

# The effect of land preparation at re-establishment on the productivity of fast growing hardwoods in South Africa

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## Abstract

Appropriate land preparation at re-establishment is of major importance to forest managers to ensure maximum survival and vigorous early growth of South African plantation forests. This work revisits a series of trials carried out over the last two decades in an attempt to evaluate the long-term effects of land preparation at re-establishment on the productivity of fast-growing hardwoods (*Acacia mearnsii* and *Eucalyptus* spp.). A wide range of land preparation techniques was tested: ploughing, ripping, subsoiling, ridging and complete site preparation (de-stumping, ripping and discing) *inter alia*. Of the eleven trials originally planted, five reached rotation age (between 9 and 11 years) and, apart from one which was destroyed by a storm at 5 years, the rest, at time of writing, were close to clearfelling. With the exception of one trial where significant growth responses were recorded, and apart from a few significant lower-order interactions, final survival, basal area and volume were not affected by land preparation when compared to a standard pitting operation. Overall, growth responses in terms of basal area and volume to various forms of surface cultivation, ripping, subsoiling and terracing ranged between +21% and -23% for all species tested. Intensive site preparation (e.g. de-stumping, ripping/subsoiling and discing) has generally not resulted in improved growth of *E. grandis* or *A. mearnsii* across a range of sites and in some cases even resulted in a reduction in site productivity. Erratic growth responses of *Eucalyptus* spp. and *A. mearnsii* to ripping were recorded. Forest management should focus efforts on less intensive and more cost-effective methods of re-establishment such as pitting, shallow ripping to mark a planting line, or surface ploughing unless a *known* growth limitation exists (such as a root-limiting compacted B horizon overlying a horizon with available water). It is conjectured that the lack of major growth responses to intensive site preparation is due to a combination of the good physical condition of forest soils in the summer-rainfall growing region of South Africa, and beneficial perforation effects of tree roots from previous rotations. The results imply that topsoil disturbance and mixing of soil layers caused by intensive site preparation may pose a threat to long-term site productivity.

**Keywords:** land preparation, site preparation, tillage, re-establishment, regeneration, *Eucalyptus grandis*, *Acacia mearnsii*

## Introduction

The South African timber industry re-establishes up to 75 000 ha of forest plantations annually from a planted area of 1.4 million ha (Forest Owners Association 1998). In order to maximise survival and accelerate canopy closure, intensive silviculture is widely practised during re-establishment. This involves intensive vegetation management, fertilisation, appropriate spacing and land preparation techniques. Many of these techniques were pioneered in South Africa following the work of Sherry (1971), Schönau and Stubbings (1983) and Schönau (1983) amongst others. Building on the success of this work, many companies and growers adopted intensive land preparation methods in the hope of improving growth. Evidence worldwide for the effectiveness of land preparation and tillage operations under re-establishment conditions has been mixed and reflects our experience in South Africa. In some studies tree survival and growth can be improved by intensive land preparation (Berg 1975; Guild 1971; Burger and Pritchett 1988) but in others no responses have been forthcoming (van Goor 1985; Madeira *et al.* 1989). Often the responses are likely to be site specific. Mason and Cullen (1986) showed that the growth of *Pinus radiata* in New Zealand improved by ripping of gravelly sands but not of loamy sands. From a soil physical perspective land preparation is frequently applied to improve soil conditions but, if applied indifferently, may negatively affect soil physical properties (Gent *et al.* 1983; Smith and van Huysteen 1992). Even so, in some cases improvements in soil physical properties following cultivation are not always translated into growth benefits. For example, Madeira *et al.* (1989) reported that disc harrowing and deep ploughing significantly decreased bulk density to a depth of 30 cm and 80 cm respectively, but this had no effect on the partitioning of *Eucalyptus globulus* biomass production. Since land preparation involves the manipulation of topsoil and plantation residue, there is likely to be a close interaction between land preparation and fertilisation (Tiarks and Haywood 1996), vegetation management (Little *et al.* 2000) and plantation residue status (Stransky *et al.* 1985; Wittwer *et al.* 1986).

A review of literature reveals limited information regarding the effects of land preparation on fast-growing hardwoods, particularly under warm temperate to sub-tropical conditions. The opposite appears to be true for softwoods, which have a long history of land preparation research in the pine growing areas of the southern United States (Morris and Lowery 1988;

Allen *et al.* 1990), South Australia (Boardman 1988) and New Zealand (Berg 1975).

A series of trials was established between 1981 and 1994 testing various land preparation and tillage methods on the growth of a range of hardwoods. The trials were carried out with *E. grandis*, *E. dunnii*, *E. grandis x camaldulensis* and *Accacia mearnsii*, which in South Africa collectively occupy about 40% of the plantation area and 90% of the hardwood area. This paper resulted from the need to review these trials in order to provide an overall perspective on the performance of land preparation and tillage methods in South Africa. This will assist the choice of appropriate land preparation methods during the re-establishment phase. Since many of the trials were clearfelled or are close to felling age at time of writing, the trial series also afforded an opportunity to evaluate whether early growth trends were carried through the entire rotation.

## Methods

### Study sites

The re-establishment trials were established in several regions of KwaZulu-Natal province, South Africa. All sites had at least one rotation of trees previously and, in some cases, several rotations (Table 1). Of the eleven trials planted, four have now been clearfelled, one has been abandoned due to storm damage and the remainder are still being monitored (Table 1). Five trials were planted to *A. mearnsii*, four to *E. grandis*, one to *E. grandis x camaldulensis*, and one to a combination of *E. grandis*, *E. dunnii* and *A. mearnsii* (Table 1). All the species used in this trial series are planted extensively, particularly in the warm temperate zone.

