RESULTS

TECTONA GRANDIS Linn
Family: Verbenaceae

The name Tectona is derived from the Greek word "Tekton" meaning a carpenter, grandis means large and refers to the size of the tree. The teak is indigenous to India, Burma and east wards to Java. In India the natural northern limit is drawn from the Aravalli in Rajasthan eastwards to Jhansi district then south eastwards to Mahanadi. It has been cultivated in Gir forest in Saurashtra for long time. In India, North Kanara and the Dangs forest produce teak of very good quality.

Teak is a deciduous tree, the leaves are rough but hairless above, densely covered with reddish brown beneath. The flowers come in great number in lax clusters at the end of branches. The fruit is about 15 mm long across, spongy, enclosed in persistent calyx. Flowers appear in monsoon, fruit ripens in winter. The leaves fall off from November to January and the tree is leafless throughout the dry season.

The teak is the most important timber tree of India. For ship building, its timber stands in class by itself and has worldwide reputation. It is also extensively used for house building, bridge and warf construction, piles, furniture and cabinate work, railway carriages and wagons, carving, wheel spokes and felloes, general carpentary and numerous other purposes.

STRUCTURE OF CAMBIUM

The cambium of Tectona grandis is nonstoried with vertically elongated fusiform cambial cells and more or less isodiametric ray cambial cells (Fig 5G). As seen in transverse section, fusiform cambial cells are arranged in regular radial files and remain radially narrow. Each radial file is composed of 4-7 layers of cells when the cambium is resting. During this period, radial walls are thick and cambial zone is surrounded by fully matured xylem and phloem elements In tangential view the radial walls are beaded (Fig. 5H) due to deeply depressed primary pit-fields and the cells are comparatively short. The nucleus is elongated, fusiform and remain close to the radial walls. During active period of growth, the radial walls are comparatively thin (Fig. 5I) and cambial zone becomes wide with 11-18 layers of cells (Fig. 4A). In active condition fusiform cambial cells are more elongated with no apparent primary pit fields on radial walls. Cambial zone remains sandwiched between differentiating xylem and phloem elements However, nucleus is oval to circular with distinct nucleolus and found in the center of the cells. In MDF cambium shows tendency towards storiedness (Fig. 5F).

Cambial rays are uni-multiseriate, heterocellular often with marginal sheath cells. Ray noding is more apparent in dormant condition. In transverse view, cambial rays are interspersed among fusiform cambial cells and run radially as continuous bands. As seen in tangential longitudinal sections, ray cambial cells are polygonal (Fig. 5E) when the cambium is active and oval during the resting period leading to the formation of intercellular air spaces at cell corners (Fig.5D) Loss and addition of fusiform cambial cells and ray cambial cells are also observed in transverse and tangential view respectively.

CAMBIAL ACTIVITY:

In MDF, cambial cells close to the xylem undergo periclinal divisions leading to the differentiation of few xylem elements in March (Fig 3A,B) Periclinal divisions in the centre of cambial zone start in June (Fig. 3C) and reaches peak in August-September forming a wide cambial zone with 11-16 layers of cells in each radial file. The divisions then decline and ceases in October (Fig. 3D). During the remaining months, the cambial zone remains narrow with radially flattened thick walled cells (Fig. 3E).

In DDF, cambial activity in the main trunk starts in June (Fig. 3F), reaching peak in July-August (Fig. 4A) with 13-20 layers of cells in the cambial zone. Cell division declines gradually and ceases in November (Fig. 3G). Cambial zone remains narrow (Fig. 3H) with 5-8 layers of cells in the remaining months. Periclinal divisions in the cambial zone of branches occur in June resulting maximum number of cells in July (Table 1 and 2). Cell division ceases in September followed by dormancy from October to May. Seasonal variation in number of cambial layers in the main stem of trees growing in MDF and DDF are presented in Figures 10 and 11 respectively.

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY:

Tectona being a tropical deciduous tree remains leafless during dry part of the year. In MDF, floral and foliar parts begin to dry in November-December respectively. Defoliation begins in January and by March trees become leafless, which continue until May. However, in MDF the reactivation of cambium starts in March when the leaf shedding just completes. New leaves appear in June and by July-August trees attain full foliage and fruit setting. The development of young leaves ceases and apical buds become dormant in September when the cambium is active with dividing and differentiating cells. However, cambial growth ceases following complete maturation of leaves and fruits.

In DDF, defoliation initiates in December. Sprouting of new leaves from dormant buds is followed by initiation of cambial cell division in June No significant variation in the phenology is observed between the trees growing in both the forest types. Cambial activity and phenology of the trees growing in MDF and DDF are presented in Table 1 and 2.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS:

Rainfall and temperature are interdependant factors. The air temperature reaches peak in May at the end of dry season, begins to fall with the onset of rains in June and reaches minimum in August (Figs.1 and 2A, B).

Dormant shoot buds are noticed in May when the temperature is highest of the year The opening of shoot buds begins in June when the maximum temperature is about 35°C. Cambial cell division and differentiation culminates when the rains are heavy. During the dry period of year the cambium remains dormant.

FUSIFORM CAMBIAL CELLS:

The fusiform cambial cells which contribute to the axial system of the main stem are randomly arranged with overlapping cell ends resulting nonstoried cambium (Fig. 5G), but in MDF the cells show tendency towards storiedness (Fig.5F). They are elongated in longitudinal plane with tappering ends in tangential view. During the period of rest they are short with abruptly tappered ends. Their radial walls are thick and beaded due to presence of numerous primary pit fields (Fig.5H) while the cells during active period are elongated with gradually tappered ends (Fig. 5I). The cytoplasm of fusiform cambial cells is highly vacuolated and stain lightly when the cambium is active. It is dense during inactive period. The cells are uninucleate and the nuclei become oval and enlarged in active period of growth. During resting period the nucleus becomes elongated and fusiform.

Cell division:

In Tectona, both periclinal as well as anticlinal divisions occur in the cambial zone The periclinal divisions tend to increase in girth of stem by the production of secondary xylem and phloem. While anticlinal divisions attribute to the increase in the circumference of cambial cylinder.

Periclinal divisions occur in the fusiform cambial cells by the formation of cell plate, running the length of the cell from one tip to the other in tangential plane (Figs. 5A,B,C). A fibrous structure, known as phragmoplast develops in the center of the dividing cell. Occasionally, the phragmoplast ring appear very close to one of the radial walls of the cells (Fig. 5A). In tangential section, most of the cambial zone cells and derivatives towards xylem, show phragmoplast around developing tangential walls in August-September in MDF and July-August in DDF

Anticlinal divisions in the fusiform cambial cells occur throughout the active period of growth (Fig.6C). However, these divisions are more frequently noticed at the end of cambial growth i.e. when the periclinal division cease in the cambial zone.

Increase in number of fusiform cambial cells involves anticlinal divisions of two types: radial and pseudotransverse. The pseudotransverse divisions may result the formation of either short or long anticlinal walls (Fig. 6A,B). Radial anticlinal division may result in the formation of a long wall running more or less entire length of the cell. This may lead to the formation of daughter cells lying side by side (Fig. 6A) thus giving storied appearance of the cambium (Fig 5F). Pseudotransverse division results the formation of more or less sigmoid wall usally near the center of the cell (Fig. 6A). This division results in the production of abrupt end walls. In MDF cambium shows inclination towards storiedness, but in DDF no such distinct storied pattern is observed.

Transverse divisions also occur in fusiform cambial cells to form either cambial ray cells or to develop into xylem parenchyma. The daughter fusiform cambial cell formed by periclinal division undergo various types of transformation. The intrusive growth results various changes in the shape of fusiform cambial cells and also help to maintain the height of rays by ray splitting. The intrusion of fusiform cambial cells into adjacent cambial ray is frequently noticed in the cambium. The flattening of cell tips is also observed during intrusive growth (Fig.6D).

Loss of fusiform cambial cells:

The loss of fusiform cambial cells from cambial zone is found to be maximum in August-September in MDF and July-August in DDF. The elimination of fusiform cambial cells is a gradual process. In the begining, progressive shortening of fusiform cambial cells occurs resulting in the contraction of size in radial file of its derivatives. The neighbouring cells expand tangentially (Fig 3D) to fill the space caused by the loss of cells. However, this phenomena of elimination of cells is always found to be confined with those which are away from cambial rays.

Dimensional changes:

Mean length:

Fluctuations in the mean length of fusiform cambial cells is found to be associated with the seasonal rhythms of cambial activity. In MDF, gradual increase in the length of fusiform cambial cells is observed from February to August with a sudden decrease in September (Fig. 5J). The length decreases from October to December, while in DDF, cell length decreases from January to April and increases from May to August (Fig. 5I) and October to December with sudden decrease in September. However, maximal and minimal length of fusiform cambial cells is noticed in August (380 μm and 385 μm) and September (293 μm and 299 μm) in MDF and DDF respectively (Fig. 12A and Table 3). The yearly average length is more in MDF (344 μm) compared to that of DDF (310 μm, Table 31)

Mean width:

No significant variation has been found in the tangential width of fusiform cambial cells in both the forests. Tangential width is maximal and minimal in April (30 μm) and December (22 μm) in MDF and September (28 μm) and February (21 μm) in DDF respectively. Annual average tangential diameter is more in moist deciduous forest (26 µm). However, maximum and minimum radial diameter is associated with initiation and peak activity of cambial cell divisions. The maximal and minimal radial width have been encountered in February-March (8 µm) and in August (4 µm) in MDF and in May-June (8 µm) and August-September in (5 µm) in DDF respectively (Table 3) Yearly average remains same (7 µm) in both the forests (Table 31)

Length Variation in relation to xylem fibre length:

The mean length of fusiform cambial cells are closely related throughout the year. However, length of xylem fibres is 4 to 5 times more than that of fusiform cambial cells in MDF and 4 to 6 times in DDF. Similar to that of fusiform cambial cells, xylem fibre length in MDF decreases from January - February and October to December and increases from March to August with sudden decrease in September (Fig.12B). In MDF, the mean length of fusiform cambial cells and xylem fibres are highest in August measuring 380µm and 1364µm and minimum in September measuring 293µm and 1075µm respectively (Table 6) While in DDF minimal length of fusiform cambial cells (299µm) and xylem fibre (1029 µm) is noticed in September and May respectively. However, in DDF, it decreases from January to March and increases from June to August and October to December with sudden decrease in September (Fig. 12B). Yearly average maximal length of fusiform cambial cells and fibres remain more in MDF (Table 34).

RAY CAMBIAL CELLS :

Ray cambial cells are more or less isodiametric or slightly elongated in the radial direction. Sheath cells are often present at the margins of the rays (Fig 5H) Rays are nonstoried, uni-multiseriate and heterocellular but multiseriate rays are predominent in the cambium. Protoplasm of ray cambial cells contain reserve metabolites like starch, lipid and protein bodies. The cambial rays undergo both the vertical and tangential fusion or splitting. In both the forests, ray cambial cells in tangential section appear polygonal and arranged compactly when the cambium is active (Fig 5E). During dormant condition they become round to oval (Fig. 5D) The change in shape leads to the formation of intercellular air spaces at the corners of the cells (Fig. 5D).

Divisional activity:

Ray cambial cells develop from fusiform cambial cells by transverse or anticlinal divisions. Fusiform cambial cells undergo radial anticlinal division at the tip or the entire cell may undergo transverse division giving rise to uniseriate cambial ray. Most of the ray cambial cells develop through the divisions at the ends or lateral sides of fusiform cambial cells. Development of ray cambial cells are observed during active period of the cambium. Tangential divisions in ray cambial cells lead to the development of xylem and phloem ray cells. The derivatives of ray cambial cells undergo relatively little change during differentiation.

Dimensional changes;

Ray height:

The cambial ray height undergoes seasonal fluctuations during the seasonal cycle. In MDF, the height decreases from January to April and May to September. However, it increases from October to December (Fig. 13A). The height increases suddenly (Table 4) reaching maximum in May (521 µm). It remains minimal in September (330 µm). In DDF, ray height decreases from February to May and June to September and the height increases in October - November (Fig. 13A). Maximal and minimal height is encountered in February (489 µm) and May (282 µm) respectively (Table 4). Yearly average of ray height is comparatively more (Table 32) in MDF (443 µm) than that of DDF (351 µm).

Ray width:

Variations in cambial ray width shows significant correlation with the seasonal activity of cambium. In MDF, cambial ray width decreases from January to March and August to December and it increases from April to July (Fig.13B and Table 4). In DDF cambial ray cell width decreases and increases randomly from January to May and increases from June to October and decreases in November-December (Fig. 13B). The maximal width varies in both the forests, it occurs maximal in July (72 µm) and October (84µm) in MDF and DDF respectively (Table 4). The minimal width of cambial ray coincides and remains same in both the forests in December (56 μm). Yearly average of cambial ray width does not show significant variation (Table 32) between MDF (66 μm) and DDF (67 μm).

Ray cambial cell diameter:

Variations in the ray cambial cell diameter is found to be closely associated with the swelling of ray cambial cells during the initiation of cell division in both the forests. In MDF, it increases from January to March and April to July ,and increases and decreases alternately in the remaining months. In DDF it decreases or increases randomly through out the year (Table 4). However, maximal diameter of ray cambial cells coincides with the initiation of periclinal divisions in cambial zone in March and June (26 μm) in both the forests respectively (Fig 14A). The ray cell diameter is minimal (20 μm) in January and April in MDF and February and May (20 μm) in DDF. Yearly average of ray cambial cell diameter remains same (23 μm) in both the forests (Table 32).

Cambial ray population:

The average number of rays per one cm tangential width of cambium ranges from 52-72 in MDF and 52-79 in DDF. Variations in number of cambial rays do not show any appreciable relation with cambial activity and dormancy. However, in MDF, number of cambial rays decreases from March to June and July to October while it increases in November and December (Fig.14B) In DDF it increases and decreases alternatively from January to August and increases from September to November then decreasing in December (Table 4). Yearly average of ray population shows no significant differences between the two forest types (Table 32).

DEVELOPMENT OF VASCULAR TISSUES:

Periclinal divisions in the cambial zone lead to the formation of derivatives of xylem centripetally and phloem centrifugally. In both the forests, these divisions start in the cells at the middle of cambial zone (Fig. 3C,F).. In MDF, differentiation of xylem precedes that of phloem while xylem and phloem differentiation start simultaneously in DDF. The development of phloem ceases first followed by xylem development (Fig. 3D,G) in both the forests. In MDF, periclinal divisions first commences in the cambial cells close to the xylem in March but no active cell division and differentiation occurs until June. In both the forests, rapid differentiation of vascular tissues occur from June-July. In MDF, periclinal cell divisions appear more frequent towards phloem side resulting more development of phloem tissues (Fig. 4C). Later the differentiation of xylem derivatives dominate over the phloem producing maximum (20-38) number of elements in August-September (Table 1). In DDF development of xylem is maximal (13-38) in July-August (Table 2, Fig. 4B) when the cambial zone possess maximal number of dividing cells (Fig. 4D). Cell divisions ceases in October and November

(Fig.3D,G) in MDF and DDF respectively. However differentiation and maturation of xylem derivatives continue till November and December in both the forests respectively. Cambial zone is surrounded by mature xylem and phloem in November and December (Fig. 3E,H) in MDF and DDF respectively. In both the forest differentiation of xylem and phloem derivatives in young branches begins in June with the initiation of cambial activity. It reaches peak in August September in both, MDF and DDF (Table 1 and 2). In the following months it declines and cambial zone remains surrounded with mature xylem and phloem in October in both the forests. The differentiation of xylem and phloem remains suspended untill May.

