C.F.I. OCCASIONAL PAPERS

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Pulp and wood densitometric properties of *Pinus caribaea* from Fiji

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(Principal investigators)

DEPARTMENT OF FORESTRY
COMMONWEALTH FORESTRY INSTITUTE
UNIVERSITY OF OXFORD

[redacted]

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with

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The Tropical Products Institute specializes in post-harvest problems and the Commonwealth Forestry Institute specilizes in the introduction, management, improvement and properties of fast growing, tropical, plantation trees.

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Pulp and wood densitometric properties of *Pinus caribaea* from Fiji

SUMMARY

Pinus caribaea is the major plantation species in Fiji and since the late 1950s approximately 25,000 ha (60,000 acres) have been planted; some mature material is being used for posts and sawn timber but the majority may be used for pulp. The present study was intended (i) to demonstrate the variation in pulp properties between individual trees and thus to indicate the feasibility of selecting trees for breeding and (ii) to determine the correlations between pulp properties and a series of chemical and anatomical characters of the wood (including density and its variation within trees) that can be examined on small samples, such as increment cores, and used to predict pulpwood properties for the whole tree.

From plantations of *P. caribaea* from Mountain Pine Ridge, Belize, growing at Drasa (10 years old), Nausori Highlands (10) and Seaqaqa (11) increment cores from 120 randomly chosen trees were examined by X-ray densitometry and 20 trees were selected covering a representative range of means and within-tree variations of density, tree diameter and form. The range of mean density at 12% moisture content was 0.441 - 0.734 g/cm^3.

From each tree, discs approximately 18 mm thick were removed at 10% intervals of height from 5 to 75% of the total height of the tree; the discs were chipped and mixed for duplicated pulping under four digestion conditions with replicated beating at 0, 1, 3, 5 and 7 minutes in a PFI mill. Basic density of whole discs was determined before pulping, chemical analysis was conducted on a portion of chips ground in a knife mill, and fibre length was determined with a fractionator for pulps from the two most severe cooks. Sheets were made on a British Standard Sheet machine and physical properties were determined by standard procedures (British Standards or TAPPI Standards).

There were considerable variations between the 20 trees in alcohol-benzene solubility (0.9 - 4.2%) and in total extractives (3.1 - 6.9%). High cellulose content was associated with low lignin content.

Trees differed in yield and Kappa number for a given digestion:-

	Severity of cooking	
	Least	Most
Yield	44.1 - 50.2	39.6 - 45.1
Kappa no.	40.0 - 63.8	21.4 - 35.0

There were no interactions between tree differences and digestion conditions so that trees could justifiably be compared by the arithmetic means of all determinations. (The precision of this was confirmed by making a 20-tree weighted mixture of chips for pulping.)

Pulp produced by the least severe digestion could be used for strong packaging paper whereas pulp from the most severe digestion would be suitable for bleaching though relatively weak; the loss of strength was about 5 - 6%. All were within the usual range of Kraft pulps.

Various techniques were used to rank the 20 trees using the data for all pulp properties and some trees could be identified as more suitable for packaging pulps, others for bleached pulp. Some individual trees were superior to the average in several technical and productive properties. Since the price differential for different grades of pulp is small, future selection is likely to be based on yield per unit area and wood density (which affects transport, use, efficient digestion and pulp yield).

Progeny tests will be necessary to evaluate the genetic component of the phenotypic variation in each pulp property discussed here. In breeding programmes many more samples will require evaluation than were considered in this study. Pulp yield and the three major pulp strength properties (burst, tensile and tear indices) were predicted as efficiently (correlation coefficient exceeding 0.6) by either mean density or by the amount of wood in a given (high) density class or by a combination of these as by chemical and fibre properties (though not for the same structural reasons). Nevertheless, these accounted for only 35-45% of the total variation in pulp properties and, while X-ray densitometry will facilitate screening of large numbers and estimation of genetic parameters, it will not replace completely the need for laboratory and commercial pulping trials for new populations or environments.

Propriétés papetières de la pâte et propriétés densimétriques du bois du Pinus caribaea des iles Fiji

RESUME

Le *Pinus caribaea* est l'essence de plantation la plus importante aux Fiji et depuis la fin des années 50, environ 25,000 ha ont été plantés; une partie des arbres arrivés à maturité sont utilisés comme poteaux ou bois de sciage mais la majorité peut etre utilisé pour la pâte.

Les objectifs de cette étude sont (i) de montrer les variations de propriétés de la pâte selon les individus d'arbres et (ii) de déterminer les corrélations entre les propriétés de la pâte et un série de caractères chimiques et anatomiques du bois (parmi lesquels la densité et sa variation à l'intérieur de l'arbre) qui peuvent etre examinés sur de petits échantillons tels que les carottes d'accroissement, et utilisés pour prévoir les propriétés de la pâte pour l'arbre entier.

Dans les plantations de *Pinus caribaea* de Mountain Pine Ridge, Belize, poussant à Drasa (10 ans), à Nausori Highlands (10 ans) et à Seaqaqa (11 ans), des carottes d'accroissement de 120 arbres choisis au hasard ont été examinés par densimétrie aux rayons X et 20 arbres couvrant une gamme représentative de densité moyenne, de variations internes de densité, de diamètre et de forme, ont ete selectionnés. L'intervalle de densité moyenne à 12% d'humidité était 0,441 - 0,734 g/cm^3.

Des disques d'environ 18 mm d'épaisseur ont été découpés de chaque arbre à des intervalles de hauteur de 10% entre 5% et 75% de la hauteur totale de l'arbre; les disques ont été hachés et mélangés pour une trituration dupliquée sous 4 conditions de digestion avec un battage répliqué a 0, 1, 3, 5 et 7 minutes dans un moulin PFI. La densité de base des disques entiers a été déterminée avant la trituration, l'analyse chimique a été faite sur une portion de copeaux hachés dans un fraiseuse à couteaux et la longueur des fibres a été déterminée grâce à un fractionneur pour pâte à partir des 2 fourneaux les plus violentes. Les feuilles ont été faites sur une machine à feuilles 'British Standard' et les propriétés physiques ont été déterminées par les methodes normalisés (British Standards ou Tappi Standards).

On a noté des variations considérables entre les arbres en ce qui concerne la solubilité alcool-benzène (0,9 - 4,2%) et dans les extractifs totaux (3,1 -6,9%). Une teneur elévée en cellulose est associée avec une faible teneur en lignine.

Les arbres diffèrent en rendement et numéro de Kappa pour une digestion donnée:

	Degré de cuisson	
	Minimum	Maximum
Rendement	44,1 - 50,2	39,6 - 45,1
Numéro de Kappa	40,0 - 63,8	21,4 - 35,0

On n'a pas trouvé d'interactions entre les différences entre arbres et les conditions de digestion. Par conséquent, on peut légitimement comparer les arbres par la moyenne arithmétique de toutes les déterminations. (La précision de ceci a été confirmée par la fabrication d'un mélange d'échantillons de 20 arbres pour trituration.)

La pâte produite par la digestion la plus douce a pu être utilisée pour faire du papier d'emballage fort, alors que la pâte produite par la digestion la plus violente aurait pu être blanchie, bien qu'elle était relativement faible - la résistance de la pâte s'était reduite par 5-6% environ. Toutes était de la gamme normale de pâte Kraft.

Des technique diverses utilisant les données de toutes les propriétés de pâte ont été utilisées pour classer les 20 arbres, et certains arbres on pu être identifiés comme mieux adaptés à la transformation en pâte d'emballage et d'autres en pâte blanchie. Certains individus étaient supérieurs à la moyenne en ce qui concerne plusieurs propriétés techniques et productives. Etant donné que les différences de prix pour différentes qualités de pâte sont faibles, une sélection future est susceptible d'être basée sur le rendement par unité de surface et la densité du bois (qui affecte le transport, l'utilisation, l'efficience de la digestion et le rendement en pâte).

Des tests de descendance seront nécessaires à l'évaluation du composant génétique de la variation phénotypique de chaque propriété de pâte dont il a été question ici. Dans les programmes d'amélioration génétique il faudra évaluer beaucoup plus d'échantillons que le nombre utilisé pour cette étude. Le rendement en pâte et les trois propriétés les plus importantes de resistance de la pâte (indices d'éclatement, de tension et de déchirure) on été prévus aussi efficacement (coefficient de corrélation dépassant 0,6) par soit la densité, soit la quantité de bois d'une classe de densité (élevée) donnée, soit une combinaison des deux, que par des propriétés chimiques ou des propriétés de la fibre. Toutefois, celles-ci comptaient seulement pour 35-45% de la variation totale des propriétés de la pâte et, alors que la densimétrie aux rayons X facilitera le triage de nombres importants et l'estimation de paramètres génétiques, elle ne remplacera pas complètement le besoin de faires des essais de trituration commerciaux et en laboratoire pour de nouveaux populations et environnements.

Propiedades papeleras de pulpa y propiedades densitométricas de madera en Pinus caribaea de Fiji

SUMARIO

El Pinus caribaea es la especie que más se planta en Fiji y desde finales de 1950 en adelante, aproximadadamente 25,000 ha (60,000 acres) han sido plantadas; material ya maduro se utiliza para postes y madera aserrada, aunque la mayoría se utiliza en la producción de pulpa. El presente estudio pretende (i) demostrar la variabilidad en las propiedades de la pulpa entre árboles individuales y así indicar la factibilidad de seleccionar árboles para mejoramiento y, (ii) determinar el grado de correlación, entre las propiedades de la pulpa y una serie de características químicas y anatomícas de la madera (incluyendo la densidad y su variabilidad dentro árboles) que pueden ser examinadas, utilizando muestras pequenas tomadas con el barreno de Pressler. Posteriormente, se utilizan las muestras para predecir las propiedades de la madera para pulpa en el árbol completo.

De las plantaciones de Pinus caribaea procedente de Mountain Pine Ridge, Belize, establecidas en Drasa (10 años de edad), Nausori Highlands (10) y Seaqaqa (11), fueron tomadas 120 muestras de árboles seleccionados al azar. Se examinaron empleando el densitómetro de rayos X; finalmente fueron seleccionados 20 árboles que cubrieron un rango representativo de promedios y de la variación de la densidad dentro árboles, diámetro del árbol y su forma. El rango de promedios de la densidad, con 12% de contenido de humedad, fue de 0.441 - 0.734 g/cm^3.

De cada árbol se tomaron discos de aproximadamente 18 mm de espesor a intervalos de 10% con respecto a la altura. Se tomaron las muestras entre el 5 y 75% de la altura total del árbol. Los discos fueron molidos y mezclados, para producir pulpa bajo cuatro condiciones de digestión, con repetidas agitaciones de 0, 1, 3, 5 y 7 minutos en un molino PFI. La densidad básica fue determinada en todos los discos, antes de transformarlos en pulpa; el análisis químico se realizó sobre una porción de las astillas elaboradas previamente en un molino de cuchillas, el largo de la fibra se tomó de las muestras más severamente cocinadas, utilizando un fraccionador de pulpas. Las laminas se elaboraron bajo las normas standard de laminado inglés. Los propiedades físicas y mecánicas fueron determinadas usando procedimientos standard (British Standards bien TAPPI standards).

Entre los 20 árboles seleccionados se encontró variación considerable, con respecto a solubilidad en alcohol-benzeno (0.9 - 4.2%) y extractos totales (3.1 - 6.9%). El contenido alto de celulosa fue asociado con el contenido bajo de lignina.

Existieron diferencias entre árboles en rendimiento y número Kappa para una digestión dada:

	Intensidad de cocinado	
	menor	mayor
Rendimiento	44.1-50.2	39.6-45.1
No. Kappa	40.0-63.8	21.4-35.0

No se encontraron interacciones entre las diferencias entre árboles y las condiciones de digestión. Por lo tanto, podría justificarse el comparar los árboles por los promedios aritméticos de todas las determinaciones. (La precisión de esto fue confirmada mediante la fabricación y cocinado de una mezcla(proporcionado) de astillas de 20 árboles.)

La pulpa producida bajo la digestión menos severa podría ser utilizada para papel de empaque fuerte, minetras que la pulpa producida bajo la condición más severa(aunque relativamente debil) podría ser utilizada para pulpa blanqueada. La pérdida de resistencia fue entre 5-6%. Todas estuvieron dentro del rango normal para pulpa Kraft.

Fueron utilizadas varias técnicas para establecer el rango de los 20 árboles, en base a todos los datos de las pulpas analizadas. Algunos árboles podrían ser identificados como apropiados para pulpa de empaque y otros para pulpa blanqueada. Algunos árboles individuales fueron superiores al promedio, en base a varias propiedades técnicas y de productividad.

Como la diferencia en precio entre los diferentes grados de pulpa es pequeña, es probable que la selección futura se base en rendimiento por unidad de área y densidad de la madera (lo cual afecta el uso de transporte, eficiencia en la digestión y rendimiento de la pulpa.

Pruebas de progenie serían necesarias para evaluar los componentes genéticos de la variación fenotípica, en cada una de las propiedades de la pulpa discutidas aquí. En programas de mejoramiento será necesario para realizar la evaluación un número mayor de muestras que él utilizado en este estudio. El rendimiento de la pulpa y las tres propiedades fundamentales de resistencia (índices de reventazón, tracción y rasgado) fueron predichas eficientemente (coeficiente de correlación superior a 0.6) tanto para la densidad como para la cantidad de madera en una determinada clase (alto) de densidad, por la combinación de ésta, o por las propiedades químicas de la fibra. No obstante, estas propiedades analizaron sólamente el 35-45% de la variación total en las propiedades de la pulpa. Aunque el densitómetro de rayos X facilitara la separación de un gran número y la estimación de parámetros genéticas, este método no podrá reemplazar completamente la necesidad de pruebas a nivel comercial y de laboratorio para nuevas plantaciones o climas.

Pulp and wood densitometric properties of *Pinus caribaea* from Fiji.

1. INTRODUCTION

Pinus caribaea var. *hondurensis* Barrett and Golfari was introduced into Fiji in 1955 and subsequently, in the late 1950s and early 1960s, modest areas of plantations were established. The success of these early plantations has led to recent annual planting programmes of 4,000 - 6,000 hectares, aimed at providing raw material for export of pulp chips and timber for local consumption. Within the field of research activities, it was early recognised that the investigation of wood properties of the species merited a high priority.

There have been a number of unpublished reports that have indicated the need for further study before Fijian *P. caribaea* could be exploited commercially.

In August, 1968, a report was published (Palmer and Gibbs, 1968) on the pulp and paper properties of 9 and 10 year old trees from Drasa, Nadarivatu and Verata. The results indicated that pulps were slightly inferior to Southern Pine pulps. A second pulping trial on material from Seaqaqa (Palmer and Gibbs, 1971) indicated a generally rather better quality comparable with the average Southern Pine pulps, although variation exists within sites (Palmer and Gibbs, 1972).

At the same time it was recognised that the species planted on different sites showed considerable variation in wood properties. It was, therefore, decided to carry out a series of trials to determine the extent of variation in the wood and attempt to relate this in the first instance to conditions of growth but later also to variation in pulp and paper properties through co-operation between the Fiji Forest Department, the Commonwealth Forestry Institute, Oxford (CFI), and the Tropical Products Institute, London (TPI).

In late 1970 and early 1971 one breast height increment core from each of 120 random trees at Drasa, Nausori Highlands, and Seaqaqa were sent to Oxford for X-ray densitometry. These showed that wood density varied very considerably between trees and to a lesser extent rate of growth and density varied between sites. The large difference between trees on all sites suggested that a considerable amount of variation might be heritable and, in view of the differences in pulp and paper properties between the earlier Seaqaqa material and that from the other sites, it was likely that the differences in wood density were being reflected in differences in pulp quality. It was, therefore, decided to select 20 trees to be pulped individually and to study the wood of these trees intensively in an attempt to relate wood density and its components to paper properties. It was also decided to compare fibre (tracheid) dimensions and paper properties at a later stage and this is in progress /1.

/1 Ong, S. (1978). A study of the variation in some structural features and some wood properties of *Pinus caribaea* Morelet. D. Phil. Thesis, Oxford.

The 120 cores were grouped into five density classes and trees were selected to span these classes which also had a good rate of growth and other favourable characters. No attempt was made to take equal samples from the three sites and selection was based entirely on mean wood density, pattern of densitometer trace (to cover the main range of trace patterns), d.b.h./1, taper and crown width/stem diameter ratio.

In mid 1972 hurricane Bebe destroyed, or rendered unfit for sampling, many of the trees originally selected but a further 20 trees were selected from the survivors; they were felled and sent for testing at CFI and TPI. The trees were distributed as follows:- Nausori Highlands 4, Drasa 4 and Seaqaqa 12.

Samples were taken at 10% intervals of total tree height from 5% to 75% height. They were 0.3 m long and were sawn at CFI to give samples for wood quality and paper tests; the latter were sent to TPI.

At the same time clonal material for grafting was collected from 10 of the sample trees (Nausori Highlands 2, Drasa 2 and Seaqaqa 6) to be grafted on root stock and replicated five times on five sites. Again the trees were selected to cover the wood density range rather than sites.

Details of environment and plantation history are given in Appendix 1A. Full details of methods of sampling and collection of material are given in Appendix 1B.

In view of the widespread importance of P. caribaea as a pulpwood plantation species throughout the tropics, and the possibilities that exist for its genetic improvement by selection and breeding of individual trees, it is felt that the results reported here will be of value far beyond the borders of Fiji. The willing cooperation of the Department of Forestry, Fiji, is gratefully acknowledged.

/1 d.b.h. is a standard forestry abbreviation for diameter at breast height.

2. PULP PROPERTIES

Review of past pulping work

In the late 1950's the pulping qualities of old trees of *Pinus caribaea* var. *hondurensis* grown in Belize were determined at the Tropical Products Institute, London, England, and the Forest Products Laboratory, Madison, Wisconsin, U.S.A. (Chittenden and Palmer, 1959; Schafer and Chidester, 1961). In both of these trials a fluffy pulp with very high tearing strength was obtained.

In subsequent examinations of young samples of *P. caribaea* grown as exotics in plantations, pulps with higher bonding strength but lower tearing strength were obtained (many reports from TPI including Palmer & Gibbs, 1967, 1968).

Whilst a considerable difference might be expected in the quality of pulp obtained from old trees grown in their natural environment compared with that from fast grown young trees from exotic plantations, the differences obtained from different samples of plantation grown material was greater than expected.

Consequently, a number of investigations have been made to try to elucidate the cause of the differences found for various samples. Unfortunately, much of the evidence obtained is inconclusive.

Amongst the variables studied are:-

(a) Age. In general pulp from young trees has better bonding properties and poorer tearing strength than pulp from older trees (Palmer and Peh, 1966).

In some investigations the bonding strength has fallen with increasing age but the tearing strength has reached a peak and stayed at that level. This effect was found with samples five and nine years old from Sabah (Palmer and Gibbs, 1967) and 10 and 15 years old from Fiji (Palmer and Gibbs, 1972a). However, in examining samples age between 11 and 24 years, from Belize, there was little difference in the bonding properties and no consistent pattern in the effect of age on tearing strength (Palmer and Gibbs, 1976).

(b) Wood density. Wood with a high density may be expected to have more thick walled fibres than wood with a low density. Consequently, it was expected that high density wood would yield pulps with higher tearing strength and poorer bonding strength than low density wood. This relationship for pulp strengths was found when examining three trees 12 years old from the same plantation in Jamaica, although the difference in the Kappa number of the pulp at constant digestion conditions could not be explained in terms of variation in wood density (Palmer and Gibbs, 1973).

