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Shoot:Root Ratio Is of Limited Use in Evaluating the Quality of Container Conifer Stock

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The ratio of shoot dry mass to root dry mass, or shoot:root ratio, is sometimes used to evaluate the drought avoidance potential of container conifer stock. A review of published data from plantation trials reveals, however, that this relationship does not hold for container conifer seedlings. It is argued that the particular cultural conditions of container production favor root proliferation beyond strict physiological needs and that, once outplanted, the root plug-soil interface imposes a stronger limit on water and nutrient absorption by the seedlings than the roots themselves. Tree Planters' Notes ***46(3):102-106; 1995.***

The evaluation of seedling stock quality is one of the primary tools for ensuring the success of plantations. This evaluation usually relies on the measurement of attributes that are then compared against contract specifications or preset standards for the selection or rejection of nursery stock. Morphological attributes such as height, diameter, and dry mass are on the front line of seedling evaluation, and account for most of the variability among seedling stocks (D'Aoust and others 1994).

One of these morphological attributes is the ratio of shoot dry mass to root dry mass, or shoot:root ratio. Conventional forestry wisdom holds that shoot-root imbalance is one of the primary causes of transplanting shock. The objective of this text is to discuss the shoot:root ratio concept and to evaluate its usefulness as a predictor of seedling survival and growth in container conifer seedlings.

The Significance of Shoot:Root Ratio

The shoot:root ratio is a morphological attribute that is commonly used for the evaluation of bareroot seedlings and, to a lesser extent, of container stock. The basis for the use of this attribute is derived from a water balance perspective: a certain amount (surface area or dry mass) of transpiring foliage needs a certain amount (surface area or dry mass) of roots to absorb soil water and offset transpirational losses. A low shoot:root ratio means that roots are abundant with respect to the foliage area, and that the seedling has a high water stress avoidance potential. A high ratio means that the roots are not as abundant, and that the seedling is more likely to suffer from water stress after planting, particularly in droughty sites or under conditions of high evaporative demand. Shoot:root ratio is thus used to evaluate the drought avoidance potential of seedlings.

The importance of this attribute for bareroot stock has been criticized (for example, Burdett 1990, Racey and others 1983). However, its relationship with seedling survival has been well demonstrated on seedlings planted in generally dry soil conditions (for example, Haase and Rose 1993, Boyer and South 1987, Rowan 1987, Larsen and others 1986, Thompson 1985, Lopushinsky and Beebe 1976). Usually, a shoot:root ratio of about 2 g/g is viewed as desirable.

The use of shoot:root ratio in container stock is based on the same water balance reasoning as in bareroot stock. As for bareroot stock, a shoot:root ratio of 1.5 to 2.5 g/g is also viewed as desirable (for example, figure 4 in Rose and others 1990; Romero and others 1986). However, judging from current experimental and field observations, we believe that shoot:root ratio is of limited value in the evaluation of container conifer stock.

Review of Results on Shoot:Root Ratio

A survey of existing literature reveals conflicting results with respect to shoot:root ratio and either growth or survival of container seedlings. In all the studies we could find (table 1), only one using seedlings subjected to drought stress in sand beds showed the negative relationship between survival and shoot:root ratio expected from a water balance reasoning (van den Driessche 1991). A subsequent experiment, also in sand beds but involving different levels of fertilization (van den Driessche 1992), produced a positive relationship between shoot:root ratio and survival. The reversal in relationship was attributed to an interaction with the

Table 1- *Studies reporting on the shoot:root ratio of container conifer seedlings*