Development, length and width of sieve tube elements:

Though a few cambial cells close to xylem divide and differentiate in March, development of phloem commences in June with the sprouting of young leaves and beginning of rains in MDF. The development of phloem is found more compared with that of xylem resulting season's 3/4 phloem development (Fig.4C). It declines gradually and ceases in October (Fig.3D) with the cessation of cambial cell division The first and last cell to differentiate in phloem are the sieve elements. In DDF, development of phloem starts with resumption of cambial activity in June and reaches peak in August-September (Table 2). Then the development declines gradually and ceases in November (Fig.3G).

During the cessation of phloem development, divisions in sieve tube mother cells are not synchronised. Sometimes sieve tube mother cell first undergo periclinal divisions followed by anticlinal division at right angle to first one or both the divisions are periclinal which leads to the production of 3-4 sieve tube members from single mother cell. A single companion cell presumably by transverse division produces a strand of 2-4 companion cells. Two to four bands of phloem fibres are produced between July and November.

Functional sieve tube elements are characterised by the presence of open sieve pores and slime (p-protein) plugs near the sieve plates (Figs. 6F, 7C). In nonfunctional elements, sieve plates are completely blocked by massive deposition of callose on their sieve plates (Figs.6G, 7B). Cessation of current year's phloem function begins in December with the initiation of leaf shedding in MDF In DDF, current year's phloem remains functional till December. However in both the forests, most of the phloem become nonfunctional by March, except a few sieve elements close to the cambial zone. By May, sieve tube elements close to the cambium also become non-functional by massive deposition of callose (Fig 7B) Following dissolution of callose these elements regain their function in June (Fig 7C) and remain functional until late July or early August. As the sieve tube element cease to function, the axial parenchyma associated with them undergo radial and tangential expansion. But those associated with fibre bands do not undergo any change in their size. The extent of phloem produced each year can be identified by the occurrence of noding in phloem rays and sieve tube elements with narrow lumen (Fig. 6E).

Length of the sieve tube members in MDF increases from May to August and increases or decreases randomly in remaining months (Table 7). Maximal (290 μm) and minimal (210 μm) length of the sieve tube elements is noticed in August and September respectively (Table 7). Its width increases from May to August while found fluctuating in rest of the months. In DDF, it decreases from February to May, July to September and October to December with minimal (212 μm) length in May and maximum (295μm) in July respectively. However, width increases or decreases randomly throughout the year (Table 7).

Sieve elements in Phloem ray:

Solitary or groups of sieve elements are encountered in the secondary phloem of Tectona. They are short and each one is associated with a single companion cell. The structure and behaviour of these ray sieve elements are similar to that of axial sieve elements. Sieve plates are simple and arranged transverse to slightly oblique on their end walls. Massive deposition of callose (Fig. 7A), collapse of companion cells and loss of cell content are also noticed in ray sieve elements. These also showed accumulation of slime (p-protein) plugs against the sieve plate, cytoplasmic strands but no sieve areas on their lateral walls. The diameter of these sieve elements are relatively more than that of adjacent parenchyma cells but more or less equal to that of axial sieve tube elements However, the sieve pores are found to be smaller. These sieve tube elements showed contact with axial sieve tube elements in all the three planes (Figs. 6J, K, 7A). The sieve plate of both the axial and ray sieve elements is simple.

Development, length and width of vessel elements:

Differentiation of xylem from cambial zone commences in March and June in MDF and DDF respectively. The cells developing into vessel elements expand laterally (Figs. 6H, I) often so strongly in some vessel elements that their ultimate-width exceeds their length. In MDF, the cells at the inner margin of cambial zone divide and differentiate into xylem elements, which is also noticed in further months. In June,, rapid cell division followed by differentiation occurs reaching peak (20-35) in August September then declines gradually and ceases in November (Fig. 3E). In DDF, xylem development begins in June with the initiation of cell division in the cambial zone culminating in July-August (Fig. 4B) with 23-38 number of cells in transverse section. The xylem development declines and ceases in December (Fig.3H). However, in both the forests, the xylem elements produced in the early part of the cambial activity are thin walled with large lumen as compared to thick walled narrow lumen elements produced at the end of the activity (Fig. 7F). Occurrence of tyloses is common in the vessels of last years xylem of both the forests (Fig 7D). Tyloses may develop from axial parenchyma cells. In both the forests, no significant variation is observed in the structure of xylem. Xylem is ring porous with distinct growth rings. Vessels are mostly solitary or rarely in multiples of 2-4 with slightly oblique to transverse end walls and simple perforation plate. Intervessel bordered pits are alternate and well developed.

In both the forests, mean length of vessel elements increases and decreases randomly and does not show any significant correlation with the length of fusiform cambial cells (Table 5). Vessel elements are usually shorter than the fusiform cambial cells. The length remains maximal in April and August (278 μm and 270 μm) in MDF and DDF respectively. In MDF the width increases from February to August and decreases in November and December. It remains same in September-October (200μm). Maximal and minimal width is noticed in August (227 μm) and February (133μm) respectively (Table 5). In DDF, the width increases and decreases alternately from January to March and increases from April to August with sudden decrease in September. However, it decreases gradually from October to December. Minimal and maximal width occur in February (132μm) and August (240μm) respectively (Table 5). The vessel elements produced during the begining of cambial cell division are wider than those produced at the termination of cambial cell division. Yearly average of vessel elements length and width is found to be more (234μm and 197μm) in MDF and DDF respectively (Table 33).

Vessel lumen diameter:

Vessel lumen diameter in MDF increases and decreases alternately from January to April and increases from May to August and decreases from September to December (Table 5). Vessel lumen diameter is found to be maximal (203μm) in August and minimal (84μm) in January and May (Fig. 15A). In DDF, it increases from April to August and decreases from October to December while in rest of the months it increases and decreases alternately (Table 5). In DDF, it is minimal in February (82μm) and maximal (Fig.15A) in October (184μm). Yearly average of lumen diameter is more (Table 33) in MDF (124μm). Vessel lumen diameter in young branches of <u>Tectona</u> growing in both the forests increases or decreases randomly throughout the year (Table 6). However maximal (123μm and 119μm) and minimal (44μm and 29μm) diameter have been observed in August, July and November, January in MDF and DDF respectively.

Number of Vessels:

The average number of vessels per 0.5 mm^2 area of xylem ranges from 7-15 during the year in MDF and 9-15 in DDF (Fig. 15B). Number of vessels decreases with the increase in lumen diameter and it increases with decrease in lumen diameter in both the forests (Table 5). Similar to that of vessel lumen diameter, vessel frequency in young branches increases or decreases randomly throughout the year. However, it is found maximal in March and November in MDF and

March in DDF. It remains minimal in August and July in MDF and DDF respectively (Table 6).

The average length, width and lumen diameter of vessel elements and number of vessels per 0.5 mm^2 area of the xylem in the main stem are represented in Table 5.

Growthring width:

Being a ring porous species growth ring boundry in <u>Tectona</u> is clearly discernible when observed under microscope by ray noding pattern (Fig. 7 E) The xylem elements with thin walls and large lumen diameter during early part of activity and vis-a-vis at the time of growth termination is visible even with naked eye. The amount of xylem increment in two successive years i.e. during 1993 and 1994 is 7.3 mm and 7.9 mm in MDF, 5.5 mm and 6.3 mm in DDF respectively

HISTOCHEMISTRY

Starch:

Starch grains are simple, spherical or oval and found only in ray cambial cells. These are not visible in fusiform cambial cells. The size and distribution of starch grains differ with the types of derivative tissues. Lightly stained small starch grains are observed in ray cambial cells while vascular elements are rich with darkly stained large starch grains.

There is no significant variation in the distribution of starch in the cambium of trees from both the forests. Ray cambial cells are found free from starch between December to May (Figs. 8A,B) when the cambium is dormant Groups of 2-6 small starch grains make their appearance in each ray cambial cell at the time of development of young leaves in June (Fig. 8C). The size, number and stainability of starch increases concomitantly with the development and maturation of young leaves. In July increase of starch content is apparent in ray cambial cells which are filled with large and lightly stained starch grains (Fig. 8D). During the active period of cambial growth, starch distribution in ray cambial cells remains same. Concomitantly with the cessation of cambial activity and ageing of the leaves, the number of starch grains diminishes gradually.

Accumulation of starch increases progressively in xylem parenchyma and fibers from December to May (Fig. 8E, F, H). Starch accumulation in phloem parenchyma decreases gradually and by May the entire phloem become devoide of starch (Fig. 8J). These is heavy accumulation of starch in axial and ray parenchyma cells of xylem and phloem in June (Fig. 8C, H, K) when the shoot buds started opening. Starch distribution declines gradually (Fig. 8G) and all the parenchyma of xylem and phloem becomes devoid of starch in August-September (Fig. 8I) and July-August in MDF respectively. Starch deposition begins from September onwards with the decline of cambial activity in xylem and phloem parenchyma which are produced in the beginning of cambial activity and spreads gradually towards combial zone.

Lipids :

Lipids occur as minute globules in both the fusiform and ray cambial cells. The globules are uniformly distributed along the cell walls and cell lumen However, some cambial cells show localised distribution of lipid bodies either along the cell walls or around the nucleus. The cambial zone and its derivatives exhibit lipids in all the months, but the size and distribution vary with the seasonal activity of cambium. In MDF and DDF there is a considerable variation in lipid distribution.

In MDF, lipid globules are more conspicuous in March (Fig. 9A) when tree undergoes complete defoliation. Cambial cells are devoid of lipid globules in June (Fig. 9D) and remains same until August - September when the cambial activity is maximal and then increases concomitantly with the cessation of cambial activity

In DDF, distribution of lipid globules in March is similar to that of MDF, but its distribution and size is apparently more in May (Fig. 9B). It decreases in June (Fig. 9C) with the bursting of dormant buds and initiation of cambial activity With the rapid cambial cell divisions in July-August the amount of lipid decreases considerably and occur as very minute globules or forming a thin line along the walls of cambial cells (Fig. 9E). Then its distribution increases gradually with the decline of cambial activity.

Proteins :

Proteins in the cytoplasm and nucleus appear as a blue coloured globules when the tissues are stained with Coomasie Brilliant Blue (CBB), cambial cells possess proteins in the form of small granules. Protein bodies are distributed in cell lumen of fusiform and ray cambial cells in both the forest types.

In MDF dormant cambial cell contain intensely stained protein bodies (Fig. 9G, H) which decreases with the initiation of cambial cell division in March (Fig. 9F) in MDF. The cells during active cell division show feebly stained negligible amount of proteins in both the cambial cells (Fig. 9I).

No significant difference in protein distribution is observed between DDF and MDF. The utilisation of protein bodies starts in June with the initiation of cambial activity in DDF. The distribution of proteins during the grand period of cambium remains similar in both the forests (Fig. 9I).

TABLE: 1

Data on phenology, average number of cambial layers and differentiating xylem and phloem in the main trunk and branches of Tectona grandis growing in MDF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Yellowing of leaves and initiation of defoliation	6 ±0 94	4 ±0 64	-	-	-	-
FEB	Yellowing of leaves and defoliation	6 ±1.47	4 ±0.82	-	-	-	-
MAR	Partial defoliation	7 ±1 22	4 ±0.83	1 ±0 53	-	-	-
APR	Complete defoliation	7 ±1 12	3 ±0.93	-	-	-	-
MAY	Complete defoliation	7 ±1.20	3 ±0.99	-	-	-	-
JUN	Sprouting of new leaves	8 ±0 72	4 ±0.50	3 ±0.53	3 ±0.77	2 ±0.46	2 ±0 69
JUL	Sprouting and maturation of new leaves.	9 ±1.42	5 ±0 67	5 ±1 00	3 ±0 79	6 ±0 67	3 ±0 59
AUG	Sprouting and maturation of new leaves, flowering.	10 ±1 40	6 ±0.66	19 ±1.37	10 ±0.74	5 ±1.68	4 ±0 68
SEP	Full foliage, flowering and fruit setting.	14 ±1.10	5 ±0.76	35 ±3.24	15 ±3.27	5 ±0 96	4 ±0 70
OCT	Full foliage, fruiting and terminal bud dormant	10 ±1 97	4 ±0.79	26 ±1.93	7 ±1 48	3 ±0 79	5 ±1 25
NOV	Full foliage with mature leaves and fruits	6 ±1.10	3 ±0 80	-	-	-	-
DEC	Full foliage and fruits	6 ±0.65	3 ±0 60	-	-	-	-

TABLE : 2

Data on phenology, average number of cambial layers and differentiating xylem and phloem in the main trunk and branches of <u>Tectona grandis</u> growing in DDF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Partial defoliation, terminal bud dormant	6 ±1 05	3 ±0.98	-	-	-	-
FEB	Partial defoliation, terminal bud dormant	5 ±1 33	3 ±0.88	-	-	-	-
MAR	Complete defolation	6 ±1 23	3 ±0 82	-	-	-	-
APR	Complete defoliation	5 ±1.18	3 ±0.57	-	-	-	-
MAY	Complete defoliation	5 ±0.99	3 ±0 57	-	-	-	-
JUN	Sprouting of new leaves, terminal bud active	6 ±0 96	5 ±0 72	5 ±1.00	6 ±0·95	2 ±0.56	2 ±0 69
JUL	Sprouting and maturation of young leaves and flowering .	13 ±1.56	6 ±0.76	16 ±2.97	8 ±0.84	4 ±1.06	3 ±0 50
AUG	Sprouting and maturation of young leaves and flowering	18 ±2.69	5 ±0 81	27 ±5 19	10 ±1.24	6 ±0 98	3 ±0 74
SEP	Full foliage with flowers, and fruits	10 ±1 35	5 ±0 85	24 ±0 83	11 ±1.35	4 ±0 78	4 ±0 55
OCT	Full foliage with mature fruit, terminal bud dormant	10 ±1.70	3 ±0 42	18 ±4.42	9 ±0 83	5 ±2 31	2 ±0 35
NOV	Full foliage with mature leaves and fruits	8 ±1 57	3 ±0 53	9 ±3 87	-	2 ±1 25	-
DEC	Yellowing of leaves and initiation of defoliation	5 ±0 87	3 ±0 51	-	-	-	-

TABLE 3

Dimentional details of fusiform cambial cells (μm) in the main trunk of Tectona grandis growing in MDF and DDF.

