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Site preparation for *Pinus* establishment in south-eastern Queensland

2. Effect of cultivation and cultivation width on growth

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Summary. The standard site preparation practice used for *Pinus* plantation establishment on well-drained soils in south-eastern Queensland is blade (subsurface, wing rip) cultivation to a width of 2.0 m and a depth of 0.2 m. This operation requires high drawbar power and is difficult to achieve in high strength soils, or in soils where roots and stumps hinder progress of the blade through the soil. The aim of the study reported in this paper was to better define cultivation growth relationships for *Pinus caribaea* var. *hondurensis* plantations in order to determine if site preparation objectives could be achieved with a reduced cultivation effort.

A highly significant 'soil type x cultivation' interaction was observed. In contrast to the growth responses observed on hardsetting soils, cultivation did not improve growth on non-hardsetting soils. There is an opportunity therefore to reduce reforestation site preparation costs by only cultivating soils that show a growth response.

The cultivation response on hardsetting soils has increased throughout the study period, and is attributed to a reduction in soil penetration resistance. The response however shows diminishing gains with increasing cultivation widths. Blade cultivation widths of 1.2 m were found to capture 97% of the gains that could be expected from widths of 2.0 m.

A significant 'family x soil penetration resistance' interaction was observed. An opportunity to increase plantation productivity by targeting better performing families to hardsetting soils is suggested.

Introduction

The Queensland Department of Primary Industries Forest Service (QDPI-FS) has established 110 000 ha of *Pinus* plantations on the coastal lowlands of south-eastern Queensland. The resource is managed on a sustained yield basis, with some 1600 ha of plantations presently being fallen and re-established annually (QDPI-FS 1992), an area which will increase to 3000 ha by the year 2005. Re-establishment of the *Pinus* crop is achieved using site-based land preparation systems (Foster and Costantini 1991*a*). These systems are founded upon knowledge of both site suitability and the *Pinus* crop growth requirements.

Site suitability is defined as the capability of a specific area to provide the conditions desired for *Pinus* growth while not compromising erosion mitigation, catchment protection and economic objectives. In the coastal lowlands of south-eastern Queensland, soil hydraulic and drainage characteristics are major determinants of site suitability. Accordingly, an evaluation system has been developed to distinguish sites that either require or do not require drainage for successful *Pinus* establishment (Foster and Costantini 1991*a*). Sites with well-drained deeper soils that do not require drainage or mounding are defined as suitability class 'A'.

Knowledge of the growth requirements of *Pinus caribaea* Mor. var. *hondurensis* Barr. *et* Golf. are summarized by Foster and Costantini (1991*b*) and are based upon a preliminary review of research and development trials conducted by Costantini and Foster (1987). Francis (1984) demonstrated that *Pinus* growth on suitability class 'A' sites was significantly improved by overall disc cultivation to 20 cm depth. Costantini and Foster (1987) reported that blade (subsurface, wing rip) cultivation of 2.0 m strips along the planting rows was as effective as overall disc cultivation in achieving the soil condition desired for *Pinus* growth. Because of their superior soil conservation qualities, strip cultivation systems and blade cultivation techniques were incorporated into the site preparation systems defined by Foster and Costantini (1991*b*) for *Pinus* establishment on suitability class 'A' soils.

Blade cultivation with a 2.0 m wing ripper, however, has a high drawbar power requirement, and is operationally difficult where stumps and roots hinder

Table 1. The effect of cultivation on profile bulk densities (g/cm^3)

Depth (cm)	Pre-site preparation				Post-site preparation			
	Blocks 1–3		Block 4		Blocks 1–3		Block 4	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
10	1.25	0.10	1.42	0.11	0.97	0.16	0.95	0.21
20	1.33	0.09	1.49	0.08	0.88	0.21	1.18	0.10

progress of the blade through the soil. Narrower rippers have proportionally lower drawbar power requirements (Koolen and Kuipers 1983) and are better able to avoid these operational problems. It is therefore desirable to better define cultivation growth relationships for *P. caribaea* var. *hondurensis* in order to determine if site preparation objectives can be achieved using a reduced cultivation effort.