Studies	Species	S:R ratio (g/g)	Effect of increased S:R ratio on growth	Effect of increased S:R ratio on survival	Drought-induced mortality?
Endean and Hocking 1973	Lodgepole pine	1.9-5.8	Increased	None	None
	(*Pinus contorta* Dougl. ex Loud.)				
Hocking and Endean 1974	White spruce	2.3-3.1	None	None	None
	(*Picea glauca* (Moench) Voss)				
Walker and Johnson 1980	Lodgepole pine	1.0-3.6	Increased	None	None
	White spruce	1.5-3.6			
	Engelmann spruce	1.5-1.9			
	(Picea engelmannii Parry ex Engelm.)				
McGilvray and Barnett 1982	Southern pines	1.5-6.0	Increased	None	Limited
Maass and others 1989	Black spruce	2.9-4.8	None	None	None
	(*Picea mariana* (Mill) BSP)				
	White spruce	1.7-5.3			
	Norway spruce	1.3-3.5			
	(*Picea abies* (L.) Karst.)				
	Red pine	2.1-3.1			
	(*Pinus resinosa* Ait.)				
	Jack pine	2.0-5.3			
	(*Pinus banksiana* Lamb.*)*				
Zasada and others 1990	Sitka spruce	1.8-4.7	None	None	None
	(*Picea sitchensis* (Bong.) Carr.)				
van den Driessche 1991	Douglas-fir	1.8-2.8	NA	Decreased	Yes
	(*Pseudotsuga menziesii* (Mirb.) Franco)				
	Lodgepole pine	1.5-1.9			
	White spruce	1.8-1.9			
van den Driessche 1992	Douglas-fir	1.9-2.3	NA	Increased	Yes
	Lodgepole pine	1.7-2.0			
	White spruce	1.8-2.3			
Lamhamedi and others (in press)	Black spruce	1.5-4.5	None	None	None

fertilization treatment. Finally, in one recent sand bed experiment (Lamhamedi and others in press), physiological and growth measurements revealed no relationship between shoot:root ratio and drought avoidance in the seedlings.

All other studies reported (table 1) were outplanting experiments in which drought-induced mortality was either low or absent. In most of these, no relationship was found between shoot:root ratio and growth. An example of such results, presented in figure 1, was obtained from the data sets from several plantation trials in British Columbia (Simpson 1991, 1994). Although shoot:root ratios were related to seedling height at planting ($r^2 = 0.33$ to 0.46), these relationships did not persist for more than 2 years after planting.

Finally, a few studies reported a positive relationship between shoot:root ratio and growth (table 1), which is contrary to the water balance reasoning. However, the greater ratios were mostly due to the larger shoots (McGilvray and Barnett 1982, Walker and Johnson 1980, Endean and Hocking 1973). The positive relationship therefore resulted from the normally greater absolute growth of the larger shoots, and not from a water balance-related advantage or disadvantage. Under conditions such as these, measurements of height or shoot mass offer a simpler and better evaluation of future growth.

Interpretation of Shoot:Root Ratio

The results reviewed above show that a strict control of root mass inside the peat plug in the nursery is of limited importance for the post-planting water balance of container seedlings. During seedling cultivation, the high levels of nutrients, water, and temperature of the rooting medium and its low density favor root proliferation (Prevost and Bolghari 1989, Friend and others 1990). When container seedlings are planted, intimate

