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Report No. 5A

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Date: August 2007

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EXECUTIVE SUMMARY

Kraft fibre and pulp properties of *Eucalyptus maidenii* at age 8- years have been shown to have excellent papermaking properties compared to age 11-years when fibres are of too-high coarseness, have higher refining requirements, and are likely to have poor formation properties. These results suggested that *E .maidenii* fibres at an even younger age may have good kraft pulp qualities. *Eucalyptus maidenii* trees aged 5- and 6-years were therefore sampled. Chip density, pulp yield and pulp fibre properties of the two age groups were similar, except for fibre length. The fibre and pulp properties of the 5-year-old *E. maidenii* sample were equivalent to those of a eucalypt market kraft pulp of superior quality. On the other hand, the shorter length of the fibres in the six-year sample (0.78 mm) compared to that of the five-year sample (0.84 mm) was sufficient to cause a reduction in handsheet bulk below that considered to be acceptable for a eucalypt market kraft pulp. The longer fibres of the 5-year-old trees than the 6-year-old may have been due to irrigation of the 5-year-old plantation.

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INTRODUCTION

Eucalyptus globulus is recognised internationally as the preferred species for the production of short-fibred pulp. New Zealand growers are prevented from planting this species by its susceptibility to fungal disease, insect attack and frosting. Kraft pulp properties of New Zealand-grown *E. nitens* and *E. fastigata* have been shown to be deficient in bulk and of inferior quality compared to *E. globulus* market kraft pulps.

Eucalyptus maidenii at age 8-years had excellent papermaking properties compared to those aged 11-years, when fibres were of too-high coarseness, had higher refining requirements and were likely to have poor formation properties (Kibblewhite *et al*. 2000). The current resource of *E. nitens* is often harvested at a sub-optimal age, when basic wood density is too low, and requires supplementing by resources of older, higher-density wood. Young plantings of *E. maidenii*, less than 5-years old, have recorded wood densities of 450 – 510 kg/m^3 and could be pulped as a pure species or used in a mixture with *E. nitens* to produce market kraft pulp.

This study examined the kraft pulp qualities of *E. maidenii* samples from trees aged 5- and 6-years, and compared these with those previously reported for 8- and 11-year-old *E. maidenii* (Kibblewhite *et al.* 2000).

EXPERIMENTAL

Sample origin and history

A 5-year-old stand of *E. maidenii* was selected, located near Waihi. This had been planted on a pasture site with a commercial seedlot from Bolaro Mountain, New South Wales, at 1000 stems per ha, and had been regularly treated with sewerage effluent by sub-surface drip irrigation. This seedlot was based on seed collected from 56 parent trees. A 6-year-old stand was represented by a provenance trial, located near Kawerau, which had been planted at 950 stems per ha on cleared manuka (*Leptospermum scoparium*) scrubland. This trial has a mix of seven different provenance seedlots, all of which were sampled. At both sites, 40 well-grown trees were measured for diameter at breast height, and pith-to-bark increment cores were collected at that height to determine their wood basic density and to estimate the stand mean. Fifteen trees of similar diameter were then chosen from each site for the pulping study (Table 1), representing the full range of basic density, and equalling the respective observed stand means.

Table 1: Tree diameter and density for the 15-tree samples.

Site/age	Diameter (mm)		Density (kg/m^3)	
	Range	Mean	Range	Mean
Waihi – 5-year-old	177 - 201	191	454 - 566	505
Kawerau – 6 year old	177 - 203	193	443 - 552	501

Log processing and chip sampling

Logs, 7 m long, were cut from the base of each sample tree and then recut into two 3.5-m logs for chipping. The 5- and 6-year-old logs were chipped separately at the TITC sawmill. Each log was chipped individually, oversize and undersize chips were removed and samples of chips collected at regular intervals to represent the whole log. The chip samples from each log were bulked, mixed and a 10- kg sample from each age class removed for kraft pulping.

