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Final results from a *Eucalyptus grandis* x *E. camaldulensis* coppice trial

Resultados finais de um teste de rebrota em *Eucalyptus grandis* x *E. camaldulensis*

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Resumo

Um teste de rebrota foi instalado em 1996, em Zululand, África do Sul, em povoamento de *Eucalyptus grandis* x *E. camaldulensis*, para investigar: os efeitos da antecipação da primeira desbrota para dois brotos por cepa (a uma altura de 2 m ao invés da altura comercial padrão de 4 m), quimicamente (com glyphosate) ou através do controle manual do crescimento da segunda brotação: e avaliar o efeito do controle de ervas daninhas na produção final. Não foram detectadas diferenças significativas entre os tratamentos, para qualquer um dos parâmetros de crescimento avaliados (altura, DAP, área basal por hectare, volume e estoque), quando as árvores foram cortadas com 7 anos de idade. Contudo, os resultados não significativos obtidos indicam a possibilidade de práticas alternativas de manejo da rebrota. O controle de ervas daninhas não mostrou benefícios em povoamentos manejados para rebrota. A brotação pode ser reduzida em um estágio mais inicial (com altura dominante de 2 m) sem perda na produtividade final. A falta de controle do crescimento da brotação secundária causa uma redução inicial, mas qualquer impacto negativo é eliminado através do desbaste seletivo (uma segunda operação de redução quando a brotação estiver com 7-8 m de altura), quando então se elimina o menor dos dois brotos por cepa. A aspersão de glyphosate a 0,6% no crescimento da segunda brotação pode ser uma alternativa viável à remoção com ferramentas manuais.

Palavras-chave: Brotação, Glyphosate, Desbaste, Controle de Ervas Daninhas

Abstract

In 1996, a coppice trial was initiated in Zululand, South Africa on *Eucalyptus grandis* x *E. camaldulensis*, to investigate: the effects of an early first coppice reduction to two stems per stump (at a height of 2 m as opposed to the standard commercial height of 4 m), chemical (with glyphosate) or manual control of secondary coppice regrowth; and to evaluate the effect of weed control on final yield. No significant treatment differences were detected for any of the tree growth parameters measured (height, diameter at breast height, basal area per hectare, volume and stocking) when the trees were felled at 7 years. These results indicate that dependent on company objectives, all of the alternative coppice management practices tested could possibly be used instead of those that are currently in use. Weed control showed no benefit in stands managed for coppice. Coppice can be reduced at an early stage (when dominant height is 2 m) without loss in final yield. Uncontrolled secondary coppice regrowth does cause an initial reduction in coppice growth, but any negative impact was eliminated through selective thinning (at the second reduction operation when the coppice is 7-8 m in height) to the original stocking by removal of the smaller of the two stems per stump. The spraying of secondary coppice regrowth with glyphosate at 0.6% proved to be a viable alternative to manual removal using hand held implements.

Keywords: Coppice, Glyphosate, Thinning, Weed control

INTRODUCTION

Previous research on coppice management in South Africa focused primarily on the effects of the number of stems remaining on the stump following the reduction operations (thinning of the shoots), and on the frequency and timing of coppice reduction on timber volume and wood properties of *Eucalyptus grandis*. These results produced coppice management recommendations which are still used today in South Africa (SCHÖNAU, 1980; SCHÖNAU, 1990; STUBBINGS and SCHÖNAU, 1980; BREDENKAMP, 1991).

In terms of the timing of the reduction operations, these recommendations state that coppice should be reduced in two operations: the first to two or three stems per stump when the

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dominant shoot height is 3-4 m, and later on to the original stocking when the dominant shoot height is 7-8 m. Experiments on the reduction of coppice of *E. grandis* in Zululand indicated that the first coppice could be reduced to two shoots per stump when the shoots were less than 3 m in height without affecting final yield (BREDENKAMP, 1991; LITTLE and DU TOIT, 2003).

The potential advantages of applying an early first coppice reduction may include the reduction in the labour units required to carry out the reduction operation. This is due to the smaller size of the stems, as well as the channelling of resources to the selected stems at an earlier age, resulting in a possible growth benefit. On the other hand, disadvantages could include an increase in the incidence of windthrow due to the poor attachment of the coppice shoots to the stump, the inability to accurately select shoots of suitable stem form at 2 m in height, and the production of more secondary coppice regrowth following reduction.

