Impact of planting stock quality on initial growth and survival of radiata pine clones and modelling initial growth and survival

Rajesh K. Sharma[1], Euan G. Mason[2] and Charles Sorensson[3]

Key words: Transplant stress, shoot: root ratio, root-fibrosity, sturdiness, survival, risks and deployment strategies.

Abstract

The effectiveness of several morphological characteristics of planting stock as indicators of field performance was assessed in an experiment established with ten radiata pine clones at Dalethorpe, Canterbury, New Zealand. Greater initial heights of three clones resulted in transplant stress. Sturdiness was the best predictor of survival in a plot level analysis and initial heights were the best predictors of survival during the first year after planting in a individual tree level analysis. Morphological differences between clones resulted in differences in survival up to age 4. Overall variability in height and diameter at breast height over bark at age 4 was more in clonal mixture plots compared to monoclonal plots. Greater variability in sizes of planting stock and dominance and suppression of clones in clonal mixture plots further enhanced the variability. Uniformity of raw materials, and risks of insect-pest and diseases were found to be important factors affecting decisions regarding choice between modes of deployment.

Introduction

The area planted with radiata pine has increased very rapidly since its introduction in New Zealand in the 1850s as it is well adapted to local conditions. Clonal forestry has expanded very quickly in the recent past due to its potential to enhance productivity. At present about 89 percent of the plantation area of the country is planted with radiata pine (New Zealand Forest Industry 2005/2006). However, there are some problems with clonal forestry which need to be resolved (El-kassaby and Moss 2004).

Clonal forestry challenges

1) Maturation: Cost effective clonal propagation, juvenility maintenance and multiplication techniques are required.
2) Quality of planting stock: Morphological or physiological standards for micro-propagated planting stock are needed for different site conditions.
3) Clonal selection: Clones need to be selected for fast growth rate, better wood quality, insect-pest and disease resistance, better form and combinations of these traits.
4) Selection methods: Should clonal selections be carried out in single tree plots or in clonal block plots?
5) Timing of selection: Some studies have reported interchanges in rank among clones.
6) Clonal deployment: Should clones be deployed in monoclonal or clonal mixtures or mosaics of monoclonal plots?
7) Growth and Yield models: There is need to develop and test effective growth and yield models for predicting behaviours of genotypes at different sites.
8) Risk analysis: We need to determine the number of clones required to keep risks of insect-pest and disease infestation within tolerable levels, and maintence of genetic diversity in clonal plantations.
9) Productivity: There is need to compare different modes of deployment for overall productivity particularly in long rotation species.
10) Cost: Need to compare the cost of production and management associated with each mode of deployment.

Considering these challenges a clonal experiment was established at Dalethorpe, Canterbury, New Zealand in Sept. 1993 with ten radiata pine clones. This paper describes the impact of quality of planting stock (micro-propagated) on initial survival and growth of radiata pine clones. Other challenges facing clonal forestry will be discussed in subsequent papers.

Quality of planting stock

Good quality of seedlings is a prerequisite for successful establishment (Trewin *et al.* 1985, Bernier *et al.* 1995). The quality of planting stock is often assessed by morphological measurements such as shoot height, stem diameter (South 2001), and shoot-root ratio or physiological characteristics such as root growth potential, root starch levels, root water potential, drought hardiness and frost hardiness. Sometimes combinations of morphological and physiological measurements are used (Duryea 1984, Menzies 1988). Nursery growers usually use morphological characteristics to describe the quality of planting stock because of ease of measurement and influence of the morphological characteristics on the physiological states of planting stock (Thompson 1984).

Genotype, transplant stress, and initial survival of planting stock jointly affect productivity, but these factors are rarely studied together in designed experiments. Initial survival and growth of planting stock depend upon quality of planting stock, care during plant transport between nursery and planting site, establishment practices, soil and climatic conditions, and their interactions. Young bare-root seedlings are prone to physical damage due to planting systems that comprise seedling lifting, packaging,

[1] *PhD candidate, School of Forestry, University of Canterbury, Christchurch*

[2] *Associate Professor, School of Forestry, University of Canterbury, Christchurch*

[3] *Horizon2 Ltd., Te Teko*

transporting and placement (Trewin and Cullen 1985, Mason and Trewin, 1987). Physical damage of roots during lifting and moisture loss during transportation and storage sometimes lead to death of damaged roots and cause transplant stress. Moisture and nutrient status of a site at the time of planting also affect the growth and survival of seedlings. So interactions between seedling state and site conditions determine establishment success, and seedling state is often assessed using morphological measurements.

