Pulping characteristics of reafforestation species grown in Solomon Islands (ODNRI Bulletin No. 32)

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OVERSEAS DEVELOPMENT NATURAL RESOURCES INSTITUTE
BULLETIN

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PULPING CHARACTERISTICS OF REAFFORESTATION SPECIES GROWN IN SOLOMON ISLANDS

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SUMMARY

Samples of *Pinus caribaea, Pinus oocarpa, Campnosperma brevipetiolata, Eucalyptus deglupta, Terminalia brassii* and *Terminalia calamansanai,* all of which have shown potential for growing in plantations in Solomon Islands, were examined to determine their potential value for the production of pulpwood chips for export.

Details are given of growing conditions, size of trees, wood characteristics, fibre dimensions and pulping by sulphate, soda and soda/anthraquinone processes.

P. caribaea, P. oocarpa, C. brevipetiolata and *E. deglupta* were all considered promising for the production of pulpwood. *T. brassii* and *T. calamansanai,* both of which required very severe chemical conditions to pulp, were not considered promising.

RESUME

Des échantillons de *Pinus caribaea, Pinus oocarpa, Campnosperma brevipetiolata, Eucalyptus deglupta, Terminalia brassii* et *Terminalia calamansanai,* essences qui ont toutes démontré une vocation de culture dans des plantations aux îles Salomon, ont été examinés pour en déterminer la valeur potentielle pour la production de copeaux pour pulpe de bois en vue de l'exportation.

Des détails sont fournis sur les conditions de croissance, la dimension des arbres, les caractéristiques du bois, celles des fibres et la pulpage par des processus au sulfate, à la soude et á la soude/anthraquinone.

P. caribaea, P. oocarpa, C. brevipetiolata et *E. deglupta* ont tous été considérés comme aptes à produire de la pulpe de bois. *T. brassii* et *T. calamansanai,* dont le pulpage exigeait un traitement chimique très fort, n'ont pas été considérés comme intéressants.

RESUMEN

Se llevó a cabo el examen de muestras de *Pinus caribaea, Pinus oocarpa, Campnosperma brevipetiolata, Eucalyptus deglupta, Terminalia brassii* y *Terminalia calamansanai,* que han demostrado tener potencial para su cultivo en plantaciones de las Islas Salomón, con objeto de poder determinar su valor potencial para la obtención y exportación de astillas para la producción de pasta de madera.

Se proporcionan detalles sobre las condiciones de cultivo, evergadura de los árboles, características de la madera, dimensiones de la fibra y producción de pasta al sulfato, a la sosa y a la sosa/antraquinona.

P. caribaea, P. oocarpa, C. brevipetiolata y *E. deglupta* fueron consideradas como especies prometedoras para la producción de pasta de papel. *T. brassii* y *T. calamansanai* no fueron juzgadas como prometedoras, ya que requieren ser sometidas a condiciones químicas muy fuertes para su conversión en pasta.

Pulping characteristics of reafforestation species grown in Solomon Islands

INTRODUCTION

In Solomon Islands the Forestry Division has a reafforestation programme involving the planting of 1400 ha per year: 50,000 ha of designated forest land is immediately available, but it is expected that the final plantation area will be greater. In addition to the area of Government-owned plantations it is expected that there will be a minimum of 10,000 ha of commercially operated plantations.

Government policy is to establish plantations for the production of sawlogs but the production of pulpwood chips for export, either from plantations grown specifically for that purpose and clear felled at relatively short rotations, or from thinnings and offcuts of species grown for timber, is expected to become a major industry.

Nineteen species, listed below, were screened as potential subjects for evaluation in this study. The list included the current major plantation species, species which had previously been planted on a major scale, and species which had given indications of promise in research trials. *Gmelina arborea* was evaluated in a previous study (Palmer *et al.*, 1984).

(i)	*Terminalia brassii*	Current major plantation species for sawlog production
(ii)	*Tectona grandis*	Current major plantation species for high quality sawlog production
(iii)	*Swietenia macrophylla*	
(iv)	*Agathis macrophylla*	
(v)	*Campnosperma brevipetiolata*	Previously major plantation species for sawlog production
(vi)	*Terminalia calamansanai*	
(vii)	*Eucalyptus deglupta*	
(viii)	*Parasarianthes falcataria*	Good growth rates, potential pulp-wood production species
(ix)	*Octomeles sumatrana*	
(x)	*Anthocephalus chinensis*	
(xi)	*Acacia mangium*	
(xii)	*Pinus caribaea*	Potential species for grassland afforestation
(xiii)	*Pinus oocarpa*	
(xiv)	*Endospermum medulosum*	Potential high quality sawlog species with indication of good growth rates

(xv)	*Eucalyptus urophylla*	Potential pulpwood and sawlog production species
(xvi)	*Artocarpus integer*	Potential sawlog production species
(xvii)	*Araucaria cunninghamii*	
(xviii)	*Cordia alliodora*	Potential high quality sawlog species
(xix)	*Calophyllum kajewskii*	

A study of published information on the utilization of all these species identified 11 species requiring evaluation. Finally six species, *Pinus caribaea, P. oocarpa, Campnosperma brevipetiolata, Eucalyptus deglupta, Terminalia brassii* and *T. calamansanai* were selected for full evaluation. The number of species evaluated was limited to six by the financial resources available. The following species, all of which have a prima facie case for evaluation, were given a lower priority because of limited availability of suitable material but should have high priority in any future investigation: *Acacia mangium, Anthocephalus chinensis, Endospermum medullosum* and *Octomeles sumatrana*.

GROWING CONDITIONS

Details of site location and growing conditions are summarized in Table 1.

SAMPLING

Each species provided one sample, which was selected by the following method.

Ten trees with random distribution within a plot were selected. Their height and girth at breast height were measured and the trees felled. The length of the tree from butt to 8 cm diameter was measured and sampling points marked at 10, 30, 50, 70 and 90% of that length. At each sampling point a number of discs, each 20 mm thick, were cut, their diameter over- and under-bark measured, the bark removed, and the discs air dried before being sent to the Overseas Development Natural Resources Institute's (ODNRI) Laboratories in London.

The age of the trees sampled was as follows:

P. caribaea	12 years 7 months
P. oocarpa	12 years 8 months
C. brevipetiolata	10 years 2 months
E. deglupta	8 years 7 months
T. brassii	8 years 11 months
T. calamansanai	8 years

EXPERIMENTAL PROCEDURES, RESULTS AND DISCUSSION

The bark content of trees was calculated from the measurement of over- and under-bark diameter.

Wood density and chemical composition were determined using the standard methods published by the Technical Association of the Pulp and Paper Industry (TAPPI) in the USA.

Wood chips were pulped in a stationary digester with forced circulation of liquor, by the sulphate, soda and soda/anthraquinone processes. Suitable pulps were bleached using a four-stage process of sequential applications of chlorine, sodium hydroxide, sodium hypochlorite and chlorine dioxide. All of the pulps were evaluated by beating in a PFI Mill, forming sheets on British Standard Sheet Machine and testing the sheets, after conditioning in an atmosphere of 23°C and 50% relative humidity, by the appropriate British and International Standard Methods.

A detailed description of experimental methods can be found in *ODNRI Bulletin* No. 7 (Palmer *et al.*, 1988).

Size of trees and wood production

The dimensions, bark content and wood density of trees are reported in Table 2.

The average dimensions of the trees of *P. oocarpa* were greater than those of the trees of *P. caribaea; P. oocarpa* had the lower bark content. These two facts indicate that *P. oocarpa* produces the larger volume of wood. However, the variability within the sample was so great that the difference was not statistically significant and the tentative conclusion would need to be confirmed by measurement of a much larger sample.

The combination of tree dimensions and bark content rank the hardwoods in the following order for volume of wood production: *E. deglupta, T. brassii, T. calamansanai, C. brevipetiolata*. The difference in dimensions between *E. deglupta* and *T. brassii* and that between *T. brassii* and *T. calamansanai* were statistically significant. The difference in dimensions between *T. calamansanai* and *C. brevipetiolata* was not significant but the latter species was placed last because the trees sampled were two years older than for the former species.

Wood density

Wood density is an important parameter in determining the economic suitability of a species for use as pulpwood, especially for export of pulpwood chips. Low density wood leads to high transport cost because wood chips have a lower bulk density than the solid wood, and high pulping costs because of low efficiency of the use of digester capacity.

The most likely use of pulpwoods grown in Solomon Islands is for export in chip form to destinations such as Japan. The Japanese Overseas Afforestation Association (JOAA) consider a wood density of 350 kg m^{-3} satisfactory (Fenton *et al.*, 1977). Consequently it was decided to measure the density of a disc at the 10% sampling point from each tree felled. If the average density of the 10 discs from each species was <300 kg m^{-3}, that species would be eliminated from the examination. The values of wood density determined at ODNRI are reported in Table 2. The values determined in Solomon Islands are not recorded but were within 10% of those determined at ODNRI.

Values for the density of *P. caribaea* (445 kg m^{-3}) and *P. oocarpa* (455 kg m^{-3}) were not significantly different. They were a further pointer towards *P. oocarpa* producing more wood per unit area, but the difference was small and, for these samples, not statistically significant. The measured density at the sampling point at 90% of the height of the tree was only 85% of that at the 10% sampling point. This finding would be of practical importance if multiple use forestry were practised, with the lower parts of the tree being used for timber and the upper parts for pulpwood.

The values of average wood densities of hardwood species were: *C. brevipetiolata*, 310 kg m^{-3}; *E. deglupta*, 390 kg m^{-3}; *T. brassii*, 325 kg m^{-3}; *T. calamansanai*, 330 kg m^{-3}. The density of *E. deglupta* was significantly higher than that of the other hardwoods. These values confirm that *E. deglupta* would be expected to produce most wood per unit area, followed by *T. brassii, T. calamansanai* and *C. brevipetiolata*.

The variation of wood density within the tree differed greatly for the different species. Wood from the uppermost sampling point of *C. brevipetiolata* was little different from that from the lowest sampling point: for *E. deglupta* the uppermost wood was 20% more dense; for *T. brassii* it was about 10% less dense; and for *T. calamansanai* it was >20% less dense.

Chemical analysis

The major chemical components of wood likely to influence their pulpability were determined and are reported in Table 3.

There was little difference between the two *Pinus* species. No difficulty was expected in pulping by the sulphate process using conditions usually applied to pines.

The lignin and holo-cellulose contents of *C. brevipetiolata* (26.1%, 68.6%), *E. deglupta* (27.2%, 72.2%) and *T. brassii* (26.3%, 69.8%), were similar to each other and to *Gmelina arborea* (26.5%, 66.8%). Consequently, all these species would be expected to be pulped using similar pulping conditions. *T. calamansanai* had a higher lignin content (29.8%) and lower holo-cellulose (62.9%); consequently this species was expected to need more severe digestion conditions and give a lower yield.

Fibre dimensions

The fibre length of all six species was determined by fractionation and the length, width and wall thickness of *P. caribaea, P. oocarpa* and *E. deglupta* determined by measurement of the magnified image. The values determined are reported in Table 4.

The samples of *P. caribaea* and *P. oocarpa* showed little difference either in the average length of fibres or in the proportion of fibres of different lengths within the sample, the average value of >3 mm being typical of tropically grown pines. *P. caribaea* had narrower, thinner walled fibres. Such fibres would be expected to be more flexible and give a better bonded sheet. The fibres were wider and thicker walled than those usually found in temperate pines, but this finding is also typical for tropically grown pines.

There was no difference in the average length of fibres from the four hardwood species. *C. brevipetiolata* and *E. deglupta* had the smallest proportion of fibres retained on the coarsest screens. Since fine fibres give paper with lower tearing strength than coarse fibres, these species would be expected to yield pulps with lower tearing strength than the *Terminalia* species. The width (18.4 μm) and wall thickness (3.2 μm) of fibres from *E. deglupta* were typical of values found in young, fast grown samples of *Eucalyptus* spp.