The study areas are located on the eastern seaboard of South Africa. The climate varies with altitude from sub-tropical on the Zululand coastal plain through warm temperate in the Natal Midlands (altitude between 800 and 1200 m) and cool temperate higher than 1200 m. Site and soil information is presented in

**Table 1.** Trial information and status

Trial number	Species planted	Date planted	Age at last measurement	Variates calculated	Stocking at last measurement (stems ha <sup>-1</sup> )	Previous land use
W <sub>1</sub>	<i>A. mearnsii</i>	02/12/81	8 years + 9 months (felled)	basal area	1401	Four rotations of <i>A. mearnsii</i>
W <sub>2</sub>	<i>A. mearnsii</i>	04/02/85	8 years + 2 months (felled)	basal area	1417	Four rotations of <i>A. mearnsii</i>
W <sub>3</sub>	<i>A. mearnsii</i>	15/04/88	9 years + 6 months (felled)	basal area volume	1846	Four rotations of <i>A. mearnsii</i>
W <sub>4</sub>	<i>A. mearnsii</i>	21/03/90	10 years + 4 months	basal area volume	1678	One rotation of <i>P. elliptii</i> and two of <i>E. grandis</i>
W <sub>5</sub>	<i>A. mearnsii</i>	07/03/94	5 years + 4 months	basal area	1426	Four rotations of <i>A. mearnsii</i>
E <sub>1</sub>	<i>E. grandis</i>	20/03/87	10 years + 4 months (felled)	basal area volume	1403	One rotation of <i>P. taeda</i>
E <sub>2</sub>	<i>E. grandis</i>	07/12/88	5 years + 4 months (abandoned)	basal area	1508	Two rotations of <i>A. mearnsii</i> and two of <i>E. grandis</i>
E <sub>3</sub>	<i>E. grandis</i>	05/03/90	10 years + 4 months	basal area volume	1566	One rotation of <i>P. elliptii</i> and two of <i>E. grandis</i>
E <sub>4</sub>	<i>E. grandis</i>	05/11/91	8 years + 8 months	basal area volume	1649	Two rotations of <i>E. grandis</i>
E <sub>5</sub>	<i>E. grandis x camaldulensis</i>	22/09/92	7 years	basal area volume	1519	One rotation of <i>E. grandis</i>
WE <sub>6</sub>	<i>E. grandis</i> , <i>A. mearnsii</i> , <i>E. dunnii</i>	06/11/91	8 years + 8 months	basal area volume	1571 1632 1467	Two rotations of <i>E. grandis</i>

Table 2. The trials in this series are located on sites between 60 and 1250 m in altitude with a mean annual precipitation (MAP) of between 817 and 1089 mm. Mean annual temperatures vary between 15.8 and 21.5°C. The soils are generally highly leached and acidic, the clay fraction being dominated by 1:1 clay minerals and iron oxides. Soil texture varies from sand on the Zululand coastal plain to clays in the Natal Midlands (Table 2). Apart from the sandy soils, organic carbon levels are generally high (>3%).

### Trial designs and treatments

A short explanation of the various land preparation treatments referred to throughout the text and in Table 3 is given below.

Pitting (P) involved digging pits manually with a hoe 50 cm in diameter and 30 cm deep at the centre. Small pits (SP) in Trial W<sub>2</sub> were only 15 cm in diameter and 15 cm deep.

*Surface cultivation* methods included hoeing, discing, ridging, ploughing, and rotovating. Hoeing (H) was a manual operation carried out by hand with a hoe. Discing (D) involved use of a heavy disc harrow to a depth of 20 to 25 cm. In trials W<sub>1</sub> and W<sub>2</sub> discing was carried out using a modified disc plough (known as a Kulla cultivator) which 'jumped' over the stumps. Ploughing (PL) was carried out with a chisel plough to 15 to 25 cm. Rotovating (RV) refers to surface tillage to about 10 to 15 cm with a rotovator. The Ridging treatment (RD) refers to ridges, 50 cm high, made by an offset discing operation.

*Ripping* (R) refers to ripping with a single tine to between 30 and 45 cm, mounted on an agricultural tractor. Ripping in trial E<sub>1</sub> was carried out using a Powertill tine with paravanes and wings on the trailing edge.

Subsoiling (S) in trials E<sub>4</sub>/WE<sub>6</sub> was carried out to 70 cm using a D155 Komatsu crawler tractor (239 kW).

*Terracing* (T) was carried out by constructing terraces 4 m apart using a Caterpillar D7N crawler tractor and subsoiling the terraces as above to 70 cm.

**Table 2.** Soil and site information for the different trials

Trial number	Coordinates latitude + longitude	Altitude (m)	Mean annual precipitation (mm)	Mean annual temperature (°C)	Soil form <sup>1</sup> Soil subgroup <sup>2</sup>	Soil depth (cm)	Geology	Soil texture (A/B horizon)	Topsoil organic carbon (%)	Potential soil limitations
W <sub>1</sub>	29°33' S 30°27' E	840	890	17.6	Inanda Humic haplustox	60 - 80	Shale	SiC/C	4.58	Depth
W <sub>2</sub>	29°33' S 30°27' E	840	890	17.6	Inanda Humic haplustox	60 - 100	Shale	SiC/C	4.59	Depth
W <sub>3</sub>	29°33' S 30°27' E	860	890	17.3	Magwa Lithic haplustox	50 - 80	Shale	SiC/C	4.03	Depth
W <sub>5</sub>	29°32' S 30°28' E	850	890	17.8	Inanda Humic haplustox	>200	Shale	C/C	5.30	None
E <sub>1</sub>	29°25' S 30°16' E	1160	1089	16.9	Kranskop Humic haplustox	>120	Dolerite	C/C	7.89	None
E <sub>2</sub>	29°25' S 30°04' E	1250	946	15.8	Magwa Typic kandiuistult	100	Sandstone /shale	L/SCL	6.29	None
E <sub>3</sub> + W <sub>4</sub>	29°46' S 30°20' E	820	828	17.8	Hutton Typic haplustult	>120	Dolerite	C/C	1.23	Compacted topsoil
E <sub>4</sub> + WE <sub>6</sub>	30°14' S 30°13' E	945	817	16.5	Lusiki Typic kanhaplustalf	80	Dwyka tillite	L/C	3.55	Water repellent topsoil & compacted B horizon
E <sub>5</sub>	28°31' S 32°09' E	60	970	21.5	Fernwood Typic quartzipsamment	>120	Recent sands	S/LS	0.40	None

1 Soil classification working group (1991)

2 Soil survey staff (1990)

*Complete site preparation (CSP)* refers to a combined operation of de-stumping carried out by a mechanical stump chipper followed by ripping and ploughing as defined above.

In trials W<sub>1</sub>, W<sub>2</sub>, W<sub>3</sub>, W<sub>4</sub>, E<sub>1</sub>, E<sub>2</sub>, and E<sub>3</sub> treatments included combinations of surface cultivation and ripping and planting of

seedlings in the old stump line or in the inter-row. These are outlined in more detail in Table 3.

