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Site preparation for *Pinus* establishment in south-eastern Queensland
1. Temporal changes in bulk density

A. Costantini, M. R. Nester and M. Podberscek

Queensland Forest Research Institute, Mail Service 483, Gympie, Qld 4570, Australia.

Summary. In south-eastern Queensland, Australia, standard site preparation practices used for *Pinus* plantation establishment are mounding (bedding) on poorly drained soils and blade cultivation (subsurface, wing rip) on well-drained soils. This paper reports the impacts of both site preparation treatments on soil bulk density over time.

Following site preparation, the extent of bulk density reduction and the nature of bulk density consolidation was affected by soil type, soil depth and the site preparation technique used. On high strength, hardsetting soils, bulk density reductions from both mounding and blade cultivation persisted throughout the 28-month period, and contrasted with non-hardsetting soils in the plantation estate, which consolidated more rapidly and had higher bulk densities relative to precultivation levels for the period 4–28 months following site preparation.

The studies reported in this paper were the first in south-eastern Queensland to investigate the impact of site preparation for *Pinus* establishment on the nature and longevity of bulk density reductions. Previously, plantation managers assumed that positive site preparation impacts would be relatively short-lived, and therefore developed a prudential policy of planting *Pinus* seedlings immediately following site preparation. For the soils studied, delays of 2–4 months, and perhaps up to 6 months, between site preparation and planting would not compromise *Pinus* growth, but would assist management planning.

Introduction

The Queensland Department of Primary Industries Forest Service manages 110 000 ha of *Pinus* plantations on the coastal lowlands of south-eastern Queensland, Australia. Taxa used in the plantation estate include *Pinus caribaea* Mor. var. *hondurensis* Barr. *et* Golf., *Pinus elliottii* Engelm. var. *elliottii*, and a hybrid between the 2 species. The physical characteristics of the soil which most influence growth and survival of the *Pinus* plantations are largely controlled by topographic and ground water characteristics (Pegg 1967; Foster and Costantini 1991*a*). Accordingly, the silviculture of plantation establishment on the coastal lowlands is site based (Foster and Costantini 1991*b*). Knowledge of both site suitability and *Pinus* growth requirements are used to prescribe site preparation treatments.

Foster and Costantini (1991*a*) have developed a site evaluation system which distinguishes soils requiring mounding (bedding) for successful *Pinus* establishment (suitability class 'B') from those that do not (suitability class 'A'). On suitability class 'A' soils, blade (subsurface, wing rip) cultivation to 20 cm depth is recommended for optimal *Pinus* growth (Francis 1984*a*).

Many surface soils in Australia's summer rainfall-dominated tropical and subtropical zones, which include the coastal lowlands of south-eastern Queensland, exhibit hardsetting characteristics upon drying (Northcote 1979). McDonald *et al.* (1990) defined hardsetting as the 'compact, hard apparently apedal condition (which) forms on drying but softens on wetting'. The hardsetting condition refers to the A horizon, and is not necessarily associated with a surface crust. When dry, hardsetting soils 'can not be disturbed or indented by pressure of (the) forefinger' (McDonald *et al.* 1990). Non-hardsetting soils in the *Pinus* estate are typically single grained (sands) or pedal when dry.

Growth responses resulting from cultivation and mounding have been attributed to: (i) decreased penetration resistance (Sands and Bowen 1978; Greacen and Sands 1980); (ii) improved aeration and infiltration (Greacen and Sands 1980); (iii) a reduction in weed competition (Lewty and Francis 1982; Francis 1984*a*); (iv) increased nutrient mineralization (Attiwill *et al.* 1985); and (v) elevation of micro site (Costantini and Foster 1987). Improvements in the soil physical environment (penetration resistance, aeration, and infiltration) result partly from reductions in bulk density.

Consequently, bulk density is a commonly assessed characteristic in soil management studies (Onstad *et al.* 1984).

