

THE ANATOMY, MORPHOLOGY, AND PHYSICAL PROPERTIES OF
THE MATURE STEM OF THE COCONUT PALM (*)

RP 92

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Summary

Anatomical and morphological features of the woody tissues of Cocos nucifera L. is briefly reviewed in Part I.

In Part II experimental data on basic physical properties through three radially displaced axes in the stem are provided and discussed. Variations through the three axes in basic density and air-dry density, vascular bundles (steles), and moisture content at the time of testing were examined; included also was a brief look at volumetric shrinkage.

Basic density appeared to decrease linearly with an increase in stem height and increased logarithmically from centre to cortex at any height of stem.

Number of steles per square inch increased substantially with stem height accompanied by a marked decrease progressively from cortex to centre.

Moisture content approximated the theoretical maximum and increased considerably with stem height and from cortex to centre.

Shrinkage for the peripheral zone was almost the same throughout in the stem. Specimens from intermediate and core zones showed high incidence of collapse.

On COCONUT STEM UTILISATION SEMINAR held on TONGA,
25-29 OCTOBER 1976, p. 65-102. Ministry of Foreign
Affairs, Wellington, New Zealand, 1977.

A large number of coconut palms, Cocos nucifera L. in Fiji are well past their peak of productivity. Together with those that will achieve this condition by 1980, these overmature* palms are estimated at five million, representing about 42 percent of the acreage under cultivation. Despite Government efforts to encourage their removal and to promote replanting through subsidies and other financial inducements, there appear to be several formidable obstacles for the copra industry to overcome.

But if uses can be found - and in particular, large-scale industrial uses that would consume vast quantities of the woody stems - this enormous fibre resource could then make a direct contribution to Fiji economy and, at the same time, provide an opening wedge into the problem of revitalising the copra industry. What has been said of Fiji may well apply as well to other copra-producing nations of the South Pacific.

Fundamental to any utilisation programme on the over-mature stem, however, is an understanding of its anatomy, morphology and basic physical properties.

In this connection, the Fiji Forestry Department, has for a number of years been monitoring the work on coconut stem utilisation at other research organisations. More recently, the Department has embarked on a Coconut Timber Utilisation Programme, which has included among other areas of research, a limited study of the physical properties of the stem conducted on a small sampling of local material.

* for the purpose of this paper, "overmature" is defined as palms 60 years of age and over. However, copra productivity in relation to the age of a palm may vary from locality to locality; in certain areas of Fiji palms 70 years and over may still provide an economic return.

This paper provides, in Part I. a digest of certain descriptive information abstracted from the literature on the anatomy and morphology of the woody tissue of Cocos nucifera L. and, in Part II, offers the results of the Department's study on its physical properties, with pertinent references to the work of other researchers on the subject.

PART I

TAXONOMIC FEATURES OF C. NUCIFERA L.

Modern interpretation of the taxonomy of Cocos leaves only C. nucifera L. in this genus. Together with several other genera, Tomlinson, (1961)* places Cocos among the Cocoid palms, a sub-division of the sub-family Coccoideae. Although Cocos nucifera is monotypic, a number of varieties are recognised. Fremond et al, (1966) separate allogamous varieties typified by the term "Tall" coconut, which reproduce by plant-to-plant cross-fertilisation, from the autogamous varieties, often referred to by the term "Dwarf", which generally show vegetative structures of reduced size, compared with the "Tall" varieties. Fremond et al list nine allogamous varieties; mention of "Fiji Tall" is omitted. "Fiji Tall" is the common tall variety grown throughout the copra-producing areas of Fiji. Whilst varieties within the "Tall" group may be classified by locality, size, number, and colour of the nuts, the question of whether these varietal differences are reflected in the quality of the woody tissue of the stem is as yet unanswered.

Botanical and Anatomical Features of the Mature Stem

*The early development of the stem involves a succession of short erect internodes from which arise numerous adventitious roots. When the full width of the stem has been achieved, succeeding internodes become more elongated and an erect trunk becomes

* Quotations in this and the section on botanical features are from Tomlinson, (1961) except as otherwise noted.

evident." According to McPaul (1964), this occurs "when the plant is four to five years old; normally the stem would grow erect, but in the search for the maximum of sunlight, it may slant in the best direction", giving the stem a reclining posture. "Prevailing winds and hurricanes also influence the growth direction of palms. A palm may sometimes have a narrower portion or "waist" in its trunk; this is due to adverse growing conditions, such as fire or drought at that particular stage of its development" (McPaul).

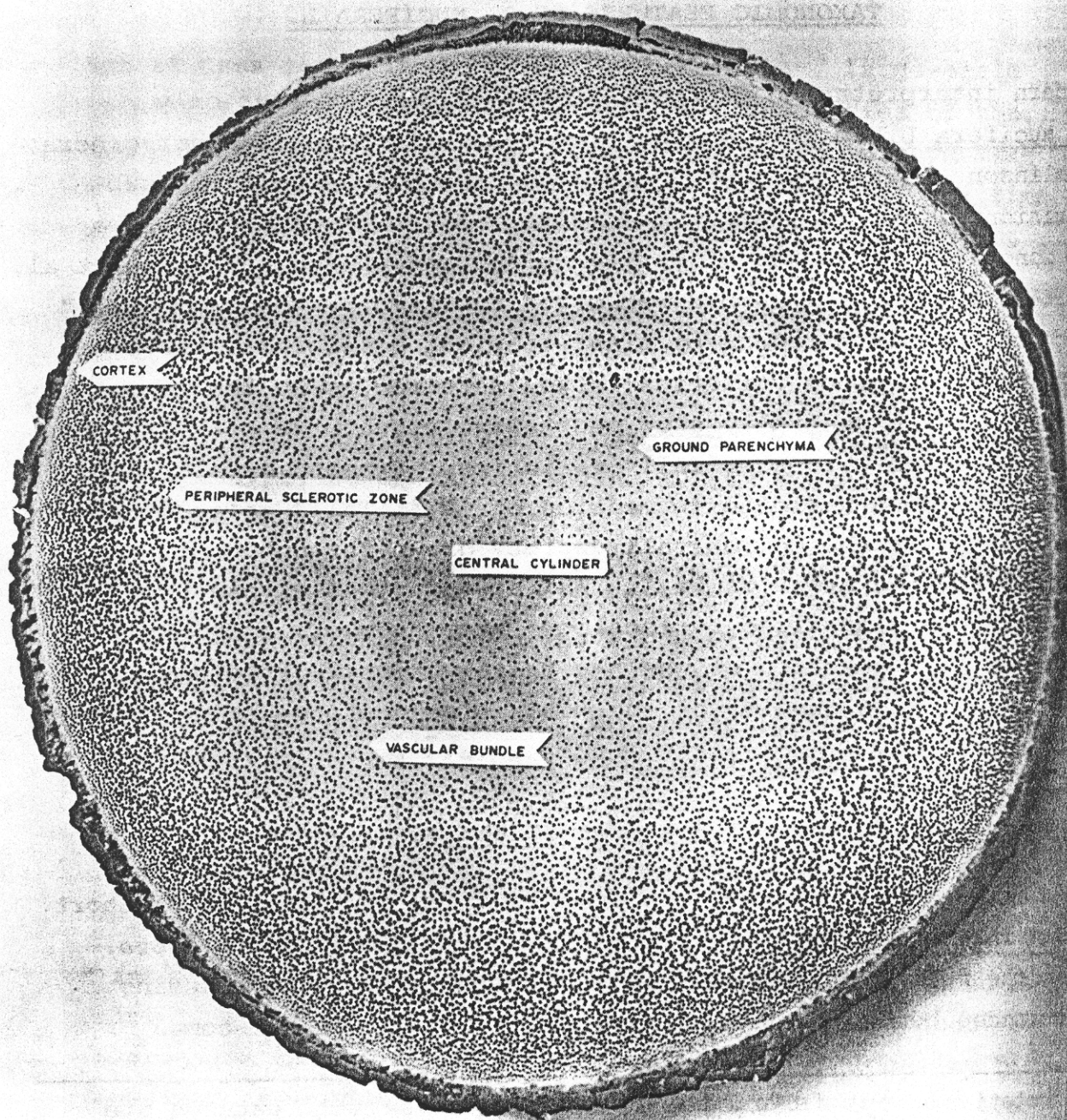


Fig. 1: Transverse section of coconut palm stem ($X\frac{1}{2}$)

Morphologically, the mature coconut stem consists of a wide, unbranched, central cylinder surrounded by a narrow cortex, shown in transverse section in Fig. 1, and in longitudinal section, Fig. 2 (after Cousins and Meylan), all derived from one minute terminal growing point situated at the top of the stem. "Apart from the specialized superficial layers, this cortex is largely made up of unspecialized ground parenchyma" containing "numerous small longitudinal fibrous strands. Apart from the large leaf traces which extend across the cortex from each leaf-base into the central cylinder, cortical vascular bundles are always few and small".



Fig. 2: Longitudinal section of coconut palm stem (X2, after Cousins and Meylan)

Measurements of cortex abstracted from Walford (1974) indicate that within approximately the first 50 feet of the stem, the average thickness is 0.39 in. (9.9 mm) with some thickening toward the bottom 0.45 in. (11.4 mm) and top, 0.44 in. (11.2 mm).

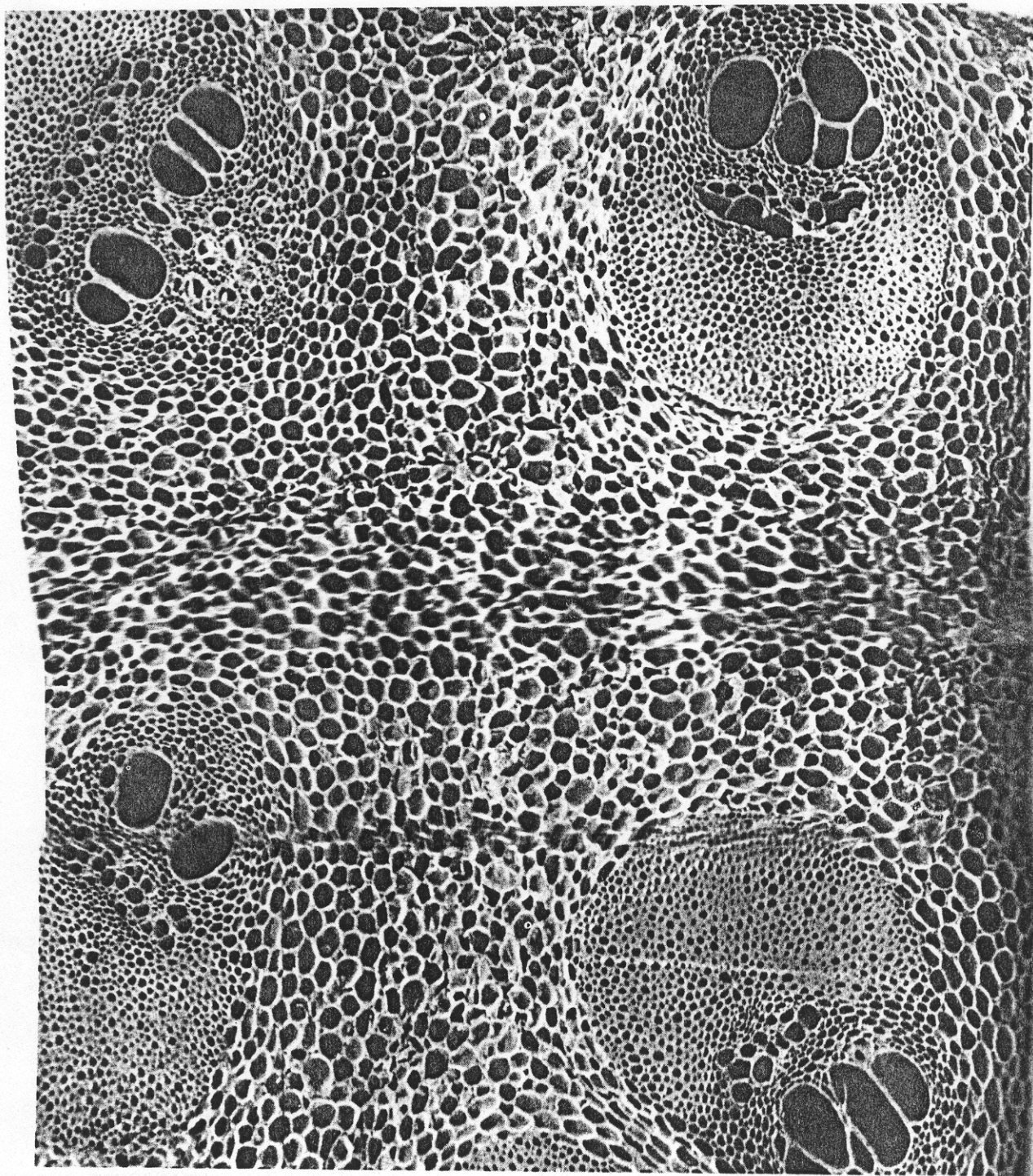


Fig. 3: Transverse section from central region of stem (X80, after Cousins and Meylan)