The number and type of treatments tested varied for each trial (Table 3). All treatments were arranged in a factorial or randomised complete block design (RCBD) with three to eight replications per site (Table 3). For those trials established to

**Table 3.** Treatments used and trial designs used for the different land

Trial number	Trial design and treatment combinations*
W <sub>1</sub>	3 x 3 x 2 factorial. Stump-line cultivation (P, D, RD) x inter-row cultivation (H, D, RV) x ripping (R and no rip). The stump-line discing was carried out with a modified disc plough (known as a Kulla cultivator) which 'jumped' over the stumps.
W <sub>2</sub>	5 x 2 x 2 factorial. Surface cultivation (P, D, RD, PL, SP) x ripping, (R and no rip). The stump-line discing was carried out with a modified disc plough (known as a Kulla cultivator) which "jumped" over the stumps. Ripping was carried out along the tree line for treatments D, P, RD and SP and between the tree lines for P.
W <sub>3</sub>	3 x 2 factorial with 3 replications arranged as a RCBD. Between row cultivation (P, RV, PL) x ripping (R and no rip).
W <sub>4</sub>	3 x 2 x 2 factorial, three replications confounded in blocks of eight plots with two additional controls (CSP and pit without fertiliser). Surface cultivation (P, PL, D) x ripping (R and no rip) x planting position (Inter-row and stump-line).
W <sub>5</sub>	3 x 2 factorial with four replications. Surface cultivation (P, R and mulch/pit) x weed control (presence or absence) plus two additional controls, burn and no burn both with weed control.
E <sub>1</sub>	3 x 2 x 2 factorial, three replications confounded in blocks of eight plots with two additional controls (CSP and pit without fertiliser). Surface cultivation (P, RV, D) x ripping (R and no rip) x planting position (Inter-row and stump-line). Ripping was carried out to a depth of 40 cm using a Powertill tine with paravanes and wings on the trailing edge pulled by a tractor.
E <sub>2</sub>	3 x 2 x 2 factorial, three replications confounded in blocks of eight plots with two additional controls (CSP and pit without fertiliser). Surface cultivation (P, PL, D) x ripping (R and no rip) x planting position (Inter-row and stump-line).
E <sub>3</sub>	3 x 2 x 2 factorial, three replications confounded in blocks of eight plots with two additional controls (CSP and pit without fertiliser). Surface cultivation (P, PL, D) x ripping (R and no rip) x planting position (Inter-row and stump-line).
E <sub>4</sub>	5 x 2 factorial, five replications analysed as a RCBD. Surface cultivation (P, PL) x ripping, (R, S and no rip). Ripping was carried out to a depth of 35 cm using an agricultural tractor whereas subsoiling was carried out to 70 cm using a Komatsu crawler (D155).
E <sub>5</sub>	A split split plot design with three replications of each treatment combination. Surface cultivation (P, R and mechanical pitting) x burning (presence or absence) x fertilisation (presence or absence). Fertilised plots received 70 kg N ha <sup>-1</sup> .
WE <sub>6</sub>	A randomised block design with eight replications of two land preparation methods (subsoiling to a depth of 70 cm and terracing) and three tree species ( <i>Acacia mearnsii</i> , <i>Eucalyptus grandis</i> and <i>Eucalyptus dunnii</i> ).

\* P - Pit; SP - Small Pit; H - Hoe; D - Disc; PL - Plough; RV - Rotovate; RD - Ridge; R - Rip; S - Subsoil; T - Terrace; CSP - complete site preparation (de-stump, rip and plough).

*A. mearnsii*, plot sizes ranged from 40 to 64 trees (4 x 10 to 4 x 16 trees). Two guard rows were used resulting in 16 to 28 measured trees per plot. For those trials established to eucalypts, the plot sizes ranged from 30 to 60 trees with the inner 12 to 26 measured per plot. The reason for the larger plot sizes used in the *A. mearnsii* trials was the planned reduction in stocking in thinning operations. The original stocking was either 2433 stems ha<sup>-1</sup> in trials W<sub>1</sub> and W<sub>2</sub>, or 2222 stems ha<sup>-1</sup> in trials W<sub>4</sub> and W<sub>5</sub>.

In general the treatments could be divided into three broad categories. Pitting, rotovating, ridging, discing and ploughing were considered as surface cultivation treatments, and ripping, subsoiling and terracing were considered as deep cultivation treatments. The third group, when present (trials W<sub>4</sub>, E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>), the controls (Table 3), consisted of pitting without the addition of fertilizer, and complete site preparation (CSP), that is destumping + deep discing + ripping + fertilising. The control treatments were originally designed to represent the extremes in terms of tree performance, with pitting without fertiliser as the baseline and CSP as the best.

All treatments in each trial were fertilised except where fertilisation was part of a factorial structure (presence and absence of fertilisation) as in trial E<sub>5</sub>, and in trials which had an additional pitting without fertiliser control (trials W<sub>4</sub>, E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>). The type and quantity of fertiliser were determined according to species planted and soil type. The trials planted to *A. mearnsii* were fertilised with 75 g superphosphate (10.5% P) and 25 g KCl (50% K), except for trial W<sub>5</sub> where the trees received 150 g superphosphate (10.5% P) and 25 g KCl (50% K). In general the eucalypts received 100 g 3:2:1 (25) except for trials E<sub>2</sub> and E<sub>3</sub> which received 150 g ammoniated superphosphate, and 45 g 4:1:1 (32) + Zn + B + Mn, respectively. Complete weed control was implemented in all trials until canopy closure to eliminate the confounding effect of a possible interaction between weed growth and land preparation.

