Technical Note

Interaction between *Eucalyptus grandis* x *E. urophylla* coppice reduction heights to single stems and secondary coppice regrowth in Zululand, South Africa

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Summary

Coppice reduction operations were implemented on *Eucalyptus grandis* x *Eucalyptus urophylla* coppice regrowth at different heights (*Reduction_ht* at 3.5, 4.5 and 6.5 m) using a single reduction method whereby coppice shoots were reduced directly to one stem $stump^{-1}$, as well as the testing of different secondary coppice regrowth control methods (*Coppice_control*). An *Additional_control* treatment was included using conventional double reduction methods where coppice shoots were initially reduced to two stems $stump^{-1}$ at 3.5 m, and thereafter to original stocking at 6.5 m. The *Coppice_control* consisted of either no coppice control, manual removal, application of glyphosate or a combination of glyphosate with an adjuvant when the secondary coppice regrowth reached a mean height of 1 m. At final measurement date, the diameters at breast height (*DBH*) in the *Reduction_ht* treatments were significantly larger than the *Additional_control* treatment. This can be attributed to the allocation of resources to the selected stems at an earlier age, resulting in a growth benefit. Stocking at the 6.5 m *Reduction_ht* was significantly higher compared to both the 3.5 m and 4.5 m *Reduction_ht* treatments, while not significantly different from the *Additional_control*. Stocking for the *Additional_control* treatment was not significantly different from both the 3.5 m and 4.5 m reduction heights. The reduced stocking for the 3.5 m and 4.5 m *Reduction_ht* treatments can be attributed to early wind-throw in the plots where coppice reduction had taken place at a younger age, and a more careful stem selection process at the later reduction height of 6.5 m. In comparison to the treatment retaining two stems $stump^{-1}$ to match original stocking (*Additional_control*), the additional stem could compensate for the tree mortality caused by wind-throw or other causes. In this trial, secondary coppice regrowth had no effect on tree growth. Due to the short duration of this trial, a longer trial period would be necessary to obtain a better understanding of the impacts of the various coppice reduction treatments, including the effect that secondary coppice regrowth may have on selected coppice stem growth if left untreated.

Key Findings

- An early coppice reduction facilitated an increase in *DBH* although the occurrence of wind-throw and secondary coppice regrowth did increase
- The higher incidence of wind-throw can be reduced by the more careful selection, possibly at 6.5 m reduction height, or with initial reduction to two stems, followed by a second reduction to the original stocking
- In this trial, secondary coppice regrowth in the untreated plots had no effect on initial tree growth

Key Words

Eucalypt

Coppice management

Glyphosate

Manual removal

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Introduction

Previous research in South Africa on coppice management primarily focused on the effects of the number of stems remaining on the stump following reduction operations (thinning of the shoots), and on the frequency and timing of the coppice reduction on timber volume and wood properties of *Eucalyptus grandis* Hill ex Maid. From these results, coppice management recommendations were developed which are still in use in South Africa (Stubbings and Schönau 1980; Schönau 1980, 1991; Bredenkamp 1991; Little 2007). Thus, current standard practice determines that coppice regrowth be systematically reduced in two operations; the first reduction to two stems stump^{-1} when the dominant stem height is 3-4 m, and thereafter the second reduction to one stem (or selectively leave the two stems in order to obtain the original stocking) when the dominant stem height is 7-8 m (Little 2007).

Due to the loss of apical dominance following these reduction operations, new coppice shoots (referred to as secondary coppice regrowth) continue to be produced on the stumps (Stubbings and Schönau 1980; Schönau 1991; Little and du Toit 2003; Little 2007; Roberts et al. 2016a). A study carried out by Little (2007) on *Eucalyptus grandis* x *E. camaldulensis* in Zululand, found that uncontrolled secondary coppice regrowth causes an initial reduction in primary coppice growth. However, this impact is eliminated during the second reduction operation to the original stocking by removal of the smaller of the two stems (Stubbings and Schönau 1980; Little 2007).