The nature and longevity of site preparation impacts on soil bulk density in the coastal lowlands have never been studied. Based on the assumption that site preparation impacts would be relatively short-lived (see Francis 1984*b*), plantation managers developed a prudential policy of planting *Pinus* seedlings immediately following site preparation. This perceived need to schedule site preparation, weed management and planting operations over a short (May–July) planting period regularly resulted in resource (labour and machinery) allocation difficulties. Poor weather and large planting programs exacerbated these difficulties. Furthermore, the policy of planting immediately following site preparation was inconsistent with the optimal weed management systems described by Costantini and Podberscek (1987) for much of the plantation estate. Knowledge of soil consolidation characteristics following site preparation was needed to improve the planning and management of plantation establishment. Therefore the studies reported in this paper were designed to quantify the impacts of both mounding and blade cultivation on bulk density over time. The studies were replicated on both hardsetting and non-hardsetting soils.

Materials and methods

Mound study

The studies were conducted in the Toolara (152°50'E, 26°00'S) *Pinus* plantation estate on red dermosol and brown sodosol soil types (Tables 1 and 2). Coaldrake (1961) has described the geology, climate, vegetation and soils of the area. The A horizons of the red dermosol and brown sodosol soil types were classified as hardsetting and non-hardsetting, respectively. Organic carbon contents of 6 bulked samples from the surface 0–5 cm for each soil type were 2.8 and 1.2% respectively. Both soil types carried improved pastures (predominantly, *Setaria sphacelata* var. *sericea* and *Trifolium repens*) and were grazed by cattle before experimentation.

Mounds were formed in December 1987 using 2 passes of an 8-disc Shearer Majestic plough. During the first pass of a disc mounder, the soil is cultivated to a depth of about 20 cm and displaced in 1 direction. The second pass cultivates the soil to a depth of about 30 cm below the original soil level in the middle of the mound, and displaces soil in the opposite direction to form the mound. Soil displaced during the second pass is inverted, with the result that surface organic material is incorporated into the mound at a depth of about 15–30 cm.

Table 1. Classification and physical characteristics of soils used in the mound and blade cultivation studies

CL, clay loam; L, loam; SL, sandy loam; LS, loamy sand; SC, sandy clay; LC, light clay; LMC, light medium clay; SCL, sandy clay loam; SCLFS, sandy clay loam fine sandy

Surface condition	Soil type		Soil description			
	Isbell (1993)	Northcote (1979)	Horizon	Depth (cm)	Texture	Structure^A
		Mound				
Hardsetting	Red dermosol	Gn 3.54	A1	0–20	CL	Strong
			A2	20–45	L	Strong
			B21	45–60	CL	Weak
			B22	60–100	CL	Strong
Non-hardsetting	Brown sodosol	Dy 5.41	A1	0–20	SL	Massive
			A2	20–40	LS	Massive
			B2	40–80	SC	Strong
			C	80–100	SC	Strong
		Blade cultivation				
Hardsetting	Red dermosol	Gn 311	A1	0–20	CL	Strong
			B1	20–40	LC	Strong
			B21	40–80	LMC	Massive
			B22	80–110	LMC	Strong
			B23	110–150	LMC	Moderate
Non-hardsetting	Red kandasol	Um 4.41	A1	0–20	SCL	Massive
			A2	20–30	SCL	Massive
			B2	30–85	SCLFS	Weak
			B22	85–100	SCLF	Moderate

^A Moist soil condition (McDonald *et al.* 1990).