"The central cylinder is abruptly demarcated from the cortex by a wide peripheral sclerotic zone made up of congested vascular bundles separated from each other by narrow layers of parenchyma. Since each vascular bundle has a massive radially-extended fibrous sheath external to the phloem and the ground parenchyma becomes sclerotic, this zone forms the main mechanical support of the palm-stem." In the lower portion of mature coconut stems,

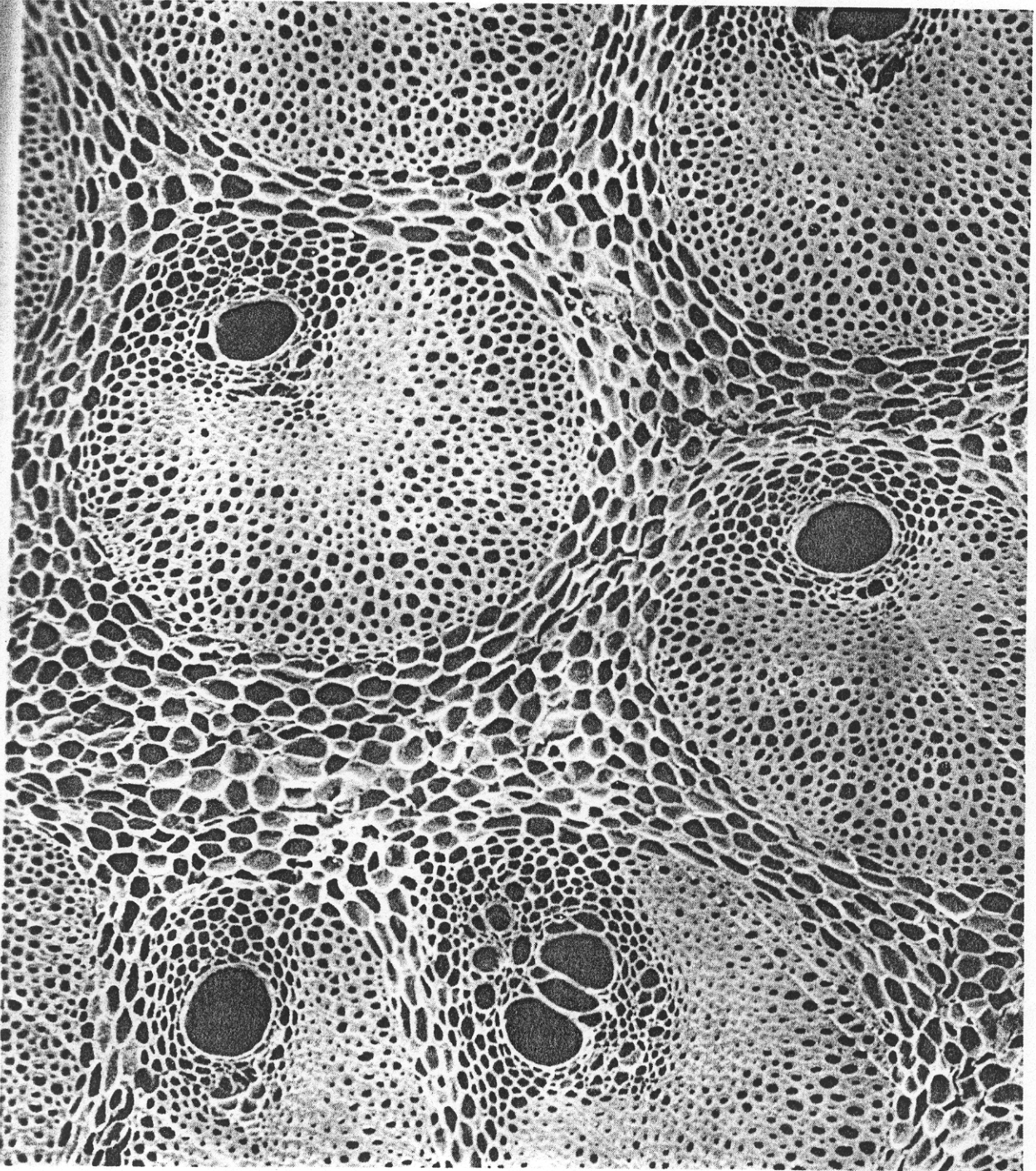


Fig. 4: Transverse section near outside of stem (X120, after Cousins and Meylan)

this zone is generally very hard, heavy, dark brown to reddish in colour, and may be three to four inches wide. Although secondary growth occurs in the ground parenchyma of the outer part of this zone in other palms, no such thickening occurs in C. nucifera L. Following McPaul's observation on "waisting", variations in stem diameter may be attributed primarily to varying ecological conditions during the growth of the stem.

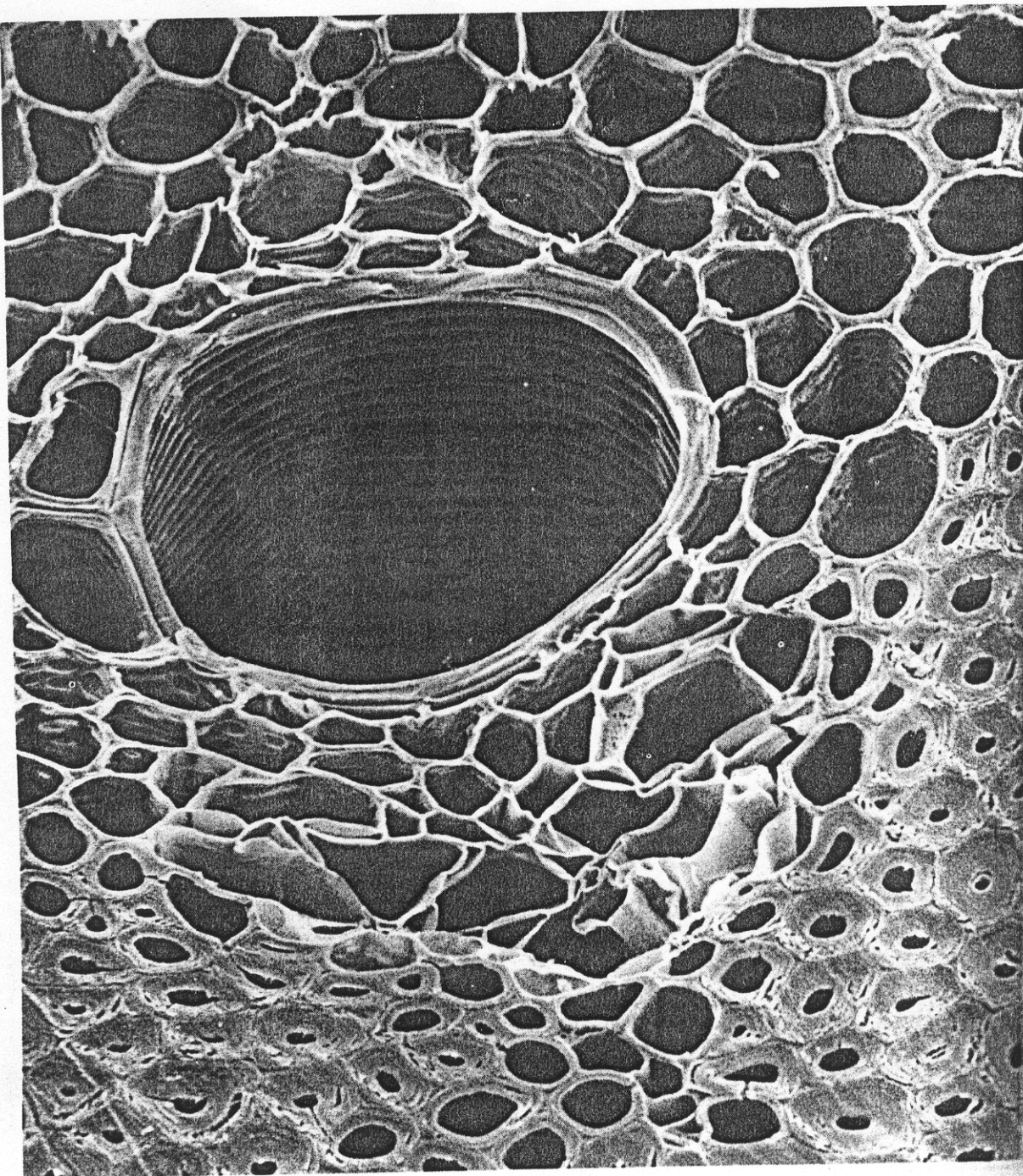


Fig. 5: Central region of a stele showing a vessel, axial parenchyma, phloem, and thick walled "collenchyma" fibres (X720, after Cousins and Meylan)

The inner part of the central cylinder contains widely scattered vascular bundles, Fig. 3 (after Cousins and Meylan) and there is a gradual transition from the concentration of bundles in the peripheral zone, Fig. 4 (after Cousins and Meylan) to this less dense tissue... The structure and distribution of the vascular bundles as seen in transverse section of the palm-trunk is related to their course in the stem before they exit at the nodes as leaf traces... Since the structure of each bundle varies considerably

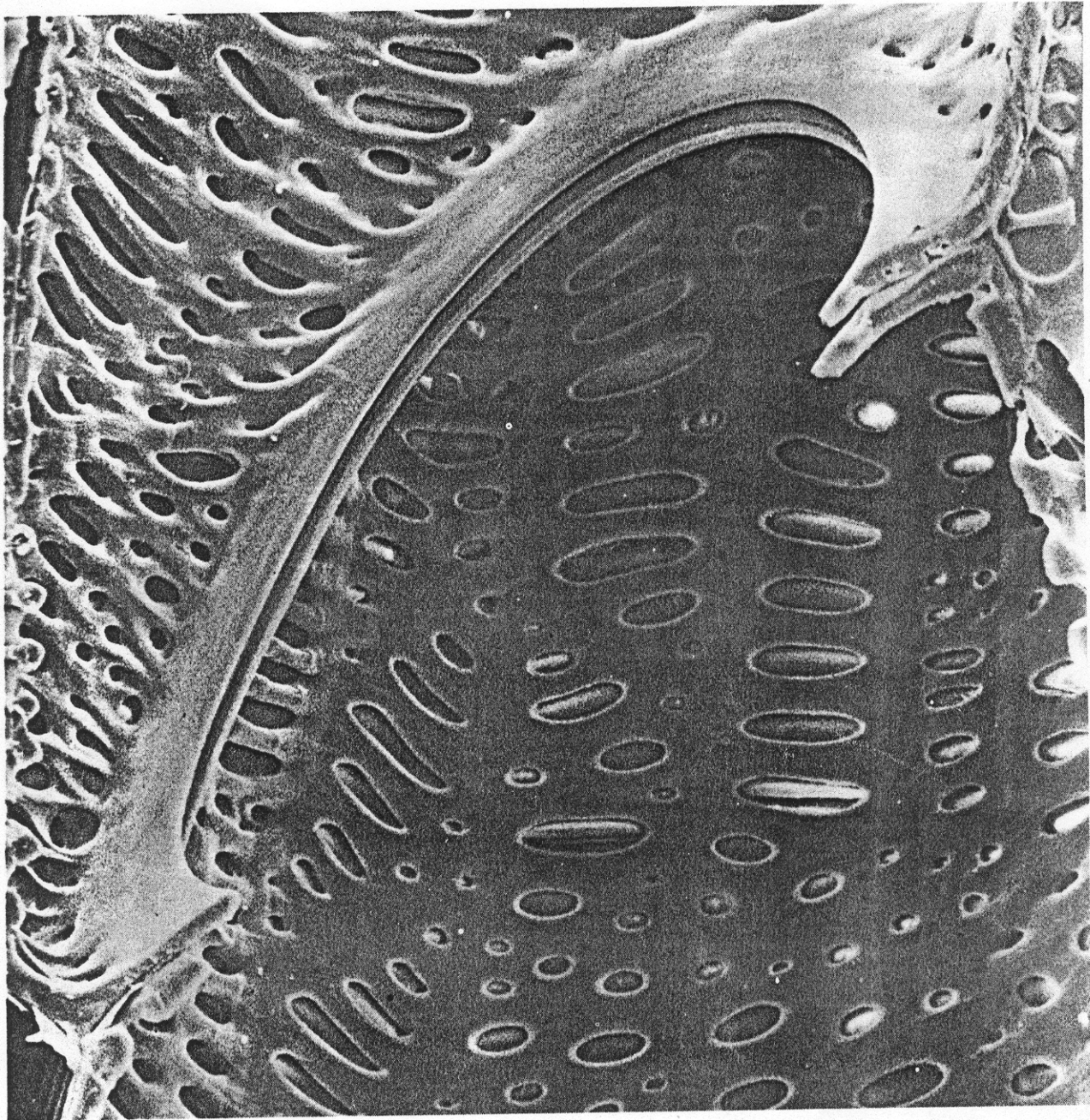


Fig. 6: Longitudinal section of a vessel showing simple perforation plate and heavily pitted walls (X1100, after Cousins and Meylan)

throughout its length, and since a single section includes parts of different bundles at all possible levels, the structure of the vascular bundles seen in transverse and longitudinal section of a single stem appears to vary considerably... External to the phloem, each bundle has a fibrous sheath which is always less developed than the peripheral bundles. The xylem is always sheathed by