Many surface soils in Australia's summer rainfall-dominated tropical and subtropical zones exhibit hardsetting characteristics upon drying (Northcote 1979). McDonald *et al.* (1990) define hardsetting as the 'compact, hard apparently apedal condition (which) forms on drying but softens on wetting'. Soils with a hardsetting surface condition do not necessarily develop a surface crust. When dry, however, hardsetting soils 'can not be disturbed or indented by pressure of (the) forefinger' (McDonald *et al.* 1990). Both hardsetting and non-hardsetting suitability class 'A' soils occur throughout the *Pinus* estate. Non-hardsetting soils in the coastal lowlands are typically single grained or pedal when dry. The study reported in this paper was designed to investigate cultivation growth relationships for *P. caribaea* var. *hondurensis* on both hardsetting and non-hardsetting suitability class 'A' soils.

Given the increased importance of genetics in professional plantation management (Zobel 1992), 3 different families (crossings of known parents with offspring further propagated as cuttings) were used in this study in order to identify any 'family X soil type' or 'family X cultivation width' interaction.

Materials and methods

Site and experimental design

The split-plot factorial experiment was conducted in the Toolara (152°50'E, 26°00'S) *Pinus* plantation estate. Whole units within the factorial experiment comprised the cultivation width factor at 6 levels (0.2, 0.5, 1.0, 1.5, 2.0, and 2.4 m) in 4 blocks of a randomised complete block design. Subunits comprised the family factor at 3 levels (families 1–3) in 2 replications of a completely randomised design. Each whole unit comprised plots of 8 by 10 trees, with the outer 2 rows of trees being used as a buffer between adjacent plots. Two replications of each family were randomly allocated to 6 rows in each whole plot. Cultivation rows were spaced 4.5 m apart and cuttings were planted at 2.1-m intervals along the rows. The 3 families used in the study were genetically superior crossings from the QDPI-FS 1988 Cuttings Propagation Program. Blocks 1–3 were located on the hardsetting red dermosol soil (after Isbell 1993) described by Costantini *et al.* (1995), with block 3 occupying a lower landscape position than blocks 1 and 2. Block 4 was located on the non-hardsetting brown sodosol soil described in Costantini *et al.* (1995). The history of the sites is also described in Costantini *et al.* (1995).

Cultivation and planting

Hand tools were used to transplant seedlings and to simultaneously achieve the 0.2 m cultivation width. The 0.2 m treatment was therefore a spot cultivation. All other treatments involved mechanical cultivation along planting rows. Tractor-drawn blade rippers were fabricated for the 0.5, 1.0, 1.5, 2.0 and 2.4 m treatments, and a single pass of the tractor was used to achieve an average cultivation depth of 20 cm for each. Blade cultivation reduced bulk density (Table 1) by lifting and aerating the soil without inversion or mixing.

Pinus stock planted in the study were raised using the cuttings propagation technology available in 1988 (Haines and Walker 1993). Cuttings were planted in 1988 and weed control was used during the first 18 months of experimentation to control competition (Table 2). All sites were fenced to exclude grazing by cattle.

Measurements

Tree height and diameter measurements were made at the time of planting and annually for the first 5 years of growth. Diameter measurements were taken at ground level (DGL) for the first 4 years and at breast height (DBH) for the fifth year.

Soil moisture assessments were made on 5 different occasions during experimentation in order to determine if cultivation affected soil moisture distribution. So that a range of soil moisture conditions could be tested, samples were taken after 2, 3, 9, 12 and 24 days of dry weather following a significant rainfall event (>35 mm rain). At each time, 9 samples were collected at 10 and 20 cm depths from both the cultivated and the uncultivated zones of the 2.0-m cultivation-width treatments in blocks 2 and 4.

Table 2. Timing and sequence of management operations during experimentation

Management operation	Timing
Cultivation width treatments	March 1988
Pre-plant weed control	March 1988
Hand planting of cuttings of all families	March 1988
Residual herbicide application	April 1988
Individual tree fertiliser application	April 1988
Post-plant weed control	July and November 1988, February 1989

Two trees from each cultivation-width treatment in blocks 2 and 4 were excavated at age 2 years in order to assess lateral root development. Trees were selected from plot buffer areas on the basis that their heights approximated average plot height. All harvested seedlings were from a single family, but not one included in the study. The position and extension of major lateral roots were sketched in plan view. Based on the centre of the stem, quadrants were defined so that the first quadrant was in the direction of cultivation.