Chemical pulping and pulp evaluation

Sulphate pulping

All of the samples were digested by the sulphate (kraft) process. On each species three sets of digestion conditions were used in which the quantity of chemical applied was varied to obtain pulps with different yields and residual lignin contents. The most severe conditions were intended to yield a bleachable grade of pulp. For most sets of conditions only one digestion was made but for one set on each of *P. caribaea, P. oocarpa, C. brevipetiolata* and *E. deglupta*, one cook was duplicated to obtain additional pulp for bleaching trials. All three digestion conditions were duplicated for *T. brassii*. Where digestions were repeated the value reported for yield, and evaluation of unbleached pulps is the mean of two determinations.

The pulping conditions, yield and physical characteristics of pulps from the two *Pinus* species are given in Table 5. Both species were pulped successfully using the same pulping conditions, and, consequently, could be pulped as a mixture. The yield of pulp from *P. oocarpa* was a little higher than that from *P. caribaea*. *P. caribaea* yielded the stronger pulp: in bursting and tensile strength the advantage was 3 to 5%, but the advantage in tearing strength was much more significant at about 20%.

Pulps from softwood species are most likely to be used in the production of sack kraft and wrapping papers. The minimum strength requirements of these grades have been quoted as:
sack kraft – tensile index >60 N m g^{-1}, tear index >14 mN m^2 g^{-1};
wrapping paper – tensile index >45 N m g^{-1}, tear index >12.5 mN m^2 g^{-1}.
Both *Pinus* species yielded pulps which met the tensile strength requirement, but neither met the tearing strength requirement. Older pine trees usually yield pulps with higher tearing strength, consequently older samples, especially *P. caribaea*, could be expected to yield pulps of higher tearing strength. Commercially the higher strength of pulps from *P. caribaea* would counterbalance the small advantage of *P. oocarpa* in yield of wood and pulp.

The pulping conditions, yield of pulp and physical characteristics of pulps from the four hardwood species are recorded in Table 6.

E. deglupta was the easiest wood to pulp and yielded the highest quality of pulp: using a relatively mild chemical concentration (15% active alkali) it yielded almost 51% of a bleachable grade of pulp. *C. brevipetiolata* required more severe conditions (17.5% active alkali) and yielded less pulp (about 48%). *Gmelina arborea* (see Table 7 which is taken from Palmer *et al.*, 1984) yielded nearly 50% of bleachable pulp using marginally more severe conditions than *E. deglupta* but less severe than *C. brevipetiolata*. The differences in digestion conditions required by these three species were so small that they could be pulped in mixture, but the proportions of the constituents of the mixture would need to be constant to maintain an output of uniform pulp. Pulps from both these species and *G. arborea* compared favourably with unbleached pulps from woods used commercially (see Table 12). They had the potential to yield bleached pulps suitable for printing and writing papers, and were subsequently used for bleaching trials.

The *Terminalia* species were much more difficult to pulp. *T. brassii* was pulped using up to 22.5% active alkali to yield 44.6% of pulp with a kappa number of 32.9. Such a pulp would not be bleachable. *T. calamansanai* was equally difficult to digest and yielded even less pulp (42% with a kappa number of 43). The difficulty in digesting *T. brassii* could not have been predicted from the determination of wood density and chemical composition. *T. calamansanai* was expected, from chemical analysis, to be difficult to pulp, but proved to be even more difficult than expected. These species could not be pulped in mixture with *C. brevipetiolata, E. deglupta* and *G. arborea*. The strength characteristics of these pulps were good for a hardwood pulp. However, as is typical of hardwood pulps, the tearing strength was lower than that of softwood pulps. Consequently, pulps from the *Terminalia* species were not suitable for use in high grade packaging papers. Since the pulps could not be bleached economically, in order to be used in printing and writing papers, it is unlikely that these *Terminalia* species could be used as pulpwood.

Chemical digestions using sulphur-free liquor

To investigate the effect of pulping without the use of sulphur, *C. brevipetiolata* and *E. deglupta* were pulped using the soda process and the soda/anthraquinone process: the digestion conditions, yield and physical characteristics of the pulp are reported in Table 8. Each species was pulped using the same alkali concentration as had been required to produce a bleachable grade of pulp when using the sulphate process. Soda alone yielded a pulp with a much higher lignin content and generally weaker than the sulphate pulp. Soda with 0.1% anthraquinone yielded a pulp with yield, lignin content and strength characteristics very similar to those obtained by sulphate pulping.

Additional digestions of *Terminalia* spp.

The results obtained in pulping the *Terminalia* species were unexpected. Chemical analysis of both species had shown that the wood had a lignin content of <30% and nothing else indicated that the wood would be difficult to pulp. Nevertheless, very severe pulping conditions applied to *T. brassii*, had yielded a pulp with a high kappa number (22.5% active alkali yielding pulp with a kappa number of 33), indicating a high lignin content of pulp. Samples of 6- to 9-year-old *T. brassii* grown in Fiji had been equally difficult to pulp (Palmer *et al.*, 1983). However, there are a number of other reports which do not mention excessive problems. Fenton (1977) reports previously unpublished Japanese work where pulp with a kappa number of 33 was obtained from an 11-year-old sample grown in Solomon Islands using 16% active alkali. Phillips and Logan (1976) reported that 4-, 6- and 9-year-old samples from Papua New Guinea needed more severe pulping conditions than *E. deglupta*; even so pulps with a kappa number of about 20 were obtained using 16% active alkali.

To confirm that these samples from Solomon Islands were difficult to pulp, all of the digestions on *T. brassii* were duplicated. The repeat digestions were within 2% of the original digestions for pulp yield, 4% for kappa number, 7% for tearing strength, 5% for tensile strength and 4% for bursting strength. Thus, the validity of the first digestions was confirmed.

Secondly a sample was digested using precisely the pulping conditions reported by Fenton *et al.* (1977), to yield 48.6% of screened pulp with a kappa number of 33. The sample being examined in the present study yielded 46.7% of screened pulp with a kappa number of 69 (Cook No. 457 in Table 9).

T. brassii was pulped by the sulphate process with 0.1% anthraquinone added to the digestion liquor to see if this increased the rate of reaction and yielded a pulp with a lower lignin content. The data, reported in Table 9, showed that in yield and lignin content pulps obtained using sulphate and sulphate/anthraquinone digestion liquors were not significantly different.

Finally both *Terminalia* species were pulped using the soda and soda/anthraquinone process: details of pulping conditions, pulp yielded and physical characteristics are reported in Table 9.

Soda pulping of both *Terminalia* species gave a slightly higher yield of pulp with a much higher kappa number than was obtained by sulphate pulping; the increased yield was probably the result of the higher lignin content. Soda anthraquinone pulping gave pulps with yields and kappa numbers similar to those obtained by sulphate pulping.

Bleaching trials

One pulp obtained from *C. brevipetiolata* and one from *E. deglupta* were bleached by a four-stage sequence of successive applications of chlorine, sodium hydroxide, sodium hypochlorite and chlorine dioxide. Details of bleaching conditions and bleached pulp characteristics for both species, with those for *G. arborea* (previously examined) are reported in Table 10.

The amount of chlorine applied in the first stage was determined by the kappa number of the bleached pulp: the chemicals applied in subsequent stages were the same for both pulps. Both pulps consumed the same amount of chlorine (9.7%) and the bleached pulps had a good brightness (*C. brevipetiolata* 87, *E. deglupta* 88.5). Only one bleaching trial was made without determining the optimum conditions; using optimum conditions or more bleaching stages it should be possible to produce a pulp with higher brightness. The loss of yield on bleaching was about 6%, and the strength of bleached pulp was related to that of the unbleached pulp: tensile and bursting strength about 10% lower and tearing strength about 10% higher. *C. brevipetiolata, E.*

deglupta and *G. arborea* could all be used to produce bleached pulp suitable for use in printing and writing papers. *C. brevipetiolata* gave the lowest yield (44.6%) and *E. deglupta* the highest (47.7%). The difference between the strongest and weakest pulp was about 10% for tensile and bursting strength: *C. brevipetiolata* 109, 6.68; *E. deglupta* 105, 6.1; and *G. arborea* 95, 6.03. In tearing strength the difference was greater, over 35%: *C. brevipetiolata* 6.8, *E. deglupta* 10.6 and *G. arborea* 9.5. Consequently, *E. deglupta* would be preferred on the basis of pulp yield and strength, followed by *G. arborea* and *C. brevipetiolata*.

Potential for production of pulpwood chips for export

The criteria considered by the JOAA to make wood suitable for the production of chips are that it should have a minimum density of 350 kg m^{-3}, that the pulp yield should be above 45% with a kappa number of 25, that the pulp should have a tensile index of 78 N m g^{-1} and a tear index of 12.8 mN m^2 g^{-1} at a Canadian Standard Freeness (CSF) value of 500, and that this strength be developed in about 4000 revolutions in a PFI mill (Fenton *et al.*, 1977). Neither the species examined nor *G. arborea* met all of these criteria. Both *Pinus* species met the criteria for density and tensile strength; if grown on a longer rotation both, but especially *P. caribaea*, would be expected to meet the tearing strength; the pulp yield was low. *C. brevipetiolata* met the criteria for pulp yield and tensile strength, but its wood density was low and the tearing strength of pulp low. *E. deglupta* and *G. arborea* met the criteria for wood density, pulp yield and tensile strength, but tearing strength was low. These five species were considered to be promising. The *Terminalia* species met only the criteria for tensile strength of pulp, but required very severe digestion conditions and cannot be considered as promising sources of pulpwood.

Comparison with commercial pulpwoods

The most useful way of assessing the potential of an unknown pulpwood is to compare it with pulpwoods used industrially. For this purpose Table 11 reports on five softwoods and Table 12 on three hardwoods that have been evaluated in ODNRI using the same techniques as were used in the current investigation.

P. caribaea and *P. oocarpa* could be pulped using the same digestion conditions as were required for the commercial pulpwoods, but for both these species the pulp yield was low. In general their pulps were weaker, but the tearing strength of pulps from *P. caribaea* approached that of pulps from fast grown pines, although not that of temperate pines.

E. deglupta could be pulped using digestion conditions similar to those suitable for hardwoods used industrially. The pulp yield was high and strength characteristics compared favourably. *C. brevipetiolata* required slightly more severe conditions, but the yield was comparable, the tensile and bursting strengths a little higher and the tearing strength a little lower. *Terminalia* species required much more severe digestion conditions, the yields were low, the lignin content of pulps so high that they could not be considered bleachable, but the tensile and bursting strengths were high.

Conclusions

1 *P. caribaea* and ***P. oocarpa***. The size of trees in the sample, the wood density and the proportion of bark in the trees all indicated that *P. oocarpa* produces more wood per unit of land used. The differences were small and would need to be confirmed with larger samples.

Easily digested by the sulphate process, both species yielded around 41% of unbleached pulp: the yield from *P. oocarpa* was the higher by about 0.5%. The pulp from *P. caribaea* had the better strength characteristics: for tearing strength the advantage was about 20%. This factor could make *P. caribaea* the preferred species for the growing conditions in Solomon Islands. The tearing strength of the pulps from *P. caribaea* was too low to be suitable for strong wrapping or sack papers, but older material would be expected to yield pulps with a higher tearing strength.

2 *C. brevipetiolata* was the slowest grown of the four hardwoods. It required slightly more severe pulping conditions than *E. deglupta*, yielding about 48% of bleachable pulp with good strength characteristics.

3 *E. deglupta* had the largest trees, the least bark and the highest density and gave the highest yield of pulp of the four hardwoods examined. It yielded just over 50% of bleachable pulp with good strength characteristics.

4 *T. brassii* and ***T. calamansanai***. Both of these species required very severe pulping conditions, and even the most severe tried did not yield a bleachable grade of pulp. The pulp yield was low (42 to 45%).

5 *G. arborea* had a higher wood density (435 kg m^{-3} at 8 years old) than *E. deglupta* (390 kg m^{-3}). Both species were pulped using the same conditions and yielded similar quantities of pulp with similar strength characteristics (Palmer *et al.*, 1984).