Over the last ten years, the South African forestry industry has seen the introduction of fully mechanised harvesting operations compared to the historically manually based operations (Längin et al. 2010). Coppiced compartments traditionally consist of a mixture of double and single stems, depending on stump survival and diameter (stump diameters <5 cm usually not coppiced and removed), as the final coppiced stems hectare^{-1} need to reflect the desired stocking level (Stubbings and Schönau 1980; Schönau 1991; Ramantswana et al. 2013). A study implemented by Ramantswana et al. (2013) on machine productivity associated with mechanised harvesting operations in coppiced and planted *Eucalyptus grandis* compartments in KwaZulu-Natal, found that processing planted trees had the highest machine productivity, followed by coppiced single stems and then coppiced double stems. Stem form had a negative influence on machine productivity for both coppiced single stems and coppiced double stems.

Stubbings and Schönau (1980) and Schönau (1991) tested various coppice reduction heights, reducing to either one or two stems stump^{-1}, or original stocking. These studies found that an early reduction (ca. 3 m) of coppice shoots and retention of only one stem stump^{-1}, improved stem form compared to retaining two stems stump^{-1}. However, disadvantages with this include an increase in the incidence of wind-throw due to the early exposure of a still poorly attached coppice shoot and the inability to accurately select the most suitable stem due to the young age of the regrowth. In addition, Little (2007) found that carrying out an early coppice reduction not only increased the presence of secondary coppice regrowth, but also the need for more operations to control the regrowth. In contrast, delayed coppice reductions may allow for improved selection following early mortality through wind or other damage (Schönau 1991).

The control of secondary coppice regrowth in South African forestry operations are usually carried out either manually, with the use of axes, machetes (bush-knives), or through the application of glyphosate as a foliar spray (Little 2007; Little and Oscroft 2010; Roberts et al. 2016a). A study by Roberts et al. (2016a) using glyphosate to manage secondary coppice regrowth in a *Eucalyptus grandis* × *E. urophylla* coppice stand in Zululand, found that there was no difference between the manual removal or the application of glyphosate on secondary coppice regrowth glyphosate when looking at the growth of the primary coppiced stems. The use of axes or bush-knives may, however, result in physical damage to the remaining stems which can result in either a reduction in primary stem growth, or result in wind-throw where damage is severe (Schönau, 1991; Little and du Toit 2003; Little 2007; Little and Oscroft, 2010). As an alternative, the application of glyphosate to secondary coppice regrowth has been shown to be more effective than the manual control method due to the elimination of physical damage to the stem, the action of glyphosate as a potential plant growth regulator when applied at low rates, as well as reduced physical injury to employees (Little 2007; Velini et al. 2008; Little and Oscroft 2010; Roberts et al. 2016a). Roberts et al. (2016a) found that the application of glyphosate at 1.2% to secondary coppice regrowth at a height of 1-1.5 m proved to be the most cost-effective treatment.

To test the validity of carrying out a "once-off" single coppice reduction operation to one stem stump^{-1}, which is highly suitable for fully mechanised harvesting operations, a trial was implemented in 2015 in Zululand, South Africa, on a coppiced stand of *Eucalyptus grandis* × *E. urophylla*. A single coppice reduction was implemented at various heights with coppice shoots reduced to one stem stump^{-1}, in contrast to the current recommended practice of two reductions. In addition, different secondary coppice regrowth control methods were also tested.

Materials and Methods

Description of trial site

The trial was implemented in May 2015 in Zululand, South Africa, on a stand of *Eucalyptus grandis* × *E. urophylla* that had been coppiced twice. The stand was situated at an altitude of 63 m above sea level with a mean annual precipitation of 1 170 mm and mean annual temperature of 21 °C. The site was situated in a sub-tropical zone (ST6), with conditions considered optimum for the growth of *Eucalyptus grandis* × *E. urophylla* (Site Index of 24 at five years of age) (Smith et al. 2005a, 2005b).

Trial design and treatments

The trial consisted of a 3 x 4 factorial combination (12 treatments) with one additional controls, arranged in split plots, replicated three times and laid out in a randomised complete block design. The whole plots consisted of three different coppice reduction heights (*Reduction_ht*) which were imposed when the coppice shoots reached a mean height of either 3.5 m, 4.5 m, or 6.5 m. In all the reduction treatments, coppice shoots were thinned to one stem stump^{-1}. Each whole plot consisted of four rows of 12 trees per row, with each row consisting of a sub-plot, of which only the inner 8 trees were measured.

