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Original article

Sampling for wood properties in trial plots of 4 *Eucalyptus* species at Ruvu, Tanzania

KFS Hamza, S Lewark

Institut für Forstbenutzung und Forstliche Arbeitswissenschaft, Werderring 6, D-79085 Freiburg, Germany

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Summary — The objective of this study was to develop an effective sampling design for a planned investigation of basic density, fibre length, fibre-wall thickness, vessel number and vessel proportion in trial plots of 16- and 17-year-old *Eucalyptus tereticornis* and 17-year-old *E camaldulensis, E paniculata* and *E citriodora* grown in Ruvu, Tanzania. The idea was to conduct the investigation stepwise starting with a higher number of samples per tree in one stand in order to get information about the variation within trees and between trees, and later including more stands with a lower number of trees per stand and a lower number of samples per tree depending on the results of the first phase and calculations of the minimum number of measurements required. Calculations indicate that at a required precision of 5% of the mean, it is possible to reduce the number of samples considerably. This will result in a substantial saving of time, manpower and other costs needed for such studies.

eucalyptus / sampling / basic density / fibre dimensions / vessel number / vessel proportion

Résumé — Échantillonnage pour quelques propriétés du bois dans des parcelles expérimentales de 4 espèces d'eucalyptus installées à Ruvu (Tanzanie). *L'objectif de l'étude est de proposer un plan d'échantillonnage efficace pour une recherche prévue sur l'infradensité du bois, la longueur et l'épaisseur des parois des fibres, le nombre et la proportion de vaisseaux dans des parcelles expérimentales d'*Eucalyptus tereticornis *âgées de 16 et 17 ans et d'*E camaldulensis, E paniculata *et* E citriodora *âgées de 17 ans, installées à Ruvu, Tanzanie. L'idée directrice de l'étude est de conduire la recherche de manière progressive en partant dans une première phase d'un nombre élevé d'échantillons par arbre dans un peuplement, afin de connaître la variabilité inter- et intra-arbre et en incluant dans une seconde phase les autres peuplements représentés par des nombres plus faibles d'arbres par peuplement et d'échantillons par arbre, ces nombres étant déterminés en fonction des résultats de la première phase et de calculs donnant les effectifs minimum de mesures nécessaires. Les calculs indiquent que, pour un niveau de précision de 5% sur la moyenne, il est possible de réduire de manière considérable le nombre d'échantillons à mesurer. Des économies substantielles en matière de temps, de main d'œuvre et d'autres coûts nécessaires pour de telles études en résulteront.*

eucalyptus / échantillonnage / infradensité du bois / dimensions des fibres / nombre de vaisseaux / proportion de vaisseaux

INTRODUCTION

Every wood research worker planning an investigation has to deal with limited resources of time and money, so that he will aim at an optimal utilization of his efforts according to the economical principle. This means achieving either a maximum of information with given resources or a required information in terms of quality and quantity with minimal input, though in most cases the possible input will be limited.

In Tanzania wood research is still very young and collecting basic information about the performance of exotic species including wood quality certainly deserves a high priority. It is conceded that many decisions cannot be deduced, but are based on the judgement of the research worker. In our case this was the decision to study basic wood properties of 4 important species of *Eucalyptus.* Although the use of disks has the advantage of getting more information, we decided to use increment cores after determining the possibility of using only one or a few samples at the base of the tree in phase 1. This was also because we were not allowed to fell more sample trees. The number of sites was limited by the layout of the trial experiment to be included.

The variables that determine the minimum number of measurements on the subsequent levels of a sampling design are the arithmetic mean and variance of the properties as well as the fixed precision level, which could be different for different purposes as suggested by the Forest Biology Subcommittee 2 (1966). At the end of the study the precision of the results achieved should be compared with the required outcome.

In our investigation, calculations of the minimum number of trees for each property to be studied and of measurements on the finest level of the design, *ie* the position within the tree, have been carried out.

Lundgren (1978) reported that a number of hardwood species have been introduced in Tanzania as early as during the German rule (1891–1914). Eucalypts are among the most important species introduced. At present Tanzania has more than 1 600 ha of eucalypts in plantations (Ahlbark, 1986) and also uninventoried amounts in private farms resulting from agroforestry programmes during village afforestation campaigns. At present, the wood from the eucalyptus is mainly used as fuel wood and to some extent as telephone, electrical and building poles for traditional houses. In the future, it is planned to use wood from the eucalypts for the production of pulp and paper, furniture, for building and as fuel.