	Length		Tangential Width		Radial width	
Month	MDF	DDF	MDF	DDF	MDF	DDF
JAN	338 ±5.42	326 ±7.77	26 ±1.49	22 ±1.60	6 ±0.29	6 ±0.28
FEB	330 ±7.37	315 ±9.61	25 ±1.68	21 ±1.78	8 ±0.32	6 ±0.23
MAR	345 ±6.23	309 ±6.94	27 ±2.15	22 ±2.76	8 ±0.50	6 ±0.49
APR	350 ±8.63	301 ±6.75	30 ±1.60	24 ±4.15	6 ±0.38	7 ±0.48
MAY	354 ±7.81	325 ±7.51	28 ±1.91	24 ±1.11	7 ±0.42	8 ±0.46
JUN	363 ±5.67	360 ±5.91	27 ±2.43	21 ±2..54	7 ±0.45	8 ±0.50
JUL	370 ±5.47	363 ±7.53	27 ±2.23	24 ±1.83	6 ±0.30	7 ±0.47
AUG	380 ±6.20	385 ±6.60	26 ±1.72	25 ±2.18	4 ±0.36	5 ±0.40
SEPT	293 ±6.33	299 ±4.17	26 ±1.83	28 ±2.16	5 ±0.30	5 ±0.48
OCT	329 ±5.81	301 ±7.92	23 ±2.29	22 ±1.91	7 ±0.47	5 ±0.43
NOV	318 ±6.29	332 ±12.46	25 ±2.07	23 ±2.12	8 ±0.34	6 ±0.46
DEC	312 ±4.82	334 ±7.61	22 ±1.84	24 ±2.77	7 ±0.35	7 ±0.41

TABLE : 4

Dimensional details of cambial rays (µm) and their population in one cm tangential width of cambium in the main trunk of <u>Tectona</u> <u>grandis</u> growing in MDF and DDF.

Month	Height		Width		Ray cell diameter		Ray population	
	MDF	DDF	MDF	DDF	MDF	DDF	MDF	DDF
JAN	508	405	67	64	20	21	64	67
	±40 27	±24.22	±1 74	±2 47	±1 94	±3 15	±22 62	±28 28
FEB	478	489	63	63	24	20	63	72
	±24 91	±36 14	±3 08	±2.00	±3.50	±3.06	±26 16	±24 04
MAR	428	340	57	71	26	22	64	55
	±28 52	±15 56	±1.13	±2.27	±2 79	±2.04	±26 16	±23 33
APR	420	328	58	63	20	23	63	61
	±29.59	±14 78	±1.54	±1.90	±3.52	±2.64	±33 94	±23 33
MAY	521	282	63	68	21	20	55	52
	±27.99	±10 79	±1.74	±1.71	±2.74	±2.47	±24 00	±22 09
JUN	454	356	69	61	24	26	52	62
	±21.93	±22 38	±1.85	±2.62	±1 85	±2.77	±34 64	±27 57
JUL	445	312	72	65	26	24	67	60
	±17.92	±22 39	±1.89	±2.35	±2.71	±1 94	±24 74	±28 28
AUG	387	296	67	68	24	26	65	62
	±18.46	±19.63	±1.72	±2.1	±2.29	±2.15	±27.32	±24 16
SEP	330	279	61	70	21	24	63	58
	±19 00	±16.86	±1.55	±1.81	±1.86	±2.49	±29.69	±16 97
OCT	438	361	60	84	23	24	59	72
	±27.79	±26.44	±2.46	±4.00	±3.11	±2.61	±33.23	±33 94
NOV	450	414	59	60	24	21	67	79
	±6 28	±27.28	±2 05	±2 38	±2.15	±2.15	±31 62	±22 62
DEC	461	351	56	56	22	23	72	69
	±22.87	±21.99	±1 83	±2.33	±2 98	±2 69	±34 76	±31 11

TABLE : 5

Dimensional details of vessel elements (µm) and average number of vessels per 0.5 mm^2 in main trunk of Tectona grandis growing in MDF and DDF.

Month	Length		Width		Lumen dimeter		No of vessels	
	MDF	DDF	MDF	DDF	MDF	DDF	MDF	DDF
JAN	220 ±7.63	207 ±7 63	167 ±16 36	167 ±11 10	84 ±9.41	83 ±6 44	15 ±1 97	12 ±2 81
FEB	202 ±6.50	204 ±10.43	133 ±10 24	132 ±8.843	87 ±5.74	82 ±7 32	11 ±1.71	15 =2 10
MAR	239 ±16 53	200 ±11 96	135 ±14 00	206 ±10.63	85 ±6.64	84 ±5.96	14 ±1 98	14 ±1 52
APR	278 ±11.79	210 ±9.84	145 ±14 06	181 ±8.92	87 ±6.46	76 ±5 19	12 ±1 88	14 ±1.73
MAY	242 ±13.73	210 ±7.09	167 ±13.48	190 ±7.43	84 ±5.31	83 ±3.58	13 ±1 82	14 ±1 92
JUN	230 ±7.70	238 ±10.97	188 ±14 50	210 ±6.73	86 ±8 41	88 ±5.87	13 ±1.63	15 ±2.56
JUL	265 ±10.70	255 ±9.75	210 ±10.31	225 ±8.16	198 ±5.30	168 ±6.04	11 ±1.61	12 ±2.24
AUG	270 ±10.90	270 ±5 82	227 ±10.54	240 ±11 81	203 ±5.91	171 ±3 93	7 ±1 68	9 ±1 44
SEP	217 ±7 66	212 ±11.00	200 ±12 20	200 ±7 64	172 ±5 36	124 ±5.47	10 ±1 54	10 ±1 57
OCT	253 ±11 72	240 ±8.29	200 ±5.36	231 ±12.47	146 ±7.80	184 ±4.27	13 ±1.82	11 ±1.70
NOV	212 ±11.36	234 ±5.40	187 ±16.40	195 ±13.66	137 ±5.20	111 ±12.40	14 ±1.56	11 ±1.12
DEC	184 ±6 55	209 ±9.18	178 ±9.34	189 ±18.13	123 ±5 23	100 ±9.34	15 ±2.55	10 ±1 29

TABLE : 6

Dimensional details of vessel lumen diameter (μm) and average number of vessels per 0.5 mm2 in the branch and length of fibres (μm) in the main trunk ot <u>Tectona grandis</u> growing in MDF and DDF.

Month	Lumen dimeter		No.of vessels		Fibre length	
	MDF	DDF	MDF	DDF	MDF	DDF
JAN	50 ±7.42	29 ±6.38	23 ±3.09	30 ±1.97	1152 ±25.62	1192 ±24.17
FEB	56 ±5.74	46 ±7.94	22 ±2.83	22 ±1.71	1135 ±29.76	1131 ±32 22
MAR	52 ±3.96	42 ±4.26	24 ±1.23	31 ±2.12	1200 ±28.82	1063 ±36.00
APR	57 ±6.46	42 ±5.24	21 ±0.74	30 ±1.77	1247 ±25.24	1093 ±27.00
MAY	53 ±9.66	49 ±7.07	23 ±1.14	22 ±1.34	1267 ±29.58	1029 ±17.38
JUN	55 ±8.58	47 ±5.96	23 ±0.84	29 ±2.56	1285 ±26.32	1146 ±34 00
JUL	117 ±7.06	119 ±6.86	16 ±2.13	14 ±1.13	1343 ±29.32	1274 ±23.18
AUG	123 ±6.69	93 ±8.29	15 ±1.44	24 ±2.55	1364 ±30.70	1335 ±22.59
SEP	60 ±5.83	66 ±5.31	22 ±1.34	24 ±1.88	1075 ±22.21	1078 ±20.00
OCT	52 ±7.64	69 ±6.62	22 ±1.96	26 ±2.04	1146 ±22.88	1111 ±28.00
NOV	44 ±7.64	56 ±8.75	24 ±1.27	26 ±1.26	1130 ±36.46	1189 ±27.79
DEC	55 ±7.78	60 ±9.04	22 ±1.29	26 ±167	1091 ±31.69	1191 ±26 79

TABLE: 7

Dimensional details of Sieve tube elements (µm) in main trunk of Tectona grandis growing in MDF and DDF.

Months	Moist deciduous forest		Dry deciduous forest	
	Length	Width	Length	Width
JAN	239 ±8.86	25 ±4.07	218 ±8.29	24 ±2.48
FEB	246 ±8.09	24 ±4.18	224 ±9.26	23 ±2.48
MAR	235 ±7.30	26 ±4.00	218 ±7.62	23 ±1.70
APR	240 ±7.73	25 ±3.77	215 ±8.89	23 ±1.61
MAY	236 ±10.40	23 ±4.32	212 ±5.54	22 ±1.61
JUN	253 ±9.32	26 ±2.24	223 ±9.55	25 ±2.06
JUL	285 ±8.47	32 ±2.25	295 ±9.41	34 ±3.68
AUG	290 ±9.13	36 ±2.25	247 ±7.42	35 ±1.68
SEP	210 ±9.13	30 ±2.89	213 ±8.62	34 ±2.67
OCT	234 ±5.85	26 ±2.66	247 ±7.42	35 ±1.68
NOV	228 ±5.85	28 ±2.23	235 ±9.82	30 ±2.06
DEC	215 ±9.84	25 ±3.17	220 ±9.22	23 ±1.27

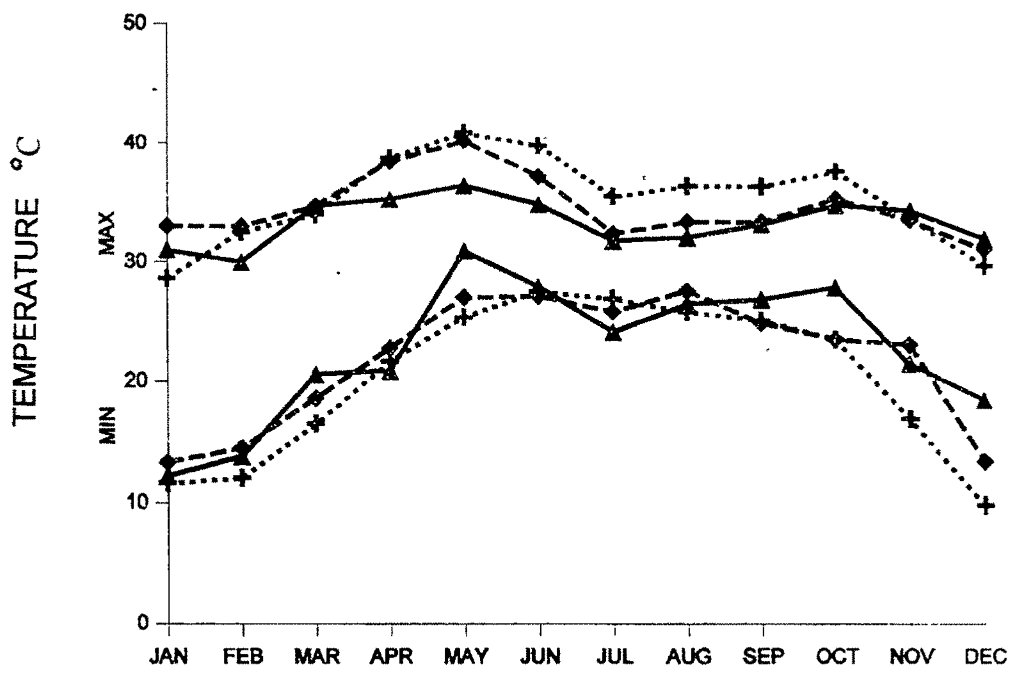


Fig. 1 Graphic representation of mean maximum and minimum temperatures of MDF, DDF and SF recorded at Indian Meteorological Centre, Ahmedabad in the year 1994.

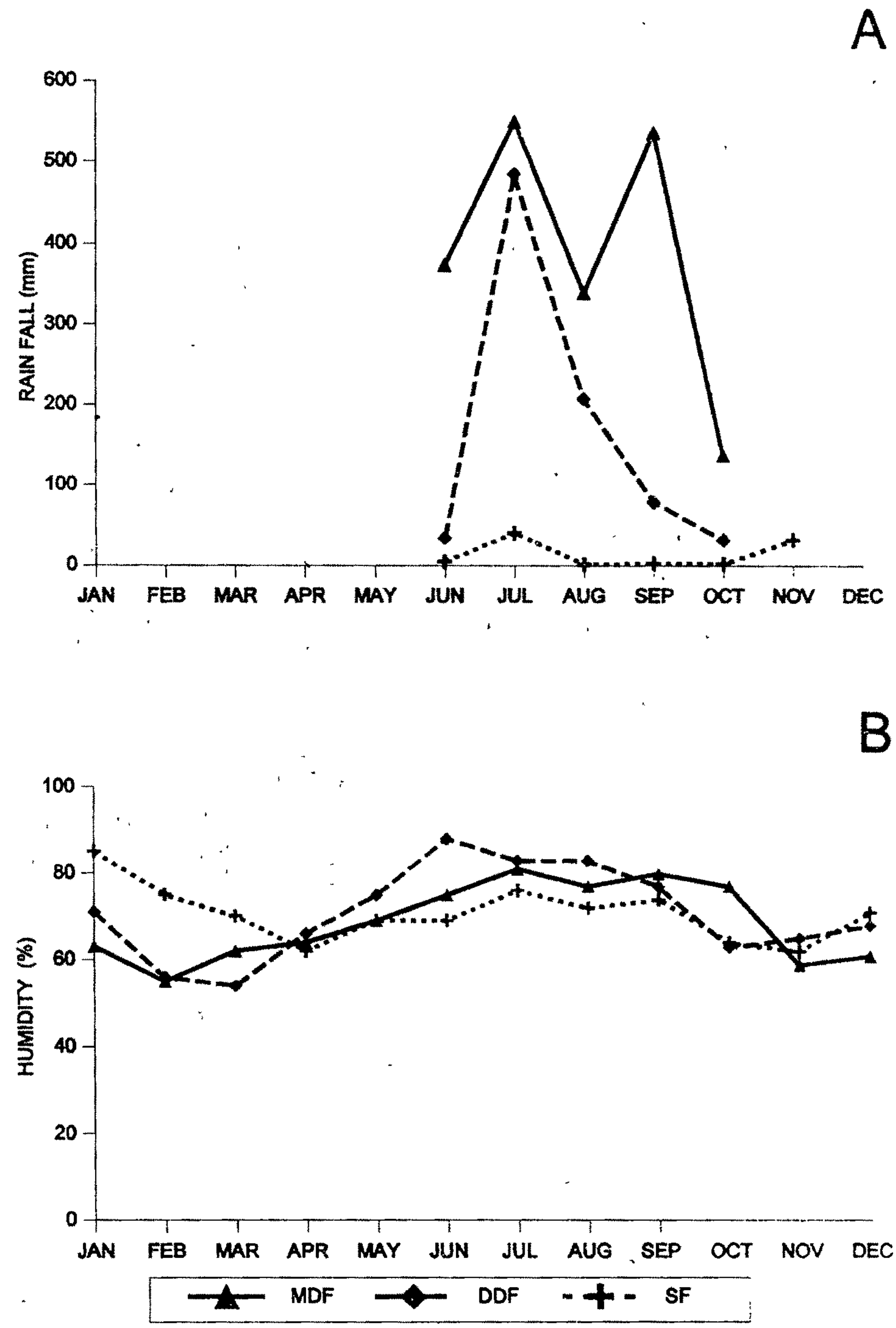


Fig. 2 Graphic representation of average rain fall (A) and relative humidity (B) in MDF, DDF and SF recorded at Indian Meteorological Centre, Ahmedabad in the year 1994.