When the least and the most dense trees of a bulk sample of trees nine years old from Sabah were examined individually, there were no significant differences in the bonding properties of the pulps obtained but the pulp from the most dense tree had the higher tearing strength (Palmer and Gibbs, 1972b).

(c) Rate of growth. In several trials trees of different sizes grown on the same site have been examined. Although these trees have had different densities and, in some cases, yielded pulps with different properties, there was no obvious correlation between tree size and property (Palmer and Gibbs, 1969; Watson, Higgins and Smith, 1971).

In a recent investigation 300 trees in a single plot in Fiji were measured and divided into three groups of 100 according to their girth. Ten trees were selected by random sampling from the 100 smallest trees and ten more from the 100 largest trees. The average density of the slow grown group was less than 4% greater than that of the fast grown group and the range of densities of individual trees was the same for each group.

Differences in chemical compositions of the woods and strength properties of the pulps obtained from each group were not significant. The slow grown group yielded a little more pulp (oven-dry pulp/oven-dry wood) than the fast grown group, but the difference was more than compensated by the higher volume of wood in the fast grown group. From these results it was concluded that in any initial selection, the fast growing trees should be chosen (Palmer and Gibbs, 1977).

(d) Growing conditions. There is evidence that soil and/or climatic conditions or an interaction of these with the genetic constitution of the tree can cause considerable difference in wood quality, and this subject needs more study.

In the present trials it was intended to elucidate some of the obscurities of past investigations. Samples from Fiji were used because past investigations had shown wide differences in density of individual trees from the same site and of the same age, which indicated there was considerable prospect of improving the uniformity of a plantation and the average quality of the wood from it.

Purpose and overall plan of present study

The pulping trials carried out at TPI had two main objectives:-

(i) to evaluate as a pulpwood each individual tree in order to demonstrate the extent of variation between trees and to indicate the feasibility of selecting trees for use as parents (seed trees or plus trees) in subsequent generations of plantations.

(ii) to generate data about the chemical composition, pulp fibre (tracheid) length and pulp characteristics of individual trees that would subsequently be used, together with other data obtained at CFI by densitometric analysis and fibre measurements on wood, in order to find (if possible) a test or tests that could be carried out on small samples such as increment cores which would predict the value of the tree for pulpwood.

A sample to represent each tree was prepared by taking an equal number of discs, approximately 18 mm thick, at 5%, 15%, 25%, 35%, 45%, 55%, 65% and 75% of the total height of the tree. By this technique the top 20% of the height of the tree was not included but, since most of this section would be discarded in logging, the sample did represent the commercially usable part of the tree. The discs were chipped and the chips were thoroughly mixed. A portion of the chips was ground in a knife mill to obtain the sample for chemical analysis.

Each sample was subjected to four sets of digestion conditions, in which the alkali dosage and the digestion time were varied in order to obtain pulps with varied degrees of digestion. Each digestion was duplicated (i.e. eight digestions per tree).

To determine the physical characteristics of the pulps a five point beating curve was made on each pulp by beating it for 0, 1, 3, 5 and 7 minutes in a PFI mill. Each beating curve was replicated (i.e. 16 beating curves per tree).

The physical characteristics of the pulps were determined by use of standard techniques to prepare and test sheets. Details of the methods used are given in Appendix 2.

Methods and results

(a) Wood density

At TPI the basic or apparent density (oven dry weight ÷ saturated volume) was determined by the method of water displacement for whole discs that is commonly used in the pulp industry. Only 15 trees were examined because, after chipping the quantity of wood required for pulping, insufficient discs of the remaining trees remained for density determinations. The data for these 15 trees are listed in Text Table 2.1.

At CFI all 20 trees were examined by X-ray densitometry of samples conditioned at 12% moisture content. This condition was selected because it is the one at which standard timber properties are reported and also because it is approximately the ambient laboratory condition; thus no swelling or shrinkage of samples would be expected in the few minutes necessary to X-ray the specimens.

Detailed discussion of the within-tree variations in density is given in Chapter 3. The correlation between CFI and TPI values for weighted tree mean density was extremely high (r = 0.976***) with TPI values ranging from 77-88% (average 81%) of CFI values depending on mean density. Data for each tree and full details of the comparisons are given in Appendix 3 (Figure 3 and Table 2).

Density is expressed either as kg/m^3 or g/cm^3 and both are of course numerically equivalent to the dimensionless specific gravity. Basic density ranged from 0.363-0.645 g/cm^3 (15 trees) and at 12% moisture content the range for 20 trees was 0.441 - 0.734 g/cm^3.

Text Table 2.1

Basic density for 15 trees

Tree number	Density, g/cm^3	Tree number	Density, g/cm^3
D2/11	0.528	S1/64	0.431
NH1/24	0.363	S2/1	0.374
NH1/40	0.384	S2/6	0.466
NH1/44	0.466	S2/37	0.450
S1/8	0.463	S2/51	0.454
S1/31	0.462	S2/79	0.525
S1/45	0.645	S2/84	0.479
S1/55	0.374	Range	0.363-0.645

(b) Fibre length

The fibre length was determined using a McNett fractionator for the pulps from two most severe cooks on each tree. The results are recorded in Text Table 2.2.

The differences in the average fibre length between trees were not great (2.78 mm to 3.21 mm). However, there were large differences between trees in the quantity of fibres in any given class, e.g. 61.5% by weight of the fibres from tree S1/55 were in the largest class, but only 31.1% of the fibres from tree D1/6 were in the same class.

(c) Chemical analysis

Some of the more important chemical constituents that affect pulping characteristics were determined on each tree.

The results are recorded in Text Table 2.3.

Although there were differences between the individual trees, there was nothing in the chemical analysis to indicate that any of the trees would

Text Table 2.2. Tree mean proportions of fibres in pulp retained by screens of different mesh size, and weighted mean fibre length

Tree identity	Retained 10	Pass 10 Retained 14	Pass 14 Retained 20	Pass 20 Retained 28	Pass 28 Retained 35	Pass 35 Retained 65	Pass 65 Retained 200	Pass 200 Mesh	Length (weighted) mm
D1/6	31.10	24.00	16.95	8.60	8.90	4.70	1.35	4.45	2.780
D1/57	50.45	17.40	12.55	6.30	5.80	3.15	0.70	3.60	3.075
D1/71	47.40	16.75	13.50	6.85	7.00	4.50	0.90	3.10	3.005
D2/11	49.15	16.20	12.70	6.50	6.75	4.10	1.10	3.50	3.020
NH1/24	35.65	23.40	14.90	8.10	7.60	4.05	1.40	4.85	2.845
NH1/40	40.80	20.15	14.55	7.25	7.45	4.50	1.50	3.75	2.915
NH1/44	51.00	16.90	11.70	5.95	6.35	3.45	1.15	3.40	3.080
NH1/51	53.30	15.45	12.10	6.40	6.35	3.15	0.85	2.35	3.115
S1/8	61.50	11.90	9.60	4.70	5.15	3.20	0.95	2.95	3.200
S1/31	50.40	17.70	12.40	6.70	5.90	3.35	0.95	2.55	3.090
S1/36	53.75	13.70	11.70	6.05	6.70	4.55	1.35	2.20	3.090
S1/45	55.00	16.05	9.85	6.65	6.40	3.45	0.80	1.85	3.150
S1/55	61.55	11.90	9.60	4.50	5.40	3.60	1.25	2.20	3.205
S1/64	54.15	13.65	11.05	5.50	6.35	3.60	1.05	4.70	3.055
S2/1	51.75	15.95	12.10	5.75	5.70	4.30	1.20	3.25	3.065
S2/6	43.80	18.90	14.60	7.50	7.30	4.00	1.15	2.75	2.980
S2/37	60.30	24.45	17.95	10.00	8.00	5.10	1.45	2.35	2.815
S2/51	60.30	13.40	10.00	4.75	5.35	3.40	1.05	1.85	3.210
S2/79	50.10	16.50	11.90	7.35	6.55	3.70	1.15	2.80	3.050
S2/84	44.70	18.30	13.35	7.85	7.15	3.90	1.35	3.40	2.970
Length assigned to fraction in calculating length, mm	3.8	3.2	2.5	2.1	1.7	1.2	0.65	0.3	

Text Table 2.3. Tree means for six chemical constituents of wood expressed as a percentage of oven dry weight of original wood

Tree identity	1% NaOH solubility	Alcohol benzene solubility	Total[/1] extractives	Holocellulose	α-Cellulose	Lignin
D1/6	10.5	1.4	3.5	64.0	42.1	27.3
D1/57	9.8	0.9	3.2	65.2	45.1	26.8
D1/71	11.3	1.3	4.3	63.8	42.0	28.3
D2/11	11.0	1.0	3.3	61.1	44.4	28.3
NH1/24	10.7	1.2	3.2	62.3	40.0	30.1
NH1/40	13.4	4.1	6.3	57.6	39.9	29.1
NH1/44	11.4	1.9	3.9	62.6	43.6	29.0
NH1/51	13.7	4.2	6.9	61.4	40.4	28.5
S1/8	10.7	1.9	3.9	63.0	44.2	27.2
S1/31	10.9	2.0	3.7	62.9	43.3	27.8
S1/36	9.6	1.0	3.1	65.9	43.6	28.6
S1/45	11.0	2.2	4.5	64.9	45.9	26.8
S1/55	9.5	1.0	3.0	65.6	42.7	28.4
S1/64	12.0	3.0	4.9	61.8	41.7	28.9
S2/1	11.4	3.1	5.0	62.7	43.4	26.4
S2/6	11.3	1.7	3.8	64.0	43.6	27.7
S2/37	12.0	2.7	5.1	64.6	41.9	28.2
S2/51	10.5	1.5	3.8	64.1	43.1	28.0
S2/79	10.9	1.8	3.9	67.1	46.0	26.9
S2/84	10.7	1.8	3.7	64.2	44.7	27.8

[/1] Total extractives = extractives in successive treatments with alcohol-benzene, alcohol and hot water.

be especially difficult to pulp by the kraft (sulphate) process.

The differences that were most apparent were (i) the four trees from the Nausori Highlands had an average resin content (alcohol-benzene solubility) that was the highest and (ii) the average cellulose content and the average lignin content were highest for both the sites on Seaqaqa. It was difficult to assess the significance of this because trees had been selected, irrespective of site, to have specific average values and patterns of density. It was possible that the effect of density was as important as the effect of site.

The greatest variation between trees was in alcohol-benzene solubility (0.9 to 4.2%) which was a measure of the quantity of resin, waxes and non-volatile hydrocarbons with some water soluble low molecular weight carbohydrates. There was a similar variation in the total extractives in successive extractions in alcohol-benzene, alcohol and hot water (3.1 to 6.9%), but since the difference between the total extractives and the alcohol-benzene extractives for each tree was fairly uniform (16 trees between 1.9 and 2.3%) it can be concluded that there was little variation in the quantity of tannin, gum, sugar and starch.

There was a tendency for high cellulose content to be associated with low lignin content.

(d) Pulping and pulp evaluation

Each tree was digested using four different digestion conditions. In all digestions the maximum temperature (170°C), the time to reach maximum temperature (1 hour) and the sulphidity (25%) were constant. The active alkali and the time at maximum temperature were varied:-

Digestion condition	Active alkali %	Time at max. temperature hours
A	16.25	3
B	16.25	4
C	17.5	4
D	20.0	4

Details of yield and Kappa number are given in Text Table 2.4.

There were considerable differences between trees in yield and Kappa number at constant digestion conditions. Using the least severe digestion conditions the total yield of pulp varied from 44.1 to 50.2% and the Kappa number from 40.0 to 63.8: with the most severe conditions the total yield varied from 39.6 to 45.1% and the Kappa number from 21.4 to 35.0.

Although the ranking of individual trees was not identical for each of the four sets of digestion conditions there was no statistically significant interaction of tree and digestion conditions (see Appendix 4, Table 2). Consequently, the trees could be ranked by using an arithmetic mean value of pulp yield and digestion conditions. These values are given in Text Table 2.6.

Text Table 2.4. Yield and Kappa number of pulp for four sulphate digestions

	Digestion condition											
	A			B			C			D		
Kappa number	Yield, oven-dry pulp % oven-dry wood Total	Screened	Kappa number	Yield, oven-dry pulp % oven-dry wood Total	Screened	Kappa number	Yield, oven-dry pulp % oven-dry wood Total	Screened	Kappa number	Yield, oven-dry pulp % oven-dry wood Total	Screened	Kappa number
D1/6	49.1	47.4	47.4	47.8	47.0	41.0	46.2	45.9	32.5	44.4	44.4	27.8
D1/57	49.9	46.6	47.0	48.5	46.9	40.2	47.2	46.2	36.0	45.1	44.8	26.6
D1/71	48.6	44.4	49.4	46.8	44.8	41.4	45.5	44.5	36.2	42.8	42.6	25.1
D2/11	50.2	44.4	63.8	48.2	45.0	52.4	47.0	45.0	47.3	44.3	44.0	35.0
NH1/24	45.7	43.8	48.4	45.0	43.6	47.6	44.2	43.6	36.4	41.8	41.8	31.0
NH1/40	44.1	43.8	43.2	43.4	43.2	37.6	42.4	42.4	34.8	39.6	39.6	23.4
NH1/44	49.5	45.4	51.6	48.0	45.6	48.0	45.5	44.9	36.8	44.2	44.0	30.6
NH1/51	46.9	42.6	58.0	44.6	42.7	45.2	42.6	42.0	33.2	40.6	40.6	26.4
S1/8	48.0	45.4	49.2	46.8	45.2	43.5	45.8	45.4	36.1	43.4	43.2	25.2
S1/31	47.4	45.6	47.7	46.6	45.3	43.8	45.2	44.8	35.4	42.8	42.8	24.6
S1/36	48.8	47.1	49.9	47.6	46.8	40.6	46.2	46.0	31.6	44.0	44.0	24.8
S1/45	49.6	45.8	44.8	48.2	45.6	39.1	46.1	45.3	32.2	44.4	44.2	24.2
S1/55	48.4	47.3	40.0	47.4	47.0	35.8	46.0	46.0	28.2	43.9	43.8	22.2
S1/64	47.8	45.6	49.7	46.4	45.4	43.5	44.8	44.6	32.6	43.3	43.2	26.8
S2/1	48.0	47.3	40.0	47.3	46.8	35.2	45.4	45.3	28.4	43.9	43.9	21.7
S2/6	48.4	46.8	43.8	47.3	46.2	39.2	45.9	45.6	29.8	44.3	44.2	24.0
S2/37	46.6	45.6	40.4	46.0	45.4	39.2	44.1	43.8	27.0	42.4	42.4	21.4
S2/51	49.4	45.4	48.6	48.0	45.5	42.4	46.6	46.0	34.5	44.0	43.8	24.6
S2/79	49.8	48.2	44.6	48.0	47.0	36.7	46.2	46.0	31.2	44.6	44.6	23.7
S2/84	47.9	46.2	43.9	46.8	46.0	37.1	45.2	44.9	32.6	43.2	43.2	24.2

Text Table 2.5. Pulp evaluation at 500 Canadian Standard freeness (Tree mean values for four duplicate digestions A-D)

	A				B				C				D			
Tree number	Beating time, mins.	Density, g/cm^3	Burst index kPa m^2/g	Tear index mNm^2/g	Beating time, mins.	Density, g/cm^3	Burst index kPa m^2/g	Tear index mNm^2/g	Beating time, mins.	Density, g/cm^3	Burst index kPa m^2/g	Tear index mNm^2/g	Beating time, mins.	Density, g/cm^3	Burst index kPa m^2/g	Tear index mNm^2/g
D1/6	6.0	0.64	6.8	13.5	5.7	0.65	6.4	12.9	5.6	0.66	6.5	12.6	5.0	0.67	5.7	12.0
D1/57	5.7	0.61	6.6	18.1	5.3	0.61	6.6	18.1	5.4	0.62	6.4	18.3	4.6	0.63	6.4	17.8
D1/71	5.5	0.64	6.6	15.9	5.2	0.65	6.6	15.7	4.8	0.66	6.6	15.4	4.4	0.68	6.0	14.4
D2/11	5.7	0.61	5.5	16.5	5.4	0.62	5.8	16.9	5.3	0.63	5.7	16.5	4.6	0.64	5.7	15.6
NH1/24	5.9	0.67	6.2	14.5	5.6	0.66	6.1	14.5	5.2	0.69	6.5	13.9	4.8	0.70	6.1	12.6
NH1/40	5.8	0.69	6.4	12.4	5.4	0.68	6.2	12.9	5.3	0.70	5.9	12.9	4.6	0.71	5.2	11.5
NH1/44	5.4	0.61	6.1	15.6	5.2	0.61	6.0	15.7	5.2	0.62	6.2	15.7	4.7	0.62	5.9	15.5
NH1/51	6.7	0.64	6.4	16.8	6.1	0.66	6.6	15.7	5.6	0.66	6.5	15.3	5.1	0.68	5.9	14.4
S1/8	5.6	0.59	6.3	17.5	5.4	0.59	6.3	18.0	5.2	0.59	6.4	17.9	4.8	0.61	6.0	17.8
S1/31	5.2	0.60	5.3	18.3	5.2	0.62	5.5	17.6	4.7	0.61	5.5	18.0	4.4	0.62	5.2	17.2
S1/36	5.4	0.62	6.3	18.0	4.7	0.63	6.6	17.1	4.9	0.63	6.4	16.3	4.4	0.64	6.1	16.3
S1/45	5.0	0.58	5.2	20.8	5.0	0.57	5.7	20.4	4.4	0.58	5.6	20.7	4.0	0.60	5.3	20.7
S1/55	5.6	0.66	7.5	13.5	5.4	0.67	7.4	13.0	5.2	0.67	7.2	13.1	4.4	0.67	6.6	13.3
S1/64	6.4	0.64	6.6	17.9	6.2	0.66	6.8	18.6	5.7	0.66	6.2	18.6	5.2	0.66	5.9	17.6
S2/1	5.7	0.64	6.8	17.4	5.2	0.64	6.7	17.8	5.2	0.66	6.3	16.0	4.8	0.66	6.2	16.5
S2/6	5.8	0.64	5.6	15.9	5.5	0.64	5.5	16.0	5.0	0.65	5.1	15.9	4.4	0.66	5.2	15.6
S2/37	5.5	0.64	6.7	14.2	5.1	0.65	6.5	14.1	4.8	0.66	6.3	13.6	4.8	0.66	5.9	13.7
S2/51	6.4	0.63	6.6	18.5	5.5	0.64	6.8	16.6	5.9	0.64	6.9	16.6	5.3	0.65	6.3	16.6
S2/79	5.2	o.59	5.2	18.9	4.7	0.60	5.5	19.0	4.6	0.61	5.8	18.8	4.2	0.61	5.2	17.4
S2/84	6.0	0.64	6.2	18.4	5.8	0.64	6.3	18.5	5.0	0.64	6.0	18.4	4.8	0.66	5.6	16.7