The sub-plots (within the *Reduction_ht* whole plots) consisted of four secondary coppice regrowth control methods (*Coppice_control*). Each sub-plot consisted of either *No_control*, *Manual_removal*, application of glyphosate (*Glyphosate_application*) or a combination of glyphosate with an adjuvant (*Glyphosate_adjuvant*). For the *No_control* treatment the secondary coppice regrowth was left untreated, while for the *Manual_removal* treatment the coppice was manually removed using a bush-knife. For the *Glyphosate_application* treatment, glyphosate (360 g a.i. L^{-1}) was sprayed onto the secondary coppice regrowth at a rate of 1.2%. The same herbicide rate was used in the *Glyphosate_adjuvant* sub-plots, with the addition of Nu-Film® IR (poly-1-p-menthene), a non-ionic sticker-spreader, in the herbicide mixture at 1.5 mL L^{-1}.

To provide a comparison against which the efficacy of *Reduction_ht* could be evaluated, two control plots per replicate (*Additional_control*) were included in the trial. These consisted of whole plots where coppice shoots were thinned in two operations; first to two stems stump^{-1} at a dominant stem height of 3-4 m, and thereafter to the original stocking when the dominant stem height was 6-7 m (as per current practice). During the reduction operations, all secondary coppice regrowth that occurred on the stumps was also removed.

Following the reduction operations, the height of the secondary coppice regrowth was regularly monitored, with the *Coppice_control* treatments implemented when the secondary coppice regrowth reached a mean height of approximately 1 m. For the herbicide treatments, glyphosate (with or without adjuvant, depending on treatment) was sprayed onto the foliage of the secondary coppice regrowth until just prior to runoff using a Solo® 15-L knapsack sprayer, fitted with a TeeJet TG1® solid cone nozzle and regulated to 2 kPa. Care was taken to limit overspray onto the bark and foliage of the main coppice stem(s).

Assessments and data analysis

At each reduction operation, the diameter at breast height (*DBH*; in cm), tree height (*Ht*; in m; n=5) of the main coppice stem(s), and the height of the secondary coppice regrowth that emerged following the previous reduction operation were measured. At the final measurement date (June 2016), heights of five trees were used to derive a regression equation (from trees with both *DBH* with *Ht* measurements) to estimate *Ht* for all the trees in the trial (Linear regression at *F*-prob $p < 0.001$, with R^2 of 0.70 and standard error of 0.582). Stocking (stems ha^{-1}) was derived from survival data and, together with *DBH* measurements, was used to calculate basal area (*BA*; in m^2 ha^{-1}) on a treatment plot basis. To allow for a comparison between treatments in terms of stem volume (m^3), a *Eucalyptus grandis* × *E. urophylla* equation (Institute for Commercial Forestry Research Internal Database, Pietermaritzburg, South Africa) for coppice stems grown in the same region was used to calculate the underbark volume per tree to a top-end underbark diameter of 5 cm (**Equation 1**).

$$\ln Vol = -13.4694 + [20.4369 \ln(Dbh - 8)] + [1.3254 \ln Ht]$$

(Equation 1)

From this, the total merchantable volume per hectare (*Vol*, in m^3 ha^{-1}) was determined using the stocking obtained from the respective treatments plots.

Plot means from the final assessment date were analysed as a 3 x 4 factorial with one additional controls using GenStat for Windows 18th Edition (VSN International, Hemel Hempstead, UK, 2013). Prior to the analysis, the data was checked to ensure that the assumptions for a valid ANOVA were not violated. Following ANOVA, an overall *F*-test was carried out, and when significant ($p < 0.05$), the treatment differences were further investigated using Student's t-tests (lsd's).

Results and Discussion

Tree growth

At the final measurement date (23 months after felling), the *DBH* of the *Reduction_ht* treatments (coppice shoots reduced directly to one stem stump^{-1}) were significantly ($p < 0.05$) larger than the *Additional_control* where coppice shoots were reduced to match original stocking (**Table 1**, **Figure 1**). Within the *Reduction_ht* treatments, no significant differences were detected for the derived variables of *BA* and *Vol* (**Table 1**). Similar results were previously observed when coppice shoots were reduced to only one stem stump^{-1}, with the largest diameter being achieved the earlier the coppice reduction was implemented (Stubbings and Schönau, 1980). The larger diameters in the *Reduction_ht* treatments are most likely due to the allocation of resources to the selected stem at an earlier age, resulting in a growth benefit (Little and du Toit 2003). However, these differences may become non-significant at a later stage owing to the decrease in absolute and relative differences with time. This was apparent in trials implemented by Stubbings and Schönau (1980) and Schönau (1991) where no differences in diameters were found between reductions carried out to one stem stump^{-1} or to the number of stems equal to the original stocking at felling.