Chip density

Chip basic density was determined in accordance with Appita method P1s-79, except that the fresh chips were not given the specified soaking period.

Chip chemical analyses

Chip samples were air-dried, ground in a Wiley mill to pass a 20-mesh screen, extracted with dichloromethane overnight in a Soxhlet extractor, reground to pass a 60-mesh screen and submitted to Paprican in Canada for chemical analysis. The total lignin was reported as the sum of the acid-insoluble (Klason) lignin plus acid-soluble lignins, determined according to Tappi Standard T222-OM88 and Tappi Useful Method UM250 respectively. Carbohydrates were determined according to Tappi Standard T249 CM85.

Pulping

Chips were pulped, as supplied, to kappa number 20±2 in a 2.0 L pressurised reactor as follows:

300 g o.d. chip charge
14% effective alkali as Na_2O
30% sulphidity
4:1 liquor-to-wood ratio
90 minutes to maximum temperature
160°C maximum temperature

H-factor was varied by varying the pulping time at maximum temperature. Pulps were disintegrated with a propeller stirrer at 1% consistency and screened through a 0.25-mm slotted flat screen. After dewatering and fluffing, kappa number, percentage rejects and total yield were determined. Kappa numbers for the two *E. maidenii* pulps that were analysed, one from 5-year old and the other from 6-year-old trees, were both 18.7.

Handsheet preparation and evaluation

Handsheets were prepared and pulp physical evaluations made in accordance with Appita standard procedures. The load applied during pulp refining with the PFI mill was 1.77 N/mm. 24-g oven-dried (o.d.) pulp charges were refined at 10 % stock concentration for 500, 1000, 2000 and 4000 revs. Handsheet data are presented on an o.d. basis.

Fibre dimension measurement

Cross-sectional kraft fibre dimensions of thickness, width, wall area and wall thickness were measured using image processing procedures described previously (Figure 1) (Kibblewhite and Bailey 1988). Measurements were made on dried and rewetted fibres reconstituted from kraft handsheets. The product, fibre width × fibre thickness, is the area of the minimum fibre cross-section-bounding rectangle. The ratio, width/thickness, is an indicator of the collapse potential of the dried and rewetted fibres. The greater the width and the lower the thickness of a fibre cross-section, the greater is the extent of fibre collapse. The relative number of fibres per unit mass of pulp was calculated using the reciprocal of the length × wall-area product. Length-weighted average fibre lengths were determined with a Metso FiberLab3 instrument using PAPRO standard procedures (Richardson *et al*. 2003).

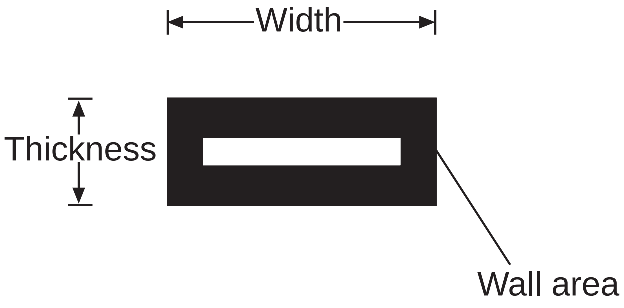

Figure 1: Cross-section diagram of a fibre dried and rewetted from a handsheet.

RESULTS AND DISCUSSION

The 5-year-old *E. maidenii* from Waihi and the 6-year-old trees from Kawerau had very similar chip density, 549 and 554 kg/m^3; kraft pulp yields, 53.0 and 52.4%; and wall thickness, both 2.43 µm (Table 2). Furthermore, delignification rate and chemical consumption were similar for both samples. The fibre length of the 5-year-old material, however, was significantly greater than that of the 6-year-old, the reverse of what might be expected. Fibre length of the 8- and 11-year-old trees in the earlier study increased strongly with age (Table 2). Relative numbers of fibres and sheet density values are different for the two samples, with the 6-year-old trees being highest. Pulp yields of the 5- and 6-year-old samples were lower by 1-2 % compared to those from older trees (Table 2), as expected (Kibblewhite *et al.* 2000). Cooking chemical requirement was also slightly greater for the 5- and 6- year-old samples.