In order to find suitable *Eucalyptus* species to be grown at Ruvu Forest Project, the Forest sector of the Ministry of Natural Resources and Tourism established trial plots of 24 provenances from 8 *Eucalyptus* species in the early 1970s. Results from silvicultural studies indicate the superiority of *E tereticornis*, followed by *E citriodora, E camaldulensis* and *E paniculata* (Mushi, 1978; Malimbwi, 1982). However, investigations of wood quality of these species have not yet been carried out. This information is also needed to form a basis for decisions concerning choice of species and their proper future utilization.

The current investigation deals with basic density and fibre dimensions among other wood properties. These characteristics have been chosen because they are accepted as indicators of various timber and pulp qualities (Tamolang and Wangaard, 1961; Dinwoodie, 1965).

Compared to softwoods, in which a lot of studies on sampling have been conducted, few studies on hardwoods have been carried out, for example, by Burley*et al* (1970), Kandeel *et al* (1977), Ezell and Stewart (1978) and Lewark (1987). In these studies different numbers of samples have been recommended, so that each research worker must decide on the necessary number of samples according to the purpose of the study.

In this paper we present the results of a sampling study to investigate several wood properties in *Eucalyptus* species.

MATERIALS AND METHODS

Collection of material

The sample trees of the 4 *Eucalyptus* species were obtained from trial plots in Ruvu forest project, Tanzania. The project is located in the Pwani region (40 km west of Dar-es-Salaam, 6°32' and 6°43' S; 38°48' and 39°02' E, 75–100 m asl). For each species the provenance with the best silvicultural performance at Ruvu was used.

We planned to conduct the investigation in 2 phases. In the first phase samples were collected from 20 *E tereticornis* trees. This was the maximum number of sample trees which could be allowed by the research centre authority. In order to select the sample trees, a survey of the diameter distribution has been carried out to ensure that the entire diameter range was represented in the samples. The diameter ranged from 12.5 to 38.5 cm. The trees were then grouped into 4 diameter classes each with a class width of 6.5 cm.

For each diameter class, 5 trees distributed throughout the entire diameter class were selected. Before felling, the north side of each selected tree was marked. After felling the total tree height of each tree was measured. Four 5-cm-thick disks, were cut from each tree at 1, 20, 40 and 60% of total tree height. The tree number and the north side were marked on each disk.

The disks were air-dried. After drying a 2-cm-thick strip running from pith to bark on the north side was cut from each disk. Later each strip was transversely cut into 3 pieces for basic density determination, fibre length measurements and wood structure determination.

The sample design used in the second phase was developed as shown in this paper. The trees were again selected on the basis of diameter distribution. Three increment cores from each tree were taken at breast height for the different properties to be studied. Laboratory work is still under way.

Figure 1 shows the different positions at which samples were taken from each tree and from each increment core.

Laboratory procedure

For the determination of basic density and fibre length in the first phase, 4 samples for each property were taken at 4 positions, *ie* 1, 33, 66 and 100% from each strip. In the second phase, 4 samples were taken from each increment core at the same relative distances from pith.

The basic density of each sample was measured using the maximum moisture content technique in both phases.

After maceration, fibre length was determined by measuring the length of 50 unbroken fibres for the first phase and 20 for the second from each sample using an image analyser (Anon, 1984).

For fibre-wall thickness, vessel number and vessel proportion determination, 4 transverse sections (20 µm thick) were cut on a sliding microtome at the same positions from each strip or increment core. Measurements were carried out using the image analyser.

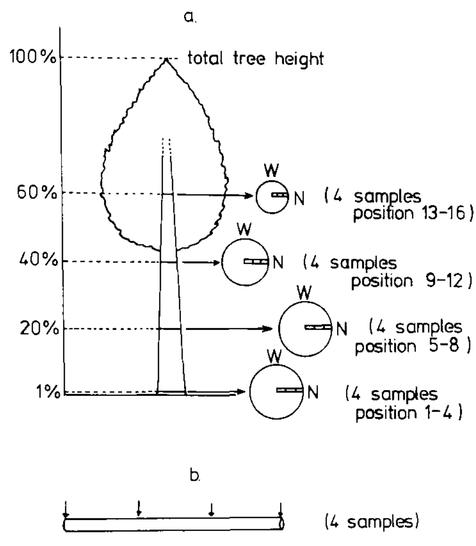

Fig 1. Different positions at which samples were taken, **a** from a tree; **b** from an increment core.

