SHOOT AND ROOT PRUNING AND EXPOSURE TREATMENTS AFFECT ROOT GROWTH POTENTIAL OF CHINESE FIR AND MASSON PINE BARE-ROOT SEEDLINGS AFTER LIFTING

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ABSTRACT

Shoot pruning, root trimming, and exposure to sunny field conditions reduced root growth potential (RGP) of 1-0 Chinese fir (*Cunninghamia lanceolata* Hook.) and Masson pine (*Pinus massoniana* Lamb.) seedlings. The total number of new roots (TNR) and number of new roots greater than 1 cm (TNR >1 cm) of Masson pine decreased by 53% and 56% respectively after removal of half the foliage and decreased by 70% and 82% respectively after pruning of all the foliage; both the TNR and TNR >1 cm of Chinese fir decreased by 11% after pruning of half the foliage and 19% and 45% respectively after pruning of all the foliage. The TNR and TNR >1 cm of Chinese fir decreased by 29% and 33% respectively after trimming of 40% of the lateral roots; those of Masson pine decreased by 69% and 78% respectively. RGP of both Chinese fir and Masson pine seedlings decreased rapidly after total exposure to only a few hours of bright sun. After the seedlings were exposed for more than 2 hours, the TNR of Chinese fir fell below 10. The TNR of Masson pine appeared to be less susceptible to exposure and TNR dropped below 20 after 4 h.

Keywords: root growth potential; seedling damage; seedling desiccation; seedling morphology; *Cunninghamia lanceolata*; *Pinus massoniana*.

INTRODUCTION

Chinese fir and Masson pine are the two main species used for reforestation in southern China, accounting for about 90% of the planting programmes. Most seedlings are raised as bare-root plants because they perform well in warm, moist climate conditions. Although these two species are generally considered easy to establish, poor survival and growth after planting are still a problem. Poor stock quality may be one of the factors causing plantation failure. Seedlings often suffer injuries during lifting, grading, and packing, and while being

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transported before and during planting. Aldhous (1972) distinguished three types of damage affecting bare-root seedlings during handling: physical damage, heat damage, and desiccation damage. This paper reports on a study of physical stress and desiccation stress as well as their effects on root growth potential (RGP).

RGP is defined as the ability of a tree seedling to initiate and elongate new roots within a prescribed period of time in a standard environment optimised to promote root growth (Simpson & Ritchie 1997). It has been widely studied and used as an important indicator of seedling quality since it was proposed by Wakeley (1949) and developed by Stone (1955). RGP (measured before planting) is considered the most reliable indicator of seedling quality among the various seedling quality tests available (Ritchie & Dunlap 1980; Ritchie 1985). It is currently the most common performance trait used to determine if seedlings are suitable for reforestation (Sutton 1990; Landis & Skakel 1988). There are also a number of reports of changes in RGP after seedlings encountered stresses in the production-handling-planting sequence (Colombo & Glerum 1984; Tabbush 1986; McCreary & Duryea 1987; Deans *et al.* 1990; Langerud *et al.* 1991; Simpson *et al.* 1994). Some studies have pointed out that reductions in RGP are highly correlated with desiccation and rough handling (Insley & Buckley 1985; Tabbush 1986, 1987; Deans *et al.* 1990).

Our purpose in conducting this research was to examine RGP under some treatments believed to reduce stock quality before planting.

MATERIALS AND METHODS

Plant Materials

One-year-old bare-root Chinese fir and Masson pine seedlings were grown at Xiashu Forest Farm of Nanjing Forestry University in 1999 and lifted on 20 February 2000. The seedling roots were not undercut, wrenched, or pruned before lifting.

Seedling Treatments

Root and shoot treatments

Seedlings (200 per species) were randomly chosen and divided into eight groups (25 plants each) for the following treatments:(1) trim 20% of lateral roots (remove one root per five lateral roots), (2) trim 40% of lateral roots, (3) trim 60% of lateral roots, (4) remove half the foliage (reduce the number of needles), (5) remove all foliage, (6) remove the top bud, (7) remove the shoot, (8) control (no pruning). Each treated seedling was immediately planted in sterilised fine sand in a round plastic bucket (40 cm in height and 30 cm in diameter) with small holes at side and bottom. The buckets were put in a greenhouse where the growth environment was as follows:

Temperature:	Daytime (8:00 a.m.– 6:00 p.m.) 22±3°C;
	Night (6:00 p.m.– 8:00 a.m.) 16±3°C;
Relative humidity:	70–80%;
Light:	natural sunlight.