Text Table 2.6. Tree means for 12 pulp properties

Property (units are given as footnotes)	1	2	3	4	5	6	7	8	9	10	11	12
Tree identity												
D1/6	46.9	46.2	578.0	4.6	18.4	0.63	5.74	85.98	3.8	13.58	1088.2	37.19
D1/57	47.7	46.1	566.4	4.5	14.3	0.59	5.69	85.22	4.2	19.96	1073.0	37.45
D1/71	46.0	44.1	551.0	4.5	35.8	0.63	5.97	87.31	4.1	16.49	1266.8	38.03
D2/11	47.4	44.6	565.4	4.6	9.8	0.59	5.08	76.72	4.4	17.61	1096.9	49.61
NH1/24	44.2	43.2	573.6	4.6	33.5	0.67	5.63	83.13	4.2	14.67	1306.5	40.83
NH1/40	42.4	42.2	572.2	4.6	35.4	0.67	5.48	80.63	4.3	13.45	1254.7	34.78
NH1/44	46.8	45.0	567.3	4.7	17.9	0.59	5.41	81.06	4.2	16.75	1088.8	41.78
NH1/51	43.7	42.0	594.8	4.4	16.0	0.63	5.63	79.35	4.4	17.36	1306.1	40.72
S1/8	46.0	44.8	563.8	4.7	11.6	0.56	5.48	81.94	4.4	18.59	1039.2	38.48
S1/31	45.5	44.6	549.9	4.7	31.5	0.59	4.84	72.86	4.6	18.03	1147.2	37.88
S1/36	46.6	45.9	540.3	4.7	19.9	0.63	5.77	84.33	4.1	17.72	1235.3	36.73
S1/45	47.1	45.2	536.2	4.7	18.1	0.56	4.95	73.62	4.7	20.75	906.7	35.06
S1/55	46.4	46.0	561.7	4.7	39.3	0.63	6.45	93.49	4.1	14.58	1479.5	31.53
S1/64	45.6	44.7	594.4	4.5	10.1	0.63	5.63	63.45	4.8	19.85	1724.2	38.14
S2/1	46.1	45.8	564.2	4.6	37.3	0.63	5.79	83.13	4.6	18.30	1646.3	31.31
S2/6	46.5	45.7	564.3	4.6	25.2	0.63	4.81	72.74	4.2	16.68	1152.6	34.19
S2/37	44.8	44.3	562.1	4.6	19.3	0.63	5.76	85.61	4.0	14.55	1219.4	32.01
S2/51	47.0	45.1	593.8	4.5	6.2	0.63	5.75	82.26	4.4	18.73	1421.7	37.54
S2/79	47.1	46.4	527.0	4.8	39.7	0.59	4.86	72.62	4.5	18.82	1020.1	34.03
S2/84	45.8	45.0	577.3	4.5	18.2	0.63	5.39	77.93	4.5	18.73	1398.5	34.45
Standard error of a tree mean	0.21	0.18	5.18	0.02	4.54	0.01	0.042	0.58	0.07	0.22	26.69	0.931
Overall mean	46.0	44.9	565.2	4.6	22.9	0.62	5.51	80.88	4.3	17.25	1243.6	37.09
Bulk sample	45.2	44.3	562.6	4.6	19.2	0.62	5.22	84.21	4.2	17.63	1227.5	33.76

1. Total yield, oven dry unbleached pulp % oven dry wood
2. Screened yield, oven dry unbleached screened pulp % oven dry wood
3. Canadian Standard freeness
4. Drainage time, seconds
5. Air resistance, Gurley, 100 cm^3/6.45 cm^2, seconds
6. Density, g/cm^3
7. Burst index, kPa m^2/g
8. Tensile index, Nm/g
9. Stretch, %
10. Tear index, mN m^2/g
11. Double folds, Kohler-Molin, 7.85 N load
12. Kappa number

All of the pulps obtained were evaluated by forming sheets on a British Standard Sheet machine and determining physical properties by standard procedures. Full pulp evaluation figures are not quoted here but, to give an indication of the effect of varying digestion conditions on pulp quality, Text Table 2.5 gives the results obtained for duplicate digestions on each tree for each set of conditions interpolated at 500 Canadian Standard freeness.

Statistical analysis of the full results of the physical properties of pulp showed that, as with pulp yield and Kappa number, there was no statistically significant interaction of tree and digestion conditions (see Appendix 4, Table 2). Consequently, we were justified in ranking the trees for physical properties of their pulps on the basis of the arithmetic mean of all determinations. These values are reported in Text Table 2.6. Beating curves for three major properties are shown in Text Figure 2.

To confirm that the arithmetic mean gave a value that was representative of the result that would have been obtained by digestion of a mixture of the 20 trees, chips from all 20 trees were mixed in proportion to volume of each tree and the series of eight digestions made on this mixture; the result is given in Text Table 2.6. In most values the experimental results obtained on the bulk sample were within 5% of those calculated; the exceptions were air porosity where the time calculated for a volume of air to pass through the paper was 16% higher than that determined on the mixed sample and the Kappa number, where the calculated value was 9% high.

The cause of the high error in estimating the air porosity was probably the very wide range of individual results used in calculating the value (6.2 to 39.7, average 22.9). The mean value for Kappa number is excessively influenced by the small number of results at the extreme of the range (13 values between 34 and 39, 20 values between 31 and 50). If the seven outlying results are left out the error in estimate reduces to about 6%.

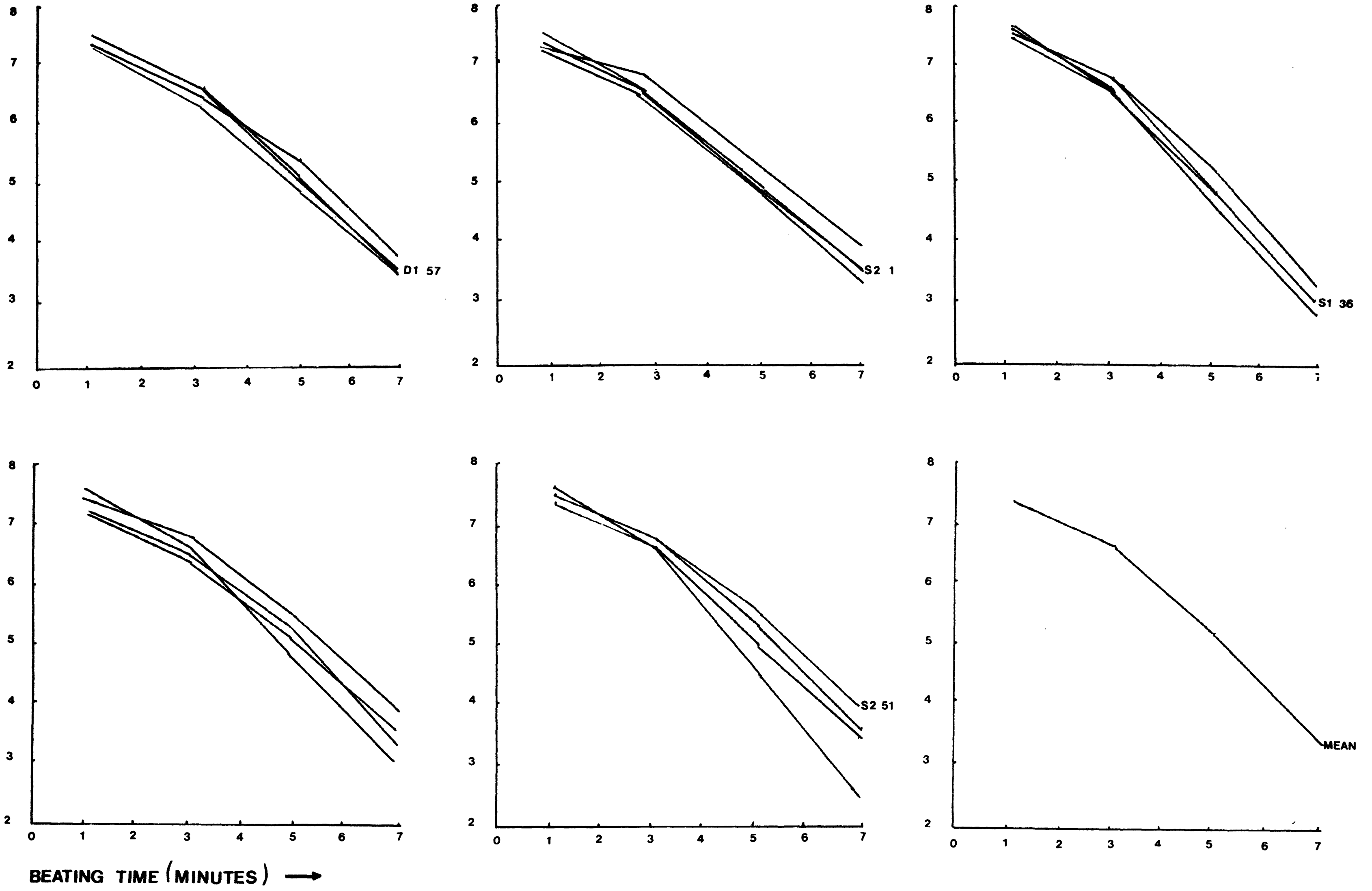
To see if the agreement between estimated and experimental values could be improved a weighted mean was calculated in which each pulp quality value was weighted by a factor corresponding to the density of the wood from which it was made and thus became more representative of the mixture of chips prepared. Usually this did improve the estimate marginally but not by a sufficient amount to justify the extra work.

(e) Discussion of pulp evaluation data

As described above, each tree was pulped using four different pulping conditions. The least severe conditions were expected to give the

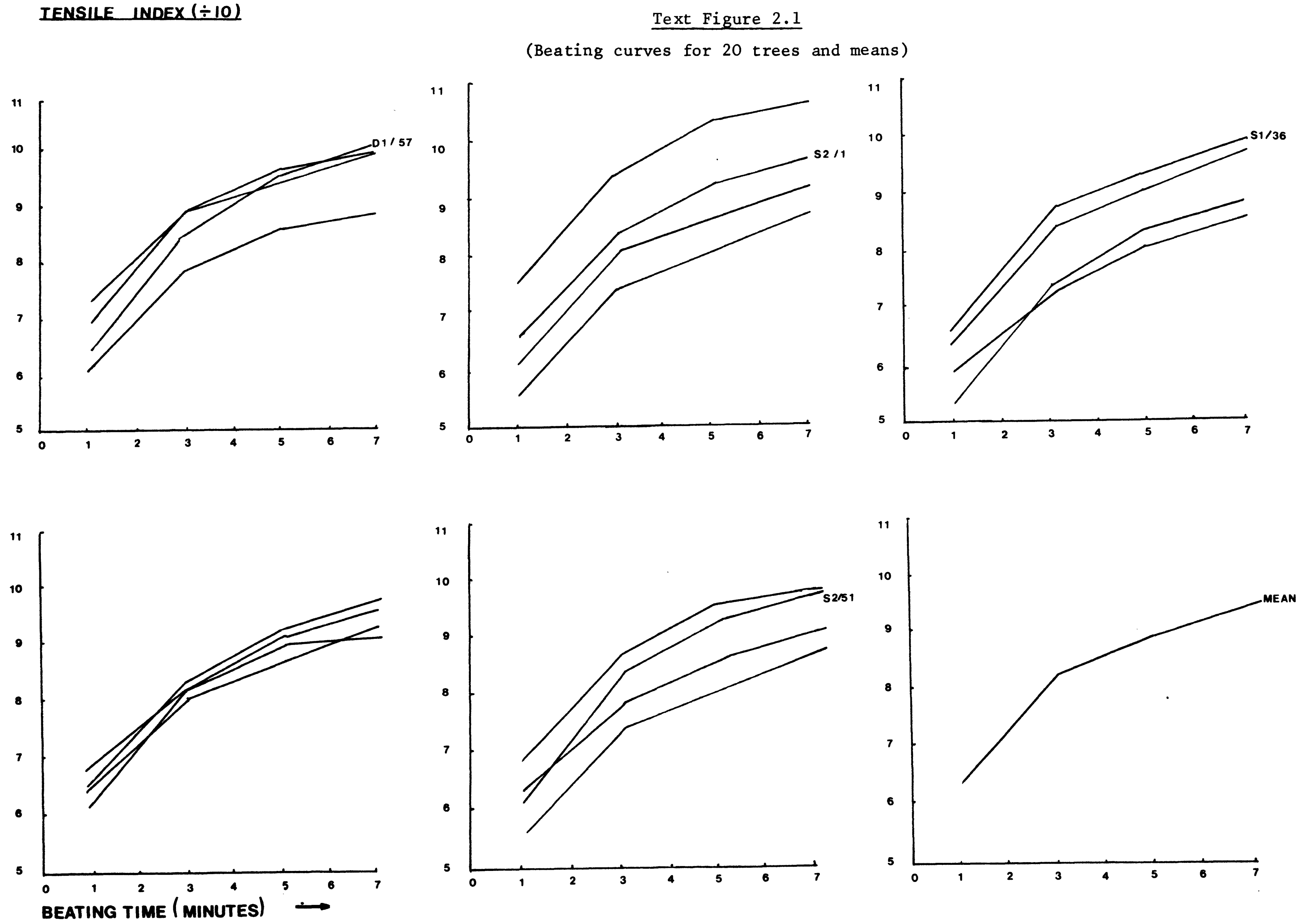
Text Figure 2.1

(Beating curves for 20 trees and mean)



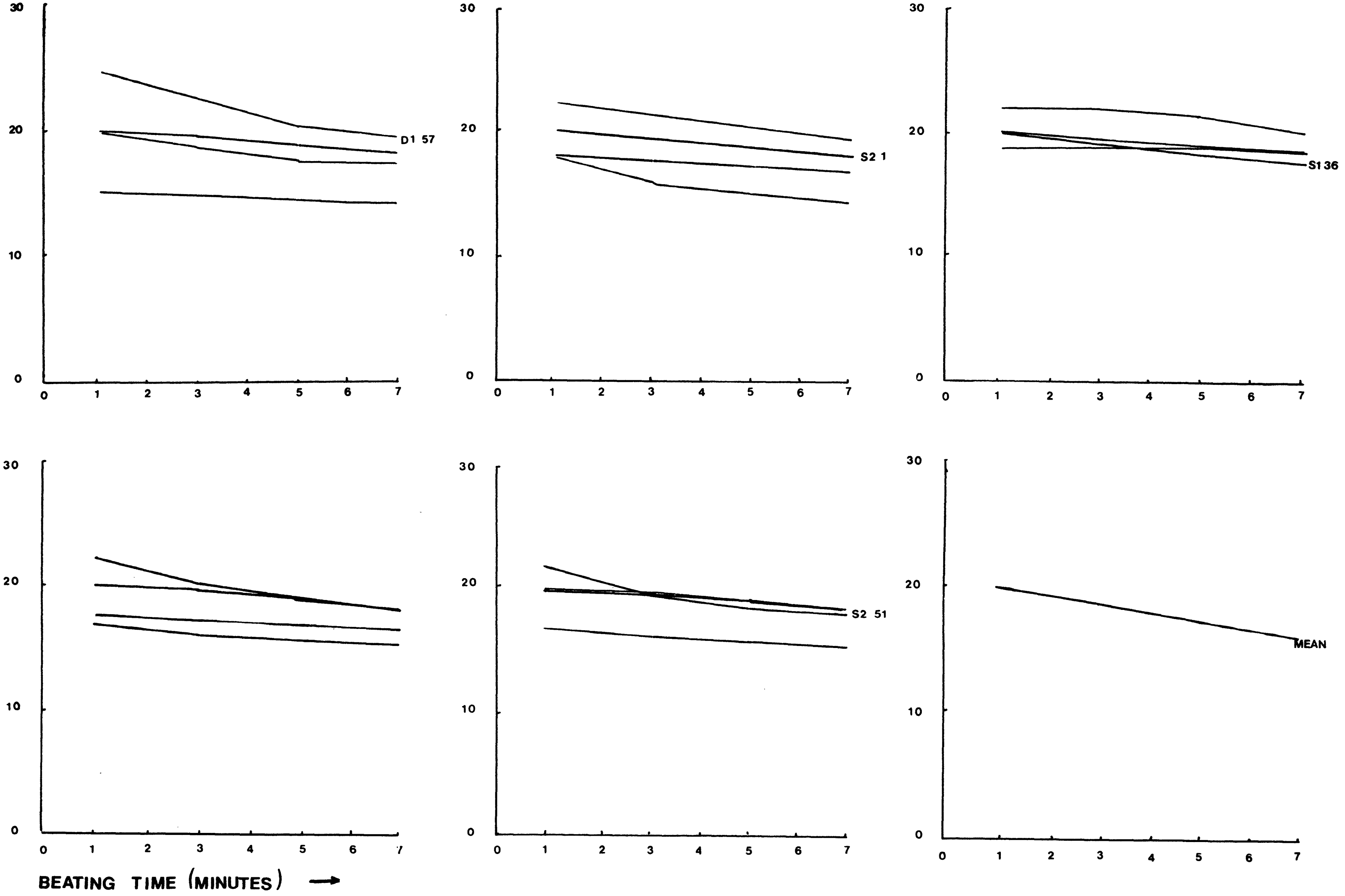
Text Figure 2.1

(Beating curves for 20 trees and means)



Text Figure 2.1

(Beating curves for 20 trees and means)



highest yield of pulp with high residual lignin in the pulp (measured by Kappa number) and the pulp would be expected to be used for strong packaging papers. The most severe conditions would give the lowest yield of pulp; however, the pulp would be expected to be suitable for bleaching but to be relatively weak. In general all of these results were found.

The average yield of screened pulp, from the least severe cooks was 45.7% with a Kappa number of 47.6; for the most severe cook comparative figures were 43.3% and 25.7. The Klason lignin content of pulp can be estimated by multiplying the Kappa number by 0.15; these results mean that the lignin content of the screened pulp has been reduced from 7.1% for the least severe cook to 3.8% for the most severe cook, and that of the 2.4% of wood substance that has been removed by further pulping 1.7% was lignin.

The pulp produced by digestion using the least severe conditions was stronger in all respects than that produced using the most severe conditions. On average the loss in strength was about 5 to 6% based on the stronger pulp.

One tree (D2/11) when pulped using the least severe pulping conditions yielded a pulp with a high Kappa number (63.8). When this tree was pulped with increasingly severe digestion conditions the pulp strength increased before falling. This could be taken as an indication that unbleached pulp with a Kappa number about 45 to 50 had the maximum strength attainable, but there was insufficient data to draw a firm conclusion.

Statistical analysis of the results of pulping and pulp evaluation had shown that since there was no statistically significant interaction between tree and digestion conditions, it was valid to rank trees by the arithmetic mean of the given property for all digestions on a single tree (see Chapter 2 (d)).

However, ranking by this means gave some problems because some pulp properties are inversely (but not highly) correlated (*e.g.* tensile and tearing strengths, $r = -0.49$). Thus the ranking list altered according to the characteristic being studied.

One way of overcoming this problem is to calculate an artificial ranking factor; for example, rank all of the trees and add the ranking position.

This is unsatisfactory because some factors are very highly correlated (*e.g.* burst and tensile strengths, r = 0.96) and these properties would, in effect, be counted twice.

A variation of this method would be to weight each ranking by a factor recognising the importance of that property. This proved to be impossible in a general case because the importance of a given characteristic varied with the likely end product.

Another method considered was to multiply together a pair of indices that are inversely correlated (tensile and tearing strengths) and rank according to the product. This was discarded because a false impression of the value of a fibre can be given where there is a gross imbalance of tensile and tearing strengths.

Finally, it was decided to find the minimum quality of market pulp acceptable for the manufacture of kraft paper, because the averages of Kappa number for the eight pulps prepared from each tree were in the range of 30 to 50, and pulps with Kappa numbers in this range would be expected to be used for kraft papers.