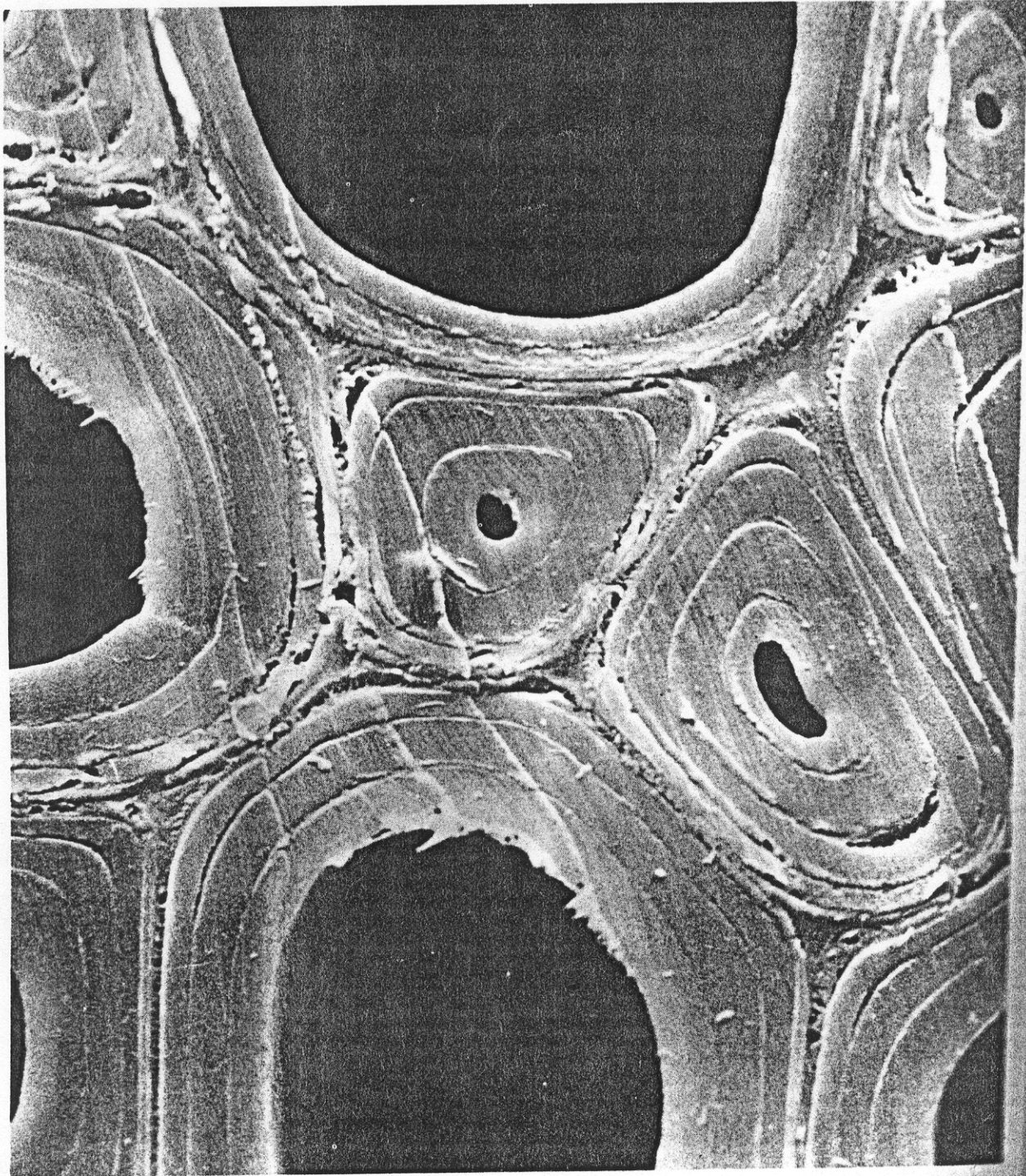


Fig. 7: Thick walled fibres showing layered structure (X5300, after Cousins and Meylan)

parenchyma. The phloem is in a single strand... The xylem usually contains two wide metaxylem vessels." Cousins and Meylan, Fig. 3, however, show clusters of several vessels in vascular bundles of the central region of the stem.

At this point it may be well to note that Tomlinson in his introductory section on the general anatomy of Cocoid palms,

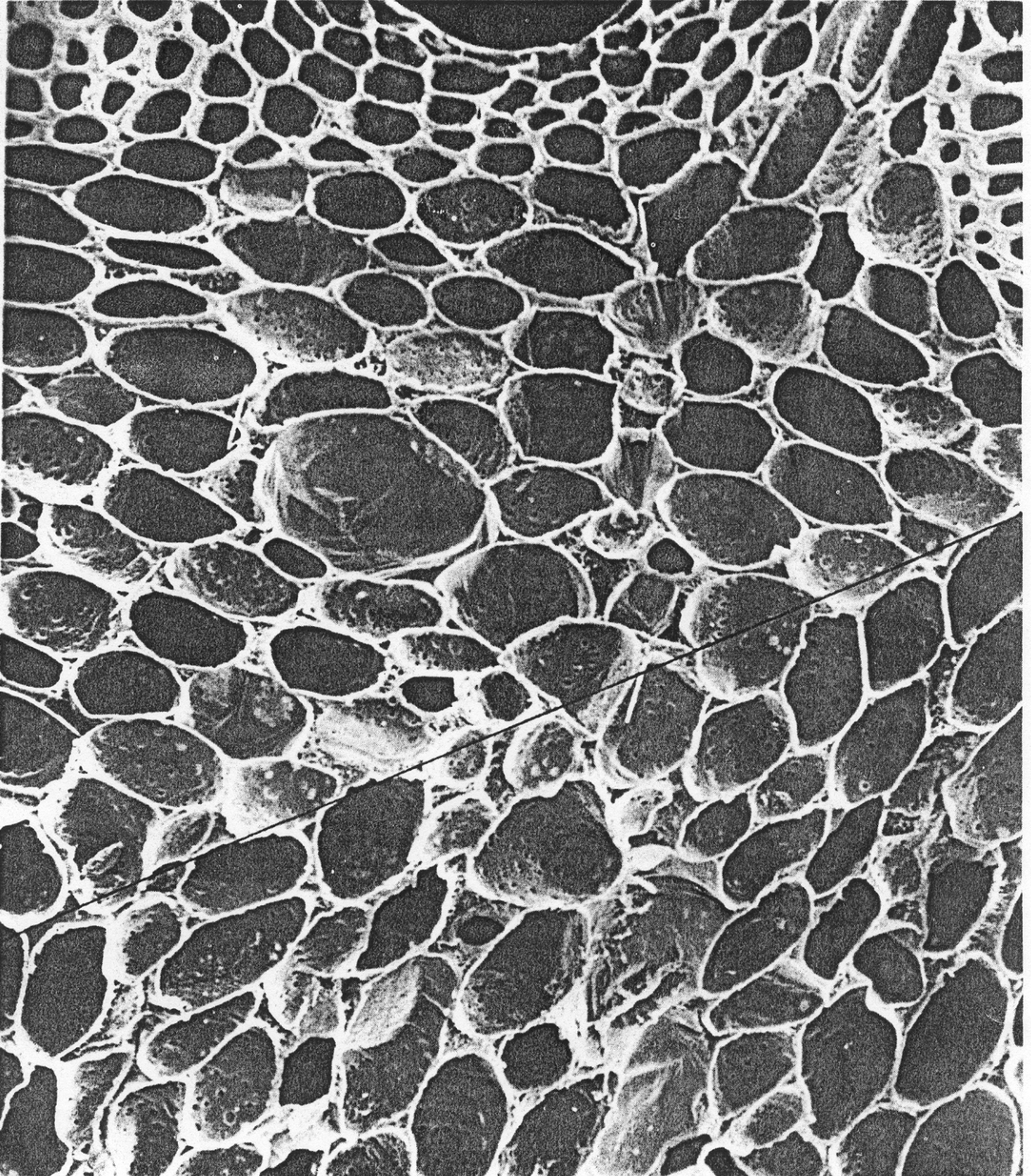


Fig. 8: Parenchyma ground tissues exposed by transverse and longitudinal cuts (X500, after Cousins and Meylan)

describes the central cylinder as having a well-developed peripheral zone of congested bundles with massive fibrous phloem sheaths, becoming very sclerotic in mature stems. His use of the word "sclerotic" would appear to imply "sclerenchyma", the term used by Kloot (1952). "The sclerenchyma fibres associated with the steles had relatively thin walls and large lumina at the centre of the section, whilst at the periphery their walls were very thick and the lumina extremely small." Cousins and Meylan, however, report: "Embedded in the soft ground tissue, are the vascular

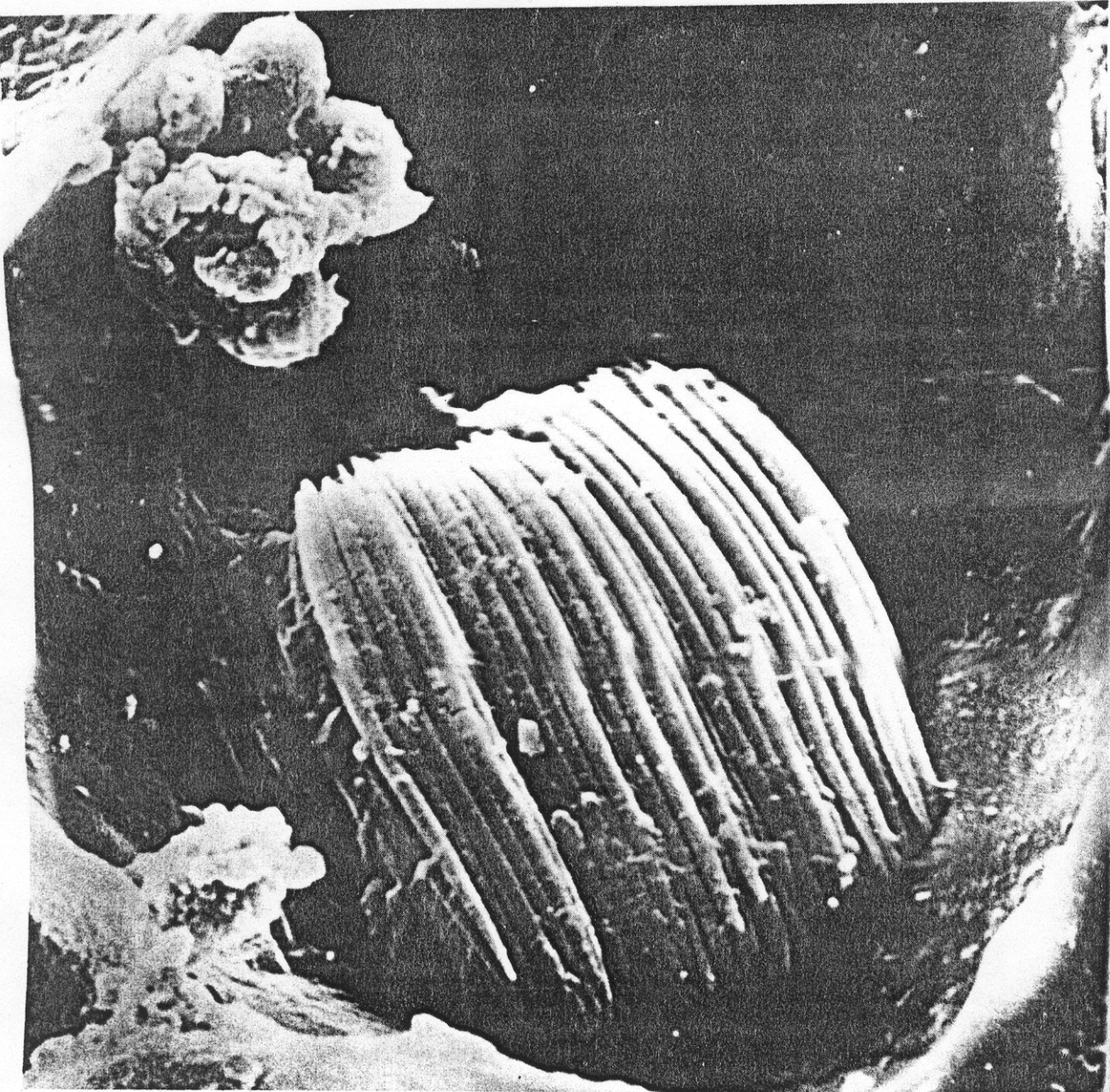


Fig. 9: A raphide bundle (calcium oxalate crystals) in a parenchyma cell (X2000 after Cousins and Meylan)

strands or steles which consist of one or more vessels associated with axial parenchyma, phloem and thick-walled fibres..., the latter making up the main mass of the bundle". In their Fig. 10 (Fig. 5 here) they refer to these thick-walled fibres as collenchyma. Cousins and Meylan further report that the vessels, "are quite long with the side walls internally covered in pits and have either simple or reticulate oblique perforation plates which have prominent over-arching borders", Figs. 5 and 6 (after Cousins and Meylan). "The thick-walled fibres, their "collenchyma", are seen to have a multilayered structure, the number of layers ranging between one and four, Fig. 7 (after Cousins and Meylan). No investigation was made into the microfibrillar structure within these layers, "though X-ray diffraction diagrams indicate that the main direction of the alignment must be close to that of the fibre axis".