Table 3. Details of the functional relationships between growth and cultivation width on the hardsetting soils

Regression values followed by the same letter are not signficantly different between families for each growth parameter
s.e.e., standard error of the estimate; CD, coefficient of determination

Year and Family	Regression constant	Regression coefficient	Signif.	s.e.e.	CD (%)
		Height (m)			
Year 1					
1	1.07a	–0.025	n.s.	0.083	—
2	0.89b	–0.031	n.s.	0.111	—
3	1.20c	–0.055	**	0.101	46.3
Year 2					
1	2.53a	–0.093	**	0.172	45.7
2	2.30a	–0.100	*	0.258	29.0
3	2.61b	–0.150	***	0.168	70.1
Year 3					
1	4.59a	–0.159	***	0.263	51.6
2	4.28b	–0.140	*	0.348	32.1
3	4.43b	–0.200	***	0.263	63.0
Year 4					
1	6.23a	–0.189	**	0.336	48.0
2	5.97b	–0.200	**	0.447	36.9
3	5.87b	–0.215	***	0.340	53.8
Year 5					
1	8.27a	–0.202	**	0.348	49.6
2	8.06b	–0.228	**	0.455	42.2
3	7.72a	–0.247	***	0.365	57.1
		Diameter of breast height (cm)			
Year 1					
1	2.9a	–0.088	*	0.273	23.4
2	2.6a	–0.160	*	0.417	30.1
3	3.3b	–0.181	***	0.306	50.4
Year 2					
1	6.6a	–0.206	**	0.434	39.6
2	6.0b	–0.245	*	0.618	31.4
3	7.2c	–0.333	***	0.473	59.0
Year 3					
1	10.5a	–0.267	**	0.589	37.6
2	9.7b	–0.209	n.s.	0.732	—
3	11.3c	–0.383	***	0.562	57.6
Year 4					
1	13.7a	–0.329	**	0.731	37.1
2	13.3b	–0.344	**	0.790	35.6
3	15.1a	–0.474	**	0.809	50.1
Year 5					
1	12.6a	–0.287	***	0.484	50.7
2	12.6b	–0.334	**	0.750	36.7
3	13.5a	–0.349	**	0.647	46.0

* $P<0.05$; ** $P<0.01$; *** $P<0.001$; n.s., not significant.

Statistical analysis

The analysis of variance technique described by Steel and Torrie (1981) for a split-plot design was used to investigate survival. Data were subjected to an arcsine square root transformation before analysis in order to satisfy the assumptions of homoscedasticity. Significant differences were separated with a protected least significant difference (l.s.d.) test.

Plots of raw data and an initial analysis of variance test for a 'cultivation x soil type' interaction suggested that the relationships between growth and cultivation width differed between blocks 1–3 (hardsetting soils) and block 4 (non-hardsetting soils). The 2 soil types were therefore analysed separately. Strong growth relationships observed on the hardsetting soils were investigated using multiple regression techniques. For all families and all growth parameters, the relationship:

$$\text{Growth} = a + b/\text{cultivation width}$$

where a and b are the regression constants and coefficients respectively, provided an excellent fit to the data. Linear regression was used to define the nature of the growth relationships. Confidence limits for the mean for each relationship were calculated using the formula presented in Steel and Torrie (1981). Significant differences in the regression constants and coefficients of the growth relationships for the 3 families were separated using the methods detailed in Brownlee (1965).

Results

Tree survival and growth

Block differences for both first and fifth year survival were significant ($P<0.05$). Survival in the fifth year was significantly greater in block 3 (87%) than in the remaining blocks (72–75%). There were no significant cultivation-width effects on survival.

There was a highly significant ($P<0.001$) 'cultivation x soil type' interaction. Strong and persistent

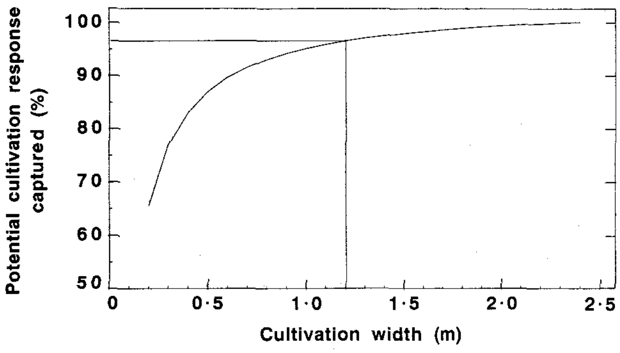

Figure 1. Predicted percentage of the potential 2.4-m cultivation-width response captured by various cultivation widths on the hardsetting soils (blocks 1–3).

