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INVESTIGATIONS INTO HEARTWOOD FORMATION IN INTENSIVELY MANAGED TEAK PLANTATIONS

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Abstract

Teak wood is widely reputed for its natural durability due to the presence of characteristic heartwood. Heartwood formation during tree growth is therefore a dictating factor of teak timber value. The present study was designed to generate information as to whether fast growth itself will result in quicker formation of heartwood and whether intensive management practices and site conditions influence the yield of heartwood in short rotation plantations. The preliminary results, based on the limited available wood material from intensively managed plantations, indicate that heartwood formation begins at the age of even before 3 years in fast grown trees of managed plantations. Heartwood percentage increases considerably with age as seen from 3- to 5 year-old trees although wide variation exists between the trees and plantation locations. Compared to the forest plantation in Nilambur, 5-year-old trees in managed plantation showed relatively high proportion of heartwood.

Microscopic observations were also made on the histo-chemical changes occurring from sapwood to heartwood region to throw light on the secondary changes taking place during heartwood formation mainly to explore the possibility of controlling heartwood formation in trees of intensively managed plantations. The decrease in starch content in the inner sapwood parenchyma cells was coupled with the first appearance of phenolic globules near the cell walls. Disintegration of starch content was followed by the appearance of colourless plastids. Soon yellowish or reddish brown amorphous mass accumulated around these plastids in parenchyma cells. At later stages, smaller phenolic globules started enlarging in size by fusion and polymerisation resulting in bigger globules. With the increase in the size of the globules the nucleus got disintegrated. The extractives were most abundant near the heartwood boundary where all the parenchyma cells, vessels and fibres were filled with them.

As the present study remains incomplete due to mid-tenure termination of the project further studies are needed to know the histochemical changes and also to substantiate above preliminary findings.

Keywords: *Tectona grandis,* managed plantation, heartwood yield, age/site effect, histochemistry, extractive, tylose.

1. INTRODUCTION

Teak, which is currently being grown at a rotation of around 50-60 years in forest plantations, is proposed to be harvested at the age of 20 years in intensively managed plantations. The effects of management practices on heartwood formation are not known. In normal forestry conditions, heartwood formation begins at the age of 4 years. The important questions are whether fast growth itself will result in quicker formation of heartwood and whether intensive management practices and site conditions influence yield of heartwood in short rotation plantations.

Silvicultural treatments such as thinning, fertiliser application and weeding are known to increase heartwood percentage and wood density in eucalypts (Wilkins 1989). Further, treatment with chemicals such as ethylene/paraquat is known to induce artificial heartwood in other tree species (Nair and Shah 1983). Only a few studies have been conducted on the anatomical changes associated with heartwood formation in teak. Datta and Kumar (1987) studied the histochemical changes in the transition zone between sapwood heartwood regions. Recently Nobuchi et al. (1996) investigated some characteristics of heartwood formation.

In the current project it was envisaged to empirically study the correlations between heartwood formation and a number of environmental factors (Appendix I) based on observations made in plantations raised by Sterling Tree Magnum (STM) Pvt Ltd in various locations of the country. An attempt has also been made in the present study to examine the histochemical changes during the transition zone between sapwood and heartwood and the effects of age and site qualities upon heartwood formation. The specific objectives this study are:

- To determine the age at which heartwood formation begins in fast-growing teak
- To examine the correlation between heartwood formation and site factors (soil type, nutrient status, weather conditions, etc)
- To establish the relationship between high input management and heartwood quality and yield.

2. MATERIALS AND METHODS

The original plan was to collect wood samples from plantations of different ages (starting from second year after planting) and locations. The sample Performa prepared for this purpose is given in the Appendix I. As the project was abandoned because of non-availability of funds from the sponsoring agency, only a very preliminary observation could be made based on the limited available sample materials (only single tree per plantation) from managed plantations of STM as shown in the Table 1. Study material consisted of 3- year-old trees from intensively managed plantations of Gandharavakottai and Tanjavur (Tamilnadu) and Sangamavalsam (Andhra Pradesh) as well as 5-year-old trees from Ambasamudram (Tamilnadu) and forest plantation in Nilambur. The trees were collected in June 1997.