"The ground tissue is parenchymatous and includes frequent scattered fibrous strands", Fig. 8 (after Cousins and Meylan).

"Although no single vascular bundle is continuous from root to leaf, vascular continuity is maintained throughout the length of the stem by anastomoses either between bundles from leaves inserted at successively higher levels; anastomoses either between the middle parts of different tissue in the central cylinder, or between the lowest extremities of one bundle and the upper part of another in the peripheral zone. The transpiration current is made complete because root-traces are inserted on the vascular bundles at the periphery of the stem base." (For a detailed description of the course of the vascular bundles, see pages 17 and 18 in Tomlinson.)

Stemata, defined as small almost isodiametric silica-cells are abundant in the stem, mostly in discontinuous files. These specialized cells contain as inclusions silica-bodies which are more or less spherical, each enveloped by the thickened basal wall of the silica-cell.

Calcium oxalate crystals reported by Cousins and Meylan, Fig. 9, are not recorded as present in Cocos by Tomlinson although he recognises their appearance in the stems of other palms where

they occur in the form of raphide clusters in distinct raphide-sacs. Each raphide-sac contains a single cylindrical cluster of needle crystals which is embedded in densely staining mucilagenous material.

Vessels in the stem according to Tomlinson, range from 1,160 to 1,630 μ in length and 170-200 μ in width with few thickening bars, Fig. 5. Sieve tubes in the stem range from 50-60 μ in width with slightly oblique sieve plates.

PART II

The Department's study on physical properties examined, essentially:

- (a) Variations in basic and air-dry density through three radially-displaced longitudinal axes in the stem.
- (b) Dispersement of the vascular bundles (steles) with height through the above axes.
- (c) Distribution of moisture in the stem near to the time of felling, through the above axes,

and included a brief look at shrinkage, as manifested through the longitudinal axis under the cortex (i.e. the peripheral high density schlerotic zone).

From the data as derived, profiles of the physical properties were ascertained and equations, where appropriate, for expressing significant relationships between variables were computed and compared with like data elsewhere reported.

Collection of Material and Field Data

The material used in this study of physical properties consisted of five whole coconut palm stems selected at random from a collection of 71 "Fiji Tall" palms felled on Vahua Levu for a sawmill conversion study by the Utilisation Division of the Forestry Department.

Upon felling, the stems were measured for height to the first frond; measurements of stump length and circumference around the base and top of the stump were also taken. From the butt end, one or two 20 ft. logs were docked from each stem.

Measurements of circumference over-bark at mid-point and length were taken for each log, and for the upper residual portion of the stem, which was not collected. Severely bowed sections were culled out where they occurred but their measurements were also recorded to complete the data for further stem volume computations.

For the five palms used in this study, however, the entire stem was collected.

The logs were treated with a liberal brushing of 2.5 percent sodium penta-chlorophenate on their ends and end-sealed with a generous coating of a commercially available contact adhesive.

On arrival at the Utilisation Station, the 20-foot logs were resawn into nominal 10-foot logs. These logs were weighed prior to conversion with a heavy-duty tractor spring calibrated to the nearest 0.1 inch. With this system, weight classes (in pounds) for "green" logs at 10-foot intervals were established.

Test Procedure

Each of the five test palms was demarcated into 3-foot (914 mm) increments from the ground line to the top end of the stem, taking into account the heights of the uncollected stumps.

At each point of demarcation, the logs were cross-cut and $\frac{3}{4}$ inch discs were resawn as shown in Fig. 10 to produce the 1 in. x 1 in. (cross-section) x 2 in. (along the grain) (2.5 x 2.5 x 50 mm) test specimens. Sample preparation covered a period of approximately 10 workdays during which time the material at the intermediate stages of preparation was sealed and stored in plastic bags.

The above sampling procedure allowed for data to be traced through three discrete longitudinal axes of the stem in uniform

increments of stem height; one axis passing through the peripheral sclerotic zone immediately under the cortex (Axis A); a second through an axis at 50 percent of the radius of the stem (Axis B); and a third through its exact centre (Axis C).

Test specimens were also prepared from the intermediate material between each of the three axes where sufficient material remained after sawing to permit this. No specimens were taken from material less than one-half inch in the radial dimension. Intermediate test material was available up to approximately 40-feet (12 m) of the stem height at which point the stem radius became too narrow for further sampling. By employing a weighted average technique, these additional test specimens, together with those from the three major axes were used to obtain weighted averages across the disc for density at each height interval. A slight modification of this method was used to estimate the total number of steles in a cross-section at 13, 25, 50 and 90 percent increments of stem height.

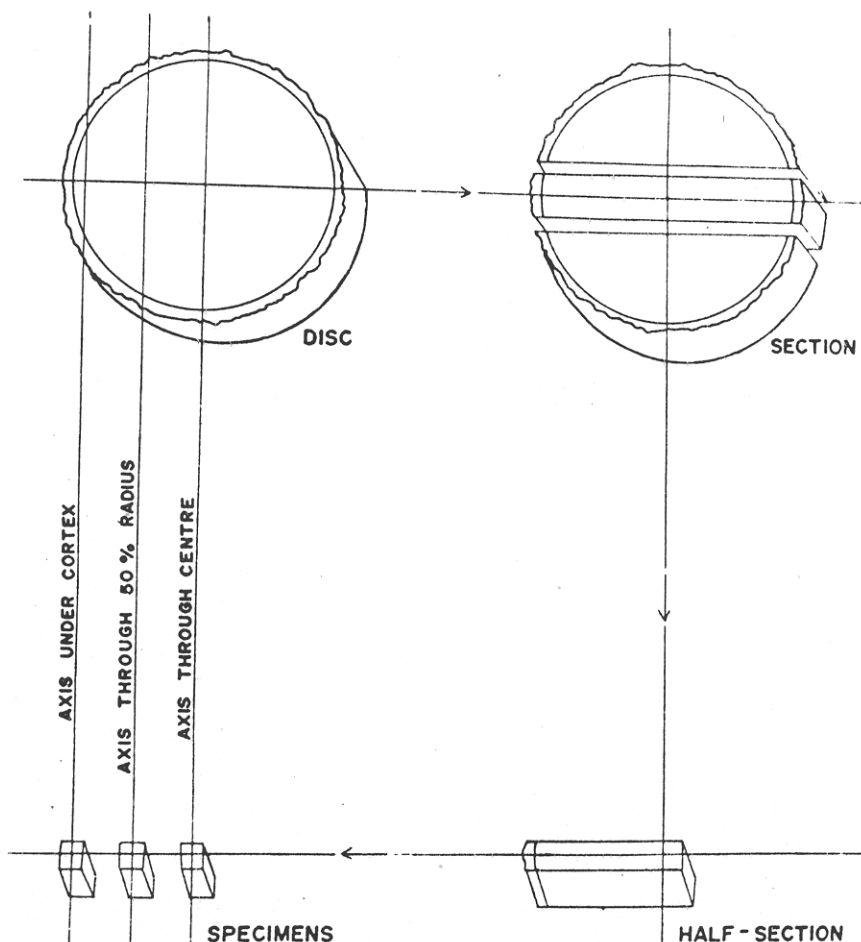


FIG. 10. SPECIMEN PREPARATION

Immediately after sawing out test specimens from the half-section, initial weights of the specimens were taken to the nearest 0.1 gm. (estimated to 0.01 gm); the specimens were then water-stored until their initial volumes could be determined and counts of the steles ascertained. When these determinations were completed, oven-dry weights and volumes were obtained from which values for basic specific gravity and density, air-dry density, green density, percent moisture content and percent volumetric shrinkage were ultimately computed.

The methods of test followed standard internationally accepted practices, using associated formulae for computations. Steles were counted by means of a one square inch clear plastic grid, subdivided into one-quarter inch units, which was superimposed over the transverse section of the test specimen and viewed through 4x magnification.

Individual stem volumes were computed by summing up the roundwood volume of the logs constituting the stem, including that residual portion not collected, and adding to this total an approximation of the stump volume. Stump volume was estimated by assuming the stump to be the frustrum of a right circular cone.

All data for the basic physical properties were accumulated and arranged for direct access to key-punch entry and computed by electronic data processing techniques.

Results

Field data and results of the experimental work on the basic physical properties of the coconut palm of Fiji are shown in the respective tables and figures.

Field data: A statistical test indicated no significant difference between the palms from each site. The average palm stem height was 69.4 feet, s.d. = ± 7.90 , (2.1 m) and the average stem volume was 42.8 cubic feet, s.d. = 1.95, (1.2 m³). Information on log weight and green density at each 10-foot plateau is shown in Table 1.

TABLE 1. Log Weight and Green Density

<u>10-Foot Plateau</u>	<u>No. of Logs</u>	<u>Average Roundwood Volume (O.B.) Cu.Ft.</u>	<u>Weight, Pounds</u>		<u>Green Density Pounds/Cubic Foot</u>	
			<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean</u>	<u>Standard Deviation</u>
First	65	8.1	491	113.4	60.8	4.21
Second	64	6.9	378	79.1	54.7	4.50
Third	58	6.4	345	62.9	53.8	4.92
Fourth	56	5.4	272	49.0	50.0	3.61
Average	(243)*	6.7	376	113.8	54.9	5.69

* Total number of logs

Experimental Data: Tests for physical properties produced the following results:

Data for stem height, basic specific gravity, steles per square inch, moisture content, and volumetric shrinkage (only for Axis A) were paired for each of the three above-mentioned test axes, and examined statistically to determine if a significant relationship could be demonstrated for each set of paired parameters. Correlation coefficients of various pairings can be seen in Table 2.

TABLE 2. Correlation Coefficients of Various Paired Parameters

Physical Properties	Axis	Correlation Coefficient
Basic Specific Gravity vs Stem Height	A	-0.7270
	B	-0.7086
	C	-0.7369
Steles Per Sq. In. vs Stem Height	A	0.9260
	B	0.9099
	C	0.8070
Moisture Content vs Stem Height	A	0.6415
	B	0.6471
	C	0.6748
Shrinkage vs Stem Height	A	0.0765
Steles Per Sq. In. vs Basic Specific Gravity	A	-0.5978
	B	-0.4816
	C	-0.4900
Log Moisture Content vs Basic Specific Gravity	A	-0.9790
	B	-0.9552
	C	-0.9741
Shrinkage vs Basic Specific Gravity	A	-0.1191
Moisture Content vs Steles Per Sq. In.	A	0.5506
	B	0.4019
	C	0.3878
Shrinkage vs Steles Per Sq. In.	A	-0.0726

Basic specific gravity, steles per square inch, and moisture content showed significant correlation with stem height for each axis.

Steles per square inch did not correlate as well with basic specific gravity.

Moisture content (plotted as its log) vs. basic specific gravity showed very high correlation for each axis, indicating a high probability that the lumina of the cells throughout the central cylinder were near to complete saturation with free water. This observation was tested against the theoretical maximum moisture content the wood could be expected to hold in relation to its

specific gravity. The theoretical curve is shown in Fig. 15.

Shrinkage for Axis A showed extremely poor correlation with stem height, basic specific gravity, and steles per square inch and, therefore, values for these parameters were not plotted. Due to a high incidence of severe collapse experienced with a large number of specimens from Axis C, shrinkage values for this axis were voided.

Although severe collapse was not as evident in specimens from Axis B, the moderately high shrinkage values of this axis were suspect of incipient collapse; consequently, data are not reported for this axis as well.

Correlation coefficients for moisture content vs. steles per square inch for the three axes were considered too low to warrant plotting.

From the empirically-derived basic specific gravity values, basic, air-dry and green densities in lb/cu.ft were computed for each 3-foot increment of stem height through each test axis. These are listed in Table 3A in Imperial units. Each entry, including those for stem diameter (over-bark), is the average result of the number of stems from which specimens were available.

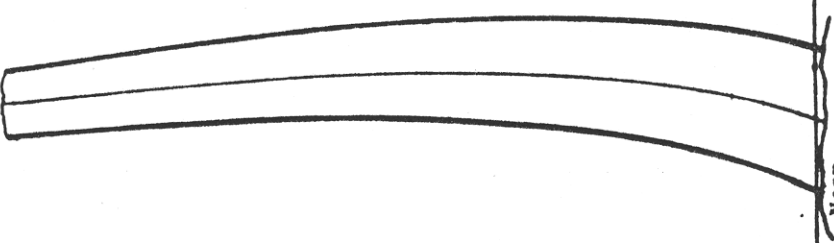
Likewise, empirical data for steles per square inch, percent moisture content, and percent volumetric shrinkage are entered in Table 3B.