Different manufacturers express the desirable quality in different ways, but information by three major U.K. manufacturers indicate a pulp with strength characteristics similar or superior to our grand average. Consequently Text Table 2.7 was assembled which indicates which trees yielded pulps superior to the average for various qualities. In this table symbols have been used to indicate the amount by which a pulp property exceeds the average. In the case of all values except air porosity and Kappa number this means a high value. In the case of these exceptions a lower figure is the desirable condition because high air porosity is essential in most grades of sack kraft paper and a lower Kappa number indicates that the wood is easier to pulp and therefore likely to require less severe digestion.

In selecting desirable trees from this table, it was decided to look first for trees that were above average in bursting, tensile and tearing strengths, because bursting and tensile strengths are highly positively correlated and both are negatively correlated with tearing strength. Four trees met this condition D1/57, S1/36, S2/1 and S2/51. Next it was decided to look at the pulp yield and all four of the selected trees had above average total yield. Only S2/1 had a low air porosity value and thus was less acceptable for sack kraft, but S2/1 was the easiest tree to digest and likely to be the most desirable tree if either a light coloured pulp or a pulp to be bleached is required.

Thus we select three trees which are likely to be preferred for packaging pulps, D1/57 which will be preferred if tearing strength is more important than bursting or tensile strengths and S2/51 and S1/36 which are preferred if bursting or tensile strength are more important than tearing strength. Tree S2/1 had above average yield and strength properties but because of its low porosity (high air resistance) it is less suitable for packaging papers, but being the easiest to digest and yielding the lightest coloured pulp was likely to be preferred if bleached pulp was required.

However, there is little difference in the price of pulp depending on its quality. Therefore having selected from desirable trees, it is likely that the final selection would be made on weight of wood obtained per unit area, wood density, which affects both transport cost and efficient use of

Text Table 2.7. Superiority of individual trees over average

Tree No.	Total yield	Screened yield	Air porosity	Burst index	Tensile index	Tear index	Double folds	Kappa number
D1/6	+	+	+++	+	++			
D1/57	+	+	++++	+	+	+++		
D1/71	+			++	++		+	
D2/11	+		++++			+		
NH1/24				+	+		++	
NH1/40				+			+	++
NH1/44	+	+	+++		+			
NH1/51			++++	+		+	++	
S1/8	+		++++		+	++		
S1/31						+		
S1/36	+	+	+++	++	+	+		+
S1/45	+	+	+++			++++		++
S1/55	+	+		+++	+++		+++	+++
S1/64			++++	+		+++	++++	
S2/1	+	+		++	+	++	++++	+++
S2/6	+	+						++
S2/37			+++	++	++			+++
S2/51	+	+	++++	++	+	++	+++	
S2/79	+	+				++		++
S2/84		+	+++			++	+++	++

+ = Above average
++ = 5% above average
+++ = 10% above average
++++ = 20% above average

digesters, and the yield of pulp from a given weight of wood. In this part of the report there are insufficient data to select on the first criterion, but on the latter two the preferred order would be, D1/57, S2/51, S1/36 and S2/1.

It must be remembered that all of the data discussed here are phenotypic values; to partition phenotypic variance into its genetic and environmental components requires progeny tests (if future commercial plantations are to be raised from seed) or clonal tests (if plantations are to be vegetatively propagated). Studies of Fijian progeny and clones are already planned but meanwhile the great variation found between the 20 sample trees and the evidence of heritability in other populations of *P. caribaea* elsewhere suggest that at least some of the observed variation will be genetic and available for future selection and genetic gain.

3. DENSITOMETRY

Experimental details

The discs to be used for densitometry were cut from the billets and examined to locate compression wood and other defects; two radii at right angles were chosen to avoid defects as far as possible.

Radial strips 1 cm wide were machined to 5 mm depth, as described by Hughes and Sardinha (1975); resin was extracted in a Soxhlet reflux condenser using a 2 : 1 benzene : ethyl alcohol mixture for 24 hours. The samples were dried in a vacuum oven, conditioned to 12% moisture content and X-rayed. Methods of preparation of X-ray films were described by Hughes and Sardinha (1975) using 17 Pkv, 25 m, 4.5 minute exposure and Industrex C film.

Densitometry was carried out with a Joyce-Loebl microdensitometer using a 10X objective, a 200 µm step distance and a single scan per strip. A trace for each strip was obtained from the chart recorder (see examples in Appendix 3, Figure 1) and a computer paper tape was delivered by a digitiser; the tape was processed through a computer program to give information of the type shown in Table 1 of the Hughes and Sardinha paper (reproduced here in Appendix 3, Table 1).

The computer program converted measurements of light transmitted through the X-ray film into tree density values by means of a calibration wedge of kemital (virtually the same density as pure cellulose). The density data obtained at each 200 µ increment across the radius were classified into nine classes of density; these were integrated into values for disc mean density weighted by the cross-sectional area represented by each recorded step. Tree mean densities were calculated from the disc densities with weighting for the volume of the stem represented by each disc. The comparison of these densitometric densities (at 12% moisture content) with gravimetrically determined basic or apparent density (oven dry weight ÷ saturated volume) shows that the latter is 77-88% of the former; this is expected from average volumetric shrinkage values (Kollmann and Coté, 1968, p. 205, who emphasise that shrinkage varies with wood density). However, there was a close fit of the two values ($r = 0.976$, see Appendix 3, Figure 3 and Table 2) although some trees appeared as outliers, particularly those from Seaqaqa (S1/45, S1/55, S2/1). Only at the extremely high density (S1/45, 0.734 g/cm^3 at 12% moisture content) did the relationship appear to change significantly and this presumably reflects the difficulty of saturating the wood.

Discussion of results

Weighted tree mean densities (at 12% moisture content) covered a wide range both before (0.441 - 0.734 g/cm^3) and after (0.438 - 0.721 g/cm^3) resin extraction; the resin content was low at the time of laboratory examination (0.7 - 1.8% of resin-free wood).

The proportions of wood in different density classes (intervals originally of 0.05 and later of 0.15 from 0.05 to 1.40 g/cm^3) were computed for each height level (fixed percentages of tree heights) and for each whole tree (Appendix 3, Table 3). There were marked differences between trees in the distribution of density. Trees with low overall density naturally had a larger proportion of their wood in low density classes; however, any two trees of similar overall density could have distinctly different patterns of distribution. This was a highlight of the densitometric results and indicated that this technique may provide more useful information than simple gravimetric density such that the extent or pattern of density variation may explain more variation in wood using characters (see Chapter 4 for correlations of pulp and wood properties). In addition densitometric variation may be related to growth patterns and conditions which can not be investigated by whole-tree pulping.

This type of variation in the within-tree distribution is illustrated in Appendix 3, Figure 2 which shows histograms of the distribution of density in five trees, two with approximately the same low density (0.45 g/cm^3, Trees 1, 2), two high (0.57 g/cm^3, Trees 4, 5) and one extremely high for comparison (0.75 g/cm^3, Tree 3). There is a wide range of density within individual trees but the important point is that trees of the same overall density had markedly different histograms of the distribution of density within the tree.

The concept of earlywood and latewood developed in temperate regions where the change of wood types (from thin- to thick-walled cells) occurred early (spring) or late (summer) in a single growing season per year. In the tropical conditions of Fiji such structural changes are more likely to be the response to high temperatures or drought and may occur more than once in a year. It is therefore undesirable to refer to earlywood and latewood but rather to low and high density wood; the densitometer allows the simple estimation of amounts of wood in predefined classes and 0.6 g/cm^3 could be a suitable boundary. At this limit Tree 1 had 18% high density wood with an average density of 0.825 g/cm^3 whereas Tree 2 had 13% with an average density of 0.730 g/cm^3. Thus Tree 1 had more and denser high density wood but Tree 2 had the same overall density because it had denser low density wood. The two trees would not be expected to yield the same kind of pulp, despite their identical densities, because of differences during cooking (see Gladstone and Ifju, 1975; Worrall et al., 1977). The identification of trees with high density juvenile corewood becomes increasingly important as rotation ages decrease (through genetically improved growth rates or through increasing international demand).

Because of the range of density both within and between the 20 trees, a selection of parameters of this variation was used in an attempt to predict, or rather to explain, more variation in pulping characteristics than could be explained by overall density alone. These included proportions of wood in each of several individual classes of density and in combinations of classes.

4. CORRELATION BETWEEN PULP AND DENSITOMETRIC VARIABLES

Linear correlations among pulp yield and strength properties

As shown in Chapter 2(d) various estimates of a tree's mean value for a given pulp property were used; for the main strength properties (burst, tensile and tear indices), these included the arithmetic mean of four beating and cooking conditions, the ocular estimate from beating curves and a computed prediction from the best fitting of 12 beating curve equations of the value at 500 CS_f and 35 Kappa. The closeness of these different estimates of a given characteristic's mean value (and the correlations between them and the other major pulp properties) are shown in Text Table 4.1. Within the experimental limits any one of these can be used for interpretative purposes. Correlation coefficients of $r = 0.42$, 0.54 and 0.65 are required for significance at the 5, 1 and 0.1% probability levels.

Total yield was most closely associated with screened yield, of course, and then marginally with tear index. Freeness was, by definition, inversely correlated with drainage but also with folding endurance.

Among the major pulp strength properties burst and tensile indices were highly, positively correlated ($r = 0.96$) while tensile index was negatively correlated with stretch and tear indices. Stretch and tear indices themselves were highly, positively correlated ($r = 0.73$).

Linear correlations between pulp strength, chemical, fibre and densitometric variables

Text Table 4.2 indicates the linear coefficients for the correlations of various estimates of yield, burst, tensile and tear strengths with selected chemical properties, fibre fractions and wood density parameters. (There were no clear relationships with tree or site characters nor with the other measured chemical, fibre or density properties with the exception of compression wood percentage - assessed by eye - which was highly negatively correlated with total yield, $r = -0.69$.)

(a) Yield. Strong correlations with total pulp yield were shown by holocellulose content ($r = 0.67$), α-cellulose content ($r = 0.81$) and lignin content ($r = -0.56$). These required time-consuming analyses of large samples and could be replaced with almost equal precision by more rapid determination of mean wood density ($r = 0.65$) or the percentage of wood in the high density class 0.66-1.10 g/cm^3 ($r = 0.62$) from small samples.

(b) Burst index. This was more closely associated with density parameters than chemical properties ($r = -0.53$ for mean density; $r = 0.59$ for percentage of wood in the low density class, 0.36-0.50 g/cm^3; $r = -0.60$ for the high density class, 0.66-1.10 g/cm^3; compared with $r = -0.45$ for α-cellulose content).

(c) Tensile index. The relationships here were virtually identical with those for burst index with tensile index being related negatively to mean density and to the amount of wood in the high density class, and positively to the amount of wood in the low density class.

(d) Tear index. For tear strength the relationships to chemical and anatomical properties are virtually the same as those for burst and tensile indices except that the arithmetic signs of these relationships were reversed (e.g. positive relationship with mean density). The correlation with the amount of wood in the high density class was approximately equal to that with α -cellulose ($r = 0.68$). Further, the proportions of fibres in the various fractions were significantly correlated with

Text Table 4.1. Matrix of simple correlations between pulp variables

	Total yield	Screened yield	Freeness	Drain. time	Air resistance	Burst index (est)	Tensile index (est)	Stretch	Tear index (est)	Double folds	Burst index (500 CSf, 35K)	Tensile index (500 CSf, 35K)	Tear index (500 CSf, 35K)
Total yield	1.00	0.86	-0.34	0.23	-0.26	-0.13	-0.05	-0.01	0.49	-0.27	-0.03	-0.05	0.49
Screened yield		1.00	-0.42	0.43	-0.01	-0.03	0.04	-0.08	0.33	-0.12	0.07	-0.01	0.38
Freeness			1.00	-0.85	-0.48	-0.35	0.21	0.01	-0.15	0.55	0.17	0.17	-0.32
Drain. time				1.00	0.50	-0.38	-0.27	0.15	0.08	-0.37	-0.15	-0.26	0.28
Air resistance					1.00	0.08	0.13	-0.11	-0.40	0.11	0.16	0.12	-0.27
Burst index (est)						1.00	0.96	-0.45	-0.37	0.34	0.85	0.92	-0.47
Tensile index (est)							1.00	-0.63	-0.49	0.34	0.83	0.97	-0.57
Stretch								1.00	0.73	0.24	-0.29	-0.62	0.74
Tear index (est)									1.00	-0.03	-0.22	-0.48	0.97
Double folds										1.00	0.43	0.29	-0.11
Burst index (500 CSf, 35K)											1.00	0.80	-0.30
Tensile index (500 CSf, 35K)												1.00	-0.57
Tear index (500 CSf, 35K)													1.00

Text Table 4.2. Matrix of simple correlations between four pulp properties and selected chemical, fibre fraction and densitometric variables

	Total yield	Burst index (est.)	Tensile index (est.)	Tear index (est.)	Burst index (500 CSf, 35K)	Tensile index (500 CSf, 35K)	Tear index (500 CSf, 35K)	Burst index (ave)	Tensile index (ave)	Tear index (ave)
Holocellulose	0.67	0.05	0.11	0.31	0.16	0.10	0.38	0.05	0.11	0.31
α-cellulose	0.81	-0.45	-0.39	0.68	-0.29	-0.35	0.75	-0.45	-0.39	0.68
Lignin	-0.56	0.25	0.22	-0.50	0.15	0.24	-0.57	0.25	0.22	-0.50
Fibre fraction 10	0.35	0.07	-0.04	0.62	0.26	0.03	0.55	0.08	-0.03	0.62
" " 14-20	-0.35	-0.02	0.09	-0.65	-0.19	0.03	-0.59	-0.02	0.09	-0.64
" " 65-200	-0.31	0.18	0.23	0.58	-0.07	0.12	-0.56	0.20	0.25	-0.70
Fibre length	0.35	0.03	-0.07	0.48	0.25	0.02	0.56	0.03	-0.07	0.62
Mean density (extracted)	0.65	-0.53	-0.47	0.59	-0.44	-0.41	0.64	-0.57	-0.46	0.56
Density class 0.36-0.50 g/cm^3	-0.48	0.59	0.55	-0.58	0.41	0.47	-0.65	0.59	0.55	-0.58
Density class 0.66-1.10 g/cm^3	0.62	-0.60	-0.56	0.66	-0.51	-0.46	0.68	-0.60	-0.59	0.61

tear index (greater strength with longer fibres and with increasing residual ends).

(e) Latewood percentage. On the basis of simple linear correlations among the measured variables, the tree mean density or the amount of wood in the high density class (both measured densitometrically from small samples) offer predictive efficiencies as great as any of the chemical (except α-cellulose for yield) and fibre fractionation variables which require complete pulping.

The "high density class" referred to here included wood with density in the range 0.66-1.10 g/cm^3. There was also some wood with higher density (1.11-1.40 g/cm^3; 0-5.40% of total wood depending on individual tree) and an arbitrary value of 0.6 g/cm^3 was adopted as the boundary between earlywood and latewood types (low and high density wood types). The use of this value instead of the amount of wood in class 0.66-1.10 g/cm^3 improved the correlation with tear index ($r = 0.69$ but decreased the coefficient for burst index ($r = -0.48$) and tensile index ($r = -0.44$) while barely affecting the relationship with total yield ($r = 0.63$). Tree mean density was virtually completely correlated with latewood percentage ($r = 0.97$ before resin extraction, 0.98 after extraction).

Non-linear correlations

All the preceding discussion in this Chapter referred to simple linear correlation analysis. In addition 11 other mathematical models (quadratic, exponential and reciprocal) were compared for each pair of variables. The improved correlation coefficients for a selection of these are shown in Text Table 4.3. Where significant improvement occurs, the best model varied between the characteristics but was generally an exponential function, e.g. yield reached a maximum value beyond which the rate of increase obtained by increasing latewood percentage, density, holocellulose or α-cellulose was relatively slow. The equations for these relationships are given in Text Table 4.4.

For burst and tensile strengths the most significant improvements were for the relationships with fibre length (though not a statistically significant correlation in either case), density and α-cellulose content. For tear index the only important improvement was with fibre length in which the asymptotic tear index value was obtained with a fibre length of 3 mm.

Multiple correlation

The above discussions referred to correlations among pairs of variables. Multiple regression analysis was used to examine the effects on total yield and on the three pulp strength properties of combinations of nine density classes and eight fibre fractions.

For total yield a linear combination of the proportions of wood in two density classes (0.21-0.35 and 0.36-0.50 g/cm^3) explained slightly more of the variation than the linear effect of the high density class (0.96-1.10 g/cm^3) with a correlation coefficient of $r = 0.68$; this was significantly smaller than the coefficient for the non-linear relationship (see Text Table 4.3).

For burst index all nine density classes explained only 54% of the total variation (multiple correlation coefficient $R = 0.732$, non significant) and they reduced to the most significant single class of 0.80-0.95 g/cm^3, in contrast to the higher class (0.96-1.10 g/cm^3) as found by individual linear regressions.

Text Table 4.3. Comparison of linear and best non-linear correlation coefficients for a selection of variables

Independent variable	Total yield		Burst index		Tensile index		Tear index	
	Linear	Non-linear	Linear	Non-linear	Linear	Non-linear	Linear	Non-linear
Density, extracted	0.65	0.68	-0.44	0.50	-0.41	0.43	0.64	0.65
Fibre length	0.35	0.35	0.25	0.48	0.00	0.49	0.56	0.68
Latewood percentage	0.64	0.71	-0.50	0.57	-0.46	0.46	0.70	0.73
Density class 0.96-1.10	0.60	0.80	-0.44	0.51	-0.42	0.43	0.70	0.73
Holocellulose	0.67	0.71	0.02	0.25	0.10	0.12	0.38	0.40
α-cellulose	0.81	0.88	-0.30	0.59	-0.36	0.50	0.75	0.76
Lignin	-0.56	0.57	0.15	0.17	0.24	0.24	-0.57	0.58

Text Table 4.4 Regressions of best fit for a selection of variables

Dependent variable, Y	Independent variable, X	Equation
Yield	Density, extracted	$Y = 28.86 + 49.94X - 33.59X^2$
	Fibre length	$Y = X/(-0.0208 + 0.0412X - 0.00413X^2)$
	Latewood percentage	$Y = 46.98 - 371.7X^{-1.966}$
	Holocellulose	$Y = 47.69 - 808400e^{-0.207X}$
	α-cellulose	$Y = 47.49 - 1227 \times 10^{25} (X^{-17.15})$
	Lignin	$Y = X/(1.896 - 0.1244X + 0.002798X^2)$
Burst index	Density, extracted	$Y = 64.45 + 1.495X - 0.6046X^2$
	Fibre length	$Y = 959.9 - 606.7X + 102.5X^2$
	Latewood percentage	$Y = X/(0.0066 - 0.0124X + 0.0287X^2)$
	Holocellulose	$Y = -437.4 + 15.73X - 0.123X^2$
	α-cellulose	$Y = -1047 + 52.63X - 0.622X^2$
	Lignin	$Y - -209.8 + 18.84X - 0.323X^2$
Tensile index	Density, extracted	$Y = 9185 + 120.1X - 68.07X^2$
	Fibre length	$Y = 168200 - 106300X + 17720X^2$
	Latewood percentage	$Y = X/(0.0000277 - 0.0000152X + 0.00000039X^2)$
	Holocellulose	$Y = -16500 + 788.2X - 6.063X^2$
	α-cellulose	$Y = X/(0.0612 - 0.00282X + 0.0000350X^2)$
	Lignin	$Y = -11160 + 1286X - 20.1X^2$
Tear index	Density	$Y = 162.7 - 15.17X + 6.045X^2$
	Fibre length	$Y = X/(0.6171 - 0.3921X + 0.0641X^2)$
	Latewood	$Y = 184.7 - 264.9X + 413X^2$
	Holocellulose	$Y = 189.6 - 1705 \times 10^{15}X^{-9.365}$
	α-cellulose	$Y = X/(-1.061 + 0.071X - 0.000925X^2)$
	Lignin	$Y = X/(-0.115 + 0.0000072X + 0.00036X^2)$

In the case of tensile index, three density classes (0.21-0.35, 0.81-0.95 and 1.21-1.40 g/cm^3) explained more of the variation (50%) than the best single linear effect (class 0.96-1.10 g/cm^3 with a correlation coefficient of r = -0.42).