6 Suitability of production of pulpwood chips for export. None of the species met all of the criteria specified by JOAA. *P. caribaea, P. oocarpa, C. brevipetiolata* and *E. deglupta* met most of them. Pulps from *T. brassii* and *T. calamansanai* met some of the pulp strength criteria but because of the difficulty in pulping cannot be considered promising.

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Table 1

Growing conditions

Species	Location: Lat.	Location: Long.	Elevation m	Annual rainfall mm	Drainage	Soil	Land system	Slope	Silviculture
P. caribaea and *P. oocarpa*	9°27′S	159°59′E	150	2032	Free	Sandstone	Lenga kiki	Gentle to moderate	Originally grassland; tree spacing 3 m×3 m; no thinning
C. brevipetiolata	7°13′S	151°10′E	76	3500	Free	Deep red clay	Ringgi	Flat	Tree spacing 10 m×3 m; no specific silvicultural treatment
E. deglupta	8°25′S	157°34′E	Below 100	3556	Free	Deep red clay	Ringgi	Almost flat to gentle	Tree spacing 10 m×3 m; no specific silvicultural treatment
T. brassii	Approx. 8°S	157°10′E	200	3500	Free	Deep red clay	Ringgi	Moderate to river	Tree spacing 7.5 m×3 m
T. calamansanai	8°25′S	157°34′E	0-20	3500-3600	Swampy; no surface drainage	Coral forming; areas of clays	Alokan	Flat	Tree spacing 10 m×3 m; no specific silvicultural treatment

Table 2

Dimensions, bark content and wood density

	Height to 8 cm diam., m		Total height, m		Diameter breast height over bark, cm		Bark by volume, %		Density, kg m^{-3}	
Species	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
P. caribaea	12.8	7.9-15.3	16.7	13.4-20.1	25.0	21.8-31.0	20	16-23	445	365-510
P. oocarpa	13.8	10.1-20.4	18.0	14.2-24.1	25.1	17.4-36.5	17	14-22	455	385-505
C. brevipetiolata	14.5	10.4-16.7	17.6	14.1-20.1	25.6	17.7-34.7	12	10-13	310	255-345
E. deglupta	29.3	23.6-32.9	34.4	29.8-36.5	28.0	21.5-34.5	5	4-6	390	335-435
T. brassii	22.0	18.4-26.5	24.8	20.5-29.2	28.2	17.0-40.1	8	6-9	325	245-365
T. calamansanai	14.8	11.3-17.2	16.9	13.6-19.8	26.6	16.7-34.2	10	9-13	330	295-360
*G. arborea**	17	10-21	22	13-30	–	–	9	8-13	435	379-512

Note: * From Palmer *et al.* (1984)

Table 3

Chemical analysis

Species	Age years	Cold water solubles	Hot water solubles	1% NaOH solubles	Alcohol-benzine solubles	Total solubles	Lignin	Holo-cellulose	Alpha-cellulose	Pentosans	Ash	Silica
P. caribaea	13	2.7	3.1	13.3	2.8	4.3	27.4	60.0	41.7	–	–	–
P. oocarpa	13	3.5	4.0	14.2	4.0	5.9	27.3	59.2	39.2	–	–	–
C. brevipetiolata	10	4.2	3.5	20.3	1.3	4.5	26.1	68.6	41.0	15.7	0.9	0.18
E. deglupta	8	2.4	2.5	11.9	1.3	3.1	27.2	72.2	45.1	13.8	0.5	0.08
T. brassii	9	4.5	5.2	20.0	1.3	5.4	26.3	69.8	40.9	10.6	0.6	0.07
T. calamansanai	8	6.9	6.6	19.0	2.2	6.9	29.8	62.9	38.8	12.1	1.7	0.33
*G. arborea**	8	4.2	4.2	13.8	4.3	6.8	26.5	66.8	43.9	13.4	0.9	0.12

Notes: All values expressed as percentage oven-dry solubles or component on oven-dry unextracted sample
Total solubles = quantity removed by successive treatments with alcohol-benzene, alcohol and water
* From Palmer *et al.* (1984)

Table 4

Fibre dimensions by projection and classification of sulphate pulps

Species	Age years	Fibre dimensions by projection: Length, mm: All fibres	Length, mm: Whole fibres	Width µm	Wall thickness µm	Fibre weight fractions by classification, %: Passed aperture, µm / Retained on aperture, µm	– / 1680	1680 / 1190	1190 / 841	841 / 595	595 / 420	420 / 210	210 / 74	74† / –	Calculated fibre length by classification mm
P. caribaea	13	2.56 (0.13)	3.63 (0.16)	31.70 (1.54)	3.23 (0.18)		55.52	13.99	9.65	5.47	6.70	4.45	1.60	2.62	3.10
P. oocarpa	13	2.67 (0.11)	3.32 (0.13)	39.13 (1.41)	5.15 (0.16)		50.80	15.50	10.70	6.74	7.21	4.52	1.17	3.36	3.03
C. brevipetiolata	10	–	–	–	–		–	–	–	10.58	42.69	34.89	6.17	5.69	0.93
E. deglupta	8	0.78 (0.02)	0.90 (0.02)	18.35 (0.55)	3.21 (0.12)		–	–	–	17.53	42.11	27.42	5.98	6.96	0.94
T. brassii	9	–	–	–	–		–	–	–	30.45	32.76	21.99	5.04	9.76	0.94
T. calamansanai	8	–	–	–	–		–	–	–	45.23	23.63	14.11	3.26	13.78	0.95
*G. arborea**	8	–	–	25.66 (0.53)	2.91 (0.07)		–	–	–	7.1	33.4	41.1	11.0	7.4	0.89

Notes: Figures in brackets are the standard error of the mean for each determination
* From Palmer *et al.* (1984)
† By difference

Table 5

Sulphate digestion conditions, unbleached pulp yield and evaluation

	Drainability CSF	*P. caribaea* 13-year-old trees			*P. oocarpa* 13-year-old trees		
Cook number		348	339	340 347	354	345	346 349
Digestion conditions							
Active alkali as Na_2O on oven-dry wood, %		15.0	17.5	20.0	15.0	17.5	20.0
Sulphidity, %		25	25	25	25	25	25
Liquor to oven-dry wood ratio		5:1	5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1
Time at maximum temperature, h		4	4	4	4	4	4
Chemical consumption							
Active alkali consumed as Na_2O on oven-dry wood, %		12.2	12.6	13.4	12.3	12.9	13.8
Yield of pulp							
Yield of oven-dry digested pulp on oven-dry wood, %		45.1	43.1	39.8	48.3	44.0	41.4
Yield of oven-dry screened pulp on oven-dry wood, %		40.2	42.0	39.6	41.4	42.5	41.1
Yield of oven-dry screenings on oven-dry digested pulp, %		10.7	2.7	0.3	14.3	3.6	0.7
Pulp evaluation							
Kappa number		49.9	34.9	24.9	59.4	37.7	28.8
Beating, revs	500	7540	6460	5980	6840	6070	5740
	300	11080	10100	9050	10500	9410	8620
Apparent density, $g\ cm^{-3}$	500	0.71	0.71	0.72	0.71	0.73	0.74
	300	0.74	0.74	0.75	0.74	0.76	0.76
Tensile index, $N\ m\ g^{-1}$	500	97.0	98.0	95.0	95.3	95.7	93.4
	300	100	101	98.2	102	97.0	97.9
Tensile energy absorption index, $mJ\ g^{-1}$	500	1850	1880	1780	1570	1640	1640
	300	2040	1870	1820	1910	1760	1700
Tear index, $mN\ m^2\ g^{-1}$	500	12.3	11.0	10.9	9.52	9.53	9.05
	300	10.8	11.1	10.5	8.87	8.90	9.03
Burst index, $kPa\ m^2\ g^{-1}$	500	6.52	6.02	6.03	5.95	6.18	5.84
	300	6.61	6.58	6.30	6.18	6.39	6.13
Folding endurance, $\log_{10}n$*	500	2.95	2.90	2.95	2.87	2.93	2.90
	300	3.00	2.98	2.94	2.92	3.03	2.92
Air resistance, s	500	9	7	10	6	9	9
	300	47	54	71	64	76	88

Note: * n = number of double folds

Table 6

Sulphate digestion conditions, unbleached pulp yield and evaluation

	Drainability CSF	*C. brevipetiolata* 10-year-old trees			*E. deglupta* 8-year-old trees			*T. brassii* 9-year-old trees			*T. calamansanai* 8-year-old trees		
Cook number		333	334 341	335	368	361 373	362	193 201	194 208	200 207	343	344	350
Digestion conditions													
Active alkali as Na_2O on oven-dry wood, %		15.0	17.5	20.0	12.5	15.0	17.5	17.5	20.0	22.5	15.0	17.5	20.0
Sulphidity, %		25	25	25	25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		2	2	2	2	2	2	2	2	2	2	2	2
Chemical consumption													
Active alkali consumed as Na_2O on oven-dry wood, %		13.2	14.5	14.8	11.1	12.6	14.0	15.3	16.4	16.8	12.8	14.2	14.6
Yield of pulp													
Yield of oven-dry digested pulp on oven-dry wood, %		51.9	48.3	46.4	53.9	51.0	48.7	47.9	45.6	44.7	46.9	44.1	42.1
Yield of oven-dry screened pulp on oven-dry wood, %		48.0	47.6	46.4	51.8	50.7	48.6	46.7	45.3	44.6	44.5	43.7	41.9
Yield of oven-dry screenings on oven-dry digested pulp, %		7.4	1.6	0.2	3.9	0.5	0.2	2.5	0.8	0.2	5.1	1.0	0.3
Pulp evaluation													
Kappa number		41.2	29.0	25.9	39.1	27.5	22.0	44.5	37.8	32.9	64.9	50.0	43.0
Beating, revs	500	790	150	210	900	640	750	970	1100	1150	640	350	–
	300	5820	6150	6640	5720	6880	6690	7020	7590	8670	5990	5880	6970
Apparent density, g cm^{-3}	500	0.74	0.73	0.75	0.66	0.66	0.65	0.79	0.80	0.80	0.70	0.67	0.68
	300	0.88	0.88	0.88	0.78	0.79	0.80	0.89	0.89	0.89	0.79	0.82	0.83
Tensile index, N m g^{-1}	500	82.3	79.9	76.2	84.9	78.3	71.9	107	105	101	92.0	78.1	77.2
	300	120	118	114	118	115	101	140	134	131	128	123	121
Tensile energy absorption index, mJ g^{-1}	500	1410	1230	1110	1220	1080	850	2080	2080	1920	1650	1280	1070
	300	2730	2730	2550	2500	2430	1950	3650	3280	3210	2980	2720	2580
Tear index, mN m^2 g^{-1}	500	7.16	8.36	8.20	10.6	9.87	10.6	9.99	9.79	10.0	7.70	9.78	9.45
	300	6.13	6.13	6.22	10.0	10.3	9.93	7.96	7.88	7.91	6.62	7.88	7.02
Burst index, kPa m^2 g^{-1}	500	4.50	3.99	3.71	4.14	3.72	3.34	6.31	6.10	5.70	4.74	3.93	3.79
	300	7.40	6.99	6.56	6.96	6.44	5.78	8.60	8.51	8.07	7.88	7.49	7.25
Folding endurance, $\log_{10}n$*	500	2.31	1.78	1.80	1.56	1.55	1.44	2.77	2.86	2.71	2.48	1.76	2.13
	300	2.96	3.11	2.63	2.73	2.68	2.51	3.29	3.29	3.20	3.17	2.95	3.17
Air resistance, s	500	62	71	82	9	9	10	93	100	100	37	25	32
	300	650	790	650	79	74	81	870	800	840	320	360	310