Plants were watered everyday but did not receive fertiliser.

Seedling exposure treatments

Another 210 seedlings of each species were randomly selected and separated into seven groups (30 plants each). Each seedling was laid separately on the ground (uncovered) beginning at 9:00 am. The exposure times for different groups of seedlings were 0, 0.5, 1, 2, 4, 6, and 7 hours. The weather conditions during exposure were as shown in Table 1.

TABLE 1–Weather conditions during exposure time

	Time								
	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Hours after treatment	0	1	2	3	4	5	6	7	8
Temperature (°C)	7	8	10	12	15	16	14	12	10
Relative humidity (%)	80	78	75	70	67	65	68	70	72

Each seedling was weighed before and after exposure so that the rate of water loss could be calculated. After each exposure treatment, five seedling shoots were randomly chosen for prompt testing of xylem water potential using a pressure chamber (model ZLZ-5 made by Lanzhou University, China). Remaining seedlings were planted in round plastic buckets and grown in the greenhouse under the same conditions as described above.

Root growth potential and seedling morphological indices measurement

At the end of 35 days, seedling roots were carefully washed free of the planting medium; the total number of new roots (TNR), number of new roots greater than 1 cm (TNR >1 cm), and the total length of new roots greater than 1 cm (TLR >1 cm) were then recorded according to the method described by Ritchie (1985).

We also measured and calculated 15 morphological traits on each of 25 control seedlings at the end of this experiment. The 15 morphological traits were as follows: height, collar diameter, length of tap root (not measured in Chinese fir), root volume (measured by using the water replacement method, not measured in Masson pine), number of lateral roots, shoot fresh weight, root fresh weight, total fresh weight, shoot dry weight, root dry weight, total dry weight, height/diameter ratio, shoot fresh weight/root fresh weight ratio, shoot dry weight/root dry weight ratio, quality index (QI). According to Dickson (1960), the quality index (QI) can be expressed as:

QI = Total dry weight (g)/[height (cm)/diameter(mm)+shoot dry weight(g)/root dry weight(g)]

Field performance test

Two hundred and ten exposure-treated seedlings (30 plants for each group, treatments as described above) were promptly planted in a well-prepared site in the Xiashu Forest Farm of Nanjing Forestry University. The field survival was checked 3 months after planting.

Experiment Design and Statistical Analysis

The experiment was a completely randomised design. Root and shoot treatments had eight levels and each level had 25 seedlings. Seedling exposure treatments had seven levels and each level had 25 seedlings.

All correlation analyses were carried out using Sigmastat (version 2.03) software. The test was conducted using one way ANOVA in SAS statistical software. The significance of the correlation analyses and one way ANOVA was determined using F-tests.

RESULTS

Effects of Shoot Pruning and Root Trimming on Root Growth Potential of Chinese fir and Masson pine

Shoot pruning had a significant effect on RGP (Table 2). TNR and TNR >1 cm of Masson pine decreased by 53% and 56% respectively after removal of half the foliage and pruning all the foliage decreased RGP by 70% and 82% respectively. Effects on Chinese fir were relatively slight in comparison to Masson pine. The TNR and TNR >1 cm of Chinese fir both decreased by 11% after pruning of half the foliage, and by 19% and 45% respectively after pruning of all the foliage. The TNR and TNR >1 cm of Masson pine decreased by 36% and 52% respectively after removal of the top bud but that of Chinese fir went up considerably. Seedlings with no shoot produced no new roots.

Root trimming also had a considerable effect on RGP (Table 2). The more the root was trimmed, the fewer new roots were produced. The extent of reduction differed by species. The TNR and TNR >1 cm of Chinese fir decreased by only 29% and 33% respectively after trimming of 40% of the lateral roots, but that of Masson pine decreased by 69% and 78% respectively.