For tear strength, two density classes (less than 0.2 g/cm^3 and 0.96-1.10 g/cm^3) explained 60% of the variation (r = 0.77) compared with the best, single, non-linear relationship (class 0.96-1.10 g/cm^3 with r = 0.73). The largest significant amount of variation in tear index was explained by three fibre fractions (10, 28 and 200 mesh) with r = 0.83.

5. CONCLUSION

Despite the inter-tree range of growth patterns and wood densities, the effect of trees on yield, Kappa number and physical properties of the pulps did not interact with cooking and beating conditions. All pulps were prepared by the kraft (sulphate) process. Least severe digestion gave the highest yield of pulp suitable for strong packaging papers; most severe digestion gave lower yields of weaker pulp suitable for bleaching. The usual correlations were found between total yield and screened yield (positive), freeness and drainage (negative), burst and tensile indices (positive), and tensile and tear indices (negative).

There is considerable difficulty in ranking pulps when several technical properties are included in the appraisal, especially since differential economic values are not easily obtainable. However, some trees were superior to the average in several technical and productive properties (even those that are generally negatively correlated) and would thus be desirable in an initial tree improvement programme.

The use of wood densitometric data obtained easily from small wood samples (equivalent to increment cores taken from standing trees) offered single and multiple linear predictions of pulp properties that were as precise, in practical terms, as those derived from chemical analysis and fibre fractionation in the pulps (which are time consuming and require destructive sampling of larger samples).

It may be argued that 20 trees form a small sample from such a variable taxon as P. caribaea, even for plantations of one seed source (Mountain Pine Ridge, Belize) growing in one country (Fiji). Nevertheless the sample was planned to cover the range of likely variability in anatomical and pulping properties. The amounts of field, laboratory and computing work were large yet they were believed necessary since no pulping studies on a single tree basis had been undertaken with P. caribaea and few with other species.

We now feel these efforts were justified in view of the inter-tree variation in pulp properties, the correlations between anatomical and pulping properties, and the significance of these results for future plantation development, tree breeding and wood use.

Although anatomical studies can not completely replace large scale and laboratory pulping trials, densitometric evaluation of increment cores will be of great help in screening large numbers of trees for future tree improvement programmes. This is now in hand with Fijian material; a doctoral student/1 is examining cores from 223 plus trees and one neighbouring random tree for each together with samples from progeny trials of some of the selections at several sites in Fiji and Queensland /2.

/1 Nuevo, C.C. Genetic variation in wood properties of Pinus caribaea from Fiji. Doctoral research, Commonwealth Forestry Institute, Oxford.

/2 Material will be collected in 1979 by Dr. D.G. Nikles, Queensland Forest Department.

BIBLIOGRAPHY

ANON. (1968) Pulping *Pinus caribaea* by the cold soda process. *Malay. For.*, *31*, (2), 145.

ANON. (1970) *10th Ann. Rept. Timber Research Unit, C.S.I.R.* (South Africa).

AZEVEDO CORREA, A. de, and REIS LUZ, C.N. (1976) Essencia Papeleira de Reflorestamento, II - O *Pinus caribaea* (variedade *hondurensis*) Introd. na Amazonia.

BURLEY, J., HUGHES, J.F., PALMER, E.R. and WORRALL, J.G. (1976) Relationships between some wood and pulp properties in individual trees of *Pinus caribaea* var. *hondurensis* from Fiji. Pap. 16th IUFRO Congr., Oslo, Norway, 5pp.

CHITTENDEN, A.E. and PALMER, E.R. (1959) Pulping trials on *Pinus caribaea* from British Honduras. *Trop. Sci.*, *1*, (1) 22-40

CHITTENDEN, A.E., JARMAN, C.G., PALMER, E.R. and HUGHES, J.F. (1967) Pulping properties of *Pinus caribaea*. *Commonw. For. Rev.*, *46*, (1), 23-35.

CHITTENDEN, A.E.,FLAWS, L.J., HAMILTON, H.R. and HAWKES, A.J. (1972) Particle boards from *Pinus caribaea* from Fiji. *Trop. Prod. Inst. Rep*. 129, 12pp.

DRAPER, N.R. and SMITH, H. (1966) *Applied regression analysis*. Wiley, New York. 407 pp.

FAIREST, R.W. (1966) Project for the evaluation for pulp. III. Primary evaluation of *Pinus caribaea* from Trinidad and Maturin for sulphate pulp. C.A. Pulpa Guayana, Caracas.

FAIREST, R.W. (1967) Evaluation of *Pinus caribaea* for pulp. *Bol. Inst. For. Lat. Amer., Merida*, *25*, 33-58.

FOELKEL, C.E.B. and BARRICHELO, L.E.G. (1975) Mixtures of cellulose pulps from *Eucalyptus saligna* and *Pinus caribaea*. *Bol. Inst. Pesq. Est. Flor.* *10*, 63-76.

GLADSTONE, W.T. and IFJU, G. (1975) Nonuniformity in the Kraft pulping of loblolly pine. *TAPPI*, *58*, 126-9.

GONIN, C.R. (1973) Physical and chemical properties of importance in pine pulpwood breeding. *In Proc.: IUFRO Div. 5 Meeting*, Cape Town and Pretoria, South Africa, 326-363. IUFRO 1200 pp.

HUGHES, J.F. and SARDINHA, R.M. de A. (1975) The application of optical densitometry in the study of wood structures and properties. *J. Microsc.*, *104*,(1), 91-103.

KOLLMAN, F.F.P. and COTE, W.A. (Jr.) (1968) Principles of wood science and technology. 1. Solid wood. Allen and Unwin, London, 592pp.

PALMER, E.R., BURLEY, J., HUGHES, J.F. and WORRALL, J.G. (1976) Comparison of pulp properties in individual trees of Pinus caribaea var. hondurensis. Pap. 16th IUFRO Congr., Oslo, Norway, 5pp.

PALMER, E.R. and GIBBS, J.A. (1967) Pulping characteristics of Pinus caribaea from Sabah. Trop. Prod. Inst. Rep. L12, 23pp.

PALMER, E.R. and GIBBS, J.A. (1968) Pulping characteristics of Pinus caribaea from Fiji. Trop. Prod. Inst. Rep. L14, 27pp.

PALMER, E.R. and GIBBS, J.A. (1969) Pulping characteristics of Pinus caribaea from Trinidad. Trop. Prod. Inst. Rep. L15, 49pp.

PALMER, E.R. and GIBBS, J.A. (1970) Pulping characteristics of Pinus caribaea var. bahamensis from Great Abaco Island, Bahamas. Trop. Prod. Inst. Rep. L23, 32pp.

PALMER, E.R. and GIBBS, J.A. (1971a) The pulping characteristics of Pinus caribaea from Seaqaqa, Fiji. Trop. Prod. Inst. Rep. L24, 23pp.

PALMER, E.R. and GIBBS, J.A. (1971b) Pulping characteristics of nine year old Pinus caribaea from Sabah. Trop. Prod. Inst. Rep. L25, 37pp.

PALMER, E.R. and GIBBS, J.A. (1972) The pulping characteristics of Pinus caribaea from the main growing areas in Fiji, 1971. Trop. Prod. Inst. Rep. L27, 60pp.

PALMER, E.R. and GIBBS, J.A. (1973) Pulping characteristics of three trees of Pinus caribaea with different densities from Jamaica. Trop. Prod. Inst. Rep. L30, 24pp.

PALMER, E.R. and GIBBS, J.A. (1975) The pulping characteristics of two samples of Pinus caribaea var. caribaea from Cuba. Trop. Prod. Inst. Rep. L41, 25pp.

PALMER, E.R. and GIBBS, J.A. (1976) Pulping characteristics of Pinus caribaea from Belize. Trop. Prod. Inst. Rep. L43, 43pp.

PALMER, E.R. and GIBBS, J.A. (1977) Pulping characteristics of Pinus caribaea from Fiji: the effect of rate of growth. Trop. Prod. Inst. Rep. L46 16pp.

PALMER, E.R. and PEH, T.B. (1966) Pulping studies of Malayan exotic species. 2. Pinus caribaea Mor. Malaya For. Res. Inst. Res. Pamphlet No. 55, 22pp.

PALMER, E.R. and TABB, C.B. (1973) Pinus caribaea - its potential as pulpwood. In: Selection and breeding to improve some tropical conifers. (editors J. Burley and D.G. Nikles). Vol. 2, 23-44. Oxford, England: Commonwealth Forestry Institute, Oxford and Department of Forestry, Queensland 466 pp.

SANCHEZ, J.R. (1967) Characteristics of sulphate pulp from Pinus caribaea of various states. Rev. For. Venez., 10, (15), 5-20.

TISSOT, M. (1968) Papermaking characteristics of some pines introduced into Africa and Madagascar. Bois For. Trop., (118), 41-55.

UPRICHARD, J.M. (1977) Kraft pulps from coconut stem-wood (Cocos nucifera): blending of coconut stem-wood pulps with those from Pinus species. In Proc. Seminar, Coconut Stem Utilisation, Tonga, October 1976, 249-97. Ministry of Foreign Affairs, New Zealand.

WATSON, A.J., HIGGINS, H.G. and SMITH, W.J. (1971) Pulping and papermaking properties of conifers from Queensland plantations. C.S.I.R.O. Div. For. Prod. Technol. Pap. No. 61, 21pp.

WONG WING CHONG and PALMER, E.R. (1973) An exploratory study of the suitability of Pinus caribaea for the production of dissolving pulps. Trop. Prod. Inst. Rep. L28, 13pp.

WONG WING CHONG. (1974) The production of particleboard from Pinus caribaea var. Hondurensis. Malays. For. 37, (2), 80-8.

WORRALL, J.G. BURLEY, J., PALMER, E.R. and HUGHES, J.F. (1978) The properties of some Caribbean pine pulps and their relationship to wood specific gravity variables. Wood and Fiber, 8 (4), 228-34.

APPENDIX 1

A. CONDITIONS OF SITES SAMPLED

(1) SEAQAQA

(i) Locality

Latitude : 16° 33' S
Longitude : 179° 8' E

Elevation : 90 m (300 feet approximately) above mean sea level.

(ii) Climatic Conditions

The general rainfall and climatic environment of the area corresponds to classification 1 of Twyford and Wright ("The Soil Resources of the Fiji Islands") i.e. :-

Lowland climate with strong dry season

Mean annual temperature	- 25.6°C (78°F)
Mean annual rainfall	- 1400 - 2540 mm (55 - 100 inches)
Average number of months with less than 10 mm (4 inches) rainfall	- 5½
Average number of months with less than 6 mm (2.36 inches) rainfall	- 3
Average soil moisture deficit during any part of year	- 76 mm (3 inches) Aug - Nov
Average surplus moisture for leaching during any part of year	- 305 mm (12 inches) Jan - April
Thornthwaite rational classification	- C_2A'a'r

Temperature

Records for Seaqaqa Forest Station are not available. The following statistics refer to Seaqaqa District Farm, approximately 6 km from the Department of Forestry Station and approximately 4 km from the plantation sampled. Periods of records : 13 - 16 years, over July 1962 - February 1978.

a) Mean monthly maximum

Jan	- 30.5°C	(86.9°F)	July	- 28.5°C	(83.3°F)
Feb	- 30.6°C	(87.1°F)	Aug	- 28.8°C	(83.8°F)
March	- 30.4°C	(86.7°F)	Sept	- 29.6°C	(85.3°F)
April	- 30.1°C	(86.2°F)	Oct	- 29.5°C	(85.1°F)
May	- 29.3°C	(84.7°F)	Nov	- 30.0°C	(86.0°F)
June	- 29.1°C	(84.4°F)	Dec	- 30.7°C	(87.3°F)

b) Mean monthly minimum

Jan	-	21.3°C	(70.3°F)	July	-	16.8°C	(62.2°F)
Feb	-	21.4°C	(70.5°F)	Aug	-	17.0°C	(62.6°F)
March	-	21.3°C	(70.3°F)	Sept	-	18.1°C	(64.6°F)
April	-	20.4°C	(68.7°F)	Oct	-	19.3°C	(66.7°F)
May	-	18.9°C	(66.0°F)	Nov	-	19.5°C	(67.1°F)
June	-	18.1°C	(64.6°F)	Dec	-	20.4°C	(68.7°F)

c) Number of days per annum with minimum temperatures below 0°C (32°F).

Nil

Rainfall and Humidity

Full records for Seaqaqa Forest Station are not available. The following figures are based on what information is recorded, supplemented with data from Seaqaqa District Farm, approximately 6 km from the Department of Forestry Station and approximately 4 km from the plantation sampled. Period of records: Jan 1958 - June 1975.

a) Mean monthly rainfall

Jan	-	393 mm	(15.5 inches)	July	-	86 mm	(3.4 inches)
Feb	-	505 mm	(19.9 ")	Aug	-	65 mm	(2.6 ")
March	-	472 mm	(18.6 ")	Sept	-	110 mm	(4.3 ")
April	-	312 mm	(12.3 ")	Oct	-	168 mm	(6.6 ")
May	-	83 mm	(3.3 ")	Nov	-	238 mm	(9.4 ")
June	-	75 mm	(3.0 ")	Dec	-	331 mm	(13.0 ")

b) Annual rainfall

2838 mm (111.7 inches)

c) Longest period recorded with less than 51 mm (2 inches) of rainfall per month

Five month period May - September 1966.

d) Mean monthly relative humidity

The closest station from which records are available is Waiqele, approximately 22.5 km directly from the plantation site.

	0600 hrs	1200 hrs		0600 hrs	1200 hrs
Jan	95.9	70.3	July	93.4	61.4
Feb	96.7	72.2	Aug	92.8	60.4
March	97.4	71.4	Sept	92.9	60.4
April	96.7	69.9	Oct	91.6	61.8
May	95.3	65.6	Nov	93.7	64.3
June	94.4	65.2	Dec	94.6	64.8

Period of records: April, 1957 - Feb, 1978, excluding 1971 (part of), 1972, 1973, and 1974 (part of).

(iii) Topography and Edaphic Conditions

Geology : The rocks from which the soil is derived are andesites, andesitic tuffs and basalt.

Slope : Gentle, with the sampled plantation having a slight north-easterly aspect.

Soil : Ferruginous latosol, Bua gravelly clay, described by Twyford and Wright typically as follows:

> " .... three inches of dark reddish brown gravelly clay, friable, with a strongly developed medium nutty structure, overlying about eight inches of reddish brown firm clays, compact in places and with a moderately developed fine nutty structure, on eight inches of weak red firm mealy clay of a moderately developed medium blocky structure, occasionally slightly mottled and this overlies a compact varicoloured mealy clay with much decomposing basalt."

Acid soluble phosphate, exchangeable calcium, magnesium and potassium contents are all low to very low. The pH is 4.4 - 4.9.

Drainage : Adequate natural drainage.

(iv) Natural Vegetation

The site typically supports naturally poor fern (Dicranopteris linearis) and mission grass (Pennisetum polystachyon), with vadra (Pandanus sp.), nokonoko (Casuarina equisetifolia), with occasional guava (Psidium guajava) and clumps of bamboo (Bambusa vulgaris).

Vegetation now within the sampled plantation is restricted, with the reduction in light, but would include scattered goat weed (Ageratum conyzoides), sour grass (Paspalum conjugatum), hibiscus burr (Urena lobata), blue rat's tail (Stachytarpheta urticaefolia), mint weed (Hyptis pectinata), white ginger (Amomum cevuga), with the climber mile-a-minute (Mikania micrantha).

(v) Plantation History

Seed origin : Seed source Belize, but records do not indicate exact origin. However, from collections made at that time, it is safe to assume it was Mountain Pine Ridge.

Nursery practice : Seeds broadcast in raised, shaded seed beds, germination occurring 7-10 days after sowing. 10 days after germination seedlings were transplanted into 50 mm (2 inch) diameter polythene pots, in which they remained until planting out 7-9 months later. The pots contained a mixture of shredded, sterilised forest soil, gravel dust or sharp sand, mycorrizal soil and NPK fertiliser. Newly potted seedlings were shaded for about 3 weeks, being watered morning and evening. Watering was reduced shortly before planting out to help harden off the seedlings.

Method of planting : Initial site preparation involved light scrub cutting and burning of the grass and fern. Planting pits at 2.7 m x 2.7 m (9 ft x 9 ft) were dug and the seedlings planted with the polythene pot carefully removed to keep the tube of soil intact round the roots.

Date of planting: Jan - Feb, 1960.

Tending : 1961 : Weeding and modest beating up operations.

1962 : Removal of some remaining competing scrub.

1964 : Pruning to 1/3rd overall height.

1965 : Following Feb 1965 storms, wind damaged stems were removed.

1968 : High pruning to 6.7 m (22 ft), 247 stems/h (100 stems/acre).

1969 : Climber cutting and thinning.

The original increment cores were collected in October, 1970, and the sample discs towards the end of 1972. (See Appendix 1B "Field Sampling and Collection of Material").

(vi) Mensurational Data

The specific sample plots from which increment cores were collected had the following basic statistics prior to core sampling:-

Plot 1 - Mean height 16.7 m (54.9 ft), mean bh diameter 20.9 cm (8.2 ins)
2 - Mean height 17.5 m (57.3 ft), mean bh diameter 22.4 cm (8.8 ins)

Three 0.04 ha (0.1 acre) plots were established within the plantation in January 1970, *i.e.* 8 months before increment cores were collected, and these gave the following average statistics:

Times pruned - 2
Average height of pruning - 8.5 m (28 ft)
Times thinned - 2
Number of trees in plot - 24
Dominant mean height - 17.9 m (58.6 ft)
Dominant mean diameter - 24.9 cm (9.82 ins)
Plot mean height - 16.3 m (53.5 ft)
Basal area - ft^2/acre - 81.3
- m^2/ha - 18.7
Plot volume (ub) - ft^3/acre - 1580
- m^3/ha - 110.6

No additional mensurational data is available for the crop immediately prior to collection of the disc samples in November, 1973.

(2) NAUSORI HIGHLANDS

(i) Locality

Latitude : 17° 48' S
Longitude : 177° 36' E

Elevation : 509 m (approximately 1670 feet) above mean sea level.