Note: * n = number of double folds

Table 7

G. arborea: sulphate digestion conditions, unbleached pulp yield and evaluation

	Drainability CSF	4-year-old trees			6-year-old trees			8-year-old trees			
Cook number		MK 842 MK 843	MK 838 MK 839	MK 844 MK 845	MK 840 MK 841	MK 834 MK 835	MK 836 MK 837	MK 830 MK 831	MK 832 MK 833	MK 826 MK 827	MK 828 MK 829
Digestion conditions											
Active alkali as Na_2O on oven-dry wood, %		12.5	15.0	16.5	12.5	15.0	17.5	12.5	13.75	15.0	17.5
Sulphidity, %		25	25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		2	2	2	2	2	2	2	2	2	2
Chemical consumption											
Active alkali consumed as Na_2O on oven-dry wood, %		11.1	12.5	12.8	11.1	12.2	13.2	11.1	11.7	12.1	13.3
Yield of pulp											
Yield of oven-dry digested pulp on oven-dry wood, %		54.0	51.3	50.2	54.8	51.8	49.8	55.2	52.8	50.9	49.4
Yield of oven-dry screened pulp on oven-dry wood, %		49.4	50.5	49.9	50.0	51.0	49.6	49.0	50.0	49.7	49.1
Yield of oven-dry screenings on oven-dry digested pulp, %		8.6	1.5	0.7	8.8	1.6	0.4	11.2	5.2	2.3	0.6
Pulp evaluation											
Kappa number		44.8	31.5	27.0	47.6	32.9	26.3	52.3	39.6	35.2	30.0
Beating, revs	500	1640	1000	842	1340	1150	844	2330	1860	2000	1450
	300	9140	6930	6980	7830	6930	7040	9030	8590	8420	8290
Apparent density, g cm^{-3}	500	0.73	0.73	0.72	0.73	0.74	0.73	0.73	0.74	0.75	0.73
	300	0.84	0.84	0.84	0.84	0.84	0.84	0.82	0.82	0.83	0.82
Tensile index, N m g^{-1}	500	79.0	76.2	72.1	80.2	78.1	74.1	78.9	80.8	82.4	74.7
	300	109	109	106	108	107	104	103	105	104	98.1
Tensile energy absorption index, mJ g^{-1}	500	1810	1750	1610	1380	1450	1410	1690	1810	1820	1540
	300	3470	3370	3160	3190	3030	2860	3010	3020	3050	2850
Tear index, mN m^2 g^{-1}	500	9.61	10.1	9.52	9.24	10.1	9.02	10.3	10.5	10.5	9.77
	300	8.05	8.28	8.09	7.71	7.64	7.92	8.94	9.32	9.22	9.06
Burst index, kPa m^2 g^{-1}	500	4.70	4.48	4.24	4.54	4.41	3.95	4.69	4.75	4.71	4.34
	300	7.15	7.37	6.99	6.91	6.76	6.46	6.70	6.77	6.61	6.21
Folding endurance, $\log_{10}n$*	500	2.45	2.32	2.06	2.35	2.23	2.01	2.36	2.42	2.49	2.20
	300	3.18	3.24	3.11	3.04	3.19	3.05	3.11	3.12	3.11	3.02
Air resistance, s	500	25	26	23	30	27	30	18	26	25	22
	300	290	300	290	380	340	350	210	220	210	230

Note: * n = number of double folds
From Palmer *et al.* (1984)

Table 8

Sulphate, soda and soda/anthraquinone (AQ) cooks digestion conditions, unbleached pulp yield and evaluation

	Drainability CSF	*C. brevipetiolata* Sulphate cook	Soda cook	Soda + 0.1% AQ cook	*E. deglupta* Sulphate cook	Soda cook	Soda + 0.1% AQ cook
Cook number		334 341	336 342	353	361 373	383	384
Digestion conditions							
Active alkali as Na_2O on oven-dry wood, %		17.5	17.5	17.5	15.0	15.0	15.0
Sulphidity, %		25	–	–	25	–	–
Liquor to oven-dry wood ratio		5.1	5.1	5.1	5.1	5.1	5.1
Maximum temperature, °C		170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1
Time at maximum temperature, h		2	2	2	2	2	2
Chemical consumption							
Active alkali consumed as Na_2O on oven-dry wood, %		14.5	14.0	13.6	12.6	12.0	12.8
Yield of pulp							
Yield of oven-dry digested pulp on oven-dry wood, %		48.3	49.0	48.0	51.0	52.4	50.9
Yield of oven-dry screened pulp on oven-dry wood, %		47.6	46.6	47.7	50.7	51.9	50.6
Yield of oven-dry screenings on oven-dry digested pulp, %		1.6	4.9	0.6	0.5	0.9	0.5
Pulp evaluation							
Kappa number		29.0	44.9	30.8	27.5	48.5	27.8
Beating, revs	500	150	1800	1790	640	1210	1170
	300	6150	8050	5990	6880	8290	6610
Apparent density, g cm^{-3}	500	0.73	0.75	0.75	0.66	0.62	0.66
	300	0.88	0.85	0.88	0.79	0.74	0.78
Tensile index, N m g^{-1}	500	79.9	79.7	84.2	78.3	68.8	74.3
	300	118	104	114	115	96.9	102
Tensile energy absorption index, mJ g^{-1}	500	1230	1240	1380	1080	760	1030
	300	2730	2260	2490	2430	1730	2060
Tear index, mN m^2 g^{-1}	500	8.36	8.26	7.66	9.87	10.4	9.74
	300	6.13	6.98	6.37	10.3	9.82	9.56
Burst index, kPa m^2 g^{-1}	500	3.99	4.21	4.46	3.72	3.03	3.58
	300	6.99	6.09	6.45	6.44	5.19	5.49
Folding endurance, $\log_{10}n$*	500	1.78	2.09	2.15	1.55	1.34	1.35
	300	3.11	2.59	2.69	2.68	2.10	2.22
Air resistance, s	500	71	59	67	9	6	9
	300	790	430	590	74	45	68

Note: * n = number of double folds

Table 9

Terminalia species, additional cooks, digestion conditions, unbleached yield and evaluation

		T. brassii				*T. calamansanai*			
Cook number	Drainability CSF	Sulphate 194	Soda 569	Soda/AQ 570	Sulphate 457	Sulphate 350	Sulphate/AQ 364	Soda 572	Soda/AQ 571
Digestion conditions									
Active alkali as Na_2O on oven-dry wood, %		20	20	20	16	20	20	20	20
Sulphidity, %		25	–	–	25	25	25	–	–
Liquor to oven-dry wood ratio		5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Maximum temperature, °C		170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1.5	1	1	1	1
Time at maximum temperature, h		2	2	2	1.5	2	2	2	2
Chemical consumption									
Active alkali consumed as Na_2O on oven-dry wood, %		16.4	15.9	16.2	14.1	14.6	15.2	14.3	16.2
Yield of pulp									
Yield of oven-dry digested pulp on oven-dry wood, %		45.6	47.5	45.0	52.2	42.1	42.7	43.0	42.2
Yield of oven-dry screened pulp on oven-dry wood, %		45.3	47.2	44.8	46.7	41.9	42.6	42.3	42.1
Yield of oven-dry screenings on oven-dry digested pulp, %		0.8	0.7	0.3	10.4	0.3	0.2	1.6	0.4
Pulp evaluation									
Kappa number		37.8	55.9	36.0	68.6	43.0	47.8	68.0	48.1
Beating, revs	500	1100	1700	1050	–	–	60	1350	820
	300	7590	9450	8220	–	6970	6960	8990	6750
Apparent density, g cm^{-3}	500	0.80	0.75	0.75	–	0.68	0.67	0.71	0.67
	300	0.89	0.84	0.87	–	0.83	0.81	0.80	0.82
Tensile index, N m g^{-1}	500	105	91	91	–	77.2	71.5	88.6	76.1
	300	134	117	128	–	121	113	119	109
Tensile energy absorption index, mJ g^{-1}	500	2080	1430	1340	–	1070	940	1450	1091
	300	3280	2450	2730	–	2580	2450	2520	2360
Tear index, mN m^2 g^{-1}	500	9.79	10.7	10.5	–	9.45	10.5	9.18	9.78
	300	7.88	8.5	7.9	–	7.02	7.62	7.66	7.41
Burst index, kPa m^2 g^{-1}	500	6.10	4.75	4.61	–	3.79	3.61	4.81	3.96
	300	8.51	6.90	7.69	–	7.25	6.66	6.96	6.96
Folding endurance, $\log_{10}n$*	500	2.86	2.25	2.42	–	2.13	1.69	2.31	1.99
	300	3.29	3.1	3.2	–	3.17	2.86	2.89	2.95
Air resistance, s	500	100	76	90	–	32	30	35	51
	300	800	400	595	–	310	310	235	330

Note: * n = number of double folds

Table 10

Bleaching conditions, bleached pulp yield and evaluation

	Drainability CSF			*G. arborea*‡	
		C. brevipetiolata	*E. deglupta*	6yr old	8yr old
Cook number		334	361	MK 836	MK 828
		341	373	MK 837	MK 829
Unbleached pulp*					
Yield of pulp on oven-dry wood, %		47.6	50.7	49.6	49.1
Kappa number		28.9	27.5	26.3	30.0
Bleaching conditions and consumption					
1 Chlorination for 1 h at 20°C, pulp consistency, 3%					
Chlorine applied as Cl_2, on oven-dry unbleached pulp, %		8.1	7.7	7.3	8.5
Chlorine consumed as Cl_2, on oven-dry unbleached pulp, %		6.6	6.7	6.6	7.3
2 Alkaline extraction for 1 h at 60°C, pulp consistency, 6%					
NaOH on oven-dry unbleached pulp, %		3.0	3.0	3.0	3.0
3 Hypochlorite for 2 h at 35°C, pulp consistency, 6%					
NaOCl applied as available Cl_2, on oven-dry unbleached pulp, %		1.0	1.0	1.0	1.0
NaOCl consumed as available Cl_2, on oven-dry unbleached pulp, %		0.8	0.7	0.8	0.8
4 Chlorine dioxide for 3 h at 70°C, pulp consistency, 6%					
ClO_2 applied as Cl_2, equivalent on oven-dry unbleached pulp, %		2.6	2.6	2.6	2.6
ClO_2 consumed as Cl_2, equivalent on oven-dry unbleached pulp, %		2.4	2.3	2.3	2.4
Total chlorine applied as Cl_2 on oven-dry unbleached pulp, %		11.8	11.3	10.9	12.1
Total chlorine consumed as Cl_2 on oven-dry unbleached pulp, %		9.7	9.7	9.7	10.5
Yield of pulp					
Yield of oven-dry bleached pulp on oven-dry unbleached pulp, %		93.8	94.2	93.6	92.8
Yield of oven-dry bleached pulp on oven-dry wood, %		44.6	47.7	46.4	45.6

Pulp evaluation					
ISO brightness, unbeaten pulp, %		87.0	88.5	88.5	87.0
Specific scattering coefficient, unbeaten sheets, $cm^2\ g^{-1}$		480	505	565	535
Beating, revs	500	–	935	300	1440
	300	6540	9500	7810	8920
Apparent density, $g\ cm^{-3}$	500	–	0.66	0.59	0.69
	300	0.90	0.80	0.82	0.82
Tensile density, $N\ m\ g^{-1}$	500	–	63.6	34.2	63.6
	300	109	105	96.4	95.1
Tensile energy absorption index, $mJ\ g^{-1}$	500	–	926	421	1360
	300	2890	1400	2710	2710
Tear index, $mN\ g^{-1}$	500	–	11.2	5.7	11.2
	300	6.80	10.6	8.3	9.5
Burst index, $kPa\ m^2\ g^{-1}$	500	–	3.16	1.56	3.65
	300	6.68	6.10	5.87	6.03
Folding endurance, $\log_{10} n^{+}$	500	–	1.32	0.64	1.82
	300	2.99	2.50	2.87	2.92
Air resistance, s	500	–	7.5	10	20
	300	620	70	210	180
Opacity, %	500	–	80.6	84.0	81.0
	300	69.0	74.0	75.5	74.0
Specific scattering coefficient, $cm^2\ g^{-1}$	500	–	425	535	415
	300	225	290	310	280

Notes:
* References to unbleached pulp in this Table are to screened unbleached pulp
\+ n = number of double folds
‡ From Palmer *et al.* (1984)