Besides these concerns regarding an early first coppice reduction, there were questions as to the necessity of weed control in coppice managed stands, as well as the potential for replacing the manual removal of secondary coppice regrowth with that of herbicides. In order to investigate these issues a trial was initiated on a stand of *Eucalyptus grandis* x *E. camaldulensis* hybrid clones that had been felled in 1996 to determine the impact of an early first coppice reduction, chemical control of secondary coppice regrowth, and weed control on final yield.

MATERIALS AND METHODS

The trial was located at Teza, Zululand in the province of KwaZulu-Natal, on a Mondi Business Paper plantation at 28° 30.688'S and 32°10.248'E. The climate is sub-tropical, with a mean annual precipitation of 916 mm and mean annual temperature of 21.8 °C. There is good rainfall distribution, with between 35 and 40% of the rainfall occurring in winter, and this combined with mild winters allows for the growth of trees throughout the year (SCHULZE, 1997). The trial was situated at an altitude of 55 m above sea level on aeolian derived soils, and as such the topsoil had a low organic carbon content (0.35%) and clay content (2.04%).

The growth rate of *E. grandis* x *E. camaldulensis* for this region of Zululand is typical for a site of lower productivity, with an estimated mean annual increment of 23 m^3 ha^{-1} $year^{-1}$ recorded under optimum planting densities when coupled with fertilization and weeding during establishment (SMITH *et al.*, 2006).

The site was originally planted to a *Eucalyptus grandis* x *E. camaldulensis* hybrid clone that was felled in September 1996. Care was taken during the felling and extraction of the timber so as not to damage any of the remaining stumps. The trees had been planted at a 3 m x 2.5 m spacing, resulting in a density of 1333 stems ha^{-1}. When the stand was felled in September 1996 there were 1299 stumps ha^{-1} remaining alive and therefore to reach the original planting density of 1333 stems ha^{-1} two stems were left on certain stumps after the second reduction operation (at height 7 m) to compensate for those that were missing. Minimal mortality following the second reduction resulted in a stocking of 1330 stems ha^{-1} (99.8% of the original stocking) when the trial was felled.

Twelve treatments arranged in a 3 x 2 x 2 factorial combination, were replicated three times and laid out in a randomized complete block design. The main factors were reduction height (RH), secondary coppice regrowth control (SCR) and weeding (W) (Table 1). Reduction height consisted of the timing of reduction operations (first reduction to two stems per stump at a height of 2 m or 4 m with the final reduction to the original stocking at a height of 7 m), secondary coppice regrowth control (regular manual removal, spraying with a herbicide, or left in situ) and weeding (complete weed control or none). Each treatment plot consisted of 7 x 8 trees, of which only the inner 3 x 4 trees were measured. The initiation and timing of events for the different treatments are listed in Table 2.

Coppice height was measured regularly during the first 15 months after felling in order to determine the timing for reduction operations, and then again just before the trees were felled (7 years). The mean actual heights of the coppice at the time of the planned 2 m, 4 m and 7 m reduction operations were 2.3 m, 4.2 m and 6.7 m, respectively. To get an indication of the amount of biomass removed during these reduction operations, the dry biomass of the coppice that was removed was weighed for the first four stumps in each plot.

Depending on the treatment (Table 1), the secondary coppice regrowth was either allowed to develop unchecked, manually removed with an axe whenever 0.75 m in height, or the foliage sprayed with glyphosate (0.6%) until runoff using a solid cone nozzle. Care was taken not to spray the foliage of the selected coppice stems. Any remaining secondary coppice regrowth was removed from all treatments when the second reduction took place at 7 m in height, after which the coppice regrowth treatments were re-imposed.

To obtain an indication of the amount of coppice regrowth (carried out at 5, 8, 15 and 87 months), the dry biomass of the secondary coppice regrowth removed from the manually controlled treatments was determined for the first four stumps in each plot at each operation. Although the secondary coppice regrowth was controlled on 7 occasions, the last two operations were not necessary due to limited regrowth.