## Measurements

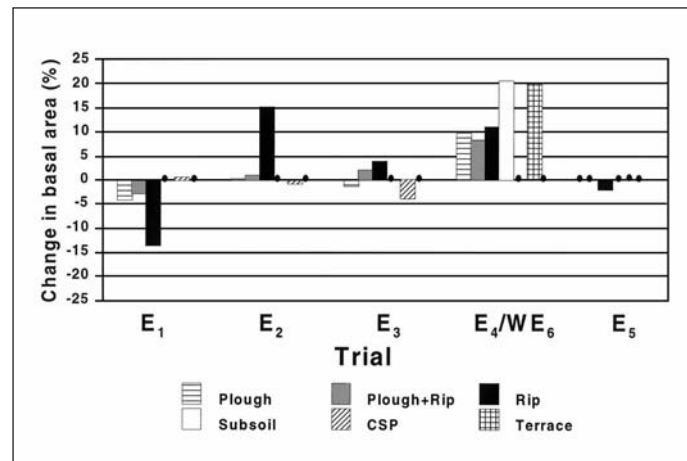
Once most trees were taller than 1.3 m, diameter at breast height (cm) was measured. Height (m) was measured only later in the rotation for some of the trials. The basal area per hectare (m<sup>2</sup> ha<sup>-1</sup>) was determined using the dbh and stocking on a treatment plot basis. Due to the large number of trials, trial designs, treatments involved and variable site conditions, a method for comparison was needed. Thus the performance of the treatments ( $ba_{\text{treatment}}$ ) relative to that of the baseline pitting treatment ( $ba_{\text{pitting}}$ ) for each trial was calculated to give the change in basal area ( $ba_{\text{change}}$ ) as shown in equation 1:

$$ba_{\text{change}} = \frac{ba_{\text{treatment}} - ba_{\text{pitting}}}{ba_{\text{pitting}}} \times 100 \quad [1]$$

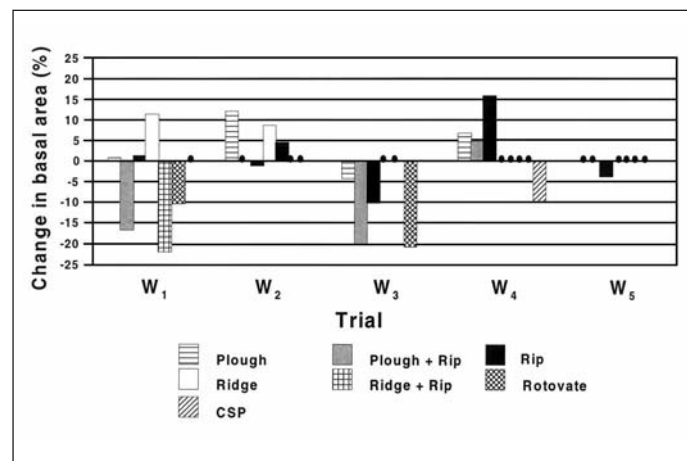
For those trials where height was measured, the volume per hectare was calculated using the volume and stocking on a treatment plot basis. Individual tree volume was determined according to the tree volume equations developed by Coetzee (1992) for *E. grandis*, Coetzee and Naicker (1999) for *E. dunnii* and Schönau (1972) for *A. mearnsii*.

## Data analysis

Before comparisons between individual treatments were made, an overall F-test was carried out (Mead and Curnow 1983). Only if the F-value was significant were treatment differences further investigated using least significant differences (LSDs). All comparisons between tree variates were analysed with Genstat<sup>®</sup> for Windows<sup>™</sup> (Lane and Payne 1996).



**Figure 1.** The effect of land preparation treatments on the growth of *Eucalyptus* spp. Growth change is expressed as a percentage change in basal area relative to the pitting treatment. Dots indicate absence of treatment in a particular trial.



**Figure 2.** The effect of land preparation treatments on the growth of *Acacia mearnsii*. Growth change is expressed as a percentage change in basal area relative to the pitting treatment. Dots indicate absence of treatment in a particular trial.

## Results and discussion

The difficulties associated in presenting data from such a wide range of trials have been addressed in two ways:

(i) A summary of main treatment effects and interactions at *F*-probability values at  $P < 0.1$  for stocking, basal area and volume data at the last measurement are given in Table 4.

(ii) Several 'operational treatments' were selected and compared with the 'minimum' land preparation treatment (pitting with fertiliser) for each trial. These results are presented in Figures 1 and 2 for eucalypts and *A. mearnsii* respectively. Note that pitting was carried out as a treatment or as part of the factorial structure in all trials except W<sub>5</sub> and, as was the case with all the other treatments, received full weed control and fertiliser. Trials

**Table 4.** *F*-probability values for main treatment effects and interactions as determined by analysis of variance. Empty cells indicate variates not determined. For brevity values are presented only at probability levels at  $P < 0.11$ 

Trial number	Treatment	<i>F</i> -probability		
		Survival	Basal area	Volume
W <sub>1</sub>	Stump-line cultivation x inter-row cultivation x ripping	0.095	-	-
W <sub>2</sub>	-	-	-	-
W <sub>3</sub>	Surface cultivation	-	0.070	-
	Surface cultivation x ripping	0.069	-	-
W <sub>4</sub>	Controls (CSP versus pit with no fertilizer)	-	0.026*	0.026*
	Ripping x planting position	-	0.060	0.038*
W <sub>5</sub>	-	-	-	-
E <sub>1</sub>	Controls (CSP versus pit with no fertilizer)	0.001**	-	-
	Ripping x planting position	-	-	0.076
E <sub>2</sub>	Ripping	-	0.080	-
	Planting position	0.053	-	-
	Surface cultivation x planting position	0.029*	0.020*	-
	Ripping x planting position	0.018*	0.011*	-
E <sub>3</sub>	Ripping	0.066	-	-
E <sub>4</sub>	Land preparation	-	0.054	0.094
E <sub>5</sub>	-	-	-	-
WE <sub>6</sub>	Land preparation	-	0.006**	0.014*

\* and \*\* indicate significance at  $P < 0.05$  and  $P < 0.01$  respectively

W<sub>4</sub>, E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> had controls which included pitting without fertiliser (Table 3), but the latter were not used for comparisons in Figures 1 and 2. Where appropriate, however, references are made to this treatment in the text and in Table 4.

#### Final survival

The effect of land preparation on final survival (stocking) was significant ( $P < 0.05$ , Table 4) in only two of the eleven trials (E<sub>1</sub> and E<sub>2</sub>), both of which were established to eucalypts. In trial E<sub>1</sub> there was a significant difference ( $P < 0.01$ ) in final survival between the controls and the land preparation treatments. Pitting without fertiliser had significantly poorer final survival (69%) compared with CSP (82%) and the average of all the land preparation treatments (87%). Final survival was affected in trial E<sub>2</sub> by a significant interaction between surface cultivation, ripping and planting position ( $P < 0.05$ , Table 4). This was possibly due to a significantly better survival when planting in the rip line in the inter-row (93%) than in the stump-line or inter-row after pitting (83 and 81% respectively), or planting in the stump-line after ripping in the inter-row (77%). The general lack of a significant response to land preparation with respect to final survival is of interest since field experience indicates that appropriate land preparation has a considerable effect on

survival. The results presented here suggest that land preparation had little effect since the planting and subsequent weed control in these research trials were of a high standard, a situation not always encountered under routine plantation conditions. The interaction between weed control and land preparation has been demonstrated by Little *et al.* (2000).