Several studies have addressed effects of morphological characteristics of seedlings on survival and growth. Anstey (1971) reported that radiata pine field growth and survival were greater with greater initial diameter. Pawsey (1972) reported that survival of *Pinus radiata* in the field was independent of seedling size whereas growth rate during the early years was found to be influenced by initial size of the seedlings. South *et al.* (1985) reported that survival of loblolly pine seedlings of root-collar diameter greater than 4.7 mm was significantly greater than seedlings of initial root-collar diameter of less than 1.6 mm and volume production at age 13 was 17.5 percent greater than seedlings of initial root-collar diameter of 3.2-4.7 mm. Mason *et al.* (1996) reported that seedling ground-line diameter (GLD) was best correlated with tree performance of radiata pine seedlings at one site while GLD squared x height was most significant at another. Mason (2001) included GLD as a predictor of survival and growth of radiata pine in a juvenile growth model, and GLD was found to be most influential when environmental conditions were harsh. Tuttle et al. (1987) reported that initial height of loblolly pine seedlings (1+0) was inversely related to total seedling height growth during the first two seasons, and a "Transplant Stress Index" (TSI) comprising the slope of the height growth versus initial height regression has been proposed as an indicator of moisture stress following planting (South and Zwolinski, 1997). South and Mason (1993) reported that taller seedlings of Sitka spruce at planting were also taller after 6 years of growth. South *et al.* (2001) found that planting larger seedlings of average diameter of 8.5 mm and 50 cm tall of Loblolly pine increased the survival slightly on one site and increased fourth year volume production with intensive management. Thompson (1984) emphasised that a quality seedling should have as low a shoot: root ratios as possible to ensure the best survival.

Genotype may interact with initial management factors, and the study reported here set out to examine the effect of genotype and plant morphology on survival and growth of radiata pine after planting in an experiment designed to compare block plantings of clones with the same clones in mixture. We did not set out to select the best clones, rather to use clones to study impacts of genotype and plant morphology on establishment success. The study had the following objectives:

- To compare morphologies of different micro-propagated radiata pine clones.
- To identify the best morphological predictors of initial growth and survival of the clones and compare these between genotypes.
- To develop initial height and ground-line basal area models for the clones.
- To compare stand structure of monoclonal and clonal mixture plots.

Materials and methods

Site

An experiment was established with radiata pine (*Pinus radiata* D. Don) clones on a hill site at Dalethorpe (latitude 42°-45'S, longitude 171°-55'E, elevation 520 m a. s. l.), 70 km west of Christchurch, Canterbury, New Zealand in September 1993. The soil at the site was well-developed silt-loam (NZ Soil Bureau, 1968). Mean annual precipitation was 1447 mm. Precipitation was distributed fairly evenly throughout the year although a marked dry period can occur during February and March (McCracken 1980).

Design of the experiment

Ten clones were deployed in a randomised complete block design with three replications of each as monoclonal treatments, plus a clonal mixture treatment. All plots were of rectangular shape (16 x 20 m), and contained 40 trees (5 x 8) except for one clonal mixture plot (64 x 20 m) that was larger (5 x 32 trees). Trees were spaced at 2 m within rows, and rows were spaced at 4 m (1250 stems/ha).

Planting material

Clones were propagated by organogenesis from controlled pollinated mature seeds that were surface sterilised and germinated into sterile tissue cultures. After propagation they were hardened off in a nursery in the North Island at the Fletcher Challenge Forests Ltd. Biotechnology Centre, TeTeko, for one year, conditioned with an undercutting and wrenching

regime, and then were transplanted as bare-root plants. All the clones were of GF (growth and form) rating between 25 and 30 (Genetics and Tree Improvement 1987). Overall initial size of the plants varied from 11 to 49 cm in height and 1.1 to 13 mm in ground-line diameter (GLD).

Establishment practices

All the plants were planted in pits of 30 cm depth in ripped lines with ripping at a depth of 30 cm. Each planting spot was further cultivated with a spade. Each randomised complete block was planted by only one person. All the plots were kept completely weed free using initially a mixture of Hexazinone and Turbuthylazene, and subsequently a mixture of Turbuthylazine, Clopyralid and Haloxyfop for 5 years following planting.

Assessments

Leaving buffer lines between the plots, the height and ground-line diameter of 18 individual trees in each plot, and 90 trees in the one big clonal mixture plot were recorded from establishment in year 1993 to 1996, and height and diameter at breast height over bark (DBH) from 1997 to

2006. Ground-line basal areas per hectare were calculated for each plot from 1993 to 1996. Observations regarding insect-pest or disease attack if any were recorded.

Transplant stress indices (TSI) proposed by South and Zwolinski (1997), defined as the "slopes of the linear relationships between shoot height at the beginning of the growth period and height increment", were calculated for each clone at the end of the first year. Percent survivals and coefficient of variation in heights for ages 1 to 4 were calculated for each clone from plot data.

At time of planting ten individuals of each clone were randomly selected for destructive sampling. Initial heights and initial diameters of these plants were recorded. Destructively sampled plants were separated into shoot, foliage and root components. These components were oven-dried and then weighed.