Fig 3 Transverse sections of cambium along with the adjacent xylem and phloem of Tectona grandis.

A Initiation of cambial cell division in March in MDF. Note the cambial cells at the inner margin of cambial zone showing swelling of (arrow) which is followed by cell division (arrowhead). X 250

B Cambial zone in March in MDF. X 250

C Initiation of cell division in the middle of the cambial zone (arrow) in June in MDF. Arrowhead indicates differentiating vessel. X 310

D Cessation of cambial cell division and development of phloem in October in MDF. Note that the differentiation and maturation of xylem is continued. X 280

E Dormant cambium in November in MDF. Cambial zone is surrounded by mature xylem and phloem elements. X 250

F Initiation of cambial cell division in DDF in June. The narrow cells in the middle of cambial zone (arrow) indicates recently formed thin tangential walls. X 300

G Cessation of cambial cell division in November in DDF. The differentiation of phloem ceases but xylem maturation is continued. X 320

H Dormant cambium in December surrounded by mature xylem and phloem elements in DDF. X 320

CZ Cambial zone, PH: Phloem, XY: Xylem

Fig.4: Transverse sections of cambium and adjacent xylem and phloem of <u>Tectona grandis</u>.

A Peak cambial activity in August in DDF. The wide cambial zone is surrounded by differentiating xylem and phloem elements. X 310

B Differentiating xylem elements from active cambial zone in DDF. X 124

C Development of more phloem than xylem in July in MDF. Arrow and arrowhead indicate growth ring boundry in phloem and xylem respectively. X 92

D Xylem and phloem development in July in DDF. Note the relatively more differentiating xylem. X 116

CZ: Cambial Zone, DP: Differentiating Phloem, DX: Differentiating xylem, V : Vessel.

Fig.5 Transverse (B) and tangential longitudinal sections (A,C-J) of cambium in *Tectona grandis*.

A Origin of phragmoplast ring (arrow) close to a radial wall. Arrowhead indicates newly formed thin pseudotransverse anticlinal wall. X 550

B Cambial zone showing newly formed thin tangential walls surrounded by phragmoplast (arrow) in September . X 700

C Initiation of cambial activity in the trees of DDF shown by periclinally dividing fusiform cambial cell. Arrows indicate phragmoplast on either ends of cell plate. X 220

D Large intercellular air spaces among ray cambial cells in May (arrows) in DDF. X 600

E Cambial ray with no intercellular spaces in active cambium in August . X 600

F Fusiform cambial cerlls showing tendency towards storiedness in MDF. X 88

G Nonstoried arrangement of fusiform cambial cells in dry deciduous forest. X 88

H Dormant cambium in May showing beaded radial walls with abrupt ends. Arrows indicate sheath cells in the cambial rays. X 88

I Active cambium with thin radial walls and elongated cell tips . X 96

J Short fusiform cambial cells in September. Note the abruptly ended cell tips. X 96

Fig.6: Transverse (C,E,H,I and K), radial (J) and tangential (A,B,D,F,G) longitudinal sections of cambium, xylem and phloem of Tectona grandis.

A Radial anticlinal wall (arrow) in the fusiform cambial cell in August in MDF. X 230

B A short (arrow) and a long (arrowhead) anticlinal wall following pseudotransverse division of fusiform cambial cells in August in DDF. X 230

C Anticlinally divided cambial cells in one of the radial rows of cambial zone (arrows). X 550

D Deformed tip (arrow) of fusiform cambial cell following intrusive growth. X 250

E Phloem ray noding (arrows) pattern of the boundary between two growth increments of phloem. Note the obliterating narrow lumen sieve elements of last season's growth . X 100

F Functional sieve elements in July showing slime (p-protein) plugs near the sieve plates in MDF (arrowheads). X 96

G Nonfunctional sieve elements (arrows) in May showing completely closed sieve plates by callose deposition and no cellular contents. X 96

H A xylem derivative enlarging to differentiate into a vessel element (arrow). X 625

I A differentiating vessel close to cambial zone. X 138

J Sieve elements in phloem rays showing their connection (arrows) with axial sieve tube members. X 250

K Ray sieve elements showing their connection with adjacent (arrows) axial sieve elements. X 240

Fig 7: Tangential longitudinal (A) and transverse (B-F) sections of phloem and xylem of Tectona grandis

A A sieve plate (arrow) connecting ray and axial sieve elements. Note the thick callose deposition on the sieve plate. X 250

B Massive deposition of callose on sieve plates of elements (arrowheads) close to the cambial zone in May. X 250

C Sieve elements next to the cambial zone showing dissolution of dormancy callose (arrowheads). Note the nonfunctional sieve elements little away from cambium with definitive callose (arrow). X 270

D A vessel showing tyloses (arrow) . X 200

E Ray noding pattern in xylem (arrows). X 128

F Xylem growthing boundry. Note the early formed xylem showing vessels with larger lumen and thin walled wide elements compared to narrow lumen vessels and thick walled elements in the late formed xylem. X 120

V : Vessel

Fig.8: Radial longitudinal sections of cambium, xylem and phloem of _Tectona grandis_.

A A starch free cambium in March in MDF. Note the heavy accumulation of starch in xylem next to the cambium. X 340

B Cambial ray cells with no starch deposition in May in MDF. X 310

C Ray cambial cells with a few small starch grains in June in DDF. X 270

D Ray cambial cells filled with lightly stained starch grains in August in DDF. X 270

E Starch grains in the lumen of xylem fibres in May in MDF. X 156

F Starch grains in the lumen of xylem fibres in May in DDF. Note the relatively more starch in fibre lumen. X 156

G Distribution of starch grains in the xylem of MDF in June. X 156

H Distribution of starch in xylem of DDF in June. X 156

I Starch free xylem in August in MDF. X 143

J Starch free phloem in May in DDF. X 143

K Heavy accumulation of starch in phloem of DDF in June . X 124

Fig 9: Radial longitudinal sections of cambium of Tectona grandis.

A Distribution of lipid bodies in fusiform cambial cells (arrows) of MDF in May. X 600

B Distribution of lipid bodies in ray cambial cells (arrows) of DDF in May. X 625

C Scanty distribution of lipid bodies (arrows) in ray cambial cells of DDF in June. X 625

D Ray cambial cells with no lipid distribution in MDF in June. X 625

E Ray cambial cells of DDF showing no lipid bodies in August. X 625

F Distribution of protein bodies in ray cambial cells (arrows) of MDF in March . X 625

G Protein bodies in fusiform cambial cells (arrows) of DDF in March. X 625

H Distribution of protein bodies in ray cambial cells (arrows) in DDF in May. X 600

I Protein bodies forming thin line on the radial walls of fusiform cambial cells (arrows)in August in MDF forest. X 600.