Table 1. Summary of analysis of variance showing mean square values of *DBH*, *Stocking*, *BA* and *Vol* for the control of secondary coppice regrowth at various coppice reduction heights for an *E. grandis* x *E. urophylla* trial in Zululand, South Africa

Source of variation	Df	DBH (cm)	Stocking (sph)	BA (m^2 ha^{-1})	Vol (m^3 ha^{-1})
Reps	2	2.341	3584	6.364	127.03
Additional_control	1	6.635*	1870^{ns}	3.551^{ns}	3.89^{ns}
Reduction_ht*Additional_control	2	2.398^{ns}	492324*	1.058^{ns}	3.51^{ns}
Residual	6	0.486	50701	1.691	24.53
Coppice_control*Additional_control	3	0.339^{ns}	17671^{ns}	2.784^{ns}	37.16^{ns}
Reduction_ht*Coppice_control* Additional_control	6	0.715^{ns}	26678^{ns}	3.989^{ns}	57.14^{ns}
Residual	18	0.963	52179	2.809	40.66
Rep.Reduction_ht*SCRC*Units* stratum	3	1.336	5829	1.606	23.57
Total	41				
Summary of data					
Grand mean		8.06	1439	7.86	25.38
Standard error of difference of means (Reduction_ht*Coppice_control* Additional_control)		0.694	161.5	1.185	4.509
Coefficient of variation % (units)		14.3	5.3	16.1	19.1
Shapiro-Wilk test for Normality		0.9200^{ns}	0.9726^{ns}	0.9184^{ns}	0.8808^{ns}

Note: * indicates significance at F-prob < 0.05, ns indicates non-significance.

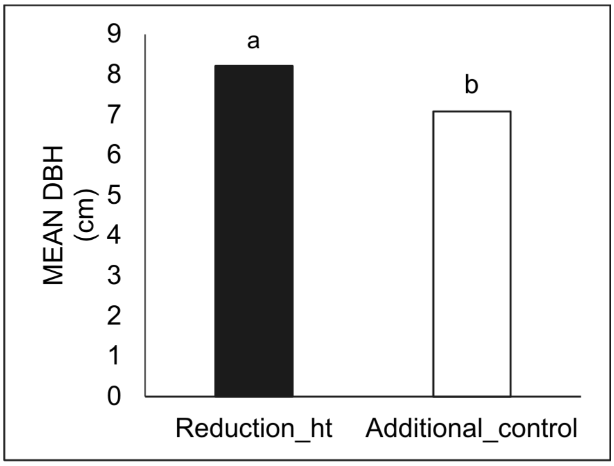

Figure 1. Mean stem diameter at breast height (*DBH*) at final measurement date (June 2016) for the control of secondary coppice regrowth at various coppice reduction heights for an *E. grandis* x *E. urophylla* trial in Zululand, South Africa. Different letters beside bars indicate significance at $p < 0.05$.

Stocking

Significant differences ($p < 0.05$) were detected for *Stocking* at the *Reduction_ht*Additional_control* level. For the 6.5 m reduction height treatment, *Stocking* was 1 666 sph and was significantly ($p < 0.05$) more than for both the 3.5 m and 4.5 m *Reduction_ht* treatments which were 1 285 and 1 358 sph, respectively (**Table 1**; **Figure 2**). However, the stocking of the 6.5 m reduction height treatment was not significantly different from the *Additional_control* (1 456 sph), and the *Additional_control* was also not significantly different from both the 3.5 m and 4.5 m reduction height treatments. The significant difference within the *Reduction_ht* treatments can likely be attributed to early wind-throw in the plots where coppice reductions were carried out earlier (resulting in a total loss of stems due to the younger and poorer attachment of these stems to the stump), as well as the more careful selection of desirable stems possible at the 6.5 m reduction height. Several previous studies on coppice reduction have also alluded to these aspects (Stubbings and Schönau 1980, Schönau 1991, Little and du Toit 2003). Thus, the benefit of retaining two stems stump^{-1} at the first reduction is to either match or overcompensate the original stocking (*Additional_control*) which in turn compensates for possible mortality that may be caused by wind-throw. As the duration of this study was only 23 months (from felling), a longer period will be required to have a better understanding of the impact of wind-throw, particularly for the 6.5 m reduction height treatment.