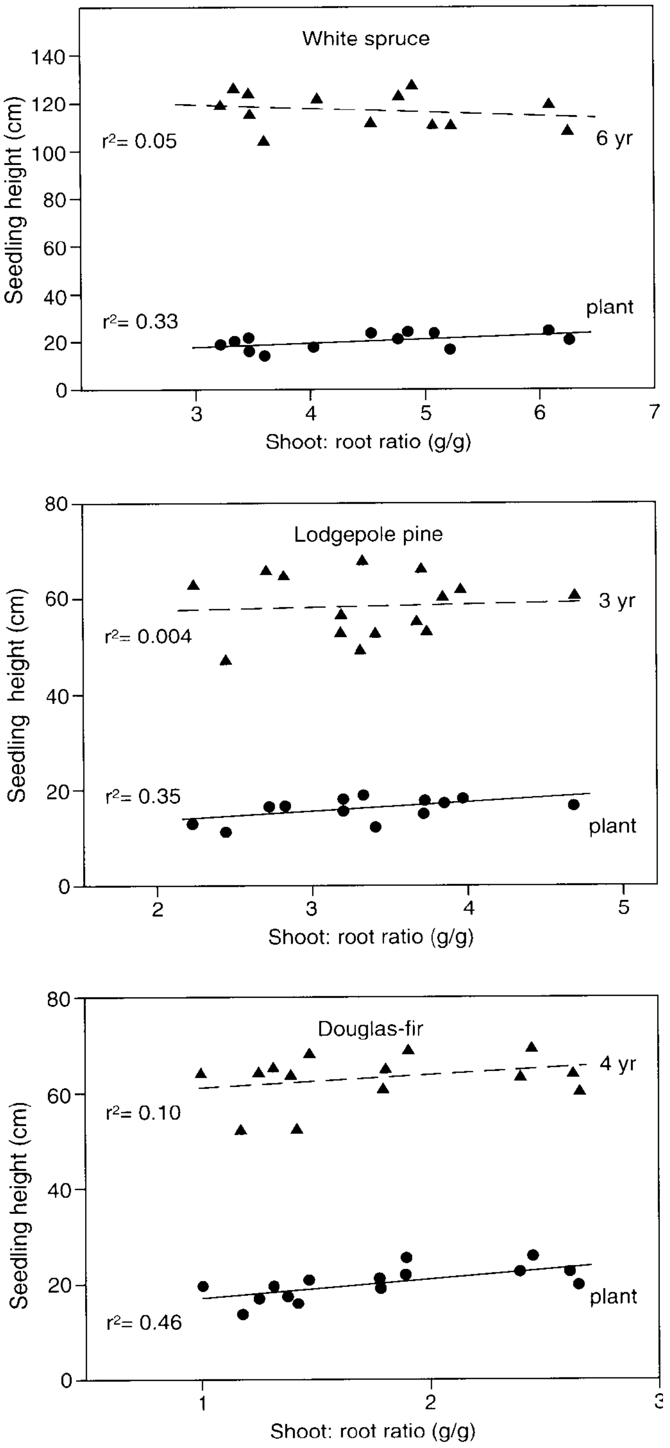

Figure 1—*Relationships between shoot:root ratio and seedling height at planting time and after 3 to 6 years in the field for white spruce, lodgepole pine, and interior Douglas-fir container seedlings.*

contact between the root and the rooting medium is maintained. The limiting factor then becomes the transfer of water and nutrients from the soil to the root plug as a whole because of the physical constraints imposed by the peat in the root plug to the movement and absorption of water (Bernier 1992, Bernier and others 1995).

In the longer term after planting, drought avoidance potential is related to the speed at which the seedling is capable of producing roots that extend outside the original root plug into the surrounding soil. Current evidence from white and black spruce shows a lack of a significant relationship between root dry mass in the peat plug and root growth potential (D'Aoust and others 1994), further weakening the link between shoot:root ratio and seedling quality.

In the field, extensive distribution of roots is more important than mass (Burdett 1990). For example, a comparison of shoot:root ratios of natural and container 2+0 black spruce seedlings planted on a boreal cutover site (unpublished data from P.Y. Bernier) is shown in figure 2. Measurements were taken in September. Natural seedlings have a much higher shoot:root ratio than the newly planted container seedlings, but the soil volume explored by their roots is far greater than the confined volume of the peat plug. The ratio in planted seedlings increases over the years, following the carbon allocation pattern dictated by local environmental con-