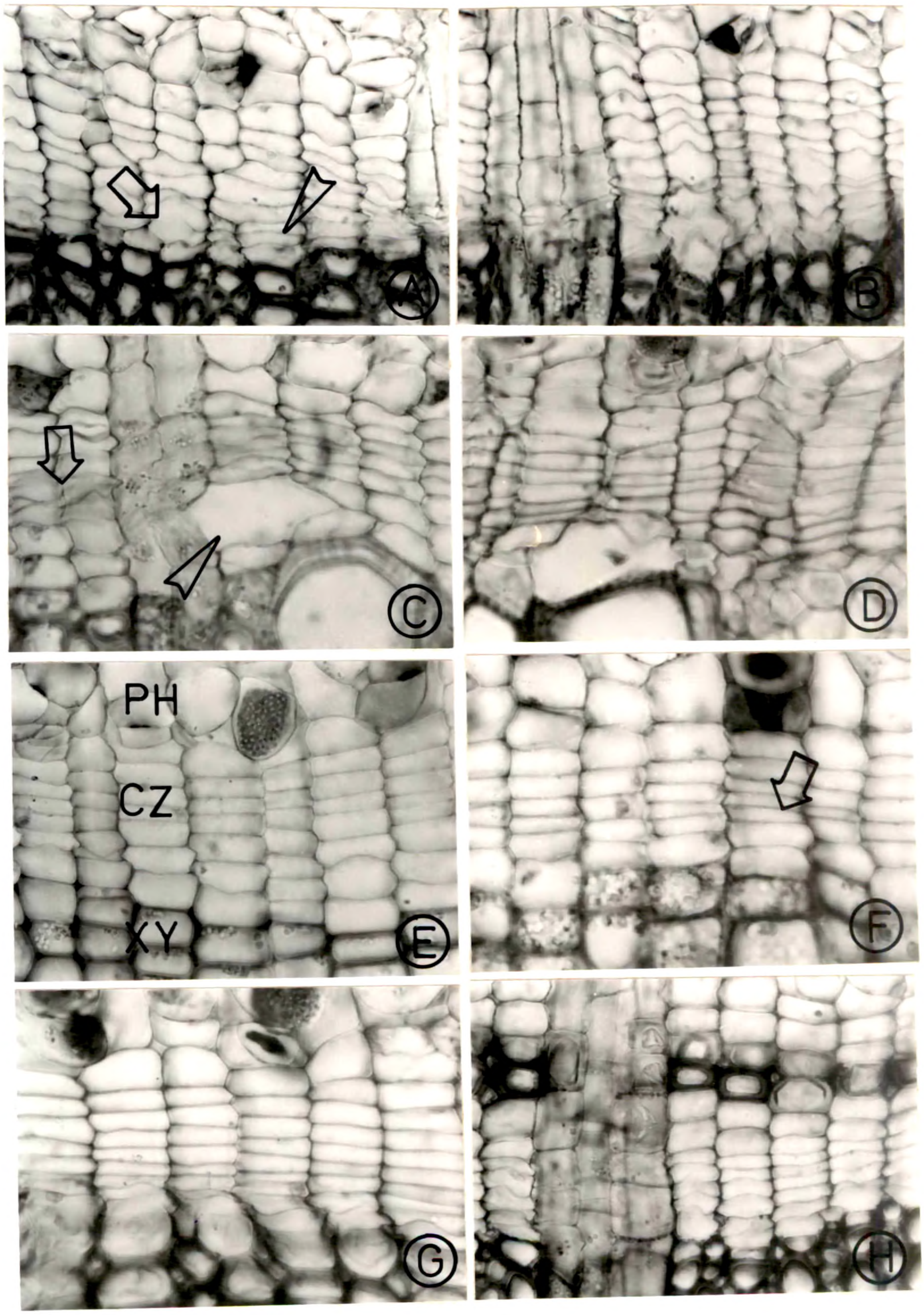


FIG. 3

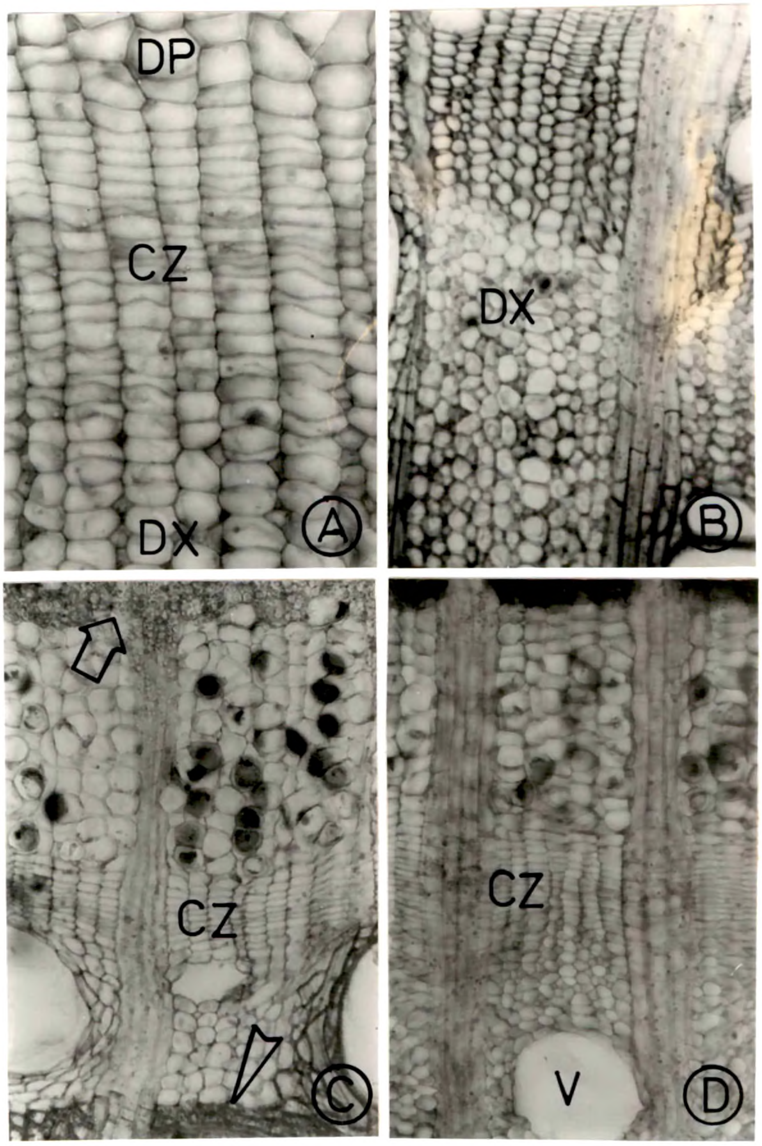


FIG. 4

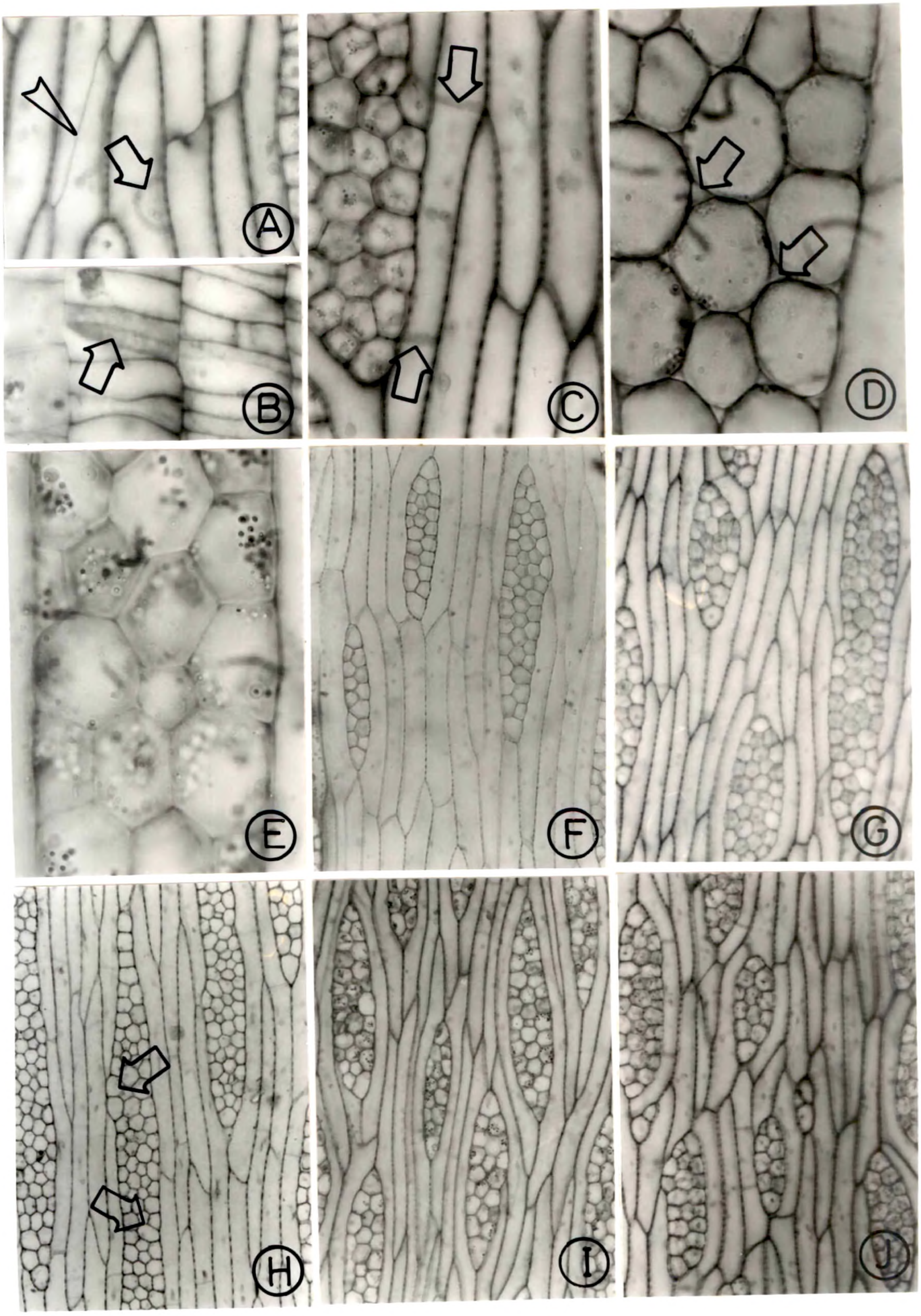


FIG. 5

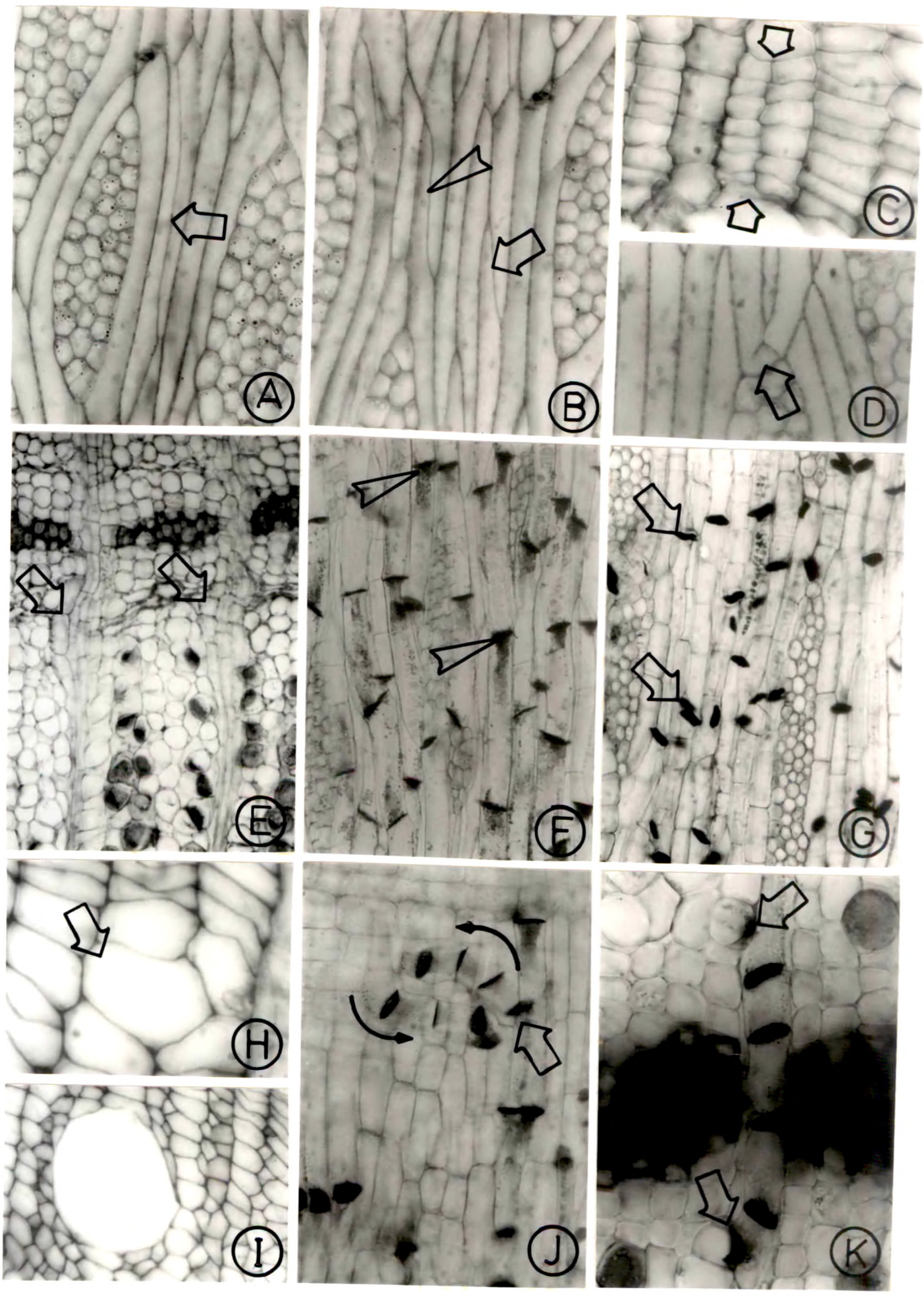


FIG. 6

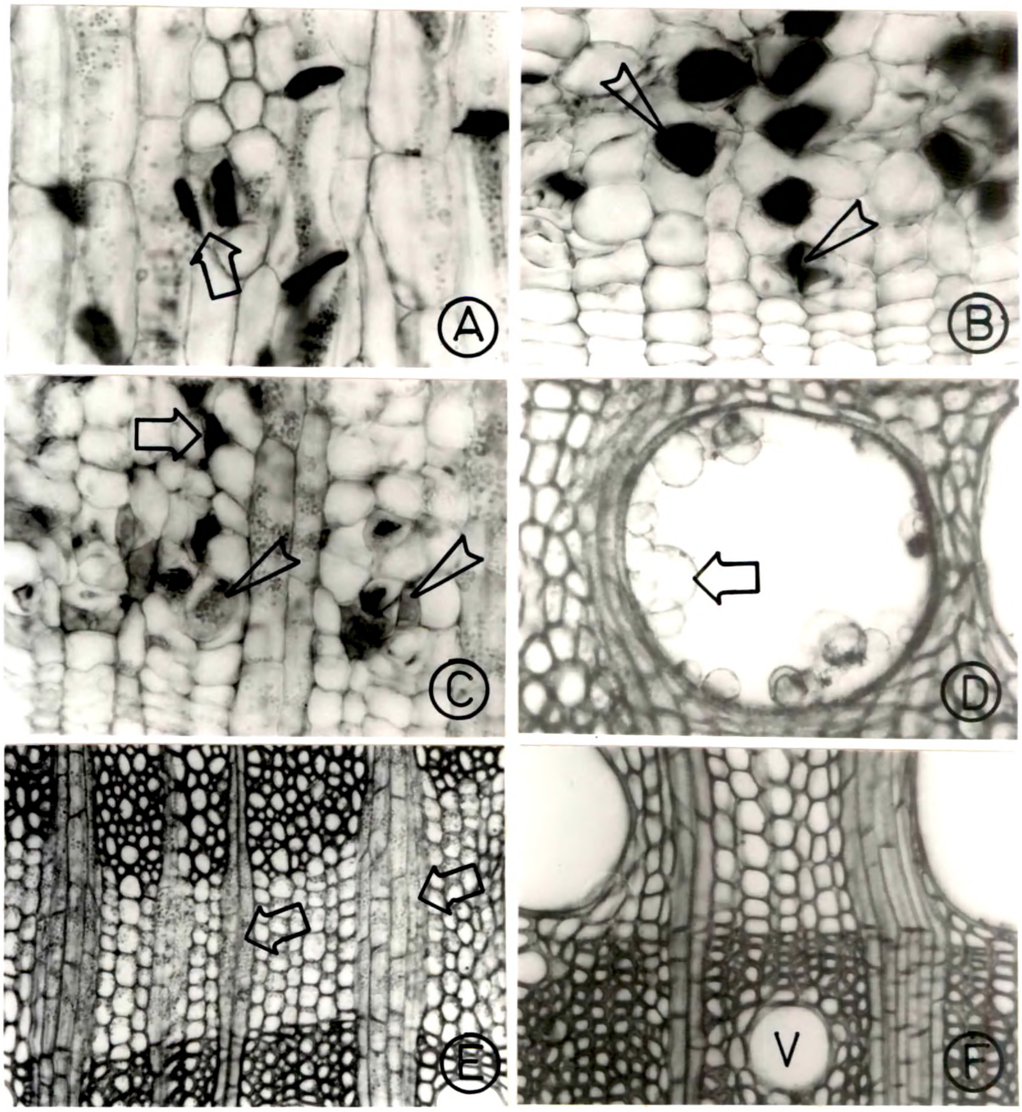


FIG. 7

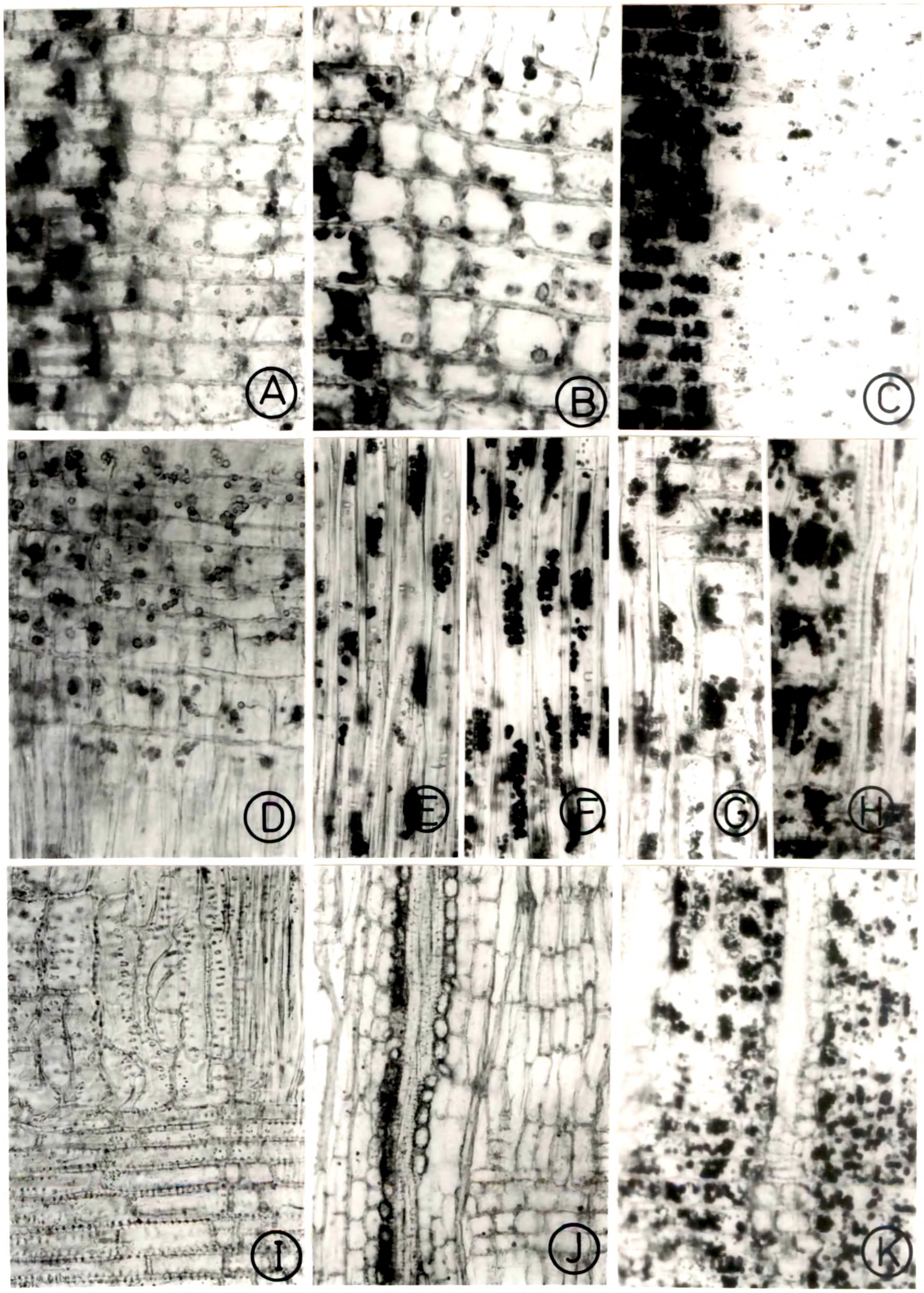


FIG. 8

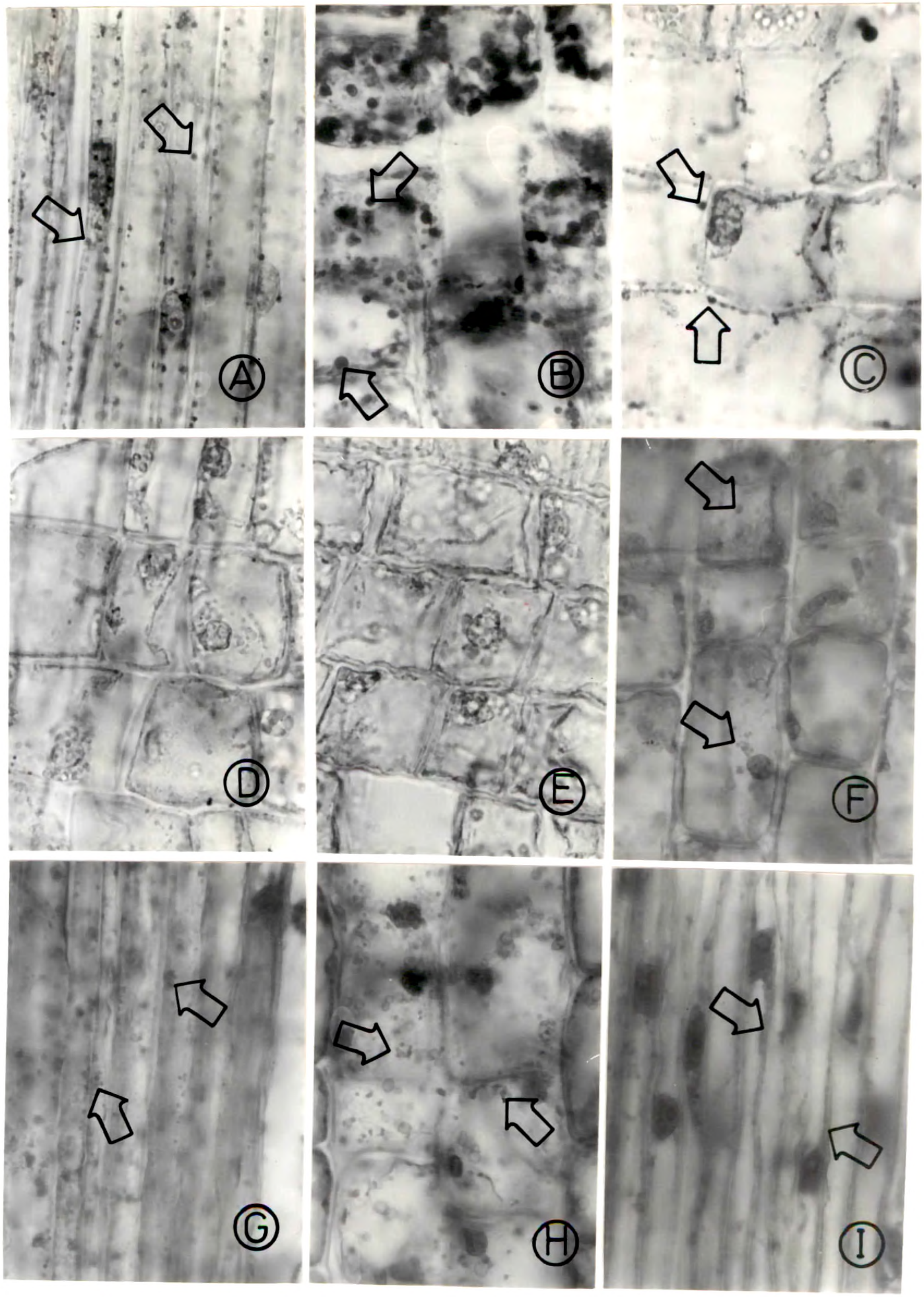
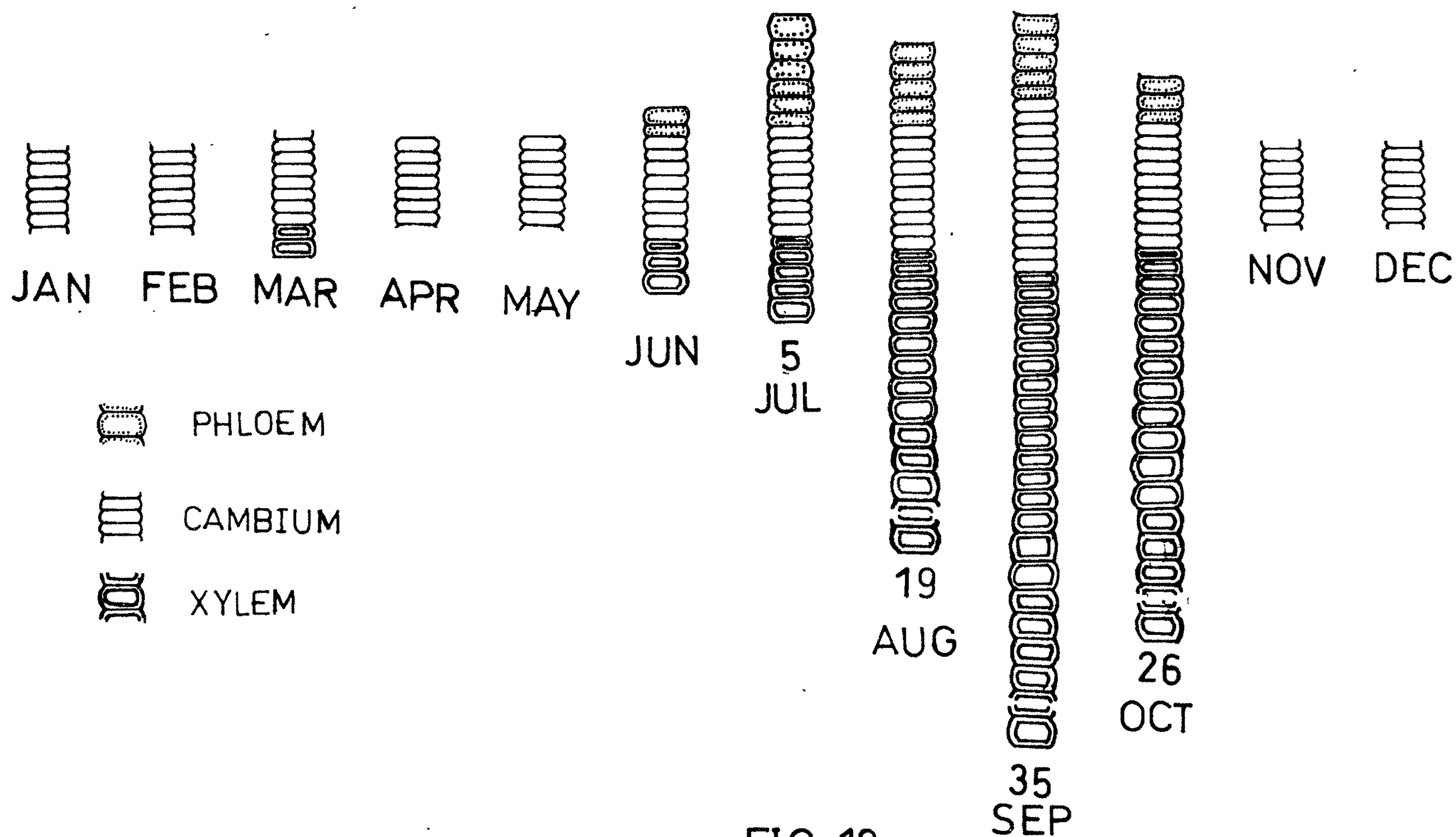


FIG. 9

Fig. 10

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Tectona grandis growing in MDF.


JAN
FEB
MAR
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MAY