Root-fibrosity, which is the ratio of fine roots biomass to total root biomass, was calculated for each clone from the destructively sampled plants. To calculate individual tree shoot biomass, foliage biomass, root biomass and root-fibrosity of the other plants, nonlinear relationships between individual heights and shoot biomass, foliage biomass, root biomass and root-fibrosity were developed from destructively sampled plant data. Initial heights and initial diameters were both tried as independent variables in these nonlinear relationships. Initial heights were chosen to develop the relationships because initial heights gave better fits than initial diameters. Values of the parameters of the relationships were used to estimate the individual tree foliage, shoot, root biomass and root-fibrosity of trees planted in the experiment and clonal values were calculated from plot data. The biomass relationships were of the form:

$$M = \alpha\, Y^{\beta} \qquad (1)$$

Where M = mass of foliage or shoot or roots or root-fibrosity, Y = height from ground level and α & β were parameters of the relationships.

Shoot: root ratio, foliage: shoot ratio and sturdiness were calculated as outlined in the next section.

Variables estimated

Proportions of above ground parts, particularly foliage, and below ground roots are important from a water balance perspective. Shoot: root ratio is used as an indicator of drought avoidance potential of seedlings (Bernier *et al.* 1995) and sturdiness as a measure of resistance to out-planting shock (Menzies, 1988). Shoot: root ratios, foliage: shoot ratios and sturdiness were calculated for each plant as follows.

$$Sturdiness = \frac{Height\ after\ planting}{GLD\ after\ planting} \qquad (2)$$

$$Shoot\text{ - }Root\ Ratio = \frac{Shoot\quad biomass}{Root\quad biomass} \qquad (3)$$

$$Foliage\text{ - }Shoot\ Ratio = \frac{Foliage\quad biomass}{Shoot\quad biomass} \qquad (4)$$

Values for each clone were calculated form plot data.

Data analysis

Procedure GLM (General linear models) of SAS (SAS-Institute 1996) was used for analysis of variance to find out whether clones differed significantly in initial heights, ground-line diameters, diameters at breast height over bark (DBH) at age 4, survivals at ages 1 and 4, shoot: root ratios, foliage: shoot ratios, sturdiness and root-fibrosity at time of planting. Initial heights and initial diameters were used as covariates in analysis of covariance to find out whether clones differed in sturdiness, shoot: root ratio, root fibrosity and survivals at age 4.

A further analysis of survival was conducted using a logistic regression procedure, testing various morphological measurements and combinations thereof as predictors of individual tree death during the first year following planting. Clone was tested as a class variable in this procedure once a model including morphological measurements had been constructed.

Linear contrasts were used during the analysis of variance to compare the overall heights, diameters and coefficients of variation in heights and diameters at the time of planting and at age 4 in both monoclonal and clonal mixture plots.

Regressions were developed from individual tree data between height increments at age 1 and initial heights after planting to estimate a transplant stress index (TSI) for each clone at the level of the entire experiment. There were too few plants in each plot for TSI to be calculated reliably within plots. South *et al.* (2003) noted that large numbers of seedlings in each experimental unit are required in order to reliably estimate TSI.

Procedure NLIN (nonlinear regression) of SAS was used to fit initial height and ground-line basal area yield models for each plot up to ages 4 and 3 respectively. Ground-line basal area was modelled than ground-line diameter, because ground-line basal area also takes into account the stand stocking. The mean height function (Mason and Whyte, 1997) used was as follows:

$$H_t = H_0 + \alpha T^{\beta} \qquad (5)$$

Where H_t = mean height at stand age T, H_0 = mean height after planting, T = stand age and α & β were estimated coefficients.

The equation fitted to mean ground-line basal area data was as follows:

$$G_t = G_0 + \alpha T^{\beta} \qquad (6)$$

Where G_t = mean ground-line basal area at stand age T, G_0 = mean ground-line basal area after planting, T = stand age and α & β were estimated coefficients.

The student-Newman-Keuls multiple range test was conducted to analyse the parameters of models fitted to individual plots.

For the survival model, initial heights and diameters,

Table 1: Mean sizes of clones at age 1 and age 4. Values in each column followed by the same letter are not significantly different according to SNK (student-Newman-Keuls multiple range) test (P<0.05). In the table variables are mean heights after Planting (MH0), mean heights at age 4 (MH4), mean ground-line diameters after planting (MD0), mean diameters at breast height over bark at age 4 (MD4).

