increased by 4 percentage points.

Conclusions

Root-binding of container stock can result in reduced survival of both seedlings and cuttings of pine. As pine and eucalyptus roots become root-bound, their ability to produce new roots decline. To avoid root-binding, most managers ship seedlings by a certain age. Is some situations, they will reduce water and fertilization to slow root growth and prolong the time before many roots become root-bound. Keeping seedlings too long in the hardening phase can reduce RGP and seedling performance.

Some tree planting guides provide minimum specifications for the diameter of planting stock but do not include a maximum RCD limit. We propose that RBIvol maximums be determined for each species. When planting guides cover a range of container types, a maximum RBIvol value can provide some indication of when root-binding might reduce plant quality. At time of shipping, nursery managers could report both the percentage of plants that exceed the RBIvol value and the number of weeks the stock has remained in the hardening phase (since both can affect outplanting survival). Additional research needs to be conducted to determine if RBIvol will be useful for non-pine genera.

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