Calculations

The necessary sample size for each property was calculated using the procedure by Hapla and Saborowski (1985) and Lewark (1987). Because the width of the confidence interval for the properties studied is not defined, the common precision level for such experimental studies was used. This is defined as $\bar{x} \pm 5\%$, *ie* a confidence interval with a width of 10% of the mean.

In order to calculate the precision depending on the number of samples for each property studied, the following formula Hapla and Saborowski (1985) was used:

$$d = (t.s)/\sqrt{n}$$

where d = precision expressed in % of the mean; t = Student's t-value; s = standard deviation for the mean; n = number of samples.

Curves for the relationship between the precision and the number of samples for each property studied were then developed. To develop the curves for the number of samples at a position, the arithmetic mean and standard deviation from positions with the lowest, intermediate and highest coefficients of variation from 20 sample trees from phase 1 were used to calculate precision. This means we worked with 3 cases (favourable, intermediate and unfavourable.

From these curves we can read the necessary number of samples on one precision level of the sample design.

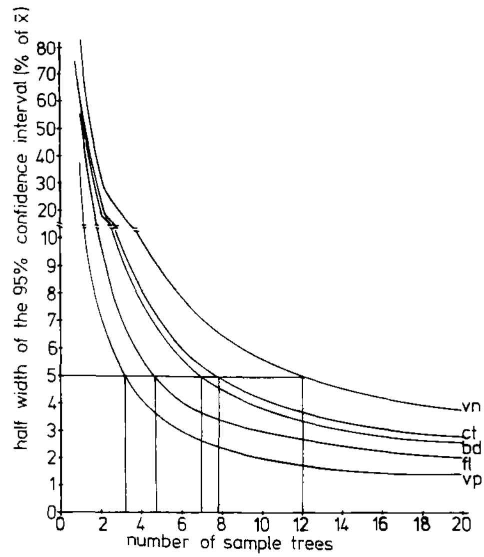

Fig 2. Necessary number of sample trees required for studying different wood properties at different relative precision. bd = basic density, $\bar{x}$ = 0.581 g/cm^3, s = 0.032 g/cm^3; fl = fibre length, $\bar{x}$ = 0.85 mm, s = 0.036 mm; ct = fibre wall thickness, $\bar{x}$ = 4.048 μm, s = 0.24 μm; vn = vessel number in 1 mm^2, $\bar{x}$ = 20.5, s = 1.62; vp = vessel proportion, $\bar{x}$ = 13.76%, s = 0.4%.

RESULTS

Number of sample trees per stand

Figure 2 shows the necessary number of sample trees required for studying different wood properties depending on the relative precision levels. It can be noted that at a required precision of 5% the number of trees needed for determination of basic density, fibre length, fibre wall thickness, vessel number and vessel proportion is n = 7, 5, 8, 12 and 4, respectively. This indicates that vessel number is a limiting property because it requires the highest number of sample trees of the properties studied. It can also be noted from this figure that a further increase in sample size above these numbers improves the precision just marginally and does not justify the costs.

Number of fibres per position needed for fibre length and fibre-wall thickness determination

Figures 3 and 4 illustrate the relationship between the number of fibres per position at different relative precision levels. In these figures it is indicated that at a precision level

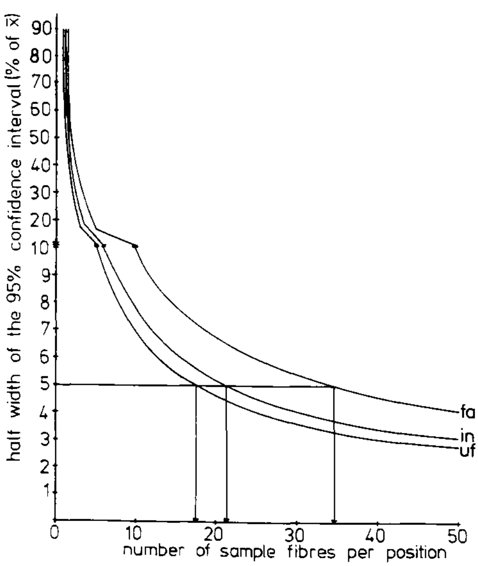

Fig 3. Necessary number of sample fibres required for determination of fibre length at different relative precision. Cases: fa = favourable, $\bar{x}$ = 0.908 mm, s = 0.131 mm; in = intermediate, $\bar{x}$ = 1.015 mm, s = 0.112 mm; uf = unfavourable, x = 0.558 mm, s = 0.055 mm.