Clone Number	MH0 (m)	MH4 (m)	MD0 (cm)	MD4 (cm)
1	0.25 a	2.71cde	0.62 b	4.29 bcde
2	0.28 a	3.13 bc	0.77 ab	4.92 bcd
3	0.25 a	2.54 e	0.73 b	3.97 cde
4	0.25 a	3.38 b	0.69 b	5.35 b
5	0.26 a	3.03 bcd	0.72 b	5.03 bc
6	0.27 a	2.62 de	0.86 a	3.86 de
7	0.33 a	2.87cde	0.66 b	4.77 bcde
8	0.28 a	2.93 cde	0.68 b	4.33 bcde
9	0.28 a	3.74 a	0.71 b	6.51 a
10	0.35 a	2.46 e	0.67 b	3.76 e

sturdiness, shoot: root ratios, foliage: shoot ratios and root fibrosity were tried as predictors of survival at age 4. Plot data were used for the survival model. A linear model gave a better fit to survival data than nonlinear models tried.

$$Y = \alpha + \beta_0 x_0 \quad (7)$$

Where Y = plot survival at age 4, and X_0 was a predictor variable.

Residual analysis was also carried out to check goodness of fits of initial growth and survival models. Plots of residuals versus predicted values, and residuals versus independent variables were inspected for bias, and SAS procedure UNIVARIATE was employed with "normal" option and the Shapiro-Wilk test was used to test for normality of residuals. Correlations between various variables were also examined to identify the best predictor of survival at age 4.

Discriminant analysis, which is used to separate two or more groups on the basis of analysing several variables simultaneously (Manly 1986) was carried out on parameters of initial height and initial ground-line basal area models fitted to each plot. Lower values of canonical discriminant functions indicated poorer performance. Separation in growth behaviours was evaluated by plotting values of canonical discriminant functions 1 and 2 calculated for each plot.

Results

Initial morphology of planting stock

Clones differed significantly in initial ground-line diameter (P=0.0055), shoot: root ratio (P<0.0001), sturdiness (P=0.001) and root-fibrosity (P<0.0001) at the time of planting but had similar heights (P=0.0567) (Tables 1 and 2). Initial height exhibited a significant negative correlation (P<0.0001) with sturdiness, whereas initial diameter of planting stock exhibited a significantly positive correlation with sturdiness (P=0.019). Clones didn't differ in sturdiness when a separate analysis of covariance was performed using initial heights and initial diameters as covariates.

Table 2: Mean values of morphological indicators shoot-root ratios, sturdiness, root-fibrosity and foliage-shoot ratio for each clone. Values in each column followed by the same letter are not significantly different according to SNK (student-Newman-Keuls multiple range) test (P<0.05).

Clone Number	Shoot: Root	Sturdiness	Root Fibrosity	Foliage: Shoot
1	5.60 c	42.17 bc	0.77bc	0.80 a
2	4.41 e	37.45 c	0.74 cd	0.76 a
3	4.10 e	34.62 c	0.90 a	0.75 a
4	5.50 c	38.80 c	0.92 a	0.88 a
5	4.84 d	36.71 c	0.90 a	0.81 a
6	7.20 a	34.65 c	0.89 a	0.86 a
7	5.28 c	52.40 ab	0.80 b	0.90 a
8	6.17 b	41.87 bc	0.91 a	0.82 a
9	5.45 c	40.19 c	0.69 d	0.81 a
10	4.12 e	54.80 a	0.73 cd	0.86 a

Table 3: Mean survival of clones at ages 1 and 4. Values in each column followed by the same letter are not significantly different according to SNK (student-Newman-Keuls multiple range) test (P<0.05). In the table TSI is transplant stress index and CVH0 & CVH1 are coefficient of variation for heights at the age 0 (just after planting) and 1 respectively.

Clone Number	Survival age 1	Survival age 4	TSI	CVH-0	CVH-1
1	100 a	100 a	0.18	19.43 a	24.63 a
2	98.15 a	96.30 a	-0.17	18.97 a	16.83 a
3	100 a	100 a	0.17	21.16 a	21.98 a
4	98.15 a	98.15 a	0.24	20.34 a	22.96 a
5	100 a	100 a	0.01	15.25 a	21.20 a
6	100 a	100 a	0.51	19.86 a	24.11 a
7	83.33 a	81.48 b	-0.28	15.35 a	23.06 a
8	100 a	100 a	0.33	18.89 a	22.76 a
9	100 a	100 a	0.46	22.67 a	23.62 a
10	96.3 a	90.74 ab	-0.12	21.10 a	23.25 a

Transplant Stress

Negative values of TSI (Table 3) for clones 2, 7 and 10 indicated that these clones faced more severe transplanting stress during first year of their growth than the other clones did.

Table 4: Height and ground-line basal area after planting and mean parameters of the models of initial height and ground-line basal area fitted for clones. Values in each column followed by same letter were not significant at 5% level according to SNK (student-Newman-Keuls multiple range) test.