In general, all forms of cultivation, ripping and cultivation position had little effect on final stocking of *A. mearnsii* (trials W<sub>1</sub> to W<sub>5</sub>). The lack of response in trials planted to *A. mearnsii* could be related to the higher levels of stocking when planted and subsequent thinning. Usually two thinnings were employed to obtain the final stocking across all treatments at about 1 and 2 years of age, and may mask any initial impacts of land preparation on tree survival. However, the fact that final survival is not affected by initial land preparation is important since windthrow is a commonly-reported problem in black wattle stands later in the rotation - due to poor initial root development which could be affected by early re-establishment practices.

## Basal area and volume

### Surface cultivation

The growth responses of eucalypts and *A. mearnsii* to site preparation are presented in Figures 1 and 2 respectively.

With the exception of trial E<sub>2</sub> where there was a significant interaction between surface cultivation and planting position, surface cultivation had a non-significant effect on growth (Table 4 and Fig. 1). Though non-significant, a chisel ploughing operation to 20 cm resulted in an 8% increase in basal area over pitting (19.0 and 17.6 m<sup>2</sup> ha<sup>-1</sup> respectively) at 8 years and 8 months of age (Fig. 1). This could have been due to the break-up of the water-repellent topsoil (Scott 1991) since the E<sub>4</sub> soils were identified as being water-repellent (Musto 1994). This water-repellency was exacerbated by burning of the plantation residues prior to treatment application. No significant growth responses to ploughing with respect to either basal area or volume were noted in any of the other eucalypt trials (Table 4).

In general, all forms of land preparation had little effect on basal area and, in the case of trials W<sub>1</sub> and W<sub>3</sub>, on final volume of *A. mearnsii*. There was, however, a significant difference ( $P < 0.05$ ) between the controls and the land preparation treatments and a significant interaction between ripping and row planting position on volume in the trial W<sub>4</sub> (Table 4). The former result is thought to be due to the surface cultivation operation breaking up the hard clayey topsoil which existed at this site; this is beneficial for containerised seedlings of *A. mearnsii* since they tend to develop good lateral root systems with a poor taproot (Sherry 1971).

Figure 2 demonstrates the large variability in the responses of *A. mearnsii* to the land preparation treatments. Although not statistically significant, the responses to ploughing vary between an 11% decrease in basal area to a 12% increase in basal area, compared with pitting. In both of the trials where rotovating was carried out, decreases in growth were recorded (a 10.3% and 20.5% decrease in basal area for trials W<sub>1</sub> and W<sub>3</sub> respectively). Ridging alone, however, resulted in a slight increase in basal area of 8.7% and 11.3% for the trials W<sub>2</sub> and W<sub>1</sub> respectively.

### Ripping and subsoiling

The responses to ripping were mixed (Figs 1 and 2). No significant growth responses to ripping as a main treatment were apparent in the trials E<sub>1</sub>, E<sub>2</sub>, E<sub>3</sub> or E<sub>5</sub>. Although the growth response to ripping was non-significant in trial E<sub>2</sub> after 5 years and 4 months ( $P = 0.080$ ; Table 4) the average basal area of the ripping treatments was 20.8 m<sup>2</sup> ha<sup>-1</sup> compared to 19.1 m<sup>2</sup> ha<sup>-1</sup> for the treatments that were not ripped. A significant interaction between ripping and planting position occurred in this trial (Table 4) with a basal area of 22.3 m<sup>2</sup> ha<sup>-1</sup> when planting into the rip line in the inter-row, compared to a basal area of 19.2 m<sup>2</sup> ha<sup>-1</sup> when planting in the stump-line ( $P < 0.05$ ) and ripping in the inter-row. This result is perhaps hardly surprising but ripping in the inter-row and planting in the stump-line was, and still is, a land preparation method occasionally practised in South African plantations.

Almost significant growth (basal area and volume) responses to site preparation were obtained in the trial E<sub>4</sub> ( $P = 0.054$ , Table 4). The latest volumes of *E. grandis* for the ripping and

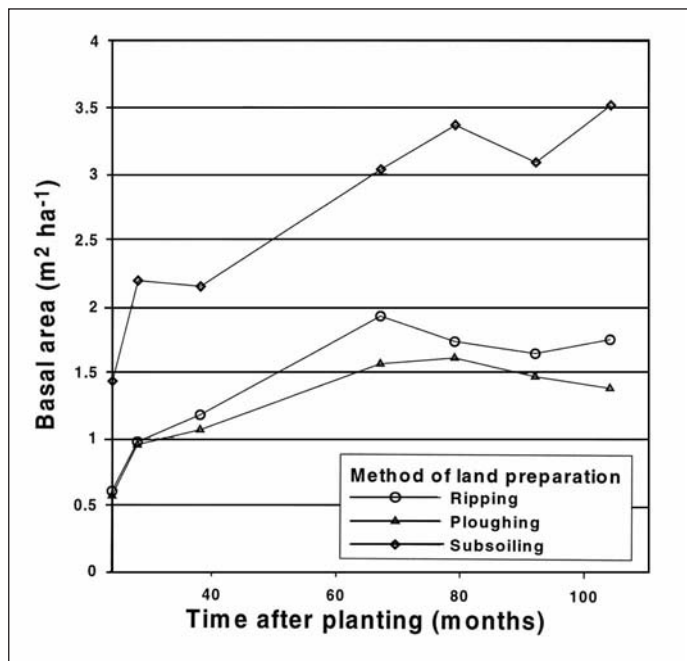
subsoiling treatments at age 8 years and 8 months were 137.7 and 154.5 m<sup>3</sup> ha<sup>-1</sup> respectively, compared to 125.8 m<sup>3</sup> ha<sup>-1</sup> for pitting. These are expressed as basal area differences in Figure 1. Interestingly, when these operations were combined with ploughing, their effectiveness decreased though the reasons for this are not clear.