TABLE 2–Effects of shoot pruning and root trimming on root growth potential of Chinese fir and Masson pine (n=25)

Species	Treatment	TNR*	TNR >1 cm
Chinese fir	Control	23.81 ab	8.32 b
	Prune half foliage	21.28 abc	7.37 b
	Prune whole foliage	19.24 abc	4.59 bc
	Remove top bud	30.72 a	13.18 a
	Remove shoot	0.00 c	0.00 c
	Trim 20% lateral roots	21.52 abc	5.92 bc
	Trim 40% lateral roots	19.60 abc	5.56 bc
	Trim 60% lateral roots	15.32 bc	1.83 c
Masson pine	Control	78.36 a	32.76 a
	Prune half foliage	36.72 bc	14.42 b
	Prune whole foliage	23.36 cd	5.76 cd
	Remove top bud	49.92 b	15.96 b
	Remove shoot	0.00 d	0.00 cd
	Trim 20% lateral roots	36.68 bc	9.38 bc
	Trim 40% lateral roots	24.60 cd	7.28 c

Note: Results in one species followed by a different letter indicate significant difference ($p<0.05$).
* TNR: Total number of new roots
TNR >1 cm: Number of new roots greater than 1cm

Effects of Exposure Treatments on Root Growth Potential and Field Survival

Our experiment showed that exposure treatments decreased RGP (Fig. 1 and 2) and field survival (Fig. 3 and 4).

After seedlings were exposed for more than 2 hours, the TNR of Chinese fir fell below 10. The TNR of Masson pine appeared to be less susceptible to exposure (after 4 h the TNR dropped below 20). The water potential of Chinese fir was –1.9 Mpa after 2 hours' exposure whereas the water potential of Masson pine was –2.28 Mpa after 4 hours' exposure (Table 3).

The field survival of Chinese fir was reduced to 40.3% and that of Masson pine dropped to 45.0% after only 2 hours' exposure (Table 3).

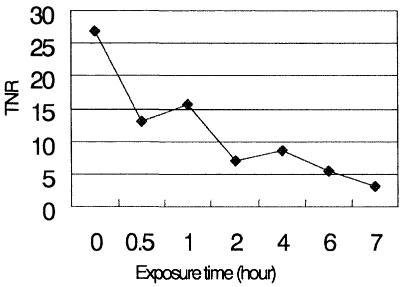

FIG. 1–Effect of exposure time on TNR of Chinese fir

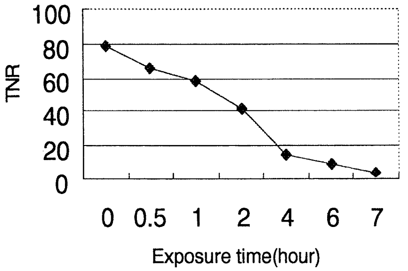

FIG. 2–Effect of exposure time on TNR of Masson pine

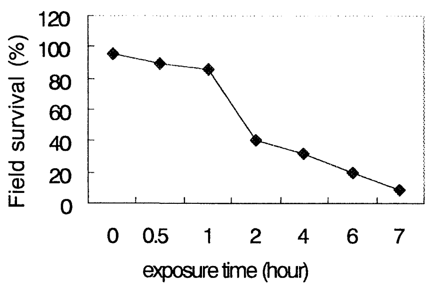

FIG. 3–Effect of exposure time on field survival of Chinese fir

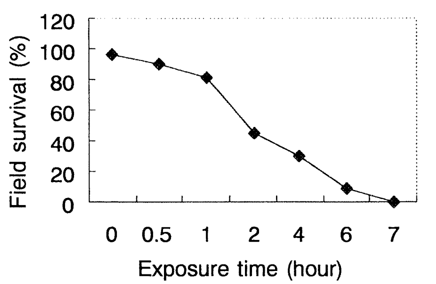

FIG. 4–Effect of exposure time on field survival of Masson pine

Relationship Between Seedling Morphological Indices and Root Growth Potential

Most morphological indices of both species were significantly correlated with TNR (Table 4). Weight indices of both species had relatively high correlation coefficients. Root-collar diameter of both species was highly correlated with TNR. The height of Masson pine, however, had a relatively low correlation coefficient and this relationship was not significant for Chinese fir. Of the calculated variables (height / diameter, shoot fresh weight / root fresh weight, shoot dry weight / root dry weight, and QI), the QI of both species had the highest correlation coefficients.