Table 4. Soil moisture distributions (%, mean ± s.d.) at different times following rainfall in the 2.0-m cultivation-width treatments

Days since significant rainfall	Cultivated zone 10 cm depth	Cultivated zone 20 cm depth	Non-cultivated zone 10 cm depth	Non-cultivated zone 20 cm depth
		Block 2		
2	28.5 ± 2.5	24.6 ± 0.9	28.2 ± 3.3	25.1 ± 3.5
3	28.6 ± 1.7	23.9 ± 1.7	26.9 ± 4.4	22.5 ± 1.7
9	22.7 ± 1.2	22.4 ± 2.5	24.5 ± 2.1	23.2 ± 1.6
12	19.1 ± 1.9	16.6 ± 2.3	21.0 ± 2.4	17.6 ± 2.1
24	14.3 ± 4.2	14.6 ± 2.0	14.8 ± 1.9	14.1 ± 2.5
		Block 4		
2	22.4 ± 4.6	18.2 ± 2.5	21.2 ± 3.3	17.1 ± 2.7
3	19.3 ± 3.3	16.5 ± 3.1	18.1 ± 3.7	15.5 ± 2.9
9	12.9 ± 3.3	13.7 ± 2.1	15.2 ± 3.0	15.7 ± 2.7
12	12.1 ± 2.5	10.2 ± 2.6	13.4 ± 4.4	11.1 ± 3.6
24	9.5 ± 1.7	8.1 ± 2.1	9.7 ± 2.1	6.9 ± 1.4

relationships were found between growth and cultivation width on the hardsetting soils, but not on the non-hardsetting soils. With the exception of the first year, height growth for families 1 and 2, and the 3rd year DGL growth for family 2, all growth relationships on the hardsetting soils were significant (Table 3). For example, increasing cultivation width from 0.2 to 1.2 m, resulted in an average 14% (0.95 m) and 12% (1.35 cm) increase in fifth year height and DBH respectively.

The relationships between both height and diameter growth and cultivation width on hardsetting soils (Table 3) show a diminishing response to increasing cultivation width, with the greatest responses observed for small increases in cultivation width beyond 0.2 m. There was no family x cultivation width interaction, and as a result, an index of year 5 volume (height x DBH^2) for all families combined was used to assess the growth gains from increasing cultivation widths (Fig. 1). Cultivation widths of 1.2 m capture 97% of the growth gains that are potentially achievable by cultivating to 2.4 m.

The growth response to cultivation beyond 0.2 m on hardsetting soils is persistent and increasing with time. The regression coefficients for both height and diameter become increasingly negative with time (Table 3), indicating that the slopes of the growth relationships are increasing from year 1–5.

There was a highly significant family x soil type interaction. No significant ($P>0.05$) persistent relationships between growth and cultivation width were found for any family on the non-hardsetting soils. In contrast there were highly significant ($P<0.001$) family differences in both height and diameter growth on the hardsetting soils (Table 3). For each parameter assessed, there were significant family differences in the regression constants, often with all family comparisons being significant (Table 3). No significant family differences in the regression coefficients were observed. The average height and DBH differences between the poorest and best performing families for the mean cultivation width of 1.3 m at age 5 years were respectively 60 (8%) and 1.0 cm (8%). Relative growth performances for the 3 families were not consistent for height or diameter. At age 5 years, family 2 height growth was significantly higher than the other 2 families, whilst family 2 diameter growth was significantly lower than the other 2 families (Table 3).

Soil moisture

There were no significant ($P>0.05$) soil moisture differences between the cultivated and non-cultivated zones in either blocks 2 or 4 (Table 4). Moisture contents were significantly higher in block 2 than in block 4 on each of the 5 measurement occasions.

Root development

At a distance of 30 cm from the centre of the stem, all harvested trees had at least 1 major lateral root in each quadrant. For the 2 trees harvested from the 0.5 m cultivation width treatment on the hardsetting soils, root penetration of the non-cultivated soil in the 2 quadrants perpendicular to the cultivation direction was limited. As a consequence, primary root development was strongly concentrated along the cultivation rows.

Discussion

Dry conditions during the spring of 1988 and during 1990 and 1991 caused limited mortality of cuttings. Survival was, however, unrelated to cultivation in all blocks.

High soil penetration resistance has been found to restrict root growth in *P. radiata* (Sands *et al.* 1979), *P. taeda* (Foil and Ralston 1967; Hatchell 1970), *P. contorta* and *P. ponderosa* (Clayton *et al.* undated), and *P. caribaea* var. *hondurensis* (QDPI-FS unpublished data), and root morphology (see Balneaves and De La Mare 1989). Cultivation of soils with penetration resistance characteristics that are limiting to root growth can therefore be expected to improve *Pinus* height and diameter growth. Mitchell *et al.* (1982) reported improved *Pinus* growth following cultivation of mechanically compacted soils. Francis (1984) reported improved *P. caribaea* var. *hondurensis* growth on previously uncultivated soils in the coastal lowlands of south-eastern Queensland.