The reasons for the mixed responses to ripping in the trial series are possibly related to the site and soil. The soils associated with trials E<sub>1</sub> and E<sub>2</sub> are friable, apedal and ferralitic, and, due to the high organic carbon content (6.29% and 7.89% respectively; Table 1) have low topsoil bulk density (<1.0 Mg cm<sup>-3</sup>). In addition the soils are relatively deep (>100 cm) and have no root-limiting subsoil horizons. In other words the soils are in good physical condition and require minimum physical disturbance. This is important since these soils are fairly typical of the important KwaZulu-Natal Midlands forestry region. Similarly, no responses to land preparation were recorded on the sandy soil of trial E<sub>5</sub>. Lack of growth response to land preparation on very sandy soils, due to their single-grain nature and poor consistence is well known (Luckhoff 1955; Mason and Cullen 1986; Norris 1995).

The positive responses to ripping and subsoiling on the trial E<sub>4</sub> (Fig. 1) are probably due to the break-up of the water-repellent topsoil and the root-limiting Bt clay subsoil horizon. Since the tillite-derived saprolite which occurs under the pedocutanic horizon is a store of water, access to this water in such a dry area is of importance to growth. Figure 3 shows the difference in current annual basal area increment between three land preparation treatments (ploughing, ripping and subsoiling) and pitting. The results indicate that the difference between subsoiling and pitting is still increasing after 104 months. Subsoiling to 70 cm has broken through the root-limiting pedocutanic horizon and improved the tree roots' ability to access deeper stores of water. Interestingly the differences in current annual basal area increment between the shallower land preparation methods of ripping and ploughing, and pitting, have decreased in the last 40 months (Fig. 3), suggesting that tree root systems in the pitted treatment are gradually overcoming any physical limitations of the soil in the upper portion of the soil profile (<35 cm) which were originally improved by ripping and ploughing.

The lack of response to ripping in the trial E<sub>3</sub> is interesting since the soil has a fairly firm to hard topsoil with a relatively high bulk density (>1.3 Mg m<sup>-3</sup>). Unlike the trial E<sub>4</sub> there is no subsoil horizon limiting access to deeper horizons, and, as it is a low productivity site, growth is generally poor. Lack of a significant response to any operation on this site is an indication that climate is the over-riding factor limiting growth. The slightly better growth on this site compared to trial E<sub>4</sub> (Fig. 4), which both have a low MAP (Table 2), is probably due to the much deeper soil in E<sub>3</sub>.

In all five *A. mearnsii* trials there was no significant growth response to ripping as a main treatment (Table 4). There was, however, a significant interaction between planting position and ripping (Table 4) in trial W<sub>4</sub>. Basal areas were significantly higher at 9 years and 4 months for trees growing on plots which were ripped between the rows and planted in the rip-line, than when planted in the stump-line (18.4 and 16.3 m<sup>2</sup> ha<sup>-1</sup> respectively). A similar result was noted for the *E. grandis*



**Figure 3.** The difference in current annual increment (basal area in  $\text{m}^2 \text{ha}^{-1}$ ) between land preparation treatments and the control (pitting) for the trial  $E_4$  (*Eucalyptus grandis*)

trial  $E_2$ . Although not significant, responses to a ripping operation alone resulted in an increase in basal area of 16% for trial  $W_4$ , a negligible change in two others ( $W_1$  and  $W_2$ ) and a slight decrease in  $W_3$  (Fig. 2). Interestingly, when a surface cultivation operation was combined with ripping, erratic growth responses were observed. Combining ploughing and ripping resulted in basal area decreases of 19.9% and 16.7% in trials  $W_1$  and  $W_3$  respectively, and a basal area increase of 4.7% in the trial  $W_4$ . The significant increase in tree volume following ripping in the inter-row and planting in the rip line ( $150.4 \text{ m}^3 \text{ha}^{-1}$ ), as opposed to planting in the stump-line following ripping ( $132.5 \text{ m}^3 \text{ha}^{-1}$ ), is clearly due to the trees in the former treatment having easier access to the subsoil via the broken surface. Despite the slight yet enhanced growth responses recorded following ridging, combining this operation with ripping resulted in a large decrease in basal area of 21.7% in trial  $W_1$  and a slight increase in basal area of 4.7% in trial  $W_2$ . Rotovating and ripping combined followed a similar pattern of growth decreases in trials  $W_1$  and  $W_3$ . It has been reported, albeit under establishment conditions, that surface cultivation operations combined with ripping can have negative effects on growth (Smith and van Huysteen 1992; Smith *et al.* 2000). This has been attributed to the creation of air pockets in the upper horizon due to the inadequacy of the mixing process and this may explain some of the variability in terms of the responses obtained above. In addition, the sites where the trials  $W_1$ ,  $W_2$  and  $W_3$  were carried out varied considerably in depth to shale bedrock (Table 2) so that ripping operations often disturbed the rock and fragments which were brought to the surface.

The lack of response to ripping in all the trials established to wattle ( $W_1$ ,  $W_2$ ,  $W_3$  and  $W_5$ ) was probably due to the nature of the soils, all of which are high in organic matter (between 4.0% and 5.3%; Table 2), possess low bulk densities, have a well developed microstructure and are of friable consistence. In trial  $W_3$ , the ripping operation caused some pieces of shale bedrock to come to the surface in some of the treatment plots. This was still apparent at the end of the experiment and may have been

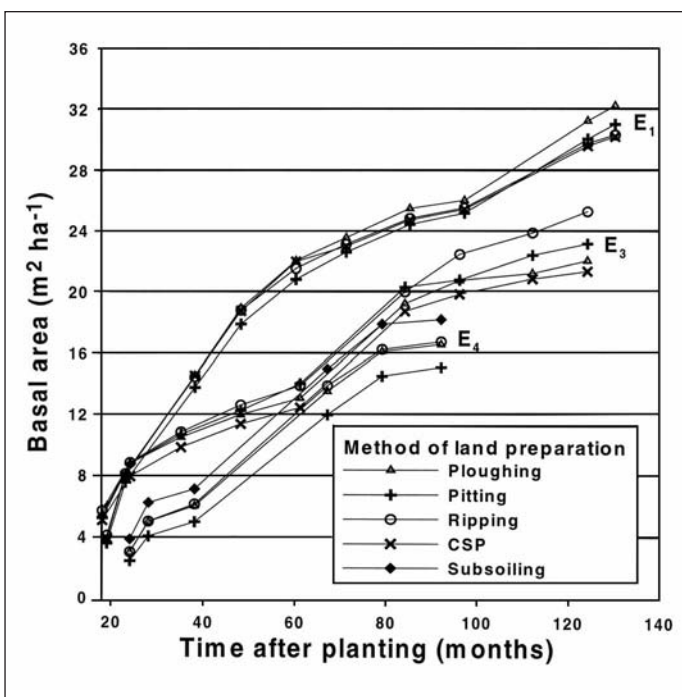
the reason for a slight decline in growth in this treatment (Fig. 2). No growth responses to ripping alone were evident from trial  $W_4$ , despite the soil having a much firmer consistence and higher surface bulk density ( $>1.3 \text{ Mg m}^{-3}$ ). As mentioned previously, nursery raised *A. mearnsii* seedlings do not have a well-developed tap-root (Sherry 1971), unlike seedlings developing from seeds from line-sowing, and this may have also contributed to the lack of growth response to ripping.