Weed growth in the weedfree treatment was controlled with glyphosate sprayed at 4 l ha^{-1} on five occasions (Table 2). The last weeding event (32 months) was not absolutely necessary due to the effect of shading following canopy closure which reduced the growth of vegetation. Assessments of the vegetation were scheduled to be carried out when tree growth responses to treatments were detected. Failure to detect significant differences between treatments meant that the vegetation was only assessed prior to felling.

The vegetation was quantified in two ways: 1) one sample of biomass was taken from a 1 m^2 quadrat in each weedy treatment plot, dried (at 80 °C), weighed and used to estimate above-ground biomass expressed in kg ha^{-1}; and 2) the percentage cover of each functional category of vegetation (woody vegetation, herbaceous broadleaved plants and grasses) was also assessed (KENT and COKER, 1996) in one 6 m^2 quadrat per treatment plot.

Diameter at breast height (Dbh) was first measured at the time of the reduction operations and then again each year until the trees were felled. These Dbh measurements were used to calculate basal area per hectare (Ba in m^2 ha^{-1}) using the stocking obtained from the respective treatment plots. To determine the final volume of the coppice, 20 trees covering a range in terms of Dbh were felled, and the underbark stem diameters measured at 1 m intervals along the stem. The volume for each 1 m section was first calculated using the formula for a truncated cone (m^3), and from these the merchantable volume on an individual tree basis was determined. The merchantable volume equates to an underbark volume up to the minimum underbark diameter (0.05 m) that can be utilized economically. Using the final height (Ht) and Dbh measurements,

Table 1. Coppice management treatments implemented on a *Eucalyptus grandis* x *E. camaldulensis* trial in Zululand, South Africa.
Tabela 1. Tratamentos de manejo de brotação implementados em um teste de *Eucalyptus grandis* x *E. camaldulensis* em Zululand, África do Sul.

Treatment factors	Treatment description
Factor 1: Reduction height (RH)#	2 m + 7 m
	4 m + 7 m
Factor 2: Secondary coppice regrowth control (SCR)	No control
	Manual removal when 0.75 m high
	Sprayed with glyphosate (@ 0.6%) when 0.75 m high
Factor 3: Weeding (W)	Vegetation not controlled (weedy)
	Chemical control of all vegetation with glyphosate @ 4 l ha^{-1} (weedfree)

the coppice was reduced in a stepwise manner: the first reduction (when 2 or 4 m high) was to two stems per stump and the second (when 7 m high) to the original stocking.

Table 2. The initiation and timing of events for the various coppice management treatments implemented on a *Eucalyptus grandis* x *E. camaldulensis* trial in Zululand, South Africa.
Tabela 2. Seqüência de eventos nos tratamentos de manejo de brotação implementados em um teste em povoamento de *Eucalyptus grandis* x *E. camaldulensis* em Zululand, África do Sul.

Treatments affected	Date of event (months after felling)	Action taken
	September 1996	Trees felled
2 m reduction	January 1997 (4 months)	1st coppice reduction to 2 stems $stump^{-1}$
4 m reduction	April 1997 (6 months)	1st coppice reduction to 2 stems $stump^{-1}$
7 m reduction	December 1997 (15 months)	2nd coppice reduction to original stems ha^{-1}
Weeding	February, December 1997; December 1998; May 1999; April 2000 (4, 15, 27, 32 and 43 months)	Complete weed control through the broadcast application of glyphosate
Secondary coppice regrowth control	March, June, December 1997; March, December 1998; April 2000; January 2002 (5, 8, 15, 18, 27, 43 and 65 months)	Secondary coppice regrowth manually removed or sprayed with glyphosate from respective treatments when 0.75 m high
All treatments	November 2003 (87 months/ 7 years)	Last measurement before trees felled

together with the merchantable volume from these 20 trees, a Schumacher and Hall (1933) equation was obtained (Equation 1).

$$log\ volume = -4.584 + log\ dbh + log\ ht \quad \text{(Equation 1)}$$

This regression accounted for 99.1% of the variation within the data set, and was used to calculate the estimated volume on an individual tree basis from the final Ht and Dbh measurements. From this the total merchantable volume per hectare ($m^3\ ha^{-1}$) was determined using the stocking obtained from the respective treatments plots.