Table 3C entries are the metric equivalent of those in Table 3A.

Values for air-dry density were calculated from basic specific gravity values; density values for the disc were obtained by a weighted average technique.

Figs. 11 through 15 illustrate the relationship among the three regression equations developed for those sets of parameters with significant correlation.

Height, ft.	No. of Stems	Diameter, ins.	Basic Density, lbs/cu.ft.			Air-Dry Density, lbs/cu.ft.			Green Density, lbs/cu.ft.				
			Under Cortex	At 50% Radius	Through Centre	Weighted Average	Under Cortex	At 50% Radius	Through Centre	Under Cortex	At 50% Radius	Through Centre	
72	1	6.00	25.3	-	6.6	17.1	27.0	-	7.4	17.5	66.8	-	55.8
69	1	6.50	26.3	-	7.0	-	30.7	-	7.9	-	68.9	-	57.6
66	2	7.23	30.8	12.4	6.7	21.2	36.3	13.9	8.6	21.9	69.6	59.2	54.7
63	4	6.86	27.1	13.4	7.7	19.5	32.8	15.3	8.7	20.2	74.1	66.1	64.9
60	2	6.99	27.5	11.5	6.4	18.9	32.1	12.5	7.3	19.5	69.2	61.5	58.3
57	4	7.40	40.4	13.3	7.6	26.3	48.4	15.2	8.5	27.4	73.8	62.3	60.3
54	3	7.86	40.7	13.3	7.5	26.4	48.7	15.2	8.5	27.5	76.1	66.5	62.0
51	5	7.54	43.2	14.9	8.6	28.5	48.9	17.1	9.8	29.8	73.0	61.4	60.0
48	5	7.65	43.2	15.2	7.8	28.5	52.0	17.4	9.9	29.8	75.6	71.5	62.7
45	5	7.97	43.9	15.8	8.7	29.1	52.9	18.2	10.0	30.5	74.9	67.3	66.6
42	5	8.19	43.6	15.2	8.7	28.8	52.5	17.4	9.9	30.1	75.1	66.2	62.8
39	5	8.67	42.0	15.5	8.6	28.0	50.4	17.8	9.9	29.3	74.9	66.9	65.1
36	5	8.93	42.8	15.2	8.9	28.2	51.4	17.4	10.2	29.5	76.5	66.5	65.0
33	5	9.23	45.2	16.0	9.7	29.5	54.6	18.4	11.0	31.0	75.0	67.1	65.9
30	5	9.21	45.4	16.9	10.2	30.5	54.7	19.8	11.7	32.0	76.5	67.0	63.8
27	5	9.57	45.4	16.6	10.5	30.1	54.7	19.1	11.9	31.6	77.7	66.2	65.4
24	5	9.68	47.3	19.2	10.9	31.9	57.3	22.2	12.4	33.6	76.3	69.5	64.5
21	4	9.98	50.5	20.7	12.2	34.4	61.5	29.0	13.9	36.4	78.3	68.0	64.6
18	5	10.29	51.0	20.4	12.6	34.9	62.2	23.6	14.4	37.0	78.0	70.4	64.0
15	5	10.28	52.0	23.4	13.4	36.9	63.5	27.2	15.3	39.2	77.8	69.5	64.9
12	5	10.33	53.9	23.0	12.5	38.7	66.0	26.8	14.4	41.2	79.0	68.0	65.2
9	5	10.97	52.1	25.2	12.6	37.9	63.6	29.4	14.4	40.4	78.7	69.7	66.0
6	5	11.57	51.9	22.5	12.8	36.4	63.3	26.1	14.6	38.7	78.1	70.4	66.2
3	5	13.05	52.9	24.5	13.0	38.1	64.7	28.6	14.9	40.5	77.2	68.7	64.5
			42.6	17.5	9.6	29.6	51.3	20.1	11.0	31.1	75.1	66.8	63.0
			9.2	4.2	2.3	6.2	11.6	5.3	2.6	6.8	3.4	3.2	3.4
			21.6	24.0	24.0	20.9	22.6	26.1	23.6	21.7	4.5	4.6	5.4



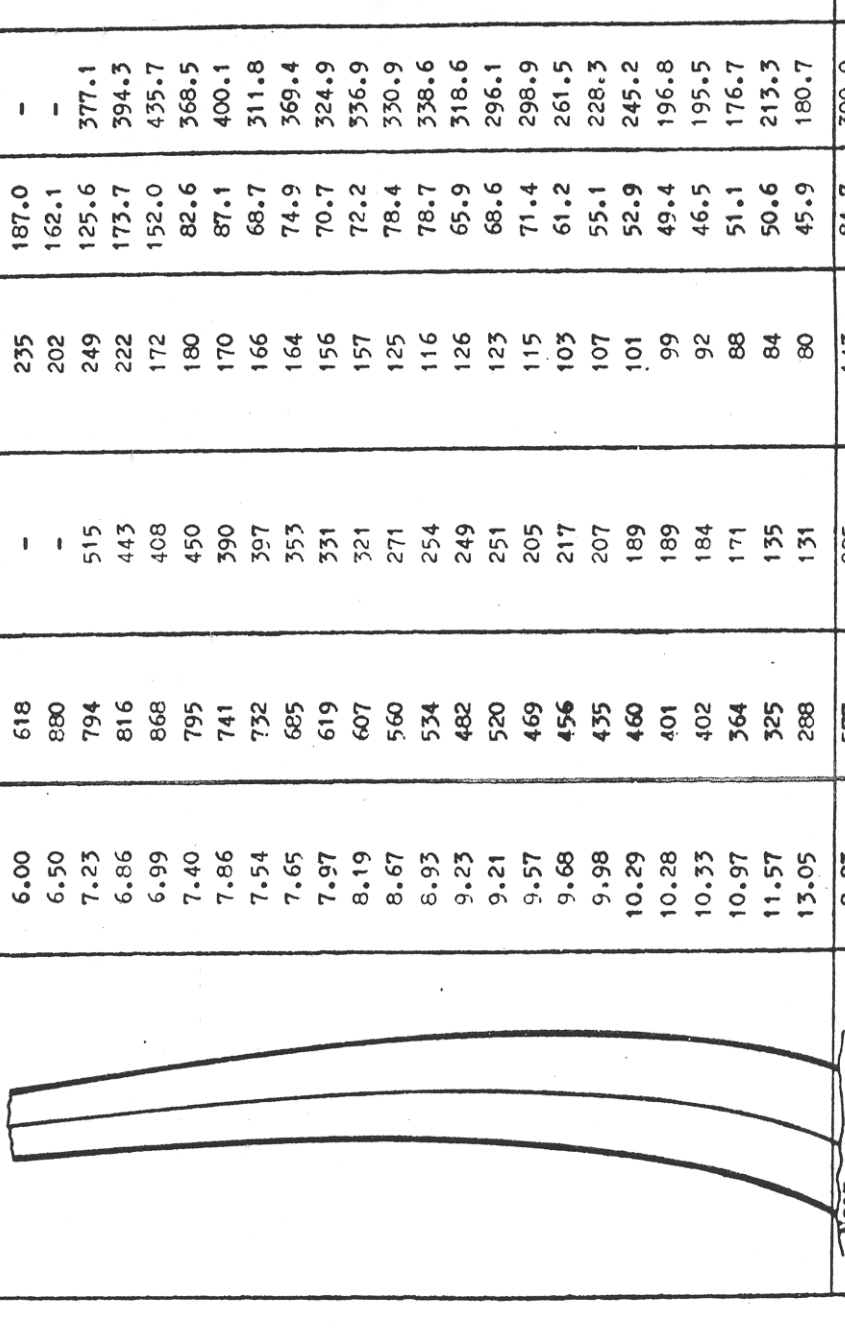
Mean
Standard Deviation

Coeff. of Var., %

* Estimated density of cross-section of stem

TABLE 3B PROFILE OF PHYSICAL PROPERTIES OF COCONUT PALM (*Cocos nucifera* L.) STEM

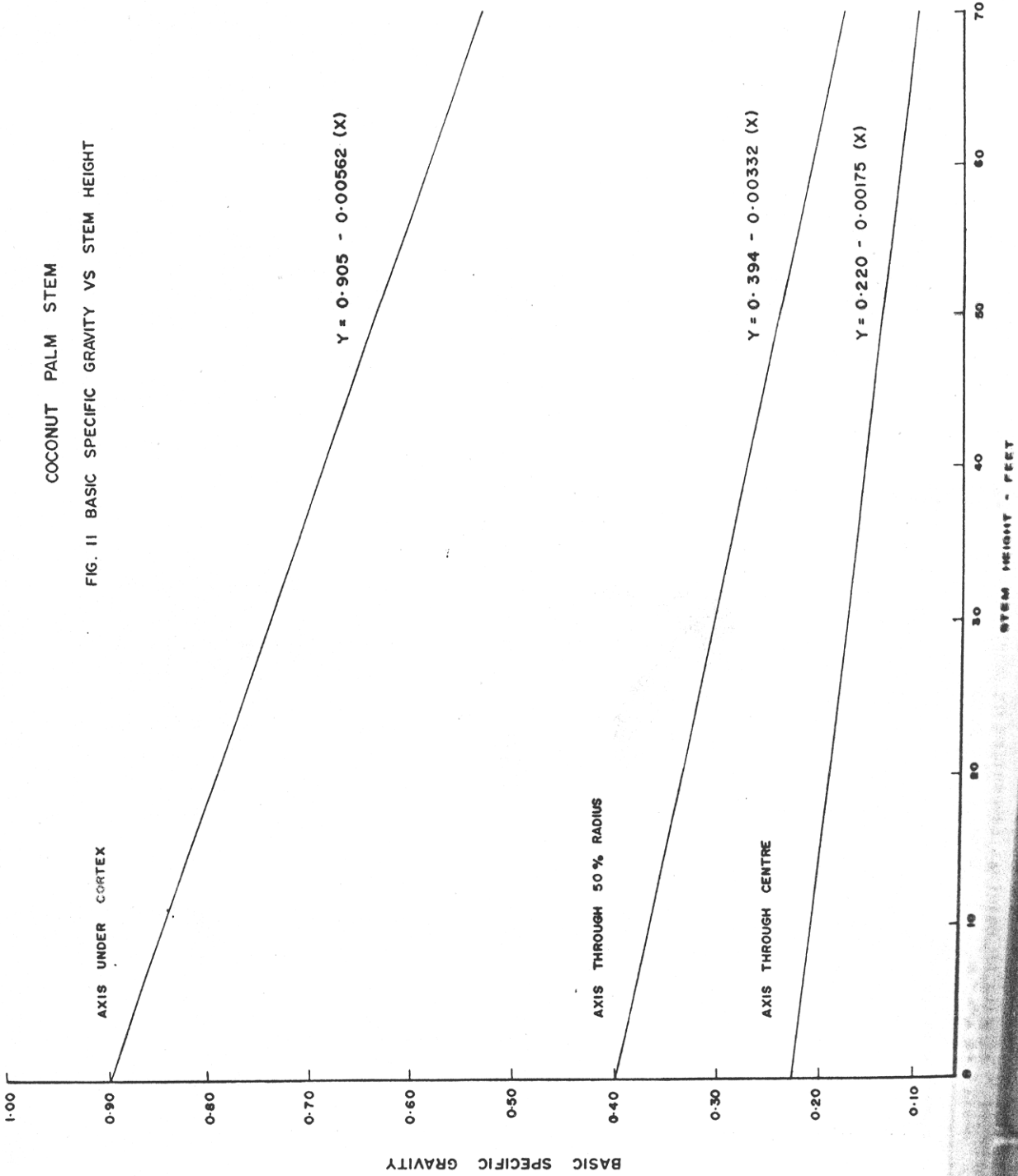
Height, ft.	No. of Stems	Diameter Overbark ins.	Stoles Per Square Inch (2.54 cm ³)			Moisture Content, Percent			Shrinkage Percent
			Under Cortex	At 50% Radius	Through Centre	Under Cortex	At 50% Radius	Through Centre	
72	1	6.00	618	-	235	187.0	-	751.0	Collapse
69	1	6.50	880	-	202	162.1	-	724.9	Collapse
66	2	7.23	794	515	249	125.6	377.1	618.0	10.7
63	4	6.86	816	443	222	173.7	394.3	746.0	13.2
60	2	6.99	868	408	172	152.0	435.7	806.9	13.6
57	4	7.40	795	450	180	82.6	368.5	698.3	8.9
54	3	7.86	741	390	170	87.1	400.1	727.8	8.8
51	5	7.54	732	397	166	68.7	311.8	596.6	9.3
48	5	7.65	685	353	164	74.9	369.4	703.6	10.0
45	5	7.97	619	331	156	70.7	324.9	655.5	10.6
42	5	8.19	607	321	157	72.2	336.9	619.3	10.3
39	5	8.67	560	271	125	78.4	330.9	655.6	11.8
36	5	8.93	534	254	116	78.7	338.6	628.9	10.6
33	5	9.23	482	249	126	65.9	318.6	580.9	10.9
30	5	9.21	520	251	123	68.6	296.1	527.0	10.3
27	5	9.57	469	205	115	71.4	298.9	523.8	10.9
24	5	9.68	456	217	103	61.2	261.5	494.2	8.9
21	4	9.98	435	207	107	55.1	228.3	430.5	9.5
18	5	10.29	460	189	101	52.9	245.2	407.5	8.9
15	5	10.28	401	189	99	49.4	196.8	386.2	9.2
12	5	10.33	402	184	92	46.5	195.5	419.9	10.8
9	5	10.97	364	171	88	51.1	176.7	423.7	10.6
6	5	11.57	325	135	84	50.6	213.3	417.2	10.9
3	5	13.05	288	131	80	45.9	180.7	394.3	8.7
		Mean	577	285	143	84.7	300.0	580.7	10.3
		Standard Deviation	177	111	49	42.3	77.4	133.8	1.3
		Coef. of Var., %	30.7	38.9	33.6	49.9	25.8	22.5	12.6