### Complete site preparation (CSP)

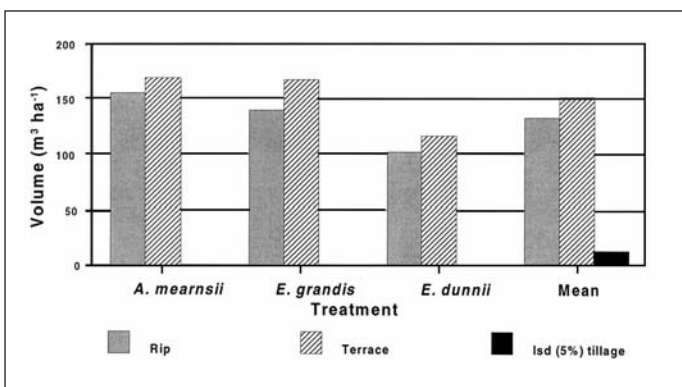
Three trials,  $E_1$ ,  $E_2$ ,  $E_3$  and  $W_4$ , used CSP (i.e. de-stumping, ripping and discing) as a 'control' (Fig. 1) along with pitting without fertiliser (Table 3). Previous establishment experience (land preparation on virgin grasslands) had led past researchers to believe that intensive site preparation would result in a significant improvement in tree growth (Smith *et al.* 2000) and, as such, this treatment was perceived to be a measure against which everything could be judged. The summary of the analyses in Table 4 shows there was no significant difference between the control treatments when compared to the rest of the treatments for these trials. Figure 1 shows that, although not statistically significant, CSP actually resulted in a slight reduction in growth of *E. grandis* in trials  $E_2$  and  $E_3$ . In the latter case the volume of the CSP treatment was  $167.2 \text{ m}^3 \text{ha}^{-1}$  compared to  $180.0 \text{ m}^3 \text{ha}^{-1}$  for pitting (a 7.8% decrease) and  $177.6 \text{ m}^3 \text{ha}^{-1}$  for pitting without fertiliser. In the trial  $W_4$  (*A. mearnsii*) the mean volume for the controls, that is, CSP and pitting without fertiliser, and the average volume for the cultivation treatments were 121.0, 122.7 and  $138.5 \text{ m}^3 \text{ha}^{-1}$  respectively, the latter volumes being significantly greater than those of the controls (lsd at  $P < 0.05 = 15.73$ ). This translates into a growth loss with CSP (14.4% decrease in volume in *A. mearnsii*) which is similar to that obtained for *E. grandis*. This shows that in the trial  $W_4$  CSP had a negative affect on growth compared to all the other cultivation treatments and similar growth to pitting without fertiliser. Interestingly, although non-significant, slight growth losses (Fig. 1) were recorded for the CSP treatments over the pitting treatment for trials  $E_2$  and  $E_3$ . As the CSP treatment was fertilised, as were all the cultivation treatments, it is possible that the de-stumping operation (stump-chipping) and the subsequent considerable disturbance of the soil due to intensive land preparation has resulted in some nutrient loss (Vitousek and Matson 1985).

The response to these intensive methods of land preparation is important since intensive site preparation was, and still is, a favoured yet expensive form of re-establishment in some parts of South Africa. The combination of topsoil disturbance and mixing of topsoil and subsoil can result in decreased nutrient availability and lower available water capacity (Madeira *et al.* 1989). Highly mechanised management practices resulting in deep soil disturbance caused decreased P, S and N foliar concentrations through reduced soil nutrient availability in young *P. radiata* stands in Spain (Merino and Edeso 1999). Similarly it has been reported that topsoil disturbance as a result of shear-pile-disk land preparation reduced nitrogen availability in young plantations of *P. taeda* (Vitousek and Matson 1985). Moreover, under operational conditions CSP is usually combined with burning of plantation residue, a practice implicated in the loss of productivity (Binkley 1986). Burning was not carried out in these trials except in trial  $E_4$  and in  $E_5$  as part of the factorial structure. Neither of these trials received the CSP treatment.

These results also show the need for the careful selection of control treatment. CSP was used as a control since it was the best land preparation treatment in trials established into grasslands both with *A. mearnsii* and *E. grandis* (Schönau *et al.* 1981). It was therefore used as a 'maximal' treatment against which everything else was to be measured.



**Figure 4.** Basal area development of *Eucalyptus grandis* following several land preparation treatments in trials E<sub>1</sub>, E<sub>3</sub> and E<sub>4</sub>



**Figure 5.** Volume ( $\text{m}^3 \text{ha}^{-1}$ ) for *Eucalyptus grandis*, *E. dunnii* and *Acacia mearnsii* at 8 years + 8 months for the ripping and terracing treatments in trial WE<sub>6</sub>

### Terracing

Basal areas and volumes for the treatments applied in trial WE<sub>6</sub> at 8 years and 8 months are presented in Figure 5. There were significant differences ( $P < 0.05$ ) in basal area between the two treatments, ripping and terracing (Table 4), and also between the three species, *E. grandis*, *E. dunnii* and *A. mearnsii* (data not presented). However, there was no significant interaction between species and land preparation. The original hypothesis for carrying out a terracing operation was to capture runoff water in a dry environment (Gardiner 1991) and the results indicate that this may have succeeded for all species but to a lesser extent for *A. mearnsii* (Fig. 5). Unfortunately, a pitting control treatment was not used, but since the trial was located

adjacent to trial E<sub>4</sub>, which showed a significant response to subsoiling, it is very likely that the terracing treatment would have showed significantly better growth than pitting. Since the trials were planted at the same time, a tentative comparison between the terracing treatment (for *E. grandis*) in WE<sub>6</sub> and the pitting treatment in E<sub>4</sub> has been included in Figure 1. The results also indicate that *A. mearnsii* is a superior species for this site since major land preparation seems to be necessary to obtain comparable growth of *E. grandis* and *E. dunnii*. Economically, this is an important consideration on low productivity sites where the high costs of land preparation may not be capitalised for statistically significant, though small, growth increases.