(ii) Climatic Conditions

The general rainfall and climatic environment of the area borders on classification 5 of Twyford and Wright ("The Soil Resources of the Fiji Islands") *i.e.* :-

Upland climate with a moderate dry season

Mean annual temperature - 19.4°C (67°F)
Mean annual rainfall - 2030 - 3810 mm (80 - 150 inches)
Average number of months in year with less than 10 mm (4 inches) of rainfall - 4

Average number of months in year with less than 6 mm (2.36 inches) rainfall - 1

Temperature

(Department of Forestry, Nausori Highlands Station, period of records 1966 - 73, excluding 1969/70).

a) Mean monthly maximum

Jan - 27.9°C (82.2°F)
Feb - 27.9°C (82.2°F)
March - 27.6°C (81.7°F)
April - 27.0°C (80.6°F)
May - 26.3°C (79.3°F)
June - 25.8°C (78.4°F)
July - 25.0°C (77.0°F)
Aug - 25.7°C (78.3°F)
Sept - 26.7°C (80.1°F)
Oct - 26.2°C (79.2°F)
Nov - 27.7°C (81.9°F)
Dec - 28.1°C (82.6°F)

b) Mean monthly minimum

Jan - 20.1°C (68.2°F)
Feb - 19.7°C (67.5°F)
March - 19.6°C (67.3°F)
April - 18.8°C (65.8°F)
May - 17.6°C (63.7°F)
June - 16.9°C (62.4°F)
July - 16.2°C (61.2°F)
Aug - 15.7°C (60.3°F)
Sept - 16.9°C (62.4°F)
Oct - 17.7°C (63.9°F)
Nov - 18.0°C (64.4°F)
Dec - 19.5°C (67.3°F)

c) Number of days per annum with minimum temperature below 0°C (32°F)

Nil

(ii) Rainfall and Humidity

(Department of Forestry, Nausori Highlands Station, period of records 1961 - 75.)

a) Mean monthly rainfall

Jan	- 357 mm (14.1 inches)	July	- 49 mm (1.9 inches)
Feb	- 493 mm (19.4 ")	Aug	- 54 mm (2.1 ")
March	- 483 mm (19.0 ")	Sept	- 81 mm (3.2 ")
April	- 195 mm (7.7 ")	Oct	- 148 mm (5.8 ")
May	- 73 mm (2.9 ")	Nov	- 212 mm (8.3 ")
June	- 62 mm (2.4 ")	Dec	- 371 mm (14.6 ")

b) Annual rainfall

2578 mm (101.5 inches)

c) Longest period recorded with less than 51 mm (2 inches) of rainfall per month

Five month period, June - October, 1966.

d) Mean monthly relative humidity

No statistical information available.

(iii) Topography and Edaphic Conditions

Geology : The plantation area is a plateau of Mba Volcanic Group rocks. Mudstones are exposed at the crest of the plantation but the characteristic augite-olivine basalt (lava) is apparent, with the typical weathering colours - red of the altered olivine, brown augite, yellowish or ochre groundmass on weathered rock surfaces, and a thick red soil overall.

Slope : Slight to moderate, up to 15°, with a westerly aspect.

Soil : Ferruginous latosol, from basic parent materials, Lewa red and brown clays. The redder colour phase is appropriate to the plantation area, described by Twyford and Wright typically as follows:

> ".... five inches of reddish brown very friable clay with a strongly developed fine and very fine nutty and fine granular structure, on ten inches of red friable clay, of strongly developed medium and fine blocky structure breaking easily to very fine fragments, very hard to dig, on red friable clay with a moderately coarse blocky structure, breaking easily to fine angular fragments and very hard to dig".

Drainage : Adequate natural drainage within plantation area.

(vi) Natural Vegetation

Prior to planting the site was dominated by mission grass (*Pennisetum polystachyon*) and fern, with scattered guava (*Psidium guajava*).

Within the plantation, light mission grass remains apparent with the climber mile-a-minute (*Mikania micrantha*).

(v) Plantation History

Seed origin : As for Seaqaqa

Nursery practice: " " "

Method of planting : Spacing 3.0 m x 2.4 m (10 ft x 8 ft).
Other comments as for Seaqaqa.

Date of planting : Feb/March 1961.

Tending : 1961 : Application of 85 g (2 ounces) NPK fertiliser per tree.

1962 : Weeding, with disc harrowing on the flats.

1965 : Hurricane damaged trees removed.

1968 : Thinned to 990 trees/ha (400/acre)
Pruning to 3.9 m (12 ft) 370 stems/ha (150/acre).

: Cattle introduced for grazing trials within plantation.

1972 : Plantation significantly damaged by Hurricane Bebe, October, 1972.

(vi) Mensurational Data

The specific plots sampled had the following basic statistics immediately prior to core sampling:-

Plot 1 - Mean height 18.5 m (60.8 ft); average bh diameter 23.1 cm (9.1 ins)
Plot 1 - Mean height 19.1 m (62.8 ft); average bh diameter 23.8 cm (9.4 ins)

Other mensurational plots established within the plantation on the dates shown indicated the following general crop statistics:

	Plot A		Plot B	
	13.7.70	26.6.73	13.7.70	26.6.73
Age - years	9.5	12.5	9.5	12.5
Stems - per acre	325	270	245	210
- per ha	805	667	605	519
Basal area - ft^2/acre	152	169	99	140
- m^2/ha	34.9	38.9	22.7	32.0
Volume - ft^3/acre	3112	4372	1851	3152
- m^3/ha	217.7	305.9	129.5	220.5
Mean height - ft	57.1	76.2	52.0	66.6
- m	17.4	23.2	15.9	20.3
Mean bh diameter - inches	9.2	10.7	8.9	11.0
- cm	23.4	27.2	21.8	27.9

(3) DRASA

(i) Locality

Latitude : 17° 35' S
Longitude : 177° 32' E

Elevation : 65 m (210 ft approximately) above mean sea level.

(ii) Climatic Conditions

The general rainfall and climatic environment of the area corresponds to classification 1 of Twyford and Wright ("The Soil Resources of the Fiji Islands"), i.e.

Lowland climate with strong dry season
See details recorded under (1) SEAQAQA.

Temperature

Closest available figures come from the Fiji Sugar Corporation Station in Lautoka, approximately 10 km directly from Drasa Forest Reserve. Period of records : 1961 - 73.

a) Mean monthly maximum

Jan -	30.3°C	(86.6°F)	July -	27.9°C	(82.3°F)
Feb -	30.4°C	(86.7°F)	Aug -	28.0°C	(82.4°F)
March -	30.2°C	(86.3°F)	Sept -	28.6°C	(83.5°F)
April -	29.8°C	(85.6°F)	Oct -	28.8°C	(83.9°F)
May -	29.1°C	(84.3°F)	Nov -	29.3°C	(84.8°F)
June	28.8°C	(83.8°F)	Dec -	30.0°C	(86.0°F)

b) Mean monthly minimum

Jan - 23.8°C (74.8°F)
Feb - 23.9°C (75.0°F)
March - 23.6°C (74.4°F)
April - 22.8°C (73.1°F)
May - 21.3°C (70.4°F)
June - 20.7°C (69.3°F)
July - 20.0°C (68.0°F)
Aug - 19.8°C (67.7°F)
Sept - 20.9°C (69.6°F)
Oct - 21.3°C (70.4°F)
Nov - 22.3°C (72.2°F)
Dec - 23.1°C (73.6°F)

c) Number of days per annum with maximum temperature below 0°C (32°F)
Nil

Rainfall and Humidity

Rainfall records refer to the Fiji Sugar Corporation Station at Drasa, immediately adjacent to Drasa Forest Reserve. Period of records : 1955 - 75. Relative humidity records refer to the Fiji Sugar Corporation Station in Lautoka, 10 km from Drasa Forest Reserve. Period of records : 1961 - 73.

a) Mean monthly rainfall

Jan - 306 mm (12.0 inches)
Feb - 400 mm (15.7 ")
March - 468 mm (18.4 ")
April - 190 mm (7.5 ")
May - 83 mm (3.3 ")
June - 71 mm (2.8 ")
July - 46 mm (1.8 inches)
Aug - 56 mm (2.2 ")
Sept - 79 mm (3.1 ")
Oct - 94 mm (3.7 ")
Nov - 158 mm (6.2 ")
Dec - 181 mm (7.1 ")

b) Annual rainfall

2132 mm (83.9 inches)

c) Longest period recorded with less than 51 mm (2 inches) of rainfall per month

6 month period May - October, 1966.

d) Mean monthly relative humidity

Jan - 73%
Feb - 76%
March - 78%
April - 77%
May - 74%
June - 74%
July - 73%
Aug - 68%
Sept - 69%
Oct - 68%
Nov - 68%
Dec - 71%

(iii) Topography

Geography : Consists of lava flows of the Ba Basaltic Group.

Slope : The area is generally undulating, with the sampled plantation having a north-easterly aspect, sloping up to 20° approximately.

Soil : The general area is characterised by ferruginous latosols from parent materials of basic and intermediate composition i.e. a similar broad soil type to that at Seaqaqa. These are the "talasiga" (sun baked) soils, induced by repeated destruction of the natural plant cover.

Drainage : Adequate natural drainage.

(iv) Natural Vegetation

The natural vegetation is similar to that of Seaqaqa, with mission grass, fern, scattered guava and nokonoko scrub.

Lighter mission grass and fern remain dominant within the plantation areas.

(v) Plantation History

Seed origin : As for Seaqaqa

Nursery practice : " " "

Method of planting : Spacing 3.0 m x 2.4 m (10 ft x 8 ft).
Other comments as for Seaqaqa.

Date of planting: Feb. 1961, (3.6 ha, 9 acres)

Tending : 1961 - Weeding

1962 - Weeding

1964 - 0.8 ha (2 acres) low pruned

1965 - Removal of some overhead scrub
- Remaining 2.8 ha (7 acres) low pruned

1968 - Pruned to half height

1969 - Thinned to 740 stems/ha (300/acre).

1972 - Removal of stems damaged in Oct, 1972, hurricane.

(Core samples were collected in Aug, 1970, and disc samples in mid and late 1973).

(vi) Mensurational data

The specific plots from which the core samples were taken, prior to collection had mean diameters and height as follows:

Plot 1 - Mean height 15.6 m (51.2 ft); mean bh diameter (ob) 19.8 cm (7.8 inches)

Plot 2 - Mean height 11.4 m (37.5 ft); mean bh diameter (ob) 14.5 cm (5.7 inches)

Other routine mensurational plots within the plantation gave the following crop statistics on the dates indicated:

	Plot 98A		Plot 99A	
	6.7.70	28.6.73	17.5.71	28.6.73
Age - years	9.5	12.5	10.5	12.5
Stems - per acre	210	140	220	160
- per ha	519	346	544	395
Basal area - ft^2/acre	66.5	59.9	72.2	62.4
- m^2/ha	15.3	13.7	16.6	14.3
Volume - ft^3/acre	1222	1166	1415	1300
- m^3/ha	85.5	81.6	99.0	91.0
Mean height - ft	51.1	56.8	54.5	60.7
- m	15.6	17.3	16.6	18.5
Mean bh diam - ins	7.6	8.8	7.7	8.5
- cm	19.3	22.4	19.6	21.6

APPENDIX 1

B. FIELD SAMPLING AND COLLECTION OF MATERIAL /1

1. DEMARCATION OF SAMPLE PLOTS

Plots for sampling were selected to cover the range of site types which would normally be planted in any large scale afforestation operation, within the limits of available plantations. The plots were sited in the oldest plantations available that were reasonably fully and evenly stocked and that were representative of the crops that could be expected on that site type:-

Drasa Forest Reserve	- Plot 1 P61 Comp. 3B19 (bottom plot)
	- Plot 2 P61 Comp. 3B19 (top plot)
Seaqaqa Forest Reserve	- Plot 1 P60 (front plot)
	- Plot 2 P60 (rear plot)
Nausori Highlands	- Plot 1 P61 (inner plot)
	- Plot 2 P61 (outer plot)

The plots defined were square or rectangular in shape, approximately 0.2 ha (0.5 acre) in size and contained approximately 100 trees. The plots were permanently demarcated with posts and indication trenches, with the plot boundaries running mid-way between rows of trees. Plot dimensions to the nearest 0.15m (0.5 ft) and compass direction to the nearest degree were recorded for each plot.

Each tree within the plot was numbered with an aluminium tag and nail, the nail corresponding exactly to the 1.83m (6 ft) mark on the upper side of the stem. The aluminium tag was supplemented with a painted number.

Girth at breast height of all trees was measured to the nearest 0.25cm (0.1 in), breast height being located by measuring 46 cm (18 ins) from the 1.83 m (6 ft) mark with a standard measure.

2. SELECTION OF SAMPLE TREES

Twenty random, healthy dominants were selected in each plot.

(i) Height. The height of each sample tree was recorded to the nearest 0.3 m (1 ft), using a hypsometer.

(ii) Stem alignment. The angle of any lean was measured by suspending a plumb bob at points on the bole 4.9 m (16 ft) from the ground, to ascertain the place where the bob, when at ground level was at a maximum distance from the stem above the basal swelling, i.e. 0.3 m (1 ft) from the ground on the upper side. This distance was recorded in cm (inches) and the compass direction of maximum lean noted.

(iii) Stem form. A rigid rod 4.6 m (15 ft) in length was placed with its bottom 0.3 m (1 ft) from the ground, to fit as closely as possible against the side of the stem showing greatest distortion. The maximum deflection from the rod of any bend or bends in the stem was recorded together with its distance from the bottom of the rod. Where there were two or more clear points of deflection i.e. bends separated by portions

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/1 At the time sampling was undertaken imperial measure was used. Units have been converted to metric equivalents and this has involved some loss of accuracy. The original imperial units quoted are the precise ones.

of the stem in contact with the rod, then each was recorded separately. Where a bend was made up of two or more bows or curves, only the maximum deflection was recorded. Similar measurements were made on the side of the stem at right angles in a clockwise direction from the side of greatest deflection.

(iv) Crown characteristics. Crown diameter was assessed by eye, by marking on the ground the extent of the projection of the crown. Widths at maximum and minimum diameter to the nearest 0.15 m (0.5 ft) were recorded. Crown length was recorded by measuring lengths to the lowest live branch and to the lowest whorl to the nearest 0.3 m (1 ft) using measuring rods, and deducting from total tree height taken by hypsometer.

(v) Adjacent trees. For each sample tree, the numbers of the five nearest trees were recorded, together with their distance and compass bearing to the nearest 10°.

3. CORE SAMPLING OF SELECTED TREES

From each sample tree, one 12 mm boring was taken at the middle of the internode nearest to breast height. Actual height was recorded. Where nodes were not clearly identified, borings were taken at breast height.

Samples were taken:-

(i) in leaning trees, from the upper side, in the direction of lean, right through the stem, with the compass bearing of the line of boring being noted to the nearest 5°.

(ii) in upright stems, in the direction of the prevailing wind, noting compass bearing.

Samples were clearly identified to indicate site, plot number and tree number, direction of boring, and were treated against sapstain before being consigned by air to the CFI, Oxford.

4. HURRICANE BEBE - OCTOBER, 1972

Subsequent to the consignment of the increment cores, the sample plots were damaged by Hurricane Bebe. The Nausori Highlands and Drasa plots were badly affected. Minor damage only was sustained at Seaqaqa.

5. SECOND STAGE SAMPLING

Following assessment of increment cores, CFI identified the following sample trees for further examination (January, 1973):-

Density class	Site	Plot	Tree No.
Over 0.65 g/cm^3	Drasa	2	11
	Drasa	1	57
	Seaqaqa	2	79
	Seaqaqa	1	45
0.6-0.65 g/cm^3	Nausori Highland	1	44
	Drasa	1	71
	Seaqaqa	1	8
	Seaqaqa	1	36

0.55-0.60 g/cm^3	Seaqaqa	2	51	
	Seaqaqa	2	37	
	Seaqaqa	2	84	
	Seaqaqa	1	31	
0.5-0.55 g/cm^3	Drasa	1	6	
	Nausori Highland	1	51	(NH-1/45)
	Seaqaqa	1	64	
	Seaqaqa	2	6	(NH-1/20)
0.45-0.5 g/cm^3	Nausori Highland	1	40	
	Nausori Highland	1	24	(NH-1/82, NH-/98)
	Seaqaqa	2	1	
	Seaqaqa	1	55	

(Numbers bracketed refer to original selections which had to be changed because of hurricane damage.)

The specific objects of the sampling at this stage were redefined:-

(i) To estimate the extent of between tree differences in pulping properties, in the hope of being able to establish relationships between pulping characteristics of individual trees and some structural features or properties which could be easily measured (*e.g.* density and pattern of density determined at breast height, cellulose-lignin content from breast height samples, and possibly fibre dimensions).

(ii) To estimate the extent of genotype-site interaction, in the hope of distinguishing the effects of environment superimposed on the basic genetical pattern of wood development.

To meet object (i), all sample trees as detailed above were felled, and 1 ft billets taken from 5%, 15%, 25%, 35%, 45%, 55%, 65% and 75% of total height.

Appraisal of pulping properties was undertaken by Tropical Products Institute.

6. CLONAL/SITE TRIALS

To meet object (ii), at time of felling, vegetative material was collected from the following trees, for grafting on to root stock and ultimately for planting out in a variety of contrasting sites. The final aim was to replicate the 10 trees 5 times at 5 sites:-

Density class	Site	Plot No.	Tree No.
Over 0.65 g/cm^3	Seaqaqa	2	1
	Nausori Highlands	1	40
0.6-0.65 g/cm^3	Seaqaqa	1	64
	Drasa	1	6
0.55-0.6 g/cm^3	Seaqaqa	2	84
	Seaqaqa	1	31
0.5-0.55 g/cm^3	Nausori Highlands	1	44
	Seaqaqa	1	8
0.45-0.5 g/cm^3	Seaqaqa	2	79
	Drasa	2	11

In the absence of adequate root stock, some of the initial vegetative material, as an interim measure, was grafted on to natural regeneration in Drasa Compt. 2B4, 2B5. At Seaqaqa additional Seaqaqa material was grafted on to roadside natural regeneration adjacent to the P.60 plantations.

Shortfalls in grafting material, and some failures, restricted the grafts available for planting and prevented all trees in all plots from being established at the same time.

The five selected sites were located at Drasa, Nabou, Nausori Highlands, Colo-i-Suva and Seaqaqa.

At each site the 10 trees were replicated as below:-

	A	B	C	D	E	F	G	H	I	J
1	S2-79	NH1-40	S2-84	S1-8	S2-1	D2-11	S1-64	S1-31	NH1-44	D1-6
2	S2-1	S1-31	S2-79	NH1-40	NH1-44	D1-6	S2-84	D2-11	S1-64	S1-8
3	S1-64	D2-11	S2-1	D1-6	S2-79	S1-31	NH1-44	S1-8	S2-84	NH1-40
4	NH1-44	D1-6	S1-64	S1-31	S2-84	S1-8	S2-79	NH1-40	S2-1	D2-11
5	S2-84	S1-8	NH1-44	D2-11	S1-64	NH1-40	S2-1	D1-6	S2-79	S1-31

Planting spacing was 3.0 m x 2.4 m (10 ft x 8 ft) and the plots were surrounded by two buffer strips of routine ungrafted planting rock.

At time of planting, if a graft from a particular tree was not available, routine planting stock was put in to provide root stock for field grafting at a later date. If further potted grafts became available, the routine stock was uprooted and discarded.

As at 15.5.78, the position was as follows:-

Drasa

Grafts and buffer surround planted 16.1.75. All grafts surviving.