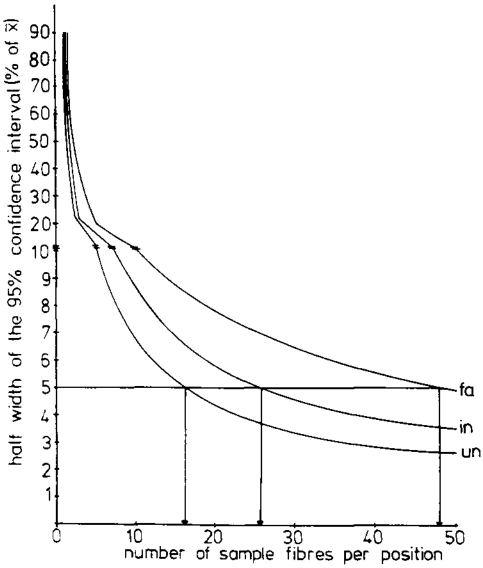

Fig 4. Necessary number sample fibres required for determination of fibre-wall thickness at different relative precision. Cases: fa = favourable, $\bar{x}$ = 4.015 µm, s = 0.702 µm; in = intermediate, $\bar{x}$ = 3.897 µm, s = 0.485 µm; un = unfavourable, x = 4.505 µm, s = 0.419 µm.

of 5% the minimum number of fibres needed for the 3 cases are:

	favourable	intermediate	unfavourable
fibre length	18	22	35
fibre-wall thickness	16	36	48

A further increase in the number of fibres would improve the precision only marginally.

Resulting sampling plan

Table I shows a summary of the sampling plan as a result of calculations, decisions and optimizations. It can be noted that for all properties studied except for vessel proportion, the number of sample trees could be reduced to less than half of those in phase 1. A reduction of the number of sample fibres required for the determination of fibre length and fibre-wall thickness was also observed.

DISCUSSION

The number of samples required in an experiment depends on both the precision of the statement to be made and the costs. The costs set a practical limit to the number of samples. Statements that do not show the required precision are, however, of limited value.

The determination of the necessary number of samples does not just aim at obtaining and maintaining precise values, but also

Table I. Summary of the resulting sampling plan.

	Phase 1		*Phase 2*			
	Used	*Product **	*Decided*	*Calculated*	*Product **	
					Species	*Total*
No of stands	1		2			
No of species	1		4			
Basic density						
No of trees/stand	20			7		
Sample positions/tree	16		4			
		320			56	224
Fibre length						
No of trees/stand	20			5		
Sample positions/tree	16		4			
Fibres/position	50			18**		
		16 000			720	2 880
Fibre-wall thickness						
No of trees/stand	20			8		
Sample positions/tree	16		4			
Fibres/position	50			16**		
		16 000			1 024	4 096
Vessel number						
No of trees/stand	20			12		
Sample positions/tree	16		4			
Sample positions/slide	4		4			
		1 280			384	1 536
Vessel proportion						
No of trees/stand	20			4		
Sample positions/tree	16		4			
Sample positions/slide	4		4			
		1 280			128	512

* Product of the Used or the Decided and/or Calculated columns; ** See figures 3 and 4 under favourable case.

at using them for setting a compromise between the practical limitations and the precision required. Therefore, for optimal planning of the research, before beginning the main experiment, it is important to determine the necessary number of samples at all levels in the study. Complete information for planning would, however, demand a cost analysis, which is beyond the scope of this study.

The reduction of number of samples observed in our study, as compared to traditional studies in which more than 30 sample trees and more than 200 fibres per position were often included, is in agreement with the results reported by Burley *et al*

(1970) for *Eucalyptus,* and Lewark (1987) and Huber (1992) for *Fagus sylvatica.* The results from these studies, however, show differences in the recommended number of samples, especially for the number of fibres per position. For basic density the numbers are almost similar. The differences may be attributed to differences in genetic make-up of the trees studied, differences in the environmental conditions under which the trees grow and differences in the parameters introduced into the calculation.