Height, ft.	No. of Stems	Diameter, mm	Basic Density, Kg/m ³			Air-Dry Density, Kg/m ³			Green Density, Kg/m ³		
			Under Cortex	At 50% Radius	Through Centre	Under Cortex	At 50% Radius	Through Centre	Under Cortex	At 50% Radius	Through Centre
72	1	152	373	-	105	432	-	118	1071	-	894
69	1	165	421	-	112	492	-	126	1103	-	924
66	2	184	494	199	107	581	223	138	1115	949	876
63	4	174	434	214	123	525	245	139	1188	1059	1041
60	2	178	440	184	103	514	200	117	1109	986	934
57	4	188	648	213	121	775	243	136	1183	998	966
54	3	200	552	213	120	780	243	136	1220	1065	993
51	5	192	693	239	138	783	274	157	1169	984	961
48	5	194	693	244	125	833	279	143	1212	1145	1005
45	5	202	703	254	139	847	291	160	1200	1079	1067
42	5	208	699	243	140	841	279	159	1204	1062	1007
39	5	220	673	249	138	807	285	159	1201	1073	1043
36	5	227	686	243	143	823	279	163	1226	1066	1042
33	5	234	725	257	155	875	295	176	1203	1076	1056
30	5	234	727	271	163	876	317	187	1225	1073	1022
27	5	243	727	266	168	876	306	191	1246	1061	1048
24	5	246	758	308	174	918	356	199	1222	1113	1034
21	4	253	809	332	195	985	464	223	1255	1090	1035
18	5	261	818	327	202	996	378	231	1251	1129	1025
15	5	261	834	375	214	1017	436	245	1246	1113	1040
12	5	262	864	369	201	1057	429	231	1266	1091	1045
9	5	279	835	404	202	1018	471	231	1262	1118	1058
6	5	294	831	360	205	1014	418	234	1252	1128	1060
3	5	331	848	393	209	1036	458	239	1237	1100	1033
		Mean	683	280	154	822	326	176	1203	1071	1009
		Standard Deviation	147	67	38	186	85	43	54	51	54
		Coeff. of Var., %	21.5	23.6	24.7	22.6	26.1	24.4	4.5	4.8	5.4
			19.6	21.5	24.7	22.6	26.1	24.4	4.5	4.8	5.4
									22.6	22.6	
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COCONUT PALM STEM

FIG. II BASIC SPECIFIC GRAVITY VS STEM HEIGHT



COCONUT PALM STEM

FIG. 12 STELES PER SQ. IN. VS. STEM HEIGHT

STELES PER SQ. IN.