Table 11

Commercial coniferous pulp woods: sulphate digestion conditions, unbleached pulp yield and evaluation

	Drainability CSF	Douglas fir Western Canada		Southern pines Southern USA		*Pinus sylvestris* England			*Pinus taeda* Southern Africa		*Pinus patula* Southern Africa	
Cook number		MK 46	MK 45	MK 95	MK 94	MK 83	MK 59	MK 24	MK 311	MK 312	MK 309	MK 310
Digestion conditions												
Active alkali as Na_2O on oven-dry wood, %		17.5	20.0	17.5	20.0	15.0	17.5	20.0	17.5	20.0	17.5	20.0
Sulphidity, %		25	25	25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		4	4	4	4	5	4	4	4	4	4	4
Chemical consumption												
Active alkali consumed as Na_2O on oven-dry wood, %		13.8	14.6	12.7	13.5	12.5	13.6	14.0	13.0	13.7	13.6	14.2
Yield of pulp												
Yield of oven-dry digested pulp on oven-dry wood, %		42.1	40.0	45.5	43.7	48.6	47.0	43.8	44.0	41.5	44.1	41.7
Yield of oven-dry screened pulp on oven-dry wood, %		40.5	39.5	43.7	42.9	45.3	46.4	43.8	43.5	41.5	43.7	41.6
Yield of oven-dry screenings on oven-dry digested pulp, %		3.6	1.1	4.0	1.9	6.8	1.2	0.1	1.2	0.2	0.8	0.3
Pulp evaluation												
Kappa number		32.1	27.3	37.1	29.5	48.7	39.3	26.9	30.6	24.7	35.0	27.8
Beatings, revs	700	1300	1000	1910	1330	1730	800	960	550	530	1030	1200
	500	5290	4150	6010	5290	6010	5580	5290	4860	4860	5000	4580
	300	8290	7150	9720	9150	9720	8870	8580	8010	8290	8010	7720
Apparent density, g cm^{-3}	700	0.54	0.55	0.60	0.61	0.58	0.56	0.58	0.58	0.57	0.56	0.59
	500	0.62	0.62	0.67	0.65	0.66	0.67	0.68	0.67	0.68	0.65	0.65
	300	0.65	0.65	0.68	0.68	0.69	0.69	0.71	0.69	0.71	0.68	0.68
Tensile index, N m g^{-1}	700	65.5	64.0	69.0	63.5	79.5	70.5	70.5	70.5	69.0	77.5	75.5
	500	86.5	85.5	83.0	81.5	104	103	101	97.5	93.5	103	96.5
	300	94.5	91.0	94.0	86.5	111	110	107	105	100	108	103
Tear index, mN m^2 g^{-1}	700	21.6	20.6	17.0	16.5	16.9	15.2	16.0	14.5	14.3	15.7	14.9
	500	18.3	17.5	15.4	14.9	15.1	13.7	13.6	12.3	11.9	13.3	12.6
	300	17.0	15.7	14.3	14.0	14.4	12.7	12.9	11.5	11.0	12.6	11.7
Burst index, kPa m^2 g^{-1}	700	4.05	3.90	4.50	4.25	5.15	4.30	4.15	4.35	4.05	4.80	4.65
	500	6.05	5.75	5.65	5.55	7.25	7.15	6.70	6.75	6.15	6.85	6.25
	300	6.85	6.40	5.90	5.85	7.75	7.65	7.35	7.15	6.55	7.15	6.85
Folding endurance, $\log_{10}n$*	700	2.94	2.82	2.80	2.73	2.98	2.85	2.82	2.86	2.81	2.91	2.90
	500	3.14	3.07	2.97	2.94	3.14	3.14	3.05	3.05	3.00	3.03	3.00
	300	3.18	3.12	3.01	3.01	3.21	3.21	3.15	3.11	3.03	3.07	3.06
Air resistance, s	700	1.5	1.5	1.2	1.1	1.8	1.3	1.6	2.8	2.4	1.8	2.3
	500	23	15	11	11	20	20	22	31	27	23	24
	300	120	100	120	110	200	140	200	220	250	220	210

Note: * n = number of double folds

Table 12

Commercial hardwoods: sulphate digestion conditions, unbleached pulp yield and evaluation

	Drainability CSF	*Fagus sylvatica* England				Mixed hardwoods Southern USA 1st sample			Mixed hardwoods Southern USA 2nd sample		
Cook number		MK 92	MK 88	MK 93	MK 87	MK 100	MK 57	MK 60	MK 97	MK 96	MK 313
Digestion conditions											
Active alkali as Na_2O on oven-dry wood, %		15.0	15.0	15.0	17.5	12.5	12.5	15.0	15.0	17.5	15.0
Sulphidity, %		25	25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		2	1	2	1	2	1	1	1	1	2
Time at maximum temperature, h		1	2	2	2	2	2	2	2	2	2
Chemical consumption											
Active alkali consumed as Na_2O on oven-dry wood, %		12.6	13.0	13.2	14.2	11.6	11.5	13.2	12.7	13.8	12.6
Yield of pulp											
Yield of oven-dry digested pulp on oven-dry wood, %		50.9	49.8	48.4	43.9	51.1	49.7	49.4	49.1	46.8	45.4
Yield of oven-dry screened pulp on oven-dry wood, %		45.4	45.2	45.8	43.4	44.1	39.1	47.8	44.3	46.4	43.4
Yield of screenings on oven-dry digested pulp, %		10.8	9.2	5.4	1.1	13.7	21.3	3.2	9.7	0.9	4.4
Pulp evaluation											
Kappa number		29.1	23.2	22.2	16.5	38.6	32.1	27.6	29.7	26.7	23.8
Beating, revs	500	3860	4150	3430	5150	3580	4580	3430	3430	3720	4430
	300	7860	9440	7860	10,010	6860	8150	7580	7440	8010	9010
Apparent density, g cm^{-3}	500	0.62	0.63	0.62	0.63	0.61	0.61	0.61	0.62	0.63	0.64
	300	0.67	0.68	0.68	0.69	0.66	0.67	0.66	0.68	0.68	0.69
Tensile index, N m g^{-1}	500	82.5	82.5	80.0	82.5	93.5	97.0	91.0	83.5	85.5	92.0
	300	96.5	97.0	95.5	95.0	105	109	107	100	98.5	103
Tear index, mN m^2 g^{-1}	500	8.45	8.40	8.35	8.05	10.5	11.2	11.0	9.50	9.15	10.3
	300	9.25	8.76	9.00	8.90	11.0	11.6	11.2	10.1	9.45	10.8
Burst index, kPa m^2 g^{-1}	500	4.80	4.95	4.86	4.85	5.95	6.14	5.55	4.95	4.90	5.85
	300	6.25	6.30	6.14	6.00	7.26	7.15	7.10	6.50	6.25	6.90
Folding endurance, $\log_{10}n$*	500	2.15	2.10	2.00	2.10	2.60	2.65	2.45	2.30	2.35	2.65
	300	2.70	2.70	2.63	2.67	2.86	2.95	2.90	2.86	2.80	2.90
Air resistance, s	500	3.70	3.4	3.00	3.2	5.0	3.7	5.0	6.3	8.3	5.6
	300	34	48	38	44	50	70	53	67	66	72

Note: * n = number of double folds

Appendices

APPENDIX 1: PULPWOOD POTENTIAL OF OTHER REAFFORESTATION SPECIES

This appendix consists of information on the potential as pulpwoods of those species, important in the reafforestation programme of Solomon Islands, not included in the present investigation.

Acacia mangium

A. mangium grown in Sabah and 9 years old had a basic density of 420 kg m^{-3}. Pulped by the sulphate process, using 14% active alkali, it yielded 52% of unbleached pulp with a kappa number of 21. At a CSF value of 300, this pulp had a tear index of 10.3, a burst index of 7.4 and a tensile index of 104. This pulp could be bleached to a good standard of brightness by a four-stage process (chlorine, sodium hydroxide, hypochlorite, chlorine dioxide). *A. mangium* was pulped successfully by the neutral sulphite semi-chemical process. It was concluded that *A. mangium* was comparable with, but a little less valuable as a pulpwood than, *Acacia auriculiformis* which is grown in Papua New Guinea for pulpwood (Logan and Balodis, 1982). Similar results were obtained by Peh *et al.* (1982), who also used samples grown in Sabah. The strength properties reported for pulp from *A. mangium* are similar to those found for *E. deglupta* grown in Solomon Islands.

Albizia falcataria

Samples grown in Fiji had a basic density of 250 kg m^{-3}. Sulphate pulping gave high yields of pulp, 53.4% to 56.5%, with kappa numbers of 27 to 47. Pulp strengths (based on average value for six pulps with different kappa numbers) were tear index 7.7, burst index 7.2 and tensile index 125 (Palmer *et al.*, 1983). These values would rank *A. falcataria* after *G. arborea* but above *C. brevipetiolata* grown in Solomon Islands.

A. falcataria usually has a rather low basic density. Fenton *et al.* (1977) reported values between 246 kg m^{-3} and 300 kg m^{-3} for samples from six countries. Often high pulp yields compensate for low wood density, but samples from Indonesia were reported to yield only 40% of pulp. Logan *et al.* (1984), based on studies of samples growing in Papua New Guinea and Malaysia, reported the sulphate pulps to be suitable for a wide range of unbleached and bleached paper products (together with pulps from *A. auriculiformis, E. deglupta, G. arborea* and *T. brassii*).

Anthocephalus chinenis (A. cadamba)

Samples of this species have been grown in many locations including Australia, Fiji, Papua New Guinea, Philippines and Sabah. The basic density of the wood was between 300 kg m^{-3} and 400 kg m^{-3}. A sample from Sabah yielded over 50% pulp with tear index of 11, burst index of 6.4 and tensile index of 88 (Anon., 1963). A sample from Fiji yielded 48% of pulp with a tear index of 8, burst index of 8 and tensile index of 130 (Palmer *et al.*, 1983). These differences are so great that it would be unwise to estimate values for a new sample without tests.

Artocarpus integer

A sample of this species growing in Malaysia was examined at the Forest Research Institute, Kepong, Malaysia. The wood had a basic density of 490 kg m^{-3} and when pulped by the sulphate process yielded nearly 47% of screened pulp. With a drainability level of about 400 CSF, the pulp had the following strength characteristics: tear index, 11; burst index, 6.4; tensile index, 95. These results indicate that *A. integer* is a promising species for use as pulpwood.

Calophyllum kajewskii

Keating and Bolza (1982) report that the basic density of samples from Solomon Islands and Papua New Guinea was between 400 and 500 kg m^{-3} and that the wood was suitable for the production of good quality pulp and paper. The data supporting this conclusion were not included.

Cleistopholis glauca

Samples from Gabon had a basic density of 290 kg m^{-3}. Sulphate pulping yielded between 46% and 51% of unbleached pulp with a tear index of 8, burst index of 3 and tensile index of 70 (Petroff *et al.*, 1968). A sample of 9-year-old trees from Sabah had a basic density of 231 kg m^{-3}. Sulphite pulping yielded 49% of pulp with a kappa number of 23, a tear index of 5.5, a burst index of 7 and a tensile index of 124 (Peh *et al.*, 1982). These values would rank *C. glauca* after *E. deglupta, G. arborea* and *C. brevipetiolata* grown in Solomon Islands.

Cordia alliodora

A sample from Honduras was reported to have a basic density of 420 kg m^{-3}, which is desirable in pulpwood. No information on pulping characteristics was found.

Endospermum medulosum

No information was found about the pulping characteristics of this species. Samples from Papua New Guinea have been examined in Australia to determine their properties as sawn timber, but the reports are not available in ODNRI.

Eucalyptus urophylla

A sample from Brazil had a basic density of 503 kg m^{-3}. Sulphate pulping yielded around 50% of unbleached pulp with a tear index between 8.6 and 10, a burst index between 2.7 and 5.5 and a tensile index between 50 and 80 (De Oliveira, 1981). These strength characteristics do not suggest a promising pulpwood. Fenton (1977) reported 'Large scale plans for pulp utilization are well advanced but few pulp tests have been located as yet'.