Clone number	H_0 (M)	Parameter estimates of height models		G_0 (m_2/ha)	Parameter estimates of ground-line stand basal area models	
		α	β		α	β
1	0.25 a	0.171881 a	1.920191 cde	0.039977 b	0.153163 a	3.067787 ab
2	0.28 a	0.233481a	1.812689 def	0.061602 b	0.137566 a	3.308896 ab
3	0.25 a	0.230678 a	1.659253 f	0.054764 b	0.19825 a	2.833023 ab
4	0.25 a	0.165854 a	2.123754 bc	0.050489 b	0.115815 a	3.242054 ab
5	0.26 a	0.180577 a	1.969448 cde	0.0544 b	0.157501 a	3.215549 ab
6	0.27 a	0.216568 a	1.716661 ef	0.076047 a	0.198465 a	2.688468 b
7	0.33 a	0.091386 b	2.40457 a	0.046361 b	0.094572 b	3.234431 ab
8	0.28 a	0.154111 a	2.047293 bcd	0.048125 b	0.126538 a	3.140132 ab
9	0.28 a	0.232895 a	1.961397 cde	0.053018 b	0.114166 a	3.636866 a
10	0.35 a	0.097037 b	2.246841 ab	0.046943 b	0.080102 b	3.435849 ab

Initial height growth

Clone 9 grew most rapidly followed by clone 4 during the establishment period (Figures 1 and 2). Slight interchanges in ranks were found at age 3. Clones significantly differed in height ($P<0.0001$) at age 4. Clones 3 and 10 were the shortest clones at age 4.

Initial height growth model

Table 4 shows the mean parameters of the height equation (5) fitted for each plot. The residuals were mostly within +/- 0.06 m of the model, and all were within +/- 0.09 m. The fitted parameters differed significantly ($P<0.0001$) between clones (Table 4).

Initial ground-line basal area growth

Clone 9 grew most rapidly in ground-line basal area followed by clones 5 and 2 (Figure 3). Clones significantly differed ($P=0.0007$) in stand ground-line basal area at age 3. Clones 7 and 10 had lowest ground-line basal area at age 3.

Figure 1 - Initial height growth of clones in monoclonal plots.

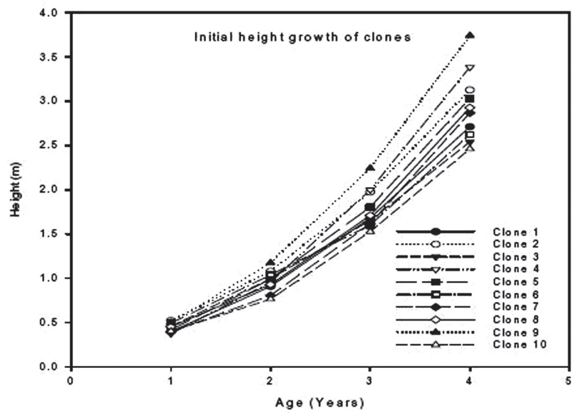


Figure 2 - Initial ground-line basal area growth of clones in monoclonal plots.

Initial ground-line basal area model

Table 4 shows the mean parameters of the ground-line basal area equation (6) fitted for each model. The residuals became smaller with age; at age 3 they were within +/- .0.1 m2/ha of the predictions. The parameters α ($P=0.027$) and β ($P=0.048$) significantly differed among clones (Table 4).

Figure 3 - Differences in height growth between clones were obvious, with clone 9 in the monoclonal plot on the right and clone 2 in the monoclonal plot on the left in this image.

Figure 4 - Clonal groupings for initial growth based on canonical functions.

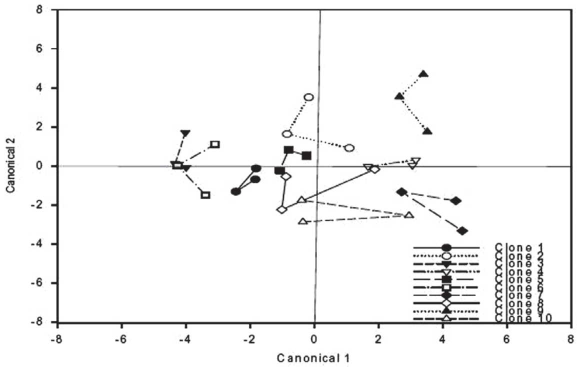
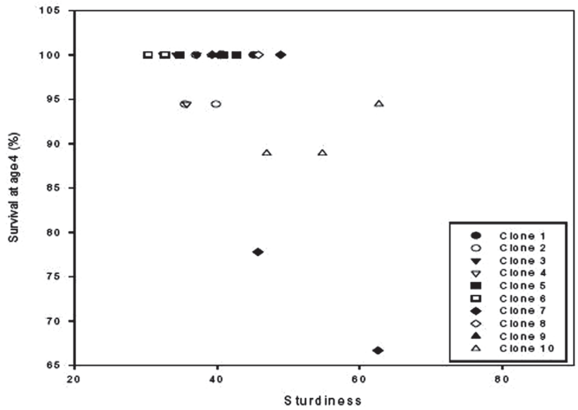


Figure 5 - Sturdiness at planting versus survival of radiata pine plants at age 4 calculated from plot data.