Table 1. Wood sample origin for estimation of heartwood proportion from trees of different ages and plantation locations

Location	Tree No.	Age (yr.)	Height (m)	DBH (cm)	Heart wood (%)
Andhra Pradesh					
Vizianagaram region	1	3.25	8.42	6.5	-
	2	3	9.08	6.7	10.9
Sangamvalsa	3	3.2	8.85	7.75	2.1
Tamilnadu					
Ambasamudram	1	5	7.0	8.1	16.3
	2	5	6.5	6.85	25.0
	3	5	6.0	6.4	-
Tanjavur	1	3	7.4	7.45	10.8
Gandharavakottai	2	3	9.0	7.55	-
	3	3	9.6	8.95	5.6
Kerala					
Nilambur	1	5	-	9.1	17.0
	2	5	-	8.5	13.0

- Denotes the absence of normal heart wood

For histochemical study, radial longitudinal sections (15 µm) from sapwood and heartwood regions were cut on a sliding, microtome for examination under microscope. The following reagents were used to reveal the histochemical aspects:

a) 1% Sudan IV for lipid droplets
b) Iodine (Potassium iodide solution) for starch
c) Phloroglucinol for phenolic compounds. (Note: These compounds could be seen even without staining. In permanent sections, they appear as dark reddish brown cells indicating the occurrence of phlobaphene resulting from the oxidation of tannins (Johanson, 1940)
d) Benedict's reagent for heartwood detection. Heartwood of older trees could be readily distinguished by its drier and darker appearance. In younger trees, staining the cut surface and testing with Benedict’s reagent could better delineate the heartwood-sapwood regions.

3. RESULTS AND DISCUSSION

3.1 Heartwood proportion in relation to age

The recorded data in Table 1 indicate that heartwood formation begins even before the age of 3 years in fast grown trees of managed plantations. It is evident that heartwood percentage increases considerably with age from 3 years to 5 years as seen from Tamilnadu and Andhra Pradesh plantation locations. Compared to the forest plantation of Nilambur, 5-year-old trees of managed plantation in Ambasamudram showed high proportion of heartwood. After the review of these preliminary observations, further sampling was planned from thinned material of different plantations to identify most suitable location for maximum heartwood volume and to analyse the determining factors. This could not be achieved due to abrupt termination of the project.

The age of the tree when the sapwood tissues change to heartwood varies widely between trees. Generally, heartwood begins to appear at 3 years of growth in teak although some of the 5-year-old and 3-year-old trees were without heartwood (Table 1). Therefore, it can be assumed that the transformation age may be between 3-5 years depending on growth rate. In older tree (above 8 years) the transformation to heartwood takes place when the sapwood width is about 1.5-2.5 cm and in younger trees at an age of less than 5 years, this takes place when the sapwood width is about 3-4.5 cm. Once the heartwood begins to form, there is a steady increase in its volume. According to Hillis (1987), there exists a close association between the age of the sapwood tissues and the formation of heartwood in a species and this age varies among different genera. For example, in *Cryptomeria japonica* it is 6-8 years, for *Robinia spp*. it is 3-4 years and for *Alstonia scholaris* it is over 100 years. In coppiced *Eucalyptus viminalis* the transformation age is between 3 and 4 years and in seed propagated trees it was at an age of less than 5 years.

3.2 Heartwood proportion in relation to site

In all the 4 sites, the heartwood was found to initiate formation after 2 years of growth . Tree-to- tree variation (due to environmental and genetic causes) is large in each site, one-third of the trees were without any heartwood. Trees from managed plantations produced paler heartwood than the heartwood of forest plantation. This observation agrees with the findings of Hillis (1987), for a closer relationship between heartwood colour and soil properties. The topography and other soil characteristics of Ambasamudram deserve special mention because the starch grains were found only in this region irrespective of the fact that all the trees were collected in the same growing season. Hillis (1987) drew a contradictory conclusion on the influence of site on heartwood formation. For example, in *Cryptomeria japonica*, the maximum rate of increase of heartwood diameter was attained with older trees in poorer sites while for *Pinus radiata* the heartwood area was higher in better sites.