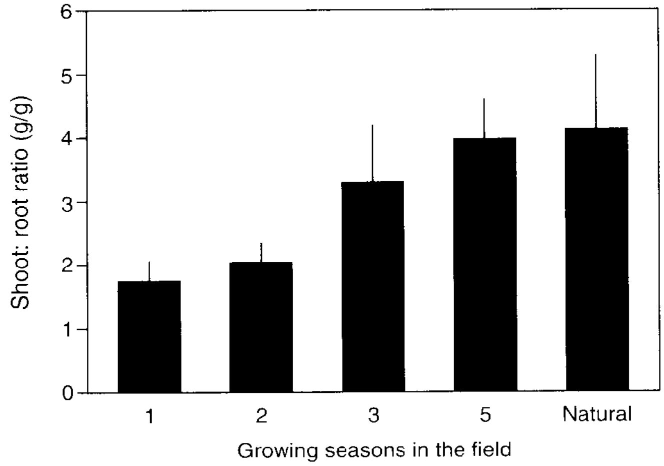

Figure 2—*Shoot:root ratios of planted container black spruce and natural black spruce seedlings on a boreal site. The vertical bar is one standard deviation from the mean (n = 14).*

ditions. Similar evolution of shoot:root ratio is reported by Walker and Johnson (1980). One also expects the final shoot:root ratio to be higher in a cool and humid climate, as in the figure 2 data, than in a hot and dry one.

This does not mean that any shoot:root ratio is acceptable. Values at either extreme can lead to problems. For a given shoot size, a very small ratio might mean an overly developed root system with mostly large suberized roots tightly clumped inside the container. A very large ratio might mean a poorly developed root system, with poor plug extractability, low potential for new root initiation, and reduced water and nutrient uptake. We think, however, that the range between these extremes is large, and that within this range, there is no relationship between this ratio and the survival or performance potential of container seedlings on most planting sites. In addition, the dramatic improvement in seedling survival when shifting from bareroot to container stock (for example, Walker and Johnson 1980) further narrows the range of field conditions under which moderate differences in shoot:root ratios might influence seedling survival.

Alternatives to the Shoot:Root Ratio

Apart from physical constraints such as plug extractability or root binding, the adequateness of a root system in container stock depends primarily on its ability to extract water from the peat plug and to quickly grow roots into the surrounding soil. Both of these functional properties are quite hard to ascertain with a static, morphological measurement. Neither appears to be adequately described by either root dry mass or shoot:root ratio. Traditional measurements of root growth capacity either at room temperature or at some lower equivalent of field temperature and concomitant physiological measurements of water movement in the plant currently offer the most information on the functional quality of the root system (Grossnickle and Folk 1994).

Measurements based on root architecture might also yield information on the growth potential of the root system. Alterations to the architecture of roots in the nursery influence the field growth of roots once the seedlings are outplanted. In container systems, copper-coating of containers is used to improve root architecture, with known positive effects on root and shoot growth after planting (Burdett and Martin 1982, Ruehle 1985). Air pruning of lateral roots in slotted containers can also achieve a similar effect. Studies have used the architecture of root systems to compare the development of seedlings (for example, Grossnickle and others 1991). There has also been some work done relating root architecture to field performance in bareroot stock (for esample, Hatchell and Muse 1990) and container stock (Simpson 1990). More work needs to be done in this field to ascertain the usefulness of this approach.

Conclusion

In conclusion, for sites with low drought-induced seedling mortality, shoot:root ratio is of limited value as a descriptor of container seedling quality because (1) the warm, moist, low-density and nutrient-rich environment of peat-based growing media favors root proliferation beyond strict physiological needs, and (2) upon planting, the soil–root plug interface becomes the controlling factor for water and nutrient transfer. Although extreme values of shoot:root ratios might indicate potential problems, values between such extremes appear unrelated to the water stress avoidance potential of the seedlings, or to the ability of the seedlings to produce soil roots. Other properties such as root system architecture or nutrient content exert more control over such functions.

The limited number of experiments in which shoot:root ratio was related to mortality does not permit us to evaluate conclusively the usefulness of this ratio under extreme conditions. However, the results from all other studies reporting on seedling growth suggest that the water balance reasoning applied successfully under such conditions to bareroot stock cannot be carried over to container stock.

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