Table 2. Particle size characteristics of soils studied

Values are means (± s.d.) of 48 samples for the mounded sites and 42 samples for the blade cultivation sites

Surface condition and depth (cm)	Particle size characteristics Sand (%)	Silt (%)	Clay (%)
	Mound		
Hardsetting			
10	44 ± 7.4	34 ± 6.3	22 ± 7.1
20	38 ± 6.8	32 ± 7.1	30 ± 7.1
30	36 ± 5.0	29 ± 3.7	35 ± 6.4
Non-hardsetting			
10	73 ± 3.3	17 ± 3.4	10 ± 2.0
20	70 ± 8.7	17 ± 2.7	13 ± 2.3
30	70 ± 9.0	17 ± 2.6	13 ± 2.9
	Blade cultivation		
Hardsetting			
10	41 ± 6.9	37 ± 4.4	22 ± 6.1
20	37 ± 5.6	33 ± 3.9	30 ± 4.6
Non-hardsetting			
10	55 ± 11.4	30 ± 8.7	15 ± 3.8
20	53v11.7	28 ± 7.7	19 ± 4.9

Mounds were engineered with a fall of 1.5 ± 0.5% according to Foster and Costantini (1991*b*). As a result, the mounded area had 2 distinct slope (and hence moisture) gradients: (i) across the mounds, and (ii) along the mounds (see Foster and Costantini 1991*c*). A Latin square design, which allows removal of any variation associated with the 2 gradients (Steel and Torrie 1981), was used in experimentation. Four replications of a 5 treatment (bulk density 0.5, 4, 9, 13 and 28 months following mounding) Latin square were established on each soil type. The mounds used in the study were spaced at 4.5 m, and measurement sites were located at 3.0 m intervals along the mounds.

After mounding, the areas were fenced to exclude grazing by cattle and entry of mechanical equipment. Weeds along the mound were controlled with manually applied glyphosate (2 kg/ha) and simazine (5 kg/ha) in September of 1988 and 1989. Rainfall recorded at the Toolara Forest Station, some 5 km from the study site, was 320, 930, 250 and 2150 mm for the 0.5–4, 4–9, 9–13 and 13–28-month periods respectively. No rainfall was recorded for the period between mounding and the first measurement.

At 0.5 and 28 months, a profile meter was used to determine mound cross-sectional morphology. The same positions were assessed on both occasions. Benchmark locations were defined using reference pegs in the inter-mound area.

Samples for bulk density determination were collected using a 6 cm internal diameter small core sampler after Costantini (1995). At each measurement location, a vertical soil profile wall was carefully prepared with a shovel blade, the centre of the sampler was aligned at the desired measurement depth, and the sampler was driven horizontally into the soil profile. Bulk density (g/cm^3) was calculated by dividing the oven dry (105°C for 48 h) mass of the soil core by its volume.

Prior to mounding, 12 bulk density samples were collected from each Latin square plot at depths of 10, 20 and 30 cm. Since there was a weak relationship between bulk density and soil moisture content on the red dermosol soil, post-mounding assessments were only made when the surface 0–10 cm of the soil profile had a moisture content between 15 and 20%. Bulk density was assessed 2 weeks after mounding at the 6 positions shown in Figure 1. Only positions A and B (Fig. 1) were assessed at the subsequent measurements. These positions were defined with respect to the top of the mound.

A 1-way analysis of variance was used to test for differences between the 0.5 month post-mounding bulk densities at positions A–F (Fig. 1) in the mound profile. Significant differences were separated with a protected least significant difference (l.s.d) test.

Plots of raw data indicated strong relationships between bulk density and time since mounding. However a preliminary analysis of variance for a Latin square design (after Steel and Torrie 1981) revealed no significant row or column effects. Therefore, multiple regression techniques ignoring row and column effects were used to investigate possible relationships between bulk density and time since mounding. Linear regression was used to define relationships that best fitted the data. Confidence limits for the mean of each relationship were calculated according to Steel and Torrie (1981).