3.3 Histochemical aspects

3.3.1 Starch

Starch grains were found only in the trees of Ambasamudram plantations. Both simple and compound starch grains were found . In the outermost sapwood zone, they were present both in the axial and ray parenchyma cells right from the cambial zone (Fig. 1). The grains decreased in number through the middle and inner sapwood regions where they confined themselves near the end walls of parenchyma cells which did not stain blue with iodine. Near the heartwood boundary they totally disappear and some colourless refractive bodies appear which later mix up with extractives. The younger sapwood ray cells contained large amount of starch grains with the amount decreasing towards older sapwood while lipid content increased simultaneously towards the inner sapwood and in the heartwood region as observed by Nobuchi et al. (1996). Datta and Kumar (1987) reported the same trend for starch but for lipid droplets it was different in the sense that they were absent in the heartwood region of the specimens (branches) observed by them.

3.3.2 Lipids

Lipids occurred as minute globules mainly in the axial and ray parenchyma cells right from the cambial region (Fig.2). The amount of lipids increased remarkably towards the middle and inner sapwood and into the heartwood. Near the heartwood boundary lipid droplets were frequent occurring in both parenchyma cells and fibres; smaller lipid globules fused with each other forming bigger globules and irregular bodies (Fig.3). Some ray cells showed a localised distribution of lipid bodies either in the centre of the cell or at one end of the cell.

3.3.3 Extractives

The decrease in starch content in the inner sapwood parenchyma cells was coupled with the first appearance of phenolic globules near the cell walls. Disintegration of starch content was followed by the appearance of colourless plastids. Soon yellowish or reddish brown amorphous mass accumulated around these plastids in parenchyma cells. At later stages, smaller phenolic globules enlarged in size by fusion and polymerisation resulting in bigger globules. Such globules later formed a network due to their irregular fusion (Fig.4). With the increase in the size of the globules the nucleus got disintegrated. The extractives were most abundant near the heartwood boundary where all the parenchyma cells, vessels and fibres were filled with extractives. The outer heartwood possessed black streaks also (Fig.5). Although the chemical nature of black streak is not known, Nobuchi et al. (1996) suggested that this material would be one of the organic substance biosynthesised during sapwood-heartwood transition. Extractives can be formed during various stages of secondary growth and are synthesised in situ (Hillis, 1977). Mostly, they are found in the heartwood only. The sapwood tissues of Ambasamudram trees contained extractives in the parenchyma cells

3.3.4 Tyloses

One of the important anatomical changes during heartwood formation is the occurrence of tyloses in the heartwood vessels. Tyloses made their appearance from the inner sapwood vessel towards heartwood (Figs.6 and 7) while they were absent in the outermost and middle sapwood tissues.
The transition from sapwood to heartwood was more abrupt and no visible transition zone was found.

3.3.5 Significance of histochemical changes in heartwood formation

The death of parenchyma cells, especially the ray parenchyma cells in inner sapwood is one of the most significant features occurring during heartwood formation. The decrease in the amount of starch towards the inner sapwood or transition zone from the outermost sapwood can be considered as one of the pre-requisites for heartwood formation and is supposed to be controlled by the age of the tree. According to Stewart (1966), the living cells are killed when the concentration of toxic substances like phenolics surpasses the lethal levels (as happening in outermost heartwood). Along with the decline in starch content towards the heartwood the increase in lipid content is interesting and the oily nature of teak wood can be attributed to the presence of large amount of lipid droplets as suggested by Nobuchi et al. (1996). The lipid distribution shows different patterns in different genera, for example, in *Melia azedarach* (Baqui et al.,1979) and in *Garuga pinnata* (Bhat & Patel, 1980), its amount decreases towards the heartwood while there is increase in *Tilia cordata*, *Betula verrucosa* and *Robinia pseudoacacia* (Holl & Poschenrieder, 1975) and in *Ougenia oojeinensis* (Bhat & patel, 1980). Therefore, it is assumed that lipid accumulation near the heartwood boundary need not be a pre-requisite for heartwood formation.