Discriminant analyses of parameters of both fitted functions for each plot showed different groupings of clones (Figure 4). The first two canonical discriminant functions explained 67 and 27 percent of variation in data respectively. Greater positive values of canonical function 1 indicated that clone 9 grew most rapidly, and greater negative values for clones 3 and 6 indicated that these clones grew slowly during the establishment period.

Table 6: Correlations between various variables studied. Higher value of sturdiness means less sturdier the plant.

Variables	Coefficient of correlation	Pr> IrI
Heights at planting and Sturdiness	0.823	<0.0001
Heights at planting and Survival at age 4	-0.577	0.0008
Heights at planting and Root fibrosity	-0.507	0.0042
Diameters at planting and Sturdiness	-0.426	0.019
Sturdiness at planting and Survival at age 4	-0.619	0.0003
Height growth rate at age 1 and survival at age 1	0.477	0.0076
Height growth rate at age 2 and survival at age 2	0.609	0.0004

Survival

Clones 2, 7 and 10 had lower survivals at age 1 compared to other clones and their survivals further decreased at age 4 (Table 3). Clone 7 had the lowest survival of 81 percent at age 4 ($P=0.0122$). These clones also tended to have more negative TSI values. Initial survival at age 1 and age 2 was correlated with height growth rate at these ages with coefficient of correlation of 0.47 and 0.60 respectively (Table 6).

Table 5: Effectiveness of various predictors of survival in survival model.

Predictor variable	r^2	Intercept	Pr> ItI	Slope	Pr> ItI
Initial Heights	0.33	123.06	<0.0001	-94.38	0.0008
Initial Diameters	0.02	87.26	<0.0001	13.22	0.4532
Sturdiness	0.38	121.18	<0.0001	-0.59	0.0003
Shoot: root ratio	0.06	85.66	<0.0001	2.08	0.1585
Root fibrosity	0.05	80.21	<0.0001	19.95	0.2166
Foliage: shoot ratio	0.03	112.08	<0.0001	-18.69	0.3483

Figure 6 - Plot of residuals versus predicted survival of radiata pine plants at age 4.

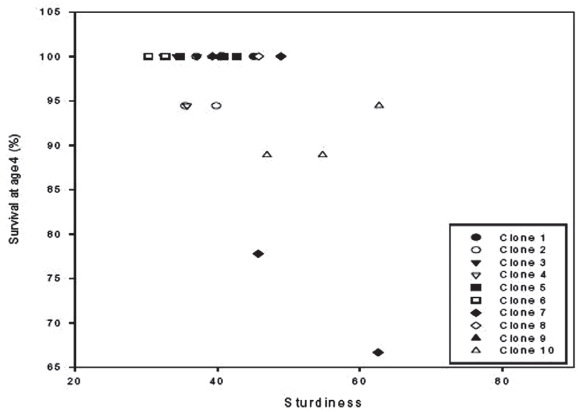
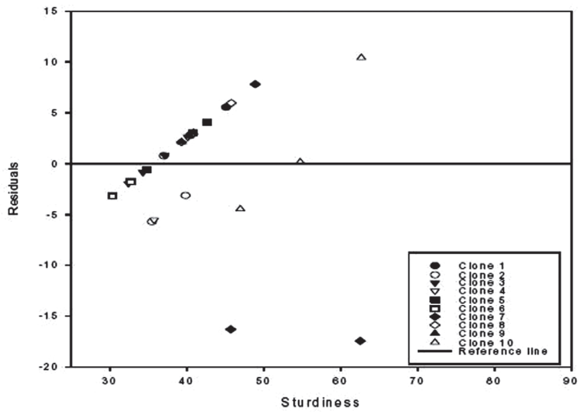


Figure 7 - Plot of residuals versus sturdiness of radiata pine plants at the time of planting.



Survival model

Sturdiness and mean initial heights of planting stock as individual factors were weakly correlated to plot-level survival at age 4 with r^2 values of 0.38 and 0.33 respectively (Table 5, Figure 5). Initial height and sturdiness were also inversely related to each other (Table 6). Residual analysis was conducted to examine the goodness of fits (Figures 6 and 7). Clone was not significant when added as an independent variable in the survival model once morphology was represented in the model:

$$Y = \alpha + \beta_0 x_0 + \beta_1 x_1 \quad (8)$$

Where Y = plot survival at age 4, and x_0 and x_1 were sturdiness or initial heights and clone as independent variables.

The logistic procedure revealed that height at time of planting was the best predictor of individual tree death, with taller trees at time of planting being more prone to mortality ($P<0.0001$). The concordance of this model was 76% and the discordance was 20%. Neither other morphological measurements nor clone were significant as additional terms in the model.