Blade cultivation study

The study was conducted on red dermosol and red kandasol soil types in the Toolara *Pinus* plantation estate (Tables 1 and 2), which had hardsetting and non-

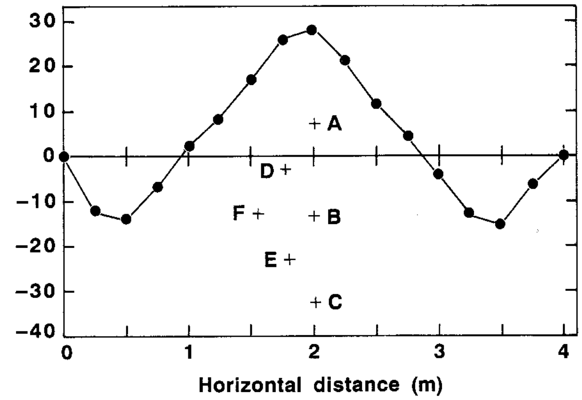

Figure 1. A typical mound cross-section showing the locations (A–F) where bulk density was assessed.

hardsetting A horizons respectively. Organic carbon contents of 6 bulked samples from the surface 0–5 cm for each soil type averaged 1.6 and 1.4% respectively. Both sites carried improved pastures and were grazed by cattle before experimentation.

Blade cultivation strips were formed in March 1988 with a single pass of a bulldozer-drawn 1.5 m wide, wing ripper set to 20 cm depth. Strips were established along contours with 4.5 m between strip centres. Soil in the strip lines was lifted and replaced without inversion or mixing. As a result, the natural slope gradients at the study sites were not disturbed, and a randomised complete block design was selected for experimentation. Three blocks with 3 replications of 5 bulk density assessment times (0.5, 3, 8, 16 and 24 months) following blade cultivation were established on each soil type.

Measurement positions for precultivation bulk density determination were located in the middle of the non-cultivated, non-trafficked inter-row. For post-cultivation bulk density determinations, measurement positions were located 30 cm off the centre line of cultivation strips.

Pinus caribaea var. *hondurensis* cuttings were hand-planted immediately following cultivation. The areas were fenced to exclude grazing by cattle and entry of mechanical equipment. Weeds in a 1.5 m wide strip along the planting line were controlled with manually applied glyphosate and simazine herbicides in April, July and November 1988, and in February 1989. Rainfalls of 290, 460, 1460 and 750 mm were recorded during the 0.5–3, 3–8, 8–16 and 16–24-month measurement periods respectively. No rainfall was recorded for the period between cultivation and the first measurement.

Plots of raw data indicated strong relationships between bulk density and time since blade cultivation. A preliminary analysis of variance for a randomised complete block design revealed no significant block effects. Therefore, multiple regression techniques ignoring block effects were used to investigate the nature of relationships between bulk density and time since blade cultivation. Linear regression was used to define relationships that best fitted the data. Confidence limits for the mean of each relationship were calculated according to Steel and Torrie (1981).

Results

Mound study

On the red dermosol and brown sodosol soils, the mounding operation produced mounds with average heights above the furrow base of 0.51 and 0.45 m respectively, and average cross-sectional areas above the furrow bases of 0.73 and 0.79 m^2 respectively. In both soil types, mounding concentrated surface organic matter into the mound profile, most conspicuously at positions A and D in Figure 1. Two weeks after mounding, the mound profiles between furrows in the red dermosol soils were peaked (Fig. 2*a*), whereas the mound profiles in the brown sodosol soils were paraboloid (Fig. 2*b*).

Changes in the morphology of the mound profile during the 0.5–28-month period also differed between the 2 soil types (Fig. 2*a*, *b*). In the red dermosol soils, both furrows were typically shallower after 28 months. Average mound heights above the furrow base and average mound cross-sectional areas decreased to 0.41 m and 0.57 m^2 respectively. In cross-section, the mounds became more paraboloid (Fig. 2*a*). In contrast, in the brown sodosol soils, 1 furrow typically scoured and the other became shallower. Surface micro-relief changes were greater on the side of the mound which experienced the scouring in the furrow. Average mound heights above the furrow and average mound cross-sectional areas decreased to 0.40 m and 0.66 m^2 respectively (Fig. 2*b*).