TABLE 3–Effect of exposure time on water loss, water potential, TNR, and field survival of Chinese fir and Masson pine seedlings

Species		Exposure time (h)						
		0	0.5	1	2	4	6	7
Chinese fir	Water loss (%)	0	7.1	8.4	14.5	26.1	30.4	35.5
	Water potential (MPa)	–0.30	–1.05	–1.55	–1.90	–2.05	–2.20	–2.38
	TNR	26.72	12.92	15.76	7.16	8.68	5.72	3.36
	Field survival (%)	95.30	90.00	85.60	40.30	32.00	19.70	8.10
Masson pine	Water loss (%)	0	8.53	11.62	24.23	28.83	35.20	37.60
	Water potential (MPa)	–0.20	–0.90	–1.70	–2.15	–2.28	–2.40	–2.45
	TNR	78.36	66.44	59.04	41.16	15.16	9.36	4.16
	Field survival (%)	95.80	90.20	81.40	45.00	30.50	8.70	0.00

TABLE 4–Relationship between seedling morphological indices and TNR (n=25)

Morphological indices	Coefficient of correlation	
	CF	MP
Height	0.28	0.54**
Collar diameter	0.54**	0.77***
Length of tap root	–	0.03
Root volume	0.75***	–
Number of lateral root	0.38	0.68***
Shoot fresh weight	0.51**	0.71***
Root fresh weight	0.73***	0.81***
Quality index (QI)	0.68***	0.75***
Total fresh weight	0.57**	0.74***
Shoot dry weight	0.55**	0.71***
Root dry weight	0.67***	0.75***
Total dry weight	0.59**	0.75***
Height/Diameter	–0.38	–0.44*
Shoot weight/root weight(fresh)	–0.65***	–0.48*
Shoot weight/root weight(dry)	–0.30	–0.29

CF: Chinese fir MP: Masson pine

Quality index = Total dry weight/[height (cm)/diameter(mm)+shoot dry weight(g)/root dry weight(g)]

* p(probability of no significant correlation)0.01<p<0.50,

** 0.001<p<0.01,

***p<0.001.

Difference in Root Growth Potential Between Chinese fir and Masson pine

There are several indices that can be used to express RGP, such as TNR, TNR >1 cm, and TLR >1 cm. These indices were significantly correlated with each other (Table 5). We selected the first two as expressive indices of RGP because measuring of TLR >1 cm is time-consuming. The difference in root growth potential between Chinese fir and Masson pine was large (Table 6). TNR of Masson pine was nearly 3.5 times that of Chinese fir and

TNR >1 cm of Masson pine was about 4 times greater. Although Masson pine developed more new roots than Chinese fir, Chinese fir new root growth occured earlier than that of Masson pine (Table 6).

TABLE 5–Correlation analyses among different expressive indices of root growth potential (n=25)

Index	Chinese fir	Masson pine
TNR and TNR >1 cm	0.81***	0.70***
TNR and TLR >1 cm	0.68***	0.61***
TNR >1 cm and TLR >1 cm	0.91***	0.93***

*** p<0.0001

TABLE 6–Difference in root growth potential between Chinese fir and Masson pine (n=25)

Species	Average time for initiating new root (days)	Duration of testing (days)	TNR	TNR >1 cm
Chinese fir	12	35	23.81	8.32
Masson pine	20	35	78.36	32.76

DISCUSSION

Effects of Shoot Pruning and Root Trimming on Root Growth Potential

In this study, RGP of Masson pine was more susceptible to shoot pruning than that of Chinese fir. The possible reason is that the initiation of new roots in Masson pine requires more current photosynthate than in Chinese fir. Although a terminal bud was considered a prerequisite for a quality seedling, removing the top bud increased the RGP of Chinese fir. Perhaps the carbohydrates in foliage used for shoot sprouting were transferred to the root. Masson pine seedlings may have a different physiological response to removal of the top bud. The reduction of RGP of both species after shoot pruning probably means that root growth requires photosynthate from the foliage. This coincides with Van den Driessche's (1987) experiment in Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in which it was found that current photosynthate was the primary carbon source for new roots. Burdett's (1990) model also assumed the utilisation of current photosynthate for new root growth. This was confirmed by our experiment in removing all of the shoots as the RGP of both species was zero, indicating that seedlings will die without energy from foliage. Our experiment also showed that the roots, especially lateral roots, have a great effect on new root initiation. So the more the root was trimmed, the fewer the new roots produced. This was possibly due to damage of many actively growing apices.