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FIGURE LEGEND

Plate 1

Cross sectional disc (from breast height) of 5-year-old tree showing the effect of Benedict's reagent for delineating the heartwood-sapwood regions (left half). Also note the droplets of phenolic globules in the inner sapwood.

Plate 2.

A. RLS from outer sapwood showing starch grains in ray parenchyma cells.

B. RLS from outer sapwood showing minute lipid droplets in axial parenchyma cell (arrows) and lipids accumulated around the colourless plastids (arrow head)

C. RLS from inner sapwood displaying accumulation of big lipid globules (arrows and irregular lipid bodies (arrow head) in axial parenchyma and fibres.

D. RLS from heartwood boundary showing extractives in fibres (arrows) and ray parenchyma cell (arrow head)

E. RLS in the outer heartwood showing black streaks in ray parenchyma cells.

F. RLS from heartwood. Note the tyloses filled vessel elements and extractives distributed cells.

G. RLS from heartwood. A vessel element Note the oil filled tyloses (arrows) and distribution of extractives on the surface of tylose membrane (arrowhead).

Plate 1

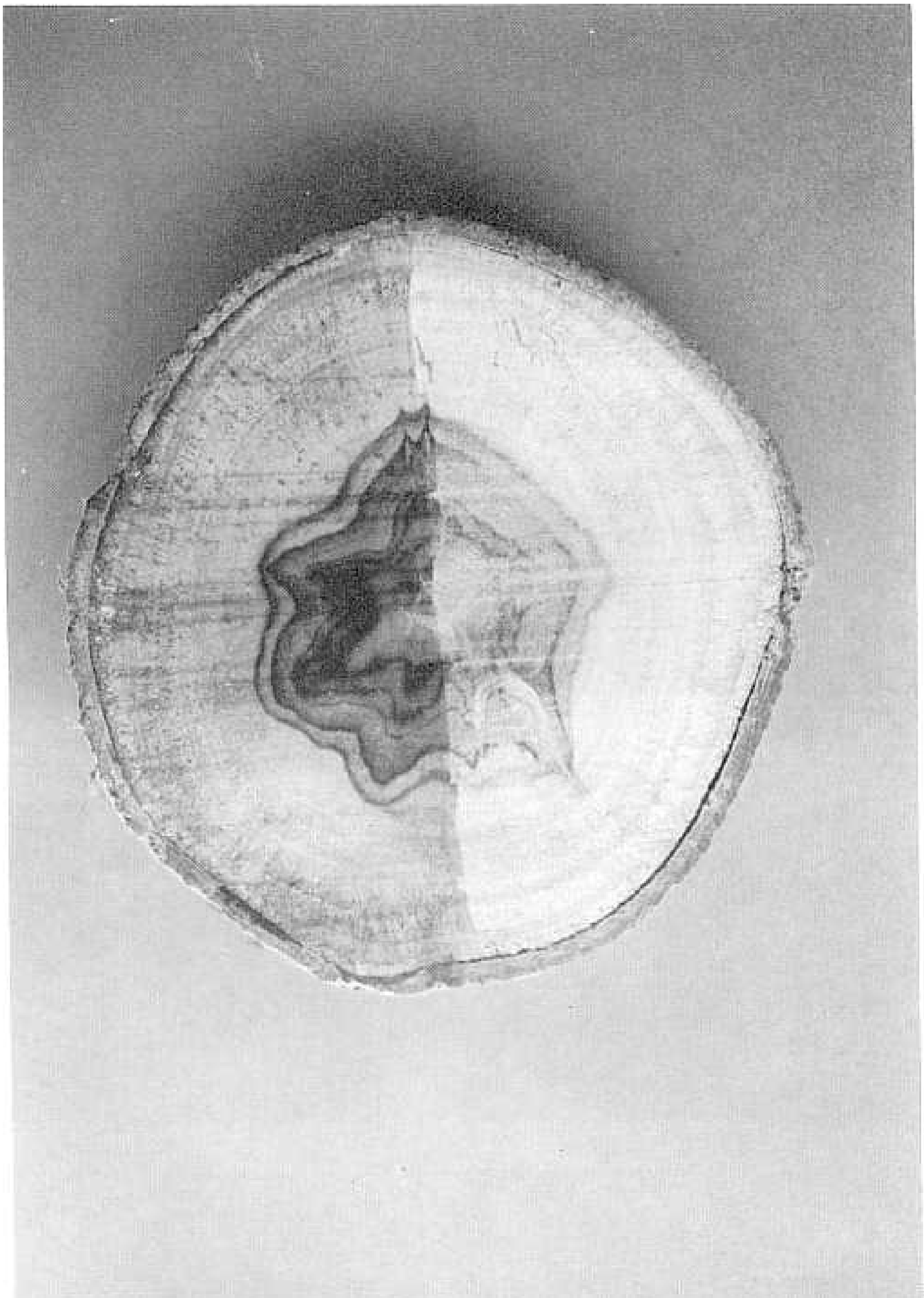
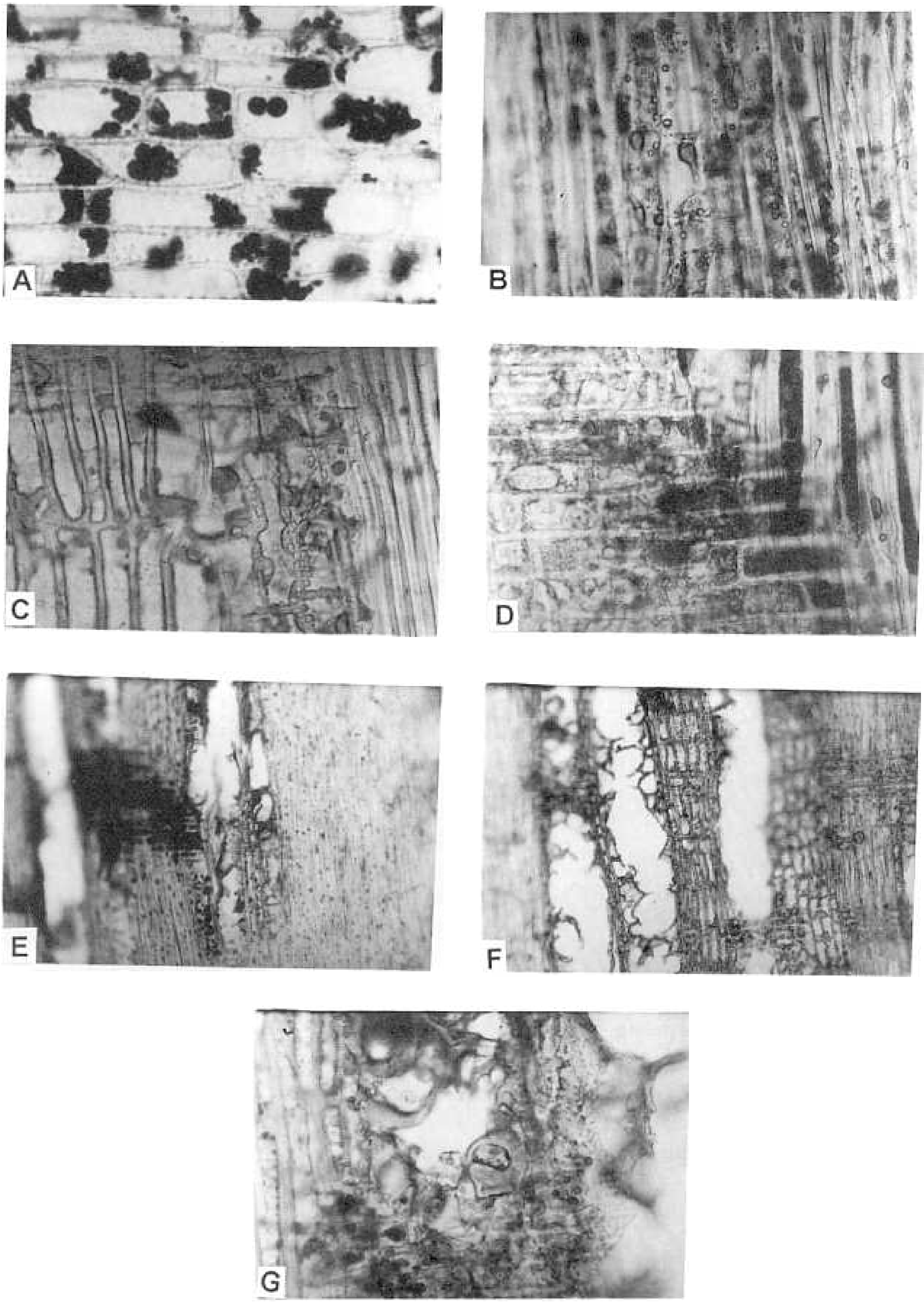


