OBSERVATIONS

DALBERGIA SISSOO (Roxb.)

A large tree attaining 60 feet and more with an erect but not straight trunk is commonly known as sissoo tree. Usually cultivated and often self sown throughout India, belongs to family Fabaceae. Leaflets are 3-5, alternate, broad-ovate, acuminate, glabrous when old. Flowers yellowish white nearly sessile, in unilateral spikes, which are arranged in short axillary panicles; ramifications of inflorescence and calyx pilose. Legume linear lanceolate, generally 2-3 seeded. Bark is thick, gray or pale brown with obliquely longitudinal shallow fissures and distant older creep cracks, which tail off into each other. The wood is diffuse porous with light colored sapwood and brownish heartwood. Sissoo wood is esteemed highly for all processes where strength and elasticity are required. It is extensively used for, boat-building, carts, carriages, agricultural implements and doors and window frames. It is an excellent and beautiful furniture wood. The raspings of the wood are used in native medicine.

NORMAL TREES

CAMBIAL STRUCTURE:

The cambium is storied with fusiform cambial cells and cambial ray cells. Fusiform cambial cells are vertically elongated and cambial ray cells are short, isodiametric and clustered in groups (Fig. 7 A). Fusiform cambial cells are arranged in radial rows and the cells are more or less rectangular in transverse sections (Fig. 5 A). During dormant period the cambial zone is narrow with 4 to 8 layers of undifferentiated cambial cells intervening between fully differentiated xylem and phloem elements (Fig. 5 A). During active period the cambial zone is wide with 6 to 14 layers of cells surrounded by differentiating vascular elements (Fig. 5 C to E). The fusiform cambial cell cytoplasm is lightly stained during active period and densely stained during dormant period. The radial walls are thicker than the tangential ones particularly during dormant period and posses deeply depressed primary pitfields at regular intervals (Fig. 7 A).

CAMBIAL ACTIVITY:

Cambial activity initiates in April (Fig. 5 B), reaches peak in August with 8 to 14 layers of cells (Fig. 5 E) and declines ceasing in November (Fig. 5 F) in the main stem. Rapid enlargement of cambial zone has been observed in August. Cambial activity is intense from July to September but becomes sluggish in October.

In the young branch, +he cambial activity begins in April, continues till July and ceases in August. Cambium in young branch becomes 4 to 10 layers when it is active and 3 to 7 layer during dormant period (Table 1).

Seasonal variation in number of cambial layer in the main stem and young branch are represented in Figure 12.

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

As a tropical deciduous tree, Dalbergia does not bear leaves all round the year. The floral and foliar parts begin to dry in November followed by partial defoliation in December. The process of leaf shedding completes in January. The trees remain completely leaf less for a month. The cambium is dormant during the period of leaf drying and defoliation. New leaves and flowers begin to sprout in February followed by fruit setting in March. The cambial reactivation starts in the first week of April. When the trees are with full foliage from May to September, the maximum activity of cambium is noticed. In October the Cambial growth is sluggish and ceases in November, when the foliage becomes old. The relation between cambial activity and phenology is represented in Table 1.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

Reactivation of cambium in normal trees is affected mainly by temperature. When the average monthly maximum temperature is $39^{o}C$ and average daily sunshine hours are 11 in April, the initiation of cambial activity is noticed. The average monthly relative humidity is high (74% to 92%) from May to September. Cambial cell divisions are maximum in August, when the average rain fall recorded is highest of the year. Cambial activity ceases in November following sudden decrease of average maximum temperature, relative humidity and rain fall.

Fluctuations in meteorological data (Maximum and Minimum temperature, rainfall, relative humidity and duration of sun shine hours) are represented in Figure 1 and 2.

FUSIFORM CAMBIAL CELLS:

Fusiform cambial cells, as seen in tangential sections are short, roughly hexangular with abruptly tapered ends. They are arranged in definite stories (Fig. 7 A). The cells undergo periclinal divisions (Fig. 7 C) producing axial elements in xylem and phloem.

DIVISIONAL ACTIVITY:

Periclinal and anticlinal divisions in the cambial zone lead to production of secondary xylem and phloem cells and to an increment in the circumference of the cambium respectively. Peiclinally dividing cell are noted by the appearance of phragmoplast in the fusiform cambial cells in tangential sections. Most of the cells show phragmoplast with developing tangential walls in August (Fig. 7 C). In October the number of cells with phragmoplast decreases. Anticlinal divisions occur through out the activity of cambium.

DIMENSIONAL CHANGES:

MEAN LENGTH:

Cell length variation is studied in relation to seasonal activity of the cambium. The average length is maximal (171 µm) in November and minimal (153 µm) in July. Cell length decreases alternately from January to March and increases from April to May. It decreases in June-July and remains same in August and

September. The average length of cell undergoes variation during active and dormant periods of cambium (Table 2).

MEAN WIDTH:

The fusiform cambial cell do not show appreciable seasonal variation in their tangential width. The maximum (17 µm) and minimum (13 µm) width of fusiform cambial cell is noticed in February and March respectively (Table 2)

LENGTH VARIATION IN RELATION TO THE XYLEM FIBRE LENGTH:

The average length of xylem fibres is greater than that of fusiform cambial cells. The fibres are 5 to 9 times longer than fusiform cambial cells during active and dormant periods of cambium. The xylem fiber length is maximal (1403 µm) in January and minimal (760 µm) in October (Table 2). The variations in the of length of fusiform cambial cells and xylem fibres are represented in Figure 14 A.

CAMBIAL RAY CELLS:

Cambial ray cells are short and more or less isodiametric giving rise to vascular rays. Cambial rays are uni, bi or multiseriate and heterogeneous. However, multiseriate rays are predominant (Fig. 7 A). The cell walls are beaded during dormant period.

DIVISIONAL ACTIVITY:

Cambial ray cells usually develop from fusiform cambial cells by lateral anticlinal or transverse divisions. Developing cambial rays are observed during active period of cambium. Tangential divisions in cambial ray cells lead to the development of ray cells in xylem and phloem. The derivatives of cambial ray cells undergo relatively little change during differentiation.

DIMENSIONAL CHANGES:

CAMBIAL RAY HEIGHT:

The variations in the mean height of rays exhibit close similarity with the variations of the mean length of fusiform cambial cells. The ray height increases in April with the reactivation of cambium. It decreases gradually from May to July and increases in August, when the maximum cambial activity is recorded. The ray height is maximal (130 µm) and minimal (93 µm) in November and July respectively (Table 4 and Fig. 15 A). In comparison, the average ray height is less than the average length of fusiform cambial cells.

CAMBIAL RAY WIDTH:

The average ray width increases and decreases alternately in the year. The ray width is maximal (41 µm) and minimal (25 µm) in August and June respectively. The mean variations in width are represented in Table 4 and Fig. 15 B.

CAMBIAL RAY CELL DIAMETER:

The tangential cambial ray cell diameter variations are gradual before the reactivation, whereas they are abrupt during and after the active period of cambium. The tangential diameter is found to be lowest (14 μm) in June to September and October and highest (18 μm) in August (Table 4 and Fig. 15 C).

CAMBIAL RAY POPULATION:

The average number of rays passing through one cm tangential width of cambium is represented in Table 4. The average number records lowest (171) in April when the reactivation of cambium occurs. The number increases gradually from May to June and decreases and increases alternately in the remaining months. The ray population is maximal in March and August (Fig. 16).

DEVELOPMENT OF VASCULAR TISSUES:

The xylem and phloem differentiation and cessation are simultaneous in April and November respectively (Fig.12). The rate of cambial cell differentiation is more in August with maximum number of differentiating xylem (14-22) and phloem (4-9) elements. The cell divisions are rapid on xylem side than phloem side. The rate of differentiating vascular elements decreases from September to October.

Phloem derivatives develop into sieve tube members, companion cells, parenchyma cells and fibres. Sieve tube elements are storied with a large P-protein body lying either in the middle or near the sieve plate of each element. The concentric phloem fibre bands are not continuous and alternate with bands containing sieve tubes and parenchyma cells (Figs. 8 A, 11 A). The sieve tube elements are with simple and transverse sieve plate (Fig. 8 B) and solitary lateral sieve areas. The parenchyma which are adjoining to the tangential bands of fibres mainly consist of rhomboid crystals. Non-functional phloem can be easily distinguished from functional one by the presence of dark contents in parenchyma cells and massive callose on sieve plates in last formed phloem.

The xylem derivatives develop into vessel elements, and bands of parenchyma (Fig. 8 C) and fibres. Xylem is diffuse porous with pitted (Fig. 11 E) solitary vessels. The parenchyma is of aliform confluent broad type. The parenchyma cells are loaded mainly with starch grains and rarely with crystals (Fig. 11 C) . The vessel elements produced at the end of the growth season have narrow lumen diameter.

DEVELOPMENT, LENGTH AND WIDTH OF VESSEL ELEMENTS:

The cells developing into vessel elements elongate slightly and expand laterally often so strongly that their ultimate width exceeds their height. The average length of fusiform cambial cells is more or less similar with the average length of vessel elements in August, November and December. The vessel element length increases and decreases alternately during active period of cambium. The length is maximal (175 µm) in May and is minimal (136 µm) in July. The average width is more than the length from January to April. The vessel element width records lowest (109 µm) in August when the cambium is at it's peak activity. The variations in average length and width of vessel elements are represented in Table 3.

VESSEL LUMEN DIAMETER:

The average vessel lumen diameter ranges from 140 µm to 186 µm in different months of the year. The lumen diameter is maximum when the cambium is active (June). The variations in average diameter is represented in Table 3 and Figure 17 A.

NUMBER OF VESSELS:

The number of vessel per 0.5 mm^2 of xylem is studied in transverse sections and represented in Table 3. The average number is less (3) in January and December and more (6) in June (Figs. 8 E, 17 B).

GROWTH RING WIDTH:

With the addition of new cells to the face of the previous year's xylem, the growth ring boundary could be discerned (Fig. 44 A). The parenchyma cells in the growth ring boundary are with either crystals or brownish tanniniferous contents (Fig. 8 D). The width of the current years and last years xylem is 4.5 mm and 4.1 mm respectively (Table 19).

HISTOCHEMISTRY:

STARCH:

Starch grains are small and round in fusiform and ray cambial cells. Cambial ray cells contains starch all through the year except when active divisions are taking place in cambium (Fig. 10 A). In xylem of main stem high accumulation of starch is observed in parenchyma before and after the cambial growth (Fig. 9 C). During the active cambial cell divisions and differentiation (June-August), both ray and axial parenchyma are with low starch content (Table 5 and Fig. 9 A). The starch grains in ray parenchyma of xylem are elongated, rod like (Fig. 10 C). In phloem, starch storage reaches peak before the commencement of defoliation. In general accumulation of starch is less during dormant period of cambium. The starch grains are round and relatively smaller in both axial and ray parenchyma cells (Fig. 9 E).

Xylem of young branch has low content of starch prior to the cambial cell division. After the cessation of activity, starch accumulation increases in both ray and axial parenchyma. Phloem starch accumulation is low in March, July and October and high in February (Table 5). The pith region of young branch has low accumulation of starch (Fig. 9 G). The overall phloem starch accumulation pattern of branch coincides with that of main stem. Seasonal starch content in cambium and parenchyma cells of xylem and phloem is represented in Table 5.

LIPIDS:

Lipid bodies are observed in both fusiform and ray cambial cells when the cambium is dormant. The size and concentration of lipid bodies are found to be more in the cambial cells and vascular elements in February (Fig. 10 D). In general the storage of lipids is more in cambial ray cells than in fusiform cambial cells.

PROTEINS:

Protein bodies could easily be detectable in cambial ray cells during dormant period. In fusiform cambial cells they are of small size and found mostly along the walls.

AFFECTED TREES

CAMBIAL STRUCTURE:

The structure of cambium is similar to that of normal trees (Fig. 7 B). The storied cambium is composed of fusiform and ray cambial cells. During dormant period the cambial zone is narrow with 4 to 8 cells in each radial file, while in active period, it is wide with 7 to 14 layers of cells.

CAMBIAL ACTIVITY:

Cambial reactivation occurs in June and the cell division reaches maximum in August (Fig. 6 E) with 8 to 14 layers of cells. The cambial activity gradually declines in October and ceases in November (Fig. 6 F). The cambium remains dormant (Fig. 6 A-C) with thick cell walls in April and May (Fig. 6 B-D). Cambial cell division and differentiation lasted for five months i.e. June to October. In young branch the activity occurs in two growth flushes. The first flush of activity begins in June and ceases in August. The second flush of activity begins in September and declines in October. The cambium remains dormant in November. Peak activity in second flush of branch cambial growth occurred in September with 8 to 12 layers of cells in cambial zone (Fig. 13).

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

Complete defoliation is not observed in affected trees. The foliar parts began to dry in December followed by partial defoliation and sprouting of new leaves in February. Flowering and fruiting are noticed along with developing new leaves in March. Reactivation of cambium begins in the first week of June, when the trees are with mature leaves and undergoing partial leaf fall. Visible symptoms of air pollution like necrosis and browning on leaves are evident in July. The maximum cambial activity is noticed from July to October when the trees are with full foliage. Abrupt cessation of cambial activity coincides with the foliage parts becoming old in November. The relation between cambial activity and phenology is represented in Table 1.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

Cambial activity is initiated when the mean maximum temperatures (35^{o}C) and average sunshine hours (8 1/2 hrs) are relatively high and moderate rainfall recorded with 82% relative humidity. The average monthly relative humidity is high (84 to 92%) from July to October when cell divisions occur actively in the cambial zone. Cambial cell divisions are maximal in August when the average monthly rainfall is highest (Fig. 4 B) and average sunshine hours are minimum (Fig. 3 A). The decrease in mean maximum temperature, relative humidity and no rainfall coincides with the cessation of cambial activity in November.

FUSIFORM CAMBIAL CELLS:

The structure, shape and arrangement of fusiform cambial cells of affected trees are similar to that of normal ones. During the active period the radial walls are thin and most of the cells show phragmoplast arc on either side of the developing tangential wall in August (Fig. 7 D).

DIMENSIONAL CHANGES:

MEAN LENGTH:

The mean length of fusiform cambial cells undergo variations during active and dormant periods of cambium. The cell length is less in active period than that of dormant period. The mean cell length ranges from 151 to 172 µm in different months of the year (Table 2).

MEAN WIDTH:

Mean fusiform cambial cell width decreases prior to the cambial reactivation in May. The cell width is maximal (28 µm) in November and minimal (13 µm) in May (Table 2).

LENGTH VARIATION IN RELATION TO THE XYLEM FIBRE LENGTH:

The average length of fibres is more during dormant period of cambium and it ranges seasonally from 981 µm to 1230 µm . In active period, the xylem fibre length increases gradually from June to August and then decreases in September with a marginal increase in October. Fibres are 6 to 8 times longer than fusiform cambial cells (Fig. 14 B).

CAMBIAL RAY CELLS:

The structure, shape and divisional activity in general is similar to that observed in normal trees.

DIMENSIONAL CHANGES:

CAMBIAL RAY HEIGHT:

The average ray height is relatively more during dormant period of cambium. The ray height is minimal (97 µm) in September and maximal (137 µm) in January (Fig. 15 A).

CAMBIAL RAY WIDTH:

The average ray width is minimal soon after the peak activity of cambium. In general the average ray width is more in affected trees. The cambial ray width ranges from 26 µm to 51 µm in different months of the year (Fig. 15 B).

CAMBIAL RAY CELL DIAMETER:

Cambial ray cell diameter decreases and increases alternately in the year. In comparison to normal trees, much variation in cambial ray cell diameter is not found in affected trees (Fig. 15 C).

CAMBIAL RAY POPULATION:

The average number of rays passing through one cm tangential width in cambium is found to be less in affected trees. The ray population is maximal (216) in August and minimal (146) in February (Fig. 16).

The variations in cambial ray height, ray width, cambial ray cell diameter and ray population are represented in Table 4.

DEVELOPMENT OF VASCULAR TISSUES:

The differentiation and cessation of phloem and xylem is simultaneous in June and November respectively. The rate of differentiation is maximal in August with an average of 47 xylem elements. Phloem differentiation is maximal in September with 6 to 7 derivatives (Table 1). The structure of phloem and xylem is similar to that of normal trees (Fig. 11 B).

DEVELOPMENT, LENGTH AND WIDTH OF VESSEL ELEMENTS :

The development of vessel elements is similar to that of normal trees. The average length of vessel elements is more or less similar to the average length of fusiform cambial cells at the end of cambial activity. The length recorded is maximum (169 µm) and minimum (136 µm) in November and January respectively. The average vessel element width ranges from 105 µm to 213 µm in different months of the year. The mean width of vessel element is more than its length except in May, November and December. The mean length and width of vessel elements is represented in Table 3.

VESSEL LUMEN DIAMETER:

The average vessel lumen diameter is less in affected trees than that of normal ones. The lumen diameter is relatively more during active period (Table 3). The diameter is maximal (113 µm) in June. The variations in vessel lumen diameter are represented in Figure 17 A.

NUMBER OF VESSELS:

The number of vessels per 0.5 mm^2 xylem ranges from 4 to 7 in the year (Table 3). In comparison to normal trees, the number of vessels is more in dormant period and is less in active period in affected trees. The variations in average number of vessels are represented in Figures 8 F and 17 B.

GROWTH RING WIDTH:

The growth ring boundary could easily be discerned in xylem. The width of the growth ring is found to be more in affected trees (Fig. 44 B). The width of the annual increment of xylem for the two successive years is 4.5 mm and 5.6 mm (Table 19).

HISTOCHEMISTRY:

STARCH:

Cambial ray cells possess starch grains all the months except in April, June, July and September. In fusiform cambial cells the starch is not localized. In cambial ray cells starch grains appear in groups (Fig. 10 B). Starch accumulation is more in axial and ray parenchyma of xylem during dormant period of cambium (Fig. 11 D and F). The high content of starch in xylem of affected trees could easily be distinguished with microscopic observations (Fig. 9 B and D). During active period of cambium (June to October) the xylem parenchyma has low content of starch. Phloem starch accumulation is more before and after the cambial activity (Fig. 9 F). The starch accumulation in storage tissues of affected trees is more than that of normal trees.

In the branch xylem, parenchyma has low content of starch prior to the cambial activity and even after the cessation of cambial activity in November. However, the cells are loaded with starch in December. In general, starch accumulation is more in branch xylem of affected trees. Dissolution of branch phloem starch starts in February, well before the beginning of cambial activity. During dormant period the branch pith region accumulates more starch (Fig. 9 H and Table 6).

LIPIDS:

Lipids are observed in both fusiform and ray cambial cells. Lipid bodies are found to be more in cambial cells during dormant period than active period. The lipid bodies are found to be less in affected trees than that of normal trees.

PROTEINS:

Much variation is not noticed in storage of proteins in affected trees from that of normal trees.

TABLE 1 : DATA ON PHENOLOGY, AVERAGE NUMBER OF CAMBIAL LAYERS AND DIFFERENTIATING XYLEM AND PHLOEM ELEMENTS IN NORMAL (N) AND AFFECTED (A) TREES OF DALBERGIA SISSOO

MONTH	PHENOLOGY		MAIN STEM		YOUNG BRANCH		XYLEM		PHLOEM	
	N	A	N	A	N	A	N	A	N	A
JAN	COMPLETE DEFOLIATION	FULL FOLIAGE	6.14 ±1.07	6.56 ±0.85	4.28 ±0.56	4.92 ±0.74	- -	- -	- -	- -
FEB	DEVELOPMENT OF LEAVES & FLOWERING	PARTIAL DEFOLIATION AND DEVELOPMENT OF LEAVES	6.4 ±0.84	6.0 ±0.88	4.9 ±0.59	3.6 ±0.53	- -	- -	- -	- -
MAR	MATURITY OF NEW LEAVES FRUITING	MATURITY OF NEW LEAVES FLOWERING & FRUITING	5.9 ±0.81	6.5 ±0.53	4.2 ±0.64	3.8 ±0.62	- -	- -	- -	- -
APR	FULL FOLIAGE	FULL FOLIAGE	8.6 ±1.70	5.6 ±1.01	5.8 ±1.25	4.4 ±0.98	3 ±0.67	- -	3 ±1.03	-
MAY	FULL FOLIAGE	FULL FOLIAGE	6.6 ±0.78	3.8 ±0.88	7.0 ±1.38	4.3 ±0.77	5.5 ±1.09	- -	3 ±1.05	- -
JUN	FULL FOLIAGE	FULL FOLIAGE (Partial leaf fall)	7.5 ±0.96	9.8 ±0.43	6.4 ±1.07	6.7 ±1.19	7.2 ±1.49	16.0 ±2.89	3.2 ±0.87	4.4 ±0.94
JUL	FULL FOLIAGE	FULL FOLIAGE	7.6 ±0.92	9.2 ±1.04	4.3 ±0.75	4.2 ±0.97	4.6 ±1.96	33 ±10.20	4.7 ±1.04	4.3 ±1.14
AUG	FULL FOLIAGE	FULL FOLIAGE	10.3 ±1.68	11.1 ±1.58	5.6 ±0.93	4.9 ±1.06	30 ±7.56	47 ±8.72	6.4 ±1.26	6.5 ±1.67
SEP	FULL FOLIAGE	FUL LFOLIAGE	10.2 ±1.20	10.4 ±1.32	3.8 ±0.73	8.6 ±1.29	14.2 ±3.57	25.8 ±6.69	6.3 ±1.61	6.8 ±2.08
OCT	FULL FOLIAGE	FULL FOLIAGE	6.6 ±2.53	10.2 ±1.61	3.7 ±1.17	3.8 ±1.19	5.6 ±0.96	33.4 ±9.10	4.1 ±1.79	4.3 ±1.86
NOV	FULL FOLIAGE	FULL FOLIAGE	5.8 ±0.68	6.1 ±0.95	4.1 ±0.92	4.2 ±0.78	- -	- -	- -	- -
DEC	PARTIAL DEFOLIATION	FULL FOLIAGE	5.8 ±0.77	6.1 ±0.84	4.6 ±1.22	4.3 ±1.05	- -	- -	- -	- -

TABLE 2 : SHOWING THE DIMENSIONAL DETAILS OF FUSIFORM CAMBIAL CELLS AND XYLEM FIBRES IN NORMAL (N) AND AFFECTED (A) TREES OF **DALBERGIA SISSOO**

MONTH	FUSIFORM CAMBIAL CELLS LENGTH (um)		CELLS WIDTH (um)		XYLEM FIBRES LENGTH (um)	
	N	A	N	A	N	A
JAN	161 ±18.84	160 ±9.42	15 ±2.01	14 ±2.25	1403 ±162.00	1110 ±113.40
FEB	162 ±7.69	172 ±10.99	17 ±2.51	15 ±2.01	910 ±119.70	1230 ±127.26
MAR	155 ±6.45	163 ±10.80	13 ±2.66	14 ±2.07	1240 ±160.65	1033 ±161.15
APR	158 ±5.65	162 ±24.96	14 ±1.87	17 ±2.07	1042 ±152.33	981 ±121.43
MAY	166 ±6.29	152 ±8.58	14 ±2.22	13 ±2.02	1111 ±141.26	1018 ±103.89
JUN	161 ±6.28	160 ±21.98	15 ±2.31	16 ±2.29	1047 ±131.80	988 ±138.00
JUL	153 ±8.32	158 ±7.58	14 ±3.14	16 ±2.15	904 ±191.02	1030 ±205.55
AUG	154 ±7.45	164 ±12.24	15 ±2.17	17 ±2.13	898 ±103.71	1186 ±131.69
SEP	154 ±10.91	155 ±8.55	14 ±1.98	16 ±1.92	978 ±165.30	1095 ±169.75
OCT	162 ±7.95	151 ±26.96	15 ±1.94	15 ±2.54	760 ±150.40	1106 ±131.47
NOV	171 ±10.36	167 ±7.06	15 ±2.35	18 ±1.89	974 ±134.41	1044 ±126.09
DEC	169 ±8.32	155 ±10.99	15 ±2.17	14 ±1.87	1098 ±129.05	1006 ±102.32

TABLE 3 : SHOWING THE DIMENSIONAL DETAILS OF VESSEL ELEMENTS AND AVERAGE NUMBER OF VESSELS PER 0.5 mm^2 IN NORMAL (N) AND AFFECTED (A) TREES OF **DALBERGIA SISSOO**

MONTH	LENGTH (um)		WIDTH (um)		LUMEN DIAMETER (um)		NUMBER OF VESSELS	
	N	A	N	A	N	A	N	A
JAN	159 ±22.68	136 ±35.28	195 ±37.8	140 ±33.39	160 ±37	120 ±41	3 ±0.67	5 ±1.11
FEB	145 ±18.9	151 ±20.79	175 ±37.8	166 ±36.54	140 ±38	125 ±35	4 ±0.92	7 ±1.25
MAR	144 ±19.59	149 ±18.64	169 ±45.04	213 ±50.8	165 ±58	142 +56	4 +1.39	5 +0.99
APR	152 ±22.05	144 ±23.27	209 ±57.97	153 ±38.26	156 ±43	139 ±43	4 ±1.28	5 ±1.03
MAY	175 ±15.12	141 ±22.90	120 ±38.60	120 ±37.19	162 ±57	130 ±45	5 ±1.11	4 ±0.83
JUN	145 ±17.94	154 ±16.50	162 ±58.39	199 ±97.98	186 ±56	113 ±58	6 ±1.20	5 ±1.33
JUL	136 ±21.54	151 ±22.55	158 ±83.39	163 ±75.65	169 ±53	164 ±34	5 ±1.31	4 ±1.20
AUG	151 ±19.81	150 ±26.83	111 ±31.31	205 ±47.89	169 ±48	150 ±50	5 ±1.08	4 ±0.67
SEP	149 ±20.38	137 ±18.11	136 ±36.69	170 ±40.82	171 ±47	138 ±57	5 ±1.26	4 ±1.00
OCT	143 ±17.29	148 ±18.59	119 ±41.52	159 ±32.68	173 ±58	155 ±39	5 ±1.48	4 ±0.09
NOV	172 ±22.25	169 ±26.42	126 ±49.23	105 ±55.33	170 ±41	137 ±51	4 ±1.07	4 ±1.03
DEC	170 ±21.05	156 ±16.52	109 ±31.13	117 ±52	180 ±26	128 ±1.03	3 ±1.02	5 ±2.84

TABLE 4 : SHOWING THE DIMENSIONAL DETAILS AND POPULATION OF CAMBIAL RAYS IN NORMAL (N) AND AFFECTED (A) TREES OF **DALBERGIA SISSOO**

MONTH	HEIGHT (um)		WIDTH (um)		RAY CELL DIAMETER (um)		POPULATION/cm	
	N	A	N	A	N	A	N	A
JAN	118 ±15.70	137 ±14.13	33 ±6.28	51 ±7.85	16 ±1.57	19 ±3.94	184 ±3.78	178 ±3.02
FEB	123 ±17.27	134 ±12.62	37 ±7.95	40 ±8.94	17 ±2.98	17 ±2.19	200 ±5.04	146 ±2.83
MAR	106 ±17.63	110 ±17.78	27 ±6.40	31 ±5.49	15 ±3.72	15 ±2.55	228 ±2.9	209 ±6.2
APR	120 ±17.47	117 ±21.08	32 ±7.72	30 ±7.19	16 ±2.77	16 ±2.95	171 ±3.1	203 ±4.0
MAY	112 ±18.99	110 ±13.81	32 ±8.32	32 ±4.78	16 ±3.24	16 ±2.81	190 ±3.8	184 ±5.3
JUN	101 ±21.98	114 ±20.62	25 ±7.74	34 ±10.04	14 ±3.45	16 ±2.84	213 ±3.4	194 ±6.0
JUL	93 ±23.55	122 ±18.84	28 ±8.32	39 ±11.09	15 ±2.90	17 ±3.6	203 ±4.0	184 ±3.5
AUG	126 ±14.25	117 ±17.11	41 ±9.55	38 ±8.29	18 ±3.33	18 ±3.73	228 ±3.6	216 ±4.9
SEP	102 ±29.4	97 ±20.72	25 ±9.16	26 ±7.56	14 ±2.19	15 ±2.85	207 ±4.6	203 ±3.8
OCT	102 ±23.94	118 ±15.18	26 ±11.11	35 ±9.35	14 ±3.95	11 ±4.27	222 ±4.6	194 ±3.3
NOV	130 ±18.35	124 ±18.11	30 ±6.56	37 ±9.42	17 ±2.80	18 ±2.95	209 ±2.9	178 ±3.5
DEC	122 ±18.84	129 ±18.35	30 ±5.49	40 ±7.59	14 ±2.85	17 ±2.19	213 ±3.1	199 ±3.9

TABLE 5 : SEASONAL STARCH CONTENT IN CAMBIUM AND PARENCHYMA CELLS OF XYLEM AND PHLOEM OF NORMAL (N) TREES OF **DALBERGIA SISSOO**

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAIN STEM														
PHLOEM		AP	■	+	+	0	0	0	0	0	0	■	+	■
		RP	■	+	+	+	0	+	+	0	■	0	+	■
CAMBIUM		FCC	x	x	x	x	x	x	x	✓	x	x	✓	x
		CRC	✓	✓	✓	✓	✓	x	x	✓	✓	✓	✓	✓
XYLEM	Cl.Cz	AP	■■	■■	■■■	■■	■■■	x	■■	x	■■	■■■	■■	■■
		RP	■■	0	+	0	+	x	0	x	■■	■■	+	■
	Aw.Cz	AP	■■■	■■■	■■■	■■■	■■■	■■■	■■■	■■■	■■■	■■■	■■■	■■■
		RP	■■	■■	■■■	■■	■	■■	■■	■	■■■	■■■	■	■
YOUNG BRANCH														
PHLOEM		AP	■■	■■■	+	0	■■	■	+	0	■■	+	■	■■
XYLEM		AP	■■	■	+	■	■■	■■	■■	■■	■■■	■■■	■■■	■■■
		RP	■■	■	+	■■	■	■■	■■■	■	■■■	■	■■	■■

AP = AXIAL PARENCHYMA, FCC = FUSIFORM CAMBIAL CELL, Cl.cz = CLOSE TO CAMBIAL ZONE

RP = RAY PARENCHYMA, CRC = CAMBIAL RAY CELL, Aw.cz = AWAY FROM CAMBIAL ZONE

TABLE 6 : SEASONAL STARCH CONTENT IN CAMBIUM AND PARENCHYMA CELLS OF XYLEM AND PHLOEM OF AFFECTED (A) TREES OF **DALBERGIA SISSOO**

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAIN STEM													
PHLOEM	AP	■■	■	0	■	■	■	■	■	–	■	■■	■■
	RP	■	■■	■	0	■	■	■	■	■■	■	0	■
CAMBIUM	FCC	x	x	x	x	x	x	x	x	x	x	x	x
	CRC	✓	✓	✓	x	✓	x	x	✓	x	✓	✓	✓
XYLEM Cl.Cz	AP	■■■	■■	■■	■■■	■■■	0	■	x	–	x	■■■	■■■
	RP	■■	■■	■■	■■	■	x	x	x	x	x	+	■■
XYLEM Aw.Cz	AP	■■■	■■■	■■■	■■■	■	■■	■■	■■■	■■	■■■	■■■	■■■
	RP	■■■	■■■	■■	■■	0	■■	–	+	■	■■	■■	■■
YOUNG BRANCH													
PHLOEM	AP	■■■	■	■	–	+	■	–	0	■■	■	–	■■
XYLEM	AP	■■■	■■■	■■■	■■	0	■■	■	■■■	x	■■■	+	■■■
	RP	■■■	■■■	■■■	0	0	x	■■	■■	+	■■■	0	■■■

AP = AXIAL PARENCHYMA, FCC = FUSIFORM CAMBIAL CELL, Cl.cz = CLOSE TO CAMBIAL ZONE

RP = RAY PARENCHYMA, CRC = CAMBIAL RAY CELL, Aw.cz = AWAY FROM CAMBIAL ZONE

Fig. 1.

A graphic representation of mean maximum and minimum temperature recorded at the meteorological Centre, M. S. University of Baroda in the year 1990.

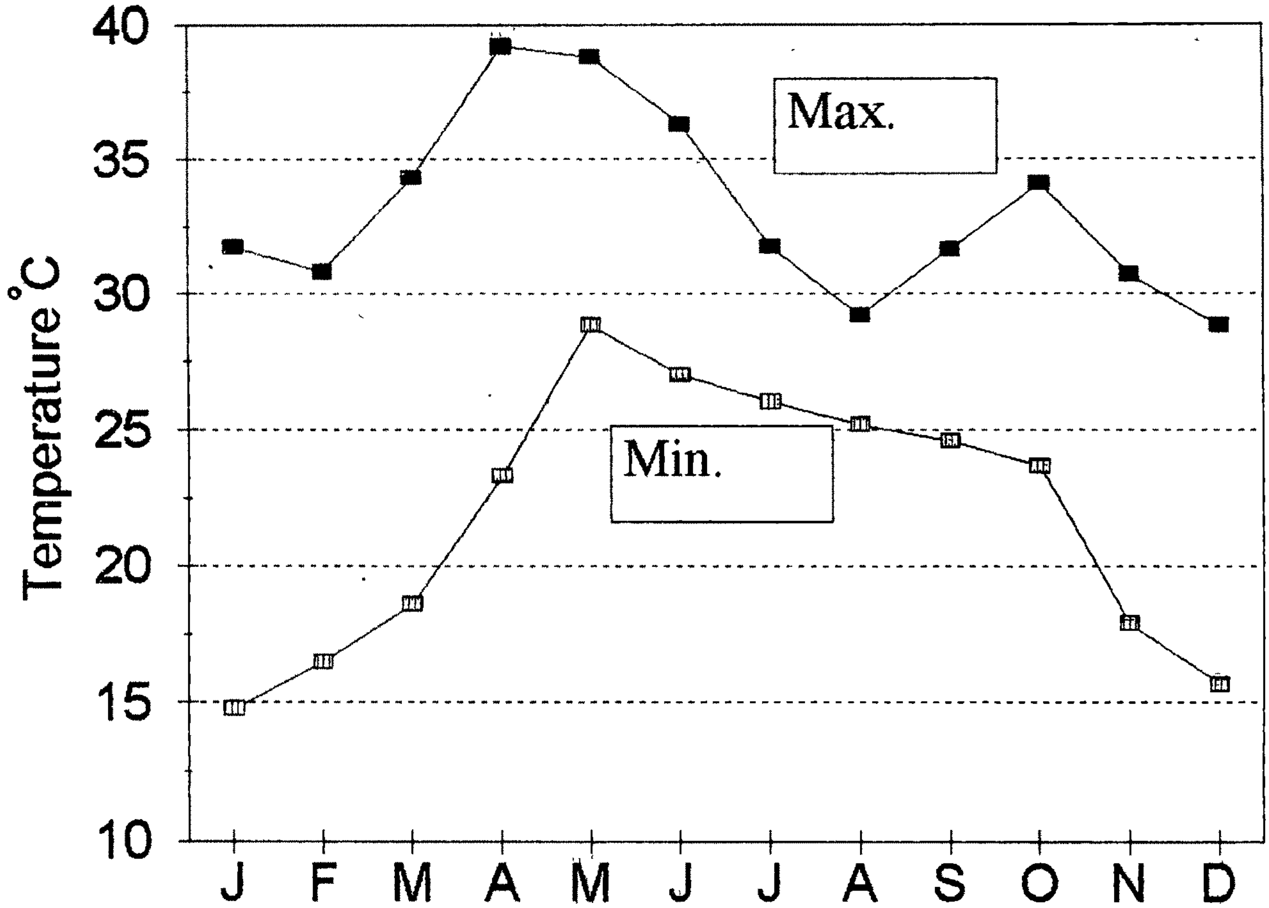


FIG. 1

Fig. 2.

A graphic representation of average rainfall and relative humidity recorded at the Meteorological Centre at M. S. University of Baroda in the year 1990.