Effects of Exposure Treatment on Root Growth Potential and Field Survival

Excessive water loss from bare-root seedlings during handling can easily happen. We found that Chinese fir seedlings lost 14.5% of their water after exposure for only 2 hours, reducing the water potential to –1.90 MPa. In this treatment, the TNR of Chinese fir was below 10 and field survival was only 40.3%. Masson pine had even more rapid water loss (Table 3), but it seemed to have a greater ability to tolerate water stress. Consequently, a substantial impact on TNR of Masson pine appeared only after 4 hours' exposure where water potential was reduced to –2.28 MPa. But Masson pine had low field survival too (Table 3). We conclude that Chinese fir has greater ability to conserve water while Masson pine is more tolerant of low water potential. We also conclude that it is very important to protect seedlings of both species from water loss during handling. Tabbush (1987) found that the survival of Sitka spruce transplants after 2 years was irreversibly reduced to 68% after exposure for 3.3 hours. Therefore, maintaining the water status of seedlings is a key factor in successful reforestation. Lopushinsky (1990) reviewed the literature on water potential in bare-root seedlings, concluding that leaf water potential should remain above –2 MPa throughout the period from lifting to replanting. McKay (1997) also noted that desiccation stress between lifting and planting is a major factor influencing nursery stock survival and growth. We suggest that roots and foliage of Chinese fir seedlings should not be exposed to sunny field conditions for more than 2 hours, and the exposure time of Masson pine seedlings should be limited to less than 4 hours.

Relationship between Seedling Morphological Indices and Root Growth Potential

Morphological indices are popular tools for the evaluation of seedling quality in China. Many kinds of morphological indices have been proposed and some of them are likely to be better predictors of seedling viability than others. Our experiment confirmed that root collar diameter is a very good predictor of RGP while height is a relatively weak predictor for both species. Among root indices, length of tap root had no relationship with RGP, suggesting that length of tap root is not important for new root growth. Lateral roots, however, are necessary for new root sprouting. All weight indices were significantly correlated with root growth potential. Therefore we can evaluate quality of seedlings by measuring their weight. But dry weight is a destructive index that should be avoided in practice. Of the desired calculated indices (height / diameter, shoot weight / root weight, and quality index), the quality index was best correlated with root growth potential.

Some studies have supported the concept that root growth potential depends at least partly on the morphological status of seedlings (Tabbush 1986; Carlson 1986; Dewald & Feret 1987). However, other researchers indicate that morphological attributes are not correlated with root growth potential (Sutton 1980, 1983; Johnsen *et al.* 1988). We found that at least some morphological indices are highly correlated with root growth potential. This indicates that morphological traits of Chinese fir and Masson pine can contribute to the variation in root growth potential. Morphological indices, if properly chosen, should be seriously considered in practice.

Difference in Root Growth Potential between Chinese fir and Masson pine

Root growth potential can be reported in many ways including TNR, TNR >1 cm, TLR >1 cm, fresh weight and dry weight of new roots, volume of new roots, etc. (Sutton

1990). The first three indices were used in this study and the results suggested that there are strong relationships among them. We propose that TNR is the preferred indicator of root growth potential of both Chinese fir and Masson pine because it can be measured easily and precisely.

Root growth potential can vary greatly between different species, families, seed sources, and stock types (Ritchie 1985). Our experiment showed that there are large differences in root growth potential between Chinese fir and Masson pine. The quantities of TNR of Masson pine were more than three times that of Chinese fir. This difference may contribute to the better survival of Masson pine after planting compared to Chinese fir. We did not measure root growth potential of different families and seed sources. Therefore, it is unclear if the difference in root growth potential between Chinese fir and Masson pine is at the species level.

CONCLUSIONS

The purpose of this study was to see to what extent the root growth potential of Chinese fir and Masson pine bare-root seedlings changed with different handling treatments before planting. We showed that:

(1) The RGP of both species decreased after shoot pruning. This probably means that current photosynthate from foliage is a requirement of new root growth.

(2) As more roots were trimmed, fewer new roots were produced. This is possibly due to the removal or damage of many actively growing apices.

(3) Both species were sensitive to water loss during handling. Chinese fir seedlings should not be exposed to sunny field conditions for more than 2 hours and the exposure time of Masson pine seedlings should be limited to less than 4 hours after lift.

(4) At least some morphological characteristics of both species are highly correlated with RGP. This indicates that morphological characteristics of both species can contribute to the variation in RGP.

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