Plate 2



Appendix I:

Performa for Field Notes for Collection of Timber Samples

Name of collector: ....

1. Timber identity
   (a) Species ....
   (b) Seed origin/ provenance ....
2. Location
   (a) State/District/Division/Range ....
   (b) Sketch map giving approximate scale of the area indicating the location of the selected trees by circled numbers 1,2,3, etc., corresponding to the numbers given on the trees. The number of particular consignment and forest and geographical features should also be indicated. Block No., and Compartment No. May also be indicated. **North direction should be indicated by an arrow in the disc/billet**
   (c) Approximate distance and direction of any nearby perennial/seasonal rivers or nullahs (give names) ....

   (d) Depth of water -table (well) ....
   (e) Geological formation and rock..
   (f) Altitude ....
   (g) Slope : Shape (Convex or concave) ....
   Length ....
   Gradient (% or degree) ....
   (h) Soil mass depth ....
   (i) Fauna (earthworms, white ants, rodents, etc.) ....

5. Site conditions
   (a) Site quality ....
   (b) History of the site (management practices, fire, grazing, felling, etc.)............ ....
6. Land form (Physiography) : Hill top/hill slope/plateau: or High terrace/alluvial plain/valley bottom ....

7. (a) Drainage external (surface) : Waterlogged / very slow / slow / medium / rapid / excessive

   (b) Internal (soil mass) : None/very slow/ slow/ medium/rapid/excessive

8 Soil Type : Red dessert/lateritic saline alkaline/black marshy/ alluvial/brown forest/ hill
9. Parent material : Formed *in situ* /transported/organic
10. Surface : Loose/Friable/Slight crusting/compact

11. (a) Moisture top soil : Wet/moist/moderately dry/dry/very dry
(b) Subsoil : Wet/moist/moderately dry/dry/very dry
12. Plant litter : Light/moderate/heavy
13. Organic matter : Little/average/high/excessive

14. Climatic factors

Mean annual temperature (^{o} C)			Mean annual rain fall (mm)			Humidity
Max.	Min.	Mean	Total	Summer	Winter	

15. Information on individual trees
(a) Distinguishing marks on : the small end, at breast height and disc cut from stump
(b) Age of the tree
(c) Total height
(d) GBH (over bark), at 1.37 m from ground level
(e) Date of felling
(f) Height of the stump
(g) Date of converting into logs for storage
(h) How are ends coated
(i) Girth of logs in cm at: Large end ....
Small end ....
16. No. And date of R?R, or dispatch voucher under which the material has been despatched. Also please give references of covering letter, if any ....
17. Signature of collector and date
18 Name and designation of dispatcher & signature with date ....

NOTE: All items are to be filled in but such items as do not apply may be crossed out. All information should be as complete as possible.