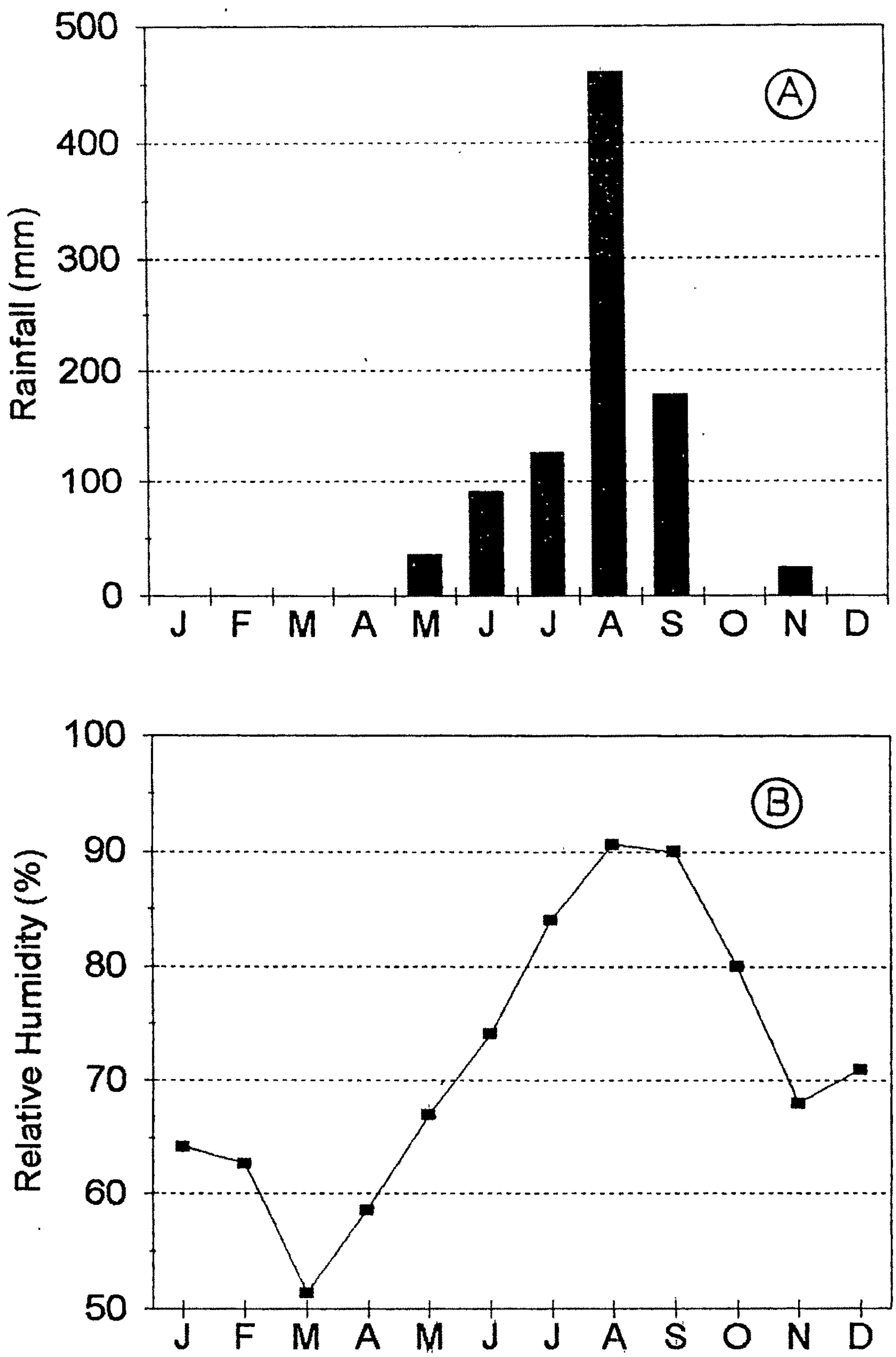
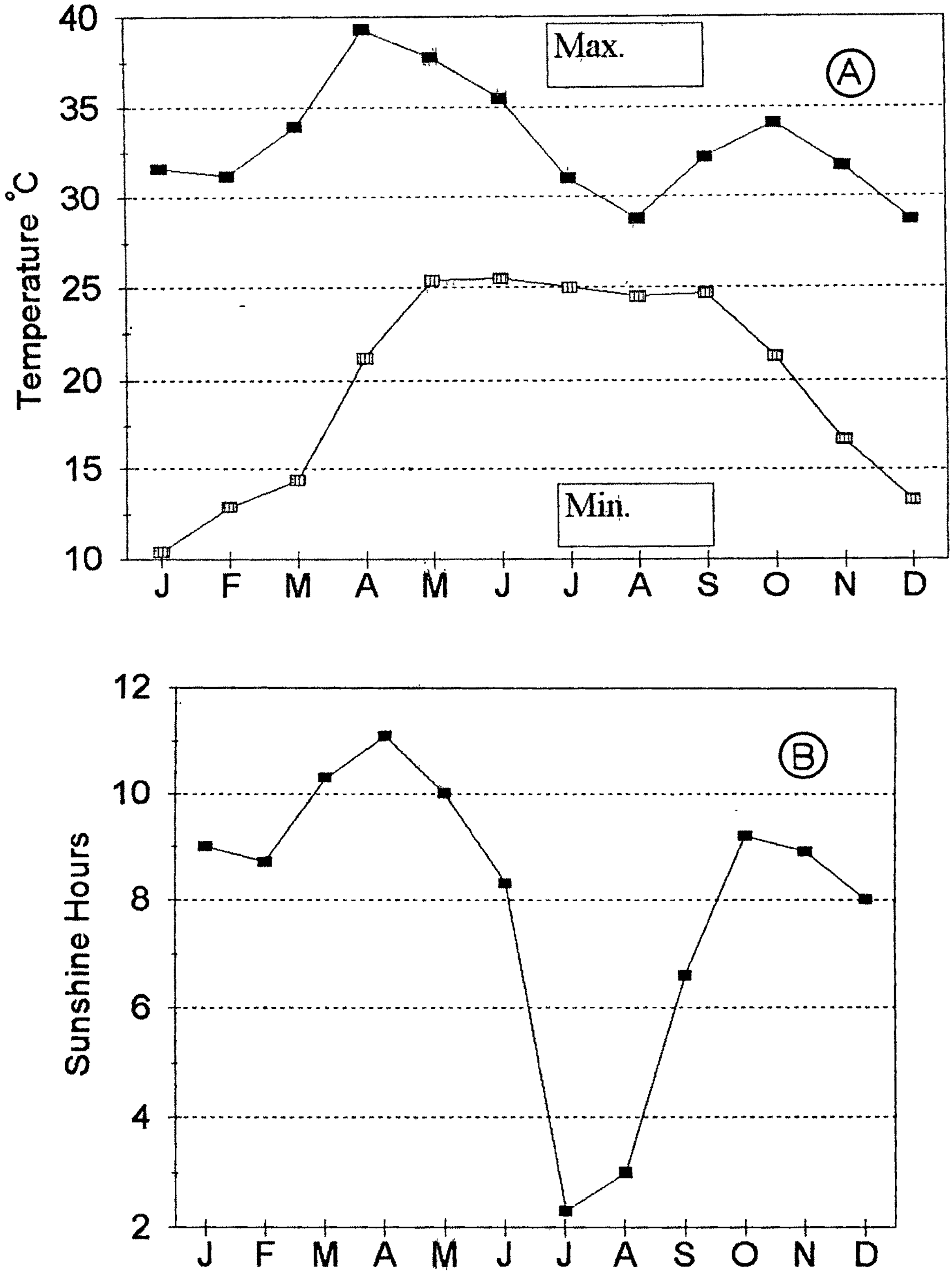

500
400
300
200
100
0
Rainfall (mm)
A
J F M A M J J A S O N D
100
90
80
70
60
50
Relative Humidity (%)
B
J F M A M J J A S O N D

FIG. 2

Fig. 3.

A graphic representation of mean maximum and minimum temperature and average sunshine hours recorded at Meteorological Centre , Vasad in the year 1990.

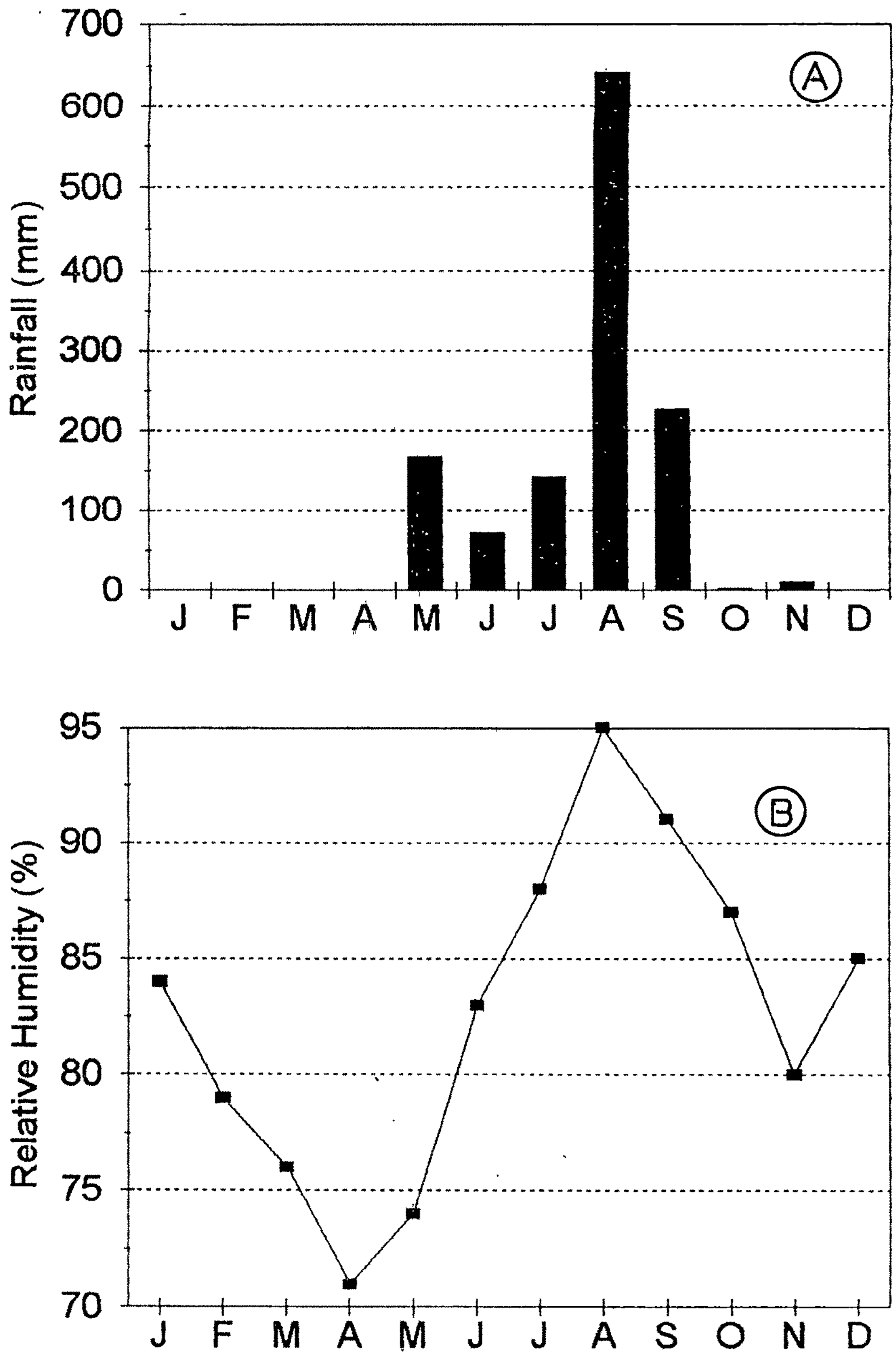


40
35
30
25
20
15
10
Temperature °C
Max.
Min.
A
J F M A M J J A S O N D
12
10
8
6
4
2
Sunshine Hours
B
J F M A M J J A S O N D

FIG. 3

Fig. 4.

A graphic representation of average rainfall and relative humidity at Meteorological Centre, Vasad in the year 1990.



Rainfall (mm)
700
600
500
400
300
200
100
0
J F M A M J J A S O N D
A
Relative Humidity (%)
95
90
85
80
75
70
J F M A M J J A S O N D
B

FIG. 4

Fig. 5

A-F: Transverse sections of cambium of normal trees.

A. Dormant cambium in March. x 325.

B. Cambial zone in April showing periclinally divided cells. x 325.

C. Cambial zone with differentiating xylem elements in May. x 420.

D. Fusiform cambial cells in May showing thin radial walls and newly formed tangential walls (arrow). x 825.

E. Cambial zone surrounded by differentiating phloem and xylem elements in August. x 194.

F. Dormant cambium in November. x 206.

CZ : Cambial Zone; DX : Differentiating Xylem; Ph : Phloem; XY ; Xylem

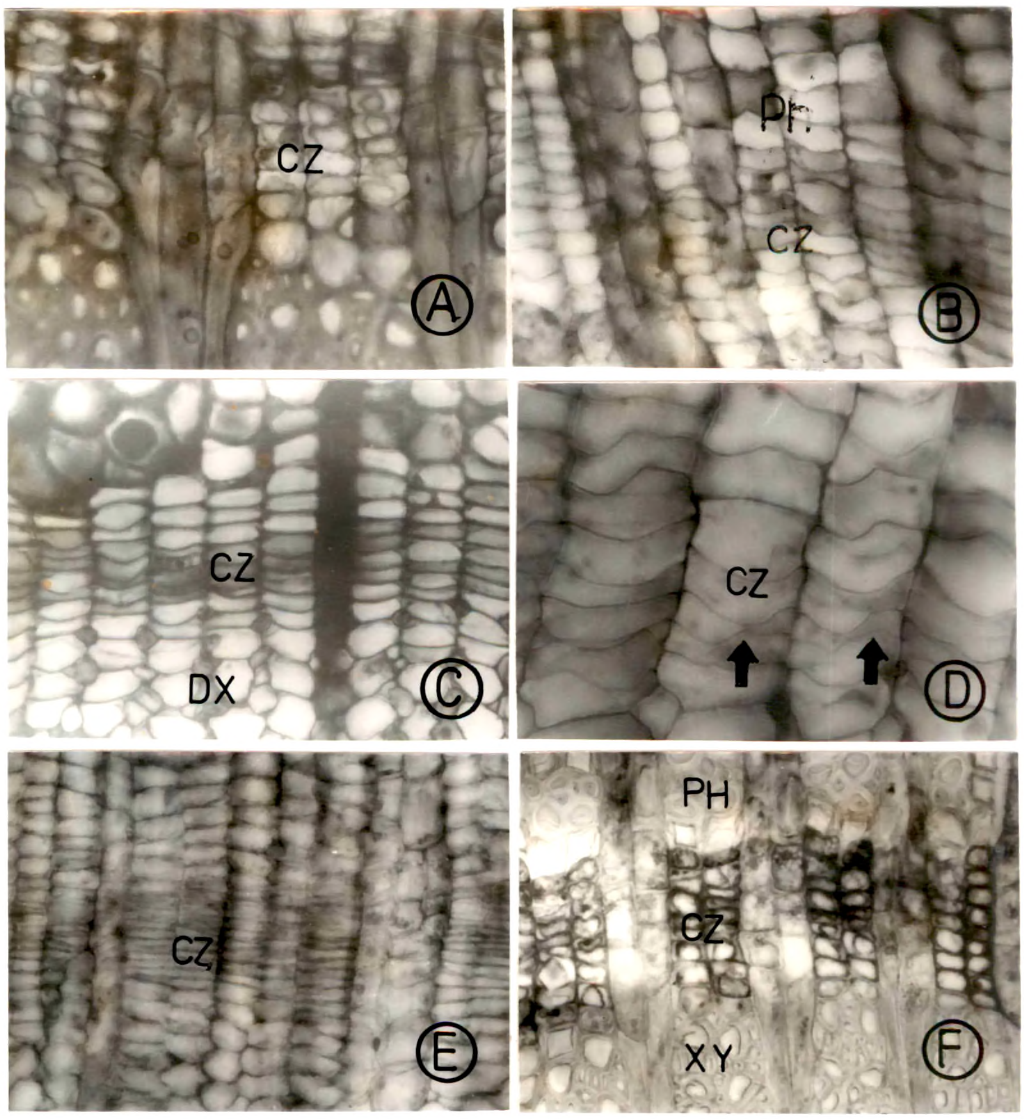


FIG. 5

Fig. 6

A-F: Transverse sections of cambium of affected trees.

A. Dormant cambium in March. x 340.

B. Inactive narrow cambial zone in April. X 260.

C. Dormant cambium in May. x 260.

D. Dormant fusiform cambial cells with thick radial walls (arrow). x 825.

E. Cambial zone with differentiating phloem and xylem elements in August. x 281.

F. Narrow cambial zone after the cessation of cell division in November. x 300.

CZ: Cambial Zone; DX: Differentiating Xylem; PH: Phloem; V: Vessel; XY: Xylem

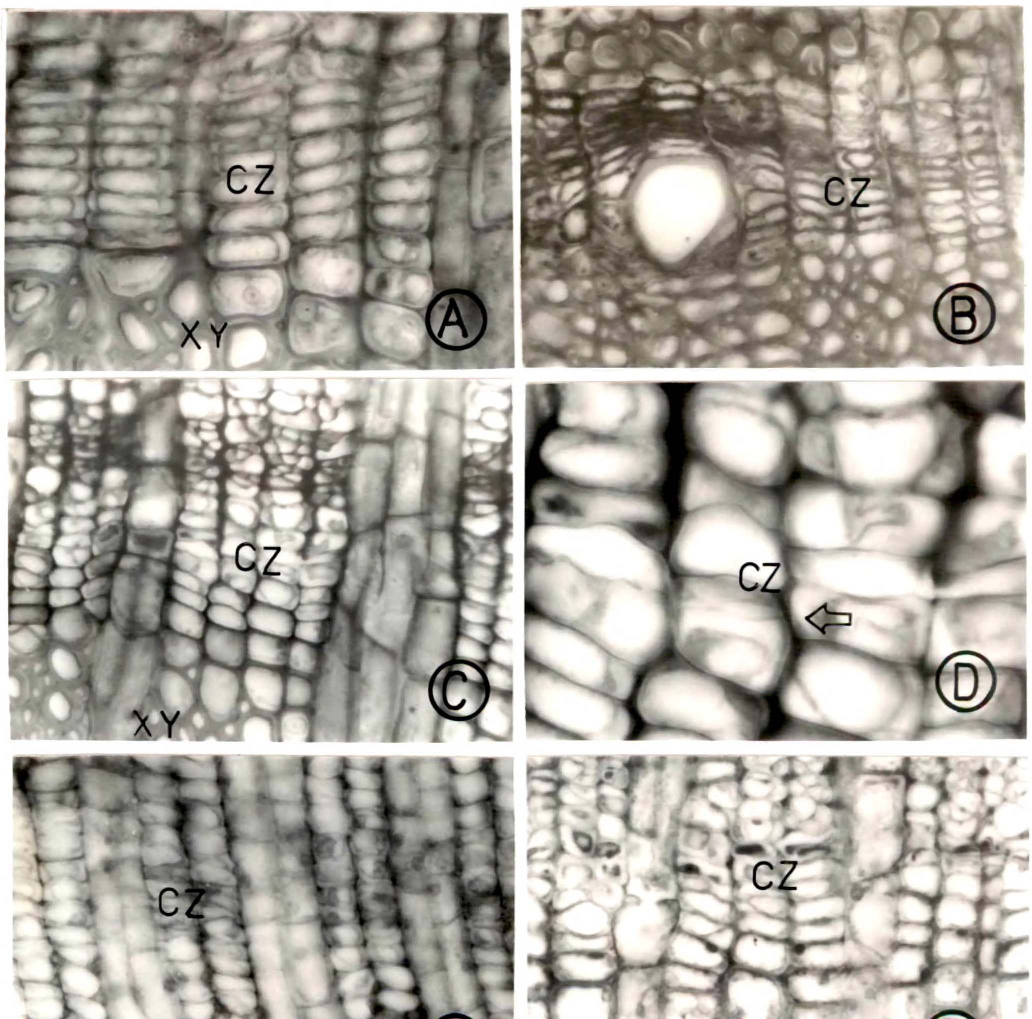


FIG. 6

Fig. 7

A-D: Tangential sections of cambium.

A. Storied arrangement of fusiform and ray cambial cells in dormant cambium of normal trees. x 237.

B. Fusiform and ray cambial cells in dormant cambium of affected trees. Arrow indicates beaded radial wall of fusiform cambial cell. x 275.

C. Active cambium of normal trees showing periclinally dividing fusiform cambial cells. Arrows indicate phragmoplast on either ends of cell plate. x 420.

D. Active cambium of affected trees showing periclinally dividing fusiform cambial cells. x 275.

CP: Cell Plate; FC: Fusiform cambial cell; RC: Ray cambial cell

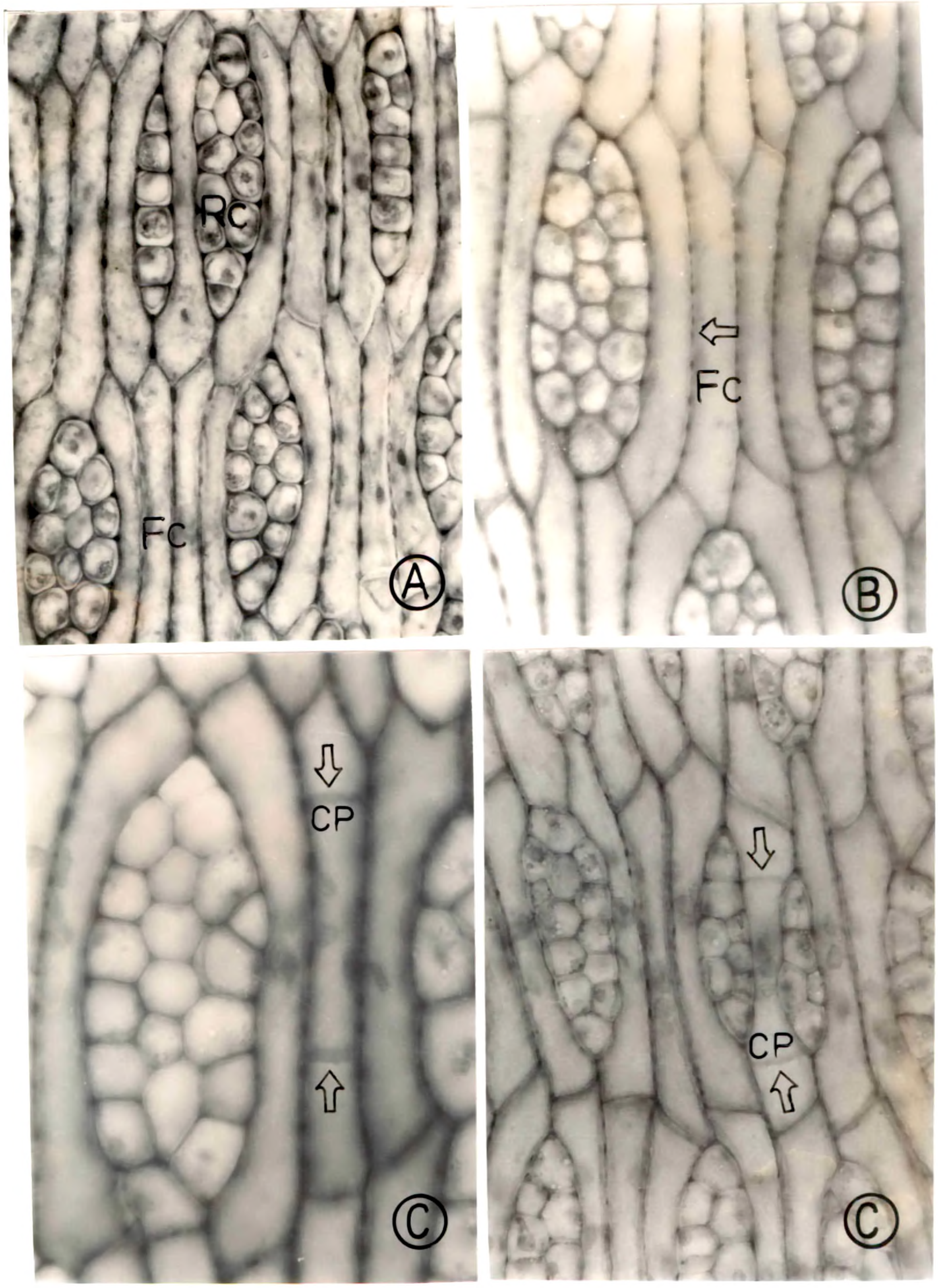


FIG. 7

Fig. 8

A-F: Transverse sections of phloem and xylem.

A. General structure of the phloem. x 120.

B. Adjacent sieve tube elements showing simple sieve plates with open sieve pores. x 750.

C. Axial parenchyma band alternating with fibre bands in xylem. x 200.

D. Xylem growth ring boundary demarcated by the tangentially com -pressed darkly stained parenchyma cells (arrow). x 219.

E. Xylem showing the distribution of solitary vessels in normal trees. x 44.

F. Distribution of solitary and radial multiple vessels in affect -ed trees. x 44.

AP: Axial Parenchyma; F: Fibres; P: Parenchyma cells; S: Sieve elements; V: Vessel

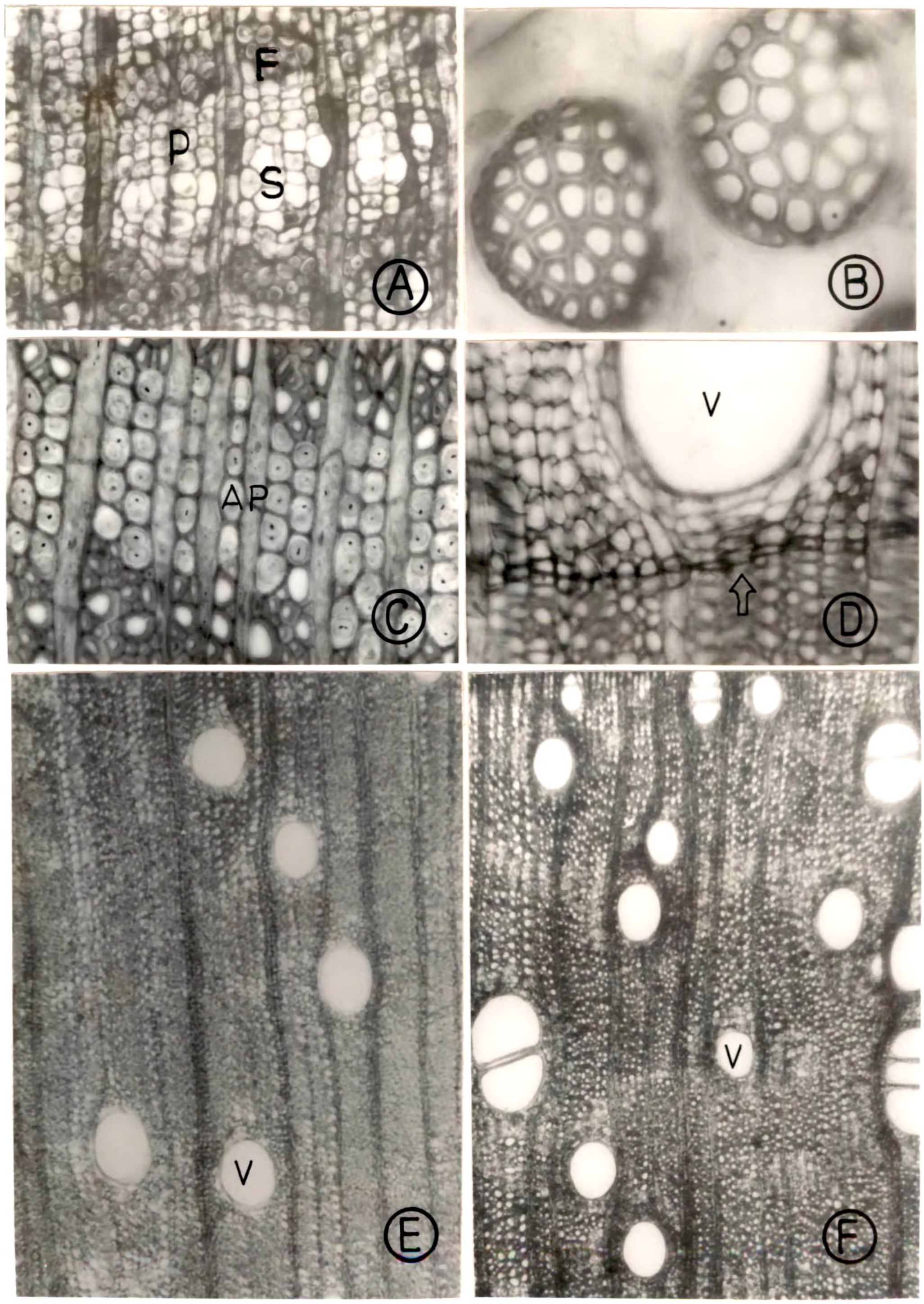


FIG. 8

Fig. 9

A-F: Radial longitudinal sections of xylem and phloem.

G-H: Transverse sections of branch.

A. Starch distribution in xylem parenchyma of normal trees in August. x 175.

B. Starch distribution in xylem parenchyma of affected trees in August. x 175.

C. Xylem axial parenchyma of normal trees with starch in Decem -ber. x 188.

D. Starch distribution in both axial and ray parenchyma of xylem of affected trees in December. x 188.

E. Starch distribution in axial and ray phloem parenchyma of normal trees in February. x 360.

F. Starch distribution in axial and ray phloem parenchyma of affected trees in February. x 420.

G. Starch distribution in young branch of normal trees. x 112.

H. Starch distribution in young branch of affected trees. x 112.

AP: Axial Parenchyma; P: Pith; RP: Ray Parenchyma; XY: Xylem

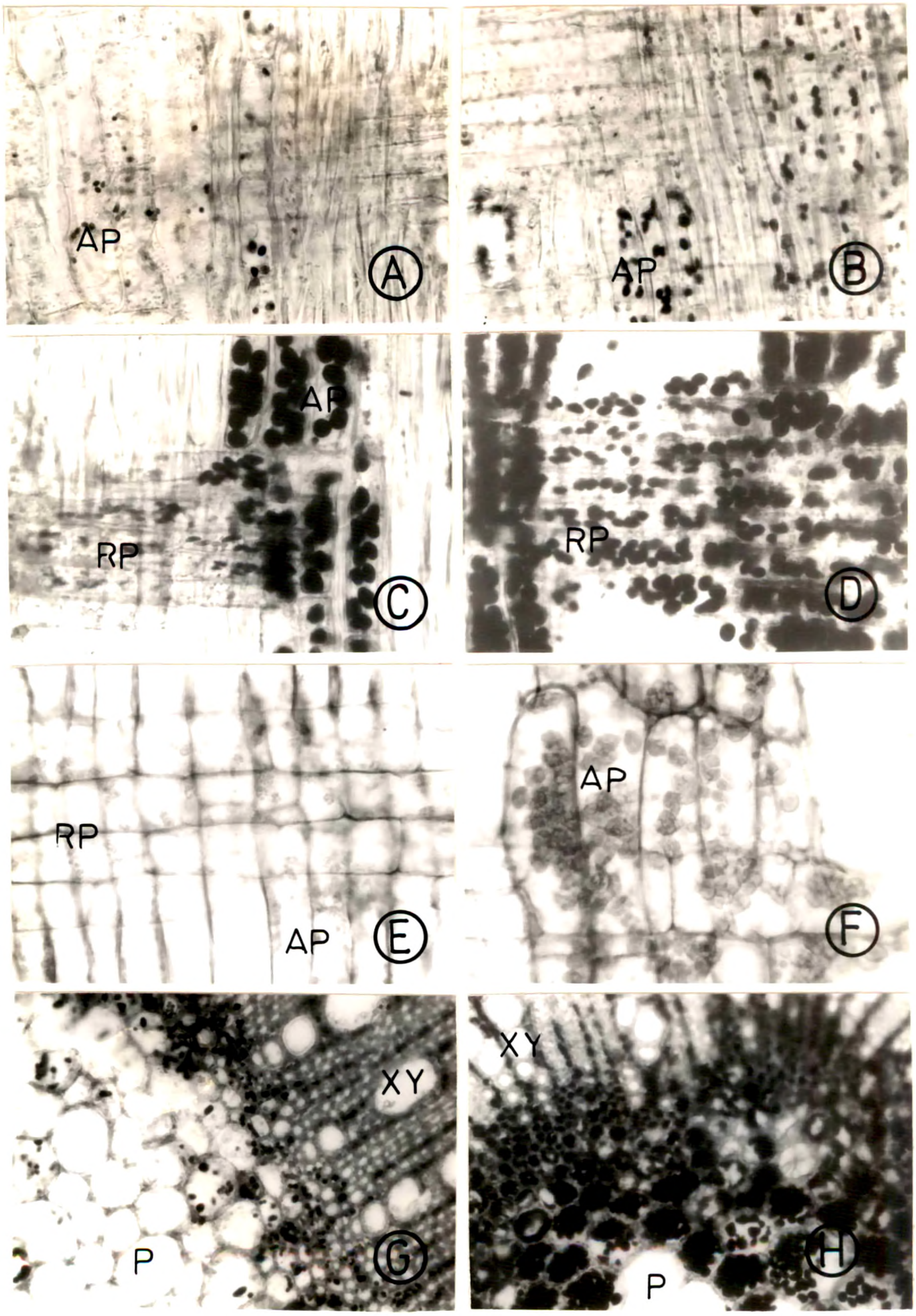


FIG. 9

Fig. 10

A-D: Radial longitudinal sections of cambium and its derivatives.

A. Distribution of total polysaccharides in cambial ray cells of normal trees. x 850.

B. Distribution of total polysaccharides in cambial ray cells of affected trees. x 850.

C. Distribution of oval and elongated total polysaccharides in axial and ray parenchyma cells of xylem. x 320.

D. Distribution of lipid bodies in fusiform cambial cells of affected trees. x 320.

AP: Axial Parenchyma; FC: Fusiform Cambial Cell; PH: Phloem; RC: Ray Cambial Cell; RP: Ray Parenchyma; Sg: Starch grains; XY: Xylem

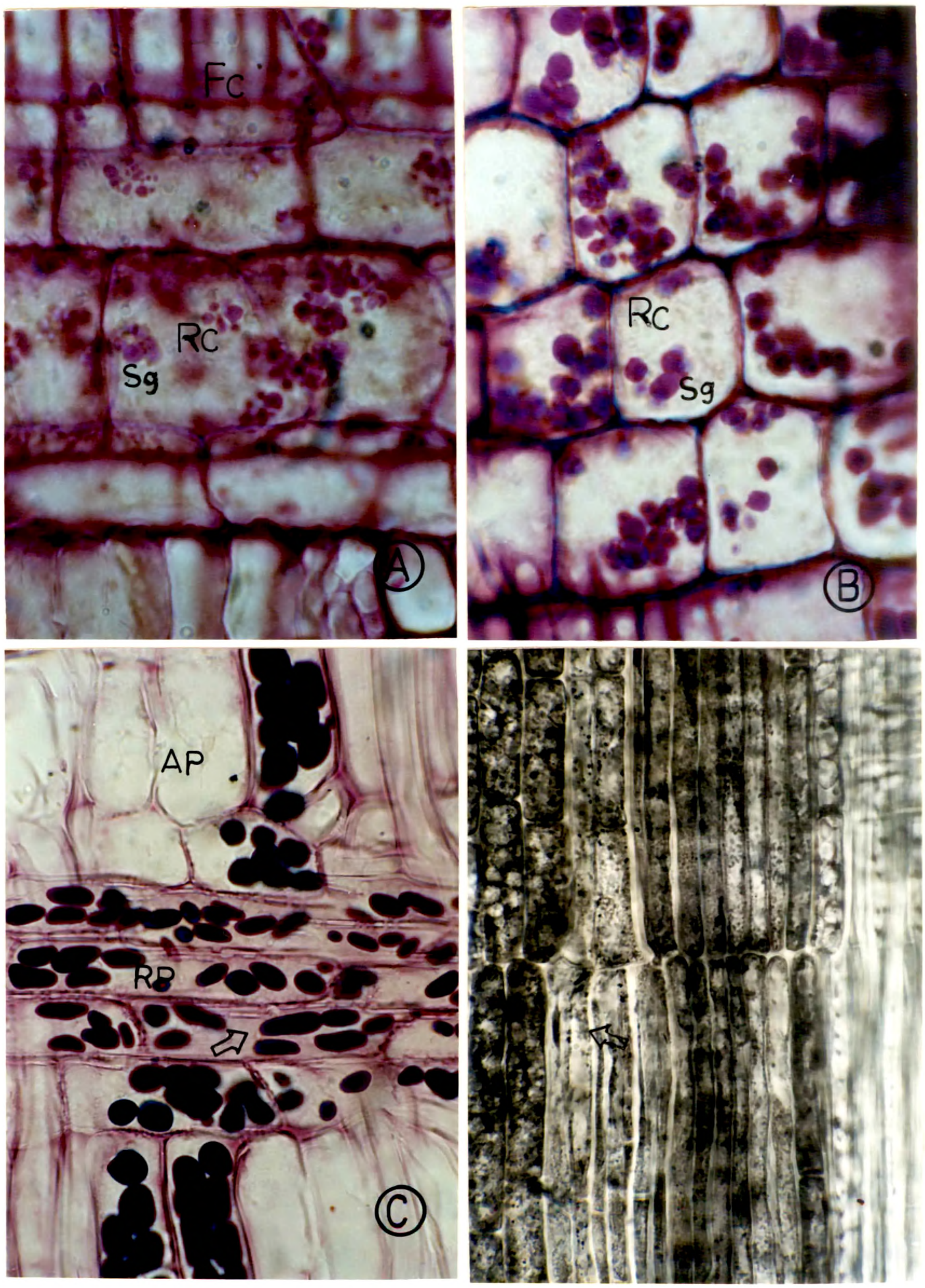


FIG. 10

Fig. 11

A-D: Transverse sections (unstained) viewed under Flourescence microscope.