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5
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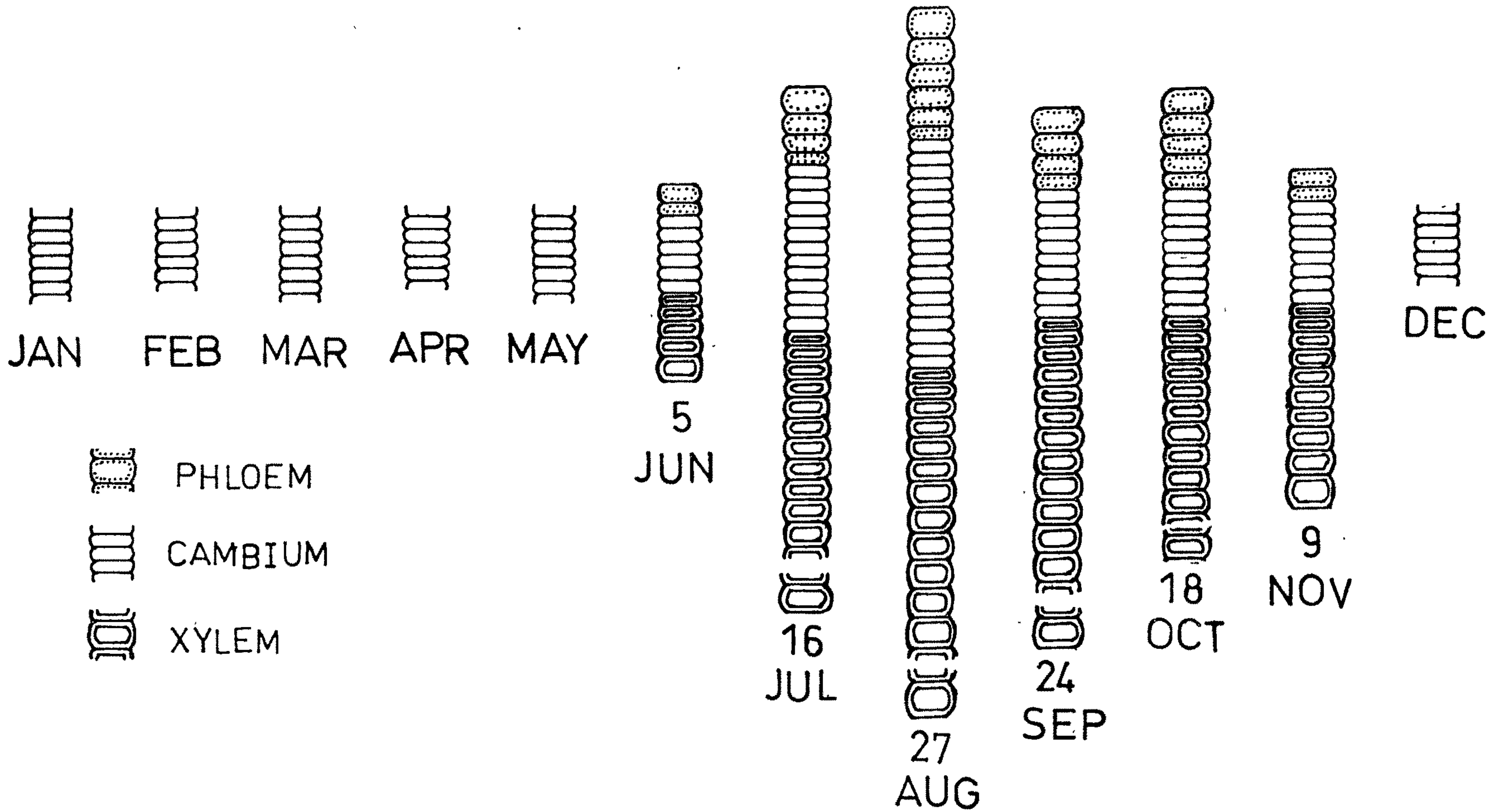
SEP
26
OCT
NOV
DEC
PHLOEM
CAMBIUM
XYLEM

FIG. 10

Fig. 11

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Tectona grandis growing in DDF.



JAN
FEB
MAR
APR
MAY
5 JUN
16 JUL
27 AUG
24 SEP
18 OCT
9 NOV
DEC
PHLOEM
CAMBIUM
XYLEM

FIG. 11

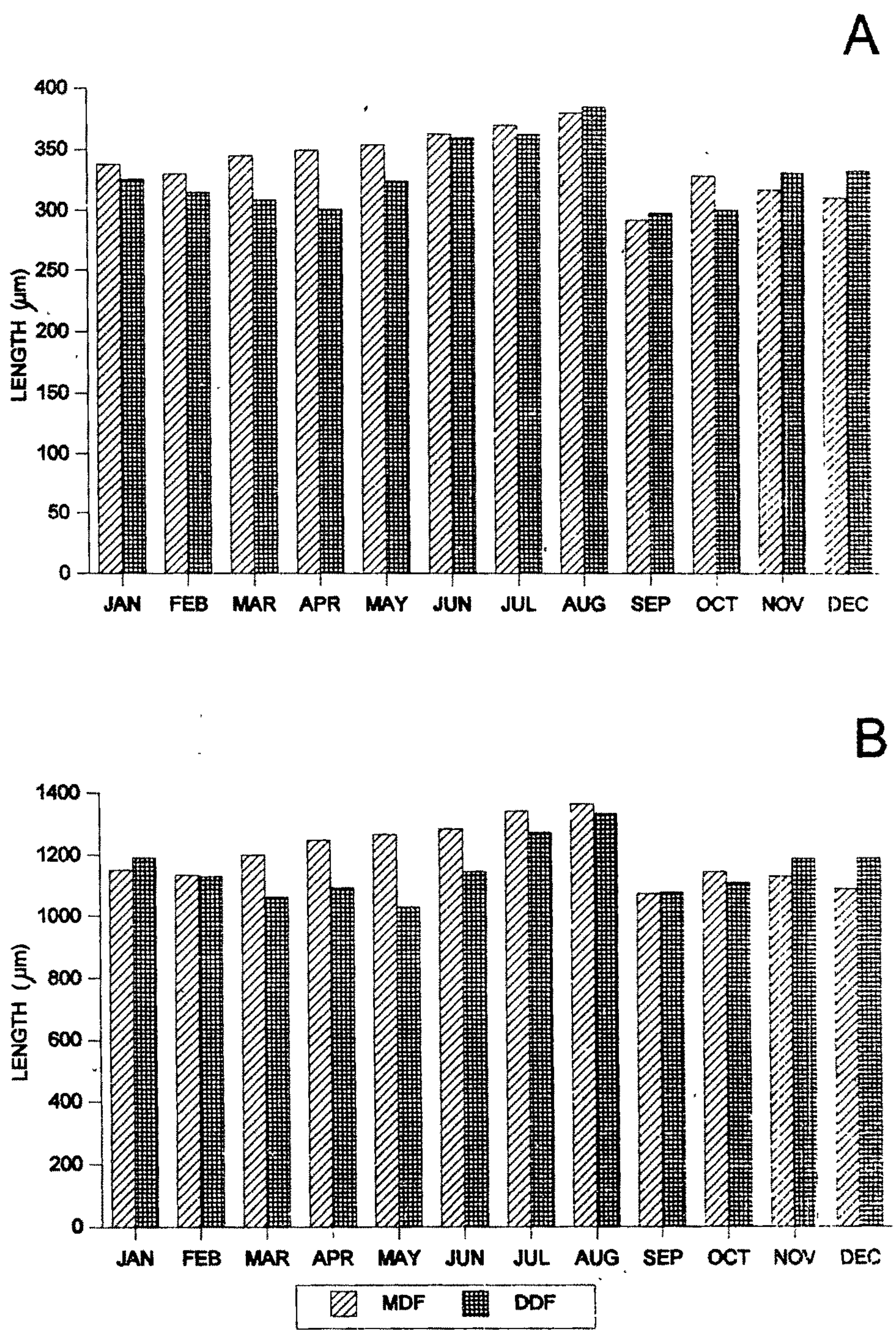


Fig. 12 Histograms showing seasonal variation in mean length of fusiform cambial cells (A) and xylem fibres (B) in <u>Tectona grandis</u>.