STEM HEIGHT - FEET

$Y = 267.7 + 8.332 (X)$

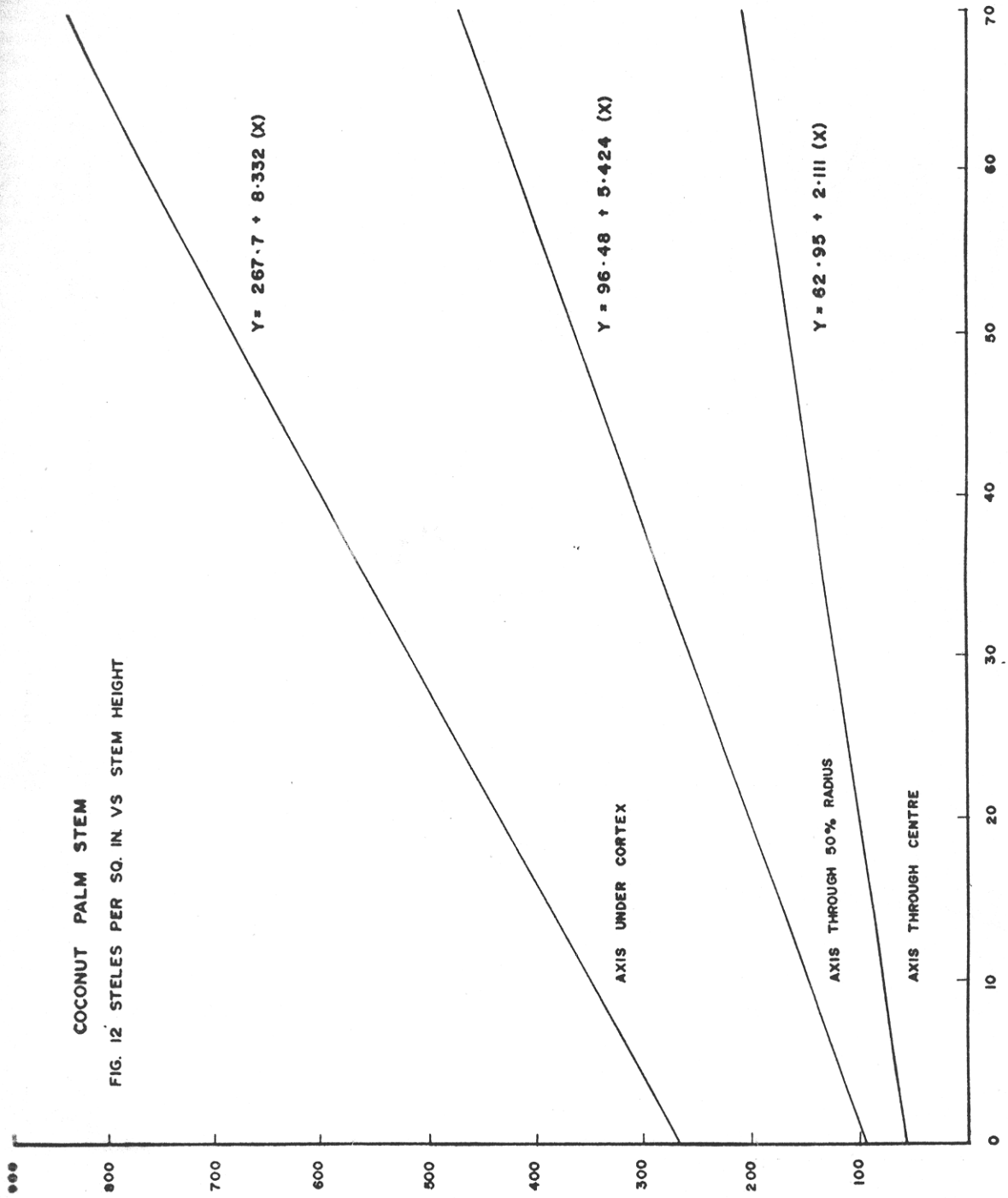
$Y = 96.48 + 5.424 (X)$

$Y = 62.95 + 2.111 (X)$

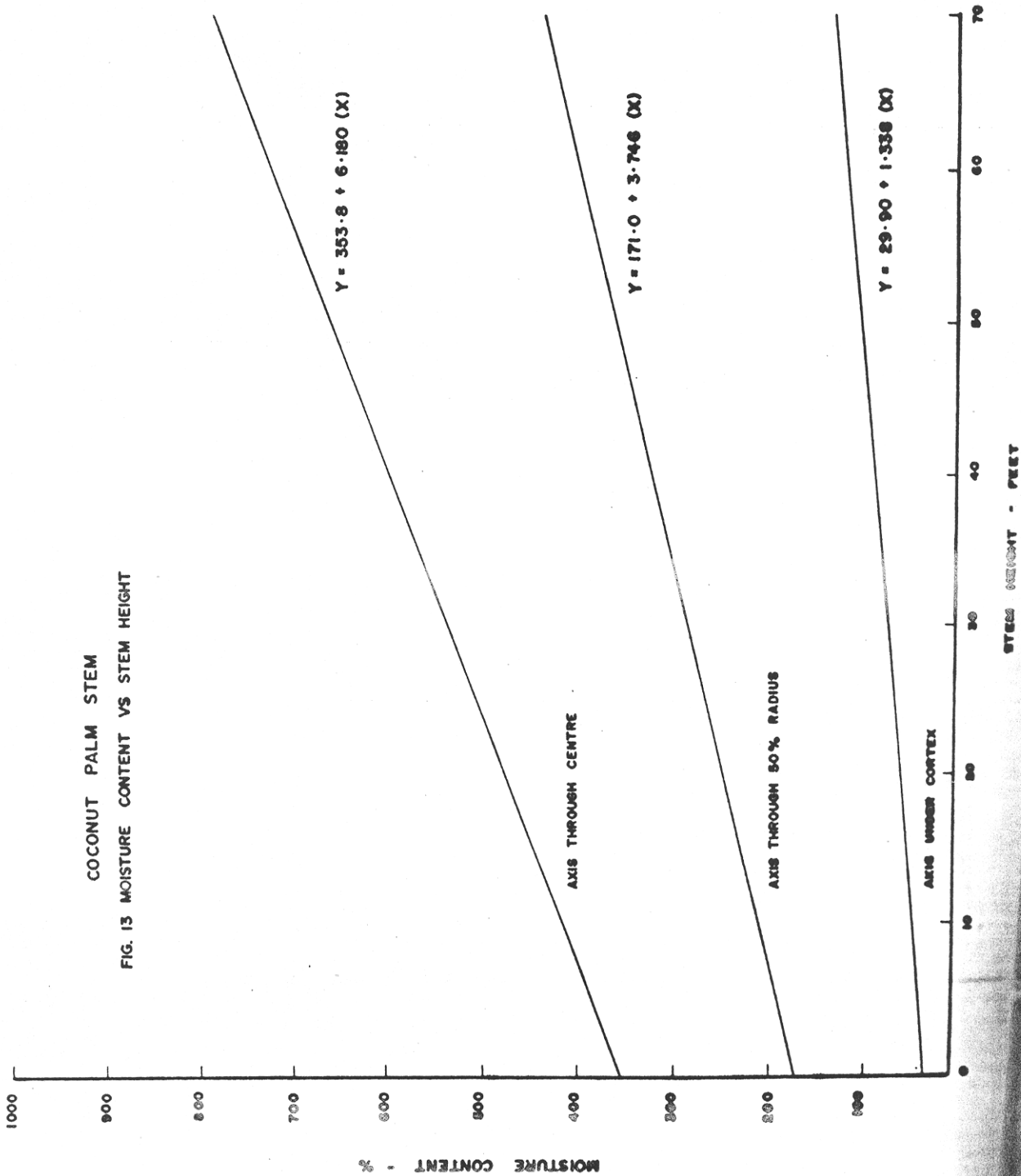
AXIS UNDER CORTEX

AXIS THROUGH 50% RADIUS

AXIS THROUGH CENTRE

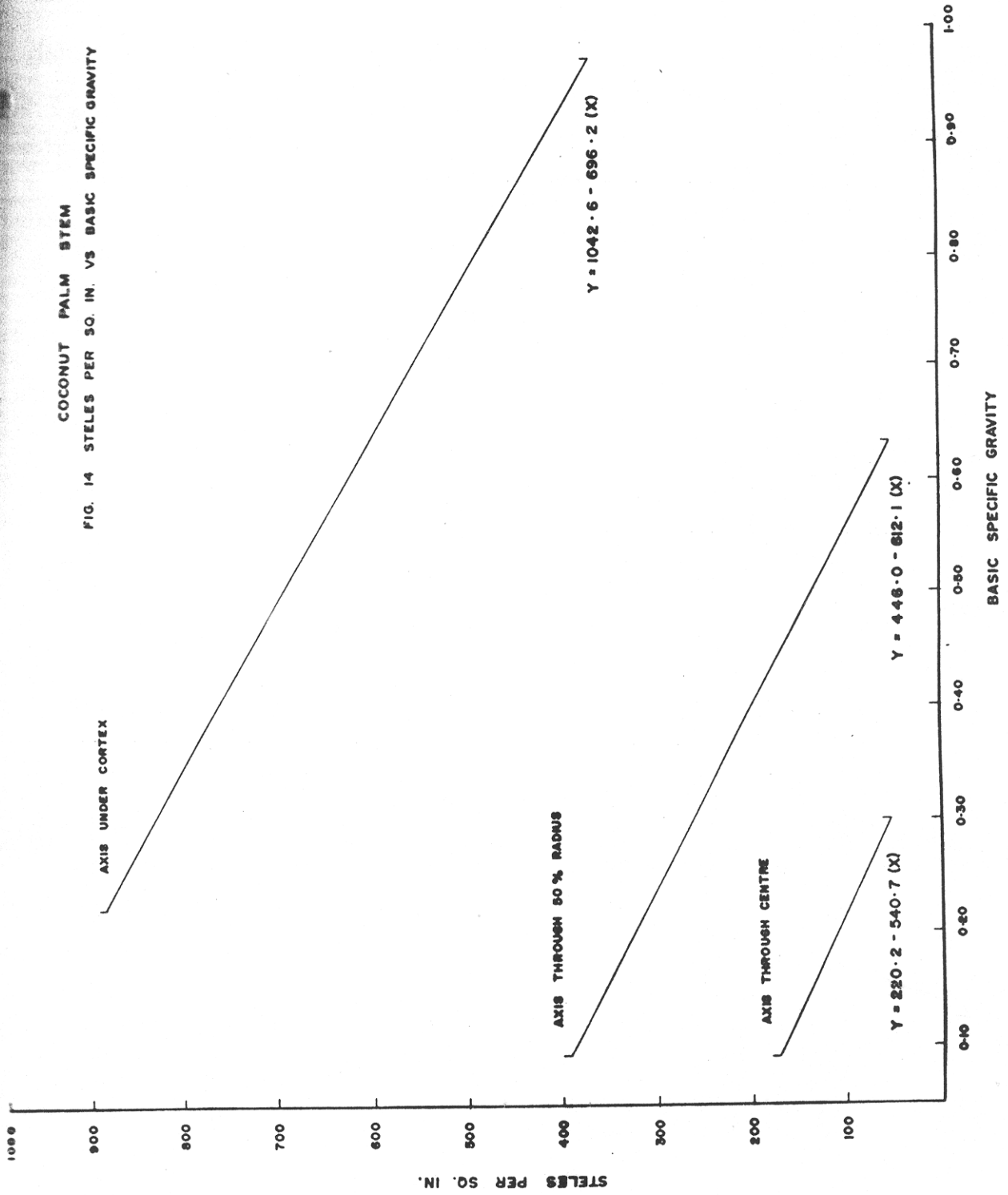


COCONUT PALM STEM
FIG. 13 MOISTURE CONTENT VS STEM HEIGHT

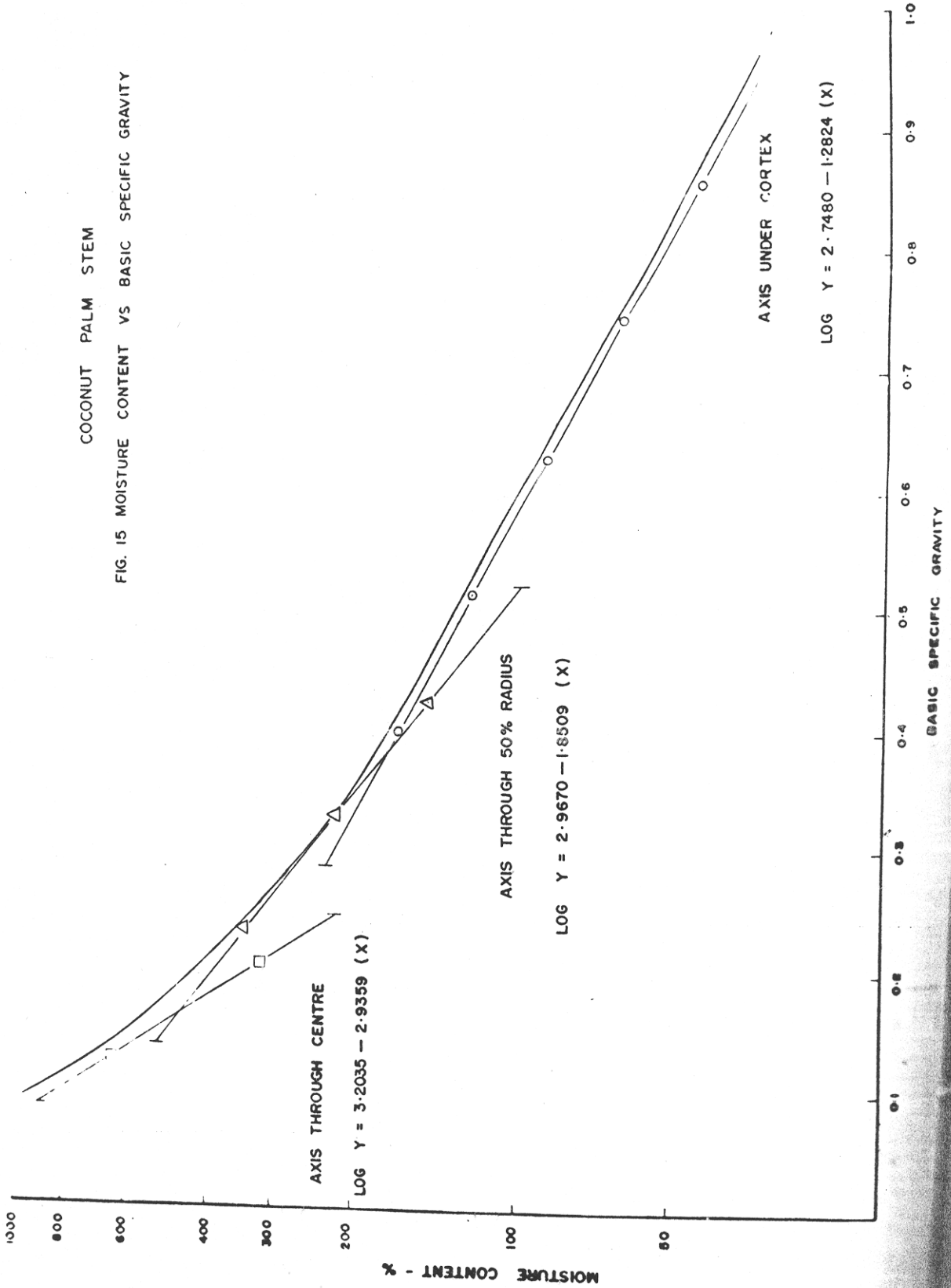


STEMS HEIGHT - FEET

COCONUT PALM STEM
 FIG. 14 STEELS PER SQ. IN. VS BASIC SPECIFIC GRAVITY



COCONUT PALM STEM
FIG. 15 MOISTURE CONTENT VS BASIC SPECIFIC GRAVITY



Discussion and Conclusions

(a) Density

CSIRO has previously established seven groups, S1 through S7, each with its own minimum standard test value, to which conventional hardwoods and softwoods are assigned by virtue of their strength from laboratory tests. High density high strength timbers must have a minimum basic density of 56 lb/cu. ft. (897 kg/m^3) to be classified in Group S1, whilst low density-low strength woods with a minimum basic density of 20 lb/cu. ft. (320 kg/m^3) fall into the last group, S7.

Coconut palm timber, as demonstrated by test data shown in Table 3A ranges from an average basic density of 52.7 lb/cu. ft. (844 kg/m^3) for the first 12 feet from ground in the peripheral zone to an average basic density of 7.0 lb/cu. ft. (112 kg/m^3) through the centre axis at the top 12 feet of the stem. From the viewpoint of practical utilisation, this wide ranging variance in density places narrow limits on cross-sectional dimensions, lengths, quantity and quality of structural timber obtainable from a stem, and circumscribes as well the end uses to which the remaining lower density material may be put. This low density wood (less than 20 lb/cu. ft) is conservatively estimated at more than 25 percent of the roundwood volume of the stem. Moreover, it is prone to collapse on drying which seriously diminishes its commercial value.

A comparison of average densities of coconut palm from New Guinea, as reported by Kloot (1952) and from Tonga, as reported by McConchie (1975), with those from Fiji as reported herein, is given in Table 4.

TABLE 4. Comparison of Average Density of Coconut Palm Stem from Fiji, New Guinea and Tonga.

Condition	Average Density, lb/cu.ft. (kg/m ³)			
	Axis A	Axis B	Axis C	Stem
Basic:				
Fiji	42.6 (683)	17.5 (280)	9.6 (154)	29.6 (474) (3)
New Guinea (1)	30.7 (492)	19.5 (312)	14.5 (232)	N/A
Tonga (2)	38.1 (610)	23.9 (383)	13.3 (213)	28.2 (451)
Air-Dry:				
Fiji	51.3 (822)	20.1 (322)	11.0 (176)	31.1 (498)
New Guinea (4)	40.3 (646)	28.2 (452)	16.7 (268)	N/A
Tonga	45.4 (727)	29.3 (469)	16.9 (270)	35.2 (564)
Green:				
Fiji	75.1 (1203)	66.8 (1071)	63.0 (1009)	N/A
New Guinea (1)	N/A	N/A	N/A	N/A
Tonga (2)	71.4 (1143)	65.2 (1044)	61.2 (980)	66.1 (1058)

- (1) Material taken from 10 logs, approximately 25 ft. (7.6 m) long and from 9 to 12 in. (229 to 305 mm) in diameter from New Guinea.
- (2) Material taken from 31 logs, with mean diameter of 8.3 in. (211 mm); logs averaged 12 ft. (3.7 m) in length.
- (3) Data obtained by weighted average method.
- (4) Data converted from nominal to air-dry density.

The three zones from which Kloot and McConchie drew their test material were larger than the axial sampling used for the Fiji material and this could account for some of the differences in data.

As may be seen in Table 3A slightly lower density values were obtained for the peripheral zone wood in the butt swell region than for the region just above it. From this point upward in the stem, density tended to decrease more rapidly through Axis A than through Axis B, and ~~more~~ so for Axis B than Axis C, with interim fluctuations

occurring at certain stem heights. These departures from a consistent linear decrease in density with stem height may be attributed, in part:

- (1) to the first four years of growth of the coconut palm during which time an increase in stem girth takes precedence over stem elongation (butt swell region) and
- (2) since no secondary thickening of the stem takes place, to responses of the apical meristem and early formative tissues to periodic changes in environmental conditions.

Basic Specific Gravity vs. Stem Height

Basic specific gravity appears to decrease linearly with an increase in height of stem for each test axis, Fig. 11, and to increase logarithmically in the radial direction from centre to cortex at any height of stem. The latter observation seems to be borne out by the closer displacement of Axis B toward Axis C, even though Axis B represents one-half of the radius, i.e. at any stem height, the difference in basic specific gravity values is larger between Axes A and B than between Axes B and C.

The linear regression equations developed in this study were derived from limited data on a small sampling of stems from a population whose stem height mean was 69.4 feet (21.2m). The longest of the five stems tested was 72 feet (21.9 m). But a significant portion of the over-mature coconut palm in Fiji may be 90 feet (27.4 m), and over, Linear extrapolation to 90 feet of the lines described by the equations in Fig. 11 may not be reasonable. One could expect, however, certainly no increase in density above 72 feet, and probably a decrease in density to a line asymptotic to the X axis. The point to be made here is that at these low densities it is questionable how much of this additional woody fibre would be suitable even for such bulk consuming uses as pulp or charcoal. If one applies the rule-of-thumb of one foot growth per year to these data, it becomes apparent that from the age of 60 years

on upward, the coconut palm becomes increasingly not only an agricultural liability but, from a forest utilisation standpoint, a "weed tree" as well.

(c) Steles per Square Inch vs. Stem Height

These parameters showed a high linear correlation, with the number of steles increasing substantially from the base to the top.

The increase in number of steles per unit area with stem height is accompanied by a marked decrease in stele and vessel diameters; in the peripheral zone at the upper region of the stem their minute size, light colour, and proximity to each other required the use of low power magnification (4x) to obtain reliable counts.

Tomlinson states in his general description of palm stem that "the number of vascular bundles per unit area of the stem is approximately the same at all heights. This is true even where the stem tapers or becomes swollen". Assuming the term "unit area of stem" to mean a cross-section of the stem, calculations of the total number of steles present in cross-section of four stems at 13, 25, 50 and 90 percent of stem height gave the following average number of steles:

<u>Percentage of Height</u>	<u>Total Number of Steles</u>
13	15,984
25	20,028
50	18,482
90	18,670
—	—
Weighted average	18,291

In the course of collecting the experimental data, it was observed that the number of steles diminished progressively for each $\frac{1}{4}$ inch of radius from just under the cortex to the centre.

Similar trends were noted at other stem heights as well; but magnitude of the counts varied correspondingly with stem heights.

When these data were recombined in units of $1/2$ square inch (161 mm^2), and overplotted on Fig. 16 (after Kloot), the over-plotted data, shown as Δ , followed the characteristic exponential curves of Kloot.