E-F: Tangential longitudinal sections viewed under scanning electron microscope.

A. Phloem and xylem of normal trees with lignified cells as seen under fluorescent light. x 77.

B. Phloem and xylem of affected trees with lignified cells as seen under fluorescent light. x 96.

C. Xylem axial parenchyma and fibres showing lignified walls in normal trees. x 240.

D. Xylem axial parenchyma and fibres showing lignified walls in affected trees. x 240.

E. Vessel element lateral walls showing alternate pitting pat -tern. x 950.

F. Xylem ray parenchyma cells showing starch grains. x 3800.

AP: Axial Parenchyma; PH: Phloem; Sg: Starch grain; V: Vessel element

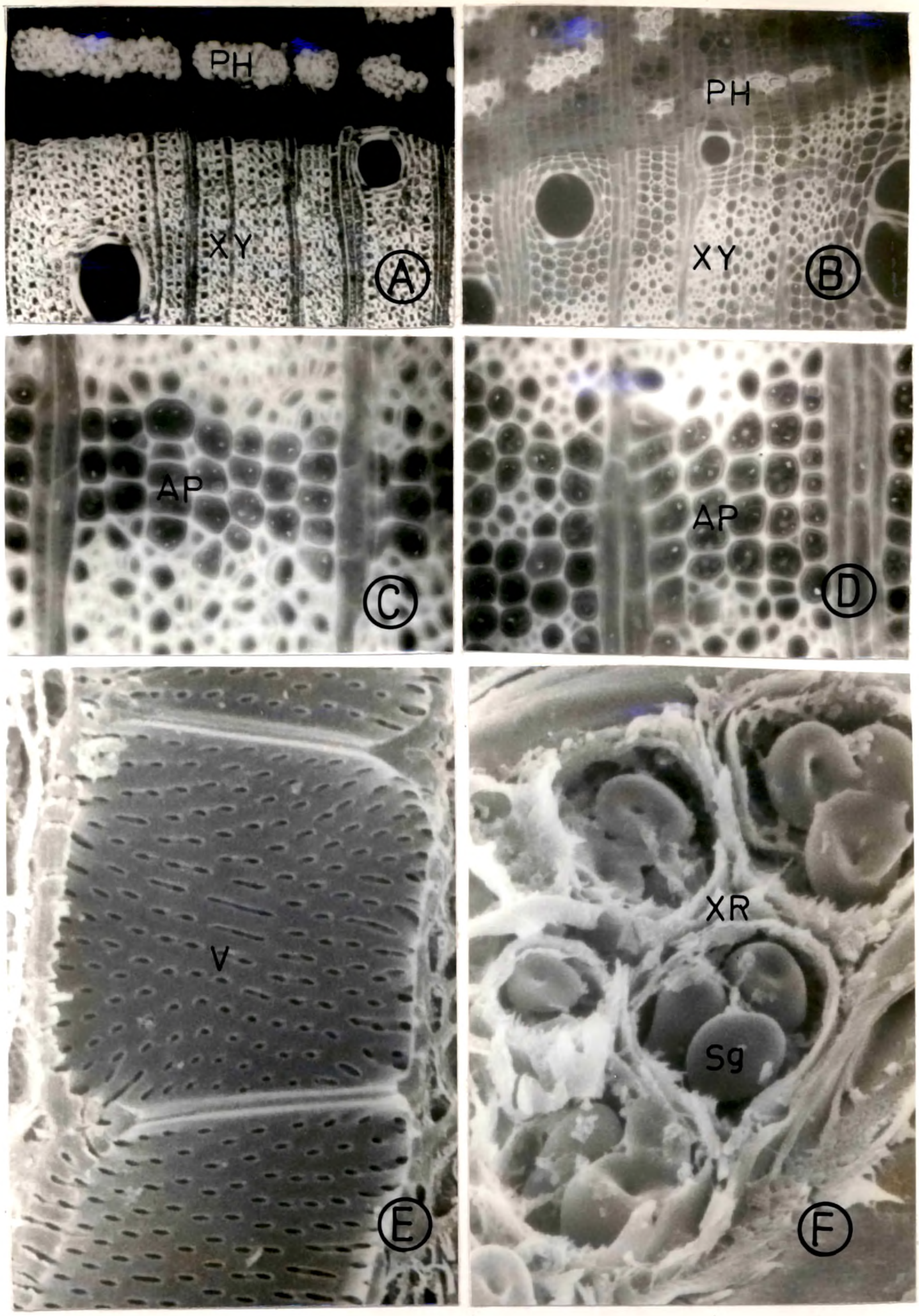


FIG. 11

Fig. 12.

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone in the main stem and young branch and differentiating xylem and phloem elements in the main stem of normal trees.

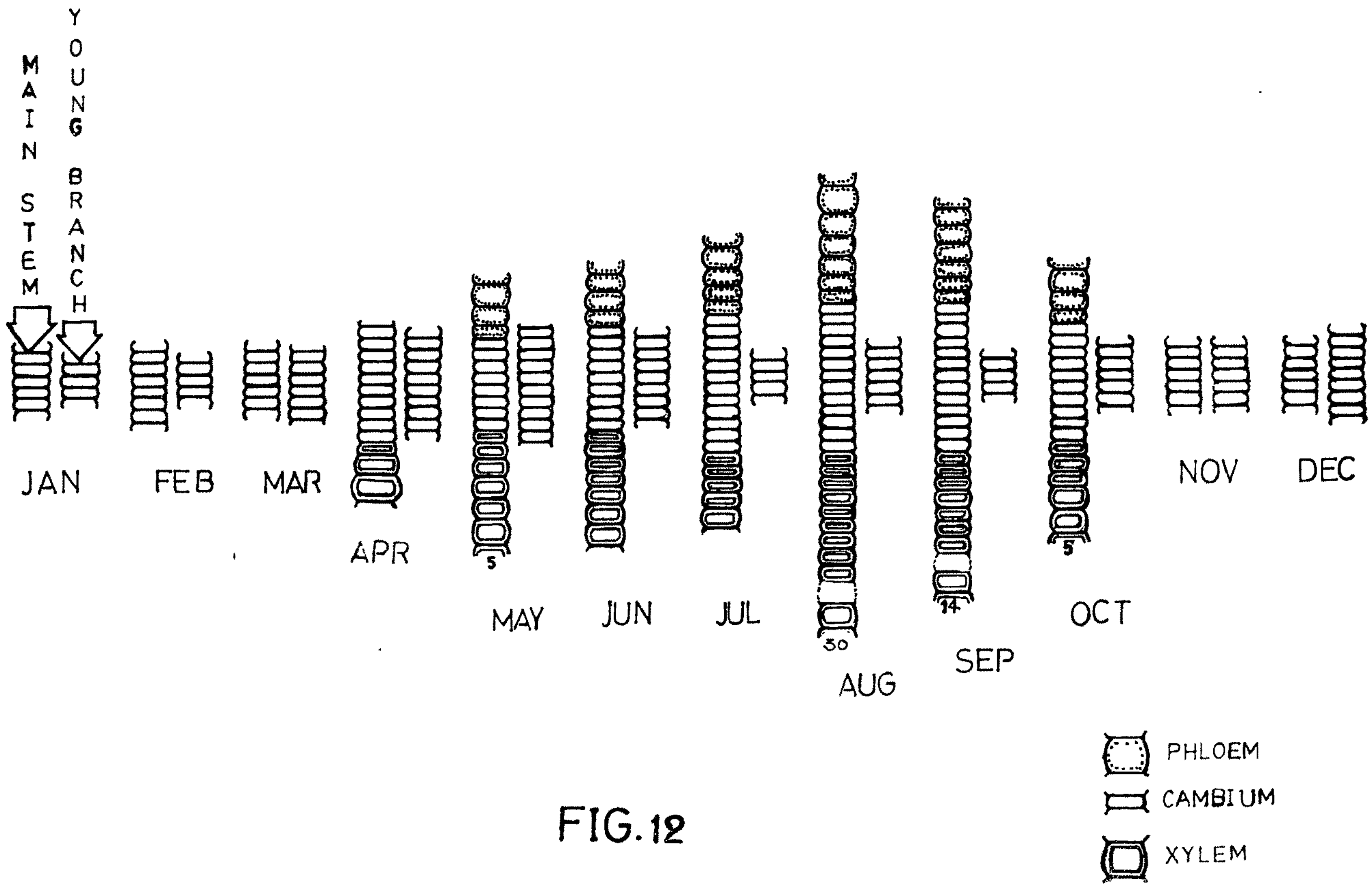

MAIN STEM
YOUNG BRANCH
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
5
30
14
5
PHLOEM
CAMBIUM
XYLEM

FIG.12

Fig. 13.

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone in the main stem and young branch and differentiating xylem and phloem elements in the main stem of affected trees.

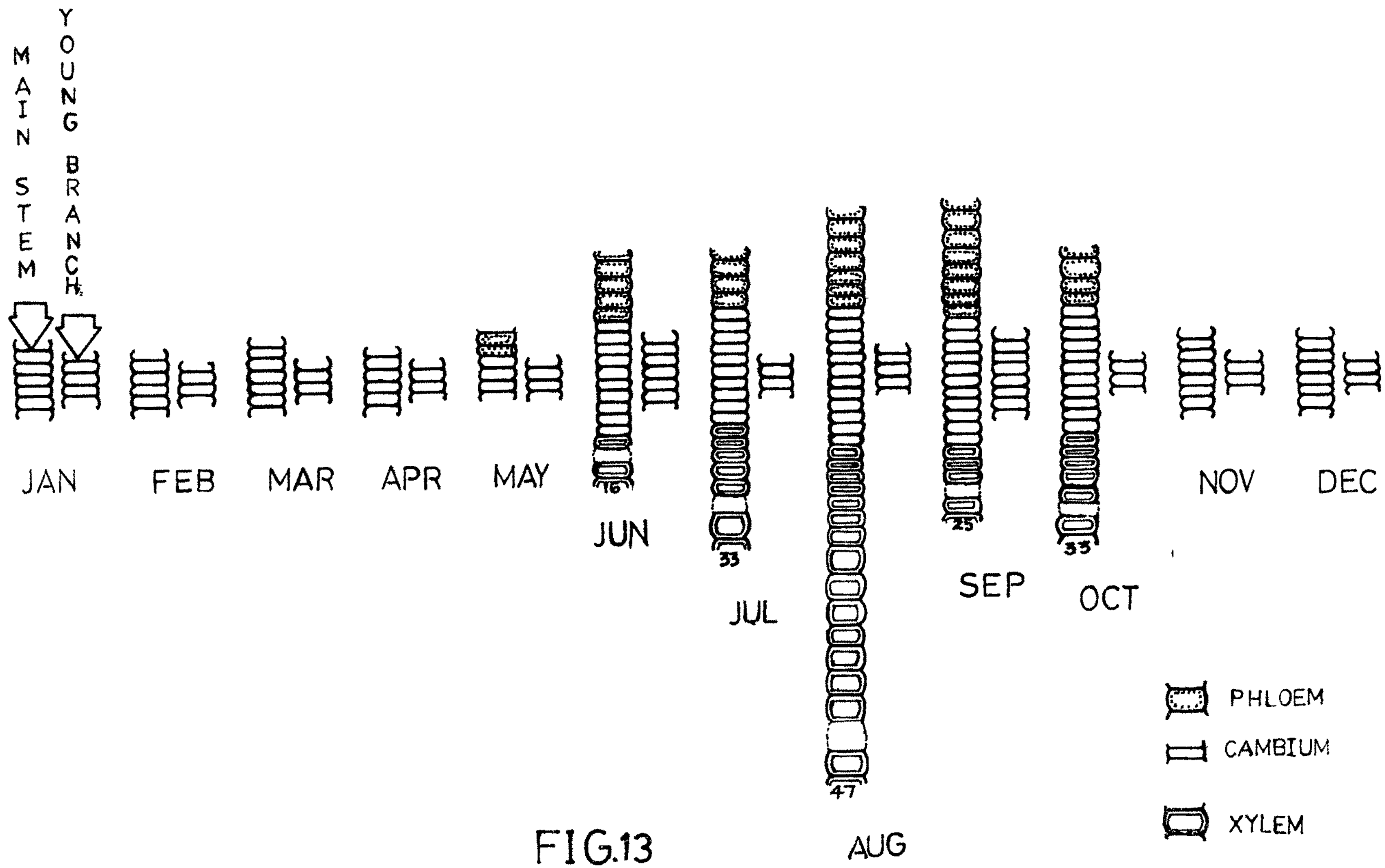

MAIN STEM
YOUNG BRANCH
JAN
FEB
MAR
APR
MAY
JUN
16
JUL
33
AUG
47
SEP
25
OCT
33
NOV
DEC
PHLOEM
CAMBIUM
XYLEM

FIG.13

Fig. 14.

Histogram showing seasonal variation in mean length of xylem fibres and fusiform cambial cells.

A: Normal B: Affected

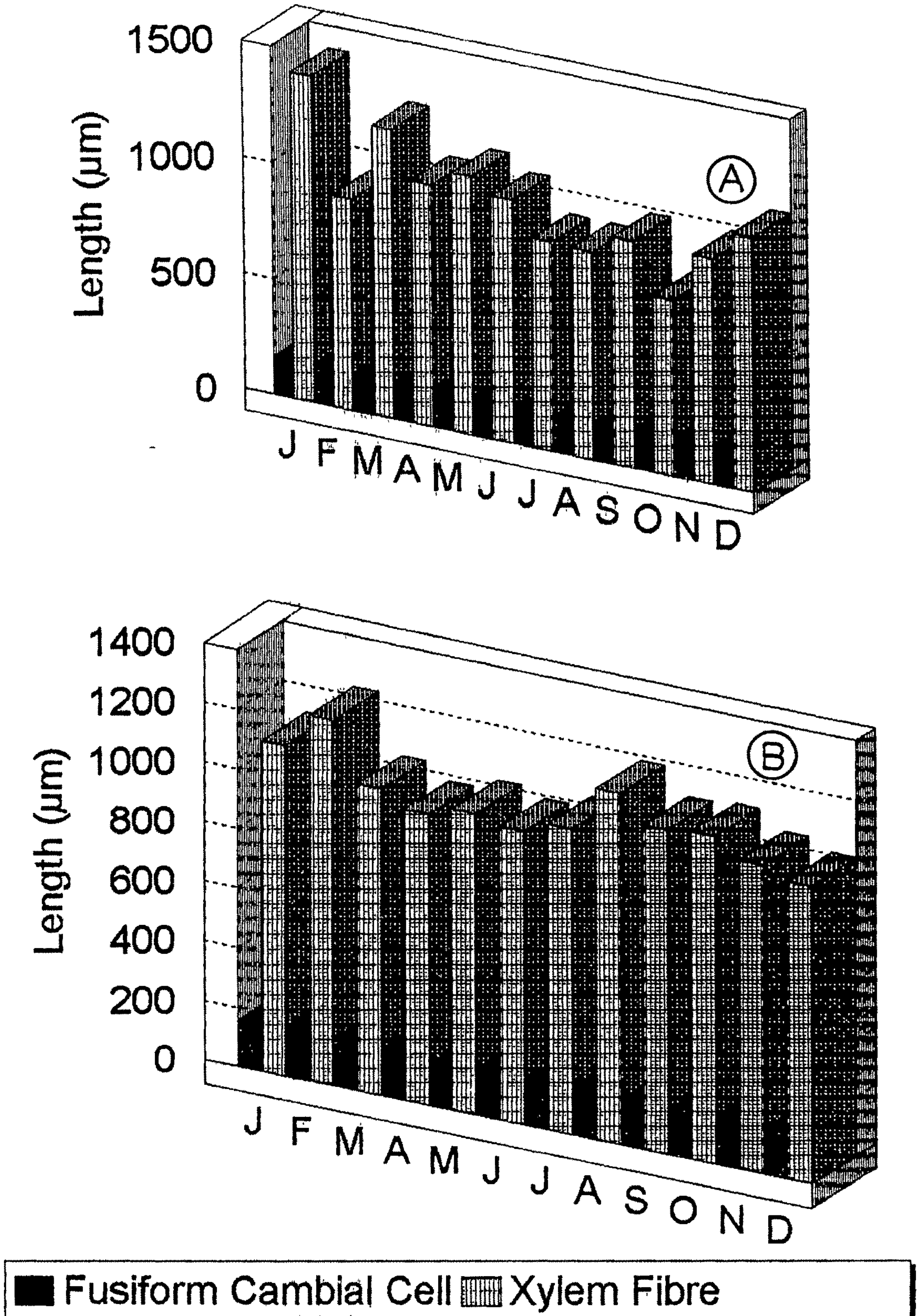

1500
1000
500
0
Length (µm)
A
J F M A M J J A S O N D
1400
1200
1000
800
600
400
200
0
Length (µm)
B
J F M A M J J A S O N D
Fusiform Cambial Cell
Xylem Fibre

FIG. 14

Fig. 15.

Graphic representation of seasonal variation in cambial ray height (A), width (B) and diameter of ray cells (C) in µm.

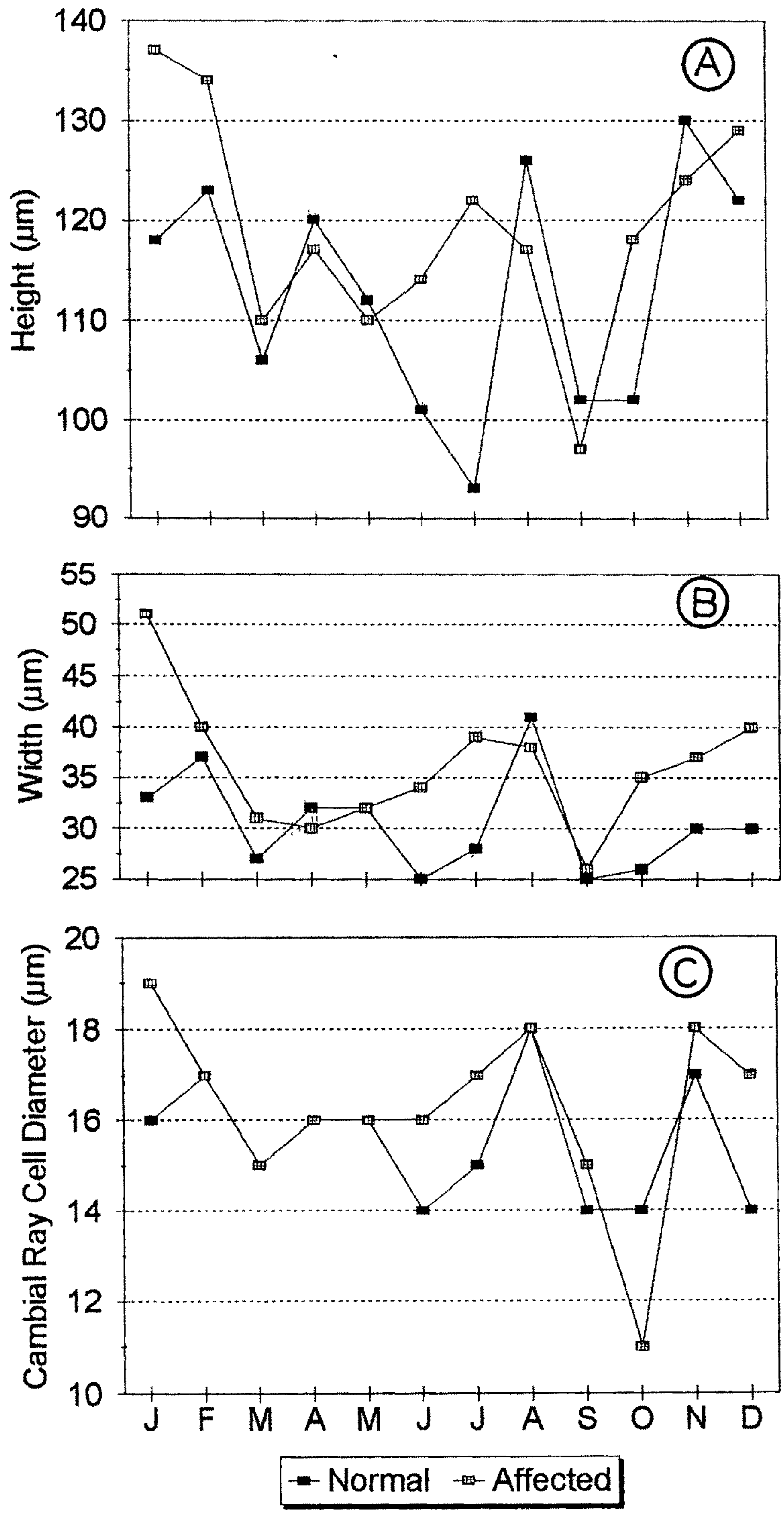
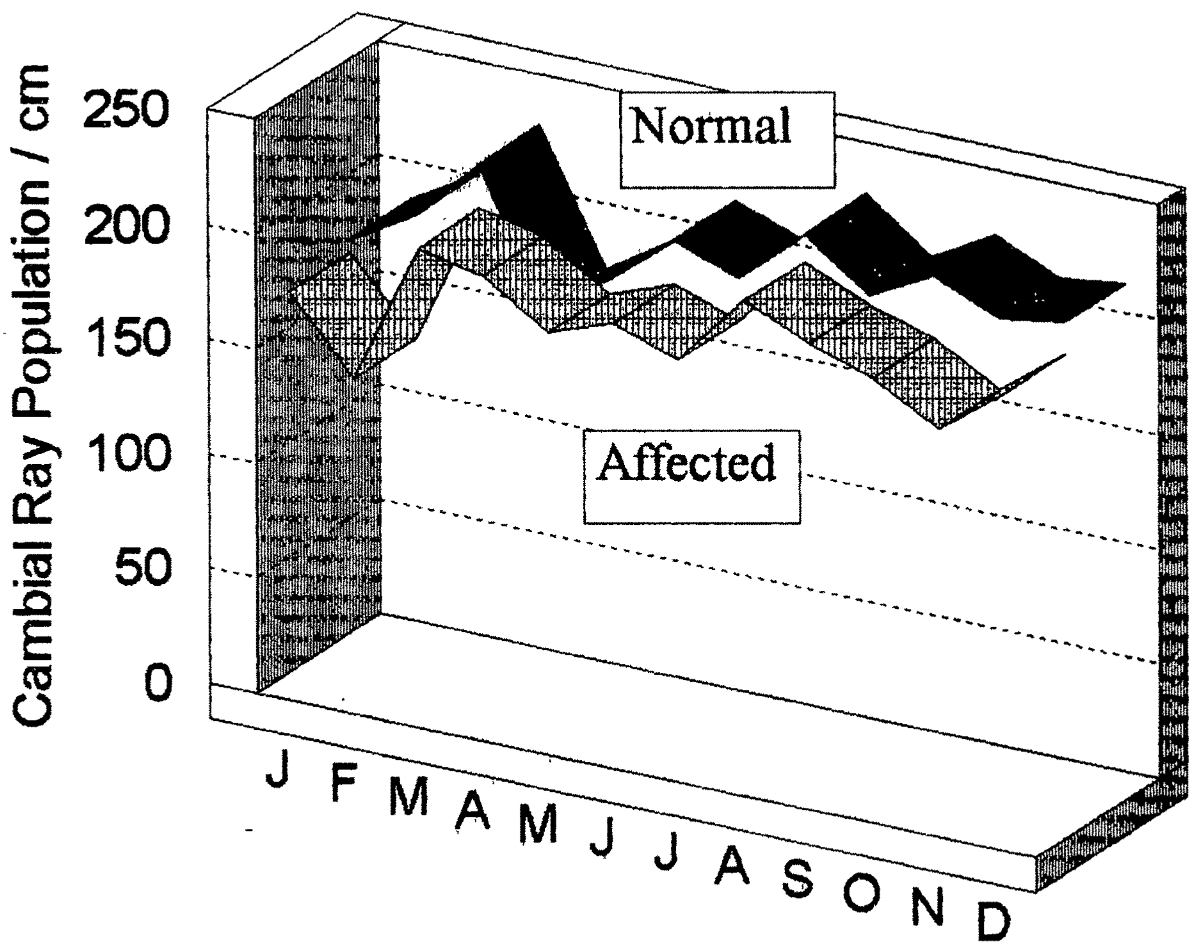

A
Height (μm)
140
130
120
110
100
90
B
Width (μm)
55
50
45
40
35
30
25
C
Cambial Ray Cell Diameter (μm)
20
18
16
14
12
10
J F M A M J J A S O N D
Normal
Affected

FIG.15

Fig. 16.

Histogram showing seasonal variation in cambial ray population in one cm tangential width of cambium.

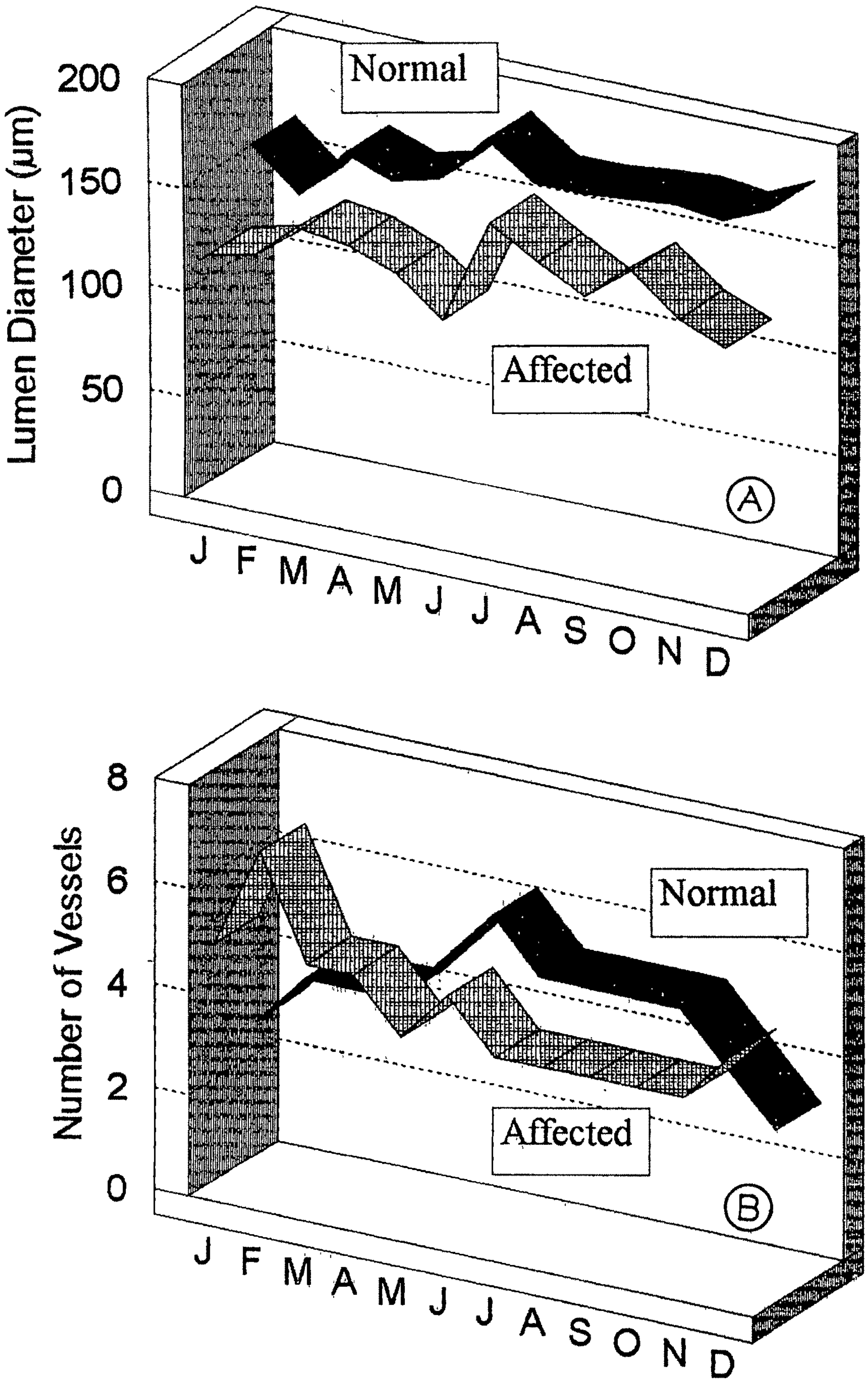


Cambial Ray Population / cm
250
200
150
100
50
0
Normal
Affected
J
F
M
A
M
J
J
A
S
O
N
D

FIG.16

Fig. 17.

Graphic representation of seasonal variation in vessel lumen diameter in µm (A) and number of vessels/0.5 mm^2 (B).



Lumen Diameter (μm)
200
150
100
50
0
Normal
Affected
A
J
F
M
A
M
J
J
A
S
O
N
D
Number of Vessels
8
6
4
2
0
Normal
Affected
B
J
F
M
A
M
J
J
A
S
O
N
D

FIG.17

<u>HOLOPTELEA</u> <u>INTEGRIFOLIA</u> (Roxb.) Planch.

A tall 15-20m high sometimes with buttressed base, common tree in deciduous forests all over India. It is usually known as Indian Elm tree or Kanju as a trade name, belongs to family Ulmaceae. Bark is grayish white with pustules. Leaves are elliptic point elongated, smooth with entire margin and round base. Flowers are minute greenish yellow, polygamous in short racemes or pyramidal clusters. Fruit is a sub-orbiculur samara with membranous wing and edible seed flat like a coin. The fruits rain down in the breeze during May-June. The wood is diffuse porous, light yellow with pleasant odor when freshly cut. No distinct heart wood. Employed in building for casts carving. Much used for fuel and charcoal. Durability uncertain.

NORMAL TREES

CAMBIAL STRUCTURE:

Cambium in <u>Holoptelea</u> is storied comprising of two types of cells. 1) Fusiform cambial cells which are arranged in definite vertical rows or tiers. 2) Cambial ray cells which are short isodiametric or horizontally elongated and clustered in groups (Fig. 20 A). The cambial initials and their immediate derivatives form cambial zone. Cambium is not active throughout the year but shows variation, resulting in two periods of growth-the active and dormant. Cambial zone is narrow during dormant period with radial files having 4 to 7 layers of cells and wide during active period with 4 to 13 layers of cells (Fig. 25). Periclinal and anticlinal divisions occur in cambial zone cells leading to an increment in the vascular tissues and cambial cylinder. Radial walls are thick with beaded pattern during dormant period (Fig. 20 C).

CAMBIAL ACTIVITY:

Cambial activity occurs in two growth flushes during the annual growth. It is initiated first in March (Fig. 18 A, B) and declines in the first week of April (Fig. 18 C). The second flush of activity begins with bulging of cambial cells towards xylem in May, with differentiating xylem elements in June (Fig. 18 D) and reaches peak in August (Fig. 18 E, F). Cambial activity is sluggish in October (Fig. 18 G) and ceases in November-December (Fig. 18 H, I). Cambial zone is with 4 to 7 layers of cells during dormant period and 8 to 13 layered during the peak activity in August.

In young branches cambium shows three growth flushes i.e. March, May to October and December. In all the three flushes the cambial zone is wide with many layers of cambial cells. Cambial cell divisions are maximal in August (Fig. 25 and Table 7).

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

The trees undergo defoliation in January-February. Cambium remains dormant during this period. Young leaves develop from March to June. During this period except in April, the cambium is fairly active. Cambial cell division reaches maximum when trees are with full foliage in August. On maturation of leaves in November, cambial activity declines and activity ceases with drying of leaves in December. Fruiting coincides with the reacrtivation of cambium in March.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

The reactivation of Cambium occurs in March when the mean maximum temperature is 34^{o}. The second flush of activity begins in May when the maximum temperature is 38.8^{o} along with fairly high (67) relative humidity. The cambial activity reaches peak in August when the season's highest rainfall (461mm) occurred. As the maximum temperature decreases, the cambium enters dormancy condition in November. The meteorological data is presented in Figure 1 and 2.

FUSIFORM CAMBIAL CELLS:

In tangential sections, fusiform cambial cells are short, roughly hexangular in outline with abruptly tapering ends. They are arranged in more or less definite horizontal rows or storeys (Fig. 20 A). At times the storied arrangement seems to be disturbed due to the elongation of the tips of the cells beyond the limit of the storey. This appears as an intermediate stage of cambium between storied and nonstoried condition. The cells are arranged in radial rows and are rectangular in transverse sections. The radial walls are thicker than tangential ones.

DIVISIONAL ACTIVITY:

Divisions of cambial cells form new xylem, phloem and cambium itself. The former is accomplished by periclinal divisions and latter by anticlinal divisions. Periclinally dividing fusiform cambial cells reveal phragmoplast on either side of tangentially growing cell walls. Such newly growing cell walls are commonly noticed during peak activity of cambium (fig. 20 D). Anticlinal divisions in cambial zone results daughter cells lying side by side maintaining the storied arrangement. However, the daughter cells enlarge tangentially which necessitates the radial expansion of cambial cylinder.

DIMENSIONAL CHANGES:

MEAN LENGTH:

The mean length of fusiform cambial cells undergoes changes during the periodicity of cambium. The average length increases from January to February and declines in March, when the cambial reactivation occurs. The length gradually decreases from July to August with an abrupt increase in September. At the end of second flush of cambial activity, cell length decreases in November and then increases in December. The minimum and maximum length of the cells are 200 um and 272 um in March and October respectively (Table 8).

MEAN WIDTH:

The tangential width of fusiform cambial cells doesn't vary much during the periodicity of cambium. The width increases from January to April and decreases in May. After a marginal increase in August the mean width remains same till the end of second flush of activity. The mean minimum and maximum width of cells are 12 µm and 16 µm in April and June respectively (Table 8).

LENGTH VARIATION IN RELATION TO XYLEM FIBRE LENGTH:

The mean length of fusiform cambial cells and xylem fibres are more or less closely related throughout the year. The length of xylem fibres is greater than that of fusiform cambial cells (Table 8). Fibres are 4.2 to 5.6 times longer than fusiform cambial cells during the annual growth period. In October, the mean length of fusiform cabial cell and xylem fibre are highest measuring 272 µm and 1302 µm respectively. Seasonal changes in length of fusiform cambial cells and xylem fibres are presented in Figure 27 A.