Chip lignin and xylose contents were marginally lower, and glucose contents marginally higher than expected for the six-year-old sample, when compared to those for the older trees of earlier studies (Table 3). Some differences between the old and new values are to be expected with the analyses being made in different laboratories using somewhat different analytical procedures. For chips from the five-year-old trees, on the other hand, lignin and xylose contents were markedly lower, and glucose contents markedly higher than those from the six-year-old trees, and very different from those for older trees from earlier studies. In summary, therefore, chip chemical composition and pulp fibre length were the only properties which showed clear differences between the five- and six-year-old *E. maidenii* samples (Tables 2, 3).

The pulp fibre dimensions of wall area, wall thickness and perimeter are very similar for the 5- and 6-year-old samples, but lower compared to those of eucalypt pulps considered to be of premium quality, e.g. *E. maidenii* 8- year and *E. globulus* 11-year, (Kibblewhite *et al.* 2000). However, the *E. maidenii* fibres from 5- and 6-year-old trees, while of low wall area, or coarseness, show a resistance to collapse comparable to that of the 8-year *E. maidenii* and 11-year *E. globulus* pulps. Therefore, compared with pulps from the older trees, numbers of fibres are increased with the retention of handsheet bulk and a consequent improvement in web formation, provided the fibres are of sufficient length.

Kraft handsheet density (or bulk which is the reciprocal of density) and tensile index values over the 500-4000 rev PFI mill refining range for the *E. maidenii* samples from 5- and 6-year-old-trees, are listed in Table 4, together with previously reported data for *E. maidenii* from 8- and 11-year-old-trees, and *E. globulus* from 11-year-old trees. The 5-year *E. maidenii* sheet density, bulk and tensile index values and interrelationships match those of the 8-year *E. maidenii (Figure 2)* and 11-year *E. globulus* pulps (Kibblewhite *et al.* 2000). In contrast, these property relationships are poor for the 6-year *E. maidenii* pulp because of the lower fibre length.

The handsheet properties of bulk, density and tensile index are important determinants of eucalypt kraft pulp quality (Kibblewhite *et al.* 2000). Eucalypt pulps most suitable for papermaking have handsheet densities within the range 600-650 kg/m3, and tensile index values within the range 80-100 N.m/g at 500 PFI mill rev (Table 4). These values are for pulps produced in the laboratory and equate roughly to 560-610 kg/m^3 and 34-54 N.m/g for market eucalypt kraft pulps. Hence, the *E. globulus* pulp made from 11-year old trees, and the *E. maidenii* pulp made from the 5- and 8-year-old trees, have fibre properties most suitable for a market kraft end-use. The tensile index and/or sheet density values at 500 rev of the six- and 11-year *E. maidenii* fall outside the ranges for a laboratory pulp and are therefore unsuitable for most eucalypt market pulp end-uses. The 6-year *E. maidenii* pulp has excellent tensile index values, fibre cross-section dimensions and fibre collapse resistance, but with fibre lengths below that required to maintain handsheet bulk.

Table 2: Chip density, and kraft pulp yield and fibre dimensions for *E. maidenii* aged 5- and 6-years; and corresponding data for *E. maidenii* trees aged 8- and 11-years, and *E. globulus* aged 11-years (Kibblewhite *et al.* 2000).

	Chip Density (kg/m^3)	Pulp yield (Kappa 20) (%)	Length (mm)	Perimeter (μm)	Wall area (μm^2)	Wall thickness (μm)	Width/ thickness	Relative number	Sheet density (@ 500 rev) (kg/m^3)
E. maidenii 5 yr	549	53.0	0.84*	38.10	57.22	2.43	1.84	115	613
E. maidenii 6 yr	554	52.4	0.78*	37.53	55.75	2.43	1.87	127	645
E. maidenii 8 yr	569	55.3	0.88	40.7	64	2.59	1.81	98	607
E. maidenii 11 yr	576	55.5	0.94	42.9	73	2.80	1.83	81	566
E. globulus 11 yr	543	54.5	0.85	40.4	62	2.48	1.81	105	629
LSD**	35	1.9	0.04	1.7	6.6	0.29	0.20	20	19

* *E. maidenii* 5-year and 6-year FiberLab3 length values after decrease of 0.06 mm based on calibration curve FS200-FiberLab3 (unreported data).