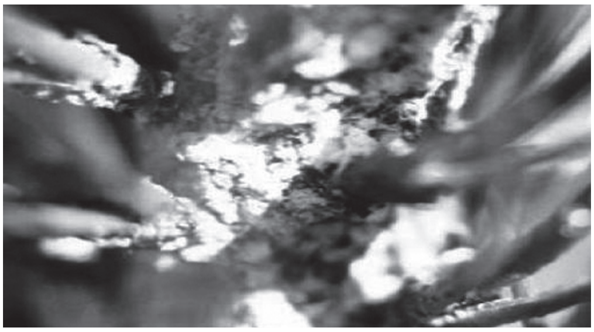
Clones in monoclonal versus clonal mixture plots

There were no significant differences in overall initial heights ($P=0.27$), diameters ($P=0.27$), and variations in heights (P P=0.13) and diameters ($P=0.32$) of individual clones at the time of planting between monoclonal and clonal mixture plots. At age 4 mode of deployment didn't affect sizes, but significantly more variation in overall heights ($P=0.004$) and diameters ($P=0.001$) was found in clonal mixtures compared to monoclonal plots (Table 7). The analysis revealed that greater variability in initial heights in clonal mixture plots led to dominance and suppression among trees with the onset of competition. Dominants grew bigger and suppressed trees grew less, which led to significantly greater variability (measured as coefficient of variation (CV)) in heights ($P=0.0041$) and diameters ($P=0.0012$) at age 4 in the clonal mixture plot compared to monoclonal plots (Table 7). Values followed by different letters under columns CV Height and CV Diameter at age 4 in table 7 represent significant differences between monoclonal and clonal mixture plots.

Risks of clonal plantings

During the second year after planting, clone 3 was severely attacked by pine woolly aphid (*Pinus laevis* (Maskell)). Every plant of clone 3, whether in clonal mixture or in monoclonal plots, was fully covered with aphids so that the bark appeared white (Figure 8). No other clones were affected during that year. The infection declined markedly in year three, appearing in trace amounts on only a few trees of a variety of clones.

Figure 8 - Clone 3 was covered in pine woolly aphid only in year 2 after planting, and no other clones were affected including its full sib relatives 7 and 10.



Discussion

Initial morphology, growth and survival

Rapid initial growth and greater survival of outplanted clones can allow managers to use lower selection ratios and ensure early site occupancy by tree crops.

Morphological and physiological state of planting stock, site conditions (soil and climatic), initial management practices and their interactions determine initial growth and survival. Rapid initial growth and high survival after transplanting require an appropriate balance between water and food requirements and supply. When plants are transplanted the roots need to establish contact with water and nutrient supplies in a new environment as rapidly as possible (Menzies, 1988) by initiating new roots so that foliage can maintain photosynthetic activity. Initial height, shoot: root ratio and proportion of biomass in foliage and fine roots are important indicators of plant water balance because greater height, greater foliage or shoot biomass could result in more transpiration and lower proportions of fine roots can result in lower uptakes of water and nutrients. In this study clones didn't differ with respect to initial height and foliage: shoot ratio but differed significantly in shoot: root ratio, initial diameters, sturdiness and root-fibrosity. Clones that faced transplant stress had greater shoot: root ratio, lower sturdiness and lower root-fibrosity compared to other clones. Shoot-root ratio should not exceed 3:1 for most of species (O'Reilly *et al.* 2002). Thompson (1984) emphasised that a quality seedling should have as low shoot: root ratio as possible to ensure the best survival. All clones in this study had greater shoot: root ratios (Table 2), and so water supply may have been more critical as a consequence.

Sturdiness indicates the balance between height and diameter. Due to positive correlations of height and foliage biomass, and of diameter and root biomass, sturdiness actually represents the likely water relations experienced seedlings following planting. A sturdiness value of 50 or less is considered a good indicator of initial survival for most species (Trewin, 2000). For radiata pine seedlings a sturdiness value between 40 and 60 is considered ideal depending upon site conditions (Menzies, 1988). Clones 7 and 10 had sturdiness values of 52 and 55 respectively which were inadequate for dry conditions. This suggests that these clones didn't have a good balance between height and diameter which likely led to an imbalance between transpiration and water uptake, contributing to transplant stress and lower survival of these clones. Sturdiness which takes into account both initial height and diameter was found to be the best predictor of plot mean survival, while height at time of planting was slightly better in the logistic model.

Clone 9 had rapid initial growth. This clone had comparatively lower initial height, lower shoot: root ratio, greater sturdiness but lower root-fibrosity than clones 7 and 10 that experienced transplant stress. Clones 7 and 10 had greater root-fibrosities and low shoot: root ratios compared to other clones. But greater initial heights and low sturdiness of these clones resulted in transplant stress and lower survival. The significant differences in initial morphology of clones and initial growth behaviours suggested that combinations of various morphological indicators should be used as criteria to determine the quality of planting stock for particular sites. The results of this study support the use of sturdiness (the balance between height and diameter) as a predictor of establishment success of planting stock, but more research is required because correlations between morphology and survival rates were relatively low.