Nabou

Grafts and buffer surround planted 5.2.75. Twelve blanks, filled on the following dates:

A3	S1-64	27.11.75	E5	S1-64	2. 3.76
B2	S1-31	27.11.75	F3	S1-31	27.11.75
B3	D2-11	27.11.75	H1	S1-31	27.11.75
C4	S1-64	2. 3.76	I2	S1-64	2. 3.76
D4	S1-31	27.11.75	J4	D2-11	27.11.75
D5	D2-11	27.11.75	J5	S1-31	27.11.75

Nausori Highlands

Grafts and buffer surround planted 3.2.75. Fifteen blanks, filled on the following dates:-

A3	S1-64	27.11.75	G1	S1-64	27.11.75
B2	S1-31	27.11.75	G3	NH1-44	2. 3.76
B3	D2-11	27.11.75	H1	S1-31	27.11.75
C4	S1-64	27.11.75	H2	D2-11	27.11.75
D4	S1-31	27.11.75	I2	S1-64	27.11.75
D5	D2-11	27.11.75	I5	S2-79	27.11.75
F1	D2-11	27.11.75	J4	D2-11	27.11.75
F3	S1-31	27.11.75	J5	S1-31	27.11.75

Colo-i-Suva

Buffer surround planted 2.1.75. Grafts planted 14.1.75. Thirteen blanks, filled on the following dates:-

B2	S1-31	11. 3.76	F4	S1-8	11. 3.76
B3	D2-11	11. 3.76	H1	S1-31	11. 3.76
B4	D1-6	dead - no replacement	H2	D2-11	24.12.75
D4	S1-31	11. 3.76	I1	NH1-44	11. 3.76
D5	D2-11	24.12.75	J4	D2-11	24.12.75
F1	D2-11	24.12.75	J5	S1-31	11. 3.76
F3	S1-31	dead - no replacement			

Seaqaqa

Buffer surround planted 27.1.75. Grafts planted 18.3.75. Twelve blanks, filled on the following dates:-

A3	S1-64	dead - no replacement	F3	S1-31	28.10.76
B2	S1-31	27.11.75	G1	S1-64	27.11.75
B3	D2-11	dead - no replacement	H1	S1-31	27.11.75
C4	S1-64	27.11.75	I2	S1-64	27.11.75
D4	S1-31	27.11.75	J4	D2-11	5.10.76
E5	S1-64	27.11.75	J5	S1-31	27.11.75

Note

The initial blanks in the plots arose either from a shortage of required grafts at the time, or failure of the planted grafts, necessitating replacement

Some surplus grafted material for some of the trees remained and rather than discard it, it was planted as an extension to the Drasa and Seaqaqa plots.

At Seaqaqa, five surplus grafts - S2-1; S1-31; S2-84; D1-6 and S1-8 - were planted on 5.10.76.

At Drasa, thirty surplus grafts were planted on 25.5.76:

NH1-40 - 2 plants
NH1-44 - 1 "
D1-6 - 3 "
D2-11 - 3 "
S1-8 - 5 "

S1-31 - 2 plants
S1-64 - 1 "
S2-1 - 5 "
S2-79 - 4 "
S2-84 - 4 "

In the Drasa extension plantings (only), the original 3.0 m x 2.4 m (10 ft x 8 ft) spacing was not followed. In this case each grafted tree was separated by a single buffer tree, between and within lines. Planting spacing of the grafts was therefore 6.0 m x 2.4 m (20 ft x 16 ft).

APPENDIX 2

EXPERIMENTAL METHODS IN PULPING INVESTIGATIONS

1. APPARENT DENSITY OF WOOD

Determined using TAPPI Standard method T 18m-53 using one piece approximately 18 mm (0.75 in) thick from each log received.

The green volume was determined by weighing the disc, which had been soaked in water until it was saturated, immersed in water. The oven-dry weight was determined by weighing this disc after it had been dried to constant weight at 105° ± 3°C.

The apparent density calculated as: $\dfrac{\text{oven-dry weight}}{\text{green (soaked) volume}}$

was expressed in kg/m^3, (numerically equivalent to g/cm^3 used in this report).

2. CHEMICAL ANALYSIS

A portion of the chips prepared for pulping was ground in an Apex knife mill. Chemical analyses were made on groundwood which passed a sieve with 420µm aperture; for some analyses, where the presence of fine material interferes with analysis, the groundwood was further sieved and the portion passing a sieve with 250µm aperture discarded.

For some analyses an extractive-free sample of groundwood was prepared by successive treatment with alcohol-benzene, alcohol and water as described in Tappi Standard, T12 os-75.;

Some or all of the following analyses were included:

(a) On material that had passed a sieve with 420µm aperture but had not been extracted:

1% Caustic soda solubility	Tappi T 4m-59

(b) On material that had passed a sieve with 420µm aperture and was extractive-free:

Acid insoluble lignin	Tappi T 222 os-74

(c) On material that had passed a sieve with 420µm aperture and had been retained on a sieve with 250µm aperture but had not been extracted:

Alcohol-Benzene solubility	Tappi T5 os-73

(d) On material that had passed a sieve with 420µm aperture and had been retained on a sieve with 250µm aperture and was extractive-free:

Holocellulose	Wise *et al*. (1946)

(e) On the material obtained in the holocellulose determination:

α - cellulose Based on Tappi T 203 os-74

but modified for gravimetric determination.

All results were expressed as oven-dry solubles or product on oven-dry unextracted wood.

3. FIBRE LENGTH

The fibre length by classification was determined using a McNett classifier and weighing the fibres retained on each screen. In previous work the average length of the fibres on each screen had been determined and these values were used in estimating the average length.

4. PULPING METHODS

The chips used for pulping were prepared by sawing the log into discs approximately 18 mm thick and then splitting along the grain with a mechanical guillotine to give a chip approximately 18 x 6 mm thick. This damages the fibres less than commercial chipping.

Digestions were made in a stainless steel pressure vessel with forced circulation and an external, electric heat exchanger.

In the kraft (sulphate) process, which is the most promising chemical process for use with tropical woods, the active chemicals are sodium hydroxide and sodium sulphide.

The concentration of chemicals was calculated using the following definitions:

(a) Active alkali = $NaOH + Na_2S$ expressed as Na_2O per cent oven-dry wood.

(b) Sulphidity = $\frac{Na_2S \times 100}{NaOH + Na_2S}$ all the compounds expressed as Na_2O

A sulphidity of 25 per cent was used in each of these experiments, chosen because published information shows there to be generally little variation in pulp quality with changes in sulphidity in the range of 20 to 30%.

The cooked chips were washed free of superficial black liquor and broken up in a propellor type disintegrator to simulate the disintegration occurring during blowing a commercial digester; the pulp was screened using a plate with 0.15 mm wide slits to remove shive, and collected on a sieve with 106 µm aperture.

The yield of pulp was determined by drying the whole of the screened pulp in a stream of air about 10% moisture. The total weight of air-dry screened pulp and the moisture content of an aliquot were determined for calculating the yield of oven-dry pulp.

The chemical consumption was determined by titrating with hydrochloric acid an ashed aliquot of the black liquor to determine the total alkali and an aliquot from which the reaction products of digestion had been removed by precipitation with barium chloride to determine the residual active alkali.

5. UNBLEACHED PULP EVALUATION

The Kappa number was determined by TAPPI standard method T 236 os-76.

The amount of permanganate consumed by pulp under specified conditions is measured and, for pulp yields of less than 70%, the percentage of Klason lignin approximately equals Kappa number x 0.15.

The physical characteristics of the pulp were determined by preparing sheets from the air-dried pulp in a British Sheet machine which had been modified for semi-automatic operation. Sheets made in this way were essentially the same as sheets prepared according to the proposals of the 'Second Report of the Pulp Evaluation Committee to the Technical Section of the (British) Papermakers' Association' (1936).

The sheets of approximately 60 g/m^2 were tested after conditioning at 23.0 ± 1.0 °C and 50.0 ± 2.0% relative humidity.

The effect of air-drying was to lower the strength of the unbeaten pulp, but the effect on beaten pulp was small.

The pulps were beaten in a PFI mill using consistency of 10% difference between the peripheral speeds of the beating elements of 2 m/s, and a beating pressure of 33.3 N/cm.

The methods used for the physical examination of each set of sheets based on 'The Second Report of the Pulp Evaluation Committee' (1936) and current British Standards were:

(a) Thickness. Ten measurements made on ten sheets placed one on top of another using a dead weight micrometer.

(b) Tensile strength, stretch and tensile energy absorbed:

Ten strips 15 mm wide were tested using a horizontal tensile tester with the jaws initially 9.0 cm apart.

(c) Tear: Using a Marx-Elmendorf tear tester; normally a group of three were torn at one time through 44 mm in two places (i.e. total tearing distance is 3 x 2 x 44 = 264 mm), three readings being obtained in this way. Sheets with high tearing strength were torn either in pairs or singly and suitable adjustment was made to the calculation of the tear factor.

(d) Burst: Eighteen tests using a Frank Schopper-Dalen type pneumatic burst tester.

(e) Folds: Using a Kohler-Molin instrument eight 15 mm strips folded through 312° and the number of double folds recorded before the strip broke under a load of 7.85 N.

(f) Air resistance: Eight sheets tested using a closed top Gurley densometer with a 577g inner cylinder. The time for 100 cm^3 of air to pass through 6.45 cm^2 was measured by the automatic timing attachment.

(g) Grammage (Basis weight) and moisture content: Determined by weighing a fixed area after standard conditioning and after drying to constant weight at 105 ± 3°C.

Physical properties of pulp sheets vary with the grammage of the sheet: consequently most strength values were reported as Indices which were independent of the grammage and were calculated as follows:

Bulk: $\frac{\text{Thickness of a single sheet,}}{\text{Grammage}}$ Units cm^3/g

Density: $\frac{\text{Grammage,}}{\text{Thickness of a single sheet}}$ Units g/cm^3

Tensile index: $\frac{\text{Average tensile strength,}}{\text{Grammage}}$ Units $\frac{Nm}{g}$

Tensile Energy Absorbed Index: $\frac{\text{Average tensile energy absorbed,}}{\text{Grammage}}$ Units $\frac{mJ}{g}$

Tear index: $\frac{\text{Average tearing force,}}{\text{Grammage}}$ Units $\frac{mN.m^2}{g}$

Burst index: $\frac{\text{Average bursting strength,}}{\text{Grammage}}$ Units $\frac{kPam^2}{g}$

All other characteristics would be affected by the grammage of the sheet and were valid only for sheets about 60 g/m^2. The values reported were the numerical average of the determinations.

Freeness: The ease with which water parts from the pulp was determined by two methods. The first, the drainage time, determined on the standard sheet machine, is the time in seconds for water at 20°C to flow from a pulp suspension through the wire from a height 350 mm above the wire until the formed sheet is no longer immersed. The procedure used was that described in the 'Second Report of the Pulp Evaluation Committee' (1936).

The second, the Canadian Standard freeness, was an empirical measure of the rate in which water will separate from a one litre suspension of 3g of pulp through a standard perforated plate, in apparatus calibrated by the Pulp and Paper Research Institute of Canada. The method is described in the 'Second Report of the Pulp Evaluation Committee' (1936).

Results obtained by the methods and calculations described would be expected to give similar results to those that would be obtained by using Tappi Standards T 205 os-71 (Forming handsheets) and T 220 os-71 (Physical Testing).

REFERENCES

BRITISH PAPER MAKERS' ASSOCIATION. (1936) Second report of the pulp evaluation committee, London, 168 pp.

BRITISH STANDARDS. London: British Standards Institute. (Various).

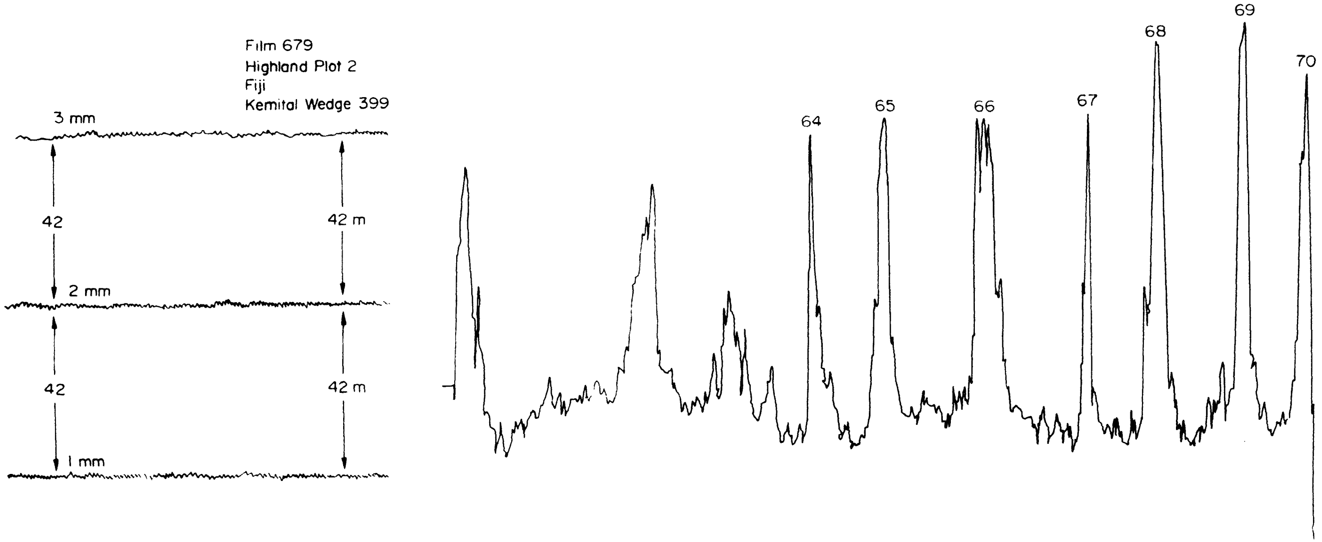
WISE, L.E., MURPHY, M. and D'ADDIECO, A.A. (1946). Chlorite holocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicelluloses. Paper Trade J. 122 (2), 35.

TAPPI. Standard and suggested methods. New York: The Technical Association of the Pulp and Paper Industry. (Various).

Reproduced from Hughes and Sardinha (1975)

APPENDIX 3
Figure 1

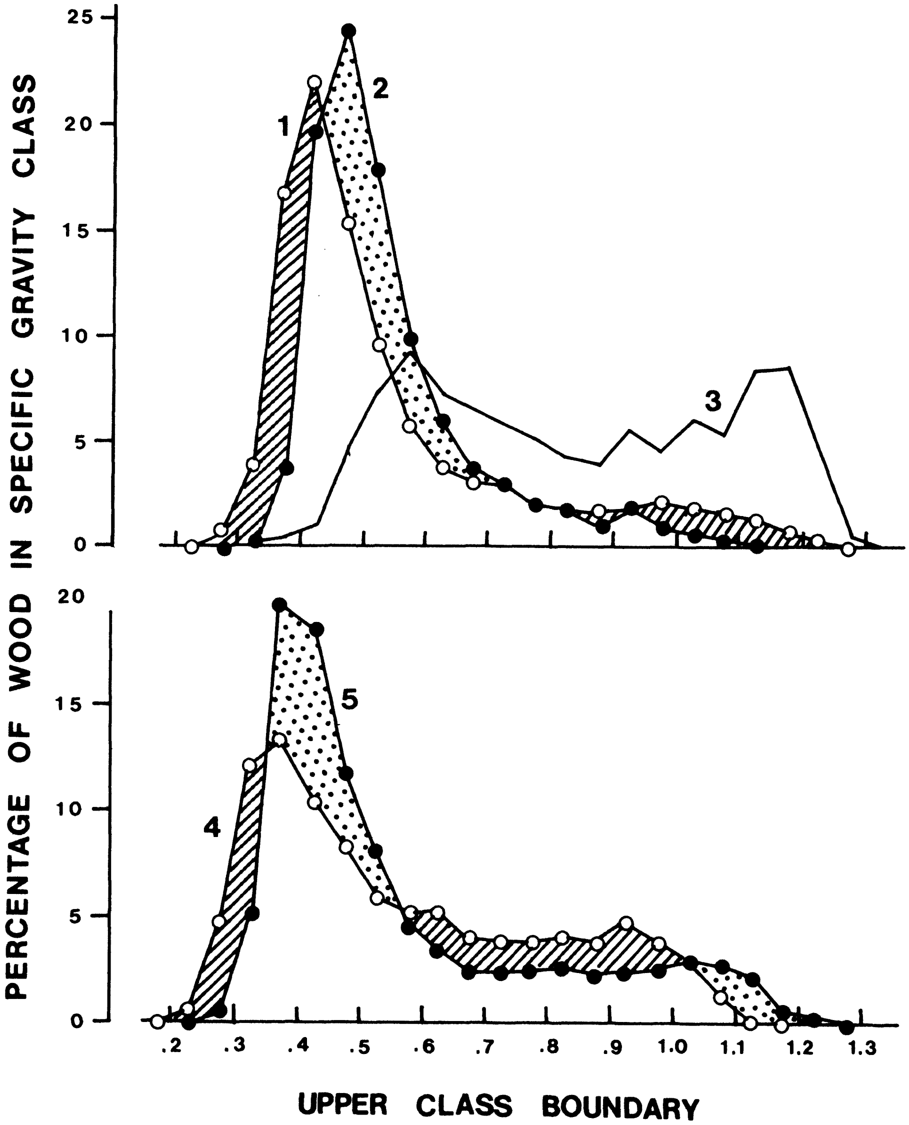
Example of densitometer trace



A chart recording of a scan of the optical densities of three plastic standards (1 mm, 2 mm and 3 mm in thickness) and a 5 mm specimen of *Pinus caribaea*.