Octomeles sumatrana

Samples from Indonesia, Malaysia, Sabah, Philippines and Papua New Guinea had a basic density between 280 and 350 kg m^{-3}; the density of a young sample from Western Samoa was between 180 and 225 kg m^{-3}. A sample (origin not stated) examined in Japan had a basic density of 300 kg m^{-3} and yielded pulp with a tear index of 11 and tensile index of 125 (Keating and Bolza, 1982).

Swietenia macrophylla

The basic density of this species is reported to be between 450 and 560 kg m^{-3}. No information on pulping characteristics is available and *S. macrophylla* is unlikely to be used for this purpose.

Tectona grandis

The basic density of this species is reported to be between 500 and 640 kg m^{-3}. It is unlikely to be used as pulpwood.

Agathis macrophylla

The basic density of samples grown in Solomon Islands and Vanuatu was between 450 and 500 kg m^{-3}. No information was found on pulping characteristics (Keating and Bolza, 1982).

Araucaria cunninghamii

Samples grown in Papua New Guinea had a basic density between 500 and 550 kg m^{-3}. Plantation grown samples pulped by the sulphate process yielded about 45% of unbleached pulp. This pulp was difficult to beat and, at a drainability value of 500 CSF, the pulp had a tear index of 11, burst index of 9 and a tensile index of 110. Virgin growth trees had long tracheids, about 5.5 mm. These trees yielded pulps with exceptional tearing strength (tear index over 200) when lightly beaten (von Koeppen and Sitzman, 1954).

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APPENDIX 2: FURTHER DATA ON TREE DIMENSIONS, WOOD DENSITY AND PULP EVALUATION

This appendix consists of tabulated data describing the dimensions and wood characteristics of all the trees examined and full pulp evaluation data. All of these data have been used in the preparation of the summary Tables in the body of the report.

List of Tables

Table I

P. caribaea: dimensions and bark content of individual trees and logs at various heights

Tree number	Tree height, m: At 8 cm diameter	Tree height, m: Total	Diameter, cm: ob bh	Diameter, cm: ub at sampling points, % of height: 10	30	50	70	90	Bark content by volume, %: Height, %: 10	30	50	70	90	Tree mean
1	14.6	17.5	28.0	22.4	19.5	18.0	13.2	8.2	28	21	21	19	26	23
2	11.2	16.8	23.5	20.7	18.3	16.8	15.0	11.1	22	18	17	15	19	18
3	11.4	15.1	25.3	22.0	18.9	17.7	15.5	9.5	23	17	18	21	18	19
4	13.7	17.9	23.0	19.7	17.6	15.4	12.9	9.6	20	18	15	15	15	17
5	7.9	13.4	21.8	18.4	16.2	15.3	13.0	9.5	20	17	20	20	18	19
6	15.3	20.1	23.0	18.2	17.6	15.3	13.5	9.5	30	23	22	21	20	23
7	11.3	14.6	31.0	24.3	22.0	18.4	16.3	9.7	24	21	19	18	26	22
8	14.5	17.5	28.5	24.4	21.3	18.3	14.6	8.9	20	16	15	15	16	16
9	13.5	16.6	24.5	18.0	16.8	15.3	13.4	11.3	26	23	20	18	18	21
10	14.2	17.1	21.5	16.3	14.6	13.0	11.1	9.5	22	17	16	17	18	18
Mean sample value	12.8	16.7	25.0	20.4	18.3	16.4	13.9	9.7	–	–	–	–	–	20

Notes: bh = breast height
ob = over bark
ub = under bark

Table II

P. oocarpa: dimensions and bark content of individual trees and logs at various heights

	Tree height, m		Diameter, cm						Bark content by volume, %					
				ub at sampling points, % of height					Height, %					
Tree number	At 8 cm diameter	Total	ob bh	10	30	50	70	90	10	30	50	70	90	Tree mean
1	16.4	20.2	25.1	19.7	16.9	14.5	12.2	9.2	23	16	14	15	20	18
2	15.8	20.1	25.5	20.8	18.7	16.9	10.7	8.5	18	18	16	18	16	17
3	13.9	17.3	30.6	25.4	22.7	20.1	15.5	12.1	19	17	13	13	16	16
4	13.9	18.2	24.6	19.9	16.0	15.0	11.4	9.2	17	12	13	10	15	14
5	20.4	24.1	36.5	29.7	26.3	21.2	14.8	8.9	24	20	19	22	27	22
6	11.0	14.2	21.4	16.5	15.3	13.8	11.5	8.4	28	19	14	15	13	18
7	10.1	14.5	17.6	14.3	13.3	12.3	10.5	8.6	21	12	14	13	16	16
8	12.5	16.9	23.0	19.0	16.1	14.6	13.1	9.0	18	13	15	12	16	15
9	11.8	16.7	20.8	18.2	15.9	15.3	11.0	8.9	20	16	13	15	16	16
10	12.4	18.0	26.1	21.5	19.6	16.5	14.3	12.0	22	17	15	12	15	16
Mean sample value	13.8	18.0	25.1	20.5	18.1	16.0	12.5	9.5	–	–	–	–	–	17

Notes: bh = breast height
ob = over bark
ub = under bark

Table III

C. brevipetiolata: dimensions and bark content of individual trees and logs at various heights

Tree number	Tree height, m		Diameter, cm						Bark content by volume, %					
				ub at sampling points, % of height					Height, %					Tree mean
	At 8 cm diameter	Total	ob bh	10	30	50	70	90	10	30	50	70	90	
1	14.9	17.6	17.7	16.3	14.8	13.1	11.4	9.0	11	4	10	11	14	10
2	14.8	17.8	28.7	26.3	23.9	20.8	19.4	16.7	11	11	11	10	12	11
3	15.5	18.4	21.8	19.2	16.5	14.8	12.7	8.5	11	12	11	13	13	12
4	15.0	18.8	28.0	26.3	21.9	20.0	15.9	10.1	9	11	8	12	14	11
5	15.8	18.6	29.4	27.0	24.0	21.0	16.4	11.2	12	13	14	12	14	13
6	16.7	20.1	34.7	32.4	31.0	22.8	16.9	12.5	10	4	12	12	14	11
7	14.6	18.2	32.8	31.0	26.2	23.2	18.8	15.5	8	11	11	13	13	11
8	10.4	14.1	22.0	20.5	17.8	16.5	14.4	12.1	12	12	13	13	13	13
9	13.4	16.1	20.7	18.2	15.8	12.0	10.8	8.0	9	13	12	15	14	12
10	14.0	16.2	20.6	19.0	16.3	15.1	13.1	8.0	13	12	12	15	14	13
Mean sample value	14.5	17.6	25.6	23.6	20.8	17.9	15.0	11.2	–	–	–	–	–	12

Notes: bh = breast height
ob = over bark
ub = under bark

Table IV

E. deglupta: dimensions and bark content of individual trees and logs at various heights

	Tree height, m		Diameter, cm						Bark content by volume, %					
				ub at sampling points, % of height					Height, %					
Tree number	At 8 cm diameter	Total	ob bh	10	30	50	70	90	10	30	50	70	90	Tree mean
1	29.5	34.0	25.1	24.0	21.2	18.2	14.5	10.3	2	3	4	5	6	4
2	30.4	35.5	23.2	28.5	24.2	21.5	16.9	10.9	3	4	4	7	9	5
3	29.7	35.7	30.6	28.7	25.1	21.4	16.1	11.3	4	5	6	8	8	6
4	28.8	35.2	26.1	24.4	21.6	18.1	15.3	10.3	4	4	5	6	9	6
5	27.5	32.8	26.4	24.1	21.3	17.8	15.0	9.9	3	4	3	6	9	5
6	30.1	35.1	30.8	29.4	24.5	20.8	16.2	11.4	3	4	5	7	7	5
7	23.6	29.8	21.5	19.9	17.4	14.9	12.9	10.1	3	4	5	6	8	5
8	32.9	36.5	32.9	31.1	27.1	22.6	17.4	10.6	3	3	4	6	7	5
9	30.9	35.3	27.0	35.8	32.3	26.5	20.7	14.3	3	3	3	5	7	4
10	29.1	34.5	34.5	24.9	20.8	17.9	14.5	10.3	4	4	4	7	7	5
Mean sample value	29.3	34.4	28.0	27.1	23.6	20.0	16.0	10.9	–	–	–	–	–	5

Notes: bh = breast height
ob = over bark
ub = under bark

Table V

T. brassii: dimensions and bark content of individual trees and logs at various heights

	Tree height, m		Diameter, cm						Bark content by volume, %					
				ub at sampling points, % of height					Height, %					
Tree number	At 8 cm diameter	Total	ob bh	10	30	50	70	90	10	30	50	70	90	Tree mean
1	20.3	22.3	24.3	21.7	19.3	17.0	13.1	9.2	9	9	8	10	12	9
2	20.7	23.3	23.3	21.0	19.5	17.7	14.4	11.3	9	8	8	10	11	9
3	22.7	24.9	23.6	22.1	21.1	17.6	13.7	11.0	8	7	6	8	8	8
4	18.4	20.5	17.0	16.3	14.7	12.7	11.0	8.6	7	8	9	10	9	8
5	23.7	26.5	28.5	26.4	24.3	21.5	13.9	11.5	4	5	5	8	10	6
6	21.3	24.7	26.6	24.5	18.5	16.2	14.8	11.3	5	6	7	8	10	7
7	20.5	24.0	28.4	26.3	23.9	20.0	16.6	12.6	5	6	6	8	9	7
8	21.7	24.9	31.2	28.6	25.6	21.8	16.7	10.7	7	8	9	7	10	8
9	24.5	27.2	38.9	35.9	25.0	22.0	15.0	9.7	4	5	5	8	6	6
10	26.5	29.2	40.1	36.8	32.8	28.4	15.5	11.8	3	4	5	8	8	6
Mean sample value	22.0	24.8	28.2	26.0	22.5	19.5	14.5	10.8	–	–	–	–	–	8

Notes: bh = breast height
ob = over bark
ub = under bark

Table VI

T. calamansanai: dimensions and bark content of individual trees and logs at various heights

	Tree height, m		Diameter, cm						Bark content by volume, %					
				ub at sampling points, % of height					Height, %					
Tree number	At 8 cm diameter	Total	ob bh	10	30	50	70	90	10	30	50	70	90	Tree mean
1	13.1	16.0	24.2	22.5	19.7	16.9	14.8	11.6	6	9	10	11	8	9
2	11.3	13.6	16.7	15.8	14.7	13.1	11.8	9.1	7	10	14	16	20	13
3	17.2	19.1	34.2	32.0	28.5	25.1	21.0	16.9	6	7	8	10	12	9
4	16.1	18.7	27.5	25.6	23.3	20.4	16.4	11.8	7	8	9	11	12	10
5	16.1	17.5	29.4	27.5	24.5	19.3	15.3	10.5	8	8	10	12	15	11
6	14.1	16.2	25.6	23.6	21.0	18.7	16.0	13.5	6	6	8	11	13	9
7	14.1	15.7	25.6	24.3	21.7	19.2	16.2	11.5	8	11	11	11	11	11
8	15.4	17.1	27.7	25.3	22.3	19.4	16.8	10.9	8	11	10	11	15	9
9	17.2	19.8	32.2	29.7	27.1	24.2	19.1	12.5	6	8	8	10	14	9
10	13.1	14.8	22.6	19.4	17.9	15.8	13.8	10.1	9	9	10	12	16	11
Mean sample value	14.8	16.9	26.6	24.6	22.1	19.2	16.1	11.8	–	–	–	–	–	10

Notes: bh = breast height
ob = over bark
ub = under bark

Table VII

P. caribaea: wood density

Tree number	Density, kg m^{-3} Height, % 10	30	50	70	90	Tree mean
1	480	495	450	430	405	470
2	490	445	435	430	410	455
3	505	465	455	450	415	470
4	435	455	425	380	370	430
5	560	500	485	455	475	510
6	425	390	400	380	345	400
7	515	505	505	485	515	505
8	395	375	325	320	305	365
9	420	410	435	380	345	410
10	460	425	415	410	395	430
Mean sample value	–	–	–	–	–	445