** Least significant difference (0.05 level) for chip-pile sampling, based on *E. fastigata* (Riddell and Kibblewhite 1999).

Table 3 : Chemical composition for *E. maidenii* aged 5- and 6-years; and corresponding data for *E. maidenii* trees aged 8- and 11-years, and *E. globulus* aged 11-years (Kibblewhite *et al.* 2000).

Sample	**Chip density**	**Pulp yield (kappa 20)**	**Total lignin**	**Carbohydrates (% of total carbohydrates)**	
	(kg/m³)	**(%)**	(%)	Glucose	Xylose
E. maidenii 5 yr	549	53.0	22.9	84.1	11.1
E. maidenii 6 yr	554	52.4	27.5	76.2	18.6
E. maidenii 8 yr	569	55.3	31.8	73.9	20.4
E. maidenii 11 yr	576	55.5	28.8	73.6	20.3
E. globulus 11 yr	543	54.5	27.4	74.6	20.4

Table 4: Handsheet density, bulk and tensile index data (o.d. basis) at four refining levels for *E. maidenii* aged 5- and 6-years; and corresponding data for *E. maidenii* aged 8- and 11-years, and *E. globulus* aged 11-years (Kibblewhite *et al.* 2000).

Sample	PFI mill rev	Apparent density (kg/m^3)	Bulk (cm^3/g)	Tensile index (N.m/g)
E. maidenii 5-year	500	613	1.63	85.1
	1000	625	1.60	94.2
	2000	Unavailable	Unavailable	Unavailable
	4000	705	1.42	119.0
E. maidenii 6-year	500	645	1.55	86.7
	1000	658	1.52	91.7
	2000	692	1.44	110.8
	4000	738	1.36	119.3
E. maidenii 8-year	500	607	1.65	81
	1000	625	1.60	91
	2000	662	1.51	104
	4000	713	1.40	125
E. maidenii 11-year	500	566	1.77	72
	1000	598	1.67	82
	2000	634	1.58	93
	4000	677	1.48	110
E. globulus 11-year	500	629	1.59	85
	1000	651	1.54	94
	2000	688	1.45	106
	4000	735	1.36	119