Because mounding alters surface micro-relief, pre- and post-mounding soil depths do not refer to the same position. Statistical comparisons have therefore not been attempted. The 0.5 month post-mounding bulk densities are, however, substantially less than the premounding bulk densities, particularly for the shallower positions, A and D (Tables 3 and 4). On both soil types, cultivation at the centre of the mound did not uniformly extend to the depth depicted by position C in Figure 1. Position C is about 30 cm below the original ground level, and approximates the limits of disc penetration during

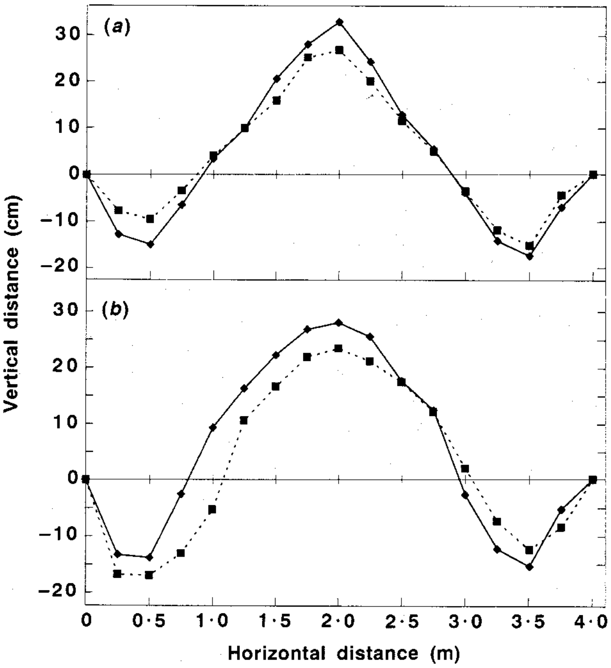

Figure 2. Mound cross-sectional morphology of (*a*) red dermosol and (*b*) brown sodosol soils, 0.5 (◆) and 28 (■) months after mounding (mean of 25 profiles).

Table 3. Initial mean (± s.d.) bulk densities (g/cm^3) in the mound study on two soil types

Soil depth (cm)	Red dermosol	Brown sodosol
10	1.34 ± 0.09	1.60 ± 0.06
20	1.42 ± 0.09	1.63 ± 0.06
30	1.42 ± 0.11	1.64 ± 0.06

Table 4. Profile bulk densities (g/cm^3) 0.5 months after mounding on two soil types

Profile positions are illustrated in Figure 1

Profile position	Red dermosol	Brown sodosol
A	0.87	1.04
B	1.19	1.51
C	1.29	1.60
D	1.01	1.38
E	1.24	1.51
F	1.16	1.51
l.s.d. ($P = 0.05$)	0.09	0.10

mounding. The total depth of cultivated soil at the mound centre in both soil types is about 60 cm.

In the hardsetting red dermosol soils, the relationship between bulk density (BD, g/cm^3) and time since mounding (T, months) was described as:

$$BD = a + bT \qquad (1)$$

(Fig. 3*a*) where a and b are the regression coefficients. For the brown sodosol soils, the data are best fitted by:

$$BD = a - b/\sqrt{T} \qquad (2)$$

(Fig. 3*b*). Bulk density consolidation rates for the period 0.5–4 months following mounding were greater in the brown sodosol soils. The relationship between bulk density and time since mounding for these soils at 20 cm depth (relative to the top of the mound) was asymptotic to 1.37 g/cm^3 (Fig. 3*b*), or 86% of the premounding bulk density at 10 cm depth (relative to the soil surface prior to mounding). At the 40 cm depth in the brown sodosol soils, bulk densities approached premounding levels after 4 months. For the period 4–28 months following mounding, bulk density reductions relative to the premounding condition, were greatest in the hardsetting red dermosol soils. After 28 months, bulk density at 20 cm depth in these soils was 78% of the premounding bulk density at 10 cm depth.