CAMBIAL RAY CELLS:

Cambial ray cells are almost isodiametric or slightly elongated in the radial direction. Rays are storied and are uni, bi and multiseriate. However, multiseriate rays are predominant in the cambium. Sheath cells are present at the margins of the rays. The protoplasm of cambial ray cells contain ergastic substances like starch, lipid and protein bodies (Fig. 20 C). Cambial rays undergo both the vertical and tangential fusion.

DIVISIONAL ACTIVITY:

Cambial ray cells originate by divisions of fusiform cambial cells. Either a complete or a part of fusiform cambial cell undergoes divisions forming cambial ray cell initial. A short cambial ray cell intial formed by lateral anticlinal division of fusiform cambial cell also gives rise to cambial ray cells.

DIMENSIONAL CHANGES:

CAMBIAL RAY HEIGHT:

The cambial ray height varies from 114 µm to 210 µm during the seasonal cycle. The ray height increases along with the length of fusiform cambial cells from January to February. During the second flush of activity the ray height decreases and reaches minimum in June. There is a gradual increase in ray height from July to September and the height decreases in October. The ray height increases sharply in November and reaches maximum in December (Table 10).

CAMBIAL RAY WIDTH:

The cambial ray width ranges from 24 µm to 37 µm. Ray width increases from January to February, then in remaining months, it decreases and increases alternately (Table 10).

CAMBIAL RAY CELL DIAMETER:

The average diameter of the cells increases from January to February and then decreases during first flush of activity. The mean maximum and minimum cambial ray cell diameter is 15 µm and 12 µm respectively (Table 10).

The variation in ray height, width of cambial ray and diameter of cambial ray cell is represented in Figure 28.

CAMBIAL RAY POPULATION:

The average number of rays per one cm tangential width of cambium ranges from 133 to 159. The variation in number of cambial rays do not show any appreciable relation with cambial activity and dormancy. The ray population increases and decreases alternately from January to April. The average number increases in October, remains same in November and decreases in December. The number of rays occurring in different months is presented in Table 10 and Figure 29.

DEVELOPMENT OF VASCULAR TISSUES:

Periclinal divisions in the cambial zone cells give rise to new cells towards phloem and xylem. Divisions occur in the cells adjacent to both phloem and xylem side. During the first flush of activity both xylem and phloem derivatives are produced and the activity ceases temporarily in April. The second flush of activity starts in May, where a few periclinal divisions occur on xylem side of cambium. Differentiation of xylem precedes that of phloem. The rate of cell differentiation exceeds that of cell divisions in cambial zone in June (Figs. 18 D and 25). The number of differentiating phloem elements are maximal in the month of August. The cambial cell division and differentiation cease in November and December respectively.

The phloem derivatives develop into sieve tube elements, companion cells and parenchyma cells. Sieve tube elements alternate with phloem parenchyma (Fig. 21 A). Discontinuous phloem fibre groups are found abundantly in non-functional phloem (Fig. 24 C). The last formed functional phloem elements close to the cambial zone lack fibres. Sieve tube elements are with simple sieve plates and linear solitary lateral sieve areas. P-protein is copious and occurs as a plug near the sieve plate. Phloem parenchyma cells are grouped in definite bands and often seen filled with rhomboid crystals. Phloem anastomoses with short sieve tube elements are commonly found (Fig. 21 C).

The xylem derivatives from cambium, differentiate into vessel members, parenchyma cells and fibres. The xylem is of diffuse porous type with solitary and radial multiple vessels. The xylem parenchyma is aliform confluent narrow type, where the parenchyma connecting adjacent pores is very thin and narrow. Vessels are interspersed inbetween the tangential fibre bands (Fig. 24 A).

DEVELOPMENT, LENGTH AND WIDTH OF VESSEL ELEMENTS:

Xylem derivatives differentiate twice during the annual growth of cambium. Vessels are mostly solitary (Fig. 21 E). Mean length of vessel elements is maximal(278 µm) in July and minimal(215 µm) in March. The average length of fusiform cambial cells and vessel elements is minimal in March. The mean length decreases and increases alternately from May to December. The average width is less than the average length of vessel elements. The mean width is lowest (95 µm) in March and highest (139 µm) in September.

VESSEL LUMEN DIAMETER:

The average vessel lumen diameter is more at the end of second flush of activity. During reactivation of cambium in both the flushes, the average diameter is less. The mean lumen diameter ranges from 95.8 µm to 131 µm during the year. The variations in lumen diameter are represented in figure 30 A.

NUMBER OF VESSELS:

The average number of vessels per 0.5 mm^2 ranges from 7 to 9 during the year. The number is highest prior to the first and second flush of activity and is lowest during the peak activity of the cambium (Fig. 30 B).

The average length, width and lumen diameter of vessel elements and number of vessels in each month are represented in Table 9.

GROWTH RING WIDTH:

Growth rings in xylem are clearly visible when observed under microscope (Fig. 44 C). The amount of annual xylem increment in two successive years i. e. during 1989 and 1990 is 4.1 mm and 4.8 mm respectively (Table 19). The boundary between two growth rings could easily be identified due to the variation in vessel lumen diameter (Fig. 21 D).

HISTOCHEMISTRY:

STARCH:

Fusiform cambial cells contain much smaller grains of starch when the cambium is dormant. However, cambial ray cell possess starch all round the year (Table 11). The xylem parenchyma of main stem are loaded with abundant starch prior to the cambial activity. The low accumulation of starch in March (Fig. 22 A) followed by total absence of starch in April coincides with the first flush of cambial activity. The axial and ray parenchyma of current year's xylem are loaded with more starch in the beginning of second flush of activity (Fig. 22 C) followed by total absence till the end of cambial activity (Table 11). The starch grains are round or oval in both the axial and ray parenchyma cells. The phloem starch accumulation is more before the initiation and cessation of cambial activity. However, starch is low during the cambial cell division and differentiation (Fig. 22 E).

In young branches starch content of xylem parenchyma is more before the initiation and after the cessation of cambial cell divisions. But, during cambial growth, the axial and ray parenchyma are devoid of starch (Fig. 22 G). Similar pattern of starch accumulation is found in phloem parenchyma also. The accumulation of starch in pith cells is less during dormant and more during active periods of cambium (Fig. 23 G, I).

LIPIDS:

Lipid bodies are located in both fusiform and ray cambial cells during dormant period of cambium. Lipid body size is relatively larger in cambial ray cells (Fig. 23 A). In active cambial cells Lipid accumulation is less (Fig. 23 C).

PROTEINS:

Proteins bodies are found in both fusiform and ray cambial cells of dormant cambium. They are present mostly along the walls of cambial cells (Fig. 23 E).

AFFECTED TREES

CAMBIAL STRUCTURE:

The structure of cambium with storied fusiform and ray cambial cells, is similar to that of normal trees (Fig. 20 B). During dormant period the cambial zone is narrow with 3 to 8 layers of cells in each radial file, while active cambial zone is wide with 4 to 13 layers of cells (Fig. 26). However, in transverse sections, cambial zone is not as wide as it is found in normal trees.

CAMBIAL ACTIVITY:

During the annual cycle only one flush of cell divisions occurs in cambium. After a period of dormancy from January to August (Fig. 19 A-D), cell divisions in fusiform cambial cells starts in September (Fig. 19 E). However, swelling of cells in May and cell divisions at few pockets of cambial zone in June and August are noticed. Cambial cell divisions are maximum in October (Fig. 19 F, G). The cell division and differentiation slow down in November, but remain active in December with a maximum number of cells in cambial zone (Fig. 19 H).

In young branches cambium is active from June to July with 3 to 6 layers, from September to October with 4 to 8 layers and in December with 4 to 9 layers of cells. In the intervening months the cambium remains inactive (Table 7).

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

Partial defoliation occurs twice during the year in affected trees. Older leaves fall off and new ones develop simultaneously in February. Partial defoliation takes place again in June. Timing of flowering and fruiting is similar to that of normal trees. The cambium is active when the trees are with full foliage. Browning, bleaching of leaves and drying of terminal shoots are observed. Visible symptoms of pollution injury, generally appears in mature leaves. Cambium remains dormant relatively for longer period in affected trees. During this period, the trees are either with full foliage or partially defoliated (Table 7).

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

Fusiform cambial cells undergo swelling with no apparent cell division and differentiation in May when the average maximum temperature is high ($38.8^{o}C$) with 35.5 mm rainfall. Divisions occur at a few pockets of cambial zone in June and August, though the average rainfall is more (Fig. 4). Cambial activity begins in September, when the mean maximum temperature is raised marginally from August. Maximum cambial cell divisions occur when the mean maximum temperature is $34.2^{o}C$ and the average sunshine hours are 9.2. Though the mean maximum and minimum temperatures gradually decrease in November and December, the cambial activity in the dry months is continued (Fig. 19 H).

FUSIFORM CAMBIAL CELLS:

The gross morphology and arrangement of fusiform cambial cells of affected trees are similar to that of normal trees (Fig. 20 B).

DIVISIONAL ACTIVITY:

Periclinal divisions occur in September after a long period of dormancy from January. Anticlinal divisions also occur when periclinal divisions are taking place in the cambial zone.

DIMENSIONAL CHANGES:

MEAN LENGTH:

The mean length of fusiform cambial cells shows variations during active and dormant periods. The mean length is minimal (215 μm) in January when the cambium is dormant and it is maximal (276 μm) in November when the cambium is active. The mean length of the cells of affected trees is more or less similar to that of normal trees (Table 8).

MEAN WIDTH:

The mean tangential width decreases in June and reaches to minimum (12 μm) in July. During active cambial cell division, no variation in mean width is observed. The mean maximum width of fusiform cambial cell is 17 μm in January. The yearly averages of cell width is similar (13 μm) in normal and affected trees (Table 20)

LENGTH VARIATION IN RELATION TO XYLEM FIBRE LENGTH:

The average length of fibres is less in affected trees and it ranges from 986 µm to 1251 µm. Fibres are 3.6 to 5.1 times longer than fusiform cambial cells in different months of the year. The length variations in fusiform cambial cells and xylem fibres are not comparable with each other during the seasonal cycle (Table 8).

The mean lengths of fusiform cambial cells and xylem fibres are represented in Figure 27 B.

CAMBIAL RAY CELLS:

The general structure and divisional activity of cambial ray cells of affected trees are similar to that of normal ones (Fig. 20 B).

DIMENSIONAL CHANGES:

CAMBIAL RAY HEIGHT:

The yearly average of ray height is less in affected trees. The mean ray height is maximum (180 µm) in December and minimum (126 µm) in July. It is more or less similar from January to March. The ray height increases in April and then decreases sharply in May. Then it decreases and increases alternately in the remaining months and remains maximum at the end of second flush of cambial activity (Table 10).

CAMBIAL RAY WIDTH:

The mean ray width is more during dormant period and less in active period . The average ray width ranges from 24 µm to 35 µm. The width gradually decreases from January to July and remains more or less similar till December (Table 10).

CAMBIAL RAY CELL DIAMETER:

The mean cambial ray cell diameter increases and decreases alternately from Januvary to December. The mean diameter is more (12 to 16 µm) during dormant period and is less (12 to 14 µm) during active period (Table 10).

CAMBIAL RAY POPULATION:

The average number of cambial rays passing through one cm tangential width is higher in affected trees. The maximum and minimum number of rays are 199 and 140 in September and January respectively. In June, the ray number increases sharply (Table 10).

The variations in average height and width of rays, cambial ray cell diameter and the ray population are represented in Figures 28 and 29.

DEVELOPMENT OF VASCULAR TISSUES:

Xylem differentiation precedes that of Phloem by a month. Phloem differentiates from cambium in October and December. However, no differentiating elements are found in November. Differentiation of xylem elements begin in September and continues upto December. The number of differentiating xylem (12 to 24) and Phloem (4 to 6) elements are maximal in October. The gross structure of Phloem and xylem is similar to that of normal trees (Fig. 24 B). Callose deposits in large amounts on sieveplates and the sieve elements are partially filled with callose at the end of growth season (Figs. 21 B, 24 D).

DEVELOPMENT, LENGTH AND WIDTH OF VESSEL ELEMENTS:

Vessels are predominantly arranged in radial multiples. The first formed vessel elements are wider compared to the later formed ones. This variation facilitates the easy discernibility of Xylem growth ring boundary. The mean length of vessel elements is maximum (259 µm) in February minimum (196 µm) in October. The average length decreases in June and September. During the annual cycle the average width of vessel elements ranges from 82 µm to 133 µm.

VESSEL LUMEN DIAMETER:

The average lumen diameter is less in affected trees (Fig 30 A and Table 9). Prior to the cambial reactivation (August), the lumen diameter is minimal (64 µm) and it is maximum (121 µm) in April.

NUMBER OF VESSELS:

The average number of vessels per 0.5 mm^2 of xylem is more in comparison to normal trees (Fig. 21 F) in all the months of the year. It ranges from 11 to 15 (Fig. 30 B).

The length, width, lumen diameter of vessel elements and the number of vessels are represented in Table 9.

GROWTH RING WIDTH:

The width of the annual increment of xylem is less in affected trees (Fig.44 D). The xylem ring produce during current years and last year's cambial growth is measured and represented in Table 19.

HISTOCHEMISTRY:

STARCH:

Fusiform cambial cells possess small granules of starch during cambial dormancy. Where as in cambial ray cells, the starch grains are present during both the dormant and active periods. However, both the cells and rays (Xylem and Phloem) are devoid of starch from June to September. The axial and ray parenchyma cells of xylem are loaded with abundant starch before the commencement of cambial growth (Fig. 22 B). The starch content, however, is low in these cells during peak activitiy of cambium. Though the cambium is not active from June to September, the xylem parenchyma of previous growth has negligible amount of starch (Fig. 22 D). Starch content is higher in phloem before and at the end of cambial activity (Fig. 22 F). In vascular tissues it becomes reduced before the start of cambial growth in August. Apparently starch accumulation is more in the main stem of affected trees.

In young branch, xylem parenchyma accumulates more starch during dormant period (Fig. 22 H). Phloem starch content is more before and at the end of cambium growth. The pith cells also accumulate high amount of starch (Fig. 23 H). During active periods of cambium pith cells have more amount of tannins (Fig. 23 J).

LIPIDS:

During dormant period, the lipid accumulation is more in both the cambial cells (Fig. 23 B). However, no lipid bodies are found in the cells during active growth (Fig. 23 D).

PROTEINS:

Small protein bodies are found in fusiform cambial cells. They are localised in active fusiform cells. Much variation is not found in distribution of protein content in cambial cells of normal and affected trees (Fig. 23 F).

TABLE 7 : SHOWING THE DATA ON PHENOLOGY, AVERAGE NUMBER OF CAMBIAL LAYERS AND DIFFERENTIATING XYLEM AND PHLOEM ELEMENTS IN NORMAL (N) AND AFFECTED (A) TREES O **HOLOPTELEA INTEGRIFOLIA**

	PHENOLOGY		CAMBIAL LAYERS MAIN STEM		CAMBIAL LAYERS YOUNG BRANCH		XYLEM		PHLOEM	
Month	N	A	N	A	N	A	N	A	N	A
JAN	PARTIAL DEFOLIATION	FULL FOLIAGE	5.4 ±0.76	5.7 ±0.72	4.0 ±0.40	4.0 ±0.51	-	-	-	-
FEB	PARTIAL DEFOLIATION FLOWERING	PARTIAL DEFOLIATION	5.6 ±0.66	5.6 ±0.77	4.2 ±0.62	4.0 ±0.46	-	-	-	-
MAR	DEVELOPMENT OF NEW LEAVES AND FRUITING	FULL FOLIAGE AND FRUITING	8.0 ±1.15	4.5 ±0.80	6.4 ±0.66	4.0 ±0.56	12.0 ±2.57	-	2.0 ±0.35	-
APR	FULL FOLIAGE	FULL FOLIAGE	5.5 ±0.84	5.8 ±1.05	4.2 ±0.76	4.0 ±0.80	-	-	-	-
MAY	FULL FOLIAGE	FULL FOLIAGE	8.0 ±1.76	4.9 ±1.12	7.2 ±0.95	4.0 ±0.46	4.0 ±1.51	-	-	-
JUN	FULL FOLIAGE	PARTIAL DEFOLIATION	6.6 ±1.56	4.6 ±0.84	5.0 ±0.99	5.0 ±1.15	29.0 ±4.38	-	-	-
JUL	FULL FOLLAGE	PARTIAL DEFOLIATION	7.8 ±1.20	6.0 ±0.67	6.4 ±0.94	5.2 ±0.84	18.0 ±4.69	-	3.5 ±0.56	-
AUG	FULL FOLIAGE	FULL FOLIAGE	10.0 ±1.56	7.0 ±1.16	8.0 ±1.76	4.2 ±0.46	22.0 ±3.91	-	5.0 ±0.66	-
SEP	FULL FOLIAGE	FULL FOLIAGE	7.6 ±0.99	6.6 ±1.32	4.5 ±0.80	4.5 ±0.92	17.0 ±3.06	3.0 ±0.82	4.0 ±1.17	-
OCT	FULL FOLIAGE	FULL FOLIAGE	9.3 ±1.53	9.0 ±1.47	4.0 ±0.76	4.0 ±0.90	14.0 ±2.15	14.0 ±3.45	3.0 ±0.96	5.0 ±1.15
NOV	FULL FOLIAGE	FULL FOLIAGE	7.0 ±0.95	9.0 ±1.30	4.0 ±0.56	3.4 ±0.42	4.0 ±0.89	7.0 ±1.80	-	-
DEC	FULL FOLIAGE	FULL FOLIAGE	5.8 ±0.99	8.0 ±1.53	5.4 ±1.05	5.4 ±0.74	4.0 ±1.17	17.0 ±2.29	-	3.0 ±0.64

TABLE 8 : SHOWING THE DIMENSIONAL DETAILS OF FUSIFORM CAMBIAL CELLS AND XYLEM FIBRES IN NORMAL (N) AND AFFECTED (A) TREES OF **HOLOPTELEA INTERGRIFOLIA**

MONTH	FUSIFORM CAMBIAL CELLS LENGTH (um)		FUSIFORM CAMBIAL CELLS WIDTH(um)		XYLEM FIBRES LENGTH (um)	
	N	A	N	A	N	A
JAN	214 ±17.72	215 ±12.86	13 ±2.53	17 ±2.65	1138 ±78.34	1106 ±74.69
FEB	218 ±14.26	234 ±13.54	13 ±1.49	13 ±1.15	1188 ±104.02	1062 ±75.47
MAR	200 ±15.86	241 ±12.86	14 ±2.41	13 ±1.49	1138 ±93.42	1125 ±65.86
APR	257 ±18.16	251 ±19.43	16 ±2.93	14 ±2.65	1201 ±98.54	1119 ±92.06
MAY	257 ±18.16	248 ±15.88	12 ±2.16	16 ±2.99	1296 ±120.99	1036 ±94.91
JUN	257 ±13.99	241 ±19.07	14 ±2.23	13 ±1.15	1201 ±75.58	1011 ±166.23
JUL	248 ±15.86	241 ±12.86	12 ±1.41	12 ±2.16	1226 ±94.89	1125 ±105.90
AUG	228 ±19.41	251 ±16.24	13 ±1.07	13 ±1.07	1150 ±86.74	1036 ±118.32
SEP	270 ±23.00	241 ±17.02	13 ±1.41	13 ±2.16	1138 ±116.85	1100 ±86.14
OCT	272 ±24.22	241 ±18.97	13 ±2.03	13 ±1.15	1302 ±67.40	1251 ±53.18
NOV	260 ±18.65	276 ±14.58	13 ±2.03	13 ±1.07	1207 ±111.37	1024 ±66.94
DEC	266 ±17.62	272 ±24.22	13 ±2.03	13 ±1.15	1201 ±85.20	986 ±80.00

TABLE 9 : SHOWING THE DIMENSIONAL DETAILS OF VESSEL ELEMENTS AND AVERAGE NUMBER OF VESSELS PER 0.5 mm^2 IN NORMAL (N) AND AFFECTED (A) TREES OF **HOLOPTELEA INTEGRIFOLIA**

MONTH	LENGTH (um)		WIDTH (um)		LUMEN DIAMETER (um)		NUMBER OF VESSELS	
	N	A	N	A	N	A	N	A
JAN	220 ±31.34	220 ±26.14	102 ±18.04	114 ±27.96	95.8 ±2.95	86.2 ±2.70	8 ±1.90	14 ±2.77
FEB	220 ±21.49	259 ±26.80	107 ±20.18	114 ±22.78	119 ±4.60	108 ±2.84	9 ±2.55	12 ±2.63
MAR	215 ±49.03	215 ±27.56	95 ±20.12	126 ±31.16	116 ±2.90	107 ±4.44	8 ±2.46	11 ±3.20
APR	228 ±37.04	228 ±25.75	101 ±28.58	133 ±29.66	118 ±2.88	121 ±4.58	9 ±2.14	12 ±2.28
MAY	246 ±31.72	240 ±30.96	126 ±24.98	107 ±21.06	125 ±3.38	100 ±2.81	8 ±2.18	15 ±5.62
JUN	234 ±30.41	228 ±22.70	120 ±21.58	107 ±24.70	113 ±2.05	88 ±2.41	7 ±1.66	12 ±1.98
JUL	278 ±32.71	215 ±22.80	120 ±30.26	114 ±26.58	118 ±1.93	113 ±2.14	7 ±2.03	13 ±3.06
AUG	228 ±28.07	240 ±29.74	101 ±26.38	82 ±21.16	103 ±3.50	64 ±2.58	7 ±2.03	12 ±2.62
SEP	240 ±21.82	209 ±29.08	139 ±26.50	107 ±22.32	119 ±2.60	94 ±2.90	8 ±2.34	12 ±2.72
OCT	253 ±17.01	196 ±27.26	133 ±27.25	82 ±17.99	131 ±3.37	75 ±2.72	8 ±2.14	13 ±3.57
NOV	272 ±31.75	240 ±35.91	126 ±30.42	120 ±25.42	129 ±3.56	118 ±3.59	8 ±1.44	12 ±3.16
DEC	253 ±40.78	214 ±26.69	120 ±21.67	113 ±29.11	109 ±2.39	94 ±3.05	7 ±1.41	12 ±1.93

TABLE 10 : SHOWING THE DIMENSIONAL DETAILS AND POPULATION OF RAYS PER 1 cm LENGTH OF CAMBIUM NORMAL (N) AND AFFECTED (A) TREES OF **HOLOPTELEA INTEGRIFOLIA**

MONTH	HEIGHT (um)		WIDTH (um)		RAY CELL DIAMETER (um)		POPULATION/cm	
	N	A	N	A	N	A	N	A
JAN	157 ±34.03	159 ±19.55	27 ±6.53	35 ±8.30	14 ±2.23	13 ±2.15	153 ±30.63	140 ±23.60
FEB	164 ±24.61	160 ±33.69	37 ±10.88	33 ±8.67	14 ±2.23	16 ±3.00	159 ±35.54	166 ±30.00
MAR	150 ±26.60	159 ±30.09	26 ±6.07	30 ±7.50	12 ±2.66	14 ±2.53	140 ±26.40	173 ±31.20
APR	156 ±29.58	170 ±22.31	29 ±5.94	28 ±6.88	15 ±2.82	15 ±3.94	153 ±34.81	153 ±29.18
MAY	148 ±31.35	140 ±30.60	28 ±5.60	26 ±6.07	14 ±2.53	14 ±2.53	133 ±26.93	146 ±29.61
JUN	114 ±33.54	148 ±36.97	31 ±8.72	25 ±6.37	14 ±2.53	13 ±2.03	146 ±28.10	186 ±28.80
JUL	120 ±24.61	126 ±2.35	24 ±6.53	25 ±6.07	12 ±2.65	12 ±2.53	150 ±30.60	173 ±31.20
AUG	159 ±19.63	171 ±29.09	30 ±6.56	26 ±5.74	14 ±2.52	13 ±2.03	139 ±25.24	179 ±28.90
SEP	188 ±20.34	172 ±15.47	29 ±5.86	24 ±3.27	13 ±1.41	13 ±2.15	133 ±30.64	199 ±34.30
OCT	156 ±32.10	148 ±26.72	24 ±5.23	24 ±4.29	15 ±2.97	13 ±1.80	146 ±33.50	166 ±21.65
NOV	205 ±40.36	169 ±25.06	29 ±8.07	26 ±5.52	15 ±2.97	14 ±2.23	146 ±36.00	173 ±30.60
DEC	210 ±31.11	180 ±20.34	30 ±7.49	24 ±3.27	15 ±2.93	12 ±2.53	139 ±27.18	146 ±29.61

TABLE 11 : SEASONAL STARCH CONTENT IN CAMBIUM AND PARENCHYMA CELLS OF XYLEM AND PHLOEM OF NORMAL (A) TREES OF <u>**HOLOPTELEA INTEGRIFOLIA**</u>

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAIN STEM													
PHLOEM	AP	■	■	+	0	0	0	+	x	+	–	x	■
	RP	–	0	+	0	+	0	0	■	+	+	+	+
CAMBIUM	FCC	x	✓	x	x	x	x	x	x	x	x	x	x
	CRC												
XYLEM Cl.Cz	AP	■■	■■	x	–	■■	x	x	x	x	x	–	+
	RP	–	+	x	x	+	x	x	x	x	x	x	–
XYLEM Aw.Cz	AP	■■	■■■	■■	x	■■	–	■	■	■■	–	+	■■
	RP	■	■■	■	x	–	+	■	0	+	x	x	■■
YOUNG BRANCH													
PHLOEM	AP	■■■	■■	■■■	x	✓	■	■	–	x	x	+	■■■
	RP	■■■	■■	■■	–	+	■	x	■■	x	■■	x	■■
XYLEM	AP	■■■	■■	■	x	✓	■■	✓	x	x	0	–	■■■
	RP	■■■	■■	x	x	x	■■	✓	■	x	x	+	■■■

AP = AXIAL PARENCHYMA, FCC = FUSIFORM CAMBIAL CELL, Cl.cz = CLOSE TO CAMBIAL ZONE

RP = RAY PARENCHYMA, CRC = CAMBIAL RAY CELL, Aw.cz = AWAY FROM CAMBIAL ZONE

TABLE - 12 : SEASONAL STARCH CONTENT IN CAMBIUM I AND PARENCHYMA CELLS OF XYLEM AND PHLOEM OF AFFECTED (A) TREES OF **HOLOPTELEA INTEGRIFOLIA**

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAIN STEM														
PHLOEM		AP	■■	■■	■■	■	+	✓	■	x	–	■	–	■■
		RP	■■	0	■■■	■	–	+	■	+	x	■■	■■	■
CAMBIUM		FCC	x	✓	x	x	x	x	x	x	x	x	x	x
		CRC	x	✓	x	✓	✓	x	x	x	x	✓	✓	✓
XYLEM	Cl.Cz	AP	■■	■■	0	■■	■	x	x	x	x	✓	■	–
		RP	0	■■	■	■■	x	x	x	x	x	x	+	x
	Aw.Cz	AP	■■■	■■■	■	■■■	■	–	✓	✓	x	■	+	■■■
		RP	■■■	■■	■■	■	–	x	x	x	x	0	+	■■■
YOUNG BRANCH														
PHLOEM		AP	■■■	■■■	■■■	■■	■■	■■	0	–	x	x	■	■
		RP	■■■	■■■	■■	■■	+	0	–	■■	x	+	–	+
XYLEM		AP	■■■	■■■	■■	■■■	■	x	x	x	x	x	■■	■■■
		RP	■■■	■■	■■	■■■	■	x	x	x	x	x	+	■■■

AP = AXIAL PARENCHYMA, FCC = FUSIFORM CAMBIAL CELL, Cl.cz = CLOSE TO CAMBIAL ZONE

RP = RAY PARENCHYMA, CRC = CAMBIAL RAY CELL, Aw.cz = AWAY FROM CAMBIAL ZONE

Fig. 18.

A-I. Transverse sections of cambium of normal trees.

A. Active cambial zone in March. x 420.

B. Periclinal divisions in fusiform cambial cells (arrow) and xylem derivatives (arrowhead). x 400.

C. Dormant cambium in April. x 219.

D. Cambial zone with differentiating xylem elements in June. x 169.

E. Cambial zone surrounded by differentiating phloem and xylem derivatives in August. x 200.

F. Active cambium in August. x 340.

G. Active cambium in September. x 400.

H. Cambial zone in October. x 420.

I. Cambial zone in December. x 480.

CZ: Cambial Zone; DX: Differentiating Xylem; PH: Phloem; RC: Ray Cambial Cell; V: Vessel element; XY: Xylem

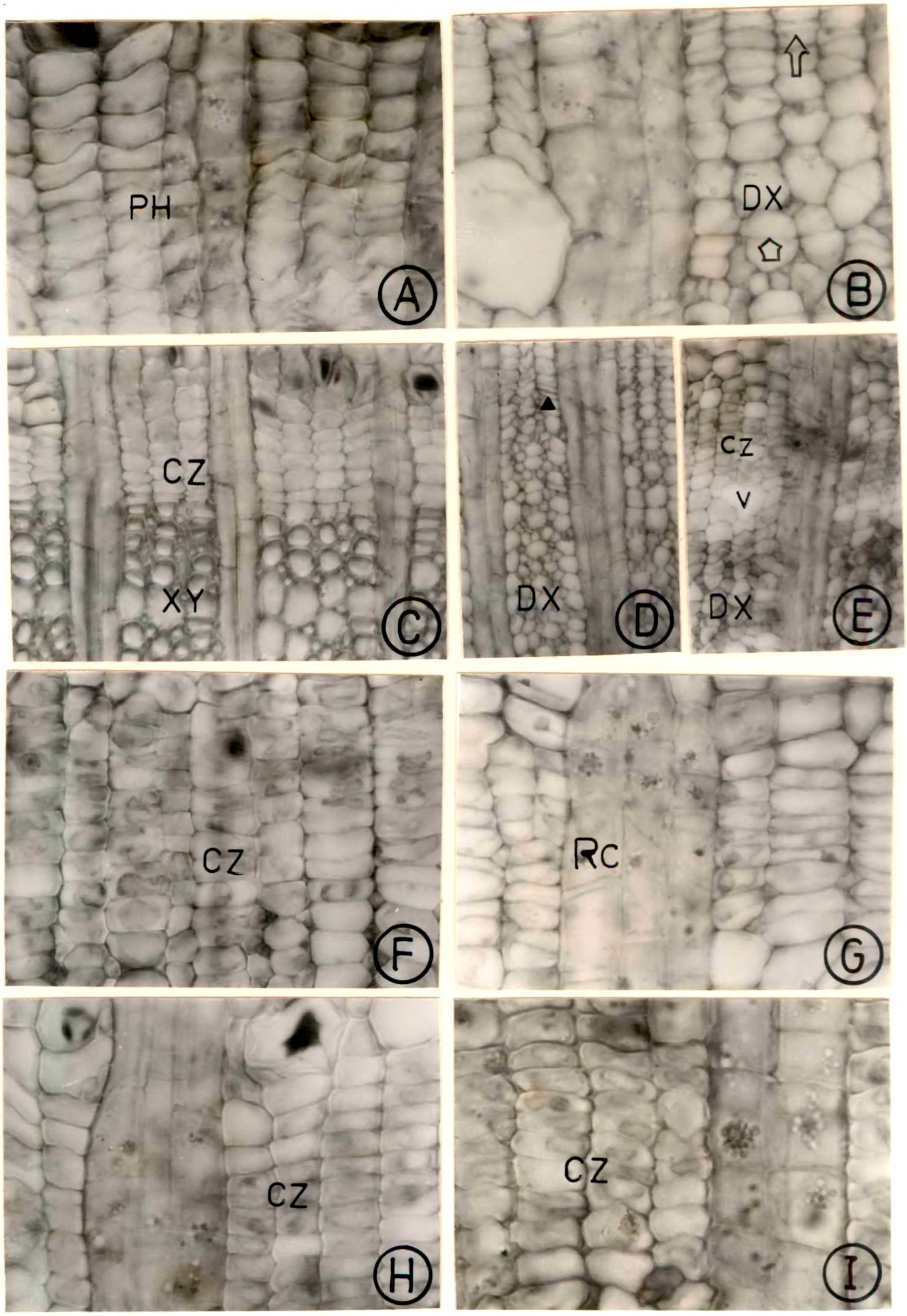


FIG. 18

Fig. 19.

A-H. Transverse sections of cambium in affected trees.

A. Dormant cambium in March. x 320.

B. Dormant cambium in April. x 350.

C. Dormant cambium in June. x 300.

D. Dormant cambium in August. x 420.

E. Actively dividing fusiform cambial cells in September. x 340.

F. Cambial zone surrounded by differentiating phloem and xylem elements. x 310.

G. Periclinal divisions in fusiform cambial cells. x 875.

H. Cambial zone in December. x 380.

CZ: Cambial Zone; DX: Differentiating Xylem

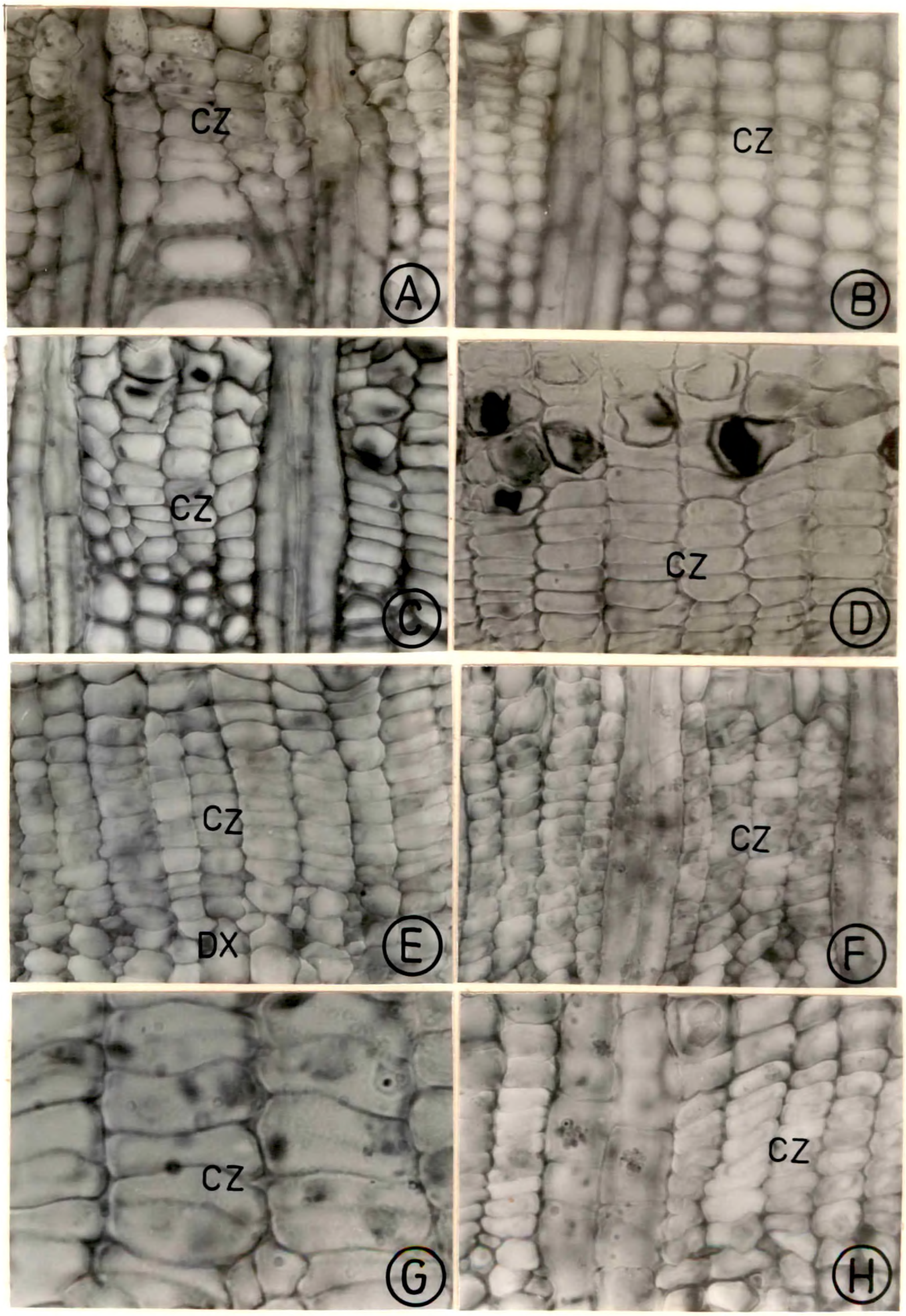


FIG. 19

Fig. 20

A-D: Tangential longitudinal sections.