Analyses of variance (ANOVA), was used to test for treatment effects. Only if the F-value was significant ($p < 0.05$) were treatment differences further investigated using the least significant difference statistic (lsd's). Prior to all analyses Bartlett's Test (SNEDCOR and COCHRAN, 1956) was used to test for homogeneity of variance.

RESULTS AND DISCUSSION

A summary of the results for the analyses of variance both prior to, and after the second reduction operation (at height 7 m), and when felled is presented in Table 3.

Stocking and windthrow

No significant differences were detected between the different treatments for stocking when the coppice was felled. An increase in the incidence of windthrow following an early reduction at height 2 m was not detected in this trial, as indicated by the lack of significant treatment differences obtained for the final stocking. It is possible that the trial design was not conducive to the detection of windthrow due to the sheltering effect of adjacent treatments, and surrounding commercial timber stands. The effect of an early reduction on the incidence of windthrow should be tested on a larger stand of trees, rather than within small treatment plots.

Coppice growth

Weeding

Weed growth in the weedy treatment plots was dominated by *Panicum maximum* Jacq. (a tufted grass), *Salacia kraussii* Harv. (herbaceous perennial), *Barleria obtusa* Nees (herbaceous perennial) and *Plumbago auriculata* Lam. (herbaceous perennial). Control of these weeds in the weedfree treatment did not produce any benefits in terms of coppice growth when compared to the weedy treatment (Table 3). Although weed abundance was higher during the initial stages of the trial, subsequent growth declined (possibly due to limited light following canopy closure) resulting in a mean weed biomass in the weedy treatments of 649.4 kg ha^{-1} when the trial was felled. This was reflected in the low percentage cover for grass, perennial broadleaves and herbaceous broadleaves (5.1, 1.1 and 8.3%) when the trial was felled. The lack of response to weed control may be in part

Table 3. Summary of analysis of variance for the coppice management treatments implemented on a *Eucalyptus grandis* x *E. camaldulensis* trial in Zululand, South Africa.
Tabela 3. Resumo da análise de variância para os tratamentos de manejo de brotação implementados em um teste em povoamento de *Eucalyptus grandis* x *E. camaldulensis*, em Zululand, África do Sul.

Source of variation#	Df	Mean squares					
		Basal area before 7 m reduction ($m^2\ ha^{-1}$)	Basal area after 7 m reduction ($m^2\ ha^{-1}$)	Height at felling (m)	Diameter at breast height at felling (cm)	Basal area at felling ($m^2\ ha^{-1}$)	Merchantable volume at felling ($m^3\ ha^{-1}$)
Replications	2	0.55	0.04	2.33	1.03	6.30	1055.9
RH	1	1.69*	0.04^{ns}	0.76^{ns}	0.08^{ns}	1.10^{ns}	69.8^{ns}
SCR	2	0.99*	0.01^{ns}	1.99^{ns}	1.91^{ns}	12.56^{ns}	1523.6^{ns}
W	1	0.36^{ns}	0.20^{ns}	0.01^{ns}	0.03^{ns}	0.11^{ns}	6.3^{ns}
RH.SCR	2	0.40^{ns}	0.08^{ns}	0.35^{ns}	0.17^{ns}	2.82^{ns}	494.9^{ns}
RH.W	1	0.10^{ns}	0.20^{ns}	3.73^{ns}	0.59^{ns}	2.21^{ns}	554.5^{ns}
SCR.W	2	0.23^{ns}	0.05^{ns}	0.77^{ns}	0.41^{ns}	6.37^{ns}	1094.8^{ns}
RH.SCR.W	2	0.28^{ns}	0.02^{ns}	0.58^{ns}	0.08^{ns}	1.02^{ns}	144.7^{ns}
Residual	22	0.23	0.07	1.34	0.59	4.63	756.0
Total	35						
Mean		4.9	3.5	19.9	13.4	19.5	165.4
Standard error (RH.SCR.W)		0.39	0.21	0.94	0.63	1.76	22.45
Coefficient of variation (units)		9.7	7.3	5.8	5.7	11.0	16.6

Note: * indicates significance at $p < 0.05$ and ns non-significance;
RH refers to Reduction height, SCR to Secondary coppice regrowth control, and W to Weeding.

attributed to the use of the existing and well established stump root system by the coppice shoots (TSCHAPLINSKI and BLAKE, 1989).