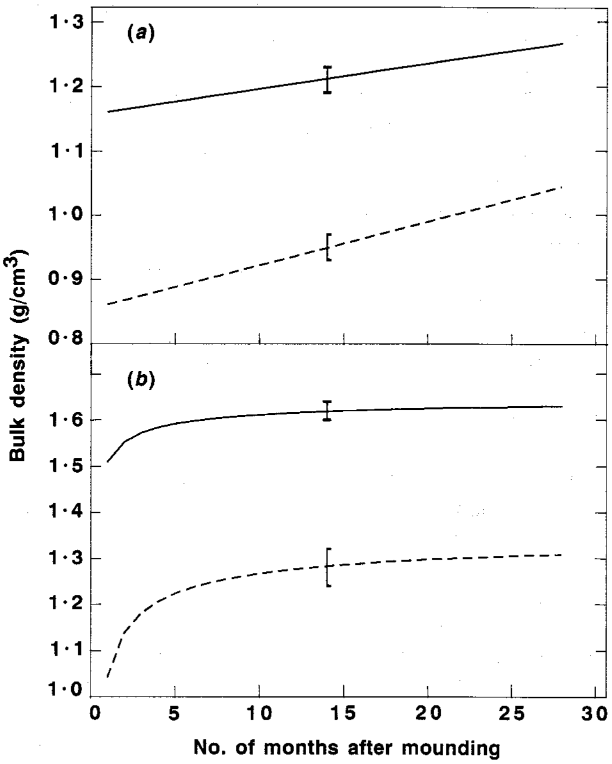

Figure 3. Predicted bulk density consolidation for mounds on two soil types, (*a*) red dermosol and (*b*) brown sodosol, at 20 (- - -) and 40 cm (——) below the top of the mound. Vertical bars indicate the 95% confidence limits for the mean time since cultivation.

Blade cultivation study

In the hardsetting red dermosol soils, large fractures were formed immediately above the depth of blade penetration. Bulk density reductions (Table 5) and initial (0.5–3 months) rates of consolidation (Fig. 4*a*) were greater at 20 cm depth than 10 cm depth. Blade ploughing tended to produce large clods, and as a result bulk density standard deviations were greater in the post-cultivation profiles. The 24-month mean bulk densities at 10 cm and 20 cm depths were 84 and 86% of the original bulk densities respectively.

Table 5. The effect of blade cultivation on mean (± s.d.) profile bulk densities (g/cm^3) in two soil types

Soil depth	Pre-blade cultivation		Two weeks post-blade cultivation	
(cm)	Red dermosol	Red kandasol	Red dermosol	Red kandasol
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

In contrast, in the non-hardsetting red kandasol soils blade cultivation achieved a high degree of solum shattering. Soil passing over the blade crumbled as it fell back into the furrow. The process resulted in some incorporation of surface organic matter throughout the ploughed layer. Large clods and fractures were not formed. Rather, surface roughness was increased, and small fractures in the surface 20 cm were observed between clumps of soil held together by grass roots. Immediately above the blade penetration depth, soil slumped into voids and large fractures were not formed. Bulk density reduction was greatest at 10 cm depth. The 24-month mean bulk densities at depths of 10 and 20 cm were 95 and 89% of the original bulk densities respectively.

At 20 cm depth on the non-hardsetting red kandasol soils, the bulk density reconsolidation data were best fitted by equation 1 (Fig. 4*a*). On the hardsetting soils at both depths and the non-hardsetting soils at 10 cm depth, the data were best fitted by:

$$BD = a + b(\log T) \qquad (3)$$

where a and b are the regression coefficients (Fig. 4*b*).

Discussion

Mound consolidation

The dimensions of the newly formed mounds were slightly less than the ideals specified by Foster and Costantini (1991*b*). However, after 28 months consolidation, the specifications for hydraulically sound design (0.4 m height and 0.4 m^2 cross-sectional area) were satisfied.