A. Storied arrangement of fusiform and ray cambial cells in normal trees. x 200.

B. Storied fusiform and ray cambial cells in affected trees. x 168.

C. Fusiform cambial cells showing prominently beaded radial walls (arrow). x 263.

D. Active cambium of normal trees showing periclinally dividing fusiform cambial cells. Arrows indicate phragmoplast at the margins of developing cell plate. x 231.

FC: Fusiform cambial cell

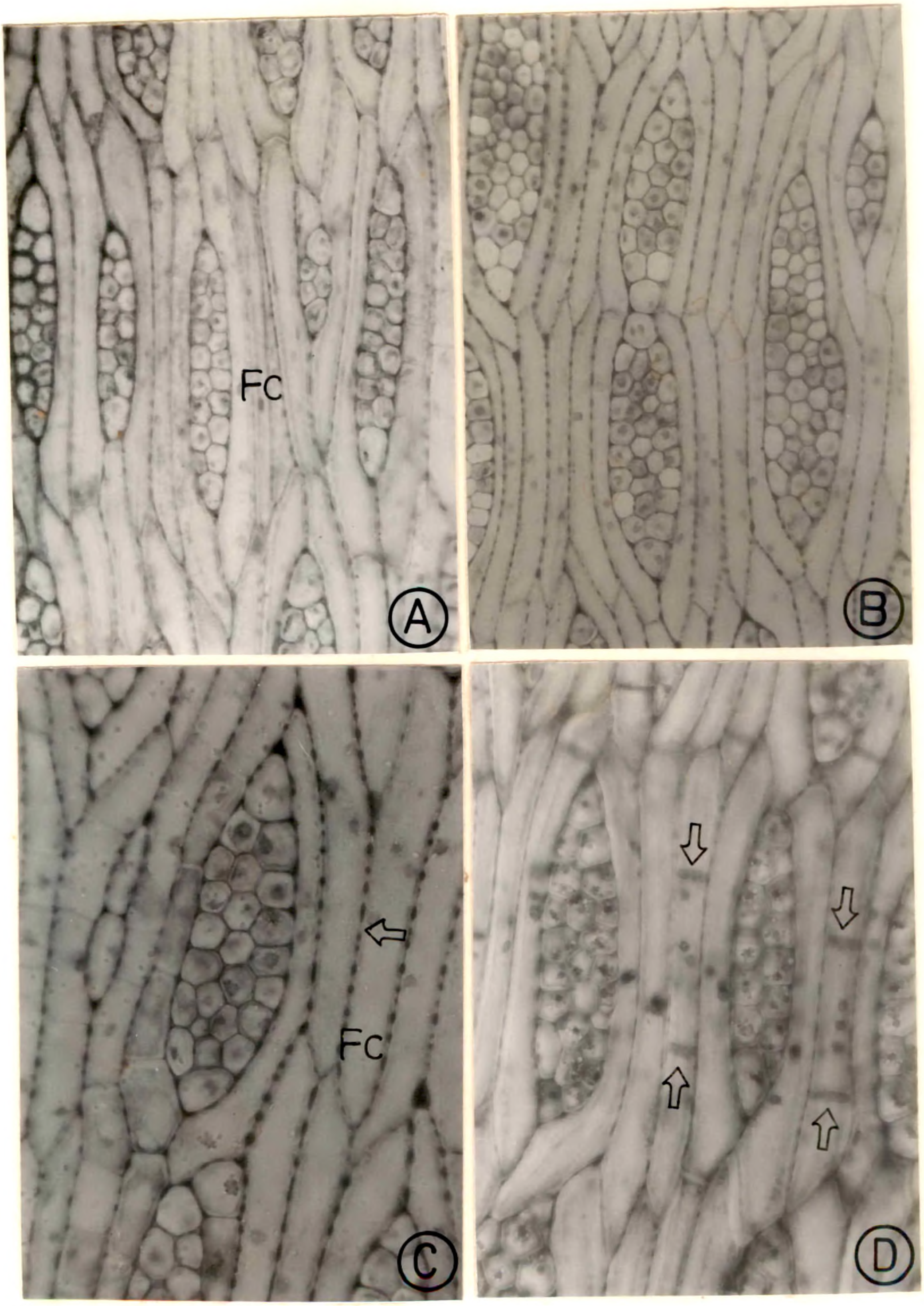


FIG. 20.

Fig. 21.

A-F: Transverse sections of phloem and xylem.

A. General structure of phloem showing alternate bands of sieve elements and parenchyma cells. x 132.

B. Massive callose deposition (arrows) in sieve tube elements of affected tress. x 128.

C. Phloem anastomoses with short sieve tube elements (arrow). x 180

D. Xylem showing ring boundary between two successive growth rings. x 112.

E. Xylem showing distribution of vessels in normal trees. x 31.

F. Xylem showing distribution of vessels in affected trees. x 31.

RB: Growth ring boundary; P: Parenchyma cells; S: Sieve elements

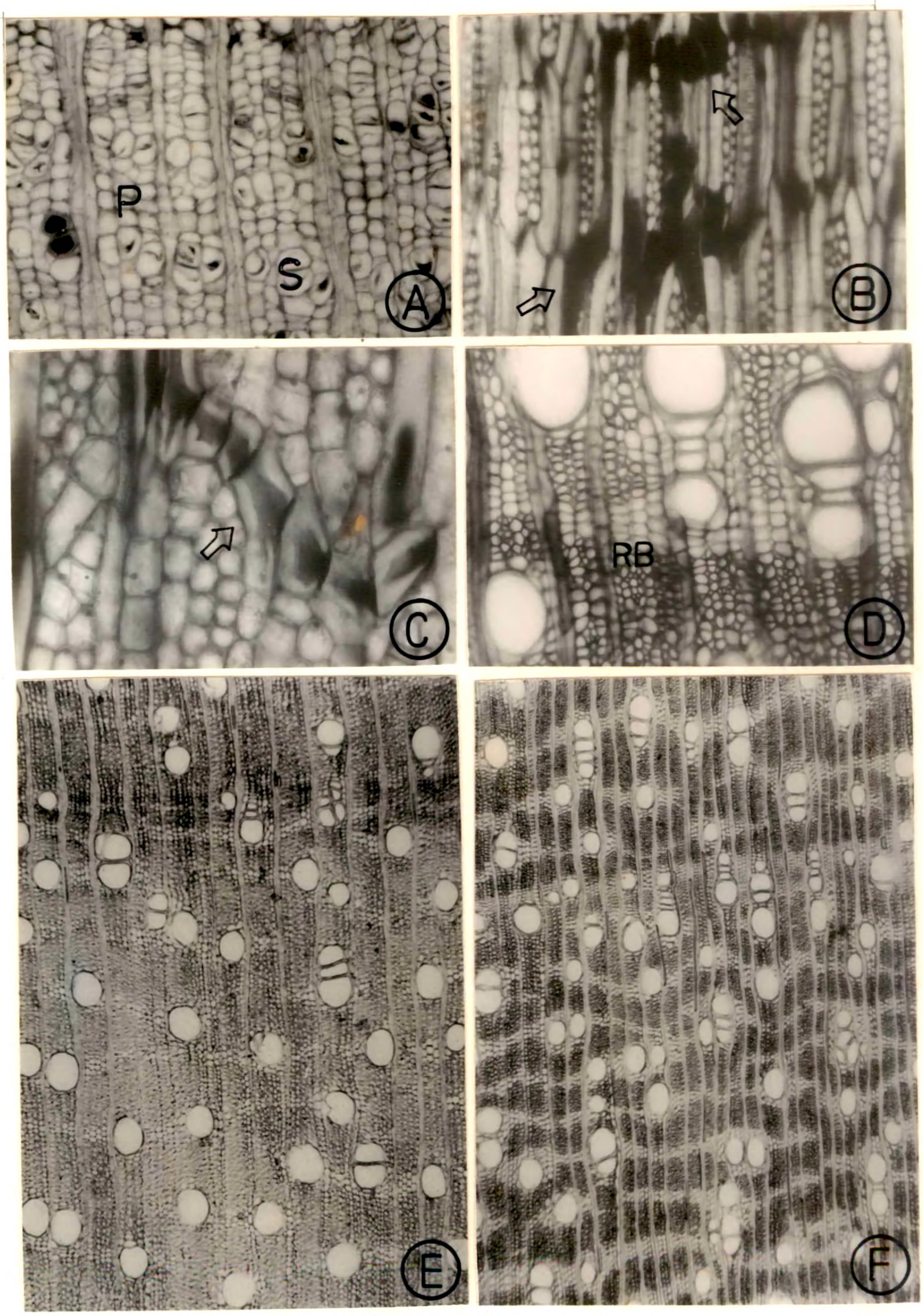


FIG 21

Fig. 22.

A-F: Radial longitudinal sections of phloem and xylem.

G-H: Transverse sections of young branch.

A. Xylem parenchyma cell of normal trees showing negligible starch in April. x 120

B. Xylem parenchyma cells of affected trees showing starch distribution in April. x 120.

C. Starch distribution in xylem axial parenchyma of normal trees in July. x 200.

D. Xylem parenchyma of affected trees with no starch content in July. x 200.

E. Starch distribution in phloem of normal trees. x 116.

F. Starch distribution in phloem of affected trees. x 120.

G. Xylem parenchyma (arrows) of young branch of normal trees showing no starch content. x 104.

H. Xylem parenchyma cells loaded with starch (arrows) in young branch of affected trees. x 104.

AP: Axial Parenchyma; RP: Ray Parenchyma

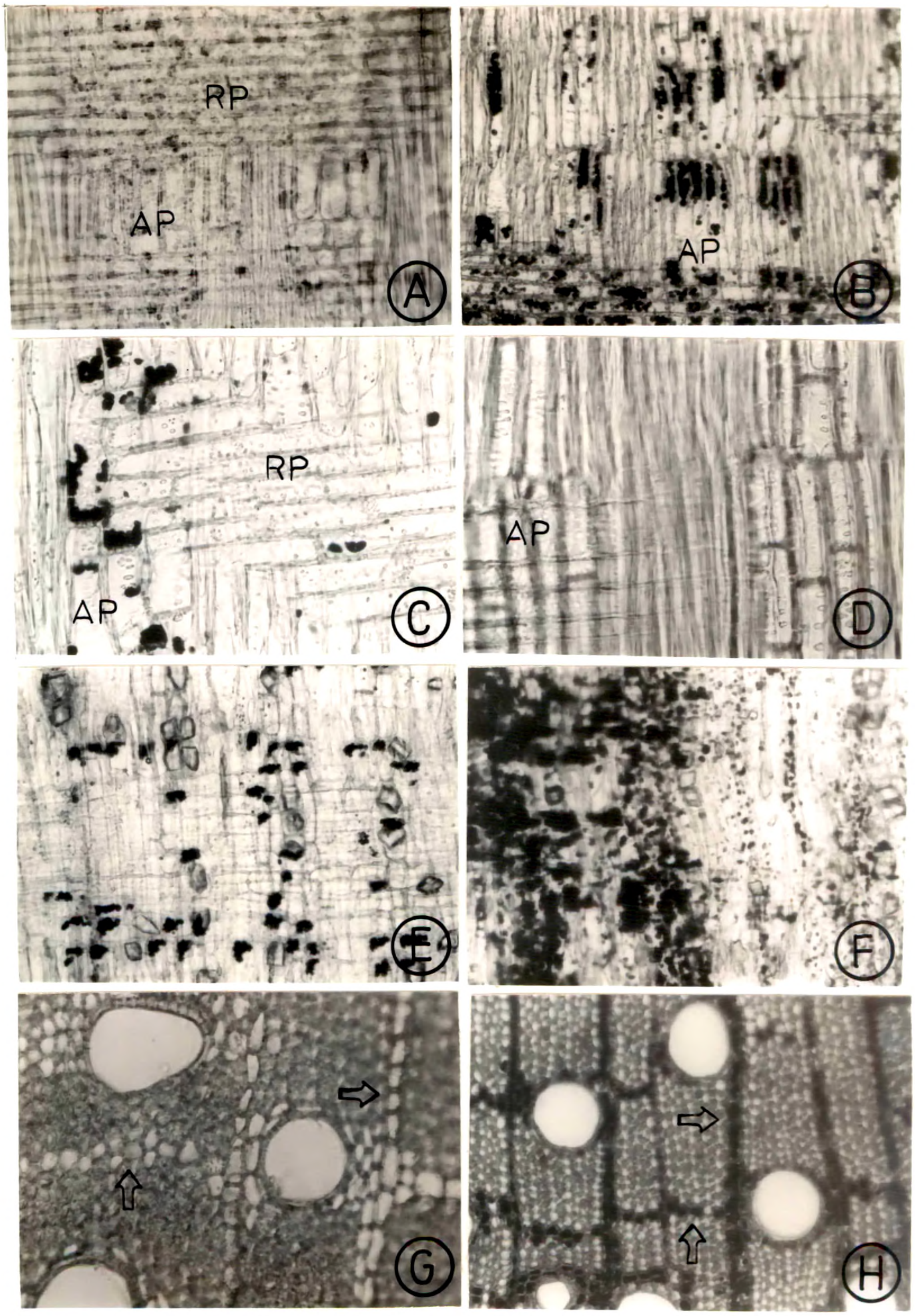


FIG. 22

Fig. 23

A-F: Radial longitudinal sections of fusiform cambial cells.

G-F: Transverse sections of young branch.

A. Lipid bodies (arrows) in dormant fusiform cambial cells of normal trees. x 350.

B. Lipid bodies (arrows) in dormant fusiform cambial cells of affected trees. x 875.

C. Lipid bodies in active fusiform cambial cells of normal trees. x 500.

D. Lipid bodies in active fusiform cambial cells of affected trees. x 500.

E. Protein bodies (arrow) in fusiform cambial cells of normal trees. x 430.

F. Protein bodies (arrow) in fusiform cambial cells of affected trees. x 750.

G and H. Starch distribution in pith region of normal (G) and affected (H) trees in February. G: x 163; H: x 188

I. Starch and tannin containing cells in the pith region of normal trees in June. x 188.

J. Tannin containing cells (arrow) in the pith region of affected trees in June. Note absence of starch in the cells. x 188.

P: Pith; XY: Xylem

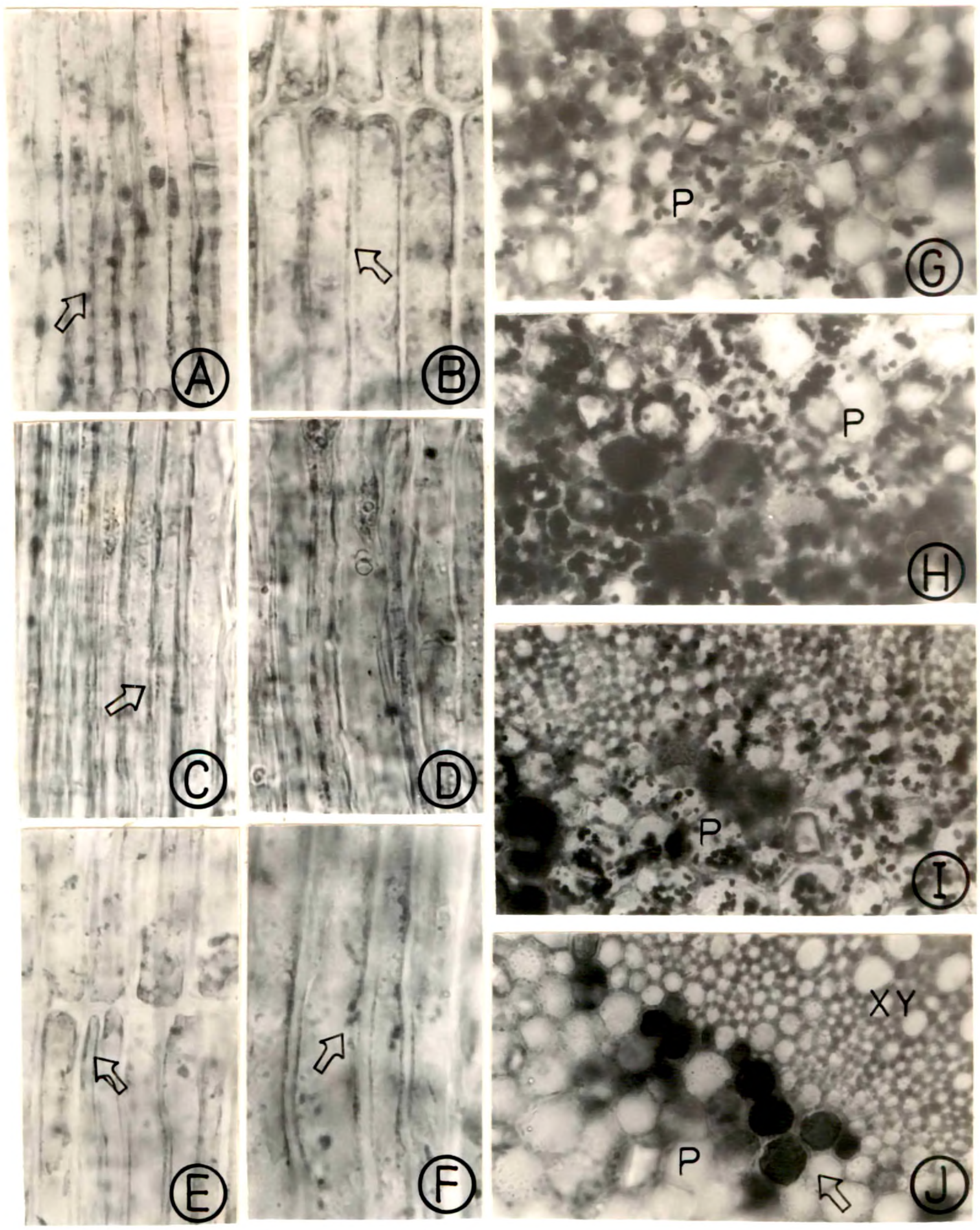


FIG. 23

Fig. 24.

A-D: Transverse sections of phloem and xylem viewed under fluorescence (A, B and D) and Polarization (C) microscopes.

A and B. Lignification of xylem elements in Normal (A) and affected (B) trees. Note the fluorescing sieve plates (arrows) in both. A: x 61; B: x 50.

C. Thick walled lignified parenchyma cells in both functional (arrow) and nonfunctional (arrowhead) phloem. Crystal containing parenchyma cells are also present in the phloem. x 128

D. Obliterated sieve elements in current year's (arrow) and last year's (arrowhead) phloem during dormancy. x 132.

PH: Phloem; XY: Xylem

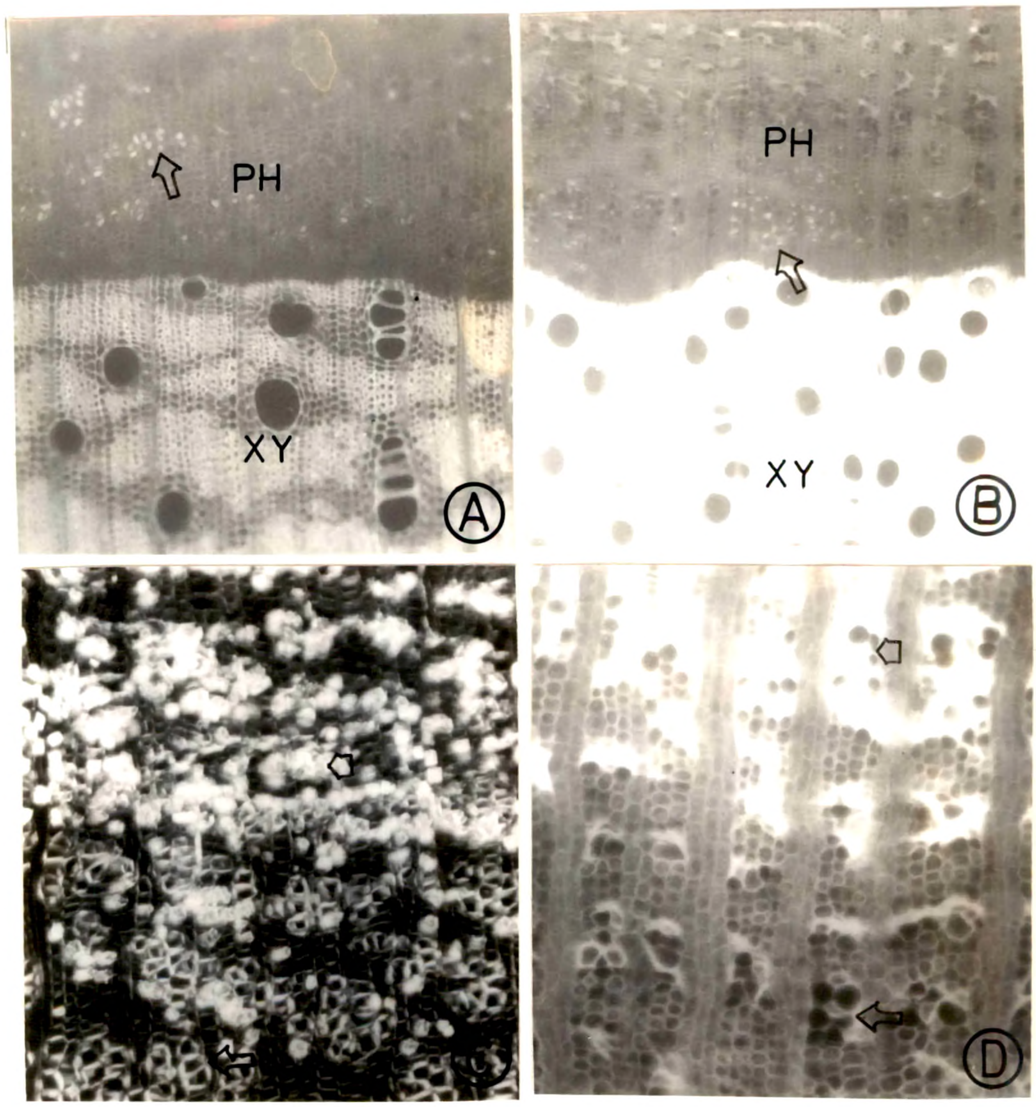


FIG.24

Fig. 25.

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone in the main stem and young branch and differentiating xylem and phloem elements in the main stem of normal trees.

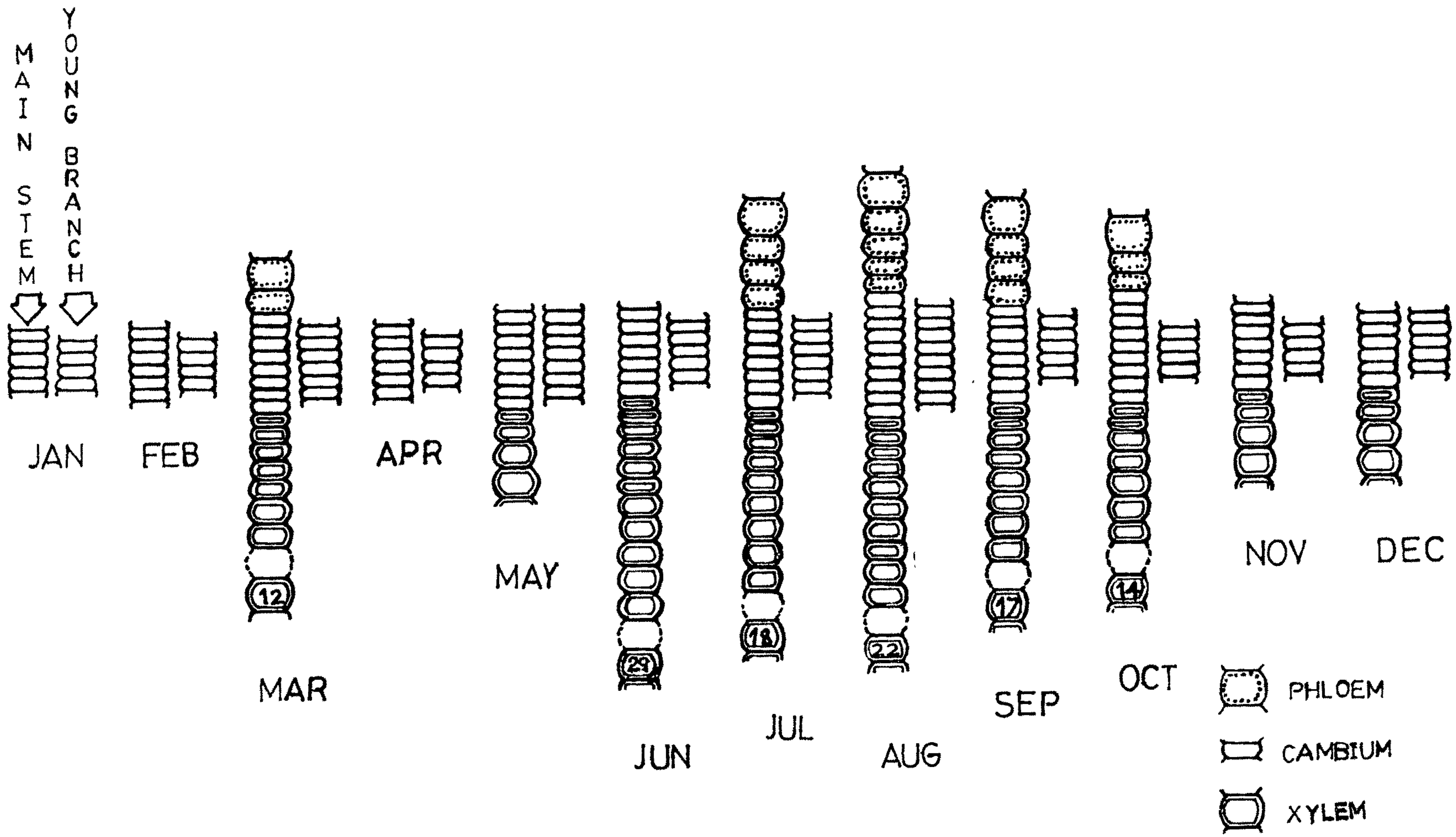

MAIN STEM
YOUNG BRANCH
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
12
23
18
22
17
14
PHLOEM
CAMBIUM
XYLEM

FIG.25

Fig. 26.

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone in the main stem and young branch and differentiating xylem and phloem elements in the main stem of affected trees.

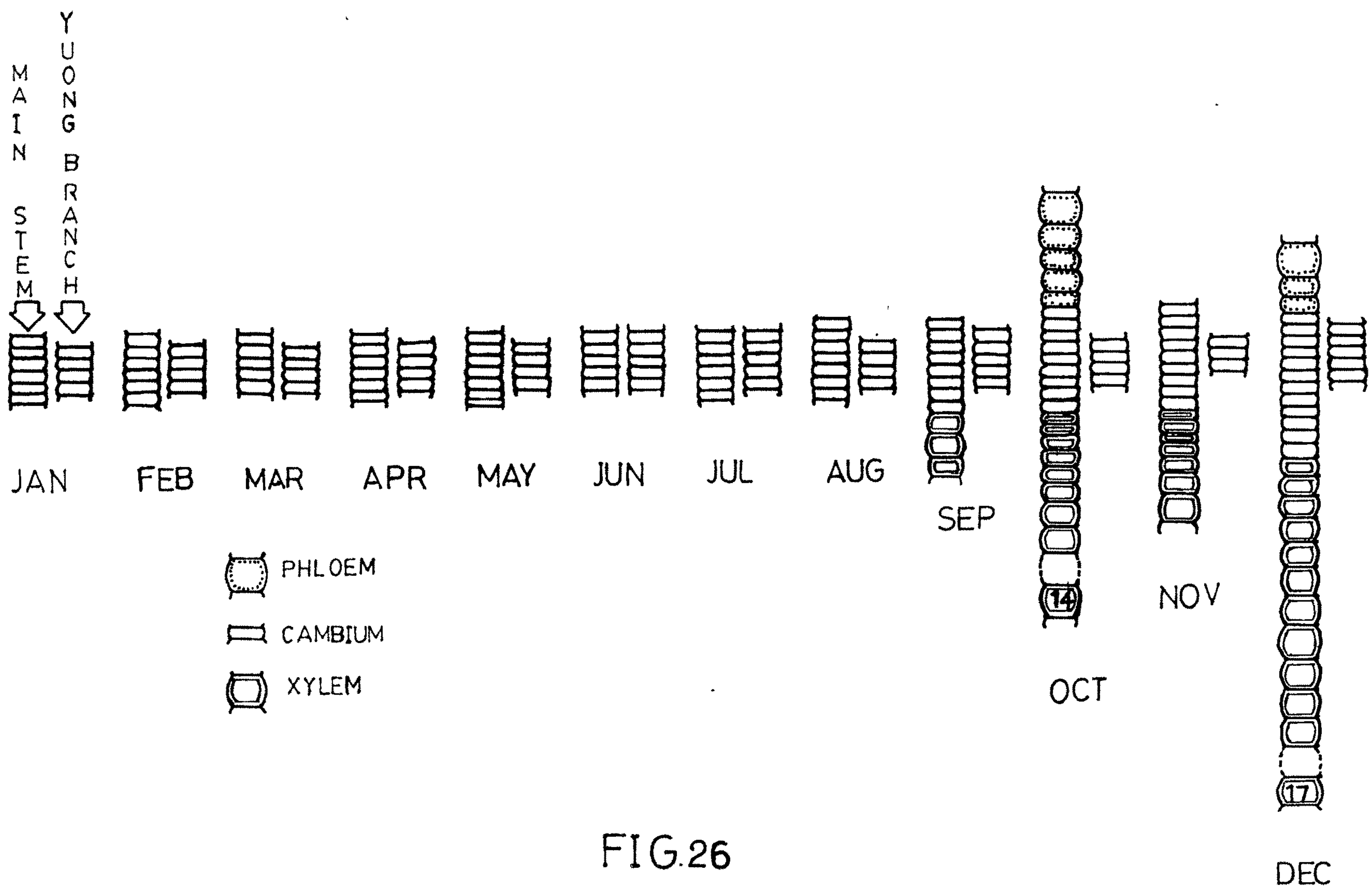
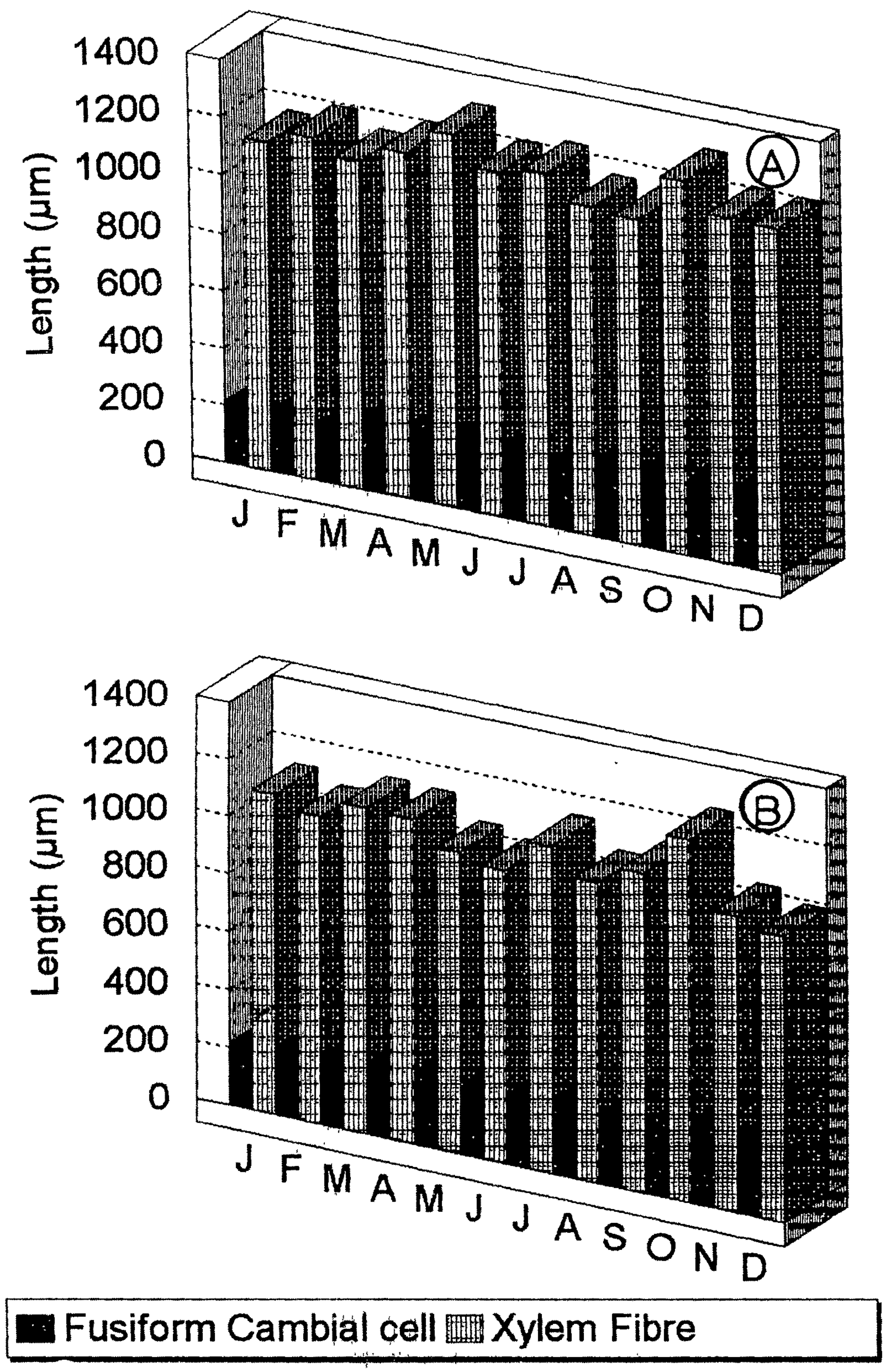

MAIN STEM
YUONG BRANCH
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
PHLOEM
CAMBIUM
XYLEM
14
17

FIG.26

Fig. 27.

Histogram showing seasonal variation in mean length of xylem fibres and fusiform cambial cells.

A: Normal B: Affected



1400
1200
1000
800
600
400
200
0
Length (µm)
J F M A M J J A S O N D
A
1400
1200
1000
800
600
400
200
0
Length (µm)
J F M A M J J A S O N D
B
Fusiform Cambial cell
Xylem Fibre

FIG. 27

Fig. 28.

Graphic representation of seasonal variation in cambial ray height (A), width (B) and diameter of ray cells (C) in μm.