Table VIII

P. oocarpa: wood density

Tree number	Density, kg m^{-3} Height, % 10	30	50	70	90	Tree mean
1	525	505	505	475	435	505
2	485	455	450	455	445	465
3	400	380	380	365	355	385
4	490	435	440	440	445	460
5	490	420	430	425	415	450
6	475	440	405	390	360	430
7	565	450	430	425	415	470
8	495	440	420	420	410	450
9	510	430	430	420	405	455
10	490	470	465	475	500	480
Mean sample value	–	–	–	–	–	455

Table IX

C. brevipetiolata: wood density

Tree number	Density, kg m^{-3} Height, % 10	30	50	70	90	Tree mean
1	250	235	245	275	285	255
2	295	290	295	290	325	295
3	295	275	265	270	280	280
4	300	290	290	290	315	295
5	330	340	360	360	365	345
6	315	340	330	365	330	330
7	340	330	335	345	335	335
8	340	305	320	320	330	325
9	285	250	230	260	260	260
10	310	265	270	260	270	280
Mean sample value	–	–	–	–	–	310

Table X

E. deglupta: wood density

Tree number	Density, kg m^{-3} Height, % 10	30	50	70	90	Tree mean
1	370	365	380	405	430	380
2	380	405	400	425	430	400
3	360	425	425	465	445	405
4	395	430	470	485	465	435
5	370	395	420	440	440	400
6	355	380	405	430	455	385
7	365	380	405	435	475	395
8	375	390	415	440	480	400
9	310	325	350	395	405	335
10	420	415	450	475	450	435
Mean sample value	–	–	–	–	–	390

Table XI

T. brassii: wood density

Tree number	Density, kg m^{-3} Height, % 10	30	50	70	90	Tree mean
1	330	320	305	285	270	315
2	330	320	310	300	300	315
3	265	250	295	250	270	265
4	255	235	245	240	235	245
5	360	335	335	360	335	345
6	320	315	320	320	330	320
7	325	335	300	320	295	320
8	340	360	335	325	345	345
9	385	360	355	310	305	365
10	320	320	305	405	300	320
Mean sample value	–	–	–	–	–	325

Table XII

T. calamansanai: wood density

Tree number	Density, kg m^{-3} Height, % 10	30	50	70	90	Tree mean
1	375	380	335	330	265	350
2	355	290	270	305	265	305
3	360	335	325	325	325	340
4	390	345	280	265	270	330
5	375	360	340	335	345	360
6	340	300	270	255	240	295
7	335	310	285	290	260	305
8	410	335	345	295	350	355
9	360	330	305	295	285	325
10	405	315	285	280	265	325
Mean sample value	–	–	–	–	–	330

Table XIII

P. caribaea, 13-year-old trees: sulphate pulp evaluation

Cook number	Kappa number	Beating	Drain-ability	Drainage time	Moisture content	Apparent density	Tensile index	Stretch	Tensile energy absorption index	Tear index	Burst index	Folding endurance	Air resistance	ISO brightness	Beating energy
		revs	CSF	s	%	g cm^{-3}	N m g^{-1}	%	mJ g^{-1}	mN m^2 g^{-1}	kPa m^2 g^{-1}	$\log_{10}n$*	s	%	Wh
348	49.9	0	745	4.4	7.6	0.40	38.8	1.5	388	27.4	2.00	2.42	0	17.5	–
		1350	735	4.5	8.0	0.61	76.7	2.6	1290	17.6	4.71	3.01	1	13.0	24
		4050	665	4.6	8.0	0.68	86.9	3.0	1690	14.5	5.63	2.95	2	11.5	67
		6750	545	4.7	8.1	0.70	95.7	2.9	1820	12.7	6.47	2.93	6	11.0	113
		9450	390	4.9	8.1	0.73	98.6	3.1	1980	11.1	6.43	3.00	23	10.5	152
		12,150	240	5.2	8.4	0.74	102.0	3.1	2050	10.7	6.83	2.98	71	10.5	196
339	34.9	0	740	4.4	7.5	0.45	45.3	1.7	492	28.4	2.25	2.63	0	21.0	–
		1350	725	4.5	7.8	0.64	72.4	2.6	1220	17.9	4.54	3.00	1	16.0	24
		4050	645	4.5	7.6	0.69	90.3	2.8	1650	12.2	5.62	2.95	2	14.0	69
		6750	480	4.7	7.7	0.71	97.8	2.9	1880	11.2	6.03	2.90	9	13.0	113
		9450	330	5.0	7.5	0.73	99.7	2.9	1860	11.4	6.45	2.97	35	12.5	155
		12,150	202	5.6	7.8	0.76	106.0	2.8	1940	10.2	7.02	3.02	170	13.0	198
340	24.9	0	735	4.4	7.3	0.45	40.2	1.6	429	28.9	2.05	2.37	0	23.5	–
		1350	710	4.5	7.4	0.85	72.0	2.5	1200	16.1	4.36	2.97	1	18.0	24
		4050	615	4.6	6.9	0.70	89.5	2.8	1670	12.0	5.66	2.99	4	16.0	68
		6750	440	4.8	7.4	0.73	94.8	2.8	1750	11.1	6.00	2.93	16	15.0	112
		9450	280	5.3	7.6	0.75	99.0	2.8	1840	10.4	6.38	2.95	92	15.0	154

Note: * n = number of double folds

Table XIV

P. oocarpa, 13-year-old trees: sulphate pulp evaluation

Cook number	Kappa number	Beating revs	Drain-ability CSF	Drainage time s	Moisture content %	Apparent density g cm^{-3}	Tensile index N m g^{-1}	Stretch %	Tensile energy absorption index mJ g^{-1}	Tear index mN m^2 g^{-1}	Burst index kPa m^2 g^{-1}	Folding endurance $\log_{10}n$*	Air resistance s	ISO brightness %	Beating energy Wh
354	59.4	0	740	4.4	7.8	0.39	34.8	1.2	280	23.40	1.53	1.84	0	16.5	–
		1350	755	4.6	8.0	0.63	73.0	2.4	1160	13.10	4.35	2.86	0	12.0	24
		4050	695	4.6	8.2	0.69	91.2	2.9	1720	9.73	5.46	2.94	2	10.5	68
		6750	510	4.7	8.0	0.71	95.6	2.6	1580	9.44	5.97	2.87	6	10.5	110
		9450	345	4.9	8.8	0.73	99.7	2.8	1830	9.14	5.97	2.90	25	10.0	154
		12,150	232	5.6	8.2	0.76	105.0	2.9	1990	8.51	6.60	2.94	230	9.5	194
345	37.7	0	750	4.3	7.4	0.43	38.8	1.4	360	24.30	1.86	2.02	0	20.5	–
		1350	735	4.4	7.4	0.65	71.4	2.3	1090	13.00	4.38	2.88	1	15.5	24
		4050	625	4.5	7.3	0.71	93.2	2.7	1610	9.75	5.63	2.96	3	13.5	68
		6750	455	4.7	7.5	0.74	94.5	2.6	1610	9.71	6.24	2.92	13	12.5	112
		9450	300	5.0	7.7	0.76	97.1	2.8	1760	8.88	6.39	3.03	80	12.0	153
346	28.8	0	730	4.5	7.3	0.43	35.9	1.4	320	25.90	1.60	1.85	0	22.0	–
		1350	720	4.5	7.5	0.66	69.6	2.4	1080	14.30	4.16	2.90	1	16.5	24
		4050	600	4.7	7.5	0.72	86.7	2.6	1490	9.99	5.49	2.89	4	14.5	68
		6750	430	4.8	7.6	0.75	95.3	2.7	1670	9.21	5.87	2.91	17	13.5	110
		9450	246	5.5	7.6	0.77	98.9	2.6	1710	8.81	6.30	2.92	190	13.0	152

Note: * n = number of double folds

Table XV

C. brevipetiolata, 10-year-old trees: pulp evaluation

Cook number	Kappa number	Beating	Drain-ability	Drainage time	Moisture content	Apparent density	Tensile index	Stretch	Tensile energy absorption index	Tear index	Burst index	Folding endurance	Air resistance	ISO brightness	Opacity	Specific scattering coefficient	Beating energy
		revs	CSF	s	%	g cm^{-3}	N m g^{-1}	%	mJ g^{-1}	mN m^2 g^{-1}	kPa m^2 g^{-1}	$\log_{10}n$*	s	%	%	cm^2 g^{-1}	Wh
Sulphate																	
333	41.2	0	600	4.7	7.5	0.58	44.4	1.0	260	6.71	1.46	0.80	9	21.5	–	–	–
		1350	465	5.7	7.8	0.78	93.1	2.8	1760	7.16	5.36	2.64	120	17.0	–	–	19
		4050	350	6.8	7.8	0.85	113.0	3.3	2470	6.56	6.92	2.87	360	15.0	–	–	55
		6750	270	8.4	7.8	0.89	124.0	3.5	2860	5.91	7.61	3.03	830	13.5	–	–	90
334	29.0	0	595	4.9	7.4	0.63	50.5	1.1	330	8.00	1.88	0.94	18	23.0	–	–	–
		1350	435	6.4	7.5	0.80	97.4	2.9	1870	7.89	5.37	2.38	160	18.5	–	–	20
		4050	360	7.4	7.4	0.86	112.0	3.4	2500	6.62	6.60	2.96	450	16.5	–	–	56
		6750	280	9.2	7.4	0.89	119.0	3.5	2770	6.05	7.05	3.12	930	15.0	–	–	91
335	25.9	0	585	4.8	7.2	0.65	54.7	1.1	370	8.45	1.93	0.87	20	24.0	–	–	–
		1350	425	6.6	7.2	0.82	94.1	2.9	1820	7.69	5.13	2.39	200	20.0	–	–	20
		4050	350	7.6	7.2	0.87	109.0	3.4	2480	6.80	6.25	2.64	470	17.5	–	–	57
		6750	300	8.5	7.6	0.88	114.0	3.3	2550	6.20	6.57	2.63	630	15.5	–	–	94
Soda																	
336	49.0	0	625	4.7	7.3	0.57	40.1	0.9	220	6.52	1.44	0.58	10	23.5	–	–	–
		1350	520	5.1	7.3	0.73	74.4	2.2	1070	8.34	3.85	1.93	53	19.5	–	–	21
		4050	425	5.7	7.4	0.81	95.1	2.9	1800	7.34	5.34	2.49	130	17.5	–	–	60
		6750	340	6.4	7.3	0.84	99.4	3.0	2020	7.08	5.93	2.57	290	18.0	–	–	100
		9450	260	7.9	7.6	0.87	110.0	3.5	2590	6.81	6.25	2.63	600	15.0	–	–	139
Soda/0.1% anthraquinone																	
353	30.8	0	585	4.9	7.1	0.63	50.0	1.1	330	8.54	1.86	0.80	18	25.0	–	–	–
		1350	550	4.9	7.4	0.71	74.2	2.1	1040	7.97	3.63	1.96	37	19.0	–	–	21
		4050	365	7.0	7.3	0.85	107.0	3.1	2200	6.80	6.15	2.57	310	16.5	–	–	57
		6750	280	8.4	7.4	0.88	116.0	3.4	2580	6.22	6.52	2.73	730	15.0	–	–	96
Bleached																	
334	29.0	0	475	5.1	7.4	0.64	41.4	1.5	420	8.41	1.88	0.96	20	82.0	84.0	480	–
		1350	450	6.4	7.5	0.80	77.8	3.2	1690	8.38	4.60	2.40	130	80.0	77.0	340	18
		4050	360	8.2	7.4	0.87	99.8	3.7	2480	7.22	6.34	2.85	370	77.0	71.5	255	56
		6750	295	9.7	7.8	0.90	110.0	4.1	2920	6.77	6.64	3.00	640	75.5	69.0	225	91