The height, shape and cross-sectional morphology of mounds differed between the 2 soil types. The extent of lateral soil displacement which occurs during disc ploughing is partly dependent upon soil strength characteristics (Koolen and Kuipers 1983). Thus in the hardsetting red dermosol soils, the second pass of the disc mounder relocated soil to the top of the mound, whereas on the non-hardsetting soil, the second pass relocated loose surface soil to the opposite side of the mound and into the opposite furrow. Consequently, mounds on both soil types consolidated differently between 0.5 and 28 months (Fig. 2*a, b*).

The physical processes which can cause surface micro-relief changes that are detected by profile meters are discussed by Costantini *et al.* (1993). For the present study, the most important of these were consolidation, soil erosion (both off the mound and along the furrow) and soil level changes associated with soil moisture content. Consolidation, which will be influenced by the nature of soil wetting and drying characteristics, tends to reduce mound height and cross-sectional area. Erosion moves soil off the mounds into the furrows, and depending upon severity, scours furrows. Between 0.5 and 28 months, these processes resulted in a reduction in mound height and a filling of the furrows on the hardsetting soils. Because loose surface soil was concentrated on one side of the mound in the brown sodosol soils, both consolidation and erosion increased furrow depth on that side (Fig. 2*b*).

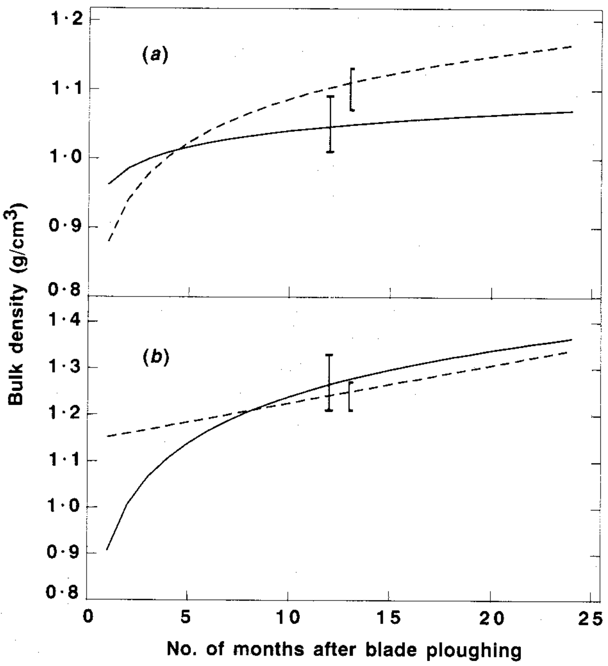

Figure 4. Predicted bulk density consolidation for blade-cultivated strips on two soil types, (*a*) red dermosol and (*b*) brown sodosol, at 10 (- - -) and 20 cm (——) below the soil surface. Vertical bars indicate the 95% confidence limits for the mean time since cultivation.

Effect of cultivation technique on consolidation

Bulk density consolidation following site preparation differed for the mounding and blade cultivation techniques. Whilst the red dermosol hardsetting soils used in the mounding and blade cultivation studies were similar in texture and structure (Tables 1 and 2), the relationships describing bulk density consolidation were quite different (Figs 3*a* and 4*a*). These differences are attributable to the different post-cultivation soil conditions. Blade ploughing produced large fractures immediately above the blade depth (Koolen and Kuipers 1983 have described a similar process). The rapid consolidation observed at 20 cm depth during the period 0.5–4 months following blade ploughing resulted from subsidence of large fractures. At 10 cm depth blade ploughing did not form large fractures. Similarly, the double pass of the mound plough produced a fine tilth with few large fractures. Where large fractures were not formed during site preparation, linear relationships were observed for bulk density consolidation (Figs 3*a* and 4*a*).