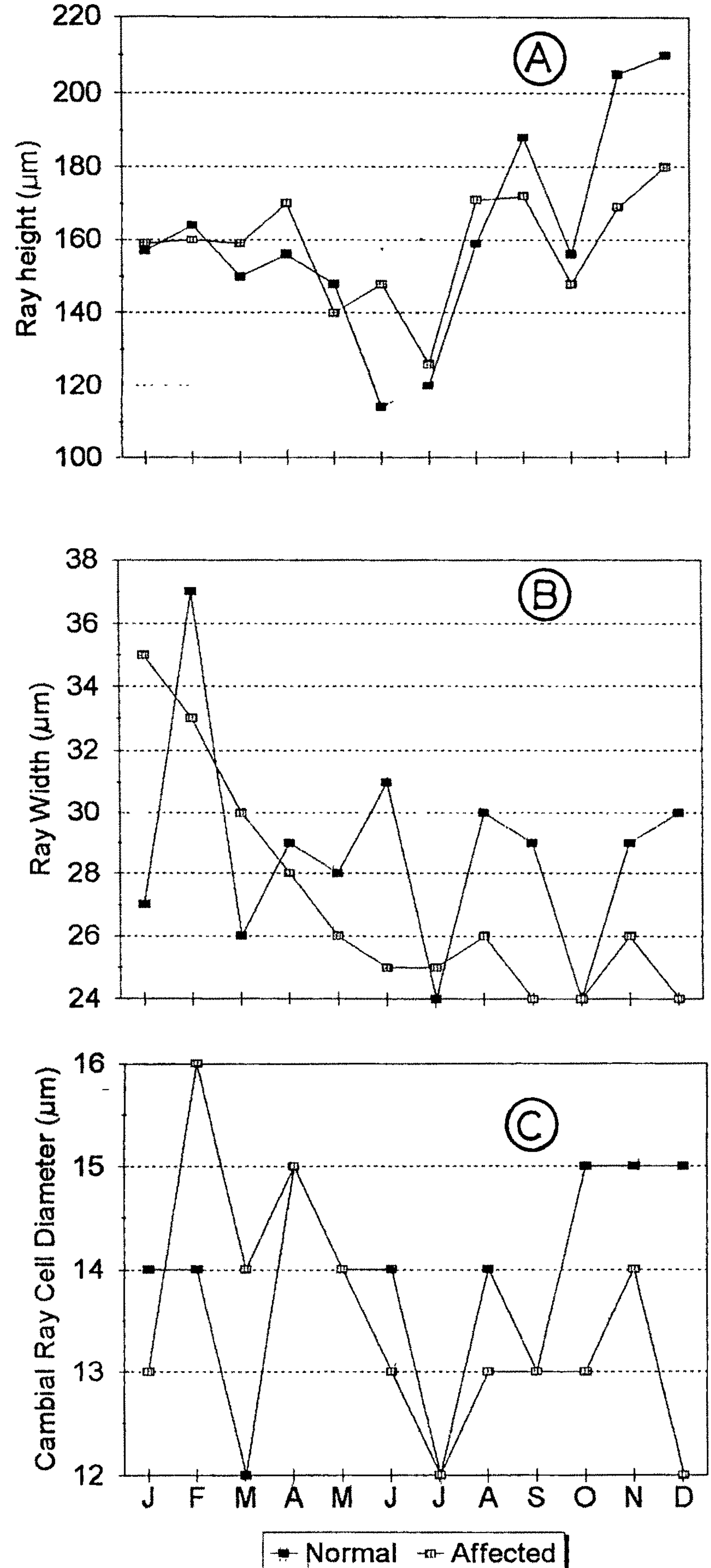
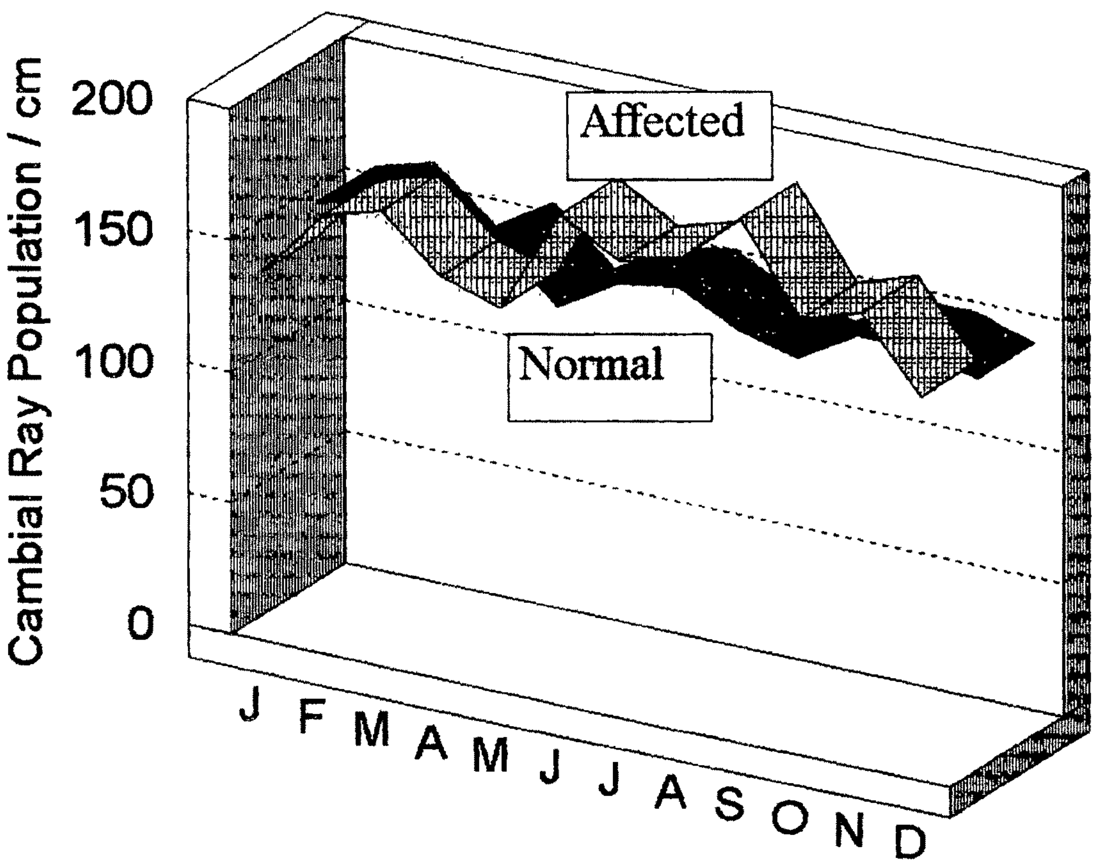

A
Ray height (µm)
220
200
180
160
140
120
100
B
Ray Width (µm)
38
36
34
32
30
28
26
24
C
Cambial Ray Cell Diameter (µm)
16
15
14
13
12
J F M A M J J A S O N D
Normal
Affected

FIG. 28

Fig. 29.

Histogram showing seasonal variation in cambial ray population in one cm tangential width of cambium.



Cambial Ray Population / cm
200
150
100
50
0
Affected
Normal
J F M A M J J A S O N D

FIG. 29

Fig. 30.

Graphic representation of seasonal variation in vessel lumen diameter in µm (A) and number of vessels/0.5 mm^2 (B).

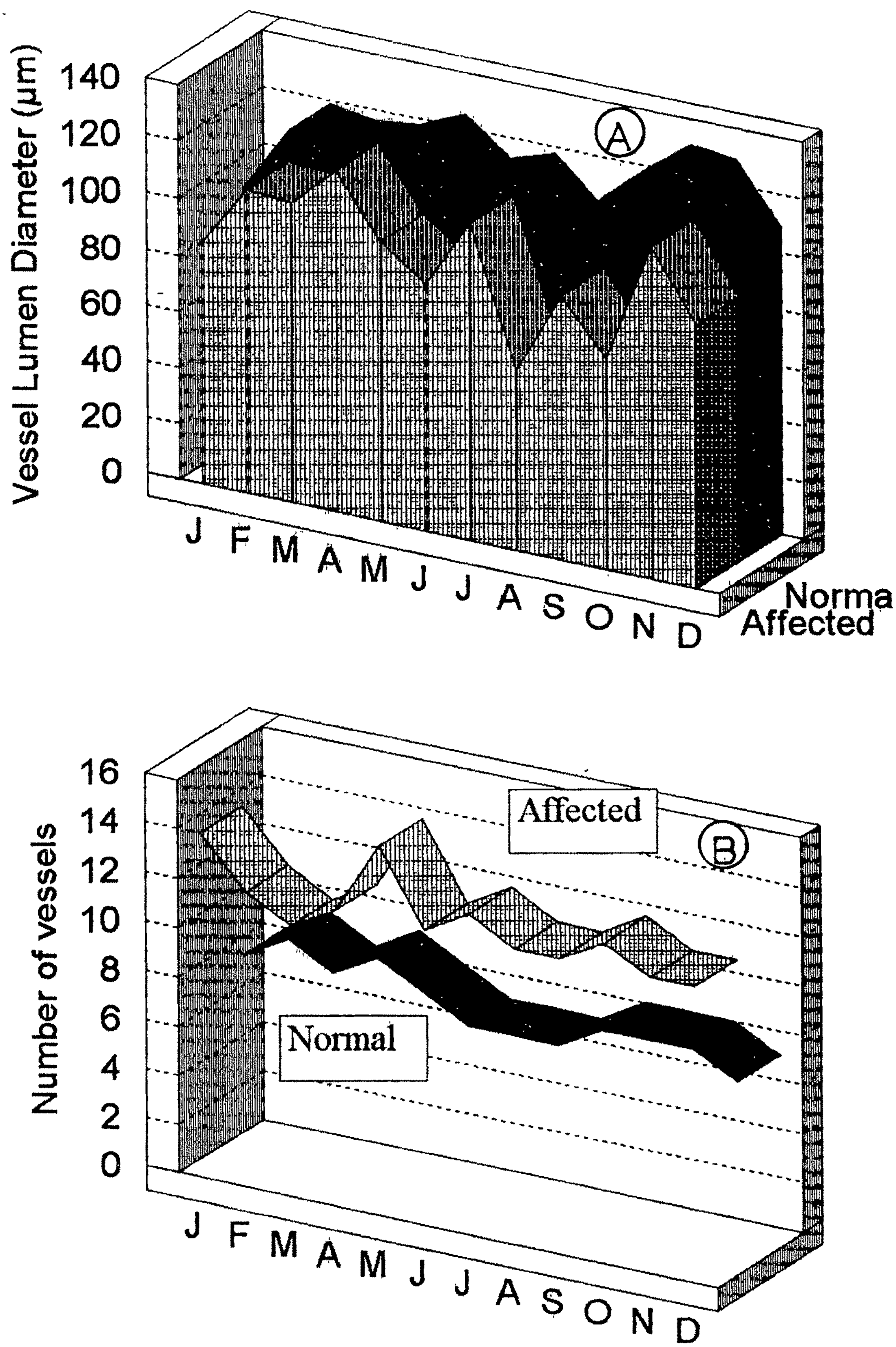

Vessel Lumen Diameter (µm)
140
120
100
80
60
40
20
0
J F M A M J J A S O N D
Normal
Affected
A
Number of vessels
16
14
12
10
8
6
4
2
0
J F M A M J J A S O N D
Affected
Normal
B

FIG.30

SYZYGIUM CUMINI (Linn.) Skeels.

Syzygium cumini is a large handsome evergreen tree attaining 70-80 feet with not very straight trunk. It belongs to the family Myrtaceae and is common throughout India. Leaves coriaceous, shining, entire, oval-oblong or lanceolate oblong, generally long acuminate. Flowers creemish, fragrant in heavy clusters. Berry oblong or subglobose, purplish black, succulent smooth when ripe and edible. Trunk covered with thick, light or dark grayish bark. Inner bark is pale reddish-brown, compact and fibrous. The bark is used for dyeing and tanning. Wood is reddish brown, tough and hard. Annual layers visible. Wood is much used for building agricultural implements, well-curbs and well-steps, where it is considered almost indestructible. Boats and canoes are made of it .

NORMAL TREES

CAMBIAL STRUCTURE:

Vascular cambium is nonstoried with long overlapping fusiform cambial cells and short polygonal cambial ray cells in tangential view (Fig. 33 A). Both the cells show beaded cell walls. Being an ever green tree, Syzygium exhibits cambial growth for longer part of the year. However the width of the cambial zone varies in different months. It is 3 to 9 layered when it is inactive and 3 to 11 layered during active growth. Both periclinal and anticlinal divisions occur in cambial cells. Cambial ray cells are invariably filled with phenolic contents (Fig. 33 A, C). During the active growth loss of fusiform cambial cells from cambial zone has been noticed.

CAMBIAL ACTIVITY:

Cambial cell divisions occur in four different flushes during the year. Cambial cells remain radially enlarged with thin cell walls for longer part of the year. Hence, true dormancy is not noticeable in the cambium. Reactivation of cambium begins in February (Fig. 31 A) followed by brief period of rest in March (Fig. 31 B). The second flush of activity begins in April and ceases in June. Cambial cell division and differentiation are suppressed from June to July (Fig. 31 D). The third flush of cambial activity begins in August lasting till October (Fig. 31 E, F). The fourth flush of activity occurs in December (Fig 31 G) after a brief spell of inactivity in November. Additive cell divisions are maximal in August with 6 to 11 layers of cells in the cambial zone (Table 13). The cambial zone becomes reduced to 3 to 5 layers of cells in November. In all the four flushes of cambial growth, the rate of activity varying periodically is indicated by the number of cells in the cambial zone and differentiating xylem an phloem elements (Fig. 38).

In young branches cambium remains active for major part of the year with no cell division in February, August and December. Peak activity is observed in January with 5 to 8 layers of cells in the cambial zone. During inactive period cambial zone remains 2 to 6 layered (Table 13).

Schematic representation of average cambial layers and its derivatives in main trunk and average number of cambial layers in young branch are shown in Figure 38.

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

Syzygium bears leaves all the year around. Trees flower in February when the cambium becomes reactivated. Flowering is followed by fruiting in April-May, when the cambium is active. Partial defoliation in June coincides with cambial inactivity. In August, when the trees are with mature leaves, the cambial growth is at its peak. The trees remain with full foliage all through the year. Divisions in cambium coincides with the flowering and sprouting of new leaves in February and December. The relation between phenology and cambial activity is presented in Table 13.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

Since the cambium is active for a longer period, the climatic factors seem to have a little effect on the duration of the cambial activity. However, the peak cambial activity coincides with the highest rainfall (461 mm) and relative humidity (90.6%) recorded for the year in August. The increase in mean maximum temperature in April (39.2 ^{o}C) and May (38.8 ^{o}C), coincides in the second flush of cambial activity (Fig. 31 C). The environmental factors seems to have no influence on cambial cell division in February and in December. Figures 1 and 2 show the graphic representation of meteorological data for the year 1990.

FUSIFORM CAMBIAL CELLS:

Fusiform cambial cells are axially elongated with overlapping cell tips in tangential view (Fig. 33 A). The cells in transections appear as rectangular in shape arranged in radial files between secondary xylem and phloem (Fig. 31 F). Fusiform cambial cells are uni-nucleated with less dense cytoplasm. The cells are lightly stained during the annual cycle. Both the radial and tangential walls of cambial cells are thin all through the year. However the radial walls are relatively thick.

DIVISIONAL ACTIVITY:

Additive and multiplicative divisions occur in fusiform cambial cells leading to radial increment of trunk and circumferential expansion of the cambial cylinder respectively (Fig. 31 A, G). Periclinal divisions occur in the cells for major part of the year. However, the width of cambial zone varies in different months due to fluctuations in the rate of periclinal divisions. Cambial zone is wider with 6 to 11 layers of cells during peak activity. The proportion of cambial cells within the vascular cylinder is maintained by frequent anticlinal divisions.

DIMENSIONAL CHANGES:

MEAN LENGTH:

The mean length of fusiform cambial cells undergoes changes seasonally. The length gradually increases from May to July and decreases in August. An abrupt increase and decrease in mean length has been observed from April to May and from September to

October respectively. The average length of fusiform cambial cells is maximal (899 µm) in December and minimal (717 µm) in April (Table 14).

MEAN WIDTH:

The mean tangential width of fusiform cambial cells shows relation with their length. The increase and decrease in width corresponds with the decrease and increase in length of cells in all months except in July and August. The mean width alternately increases and decreases from January to December. The maximum (30 µm) and minimum (22 µm) width are observed in February, April and June, November respectively. The variations in mean width are presented in Table 14.

LENGTH VARIATION IN RELATION TO XYLEM FIBRE LENGTH:

The average length of xylem fibres is 1.7 to 2.3 times longer than fusiform cambial cells. The mean length of both the cell types are closely related in January, from April to June and in December. The average xylem fibre length is maximal (1820 µm) in December and minimal (1532 µm) in September. However there is no seasonal correlation between the lengths of fusiform cambial cells and xylem fibres (Fig. 38 A).

CAMBIAL RAY CELLS:

Cambial ray cells are small, isodiametric or radially elongated, uni-nucleate cells. Cambial ray cells and their derivatives are filled with dark contents which are identified as phenolic substances. These substances emit light fluorescence when observed under fluorescence microscope (Fig. 37 A). Cambial rays are heterogeneous with smaller procumbent and longer upright cells. In tangential sections the cambial ray cells appear polygonal in shape (Fig. 33 C). The rays are uni, bi or multiseriate. However multiseriate rays are predominant in the cambium. Cambial ray cells possess distinctly beaded cell walls. Fusion of cambial rays is common in Syzygium. Rays which are adjacent fuse together vertically or laterally (Fig. 33 C). Tangential and radial fusion involve the increase in width and length of rays respectively. In radial fusion the intervening fusiform cambial cell may be lost or undergoes segmentation.

DIVISIONAL ACTIVITY:

Cambial ray cells originate through the divisions of ends or sides of fusiform cambial cells. The lateral divisions resulting the origin of cambial ray cell initial occur at any position along the lateral wall. Cambial ray cells also increase in number by transverse anticlinal divisions. Biseriate rays develop through vertical or slightly oblique anticlinal divisions of cambial ray cells in a uniseriate ray (Fig. 33 C). Formation of more than one ray cell initial simultaneously form a single fusiform cambial cell has been observed frequently. The newly formed cambial ray cells are filled with dark phenolic contents through the fusiform cambial cells are free of such contents (Fig. 33 A, C).

DIMENSIONAL CHANGES:

CAMBIAL RAY HEIGHT:

The mean ray height gradually increases from April to July, then decreases in August. In September ray height is maximal (420 µm) followed by abrupt decrease in October with a minimum ray height (261 µm). Ray height increased sharply in the first quarter of the year and then gradually in November and December (Table 16).

CAMBIAL RAY WIDTH:

The average ray width increases from March to July, decreases in August-September and then increases in October-November. The average ray width is maximal (56 µm) in November and minimal (35 µm) in March (Table 16).

CAMBIAL RAY CELLL DIAMETER:

The average cambial ray cell diameter increases and decreases alternately in the year. The mean maximum and minimum ray initial diameter is 29 µm and 20 µm in November and March respectively (Table 16).

CAMBIAL RAY POPULATION:

The average number of rays for one cm tangential width of cambium ranges from 110 to 139 during the annual growth (Table 16). Soon after the peak activity of cambium, the number of rays increased sharply in September. In the remaining months their number fluctuates alternately.

The variations in average cambial ray height and width, average diameter of cambial ray cell and the average number of cambial rays/cm are represented in Figure 41 and 42.

DEVELOPMENT OF VASCULAR TISSUES:

The development of vascular tissues takes place in four different flushes. The phloem and xylem derivatives are produced simultaneously in the first flush of activity. Whereas during second flush, xylem differentiation precedes that of phloem. However, in the third and fourth flush of cambial activity, the initiation and cessation of phloem and xylem derivatives are simultaneous. The phloem and xylem differentiation (Fig. 31 E) is maximal in August with average number of 5 and 20 derivatives in each radial file respectively (Fig. 38).

In *Syzygium*, the phloem derivatives develop into sieve elements, companion cells, parenchyma cells and fibres. Fibre bands are discontinuous and appear as patches, alternating with parenchyma cells and sieve tube elements (Fig. 34 A). The vertically elongated narrow sieve tube elements are arranged in non-storied manner. The end walls of sieve tube elements are oblique with an elongated scalariform compound sieve plate (Fig. 34 B). The sieve areas on the lateral walls are aggregate and linear. Each sieve tube member is associated with 3 to 7 companion cells. Axial parenchyma cells posses druse crystals of calcium oxalate. Fibre groups differentiate from the derivatives of fusiform cambial cells. The cambial zone is flanked by either axial parenchyma or sieve elements. Phloem ray cells are filled with dark phenolic contents. The sieve elements remain functional for one year followed by deposition of callose on the sieve plates.

Cambial derivatives towards xylem develop into vessel elements, axial parenchyma and fibres. Xylem is diffuse porous with solitary and radial multiple vessels. The vessel elements are interspersed between the fibre and parenchymatous bands. Xylem ray cells are filled with phenolic contents and starch grains. Occurrence of tyloses is common in the vessels of last years xylem (Fig. 34 C). Tyloses may develop from axial or ray parenchyma cells. In the latter case they are filled with phenolic contents or starch grains. Vessel elements are elongated with a narrow tail (Fig. 37 G, H) and their walls show characteristic vestured pits (Fig. 37 D) along with normal pits (Fig. 37 E). Fibres show thick lignin deposition at cell corners and in the inner secondary wall layer (Fig. 37 B). Window pits are found on both vessel elemnts and ray parenchyma (Fig 37 G, I).

<u>DEVELOPMENT</u>, <u>LENGTH</u> <u>AND</u> <u>WIDTH</u> <u>OF</u> <u>VESSEL</u> <u>ELEMENTS</u>:

The vessel elements differentiate during second, third and fourth flush of cambial activity. The developing vessel element enlarges radially and tangentially before the deposition of secondary wall. However the tangentially expansion is less, hence they show relatively more radial diameter in transverse sections (Fig. 3 F). The mean length of vessel elements doesn't show any correlation with that of fusiform cambial cells. Vessel element length is maximal (894 µm) in December and minimal (679 µm) in July. The average length of vessel element is more when the cambium is active. Vessel element length increases and decreases alternately in the year. Mean vessel width increases from January to April. Mean maximum and minimum vessel width are 253 µm and 137 µm in December and September respectively. The mean length and width of vessel elements are presented in Table 15.

VESSEL LUMEN DIAMETER:

The average vessel lumen diameter increases and decreases alternately in the year (Table 15). The lumen diameter is maximum (206 µm) in December and minimum (135 µm) in January. The mean vessel lumen diameter is represented in Fgure 43 A.

NUMBER OF VESSELS:

The average number of vessels per 0.5 mm^2 of xylem ranges from 6 to 9 in the year (Table 15). The number of vessels are more in xylem at the end of peak cambial activity. The average number vessels for the year is represented in Figure 43 B.

Compared to the affected trees vessel number is less but they have more lumen diameter (Fig. 34 E).

GROWTH RING WIDTH:

Growth rings in xylem are clearly visible when observed under microscope (Fig. 44 E). Growth ring boundary could easily be discerned (Fig. 34 D). The amount of annual xylem increment in two successive years (1989 and 1990) has been represented in Table 19. The amount of xylem produced in last year is marginally higher (5.2 mm) than the current year`s (5.0 mm).

HISTOCHEMISTRY:

STARCH:

Fusiform cambial cells possess small granules of starch in November and December (Table 17). As cambial ray cells are filled with phenolic contents neither polysaccharides nor starch is found except in November (Fig 36 A). Accumulation of starch in xylem of main stem varies in different months of the year. Current year's xylem parenchyma has low starch than the previous year's. High starch content is noticed in current year's xylem parenchyma cells compared to that of previous year when the cambial cell divisions are suspended. Starch accumulation is maximal in July in both axial and ray parenchyma of xylem. During reactivation of cambium, the xylem axial and ray parenchyma starch is low or no accumulation at all (Fig. 35 C). The starch grains in ray parenchyma are embedded within the phenolic contents (Fig. 36 B). Starch grains appear small and round in both the axial and ray parenchyma cells of xylem and phloem throughout the year. As Syzygium is an evergreen tree, there is no definite pattern observed in seasonal accumulation of starch. Phloeic starch content is much less in comparison to xylem (Fig. 35 A). Soon after the second and third flush of cambial activity, starch accumulation is high in phloem axial parenchyma (Table 17).

In young branches the starch accumulation in xylem is similar to that of main stem except in July. When the cambium is dormant in November, there is no starch accumulation in axial and ray parenchyma of xylem (Fig. 35 E). Starch accumulation is more in June and December. During the active cambial growth the phloeic starch content is more and it is less when the growth is sluggish (August to October). Seasonal starch accumulation in cambium and parenchyma cells of xylem and phloem of main stem and young branch is presented in Table 17.

LIPIDS:

Lipid bodies are localized only in fusiform cambial cells. They are not traceable in cambial ray cells due to the high phenolic contents. At the end of third flush of activity, dark lipid bodies are distinctly seen along the tangential cell walls (Fig. 35 I). Lipids are observed only when there are no cell divisions in cambium.

PROTEINS:

Like lipid bodies, protein granules are also localized in fusiform cambial cells only. At the end of second flush of cambial activity the protein granules are clearly visible (Fig. 35 G). The cells do not exhibit protein bodies when the cambium is active.

AFFECTED TREES

CAMBIAL STRUCTURE:

The cambium is nonstoried with large fusiform and short cambial ray cells. The structure of cambium is similar to that of normal trees. The cambial zone is 2 to 7 and 4 to 12 layers wide during dormant and active periods of cambium respectively (Table 13).

CAMBIAL ACTIVITY:

Cambial growth occurs in three flushes. Cambial cells remain inactive in February and March (Fig. 32 A, B) in contrast to normal trees, where the first flush of cambial activity occurs during the same period. The first flush of activity occurs in April-May (Fig. 32 C) followed by no cambial cell division in June and July. The second flush of divisions begins in August (Fig. 32 E) and ceases in November followed by third flush of divisions in December (Fig. 32 G). The cambial zones becomes 4 to 8, 4 to 1 and 4 to 12 layered during the first, second, and third flush of cambial activity. Cambial cell divisions are maximum in August and December (Fig. 32 E, G). In the intervening months the cambium remains inactive (Fig. 32 D). The cambial zone is narrow with 2 to 5 and 3 to 5 layers in February and November respectively (Table 13).

In young branches the cambial zone is 3 to 8 and 2 to 6 layered during active and rest periods (Table 13). Peak cambial activity is observed in September. The number of cambial layers in main stem and young branch are represented in Figure 39.

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

The trees bear leaves all through the year being an evergreen. Cambium remains inactive in July when the partial defoliation occurred, however new leaves developed simultaneously. Flowering is observed in February followed by fruiting in May - June. The peak cambial activity in August and December coincides with full foliage of trees. A few trees which are close to the fertilizer factory are completely leafless in September, while others are with full foliage. These trees develop their full crown in December. The relation between cambial activity and phenology is presented in Table 13.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

When the mean maximum temperature is highest (39.20 ^{o}C) in April, reactivation of cambium is observed. Maximum cambial cell divisions and differentiation of August coincide with the season's highest rainfall (461 mm) and relative humidity (90.6 %). The rate of cambial cell divisions decline in October when there is an abrupt decrease in average rainfall. However the third flush cambial activity occurred in December when mean maximum temperature is low (28.80 ^{o}C). Meteorological data is provided in Figures 3 and 4.

FUSIFORM CAMBIAL CELLS:

The gross structure, shape, arrangement and divisional activity of fusiform cambial cells of affected trees are similar to that of normal ones (Figs. 33 B, 32 E).

DIMENSIONAL CHANGES :

MEAN LENGTH:

The average length of fusiform cambial cells increases and decreases alternately from January to August. There is a gradual increase of average length from September reaching maximum (878 µm) in December . The mean cell length varies from 723 µm to 878 µm. The average length of the cells is maximal in December, when the divisions reach peak in cambium.

MEAN WIDTH:

The mean tangential width of fusiform cambial cell is maximal in February (26 µm) and minimal from October to December (20 µm). The minimum width of cells coincides with the maximum length in December.

The mean length and width of fusiform cambial cells are presented in Table 14.

LENGTH VARIATION IN RELATION TO XYLEM FIBRE LENGTH :

The average length of fibre is 1.6 to 2 times more than fusiform cambial cells. The average length of fibre ranges from 1279 µm to 1730 µm. The fibre length is minimal during the second flush of cambial activity and maximal when the cambium is inactive in June. The fibre length gradually increases from January to March and decreases in May when the fusiform cambial cell length is considerably less. When the average length of fusiform cambial cell increased in June, correspondingly the fibre attains maximum average length. The variation in the length of fusiform cambial cell and xylem fibres is represented in Figure 40 B.

CAMBIAL RAY CELLS:

The structure, shape and divisional activity of cambial ray cells in affected trees appear similar to that of normal ones (Fig. 33 D). The phenolic content in cambial ray cells appear less denser than that of its derivatives (Fig. 32 F).

DIMENSIONAL CHANGES:

CAMBIAL RAY HEIGHT:

The mean ray height is found to be more in affected trees. The average height gradually increases from January, reaching maximum (421 µm) in April. In the remaining months, the average height fluctuates alternately (Table 16).

CAMBIAL RAY WIDTH:

The average ray width ranges from 32 µm to 56 µm. Mean ray width increases gradually from January to March along with ray height. Cambial ray width is maximal at the end of second flush of cambial activity in October (Table 16).

CAMBIAL RAY CELL DIAMETER:

Average cambial ray cell diameter is less in the beginning of first flush of cambial activity. The maximum average cambial ray cell diameter is 32 µm in October. The average diameter increases and decreases alternately in the remaining months (Table 16).

The variation in length and width of cambial rays and cambial ray cell diameter is presented in Figure 41 (A-C).

CAMBIAL RAY POPULATION:

The average number of cambial rays per one cm tangential width of cambium is found to be more in affected trees compared to that of healthy ones (Table 16). During the annual cycle of cambium, the number of rays varies from 110 to 150. Ray number is more when the cambium is active. The average ray population is represented in Figure 42.

DEVELOPMENT OF VASCULAR TISSUES:

The development of xylem and phloem occurs in three flushes. Xylem differentiation precedes that of phloem during the first flush of cambial activity. In the remaining two flushes, the differentiation and cessation of xylem and phloem elements are simultaneous (Fig. 39). The amount of phloem produced for the growth season of current year's is found to be less in affected trees. The structure of phloem and xylem elements is similar to that of normal trees. However, the xylem fibres show thin cell wall in affected trees compared to that of normal ones (Fig. 37 C). The average number of differentiating xylem and phloem elements are relatively less in affected trees (Table 13). The phloem (1 to 6) and xylem (10 to 18) derivatives are maximal in August (Figs. 39, 32 E).

DEVELOPMENT, LENGTH AND WIDTH OF VESSEL ELEMENTS:

The development of vessels is similar to that of normal trees. Average vessel element length decreases gradually from January to March. The maximum and minimum vessel element lengths are 884 µm and 688 µm in December and May respectively. Vessel length increases and decreases alternately in the remaining months of the year. The yearly average of vessel element lengths are 782 µm and 809 µm in affected and normal trees respectively (Table 20). The average width of vessel fluctuates alternately in the year. It is maximal (182 µm) in October and minimal (103 µm) in January. In general the average vessel element width is less in the xylem of affected trees (Table 15).

VESSEL LUMEN DIAMETER:

Average maximum and minimum vessel lumen diameter is 156 µm and 103 µm respectively (Table 15). The yearly averages of the lumen diameter is less in affected trees than that of normal ones (Table 20), and monthly observations are represented in Figure 43 A.

NUMBER OF VESSELS:

The average number of vessels per 0.5 mm^2 of xylem seasonally varies from 8 to 17 (Table 15). The average number is more in affected trees except in March and September (Figs. 43 B, 34 F).

GROWTH RING WIDTH:

The width of the annual increment of xylem is found to be less in affected trees (Fig. 44 F). The growth ring boundary could easily be discernible with 2 to 3 layers of thick walled narrow fibres and narrow vessels produced at the end of cambial growth (Fig. 37 F). The xylem ring produced during current year's and last year's cambial growth is measured and represented in Table 19.

HISTOCHEMISTRY:

STARCH:

Accumulation of starch in cambial cells is similar to that of normal ones. Of all the elements of xylem, axial parenchyma accumulate more amount of starch (Fig. 35 D). Starch concentration in xylem decreases gradually from January to March. Starch accumulation is more in xylem ray parenchyma of affected trees in February. Axial parenchyma cells are filled with large amounts starch in July and august. However, the starch content is low in current year's xylem compared to that of previous year's. Accumulation of starch is more or less same from June to December. Prior to the cambial reactivation in April low content of starch is observed (Table 18). Starch accumulation in axial parenchyma of phloem is uniform from June to December, however in April it occurs in large amounts. The phloic starch content is more in affected trees than that of normal ones (Fig. 35 B).

In young branches starch accumulation is more in ray parenchyma of xylem (Fig. 35 F). The axial parenchyma cells show more starch in July and August (Table 18). Branch phloem has low content of starch than that of main stem. However, the parenchyma cells of phloem accumulate more starch in August.

LIPIDS:

Storage of lipids in cambial cells is similar to that of normal ones. The accumulation of lipids is modest in fusiform cambial cells of affected trees (Fig. 35 H).

PROTEINS:

Protein granules are localized in the fusiform cambial cells (Fig. 35 J). As cambial ray cells are filled with phenolic contents, localization of proteins is not discernible.