Costantini *et al.* (1995) demonstrated that cultivation of the hardsetting soil type in this study resulted in a significant and persistent reduction in bulk density over a 28-month observation period. It is postulated that the observed cultivation growth responses on hardsetting soils were attributable to a reduction in bulk density (via its impact on soil penetration resistance and possibly aeration). Competition and soil moisture effects were not important in explaining the cultivation responses because: (i) weed control operations ensured that there were no competition differences between cultivation width treatments; and (ii) over a range of soil moisture conditions, cultivation to 2.0 m width did not affect soil moisture distribution between cultivated and uncultivated zones in either blocks 2 or 4.

An economic evaluation of the optimum cultivation width for hardsetting soils was not attempted. Because soil mechanical resistance to cultivation implements and hence drawbar power requirements are dependent upon soil moisture (Koolen and Kuipers 1983), the cost function in an evaluation would be dependent upon moisture conditions at the time of cultivation. What can be noted from Figure 1, however, is that slightly more than 97% of the potential fifth year growth response from cultivation to 2.4 m is achieved by cultivation to 1.2 m. Blade ploughs with a span of 1.2 m can be purchased commercially, manoeuvred easily to avoid stumps, and drawn by a wheeled tractor.

Results of this study suggest that the cultivation width requirements on hardsetting class 'A' soils in the coastal lowlands of south-eastern Queensland could be downgraded from 2.0 to 1.2 m with minimal loss of *P. caribaea* var. *hondurensis* growth. Further research into the orientation and development of lateral roots would be required if cultivation widths less than 1.0 m were contemplated. The limited colonisation of the uncultivated hardsetting soil in the 0.5 m cultivation width treatment, and the concentration of roots along the cultivated strip, suggest that slow growth and poor windfirmness may be problems, at least when the plantation is at a young age.

The finding that cultivation beyond 0.2 m has not improved *P. caribaea* var. *hondurensis* growth on non-hardsetting soils is based on evidence from 1 block. There is a need to test this finding more rigorously in time and space. However, for the following reasons, it is likely that the finding is robust: (i) the lack of a growth response has been consistent for all 3 families tested; and (ii) Costantini *et al.* (1995) demonstrated that unless organic matter was incorporated into the soil profile, the cultivated non-hardsetting soil type in this study had substantially consolidated within 4 months. The rapid consolidation characteristics of the non-hardsetting soils can be expected to limit expression of any benefits to crop productivity resulting from decreased bulk density.

The processes underlying the cultivation growth responses on suitability class 'A' soils needs to be further investigated. An understanding of the nature of the 'cultivation x soil type' interaction on the coastal lowlands of south-eastern Queensland can be used to improve site preparation efficiency. If cultivation other than disturbance of 0.2 m at planting is not required on non-hardsetting soils, then site preparation costs can be reduced by excluding mechanical cultivation. In order to target cultivation operations to soil types which support positive *Pinus* growth responses, forest managers will require a field-based soil classification system which distinguishes class A soil types that support a cultivation growth response and those that do not.

For the reasons discussed, the observed family x soil type interaction is likely to represent a family x bulk density (soil penetration resistance) interaction. The results suggest that families do differ in their tolerance of high strength soils, and that plantation productivity may be improved by targeting tolerant *P. caribaea* var. *hondurensis* families to high strength, hardsetting soils.

Conclusions

The site preparation standards presently prescribed for reforestation of well-drained soils in the coastal lowlands of south-eastern Queensland (blade cultivation to 2.0 m width and 0.2 m depth) can be reduced without compromising *P. caribaea* var. *hondurensis* growth. On hardsetting soils, 1.2 m wide cultivation strips captured 97% of the growth gains that are potentially achievable from total site cultivation. The cultivation responses on these soils have persisted and increased over the 5-year measurement period. In contrast, on non-hardsetting soils, cultivation beyond the 0.2 m width required for planting did not improve growth. Plantation establishment costs can therefore be reduced by restricting cultivation to soil types that support an economic cultivation growth response. Further research on soil processes is needed in order to distinguish these soils.

The discovery of a family x soil penetration resistance interaction suggests that plantation productivity can be improved by selecting families for suitability to soils with high penetration resistance characteristics. Research is needed to identify these families and to help target them to appropriate suitability class A soils.

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