Initial height, shoot: root ratio and root-fibrosity can be manipulated by top pruning, root cutting and wrenching practices in nurseries. Standards for radiata pine seedlings and cuttings have been developed for some morphological indicators, but as clonal forestry with micro-propagated

Table 7: Comparison of overall sizes and coefficient of variation (CV) of monoclonal versus Clonal mixture plots at time of planting (Age 0) and at age 4 using contrast statements in analysis of variance. Values in each column followed by same letter were not significant at 5% level.

Clone/Plot	Mean height		Mean Diameter		CV Height		CV Diameter	
	Age 0	Age 4	Age 0	Age 4	Age 0	Age 4	Age 0	Age 4
1.00	0.25 a	2.71 a	0.62 a	4.29 a	19.43 a	13.50 b	22.63 a	25.90 abc
2.00	0.28 a	3.13 a	0.77 a	4.91 a	18.97 a	11.20 b	20.89 a	18.46 c
3.00	0.25 a	2.54 a	0.73 a	3.97 a	21.16 a	10.16 b	23.20 a	22.52 bc
4.00	0.25 a	3.38 a	0.69 a	5.35 a	20.34 a	13.99 b	27.67 a	19.73 bc
5.00	0.26 a	3.03 a	0.72 a	5.03 a	15.25 a	11.73 b	23.06 a	21.62 bc
6.00	0.27 a	2.62 a	0.86 a	3.86 a	19.86 a	16.91 ab	23.35 a	35.55 a
7.00	0.33 a	2.87 a	0.66 a	4.74 a	15.35 a	16.89 ab	28.61 a	25.91 abc
8.00	0.28 a	2.93 a	0.68 a	4.33 a	18.89 a	18.04 ab	23.84 a	32.41 ab
9.00	0.28 a	3.74 a	0.71 a	6.51 a	22.67 a	11.55 b	26.94 a	21.46 bc
10.00	0.35 a	2.46 a	0.67 a	3.76 a	21.10 a	16.86 ab	25.96 a	25.56 abc
Clonal Mixture	0.25 a	2.83 a	0.67 a	4.39 a	24.64 a	21.96 a	21.91 a	35.58 a

planting stock has become feasible there is need to develop standards for micro-propagated planting stock quality for different site conditions. Matching of species or genotypes to site condition is very important to promote healthy water relations of planting stock following planting. This experiment was established in Sept. 1993 and climatic data revealed that the total rainfall at the site during Oct. 1993 was only 39.2 mm which might have also contributed to transplant stress and lower survival of some clones.

The parameters of initial growth models in this study showed that different genotypes had different growth patterns. The discriminant analysis of parameters indicated that genotypes can be selected for particular sites by analysing the parameters of the initial growth models.

Clonal deployment

Greater variability in initial heights between clones deployed in clonal mixture plots and during the establishment period might have set the stage for competition-related stand dynamics when sizes start influencing growth of neighbours. The dominance and suppression of clones at canopy closure (around age 3) might have led to significantly greater variability in both heights and diameters (Tables 7). Pawsey (1972) compared the growth of planting stock in mixed and segregated plots and reported that competition slowed down the diameter and height growth of seedlings and also resulted in greater variability in mixture plots than segregated plots by age 8.5 years. Uniformity in raw material for greater product recovery is a trait desired by the forest industry, which suggests that using uniform planting stock and monoclonal deployment may enhance uniformity of raw material. Greater susceptibility to insect-pest attack exhibited by one clone suggests that the deployment of such clones monoclonally involve greater risks. Therefore, when the risk of insect-pest and disease is of main concern, then clonal mixture may be a preferable mode of deployment. Libby (1987) suggested two modes of clonal deployment “widespread intimately mixed plantations” and “mosaics of monoclonal plots”. The benefits of greater uniformity and minimum risk might be achieved by deploying clones in “mosaics of monoclonal plots” mode of deployment.

Conclusions

Clones differed significantly with respect to most of the morphological characteristics (initial ground-line diameters, shoot: root ratios, root-fibrosity, sturdiness, and heights) that were related to survival at age 4. Height at time of planting was the best predictor of survival of clones at age 1, and initial height was also the best predictor of transplant stress index, however correlations between initial height and survival was relatively low. Clones that exhibited poor survival had more negative TSIs and lower sturdiness than those that had 100% survival.

During the first year after planting clone survival ranged from 100% for six clones to as low as 83% for the clone most prone to mortality. Differences in mortality between clones were related to plant morphology, and so after initial height had been added to a logistic model of mortality, clone was insignificant as a class variable. Sturdiness was slightly superior to initial height in a plot-level analysis.

Analyses of parameters of models of initial height and basal area showed that clones differed markedly in initial growth.

Clones planted in mixed plots exhibited significantly greater size variation than monoclonal plantings at age 4.

One clone was covered in pine woolly aphid during the second growing season, highlighting the risks of planting monoclonal stands.

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