TABLE 13 : THE DATA ON PHENOLOGY, AVERAGE NUMBER OF CAMBIAL LAYERS AND DIFFERENTIATING XYLEM AND PHLOEM ELEMENTS IN NORMAL (N) AND AFFECTED (A) TREES OF **SYZYGIUM CUMINI**

PHENOLOGY			CAMBIAL LAYERS MAIN STEM		YOUNG BRANCH		XYLEM		PHLOEM	
Month	N	A	N	A	N	A	N	A	N	A
JAN	FULL FOLIAGE	FULL FOLIAGE	7.1 ±0.97	5.0 ±0.80	5.9 ±0.83	4.3 ±0.88	– –	– –	– –	– –
FEB.	FULL FOLIAGE FLOWERING	FULL FOLIAGE FLOWERING	7.9 ±1.20	3.6 ±0.63	4.3 ±0.85	4.2 ±0.64	5.1 ±1.06	– –	2.0 ±0.76	– –
MAR.	FULL FOLIAGE	FULL FOLIAGE	6.7 ±0.80	4.4 ±0.66	4.4 ±0.66	3.4 ±0.53	– –	– –	– –	– –
APR.	FULL FOLIAGE	FULL FOLIAGE	7.0 ±1.24	6.2 ±0.94	4.0 ±0.73	5.7 ±0.81	2.6 ±0.82	3.6 ±0.57	– –	– –
MAY	FULL FOLIAGE FRUITING	FULL FOLIAGE FRUITING	4.8 ±0.78	5.3 ±0.86	4.5 ±0.64	3.5 ±0.60	2.2 ±0.51	3.7 ±1.10	2.6 ±0.76	2.6 ±0.76
JUN.	FULL FOLIAGE PARTIAL LEAF FALL	FULL FOLIAGE FRUITING	5.4 ±0.91	4.9 ±0.84	3.6 ±0.56	3.2 ±0.68	– –	– –	– –	– –
JUL.	FULL FOLIAGE	FULL FOLIAGE (Partial leaf fall)	5.4 ±0.77	4.9 ±0.74	4.3 ±0.91	5.5 ±0.80	– –	– –	– –	– –
AUG.	FULL FOLIAGE	FULL FOLIAGE	8.9 ±1.11	7.2 ±1.12	2.4 ±0.63	3.1 ±1.08	20.0 ±4.40	14.6 ±1.93	5.0 ±0.74	3.2 ±1.11
SEP.	FULL FOLIAGE	FULL FOLIAGE	6.2 ±1.24	6.5 ±1.16	4.6 ±0.80	6.0 ±1.22	8.0 ±1.39	8.0 ±1.66	4.0 ±0.83	2.6 ±0.73
OCT.	FULL FOLIAGE	FULL FOLIAGE	6.9 ±1.32	5.4 ±0.84	4.3 ±0.81	3.1 ±0.43	6.5 ±1.65	1.4 ±0.49	3.2 ±0.61	1.2 ±0.40
NOV.	FULL FOLIAGE	FULL FOLIAGE	4.4 ±0.52	3.8 ±0.65	4.4 ±1.40	3.6 ±0.59	– –	– –	– –	– –
DEC.	FULL FOLIAGE	FULL FOLIAGE	5.5 ±1.65	6.1 ±1.81	3.6 ±0.56	5.1 ±1.27	10.7 ±1.74	12.7 ±2.68	2.7 ±0.65	2.6 ±0.84

TABLE 14 : DIMENSIONAL DETAILS OF FUSIFORM CAMBIAL CELLS AND XYLEM FIBRES IN NORMAL (N) AND AFFECTED (A) TREES OF **SYZYGIUM CUMINI**

MONTH	FUSIFORM CAMBIAL CELLS LENGTH (um)		FUSIFORM CAMBIAL CELLS WIDTH(um)		XYLEM FIBRES LENGTH (um)	
	N	A	N	A	N	A
JAN	787 ±124.70	717 ±67.67	27 ±5.50	24 ±4.37	1696 ±252.37	1544 ±214.71
FEB	741 ±73.70	800 ±89.40	30 ±6.18	26 ±2.89	1752 ±225.79	1579 ±246.83
MAR	840 ±105.40	723 ±111.99	27 ±4.80	22 ±4.26	1724 ±189.04	1594 +174.61
APR	717 ±54.59	805 ±128.28	30 ±5.06	20 ±3.00	1695 ±195.86	1460 ±166.80
MAY	827 ±106.42	764 ±79.50	26 ±5.20	24 ±4.24	1720 ±206.72	1279 ±165.40
JUN	840 ±89.92	876 ±69.71	22 ±5.48	23 ±5.28	1792 ±267.57	1720 ±181.19
JUL	880 ±88.09	745 ±132.08	29 ±4.89	25 ±4.72	1655 ±200.65	1593 ±211.54
AUG	816 ±93.47	832 ±79.58	26 ±4.12	24 ±5.58	1748 ±208.37	1592 ±172.37
SEP	865 ±93.26	804 ±89.44	27 ±4.80	21 ±4.53	1532 ±217.67	1640 ±196.97
OCT	742 ±75.68	807 ±48.05	24 ±3.48	20 ±2.99	1767 ±211.13	1561 ±211.11
NOV	811 ±88.11	808 ±54.99	22 ±3.42	20 ±3.44	1596 ±192.21	1586 ±188.40
DEC	899 ±90.03	878 ±99.72	26 ±2.89	20 ±2.94	1820 ±205.11	1691 ±217.60

TABLE 15 : DIMENSIONAL DETAILS OF VESSEL ELEMENTS AND AVERAGE NUMBER OF VESSELS PER 0.5 mm^2 IN NORMAL (N) AND AFFECTED (A) TREES OF **SYZYGIUM CUMINI**

MONTH	LENGTH (um)		WIDTH (um)		LUMEN DIAMETER (um)		NUMBER OF VESSELS	
	N	A	N	A	N	A	N	A
JAN	878	866	173	103	135	103	10	17
	±156.59	±216.60	±44.88	±25.86	±34.50	±28.00	±2.74	±3.60
FEB	721	819	175	157	183	156	6	8
	±184.69	±157.42	±45.46	±39.06	±37.20	±52.30	±1.76	±2.21
MAR	860	809	176	141	163	131	11	10
	±173.30	±170.95	±57.05	±40.30	±34.80	±31.80	±1.80	±1.84
APR	760	693	200	108	145	108	9	13
	±138.41	±146.15	±43.17	±23.75	±36.54	±21.42	±1.91	±2.72
MAY	815	688	157	153	166	140	7	11
	±126.19	±102.80	±40.40	±36.56	±44.58	±42.80	±1.67	±2.43
JUN	761	847	223	139	183	128	7	10
	±127.77	±151.10	±40.95	±31.90	±36.61	±25.45	±1.99	±2.15
JUL	694	721	150	104	147	108	7	14
	±140.74	±171.11	±41.03	±26.60	±28.90	±26.58	±1.20	±2.79
AUG	835	737	232	152	166	125	6	11
	±140.85	±122.00	±42.14	±34.38	±28.04	±23.20	±1.50	±2.89
SEP	874	804	137	117	138	109	19	15
	±149.47	±132.40	±28.62	±28.66	±35.49	±23.27	±3.97	±3.22
OCT	822	798	182	182	144	134	6	10
	±137.30	±151.05	±38.28	±44.11	±33.42	±28.38	±1.63	±2.81
NOV	791	721	166	146	149	109	8	12
	±143.74	±126.28	±32.90	±26.80	±25.90	±30.22	±2.41	±4.55
DEC	894	884	253	153	206	121	6	9
	±156.07	±121.70	±49.05	±37.21	±34.53	±23.93	±1.84	±2.84

TABLE 16 : DIMENSIONAL DETAILS AND POPULATION OF CAMBIAL RAYS IN NORMAL (N) AND AFFECTED (A) TREES OF **SYZYGIUM CUMINI**

MONTH	HEIGHT (um)		WIDTH (um)		RAY CELL DIAMETER (um)		POPULATION/cm	
	N	A	N	A	N	A	N	A
JAN	279 ±69.06	228 ±81.90	42 ±13.00	32 ±13.11	21 ±5.00	23 ±4.18	127 ±14.5	131 ±18.60
FEB	310 ±99.40	312 ±131.90	48 ±16.51	40 ±13.27	26 ±5.94	24 ±5.41	120 ±17.70	119 ±23.10
MAR	314 ±100.11	340 ±145.05	35 ±11.71	43 ±18.25	20 ±4.32	24 ±6.08	127 ±20.90	138 ±20.00
APR	277 ±84.42	421 ±163.09	44 ±12.08	41 ±14.70	23 ±6.02	22 ±5.39	120 ±16.20	142 ±11.27
MAY	301 ±138.87	298 ±141.18	47 ±16.89	39 ±15.26	24 ±6.34	26 ±4.83	111 ±13.80	124 ±20.10
JUN	323 ±153.80	300 ±116.39	47 ±15.87	40 ±13.27	26 ±6.06	23 ±5.96	120 ±16.50	144 ±16.00
JUL	364 ±146.48	319 ±98.75	49 ±17.63	47 ±12.24	23 ±4.46	24 ±5.44	116 ±21.00	127 ±15.00
AUG	310 ±131.96	364 ±197.43	42 ±14.45	44 ±16.99	26 ±6.50	27 ±5.09	111 ±16.80	141 ±14.10
SEP	420 ±145.27	364 ±128.14	40 ±11.57	38 ±12.21	25 ±5.74	24 ±5.34	139 ±20.70	142 ±19.30
OCT	261 ±120.20	371 ±147.85	44 ±16.60	56 ±19.33	28 ±8.14	32 ±8.36	111 ±19.50	110 ±20.00
NOV	350 ±125.50	402 ±154.43	56 ±27.46	42 ±13.94	29 ±7.02	26 ±5.72	110 ±13.30	136 ±19.60
DEC	373 ±115.19	367 ±149.69	47 ±15.39	35 ±15.99	25 ±5.36	23 ±5.54	116 ±15.50	150 ±20.90

TABLE 17 : SEASONAL STARCH CONTENT IN CAMBIUM AND PARENCHYMA CELLS OF XYLEM AND PHLOEM OF NORMAL (N) TREES OF **SYZYGIUM CUMINI**

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAINSTEM														
PHLOEM		AP	–	+	0	0	–	■■	0	0	■	■	+	–
		RP	–	+	x	–	–	+	0	+	0	■	x	–
CAMBIUM		FCC	x	x	x	x	x	x	x	x	x	x	✓	✓
		CRC	x	x	x	x	x	x	x	x	x	x	✓	x
XYLEM	Cl.Cz	AP	0	+	+	■■	■	■■	■■	x	x	x	+	x
		RP	0	–	x	x	–	+	■	x	x	x	x	x
	Aw.Cz	AP	0	■■	+	■■	–	■	■■■	■■■	■■	■■■	0	■■■
		RP	■	+	x	–	+	+	■■■	0	0	+	–	0
YOUNG BRANCH														
PHLOEM		AP	■■	✓	–	+	■■	–	+	–	+	–	■	–
		RP	x	–	x	–	x	+	–	+	0	+	x	0
XYLEM		AP	0	x	–	■	■	■■■	x	■	x	x	x	■■■
		RP	+	+	■■	+	■■■	■■■	x	■■	x	x	+	■■■

AP = AXIAL PARENCHYMA, FCC = FUSIFORM CAMBIAL CELL
RP = RAY PARENCHYMA, CRC = CAMBIAL RAY CELL
Cl.cz = CLOSE TO CAMBIAL ZONE
Aw.cz = AWAY FROM CAMBIAL ZONE

TABLE 18 : SEASONAL STARCH CONTENT IN CAMBIAL AND PARENCHYMA CELLS OF XYLEM AND PHLOEM OF AFFECTED (A) TREES OF **SYZYGIUM CUMINI**

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAINSTEM														
PHLOEM		AP	0	0	–	■■	0	■	■	■	■	■	■	■
		RP	+	–	x	x	x	–	+	+	0	0	+	–
CAMBIUM		FCC	x	x	x	x	x	x	x	x	x	x	✓	x
		CRC	x	x	x	x	x	x	x	x	x	x	x	x
XYLEM	Cl.Cz	AP	+	■	0	■	+	+	0	x	x	x	+	+
		RP	+	x	x	x	x	0	■	x	x	x	–	–
	Aw.Cz	AP	■■	■	0	■	+	■■	■	■■	■	+	■	■
		RP	■■	x	0	0	■	0	■	0	0	■	0	■
YOUNG BRANCH														
PHLOEM		AP	–	+	0	x	–	x	–	■	0	–	+	+
		RP	+	+	+	x	■■	–	–	■	+	+	+	+
		C	x	x	x	x	x	x	x	x	x	x	x	x
XYLEM		AP	–	✓	0	–	–	–	■■	0	+	–	■■	■
		RP	■	0	■■■	■	0	+	■	■■■	■■	■■	■■■	0

AP = AXIAL PARENCHYMA, FCC = FUSIFORM CAMBIAL CELL
RP = RAY PARENCHYMA, CRC = CAMBIAL RAY CELL
Cl.cz = CLOSE TO CAMBIAL ZONE
Aw.cz = AWAY FROM CAMBIAL ZONE

TABLE - 19 : RADIAL EXTENT OF ANNUAL XYLEM INCREMENT IN TWO SUCCESSIVE YEARS.

GROWTH YEAR -	1989		1990	
NAME OF THE TREE	NORMAL (mm)	AFFECTED (mm)	NORMAL (mm)	AFFECTED (mm)
<u>DALBERGIA</u>	4.1	4.5	4.5	5.6
<u>HOLOPTELEA</u>	4.1	2.8	4.8	2.7
<u>SYZYGIUM</u>	5.2	3.1	5.0	3.0

TABLE 20. Showing the yearly averages of number and dimensions of cambial cells and their derivatives.

NAME OF THE TREE	CAMBIAL CELL LAYERS MAIN STEM		CAMBIAL CELL LAYERS YOUNG BRANCH		FUSIFORM CAMBIAL CELL LENGTH (um)		FUSIFORM CAMBIAL CELL WIDTH (um)		CAMBIAL RAY HEIGHT (um)		CAMBIAL RAY WIDTH (um)		CAMBIAL RAY CELL DIAMETER (um)		POPULATION/ cm		VESSEL MEMBER LENGTH (um)		VESSEL MEMBER WIDTH (um)		VESSEL MEMBER DIAMATER (um)		NUMBER OF VESSELS		XYLEM FIBRE LENGTH (um)	
	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A
DALBERGIA	7	8	5	5	162	160	15	15	113	119	31	36	16	16	211	190	153	152	149	159	158	138	5	5	1030	1069
SYZYGIUM	6	5	4	4	815	805	26	23	323	342	45	42	25	25	119	134	809	782	185	138	160	123	9	12	1708	1570
HOLOPTELEA	7	6	5	4	246	246	13	13	161	159	29	28	14	14	145	167	241	225	116	110	116	97	8	13	1199	1081

N = NORMAL

A = AFFECTED

FIG. 31.

A-G: Transverse sections of cambium of normal trees.

A. Periclinally dividing (arrow) fusiform cambial cells in February. x 300.

B. Dormant cambial zone in March. x 420.

C. Cambial zone in May. x 370.

D. Dormant cambial zone in June. x 294.

E. Differentiation of xylem elements from active cambial zone. x 375.

F. Cambial zone with periclinally dividing fusiform and ray cambial cells. Arrow indicates ray cambial cells filled with less dense phenolic contents . x 400.

G. Active cambial zone in December. Arrow indicates recently divided fusiform cambial cell. x 330.

CZ: Cambial Zone; DX: Differentiating Xylem; RC: Ray Cambial Cell; V: Vessel Element

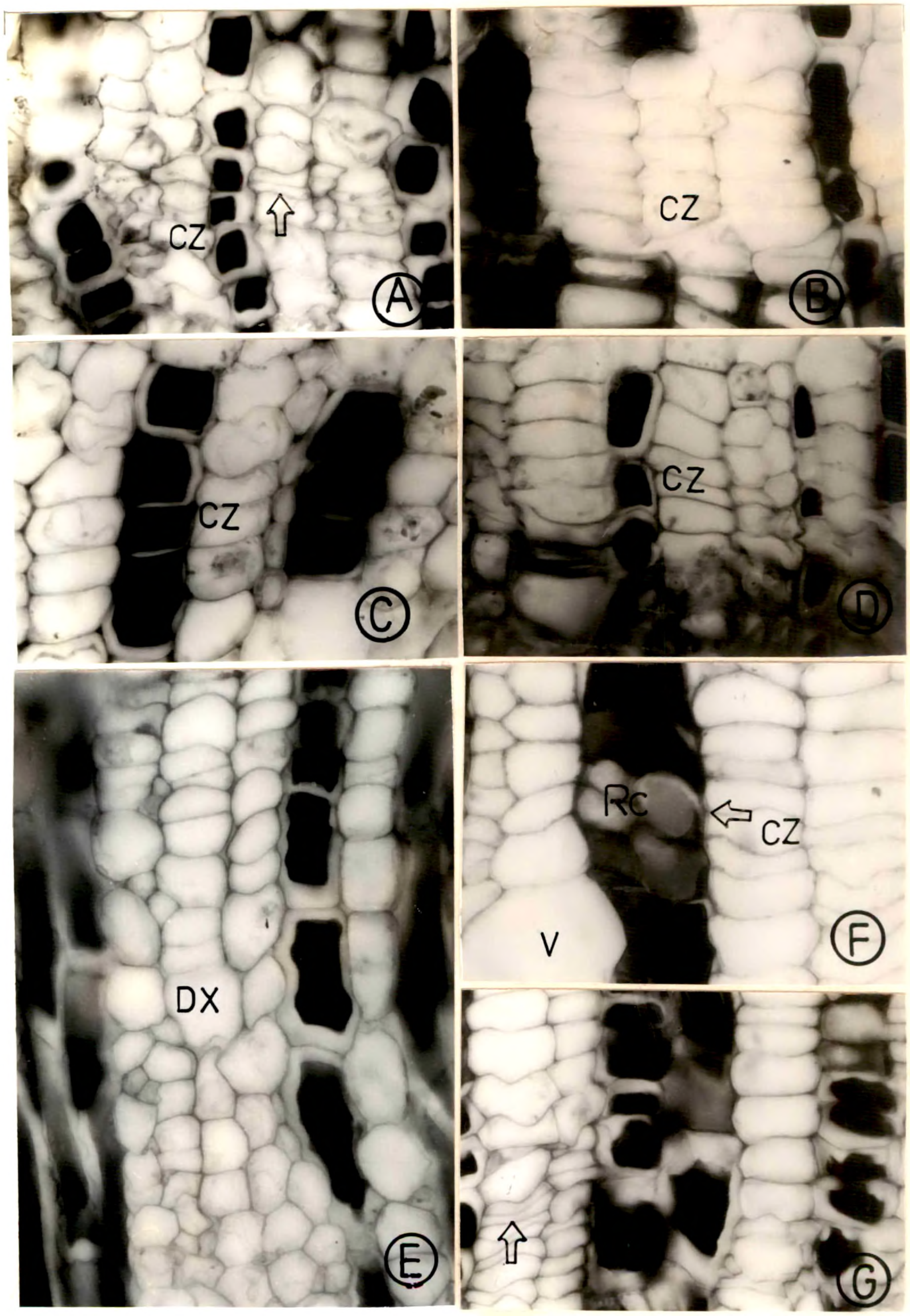


FIG. 31

Fig. 32.

A-G: Transverse sections of cambium of affected trees.

A. Dormant narrow cambium surrounded by mature xylem and phloem elements in February. x 400.

B. Dormant cambium in March. x 400.

C. Swelling of fusiform cambial cells towards phloem and xylem side. x 400.

D. Dormant cambial zone in June. x 400.

E. Cambial zone surrounded by differentiating xylem and phloem elements in August. x 250.

F. Active cambial zone in September. x 330.

G. Cambial zone with differentiating elements in December. x 330.

CZ: Cambial Zone; DX: Differentiating Xylem; PH: Phloem; V: Vessel Element

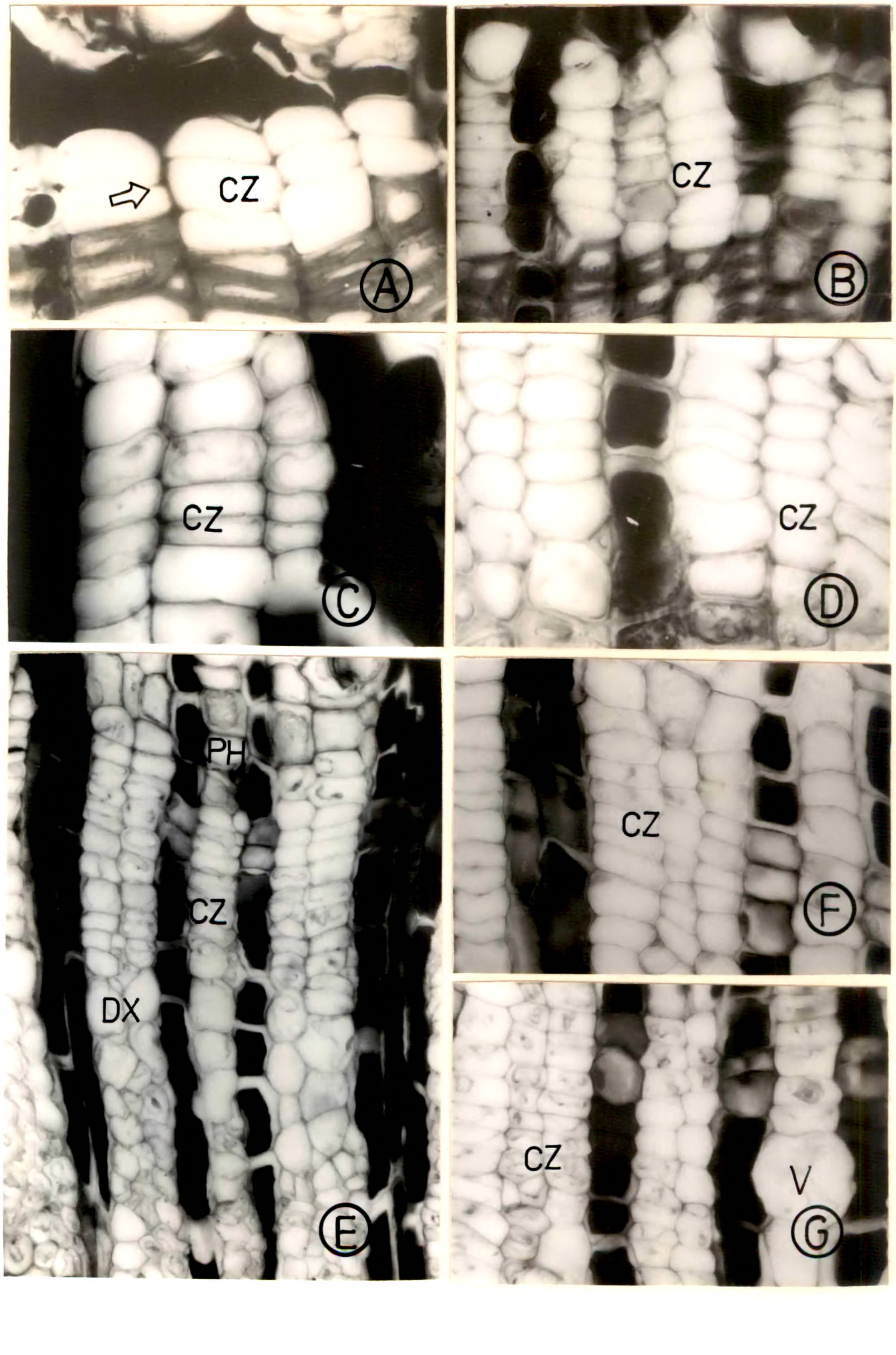


FIG. 32

Fig. 33.

A-D: Tangential longitudinal sections of cambium.

A. Nonstoried arrangement of fusiform and ray cambial cells in normal trees. x 184.

B. Fusiform cambial cells of affected trees showing beaded radial walls (arrow) in March. x 250.

C. Fusion of radially adjacent cambial rays (arrow). Arrowhead indicates a ray cambial initial. x 160.

D. Two celled cambial ray with dark phenolic contents (arrows). x 250.

FC: Fusiform Cambial Cell

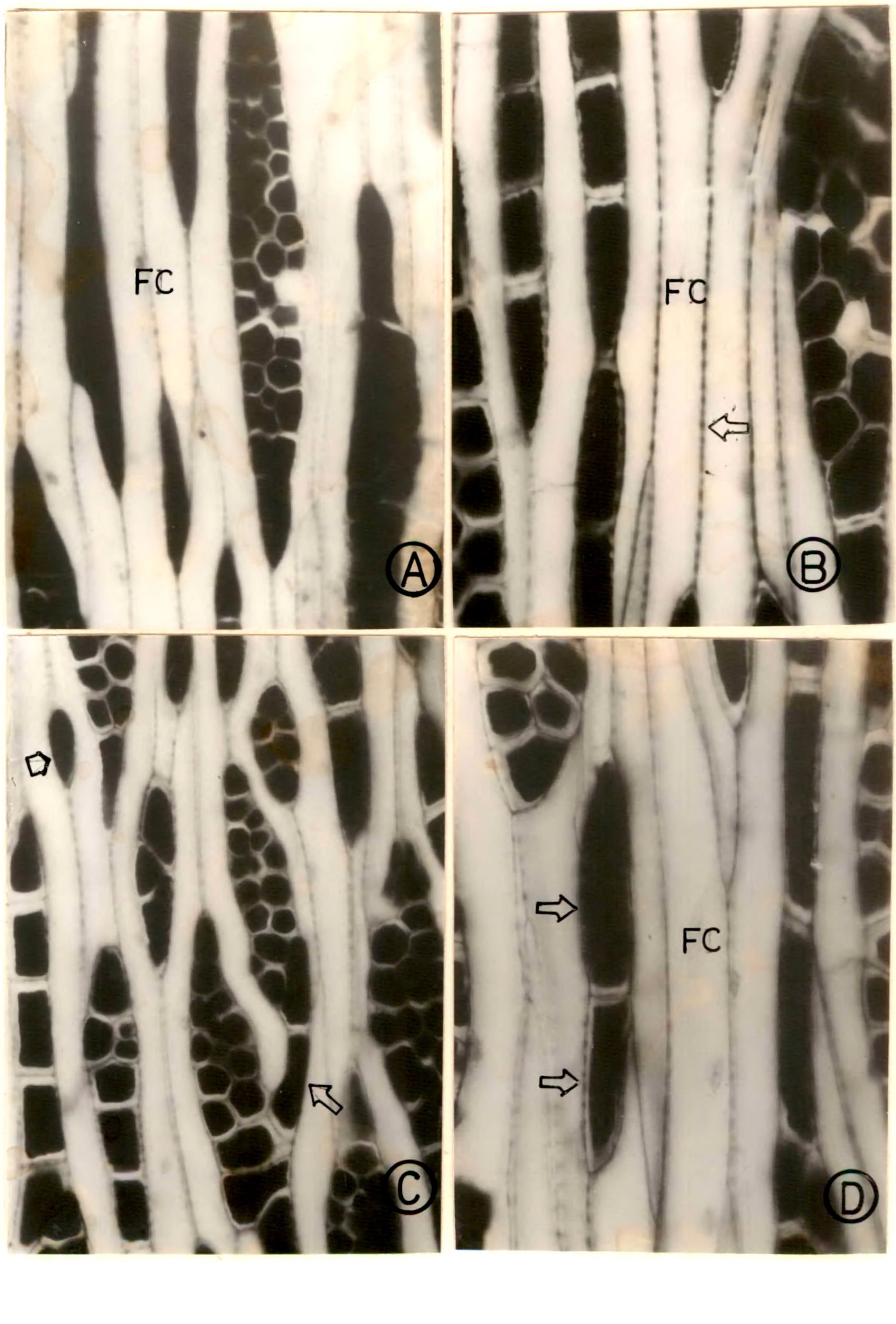


FIG. 33

Fig. 34.

A-F: Transverse sections of phloem and xylem.

A. General structure of phloem showing sieve elements, parenchyma cells with dark contents and isolated fibre groups (arrows). x 120.

B. Compound scalariform sieve plates in phloem. x 238.

C. Tyloses with dark contents in a vessel element (arrowhead) . x 250.

D. Demarcation of xylem growth ring boundary by the presence of thick walled narrow elements. x 156.

E. Distribution of vessels in normal trees. x 33.

F. Distribution of vessels in affected trees. x 33.

RB: Ring Boundary; SP: Sieve Plate; V: Vessel Element

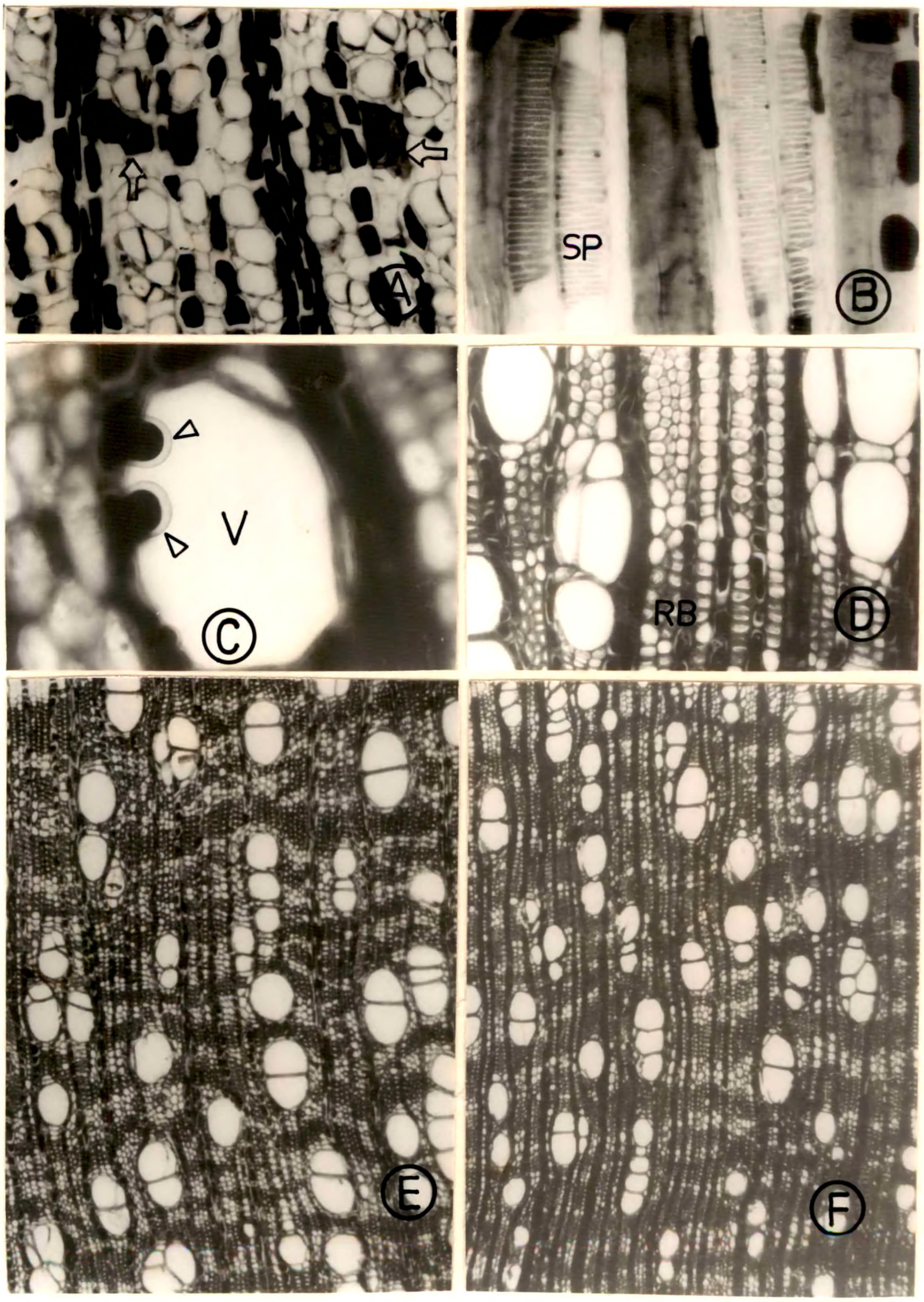


FIG. 34

Fig. 35.

A-D: Radial longitudinal sections of xylem and phloem.

E-F: Transverse sections of young branch.

G-J: Radial longitudinal sections of fusiform cambial cells.

A. Phloem ray parenchyma showing sparsely distributed small granules of starch in normal trees. x 244.

B. Distribution of starch in phloem ray parenchyma of affected trees. x 380.

C. Xylem axial parenchyma with sparsely distributed starch in normal trees. x 400.

D. Starch distribution in xylem axial parenchyma of affected trees. x 400.

E. Branch xylem parenchyma cells showing no starch contents (arrows) in normal trees. x 120.

F. Branch xylem parenchyma cells with starch content (arrows) in affected trees. x 120.

G. Protein bodies (arrow) in dormant fusiform cambial cells of normal trees. x 210.

H. Protein bodies (arrow) in dormant fusiform cambial cells of affected trees. x 210.

I. Lipid bodies along the walls of dormant fusiform cambial cells (arrow) in normal trees. x 850.

J. Lipid bodies along the walls of dormant fusiform cambial cells in affected trees. x 700.

AP: Axial Parenchyma; RP: Ray Parenchyma

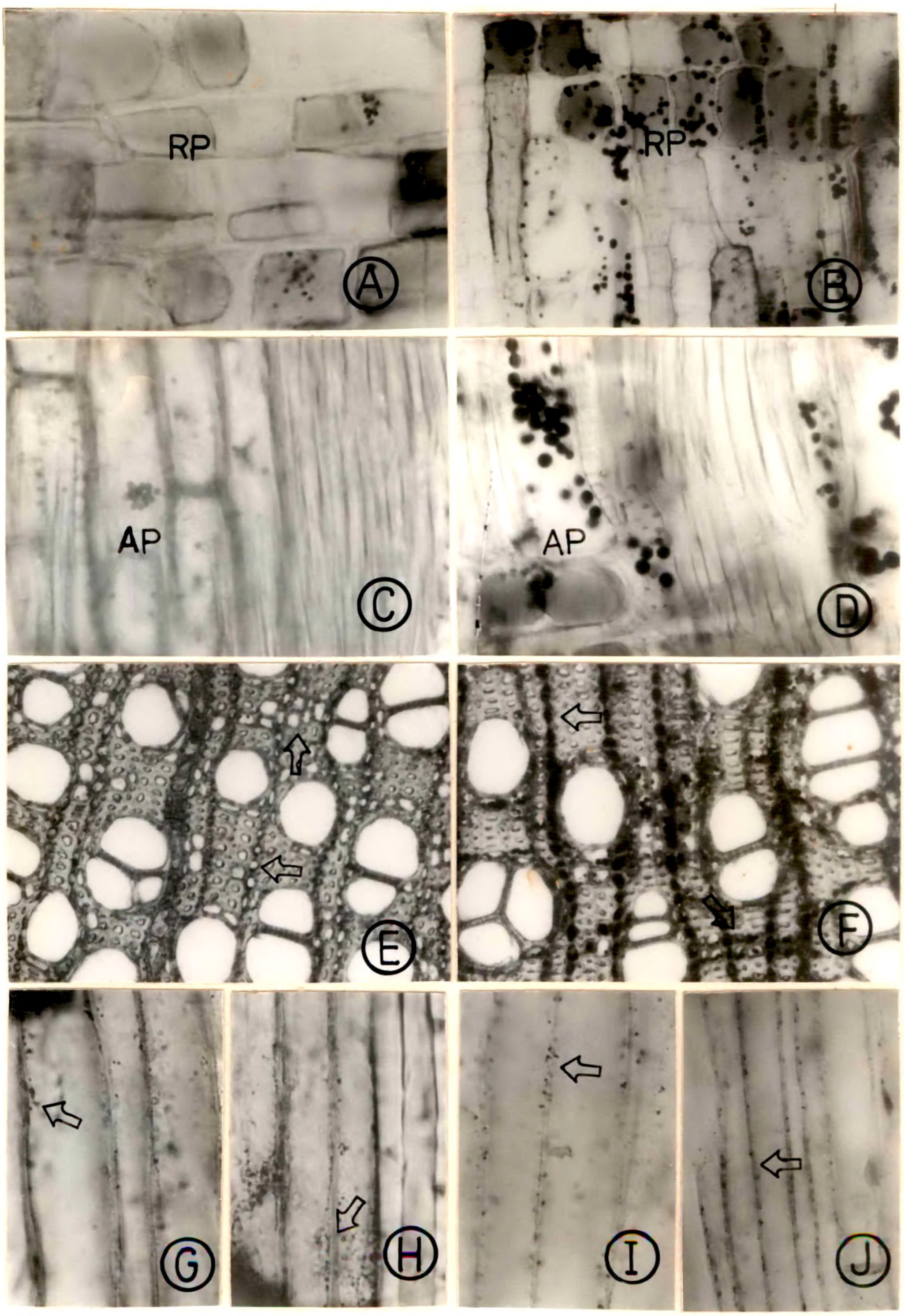


FIG. 35

Fig. 36.

A. Radial longitudinal section of cambial zone stained with Periodic acid-Schiff's reagent for total polysaccharides. Ray cambial cells show dark catechol type of tannin contents (arrowhead). Arrows indicate large primary pit-fields on radial walls of fusiform cambial cells. x 357.

B. Radial longitudinal section of xylem stained for total polysaccharides. Total polysaccharides are often obscured by the tannin contents in parenchyma cells. x 223.

FC: Fusiform cambial cell; RC: Ray Cambial Cell; RP: Ray parenchyma; Sg: Starch grains.