The use of 3 different defined cases in calculating the necessary number of samples gives the researcher important additional information, which will enable him to make rational decisions by taking into consideration the range of variation between the 3 cases.

The reliability of estimations of whole tree mean values by measurements from one or few samples at the base of the stem has been proved by a number of researchers. This has been done, for instance, for fibre length by Ezell and Stewart (1978) for *Liquidambar styraciflua* and for basic density by Lewark (1987) for *Fagus sylvatica.* The results from our own correlations between values from the base of the tree and the mean of 16 positions for the tree in phase 1 are in agreement with the above values. These results justify the use of increment cores in phase 2 of our study as shown in the summarised sampling plan in table I. The use of few samples and short increment cores will result not only in minimum destruction to the standing trees, but also in substantial saving of time, manpower and other costs required to conduct such studies.

In order to conduct correlation and regression analyses, a higher number of sample trees may be needed than if only reliable average values are wanted. The use of a higher number of samples when single measurements do not cost much is an advantage because it gives a statistical safety. But if the costs are high, it is encouraged to take a certain risk. It is generally conceived that the use of more replications or more stands is more important than the use of a single stand and more samples. It should also be noted that a higher precision may be needed if the purpose of the sampling is to assess wood properties of individual trees to be used in seed orchards, breeding programmes or to establish patterns of variation.

One leading idea in revealing the development of the sampling design chosen was that this study may serve as a model for future wood property studies in Tanzania where the required large-scale studies can be conducted satisfactorily using samples at breast height. But local suitability trials must be performed if such studies are to be conducted on different species or the same species in different areas.

REFERENCES

Anon (1984) IBAS-Intractive image analysis system. *Kontron Bildanalyse GmbH,* 4, 1-18

Ahlback AJ (1986) Industrial Plantation in Tanzania: Facts, Problems, Challenges. Ministry of Land, Natural Resources and Tourism. Planning Section of the Forest and Beekeeping Division, 197 p

Burley J, Posner T, Waters P (1970) Sampling techniques for measurement of fibre length in *Eucalyptus* species. *Wood Sci Technol* 4, 240-245

Dinwoodie JM (1965) The relationship between fibre morphology and paper properties: a review of literature. *Tappi* 48, 440-447

Ezell AW, Stewart JL (1978) The use of single samples to predict average fibre length of entire sweetgum trees. *Tappi* 61, 121

Forest Biology Subcommittee 2 (1966) Needs for improvement in methods for small sample measurement of wood and fibre properties. *Tappi* 49, 87-91

Hapla F, Saborowski J (1984) Überlegungen zur Wahl des Stichprobenumfangs bei Untersuchungen der physikalischen und technologischen Holzeigenschaften. *Forstarchiv* 55, 135-138

Huber D (1992) Untersuchungen über die Variation der Faserlänge bei der Rotbuche (*Fagus sylvatica* L). Diplomarbeit, Universität Freiburg, 47 p

Kandeel ESA, Bandran OA, Tewfik SA (1977) Sampling for fibre length in small tropical harwood samples. *Wood Sci* 9, 140-143

Lewark S (1987) Untersuchungen an Buchenbeständen Nordwestdeutschlands über die Variation der Rohdichte. Schriften aus der Forstlichen Fakultät der Universität Göttingen und der Niedersächsischen Forstlichen Versuchsanstalt. Band 88. J.D. Sauerländer's Verlag Frankfurt am Main, 118 p

Lundgren B (1978) Soil conditions and nutrients cycling under natural and plantation forests in Tanzania highlands. Reports in Forest Ecology and Forest Soils, 31. Dept of Forest soils, Swedish Univ of Agric Sciences, Uppsalla, 68 p

Malimbwi RE (1982) Evaluation of the performance of Eucalyptus species and provenance trial established at Ruvu, Tanzania. BSc For Special Project, University of Dar-es-Salaam, Morogoro, 28 p

Mushi JA (1978) Growth of Eucalyptus species at Ruvu, Tanzania. Silviculture Research Note No 31 (New Series) Lushoto, Tanzania, 4 p

Tamolang FN, Wangaard FF (1961) Relationship between hardwood fibre characteristics and pulp-sheet properties. *Tappi* 44, 3, 201-216