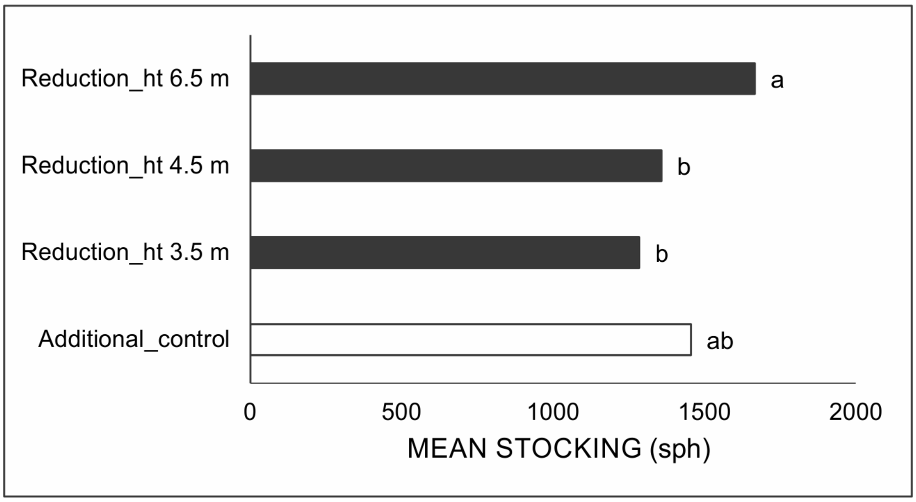

Figure 2. Stocking count at final measurement date (June 2016) for the control of secondary coppice regrowth at various coppice reduction heights for an *E. grandis* x *E. urophylla* trial in Zululand, South Africa. Different letters beside bars indicate significance at $p < 0.05$.

Secondary coppice regrowth

No significant differences were detected for any of the derived variables for the different *Coppice_control* methods at the final measurement date (June 2016). Similarly, as observed in several other studies, no differences were found between the manual and chemical control of secondary coppice regrowth on primary coppice growth (Little and du Toit 2003, Little 2007, Little and Oscroft 2010, Roberts et al. 2016). Although carrying out an early first coppice reduction led to increased secondary coppice regrowth, there was no significant effect of this regrowth on the growth of the selected coppice stems (primary coppice growth). This was contrary to what was expected, since Little (2007) has previously shown that untreated secondary coppice regrowth can cause an initial reduction in primary coppice growth. In this present study, the reason(s) for the increased secondary coppice regrowth not reducing growth of the selected coppiced stems is unclear. However, a possible explanation could be due to the combination of drought, early canopy closure and the short duration of the trial limiting the development of secondary coppice regrowth to the degree that it had no influence on growth of the selected stems.

Conclusion

At the time of the final measurement of the trial (23 months after felling), *DBH* was found to be significantly larger for the stems reduced directly to one stem stump^{-1} (*Reduction_ht* treatments) compared to those where stems underwent the standard two reduction operations. However, comparing the mean *Stocking* of these treatments indicated that reduction to one stem at 3.5 or 4.5 m resulted in lower stocking, likely due to wind-throw. Given that these results were evaluated only one year and eleven months after felling, growth differences observed may become no longer significant at a later stage owing to the decrease in absolute and relative differences over time. In terms of secondary coppice regrowth control, the untreated coppice regrowth had no influence on tree growth at final measurement. It is suggested that a combination of drought, canopy closure and short trial period could be the cause of secondary coppice regrowth not influencing primary stem growth. However, since several previous studies have shown the importance of controlling secondary coppice regrowth, it would be advisable not to view the results of this present study in isolation. As other studies have shown that reducing coppice shoots straight to one stem stump^{-1} gives better stem form, reducing coppice shoots at a height of 4.5 m would be preferred for mechanised harvesting.

Acknowledgements

The Council for Scientific and Industrial Research (CSIR) are thanked for providing the funding for this research project. Mondi Mtunzini provided the land and labourers for the trial, and their assistance is greatly appreciated. Kylle Schwegman and Jason Mennell are gratefully acknowledged for their help with the trial implementation, maintenance and measurement.

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