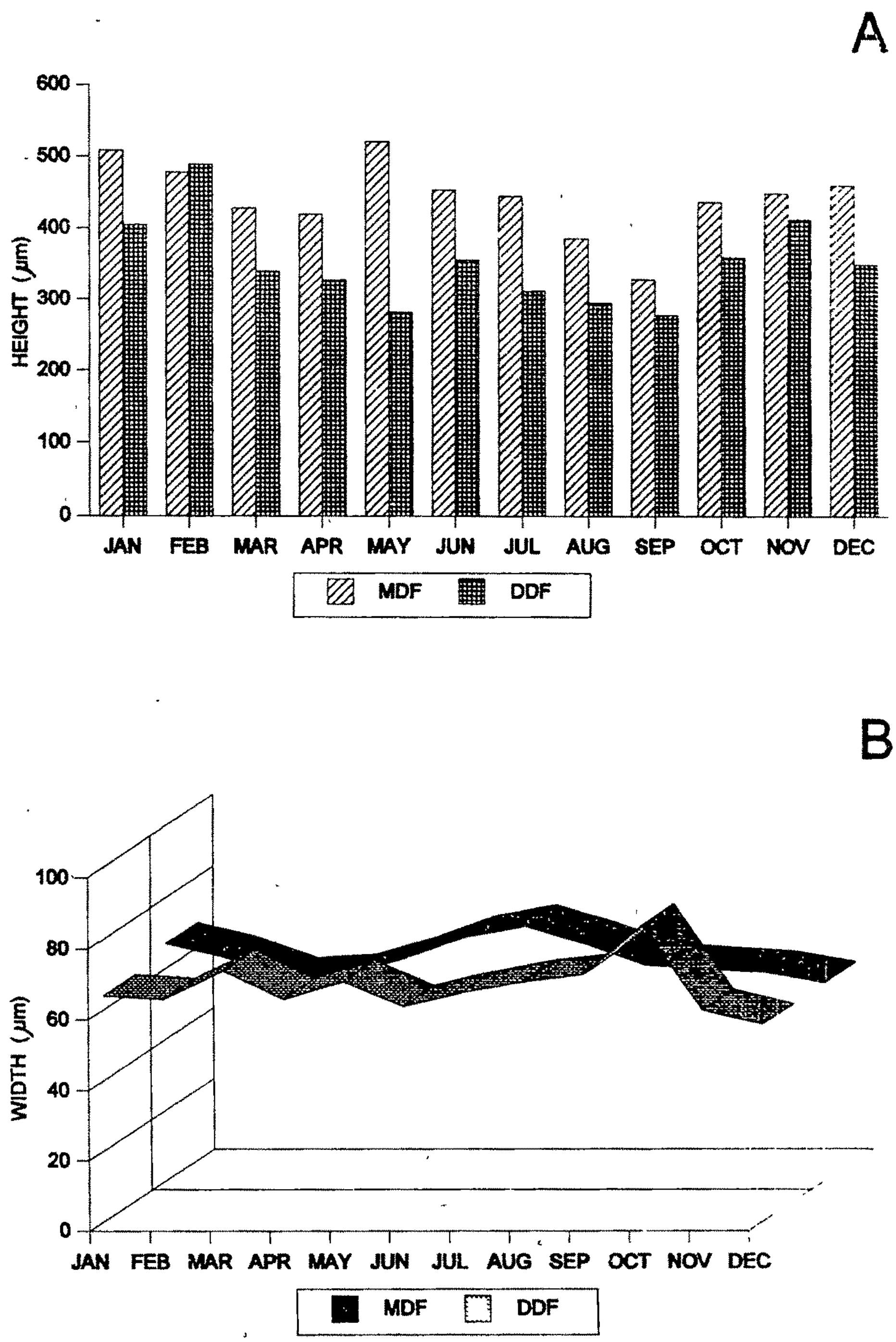


Fig. 13 Graphic representation of seasonal variation in cambial ray height (A) and ray width (B) in Tectona grandis.

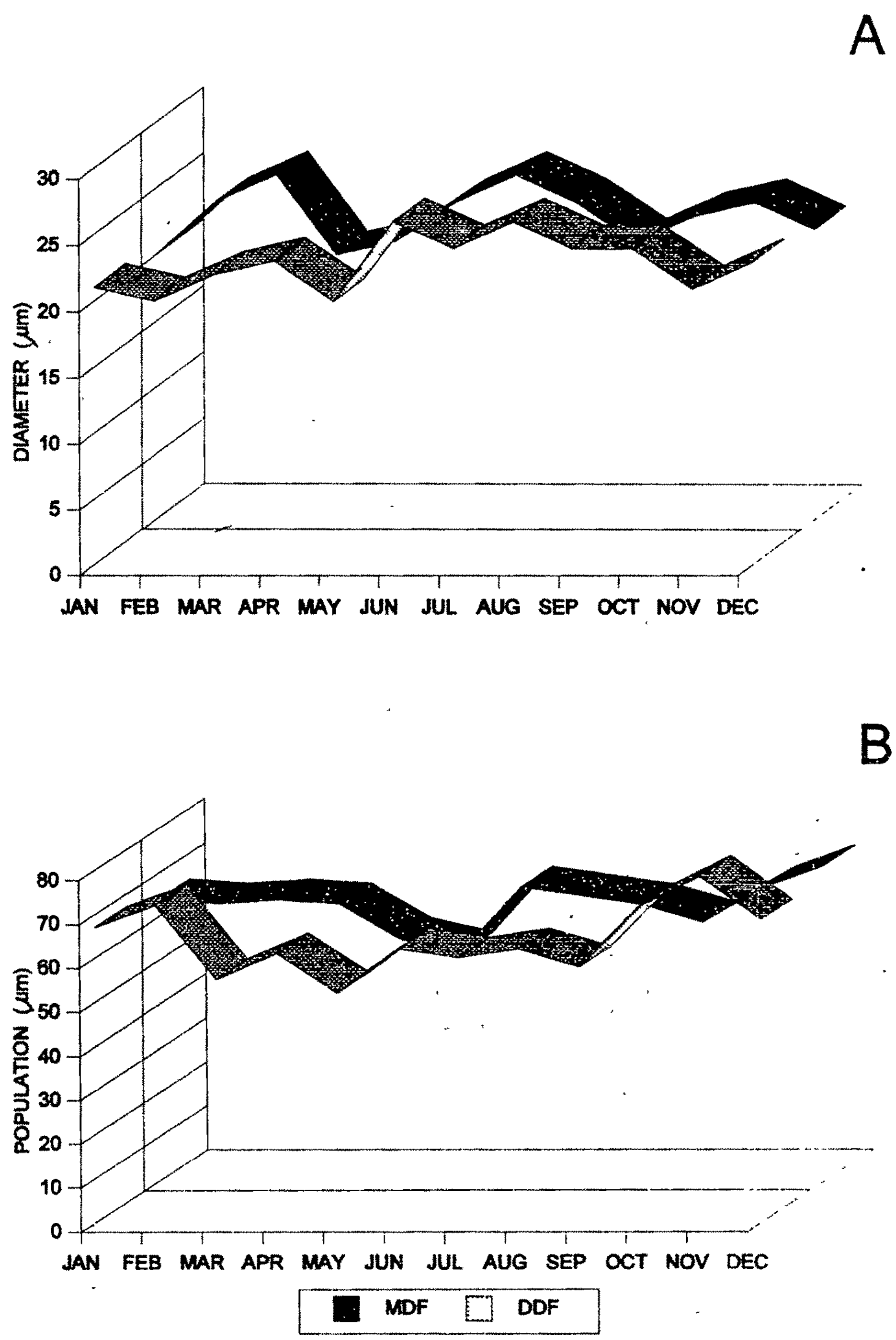


Fig. 14 Graphic representation of seasonal variation in ray cambial cell diameter (A) and ray population in 1cm tangential width of cambium (B) in <u>Tectona grandis</u>.

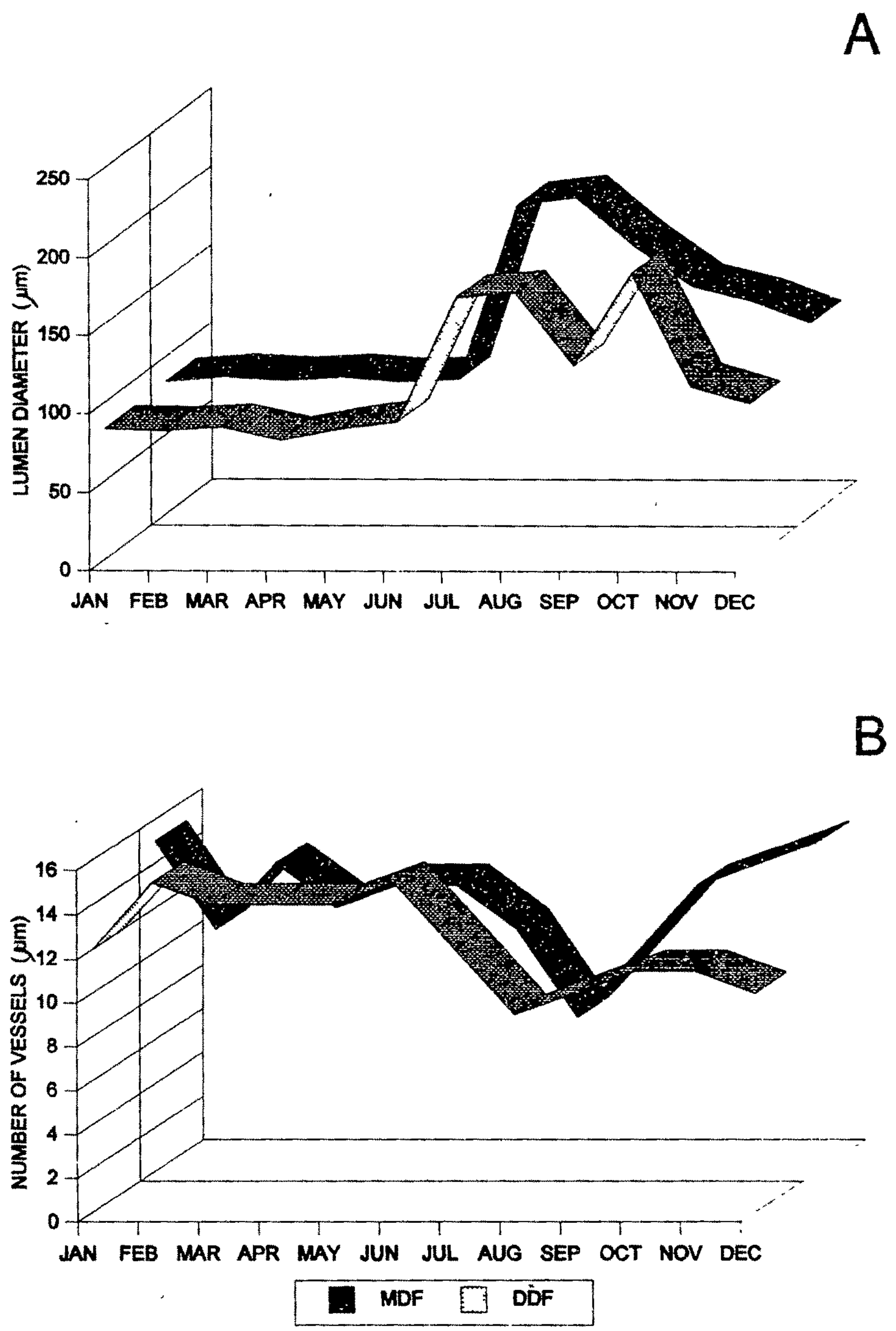


Fig. 15 Graphic representation of seasonal variation in vessel lumen diameter (A) and number of vessels per 0.5 mm2 (B) in Tectona grandis.

<u>ACACIA</u> <u>NILOTICA</u> (L) Del.

Family : Mimosaceae (Leguminoceae)

The name <u>Acacia</u> is used by Pliny and is derived from the greek word "akakia" from "akis" meaning a point, refers to the tree having thorns.

A small or medium sized tree with dark coloured rough bark. Young trees armed with strong straight Ivory-White spines which may be two inches long These thorns occur in pairs at the base of leaf stalk and are absent on old trees. Branches subject to browsing by cattle are particuarly well armed. Leaves being compound are divided into a great number of very small leaflets. Flowers occur in golden (Yellow) balls about ½ in. in diameter, the individual flower being very small. Fruit is grey velvety pod more or less constricted between the seeds (lomentum).

It is believed to be indigenous to the Deccan and Sindh, also Arabia and Northern Africa. It is cultivated or self sown throughout the greater part of India. The timber is hard, heavy and durable and is used for many purposes in villages especially for making cart wheels, for well curbs, sugar rollers, oil presses, rice pounders, agricultural implements, mallets, axe handles and tent pegs. It is also used for railway sleepers. It is an excellent fire wood and makes good charcoal The branches are much used for fencing the fields. From wounds in bark a gum exudes which is used in place of gum arabica. The pod can be used for tanning and they are eaten by goats when they fall from the tree.

STRUCTURE OF CAMBIUM :

The cambium of Acacia nilotica is nonstoried (Fig. 17F) with vertically elongated fusiform cambial cells and isodiametric ray cambial cells. Fusiform cambial cells are arranged in radial file and appears more or less rectangular in transverse sections (Fig. 16A). Cambial zone remains narrow with 4-6 layers of cells in dormant condition (Fig. 16C). These undifferentiated cambial cells are sandwiched between completely mature xylem and phloem elements. During active period the cambial zone is wide with 8-18 layers of cells surrounded by differentiating vascular elements (Fig. 17A). Radial walls of fusiform cambial cells are thick and possess beaded walls due to presence of primary pit fields when the cambium is dormant. The radial walls appear thin and more or less uniform with no beaded appearance in tangential sections during active state of cambium

CAMBIAL ACTIVITY :

Radial growth in the trees of Acacia nilotica growing in MDF continues for major part of the year. Cambial growth remains suspended in March and May (Fig. 16A,B,C). During these months cell division and differentiation are not encountered. Periclinal divisions in cambial zone reaches peak in August (Fig. 17A) with 14-18 number of cells in each radial file.. While cambial zone remain narrow with 4-8 number of cells showing no divisions in March and May (Fig 16 A,C). Cambial cell division in young branches does not match with that of main trunk. Cell division in branch cambium begins in patches in the month of January, reaching peak in April with 5-6 number of cells in each radial file. The divisions decline gradually and ceases in November. Cambial zone remains narrow with 3-4 number of cell layers in December.