Effect of soil type on consolidation

Bulk density consolidation differed on the hardsetting and non-hardsetting soil types in both studies. In the summer rainfall-dominated zones of Australia, non-hardsetting soils are typically single-grained or pedal in the dry, as well as in the wet, state (Northcote 1979). The former, which includes the non-hardsetting soils reported here, are more prevalent in the coastal lowlands of south-eastern Queensland. In both studies, the A horizons of the hardsetting and non-hardsetting soils belonged to the clay loam and sandy loam texture groups of Northcote (1979) respectively. At all measurement periods between 4 and 28 months in the mound study, the reduction in bulk density relative to the premounding condition was greater on the hardsetting clay loams than on the non-hardsetting, single-grained, sandy loams. Bulk density consolidation was relatively more rapid during the first 4 months on the non-hardsetting, sandy loams. These trends were similar to those observed in the mounding study.

The observed effects of texture on bulk density consolidation are consistent with cultivation response durations reported in the literature. For example, Cassels (1982) reported a study following double cultivation of a loamy sand where bulk density of the surface 0–14 cm increased from 1.32 to 1.56 g/cm^3 in the first 2 weeks, and to 1.64 g/cm^3 in 2 months. In contrast, cultivation effects which persisted for at least 12 months were reported for a loam soil in the United States corn belt by Burwell *et al.* (1963). In a rainfall simulation study which excluded raindrop impact energy, Onstad *et al.* (1984) reported that cultivation effects in 4 loamy soils persisted after 4 irrigations and 15.2 cm of rainfall.

Effect of incorporated organic matter on consolidation

The non-hardsetting soils described in this paper had single-grained, massive-structured A horizons with low organic carbon content and low silt plus clay content (Table 2). Each of these characteristics are known to increase the impact of compacting forces on bulk density (see Dexter and Tanner 1974; Northcote 1979; Greacen and Sands 1980). For example, bulk density consolidation was less in the non-hardsetting soils where site preparation incorporated organic matter (surface litter and grass biomass) into the soil profile. Both site preparation techniques incorporated organic matter at 20 cm depth on the non-hardsetting soils, and as a result, bulk density consolidation at this depth was less than it was at 10 cm depth in the blade plough study and at 40 cm depth in the mound study.

Management implications

In both the mounding and blade cultivation studies, consolidation resulted from natural processes, including rainfall impact, strength changes resulting from infiltration and percolation of water, surface sealing and strength changes resulting from wetting and drying (see Camp and Gill 1969; Onstad *et al.* 1984 for descriptions of the processes). The studies reported in this paper were conducted in above average rainfall years. The observed rate of consolidation can therefore be expected to equal or exceed that of typical rainfall years. It should be noted, however, that the results assume the exclusion of grazing animals and machinery traffic, both of which have the potential to rapidly compact cultivated soils, possibly to greater than precultivation levels.

The different consolidation processes for hardsetting and non-hardsetting soil types have been observed to affect *Pinus* growth responses to cultivation (Costantini *et al.* 1995). The studies reported in this paper have demonstrated that bulk density impacts of site preparation on high-strength, hardsetting soils are persistent for at least 2 years. With the exception of subsidence of large fractures, rapid initial consolidation following site preparation of these soil types was not observed. Therefore, whilst it is desirable, it may be assumed not to be critical that *Pinus* seedlings be planted immediately following site preparation on these soil types. If necessary, delays of 2–4 months, and perhaps up to 6 months, could be used to facilitate management.

Conclusions

Mounding operations on poorly drained soils and blade cultivation operations on well drained soils in the coastal lowlands of south-eastern Queensland both significantly reduced bulk density. The extent of these reductions and the nature of bulk density consolidation following site preparation are shown to be affected by soil depth, soil type and technique used. On high strength, hardsetting soils, significant bulk density reductions persisted throughout the 28-month study period. In contrast, on non-hardsetting soils with a single-grained massive structure, consolidation rates immediately following site preparation were higher, and bulk density levels 4 months after site preparation were less relative to precultivation conditions. On the non-hardsetting soils, however, bulk density consolidation was moderated by a larger proportion of incorporated organic matter. It can be expected that delays of 2–4 months, and perhaps up to 6 months, between site preparation and planting will not compromise *Pinus* growth.

Acknowledgments

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