### Longevity of growth responses

Significant growth responses of *E. grandis* to land preparation in the trial E<sub>4</sub> have existed since the inception of the trial and have just become non-significant ( $P < 0.05$ ) at the last measurement. These responses increased with time up until 70 months for the ploughing, ripping and subsoiling treatment (Fig. 3). However, it is apparent that the peak response period (i.e. maximum difference in basal area between treatment and control) is between 65 and 80 months for the ploughing and ripping treatments which thereafter decreased with time (Fig. 3). This is characteristic of a Type 1 response where the increase in volume (or basal area) occurs early in the rotation but diminishes in time so that both the response curve and the control reach an asymptote at some point in time (Snowdon and Waring 1984). The subsoiling treatment, however, appears to have had a major effect on site productivity and the increase has been sustained for 104 months (Fig. 3), indicating a Type 2 response where a plot of basal area against time reaches an asymptote higher than the control (Fig. 3). Since peak mean annual increment (MAI) for this spacing ( $1708 \text{ stems ha}^{-1}$ ) and site corresponds to the peak response period to land preparation (Fig. 4), any delay in felling the trees beyond peak MAI will result in a loss in the benefit accruing from land preparation with the possible exception of the subsoiling treatment.

To illustrate the development of basal area over time with respect to land preparation, a number of selected treatments have been chosen from the trials E<sub>1</sub>, E<sub>3</sub>, E<sub>4</sub>, W<sub>3</sub> and W<sub>4</sub> (*E. grandis* and *A. mearnsii* respectively). For the trials E<sub>1</sub>, E<sub>3</sub> and W<sub>4</sub> these are pitting (in the inter-row), ploughing (planting in the inter-row), CSP (not E<sub>4</sub>) and ripping (inter-row and planting inter-row) and subsoiling (only E<sub>4</sub>). For the trial W<sub>3</sub> the treatments illustrated are pitting, ripping, rotovating/ripping and ploughing/ripping. The results are presented in Figures 4 and 6 for *E. grandis* and *A. mearnsii* respectively, and indicate that in all cases the growth curves for individual treatments are diverging with time. All the treatments (better or worse) are diverging with respect to the pitting treatment. Apart from the ripping treatment in W<sub>4</sub>, growth was not significantly different between treatments. This may indicate that these treatments are affecting long-term site productivity since they are characteristic of a Type 2 response explained previously (Snowdon and Waring 1984). The trial site at Baynesfield (W<sub>4</sub> and E<sub>3</sub>) is a low-productivity site, and the results from a nearby spacing trial show that peak MAI for such a site and spacing occurs at about 11 to 12 years for *E. grandis* (ICFR 2000). It may be that the peak growth response in terms of treatment differences is occurring close to peak MAI as in trial E<sub>4</sub> (Figs 3 and 4).

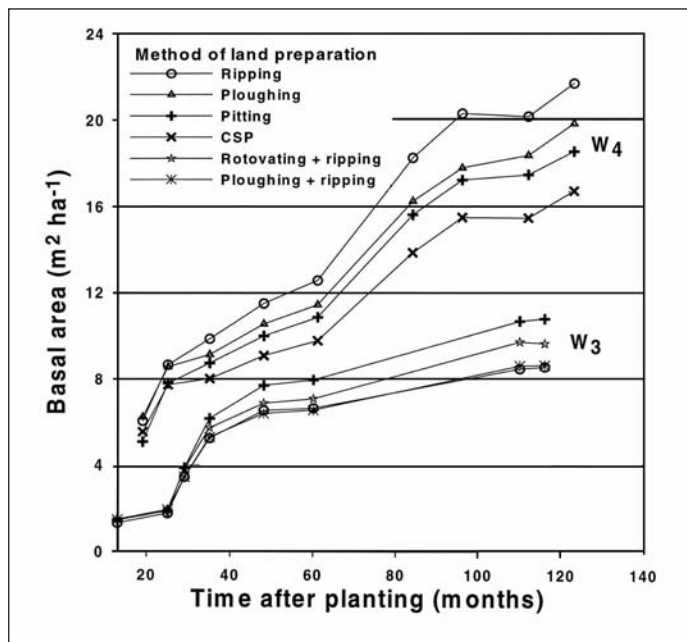


Figure 6. Basal area development of *Acacia mearnsii* following several land preparation treatments in trial W<sub>3</sub> and W<sub>4</sub>

### Implications for forest management

When considering growth responses to land preparation a factor to consider is not only the percentage increase in growth but what this translates into with respect to increase in wood volume. In areas of low to moderate productivity, increases in growth must be substantial to carry the costs of land preparation since large percentage increases in growth over the control treatments may be only several cubic metres of timber per hectare, whereas in a highly productive area small percentages may result in large volume increases. The land preparation trial series has proved to be a valuable empirical data set from which reasonably reliable recommendations can be made. While the trends elucidated in this report can form a foundation for practical application, the extrapolation of results to other sites should be treated with caution since the processes of cause and effect are not fully understood.

Despite the valuable body of knowledge which has been built up by this series of trials, many of the treatments applied were implemented in the hope of gaining responses without due consideration of their effect on key growth processes. It would appear that the thinking behind the trials (similar to sentiments expressed by many silvicultural foresters in South Africa) is that soil physical conditions limit productivity of forest plantations. Indeed, intensive site preparation is often undertaken in order to alleviate perceived growth limiting conditions. These results suggest, however, that soil physical conditions in the summer rainfall growing region of southern Africa are by and large not growth limiting, being characterised by friable consistence, well micro-aggregated structure, and good aeration coupled with low bulk density. It is possible that this, combined with beneficial perforation of soils by tree roots from previous rotations (e.g. Nambiar and Sands 1990), has contributed to a lack of growth response to land preparation under re-establishment conditions. It is suggested that under South African conditions factors limiting growth are primarily climatic rather than soil related, and thus cannot be readily changed by land preparation. The interactive effects of land preparation, nutrition, plantation residue management and vegetation management on processes

which drive productivity should provide the focus for future research.

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