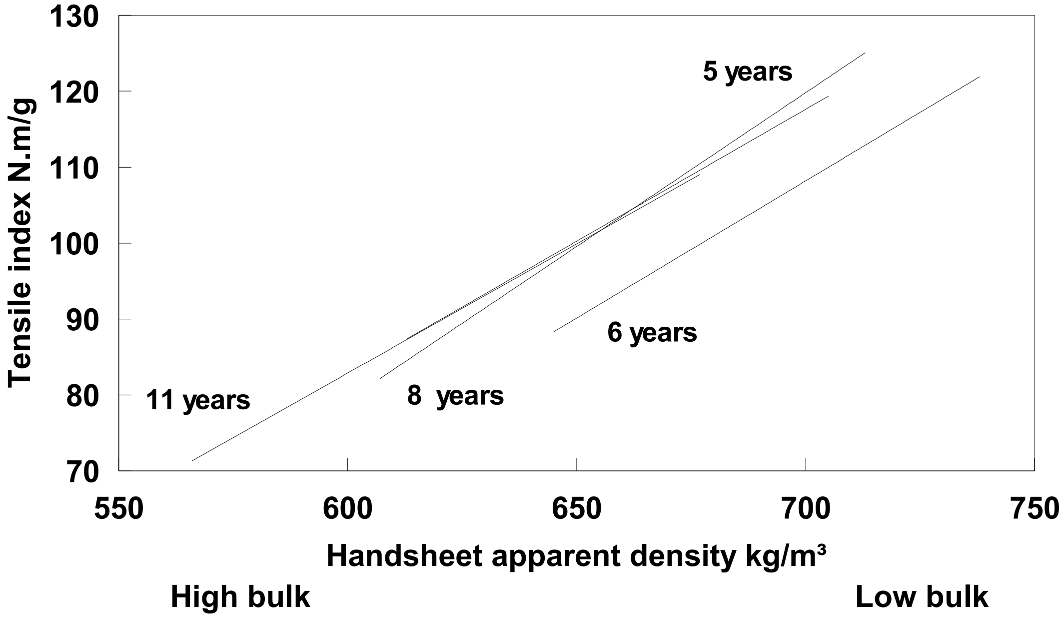

Figure 2: Handsheet tensile index *versus* apparent density regressions based on four PFI mill refining levels for the 5-, 6-, 8- and 11-year *E. maidenii* pulps (Table 3).

The longer fibre length of the pulp, and the very different chemistry of the chips, from 5-year-old trees from the irrigated pasture site at Waihi versus the 6-year-old trees from the scrub site at Kawerau may be due to a combination of genetic and environmental effects. As the trees sampled from both sites were based on large numbers of parents, though not from the same populations, it seems unlikely that the chip chemistry and fibre length differences are primarily genetic. The site at Waihi was a previously topdressed pasture which, after tree planting, had been repeatedly irrigated with sewerage effluent (Gearing *et al.* 2003), in contrast to the untreated site at Kawerau, previously covered by manuka scrub. It seems likely that irrigation plus fertility have given the 5-year-old trees longer fibres than expected for their age. Beadle *et al.* (2001) reported an increase in the fibre length of 6-year-old *E. nitens* in response to irrigation in an experiment in southern Tasmania.

Compared to all other *E. maidenii, E. globulus* and *E. nitens* samples previously assessed (Kibblewhite *et al.* 2000), the very high chip glucose, and low lignin and xylose contents from the five-year-old irrigated material is noteworthy. A high glucose (cellulose) content in a pulp can only be expected to retain or increase fibre collapse resistance and, together with longer fibres, increase handsheet bulk. Hence, the chemistry of the five-year-old sample show it to be the odd-man-out, probably as a result of intensive irrigation with sewerage effluent.

CONCLUSIONS

The fibre and pulp properties of the 5-year-old and 6-year-old *E. maidenii* samples are very similar, except for fibre length (and chip chemical composition). The 5-year sample has the longest fibres (0.84 mm) and has excellent papermaking properties. With high numbers of fibres/mass the 5- and 6-year-old are probably superior to the 8-year *E. maidenii* and 11- year *E. globulus* samples reported previously. However, the shorter fibre length of the 6-year *E. maidenii* sample (0.78 mm) is below the critical value required to produce the handsheet bulk of a premium kraft pulp.

The abnormally high glucose content, but low lignin and xylose contents, of the chips from 5-year-old trees, together with the excellent papermaking properties of the pulp made from them, are noteworthy. The chemistry of the five-year-old material is out-of-line with that of all other eucalypt samples previously assessed (Kibblewhite et al. 2000), including the six-year-old *E. maidenii* of this study (Table 3). It is suggested that the excellent papermaking properties obtained with chips from the five-year-old trees (compared to the six-year-old material) could be related to the irrigation of trees with sewerage effluent. The pulp from the six-year-old material is deficient in handsheet bulk, indicating for the Kawerau site that stand rotation age should be increased by at least one year.

Further pulp quality assessment of *E. maidenii* tree-age, growing-site and nutrient/water trials are suggested:

- The apparent effect of stand irrigation with sewerage effluent on crop rotation age and pulp quality needs to be confirmed.
- Interactive influences of rotation age, growing-site and seed-source on pulp quality also need to be further understood.

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