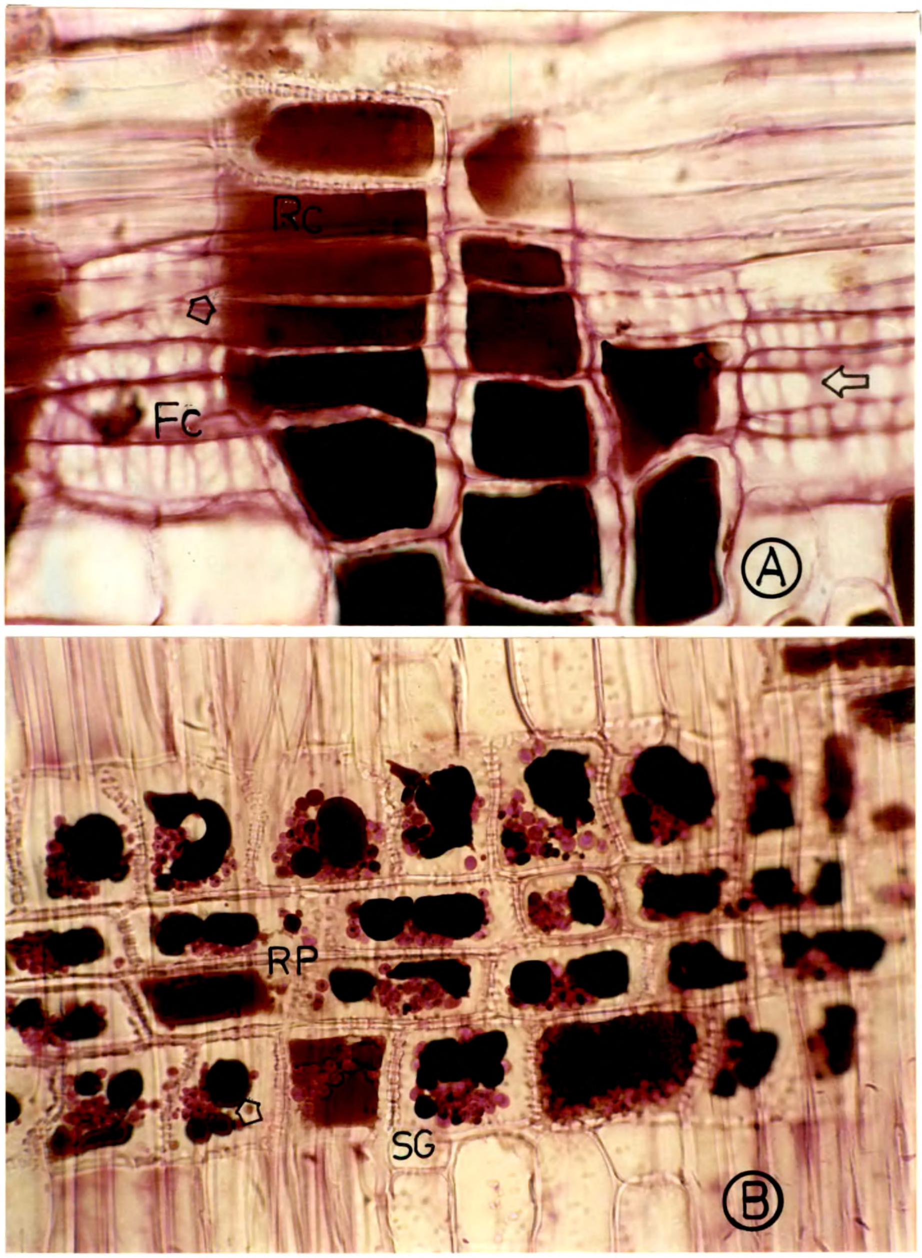


FIG. 36

Fig. 37.

A-C and F: Transverse sections (Unstained).

D, E and G-I: Macerated xylem elements.

A. Lignified elements of xylem and phloem seen under fluorescent light. Arrowheads indicate fluorescing phenolic contents in ray cells. x 100.

B. Lignified xylem fibre of normal trees as seen under floures-cence microscope. Note (arrow) more lignification of middle lamella and inner most layer of secondary wall. x 250.

C. Lignification of xylem fibres as seen under flourescence microscope. Note (arrow) relatively less lignified middle lamella and inner secondary wall layer. x 250.

D. Vestured bordered pits on outer surface of the vessel element wall seen under scanning electron microscope. Note (arrow) the bordered pits with totally closed pit apertures. x 3450.

E. Bordered pits on the inner surface of the vessel element seen under scanning electron microscope. x 2100.

F. Xylem growth ring boundary as seen under polarization micro-scope. Note (arrow) the discernibility of ring boundary by the thick walled highly birifringent fibres. x 685.

G. Scanning electron micrograph of a vessel element exhibiting vestured bordered pits (arrow) and large window pits (arrow-head) on the outer wall surface. x 650.

H. Scanning electron micrograph of a vessel element tail portion showing bordered pits (arrow) and window pits (arrowhead). x 2600.

I. Scanning electron micrograph of a xylem ray parenchyma cells showing large window pits (arrow). x 2100.

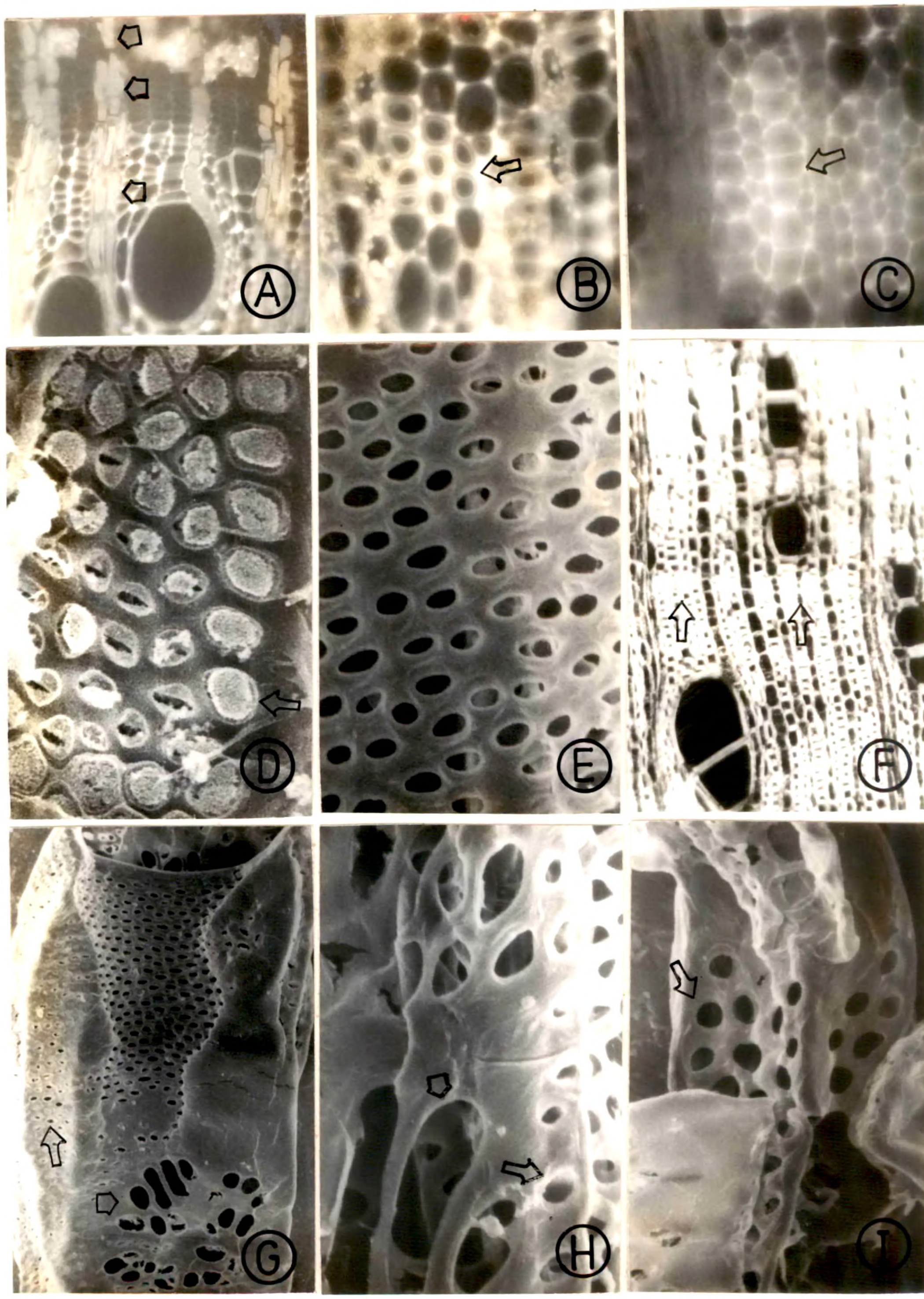


FIG.37

Fig. 38.

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone in the main stem and young branch and differentiating xylem and phloem elements in the main stem of normal trees.

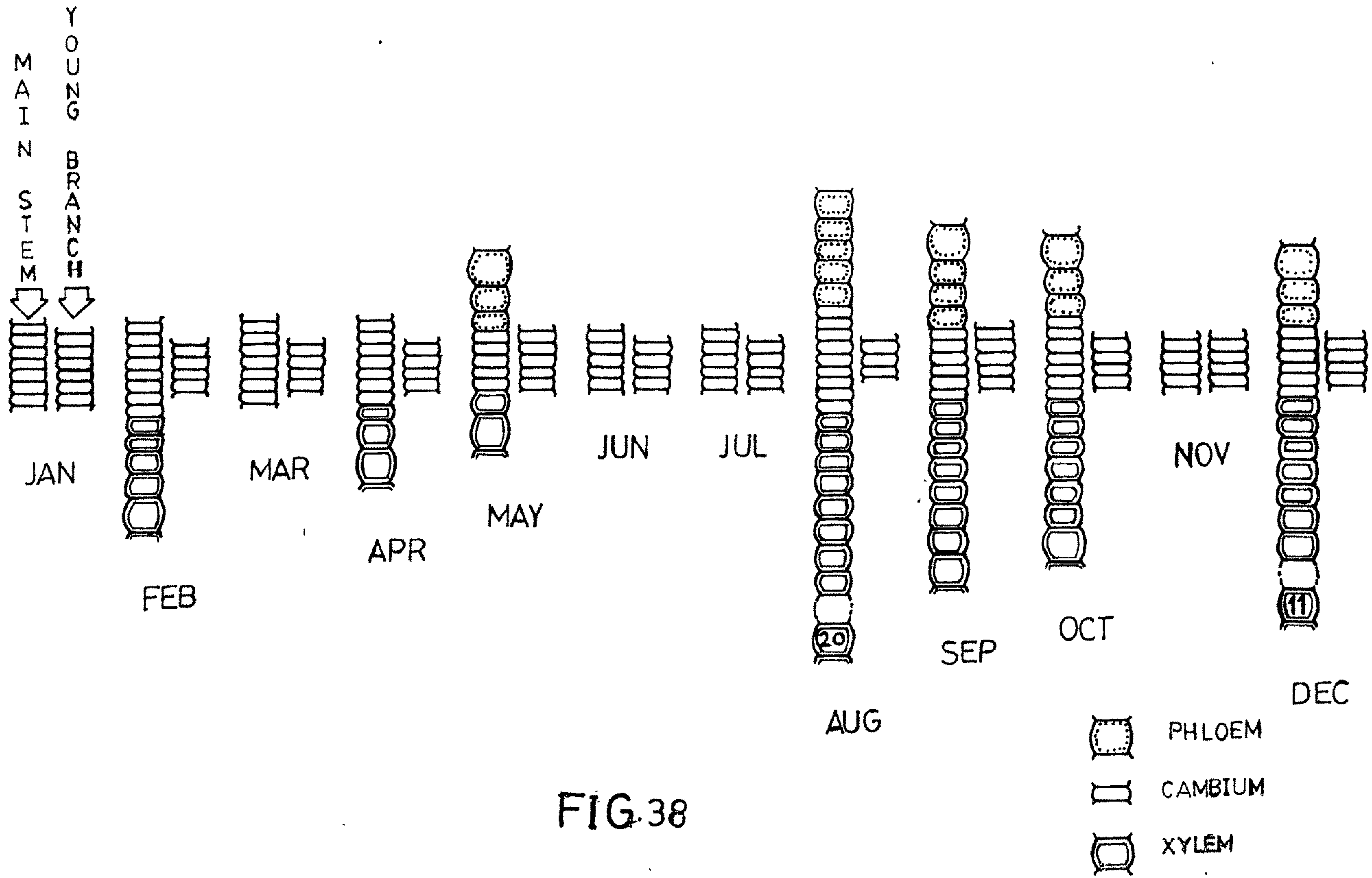

MAIN STEM
YOUNG BRANCH
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
20
SEP
OCT
NOV
DEC
11
PHLOEM
CAMBIUM
XYLEM

FIG.38

Fig. 39.

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone in the main stem and young branch and differentiating xylem and phloem elements in the main stem of affected trees.

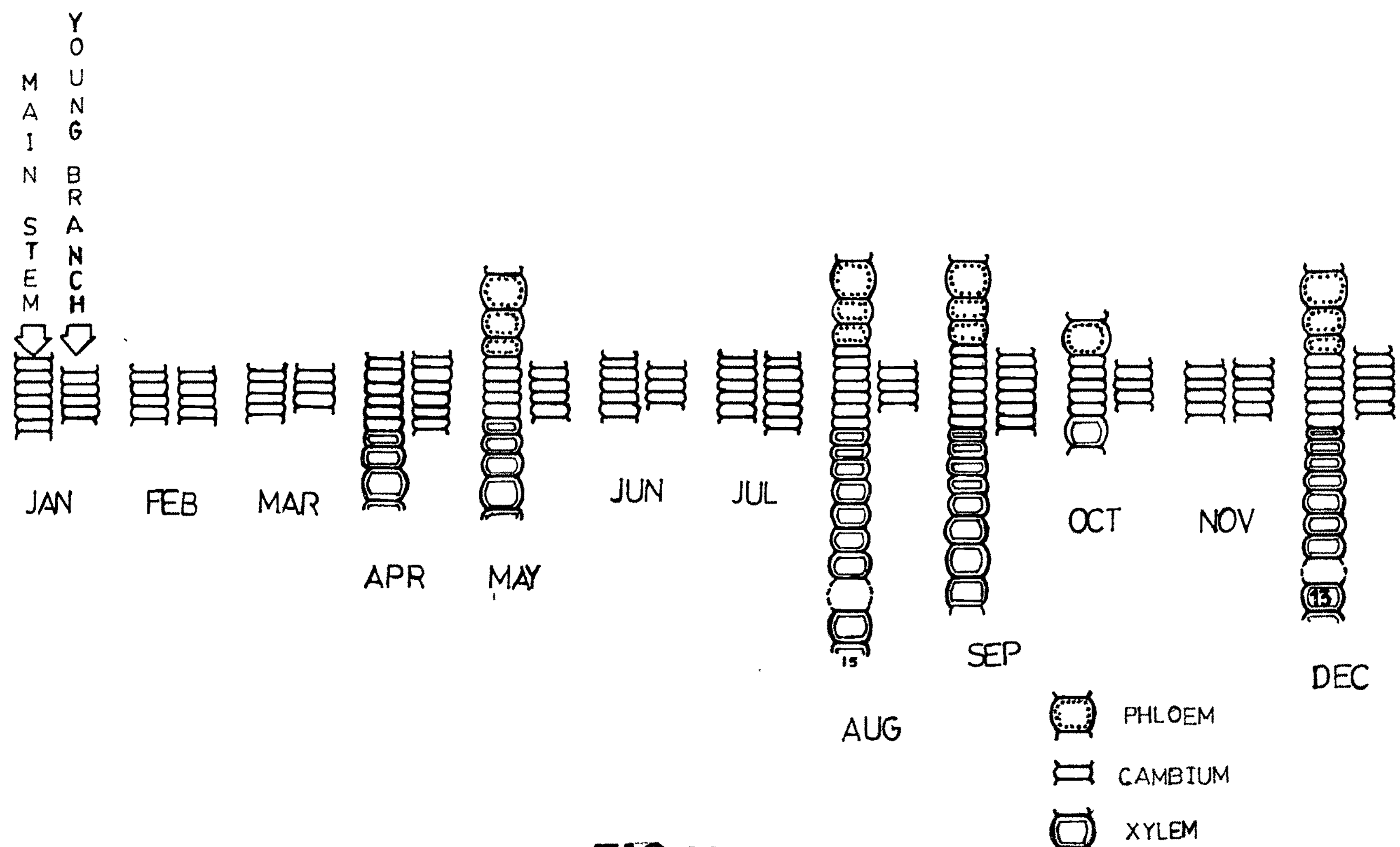

MAIN STEM
YOUNG BRANCH
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
15
13
PHLOEM
CAMBIUM
XYLEM

FIG.39

Fig. 40.

Histogram showing seasonal variation in mean length of xylem fibres and fusiform cambial cells.

A: Normal B: Affected

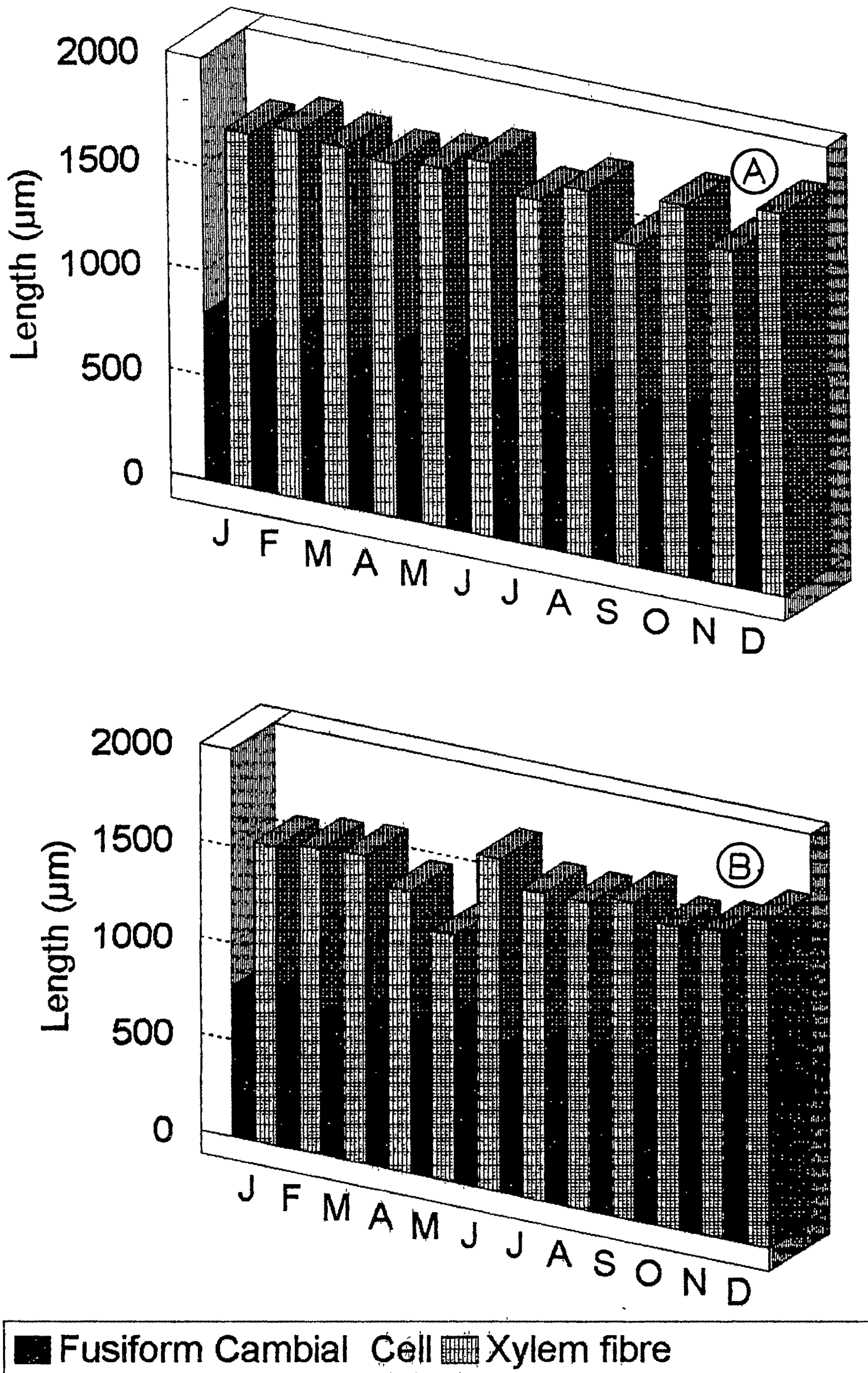
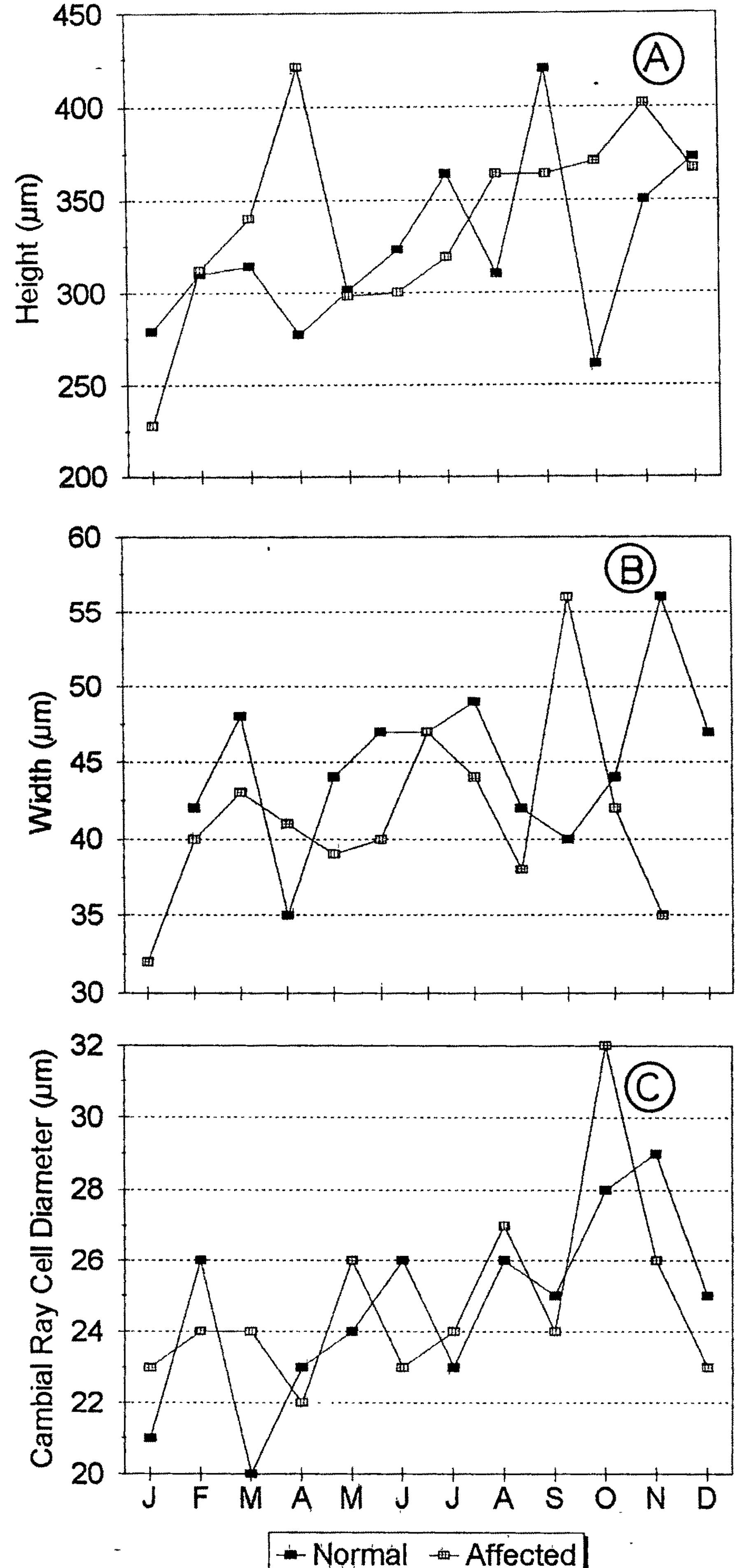

A
Length (µm)
2000
1500
1000
500
0
J F M A M J J A S O N D
B
Length (µm)
2000
1500
1000
500
0
J F M A M J J A S O N D
Fusiform Cambial Cell
Xylem fibre

FIG. 40

Fig. 41.

Graphic representation of seasonal variation in cambial ray height (A), width (B) and diameter of ray cells (C) in μm.



A
Height (µm)
450
400
350
300
250
200
B
Width (µm)
60
55
50
45
40
35
30
C
Cambial Ray Cell Diameter (µm)
32
30
28
26
24
22
20
J F M A M J J A S O N D
Normal
Affected

FIG. 41

Fig. 42.

Histogram showing seasonal variation in cambial ray population in one cm tangential width of cambium.

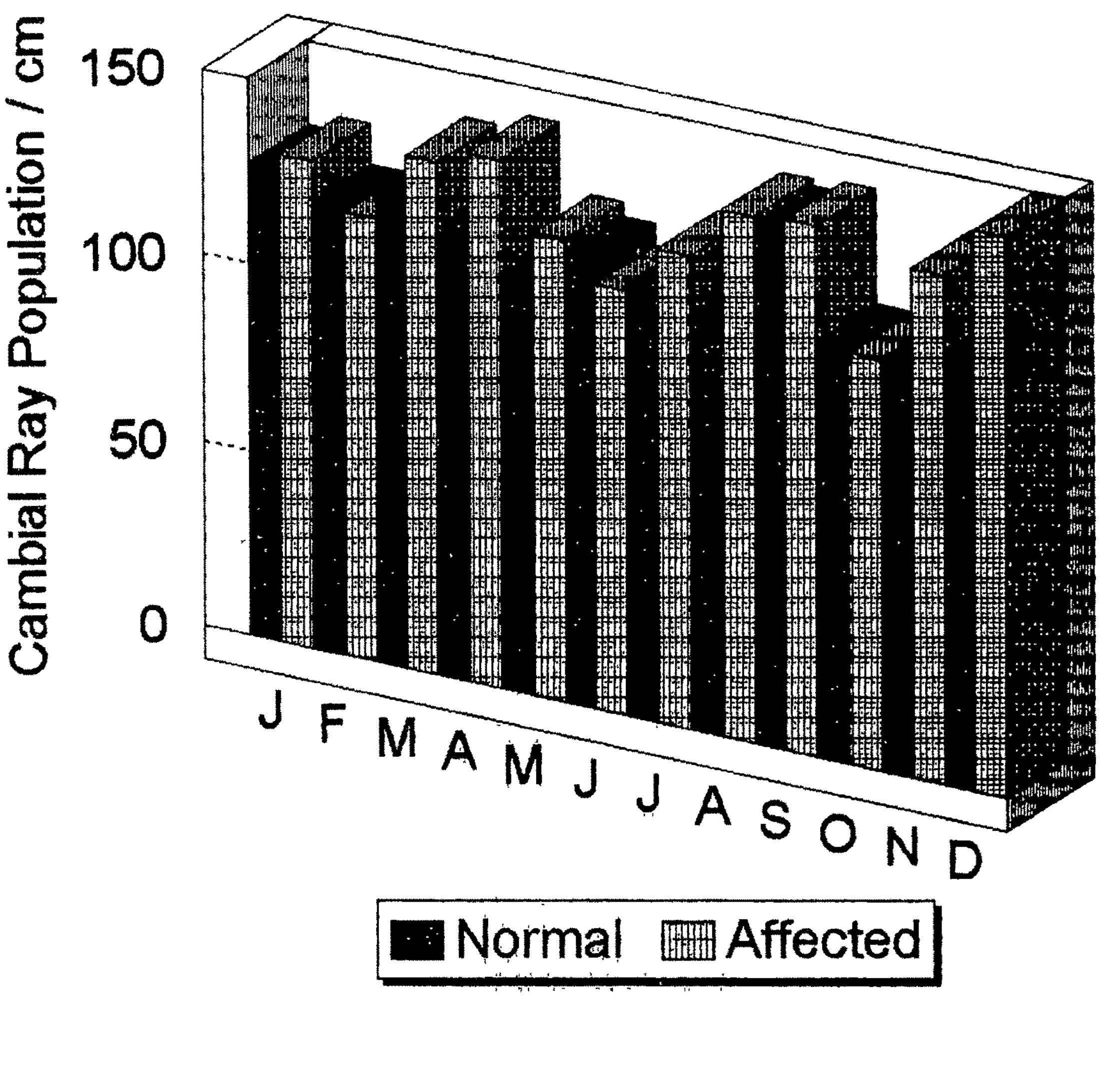

Cambial Ray Population / cm
150
100
50
0
J
F
M
A
M
J
J
A
S
O
N
D
Normal
Affected

FIG. 42

Fig. 43.

Graphic representation of seasonal variation in vessel lumen diameter in µm (A) and number of vessels/0.5 mm^2 (B).

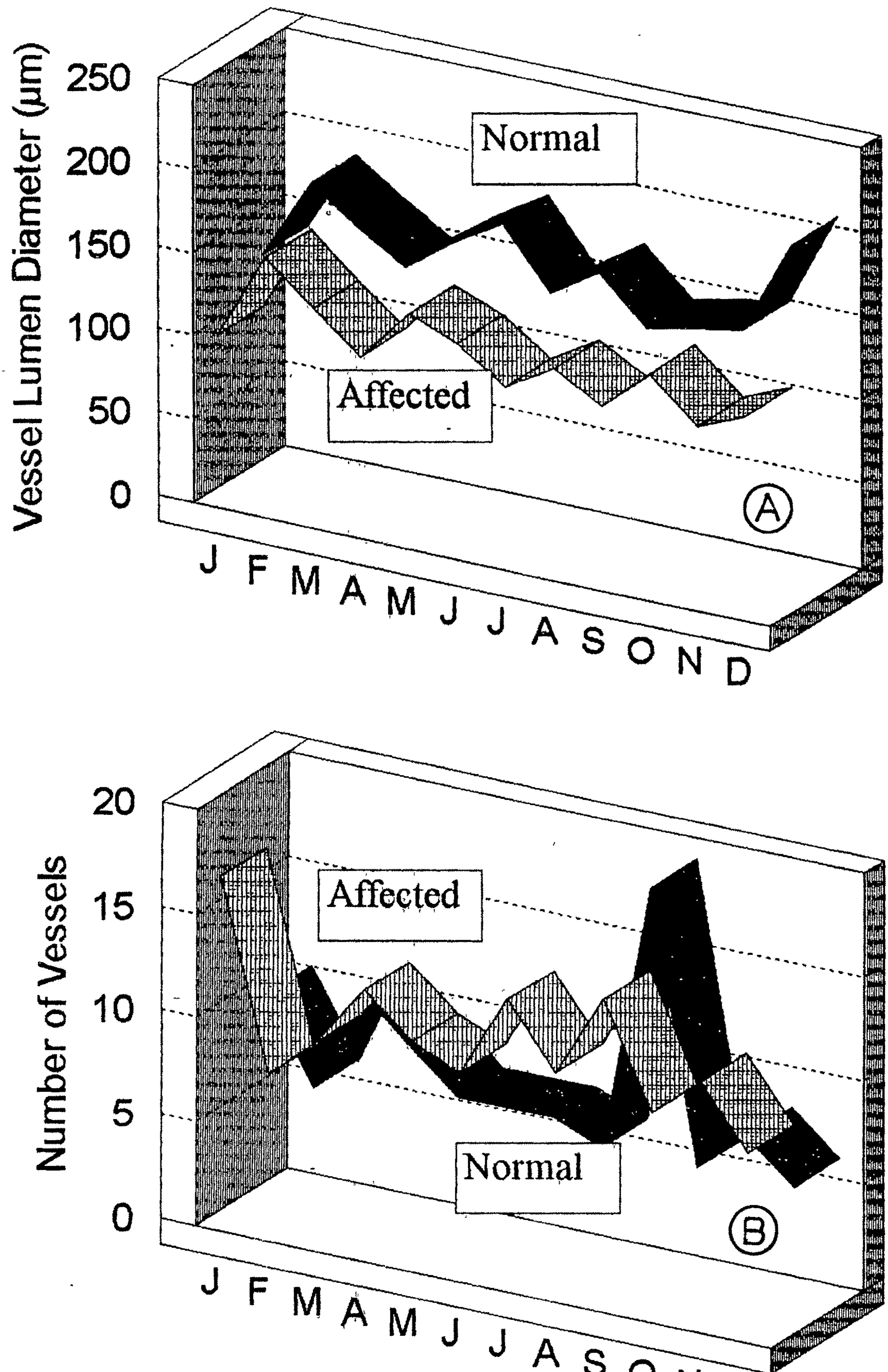

Vessel Lumen Diameter (µm)
250
200
150
100
50
0
Normal
Affected
A
J F M A M J J A S O N D
Number of Vessels
20
15
10
5
0
Affected
Normal
B
J F M A M J J A S O N D

FIG. 43

Fig. 44.

A-F: Transversely cut blocks of xylem as seen under Stereo zoom microscope.

A and B : Xylem growth rings in normal (A) and affected (B) trees of Dalbergia. x 73.

C and D : Xylem growth rings in normal (C) and affected (D) trees of Holoptelea. x 112.

E and F : Xylem growth rings in normal (E) and affected (F) trees of Syzygium. E: x 112; F: x 179.

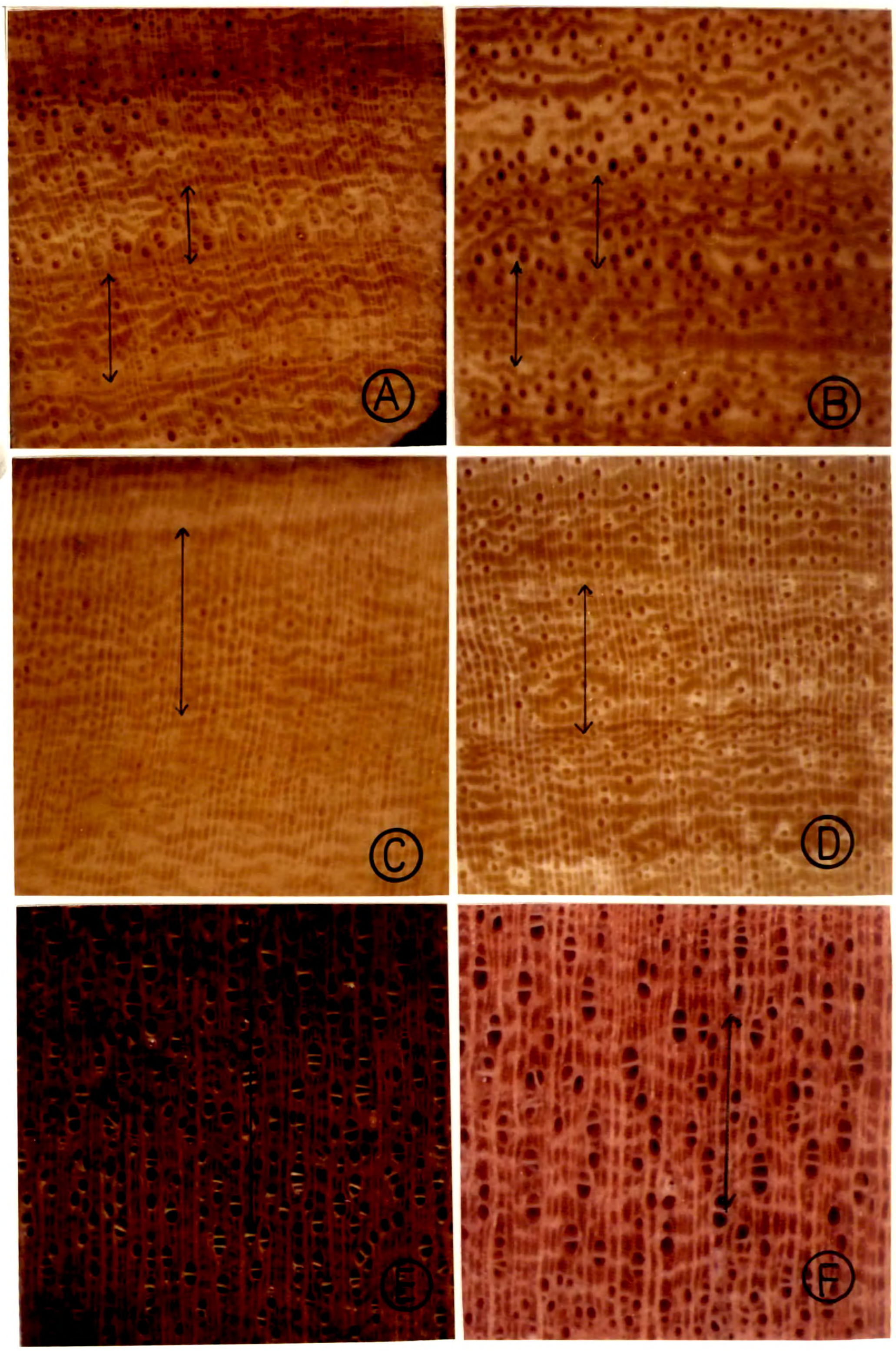


FIG. 44