APPENDIX 3
Figure 2

Histograms of distribution of density classes

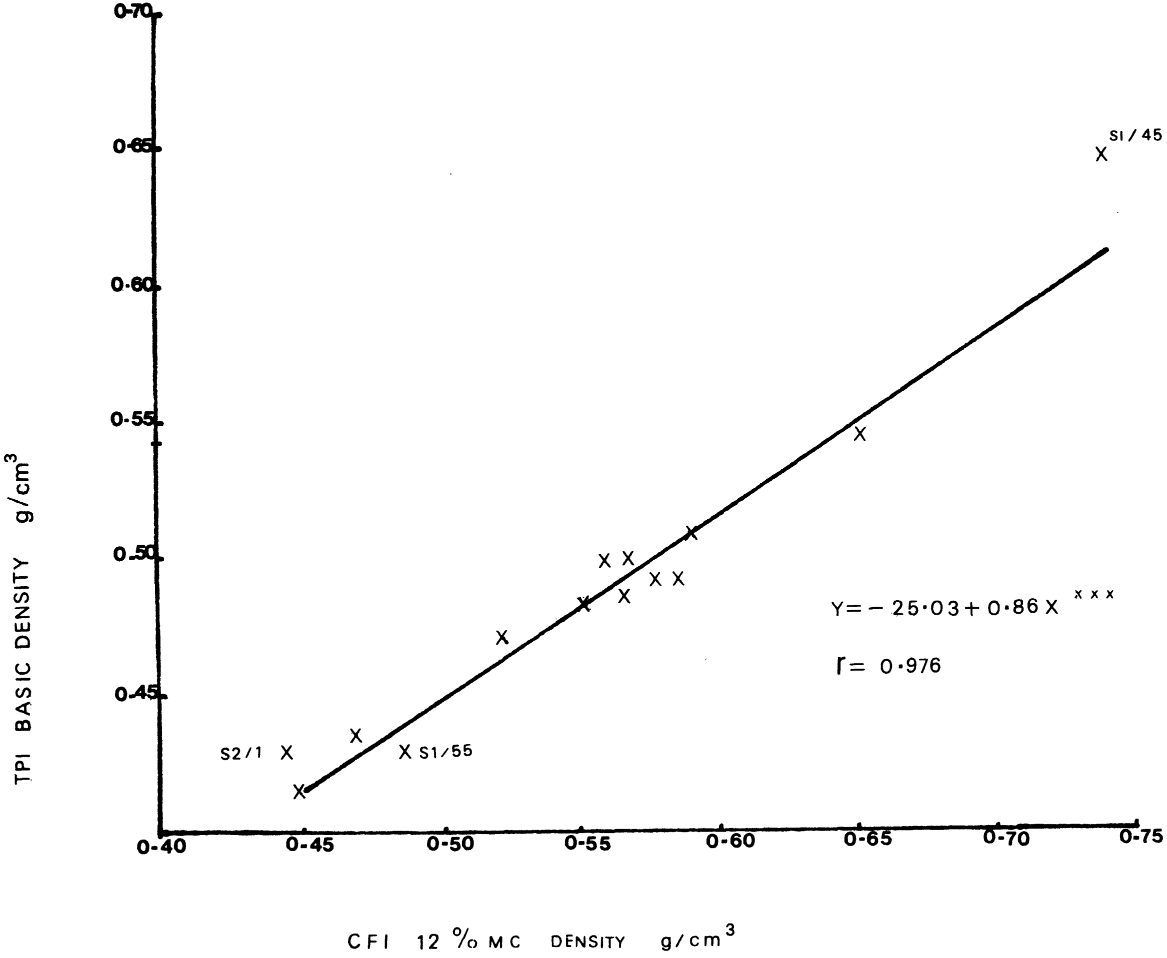


	Tree identity	Basic density (g/cm^3)	Sheet density (g/cm^3)	Burst index (k Pa m^2/g)	Tensile index (N m/g)	Tear index (mN m^2/g)
1	S1/55	0.374	0.63	6.45	93.49	14.58
2	S2/1	0.374	0.63	5.79	83.13	18.30
3	S1/45	0.645	0.56	4.95	73.62	20.75
4	NH1/44	0.466	0.59	5.41	81.06	16.75
5	S2/6	0.466	0.63	4.81	72.74	16.68

APPENDIX 3

FIGURE 3

RELATIONSHIP BETWEEN BASIC DENSITY AND X-RAY DENSITY AT 12% MOISTURE CONTENT FOR 15 TREES



APPENDIX 3
Table 1

Reproduced from Hughes and Sardinha (1975)

An example of a summary, produced by computer program, of the data recorded of the variation in density along a radius
Analysis of radius number 67933·200

YEAR	WIDTH	MEAN	SD	CV	MAXIM	MINIM	RNGDENS	PC/TOT	PCT TRAN	PC. GE.	PC. GE. TR
Low density (LT. 0·399)											
1964	11·80	0·3651	0·0253	6·93	0·3972	0·3117	0·0855	33·15	0·61	66·85	0·96
1965	3·80	0·3537	0·0236	6·68	0·3985	0·3235	0·0750	57·58	0·86	42·42	0·71
1966	3·60	0·3791	0·0109	2·88	0·3919	0·3577	0·0342	32·14	0·60	67·86	0·97
1967	6·80	0·3617	0·0246	6·80	0·3985	0·3078	0·0907	80·95	1·12	19·05	0·45
1968	4·60	0·3509	0·0203	5·79	0·3932	0·3209	0·0723	62·16	0·91	37·84	0·66
1969	4·00	0·3529	0·0277	6·44	0·3959	0·3209	0·0750	51·28	0·80	48·72	0·77
Medium density (0·400–0·499)											
1964	15·00	0·4345	0·0250	5·76	0·4958	0·3998	0·0960	42·13	0·71	24·72	0·52
1965	1·20	0·4544	0·0168	3·69	0·4735	0·4327	0·0408	18·18	0·44	24·24	0·51
1966	4·40	0·4234	0·0251	5·93	0·4853	0·3998	0·0855	39·29	0·68	28·57	0·56
1967	1·00	0·4456	0·0351	7·89	0·4866	0·4038	0·0829	11·90	0·35	7·14	0·27
1968	0·40	0·4136	0·0158	3·82	0·4248	0·4024	0·0224	5·41	0·23	32·43	0·61
1969	2·40	0·4315	0·0295	6·83	0·4879	0·4011	0·0868	30·77	0·59	17·95	0·44
Medium high density (0·500–0·599)											
1964	4·00	0·5472	0·0301	5·51	0·5958	0·5024	0·0934	11·24	0·34	13·48	0·38
1965	0·40	0·5451	0·0604	11·09	0·5879	0·5024	0·0855	6·06	0·25	18·18	0·44
1966	0·40	0·5241	0·0139	2·66	0·5339	0·5142	0·0197	3·57	0·19	25·00	0·52
1967	0·00									7·14	0·27
1968	0·80	0·5744	0·0207	3·60	0·5971	0·5510	0·0460	10·81	0·34	21·62	0·48
1969	0·00									17·95	0·44
High density (GE. 0·600)											
1964	4·80	0·7274	0·0844	11·60	0·9074	0·6155	0·2919	13·48	0·38		
1965	1·20	0·8134	0·1296	15·93	0·9508	0·6050	0·3459	18·18	0·44		
1966	2·80	0·7943	0·1274	16·04	0·9390	0·6063	0·3327	25·00	0·52		
1967	0·60	0·7374	0·1884	25·64	0·9521	0·6194	0·3327	7·14	0·27		
1968	1·60	0·9658	0·1650	17·08	1·0889	0·6115	0·4774	21·62	0·48		
1969	1·40	0·9719	0·1567	16·13	1·1100	0·6707	0·4392	17·95	0·44		
Whole ring										AREA	
1964	35·60	0·4637	0·1238	26·69	0·9074	0·3117	0·5957			3981·5382	
1965	6·60	0·4672	0·1834	39·25	0·9508	0·3235	0·6273			1613·1488	
1966	11·20	0·5055	0·1825	36·10	0·9390	0·3577	0·5813			3363·7740	
1967	8·40	0·3983	0·1096	27·50	0·9521	0·3078	0·6444			3040·0635	
1968	7·40	0·5114	0·2625	51·32	1·0889	0·3209	0·7680			3045·4670	
1969	7·80	0·4882	0·2411	49·39	1·1100	0·3209	0·7891			3582·5550	

Linear transformation equation: $Y = 1{\cdot}19402 - 0{\cdot}00112X$
Overall mean = 0·4700 *O* Overall Length = 77·00

Reproduced from Hughes and Sardinha (1975)

APPENDIX 3

Table 2

Comparison of basic and X-ray (12% moisture content) density for unextracted samples in 15 trees

Tree number	TPI (basic)	CFI (12% m.c.)	$\frac{\text{TPI}}{\text{CFI}}$ %	$\frac{\text{CFI-TPI}}{\text{CFI}}$ %	$\frac{\text{CFI-TPI}}{\text{TPI}}$ %
D2/11	0.528	0.649	81.4	18.6	22.9
NH1/24	0.363	0.449	80.8	19.2	23.7
NH1/40	0.384	0.465	82.6	17.4	21.1
NH1/44	0.466	0.566	82.3	17.7	21.5
S1/8	0.463	0.574	80.7	19.3	24.0
S1/31	0.462	0.581	79.5	20.5	25.8
S1/45	0.645	0.734	87.9	12.1	13.8
S1/55	0.374	0.485	77.1	22.9	29.7
S1/64	0.431	0.516	83.5	16.5	19.7
S2/1	0.374	0.441	84.8	15.2	17.9
S2/6	0.466	0.562	82.9	17.1	20.6
S2/37	0.450	0.550	81.8	18.2	22.2
S2/51	0.454	0.563	80.6	19.4	24.0
S2/79	0.525	0.672	78.1	21.9	28.0
S2/84	0.479	0.585	81.9	18.1	22.1
Range					
Max:	0.363	0.441	77.1	12.1	13.8
Min:	0.645	0.734	87.9	22.9	29.7

X-ray (12% moisture content) density for unextracted samples in five trees

Tree number	CFI (12% m.c.)
D1/6	0.522
D1/57	0.633
D1/71	0.573
NH1/51	0.524
S1/36	0.579

Footnote

After Soxhlet extraction of resin, density decreased by less than 1%.

APPENDIX 3

Table 3 . Tree means for proportions of wood in different classes of density (g/cm^3) and weighted mean density before and after resin extraction (12% moisture content)

Tree identity	Density class									Mean density unextracted	Mean density extracted
	0.05 -0.20	0.21 -0.35	0.36 -0.50	0.51 -0.65	0.66 -0.80	0.81 -0.95	0.96 -1.10	1.11 -1.25	1.26 -1.40		
D1/6	0.02	2.34	55.32	26.66	6.63	3.04	3.27	2.67	0.04	0.5220	0.5221
D1/57	0.03	5.27	35.14	20.24	10.28	9.80	14.16	5.12	0.00	0.6329	0.6258
D1/71	0.00	1.69	39.42	31.32	13.12	7.19	5.72	0.52	0.00	0.5731	0.5684
D2/11	0.08	4.11	32.93	17.52	13.31	17.54	13.39	1.13	0.00	0.6489	0.6339
NH1/24	0.01	33.06	41.64	11.29	7.34	4.37	2.09	0.20	0.00	0.4468	0.4416
NH1/40	0.05	23.86	52.42	12.99	5.24	4.02	1.25	0.15	0.00	0.4654	0.4413
NH1/44	0.12	5.93	50.30	16.33	7.65	7.59	8.83	3.19	0.04	0.5655	0.5539
NH1/51	0.01	6.31	53.99	20.43	9.68	6.36	3.17	0.06	0.00	0.5241	0.5070
S1/8	0.32	12.32	43.57	13.21	7.87	7.63	10.44	4.65	0.00	0.5742	0.5576
S1/31	0.30	10.67	42.43	17.88	8.24	8.05	9.09	3.33	0.03	0.5807	0.5643
S1/36	0.06	6.30	42.79	20.80	11.95	9.25	7.34	1.50	0.00	0.5790	0.5649
S1/45	0.04	1.32	21.61	19.70	13.35	16.27	22.31	5.40	0.00	0.7336	0.7212
S1/55	0.28	9.55	57.64	18.36	6.13	4.98	2.90	0.17	0.00	0.4846	0.4796
S1/64	0.16	11.71	55.53	15.71	7.67	6.69	2.60	0.02	0.00	0.5160	0.4921
S2/1	0.84	42.72	31.03	9.78	5.62	5.97	3.71	0.30	0.00	0.4413	0.4383
S2/6	0.30	17.43	32.41	16.60	11.88	12.87	8.34	0.16	0.00	0.5618	0.5536
S2/37	0.12	4.57	51.56	21.38	9.37	6.05	5.51	1.49	0.00	0.5502	0.5350
S2/51	0.09	7.91	42.01	19.14	13.43	11.22	5.91	0.28	0.00	0.5627	0.5543
S2/79	0.25	2.76	27.93	28.5	14.72	10.26	11.21	4.32	0.06	0.6722	0.6405
S2/84	0.36	5.83	39.40	21.49	13.01	10.73	8.68	0.48	0.00	0.5846	0.5755
MEAN	0.17	10.78	42.45	18.97	9.82	8.49	7.50	1.76	0.01	0.5610	0.5485

APPENDIX 4

STATISTICAL ANALYSIS AND INTERPRETATION

(i) The underlying model

For evaluation of the 12 pulp properties, samples from 20 trees were subjected to four cooking conditions (duplicated); samples from each cook were beaten for four different beating times and replicated twice. The underlying model for the analysis of variance is indicated in Table 1 of this Appendix; it assumed that the effects of Trees, Duplicates and Replicates were random (variance component V) while the effects of Cooks and Beating Times were fixed (ϕ); interactions of fixed and random factors were themselves random.

(ii) Preliminary examination of data

For each pulp property the distribution of the data were examined by frequency histograms. The pooled data generally indicated four peaks corresponding to the four different cooking conditions; thus histograms were produced for each cook separately. Within each cook, for some properties, there were four minor peaks indicating that the means for beating times differed. The number of samples within each was too small to test meaningfully for skewness and kurtosis but the visual examination did not suggest that sufficient variation in sample variance occurred to make transformations necessary.

(iii) Analysis of variance and variance components

The analysis of variance indicates the level of statistical significance of the different sources of variation; throughout this report the following convention is adopted:-

***	indicates significant at 0.1% probability level
**	indicates significant at 1.0% probability level
*	indicates significant at 5.0% probability level
	Otherwise not significant (n.s.) at 5.0% probability level

The analysis of variance components indicates the relative sizes of individual sources of variation and, when expressed as a percentage of total variation, they offer an immediate indication of the practical importance of factors regardless of their statistical significance. They were also used to decide optimum sampling strategies in future studies, _e.g._ with large components for trees and small components for duplicate cooks and replicate beating times, a future study should sample more trees and economise on laboratory analysis.

Thus, although the analysis of variance attributed statistical significance to the effects of most factors and their interactions on most pulp traits, the variance components (Table 2 of this Appendix) indicated that few of these effects were meaningful in practice. Thus, the effects of trees, cooks and beating times were important statistically and practically but their interactions were negligible except for the beating x cook interaction effect on air resistance (24.6% of total variation; the effect of beating time itself accounted for 31.9% and the remainder was evenly distributed over all other sources, indicating in fact that there was little systematic variation in this trait).

In the absence of interaction effects the data were averaged over main effects (see Text Table 2.6) and used in multivariate and regression/ correlation analyses.

(iv) Regression and correlation analysis

Where significant effects on pulp properties were attributed to beating times and cooking conditions, regression analysis was undertaken to fit the best model (of 12 tested) to the relationships between the pulp variable and either beating time or Canadian Standard freeness (as a linear measure of cooking conditions which in fact varied in temperature and chemical content). Some beating curves are illustrated in Text Figure 2.1 The best model was then used to calculate for each tree the value of the pulp property at 35 Kappa and 500 CSf, a combination considered to be on the border between bleachable and unbleachable pulps. (These individual predicted values were virtually identical to those obtained by eye from hand-drawn graphs and to those derived as arithmetic tree means averaged over all cooking conditions and beating times.)

The relationships between these tree values and various chemical, morphological and anatomical traits were examined by simple and multiple correlation analysis in which the coefficients of determination (r^2) or multiple determination (R^2) indicate the closeness of the data to the underlying regression model whereas the corresponding correlation coefficients (r and R) offer a statistical test of the association between two or more variables. Values of r^2 = 80-90% are commonly quoted in studies of the relationship between anatomical and pulp properties. However, as pointed out by Worrall et al. (1977) a minor change in r^2 (the coefficient of determination) represents a major change proportionally in $1-r^2$ (the amount of non-determination) of a particular relationship. The problem is that most authors consider as error only the lack of fit while forgetting the pure error (see Draper and Smith, 1966).

The simple correlations between all pairs of pulp properties are shown in Text Table 4.1 and between selected pulp and other variables in 4.2.

(v) Multivariate analysis

The multivariate relationships of all traits were studied by means of stepwise multiple regression and canonical analysis /1. These are methods of reducing the overall variation in many characteristics to a small number of biologically or technologically meaningful factors (see e.g. Andrew, 1972 /2).

Principal component analysis derives linear combinations of a set of p correlated responses on n observations so that the variance of each such

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/1 Fernandez de la Reguera, P.A. (1976). A statistical study of the variation and correlations of wood and pulp properties of *Pinus caribaea* trees from Fiji. Unpubl. M.Sc. Thesis, University of Oxford. 101 p.

/2 Andrew, I.A. (1972). The application of multivariate statistical techniques to the analysis of variation within and between fast growing tropical tree species. Unpubl. M.Sc. Thesis, University of Oxford. 149 p.

combination taken in turn is maximised. Canonical analysis relates components for one group of properties (e.g. pulp variables) to components for another group (e.g. anatomical properties). Forward stepwise multiple regression was used to select variables among the densitometric, chemical and fibre fraction variables that could be used to predict some of the pulp group properties. The multivariate analyses were handicapped by being based on only 20 tree means for each property (a small number in relation to the number of variables).

The results of the multivariate analyses did not add a large amount of information and are not presented in this report. They will be given in a CFI Occasional Forestry Paper.

APPENDIX 4

Table 1

Format for analysis of variance of underlying model

Entry	Test against entry	Source of variation	Degrees of freedom	Fixed (F) or Random (R) effect	Expectation mean square
1	4	Trees	19	R	$V_r + 2V_{bd} + 8V_d + 64V_t$
2	3	Cooks	3	F	$V_r + 2V_{bd} + 8V_d + 16V_{ct} + 320\phi_c$
3	4	Cooks x Trees	57	R	$V_r + 2V_{bd} + 8V_d + 16V_{ct}$
4	9	Duplicates in cooks and trees	80	R	$V_r + 2V_{bd} + 8V_d$
5	6	Beating times	3	F	$V_r + 2V_{bd} + 16V_{bt} + 320\phi_b$
6	9	Beats x Trees	57	R	$V_r + 2V_{bd} + 16V_{bt}$
7	8	Beats x Cooks	9	F	$V_r + 2V_{bd} + 4V_{bct} + 80\phi_{bc}$
8	9	Beats x Cooks x Trees	171	R	$V_r + 2V_{bd} + 4V_{bct}$
9	10	Beats x (Duplicates in cooks and trees)	240	R	$V_r + 2V_{bd}$
10		Replicates in all samples	640	R	V_r

APPENDIX 4
Table 2
Relative importance of variation (variance components expressed as percentages of total variation (for 12 pulp properties

Source of variation	Degrees of freedom	Total yield	Screened yield	Canadian Standard freeness	Drainage time	Air resistance	Density
Trees	19	27.34	48.64	0.94	4.94	2.25	31.56
Cooks	3	67.46	40.43	2.30	6.23	7.96	7.19
Cooks x Trees	57	0.00	2.62	0.00	1.06	1.58	0.13
Duplicates in Cooks and Trees	80	5.19	8.31	0.46	0.75	0.48	1.56
Beating Time	3	0.00	0.00	92.52	54.52	31.91	54.69
Beating Time x Trees	57	0.00	0.00	1.40	7.84	6.30	1.34
Beating Time x Cooks	9	0.00	0.00	0.98	11.19	24.63	0.06
Beating Time x Cooks x Trees	171	0.00	0.00	0.00	2.60	4.80	0.00
Beating Time x (Duplicates in Cooks and Trees)	240	0.00	0.00	0.18	2.40	6.30	0.00
Replicates in all samples	640	0.00	0.00	1.22	8.46	13.78	3.47

	Degrees of freedom	Burst index	Tensile index	Stretch	Tear index	Double folds	Kappa number
Trees	19	11.04	13.42	24.51	46.40	44.58	14.62
Cooks	3	0.89	0.33	3.39	3.03	1.43	78.67
Cooks x Trees	57	0.89	1.10	1.56	0.03	1.02	0.68
Duplicates in Cooks and Trees	80	0.53	0.58	10.90	3.08	3.51	6.04
Beating Time	3	81.39	78.46	5.14	35.60	24.00	0.00
Beating Time x Trees	57	2.06	0.68	7.29	4.03	3.80	0.00
Beating Time x Cooks	9	0.00	0.01	0.38	0.72	0.32	0.00
Beating Time x Cooks x Trees	171	0.00	0.00	0.00	0.00	0.00	0.00
Beating Time x (Duplicates in Cooks and Trees)	240	0.00	0.00	0.00	0.00	0.00	0.00
Replicates in all samples	640	3.20	5.41	46.83	7.11	21.34	0.00