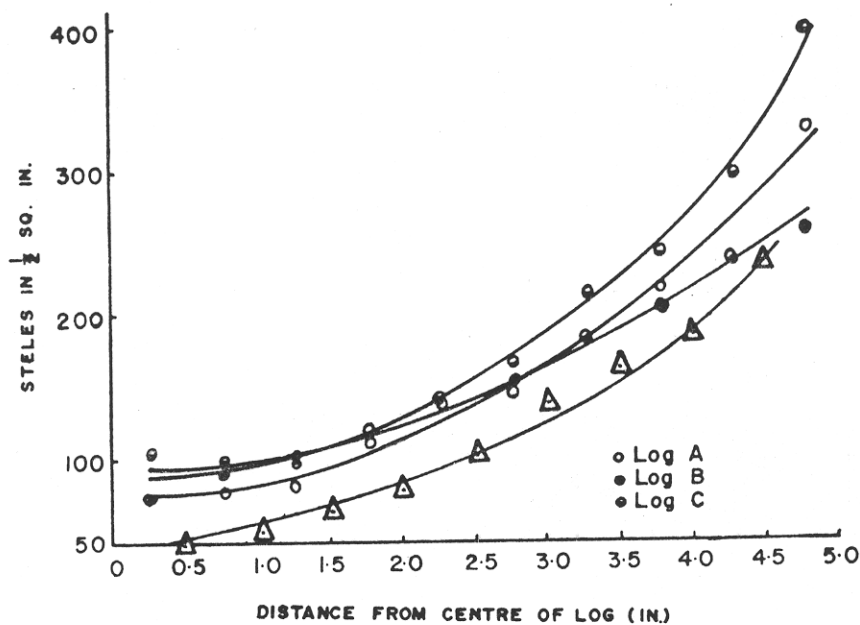


FIG. 16- Steles counts in unit areas along a radius

(d) Moisture Content vs. Stem Height

Moisture content of wood is a transitory variable, and its measurement depends primarily on external conditions at the time of test. The data of Fig. 13 indicates that moisture content in coconut palm is wide-ranging; it rises rapidly with increased stem height and markedly so from the peripheral zone to the centre of the central cylinder.

The near to saturation moisture contents obtained at test indicated little drying had occurred from the time of felling to test. This was verified by calculations made for the theoretical moisture content referred to previously. All but 15 of the 301 test values fell close to but below the theoretical curve, the 15 above are considered over-estimations resulting from experimental error.

- (e) Steles per Square Inch vs. Basic Specific Gravity
 Correlation between these parameters along each of the three test axes in this study does not seem to be as good as that which Klotz was able to obtain for cross-sections of the wood, Fig. 17 (after Klotz). Klotz's results approximate the equation: $Y = 810.3(X)$.

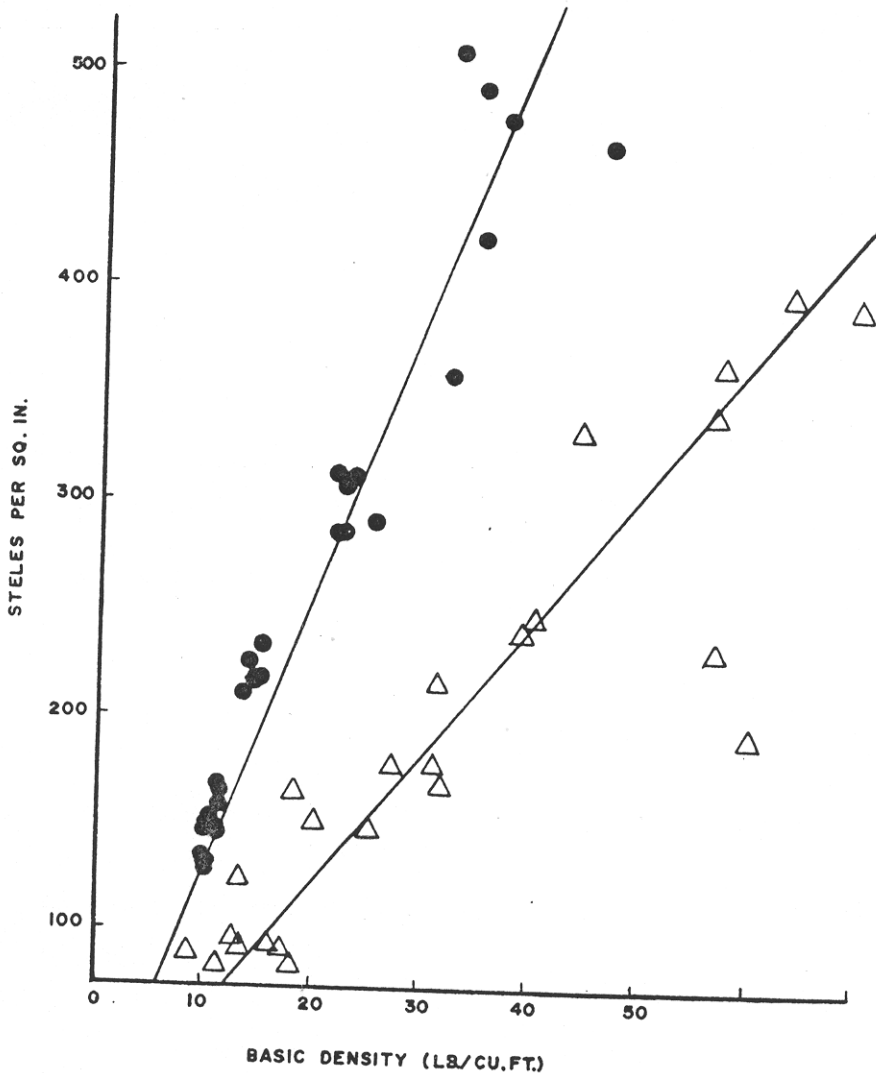
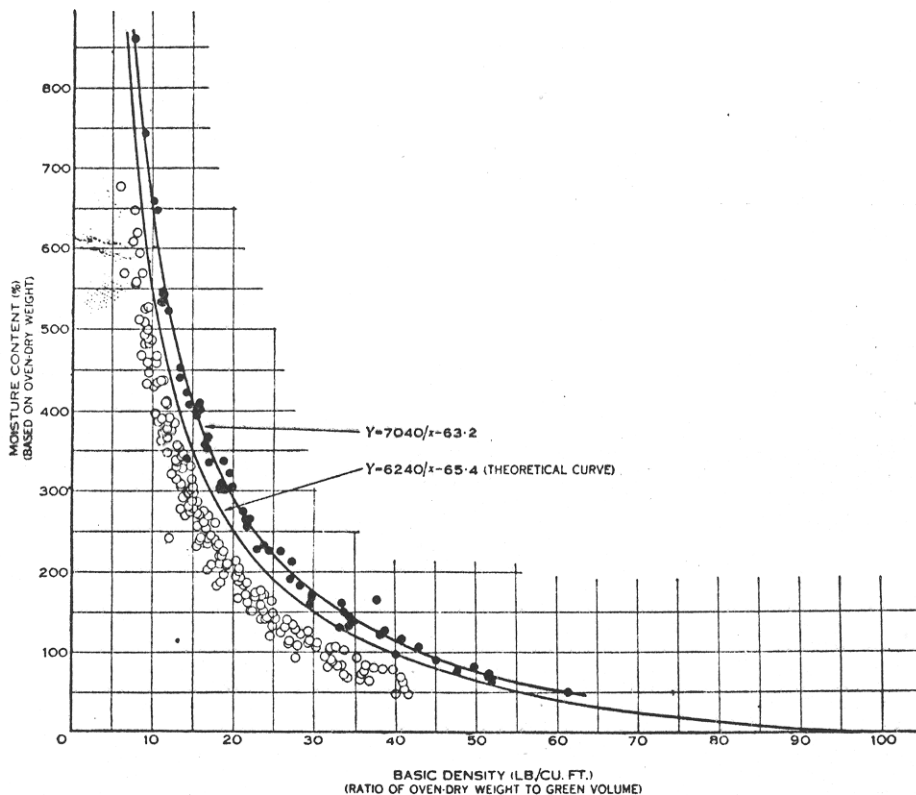


Fig. 17 - Correlation between stiele count and density (after klotz)

Overplotted on Fig. 17 are data from this study taken from five stems across a radius at the 9-foot height increment. Twenty-five values converted to basic density and shown as Δ are plotted, including values recorded for specimens intermediate to Axes A and B, and B and C. These results approximate the equation: $Y = 382.8(x)$.

Moisture Content vs. Basic Specific Gravity

Moisture content showed a high correlation with basic specific gravity. The data of Fig. 15 follow closely that of Klot, (Fig. 18) which he obtained from small clear specimens for shear, bending, hardness and compression tests. Moisture content-specific gravity values for the first three properties, however, lay near to but below the theoretical curve; compression tests values were above the theoretical curve yet produced a correlation coefficient of 0.994. Klot calculated that "coconut wood substance would require to have an impossibly high (specific gravity) value of 1.73", well above the commonly accepted value of 1.53. Over-estimation of the moisture content values from the compression tests due to volatile extractives could not explain this anomaly either since no significant differences could be detected between results for moisture content obtained by toluene extraction and the usual oven-dry methods.



(g) Shrinkage

As previously stated only shrinkage values for Axis A were analysed since specimens from Axes B and C showed evidence of collapse ranging from incipient to severe. Analysis of the data for shrinkage vs. stem height, basic specific gravity and stele count, respectively, indicated extremely poor correlation.

Volumetric shrinkage for Axis A averaged 10.3 percent and compares well with McConchie's figure of 11.1 percent for Tongan material from the outer stem section. Mid-section volumetric shrinkage from Tonga was 11.6 percent; however, McConchie reports volumetric shrinkage of 22.4 percent from green to air-dry and 23.3 percent from green to oven-dry for the inner stem section. These average figures evidently include material that had collapsed.

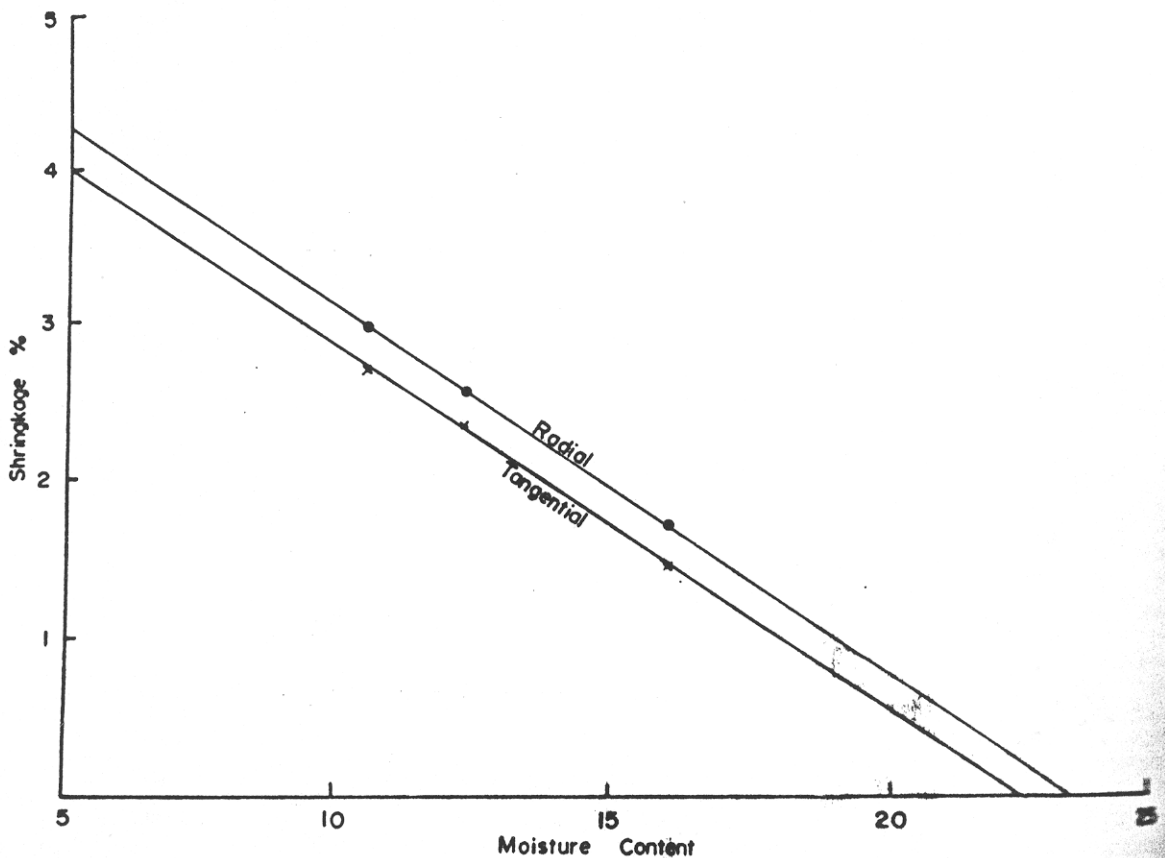


Fig. 19 The tangential and radial shrinkage intersection points for coconut, [after McConchie]

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