Young coppice shoots may be able to obtain the necessary nutrients and moisture from a larger soil resource base than that available to newly planted seedlings, therefore increasing their ability to compete with weeds during the establishment phase. In addition, some of the nutrient and water requirements may come from that already existing in the stumps and associated roots (BAMBER and HUMPHREYS, 1965).

The rapid initial growth rate of the coppice shoots when compared to seedlings (BLAKE, 1980; TAYLOR *et al.*, 1982), combined with their slightly elevated position on the stump, and may also have contributed to their competitive ability. The lack of response to weed control has been confirmed in other *Eucalyptus* coppice trials (LITTLE and DU TOIT, 2003; LITTLE, 2004). However, it is recommended that where competitive woody species occur, selective control can be carried out. This will help to reduce under-canopy fuel loads and risks of uncontrolled fires, reduce the seed bank of unwanted vegetation, and improve access for silvicultural operations (DENNY and SCHUMANN, 1993).

Reduction height

There was no significant effect of an early first coppice reduction to two stems at a height of 2 m as opposed to 4 m on the final yield (Table 3). Although the mass of the coppice removed was less for the earlier 2 m reduction (1.53 kg stump^{-1} versus 2.56 kg stump^{-1} for the 4 m reduction), the lack of significant differences in final yield between these two treatments is probably due to the selective thinning at 7 m to the original planting density, whereby the smaller of the two stems per stump was removed. Prior to carrying out the second reduction at height 7 m there was a significant difference ($p < 0.05$) in terms of basal area ha^{-1} (Table 3) with the 4 m reduction recording a 0.43 m² ha^{-1} increase over that of the 2 m reduction treatments. This was unexpected and can in part be explained by the higher stem density in the 4 m reduction treatment of 2407 stems ha^{-1} when compared to 2130 stems ha^{-1} for the 2 m reduction treatment.

Secondary coppice regrowth

Regrowth of secondary coppice following the initial coppice reduction treatments (at 2 m and 4 m) was either removed manually when 0.75 m and weighed, sprayed with glyphosate, or left on the stump. Although carrying out an early first coppice reduction led to increased secondary coppice regrowth (0.19 versus 0.04 kg stump^{-1}) between the first and second reduction, as well as an increased frequency of control (3 operations versus 2), there was no significant effect of this regrowth on the growth of the selected coppice stems for both treatments, both prior to and after the 7 m reduction (Table 3).

However, the method of controlling secondary coppice regrowth significantly affected the growth of the selected coppice stems, particularly before the second reduction operation (Table 3). Although the removal of secondary coppice regrowth resulted in better stem growth when compared to where it was left, only the chemical control treatment was significantly different (Ba ha^{-1} for: chemical control 5.2 m² ha^{-1}; manual control 4.8 m² ha^{-1}; no control 4.7 m² ha^{-1}; $LSD_{0.05} = 0.4$).

Despite the selective thinning of the smaller coppice at the 7 m reduction that removed any treatment differences, re-imposition of the secondary coppice regrowth treatments after the second reduction was only significant at $p < 0.10$ when felled, with the chemical removal treatment resulting in a 6.8 and 10.7% increase in Ba ha^{-1} over the manual removal and no removal treatments. In contrast to the chemical or manual removal treatments where secondary coppice regrowth was negligible after 27 months, 61.1% of the stumps where it was not controlled had coppice regrowth at felling with a mean Dbh and Ht of 3.33 cm and 6.08 m, respectively.

Of the two methods tested for coppice regrowth control, glyphosate gave better control than manual removal. Glyphosate, a systemic herbicide, resulted in the death of the coppice regrowth following translocation of the active ingredient without negatively affecting the performance of the remaining coppice stems. This result has been confirmed in a similar trial carried out on *Eucalyptus grandis* seedlings in Zululand (LITTLE and DU TOIT, 2003). As there was no significant difference in coppice volume between these methods of controlling secondary regrowth and the control, spraying with glyphosate would seem the logical choice. Besides the economic benefits, damage to the remaining stems or bark through manual control will also be minimized.

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