Note: * n = number of double folds

Table XVI

E. deglupta, 8-year-old trees: pulp evaluation

Cook number	Kappa number	Beating	Drain-ability	Drainage time	Moisture content	Apparent density	Tensile index	Stretch	Tensile energy absorption index	Tear index	Burst index	Folding endurance	Air resistance	ISO brightness	Opacity	Specific scattering coefficient	Beating energy
		revs	CSF	s	%	g cm^{-3}	N m g^{-1}	%	mJ g^{-1}	mN m^2 g^{-1}	kPa m^2 g^{-1}	$\log_{10}n$*	s	%	%	cm^2 g^{-1}	Wh
Sulphate																	
368	39.1	0	595	4.9	7.9	0.53	46.1	1.0	250	6.54	1.61	0.50	2	22.0	–	–	–
		1350	475	5.5	7.8	0.69	93.2	2.5	1460	11.20	4.72	1.82	13	19.0	–	–	18
		4050	370	6.7	8.1	0.75	112.0	3.1	2220	10.70	6.32	2.60	41	18.0	–	–	52
		6750	250	8.5	8.0	0.80	122.0	3.4	2630	9.70	7.31	2.71	110	16.5	–	–	88
361	27.5	0	585	4.7	7.9	0.54	47.7	1.0	260	6.68	1.59	0.70	3	24.5	–	–	–
		1350	465	5.1	7.7	0.69	88.8	2.4	1370	10.70	4.49	1.81	14	22.0	–	–	18
		4050	385	6.4	7.6	0.75	106.0	2.8	1930	11.20	5.82	2.21	33	20.5	–	–	52
		6750	305	7.3	7.8	0.79	115.0	3.3	2410	10.30	6.41	2.66	68	19.5	–	–	87
		9450	244	8.4	7.8	0.80	116.0	3.5	2670	10.20	7.06	2.92	120	19.0	–	–	122
362	22.0	0	570	4.9	7.3	0.53	46.0	1.0	240	6.07	1.49	0.48	3	26.0	–	–	–
		1350	470	5.9	7.1	0.69	81.3	2.1	1120	11.60	3.96	1.74	15	23.5	–	–	20
		4050	390	6.8	7.1	0.75	97.8	2.8	1810	10.60	4.99	2.15	36	21.5	–	–	55
		6750	300	8.0	7.4	0.80	101.0	2.9	1950	9.93	5.80	2.52	83	20.0	–	–	92
Soda																	
383	48.5	0	595	4.7	7.7	0.46	32.2	0.6	110	3.97	1.05	0.15	1	23.0	–	–	–
		1350	495	5.2	7.6	0.63	70.4	1.8	798	10.50	3.12	1.38	6	20.5	–	–	20
		4050	425	5.6	7.5	0.68	86.4	2.2	1230	10.50	4.23	1.63	15	19.5	–	–	54
		6750	335	6.1	7.7	0.73	92.1	2.7	1600	10.10	4.84	1.99	31	19.0	–	–	92
		9450	275	6.8	7.8	0.75	101.0	2.8	1820	9.64	5.46	2.15	57	18.0	–	–	127
Soda/0.1% anthraquinone																	
384	27.8	0	585	4.8	7.4	0.51	41.3	0.8	200	5.20	1.35	0.32	2	25.0	–	–	–
		1350	490	5.3	7.4	0.67	77.2	2.2	1110	10.00	3.76	1.44	11	22.0	–	–	19
		4050	390	6.4	7.6	0.74	96.5	2.8	1730	10.10	4.91	2.06	31	20.0	–	–	53
		6750	295	7.1	7.7	0.78	103.0	3.1	2070	9.54	5.52	2.23	73	19.0	–	–	94
Bleached																	
361	27.5	0	535	5.0	7.6	0.55	34.9	1.1	250	5.64	1.43	0.48	3	84.0	84.0	505	–
		1350	490	5.7	7.6	0.69	71.5	2.4	1130	12.50	3.66	1.55	12	83.0	79.5	400	19
		4050	420	6.6	7.6	0.75	88.0	3.0	1720	11.20	4.85	2.09	25	81.5	77.0	340	56
		6750	340	7.4	7.7	0.79	101.0	3.4	2240	10.60	5.61	2.50	53	80.0	74.5	300	93
		9450	310	8.2	7.8	0.80	104.0	3.6	2400	10.70	6.09	2.48	70	79.5	74.0	295	126

Note: * n = number of double folds

Table XVII

T. brassii, 9-year-old trees: pulp evaluation

Cook number	Kappa number	Beating	Drain-ability	Drainage time	Moisture content	Apparent density	Tensile index	Stretch	Tensile energy absorption index	Tear index	Burst index	Folding endurance	Air resistance	ISO brightness	Beating energy
		revs	CSF	s	%	g cm^{-3}	N m g^{-1}	%	mJ g^{-1}	mN m^2 g^{-1}	kPa m^2 g^{-1}	$\log_{10}n$*	s	%	Wh
Sulphate															
193	44.5	0	575	5.0	8.3	0.70	72.8	1.3	610	13.10	2.89	1.63	22	18.0	–
		1350	485	6.1	8.4	0.81	114.0	3.0	2380	9.50	6.90	2.95	140	16.0	21
		4050	395	7.2	8.6	0.86	133.0	3.6	3350	8.62	8.20	3.21	340	15.0	56
		6750	305	8.7	8.0	0.89	139.0	3.8	3630	8.01	8.55	3.28	760	14.00	92
		9450	246	10.7	8.0	0.90	144.0	3.9	3800	7.58	9.15	3.38	1300	13.5	125
194	37.8	0	570	5.1	7.7	0.68	69.8	1.3	620	12.60	2.93	1.68	25	19.0	–
		1350	490	6.2	7.8	0.82	109.0	2.9	2240	9.53	6.39	2.95	140	17.0	20
		4050	415	7.2	7.8	0.86	126.0	3.4	3010	8.48	7.58	3.08	300	16.0	56
		6750	320	8.8	7.7	0.88	132.0	3.5	3210	8.04	8.41	3.26	600	15.0	93
		9450	260	10.8	7.7	0.90	138.0	3.7	3480	7.52	8.62	3.31	1100	14.0	128
200	32.9	0	565	5.2	6.7	0.68	66.7	1.2	560	11.90	2.76	1.55	31	20.0	–
		1350	490	6.2	7.4	0.81	104.0	2.7	2040	9.93	5.95	2.80	140	18.5	20
		4050	415	7.5	7.7	0.86	119.0	3.2	2660	9.02	7.11	3.08	280	17.0	57
		6750	350	9.0	7.5	0.88	127.0	3.4	2990	8.43	7.92	3.17	570	15.5	93
		9450	280	10.9	7.6	0.90	132.0	3.6	3300	7.68	8.06	3.21	1000	15.5	129
Soda															
569	55.9	0	617	4.7	8.0	0.57	44.5	0.8	220	8.20	1.60	0.71	8	21.1	–
		1350	514	5.4	8.4	0.75	86.7	2.3	1300	11.00	4.53	2.15	60	17.3	21
		4050	427	6.2	8.0	0.80	112.0	2.8	2060	9.20	5.88	2.77	155	16.3	64
		6750	342	7.1	8.1	0.83	112.0	3.0	2210	8.40	6.70	3.00	285	15.1	106
		9450	297	8.1	8.2	0.84	117.0	3.3	2450	8.50	6.90	3.10	400	15.0	144
Soda/anthraquinone															
570	36.0	0	558	4.9	7.8	0.63	62.7	1.2	490	11.90	2.63	1.38	23	20.8	–
		1350	483	6.0	7.8	0.78	99.4	2.4	1580	10.00	5.19	2.73	110	17.9	22
		4050	412	7.1	7.7	0.83	117.0	2.9	2235	9.00	6.83	3.00	230	16.5	60
		6750	331	9.0	7.7	0.86	128.0	3.4	2800	7.90	7.64	3.16	490	15.6	100
		9450	274	10.5	7.8	0.87	125.0	3.3	2625	7.80	7.73	3.19	680	14.7	140

Note: * n = number of double folds

Table XVIII

T. calamansanai, 8-year-old trees: pulp evaluation

Cook number	Kappa number	Beating revs	Drain-ability CSF	Drainage time s	Moisture content %	Apparent density g cm^{-3}	Tensile index N m g^{-1}	Stretch %	Tensile energy absorption index mJ g^{-1}	Tear index mN m^2 g^{-1}	Burst index kPa m^2 g^{-1}	Folding endurance $\log_{10}n$*	Air resistance s	ISO brightness %	Beating energy Wh
Sulphate															
343	64.9	0	595	4.9	7.7	0.58	50.2	1.2	370	6.94	1.86	1.15	9	18.0	–
		1350	455	5.9	7.6	0.73	107.0	3.0	2120	7.71	5.85	2.87	69	16.0	19
		4050	360	7.4	7.6	0.78	124.0	3.4	2740	6.93	7.42	3.11	180	15.5	54
		6750	275	8.9	7.7	0.80	129.0	3.6	3070	6.55	8.01	3.19	400	14.5	87
344	50.0	0	560	4.9	7.2	0.59	53.2	1.2	380	10.10	2.02	0.97	10	19.5	–
		1350	425	6.8	7.7	0.74	101.0	3.1	2050	9.36	5.71	2.49	82	16.0	20
		4050	340	8.8	7.6	0.79	115.0	3.2	2410	8.52	6.82	2.86	170	15.0	56
		6750	280	9.8	7.3	0.83	127.0	3.5	2880	7.56	7.83	2.99	500	14.5	94
350	43.0	0	575	5.1	6.9	0.61	53.6	1.1	360	10.20	1.97	0.93	12	20.0	–
		1350	435	7.0	7.6	0.74	96.9	2.8	1800	8.49	5.43	2.78	66	17.0	20
		4050	385	7.6	7.6	0.80	110.0	3.2	2340	7.62	6.53	2.94	140	16.0	56
		6750	305	8.8	7.2	0.83	120.0	3.2	2560	7.02	7.22	3.17	290	16.0	92
		9450	242	11.6	7.6	0.84	126.0	3.7	2990	7.19	7.63	3.07	520	15.0	129
Sulphate/anthraquinone															
364	47.8	0	555	5.3	7.5	0.61	53.1	1.3	420	11.00	2.16	1.11	12	19.0	–
		1350	430	6.8	7.7	0.74	94.4	2.7	1690	9.17	5.36	2.40	78	17.0	20
		4050	370	8.5	7.4	0.79	111.0	3.2	2320	7.60	6.52	2.87	180	16.5	56
		6750	305	9.4	7.5	0.81	113.0	3.3	2450	7.61	6.68	2.86	260	15.5	90
		9450	204	14.7	7.7	0.84	113.0	3.2	2360	7.02	6.27	3.04	630	14.5	135
Soda															
572	68.0	0	616	5.8	7.9	0.54	48.8	1.0	310	9.08	1.76	0.96	4	19.5	–
		1350	501	5.3	8.1	0.71	88.6	2.5	1460	9.18	4.81	2.31	35	16.5	21
		4050	426	6.0	7.9	0.77	110.0	3.0	2140	8.40	6.44	2.73	80	15.5	63
		6750	363	6.4	8.1	0.79	113.0	3.3	2420	7.82	6.31	2.89	140	14.7	101
		9450	288	7.8	7.8	0.80	120.0	3.3	2540	7.63	7.10	2.89	255	14.4	142
Soda/anthraquinone															
571	48.1	0	570	5.8	8.2	0.58	55.1	1.3	450	10.60	2.32	1.23	12	19.5	–
		1350	455	6.3	7.9	0.73	89.6	2.6	1500	9.26	5.01	2.49	76	17.0	20
		4050	375	7.5	8.0	0.79	113.0	3.2	2320	7.72	6.35	2.81	173	15.0	60
		6750	303	9.7	8.1	0.82	109.0	3.4	2360	7.41	6.96	2.95	330	14.0	97
		9450	237	11.4	7.9	0.84	118.0	3.3	2540	7.13	6.82	3.00	565	13.5	139

Note: * n = number of double folds

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