In DDF, cambium of main trunk remains active throughout the year with grand period of activity in August-September (Fig. 17B). In this month, cambial zone is wider, possessing 10-15 number of cells in each radial file, while sluggish growth in cambial zone is observed between December to February. However, branch cambium shows two flushes of growth. The first flush of cambial cell division occurs in January and ceases in April. Cambium remains dormant in May and reactivation occurs in June reaching peak in July-August and ceases in October. Cell division in cambial zone ceases in November-December.

Trees of <u>Acacia</u> growing in SF show two distinct growth flushes. The first flush of periclinal divisions in cambium commences in January (Fig.16D) culminating in April (Fig. 17C) with 11-18 number of cells in cambial zone. In May cambial zone shows no cell division and becomes surrounded by maturing elements until September (Fig. 16E). The second flush of cambial cell divisions start in October (Fig. 16F,G) and ceases in December. In branches, however, cambial cell division initiates in June and ceases in September. Cambium remains inactive till November. Reactivation of cambial activity in young branches occurs in December and remains continue till April ceasing in May. Cambial zone possesses 4-6 layers of cells during active period of growth

Seasonal variation in number of cambial layers in the main stem of trees growing in MDF, DDF and SF are presented in Figures 22,23 and 24 respectively.

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY :

Defoliation and sprouting of young leaves appears simultaneously in Acacia nilotica. Therefore, trees remain evergreen. In MDF, trees flower in June followed by fruit setting in August and this phenomena continues until December. Extension growth of apical shoots are found throughout the year. However, in DDF and SF development of flower bud commences in February followed by flowering and fruiting until November.

Phenological observations, however, do not show any significant correlation with cambial cell division, except in DDF. Cambial activity in MDF occurs for the major part of the year. Where as it remains suspended for a brief period in March and May when the trees are with young leaves and flowers. In DDF, development of flowers and extension growth of apical shoot coincide with the lateral growth (radial) of the main stem. Cambium remains active throughout the year In SF cambial activity does not show significant correlation with phonology Periclinal divisions in the cambial zone are suspended between June and September, though the development of young leaves and flowers is a continuos process. The relation between cambial activity and phenology of Acacia trees growing in MDF, DDF and SF is presented in tables 8 , 9 and 10 respectively.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS :

As aformentioned Gujarat state possesses considerable variations in climatic factors. The MDF is famous for its heavy rainfall and comparatively low temperature in summer. In contrast with the MDF, SF is also famous for its high temperature during summer, cold winters and low rainfall while DDF meteorologically lies in between MDF and SF.

In MDF cambial division occurs for major part of the year but no activity is observed in March and May though the temperature is maximum in May (37°C) Cambial cell division and differentiation of its derivatives culminates in August when the rains are heavy, The peak cambial activity declines gradually parallel with rains and ceases in March and May during the drier part of the year. In DDF, cambium remains active throughout the year, reaching its vertex between August and October when the rainfall is maximum. In SF, however, radial growth in main stem occurs in two growth flushes. The first flush of cambial division commences in January when the temperature is lowest of the year (28.6°C). Cambial activity is recorded maximum during the year in April and ceases when the temperature is maximum (40.3°C). Interestingly cambium remains inactive from June to September, a major part of the rainy season. Reactivation of cambium during second flush begins in October when the rains are scarce. However, Acacia trees growing in SF does not show any significant correlation between cambial cell division and climatic factors. Fluctuations in meteorological data (maximum and minimum) temperature, rainfall and relative humidity are represented in Figs. 1 and 2A,B.

FUSIFORM CAMBIAL CELLS:

Fusiform cambial cells as seen in tangential view are elongated with overlapping cell tips (Fig. 17F). These cells undergo anticlinal (Fig. 16A) and periclinal divisions (Fig. 17D). Anticlinal divisions (Fig. 17E) leads to the increase in the circumference of cambium and periclinal division adds axial elements in xylem and phloem. However, twisting (Fig. 17I) and loss of fusiform cambial cells from the cambial zone is a common phenomena in the trees of all three regions (Fig. 16H). However, the extent of loss varies, thus the loss of cells is often noticed in the cambial zone of SF trees. During the process of growth fusiform cambial cells undergo various developmental changes. Development of ray cambial cells from fusiform cambial cells (Fig. 18B) loss of cells from intervening rays leading to the fusion of cambial rays (Fig. 18C) and splitting of ray by growth (Fig. 18A) are noticed. Intrusive growth of fusiform cambial cells lead to the bifurcation of cell tips and bending of cell ends leading to the abnormal development of fusiform cambial cells (Fig. 18D).

Divisional activity:

Periclinally dividing cambial cells are noticed with formation of phragmoplast in both the transverse (Fig. 16F,G) and tangential view (Fig. 17D) In MDF, though the periclinal divisions in fusiform cambial cells occurs throughout the year, their frequency is noticed maximum in August, while in DDF, the divisions occur throughout the year. The divisions are maximum in August-September (Fig. 17B) and April in DDF and SF respectively.

Dimensional Changes :

Mean length:

The dimensional study of cells show fluctuation in cell length parallel with that of season. However, in MDF the mean length is minimal in February (273 µm) and maximal (Fig. 25A) in October (398 µm). It increases from June to October then decreases gradually from November to March with sudden increase and decrease in April and May respectively (Table 11). In DDF, minimal and maximal length of the cambial cells have been encountered in February (256 µm) and October (367 µm) respectively (Fig. 25A). However, it increases from June to October and length declines form November to February, then increasing (Table 11) in March-April (Fig. 17F). In SF cambial cell length is found to be minimum (267µm) in April (Fig. 17G) and maximum (384 µm) in November (Fig 25A) However, it increases from January to March and May (Table 11). Compared among all the three regions, yearly average of fusiform cambial cell length remains maximum (330 µm) in MDF and minimal (300 µm) in DDF (Table 31).

Mean width:

Tangential width of fusiform cambial cells does not show appreciable variation with the seasonal activity. However, maximal (24 µm) tangential width remains similar in all the three regions in June, December and May in MDF, DDF and SF respectively. Less width was recorded in February (15 µm) in MDF, April (12 µm) in DDF and April, June and August (16 µm) in SF (Tables 11, 31).

The radial width of fusiform cambial cell increases following swelling of the cells prior to the commencement of periclinal division (Fig. 17H). The width of cells remains relatively less (4 µm) during the peak activity due to the rapid periclinal divisions in the new daughter cells. However, in MDF it remains maximum (6 µm) in February, May, July, September and November and minimal (4 µm) in August (Table 11). In DDF, it is maximum (7 µm) in October and November while in SF it remains maximum (7 µm) in July-August and minimum (4 µm) in April (Tables 11, 31).

Length variation in relation to xylem fibre length:

The average length of xylem fibre is found to be 4-6, 5-6 and 4-7 times greater than that of fusiform cambial cells in MDF, DDF and SF respectively

(Fig.25B). However, maximum length of xylem fibres coincides with maximum length of fusiform cambial cells. It is maximal (1666 µm, and 1503 µm) in October in both, MDF and DDF respectively (Table 14). In SF it is maximal (1746 µm) in May. In MDF and DDF minimal length of fibre does not show such correlation with minimal length of fusiform cambial cell (Fig. 25B). In SF, minimal length of fusiform cambial cells coincides with that of fibres in April. Though in both, MDF and DDF minimal cambial cell length (273 µm and 256 µm) is observed in February, fibre length is found to be minimum (1154 µm and 1261 µm) in May in both the forests respectively (Table 14). On comparison of yearly average lengths of xylem fibres among all the three forests, the trees of DDF show maximal length (1380 µm) though yearly average of fusiform cambial cells is minimal (Tables 31, 34).

RAY CAMBIAL CELLS:

Ray cambial cells are short and more or less isodiametric giving rise to vascular rays in xylem and phloem. They are uni to multiseriate and heterocellular but multicellular rays are predominant.

Divisional activity:

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

Dimensional changes:

Cambial ray height:

Variations in cambial ray height do not show any correlation with season and activity of the cambium. In MDF, it increases and decreases alternately throughout the year and maximal and minimal height (430 µm and 292 µm) is recorded in April and July respectively (Fig. 26A). In DDF, ray height increases and decreases alternately from January to May. Then it increases from June to December. It remains minimum (249 µm) in February and maximum (395 µm) in December (Fig. 26A). In SF, similar to that of DDF, it increases and decreases unsequentially from January to June and increases from July to November with sudden decrease in December. However, maximal and minimal height (480 µm and 259 µm) are encountered in June and December respectively (Fig. 26A) Yearly average of cambial ray height among all the three forests show maximal height (374 µm) in SF while it remains minimal (336 µm) in DDF (Table 32).

Cambial ray width:

No definite correlation exists in the seasonal changes of ray width among all the three forests. In MDF and DDF, it increases and decreases alternately throughout the year while in SF it decreases from April to August and October to December while it increases and decreases alternately from January to March (Table 12). However, minimal and maximal width is observed in May and August (49 μm and 85 μm), June and December (45 μm and 84 μm), July and March (54 μm and 83 μm) in MDF, DDF and SF respectively (Fig. 26B). The yearly average width of cambial rays is maximum (65 μm) in SF and minimum (55 μm) in DDF (Table 32).

Ray cambial cell diameter:

Ray cambial cell diameter shows fluctuations parallel with seasonal activity of cambium. In MDF, it remains minimal (14 μm and 15 μm) in March and May when the cambium is dormant and is maximal (23 μm) in August when the cambium reaches peak (Table 12). In the intervening months it increases and decreases alternately (Fig. 27A). In DDF, however, tangential diameter of ray cambial cells does not coincide with seasonal activity and is found maximum (20 μm) in December and minimum (13 μm) during the grand period of activity in July. It increases and decreases unsequentially throughout the year (Fig. 27A). In SF, the diameter is minimum (14 μm) in August and maximum (22 μm) in December. However, the diameter remains more or less similar from June to September during the dormant period. It increases from October to December.

Yearly average of ray cambial cell diameter does not show significant changes among the three forests (Table 32).

Cambial ray population :

The average number of rays coincides with peak activity of cambium which records minimum in August (41), July (49) and May (41) in MDF, DDF and SF respectively. The number is maximal in March (66), June (79) and February (72) in MDF, DDF and SF respectively (Table 12) . Ray population shows random variations in MDF and DDF. In SF, their population remains more or less similar from June-October (Fig. 27B). Yearly average of ray population for one cm tangential width of cambium stands maximal (65) in DDF and minimal (54) in SF. The average number of rays passing through one cm tangential width of cambium are presented in Table 32.

Development of Vascular tissues :

Development of xylem preceds that of phloem in both MDF and SF. In DDF, development of xylem and phloem remains continuous throughout the year. Divisions in cambial zone shows more inclination towards xylem. However, xylem mother cell undergo further periclinal (Fig. 19A) divisions at the time of xylem differentiation. In MDF, differentiation of xylem starts in June culminating in September and January with 16-30 and 17-32 number of cells respectively. The differentiation of xylem and phloem remains suspended in March and May while in DDF it continues throughout the year. Differentiation of xylem reaches peak in September with maximum (22-34) number of derivatives. It declines gradually in October and becomes slugish from February to May (2-12). The differentiation is rapid following the onset of rains in June. The development of phloem derivatives is noticed maximum (4-7) in July-August. In SF, development of vascular tissues occurs in two flushes. The first flush of xylem development commences in January reaching peak in April (22-30), then ceases in May following suspension of cell division in cambium but maturation of xylem elements continues. The xylem and phloem development remain suspended from June to September. Second flush of xylem growth starts in October with maximum (13-20) number of differentiating cells and ceases in December, but maturation of xylem derivatives continues. During the first flush of cambial growth phloem development starts in February followed by maximum differentiation of phloem elements in March and April In second flush development of phloem starts in October and ceases in December Development of vascular tissues in trees growing in MDF, DDF and SF is presented in Tables 8,9, 10 and Figures. 22,23 and 24 respectively.

Development length and width of sieve tube elements :

During the course of phloem development sieve tube mother cells undergo vertical and lateral expansion and thus remain larger than fusiform cambial cells In some months length of sieve tube element is found to be less than that of fusiform cambial cells. In MDF, the length of sieve tube element is more from January to April and less in the remaining months except in July and October (Table 15) However, maximal length of sieve element (403 µm) coincide with maximal length of fusiform cambial cells in October while minimal length (276 µm) is encountered in May. However, similar to that of fusiform cambial cells, the length of sieve tube elements increases and decreases alternately from January to September and then it decreases gradually from October to December (Table 15). In DDF, compared to fusiform cambial cells, length is more from January to June and November-December. The minimal (280 µm) and maximal (348 µm) length of sieve tube elements in March and November do not show any correlation with that of fusiform cambial cells. However, in SF, the length remains less from January to March and May to September while it remains more as compared with fusiform cambial cells in April and from October to December. The length increases from January to March and April to June, while it decreases in August-September (Table 15). The average minimum (265 µm) and maximum (396 µm) length of seive tube element is encountered in July and November respectively (Table 15) The yearly average of sieve elements is observed maximum (327 µm) in MDF and minimum (304 µm) in SF. The width of sieve elements is minimum (23 µm) in February, April (23 µm) and February (16 µm) and maximum in October (32 µm), January (30 µm) and September (31 µm) in MDF, DDF and SF respectively

Sieve elements in phloem rays

Radially arranged sieve tubes are encountered either solitary or in groups of 1-3 uniseriate as well as multiseriate rays of secondary phloem. Ray seive elements have compound sieve plate (Fig. 18E) on transverse to slightly oblique end walls The diameter of these elements is relatively more than that of adjacent ray parenchyma cells but more or less equal to that of axial sieve elements These sieve tube elements maintain contact with the adjacent axial sieve elements They also show massive deposition of callose, collapse of companion cells, obliteration, loss of cell contents, accumulation of slime (p-protein) against the sieve plate and cytoplasmic strands. However, no sieve areas are observed on their lateral walls. Though the sieve elements are observed in both uniseriate as well as multiseriate phloem rays, they are distributed characteristically at the extreme radial ends or at the margin of rays.

Development, length and width of vessel elements:

The cells developing into vessel elements enlarge radially (Fig.19B) and in certain months their ultimate width exceed their length. However, in all the three forests, compared to fusiform cambial cells, vessel elements are slightly shorter The development of short vessel elements is associated with the formation of transverse division in vessel element mother cell. In MDF, minimum (192 μm) and maximum (291 μm) length of vessel elements coincide with that of fusiform cambial cells in February and October respectively. Similar to that of fusiform cambial cells, vessel element length increases from May to October and decreases and increases alternately in the remaining months (Table 13). In DDF also, vessel elements remain shorter than fusiform cambial cells but they do not show significant correlation with the length of cambial cells. However, maximal and minimal length of vessel element is encountered in February (237 µm) and December (177 µm) respectively. The minimal length of vessel elements is found exactly opposite to that of fusiform cambial cells. Vessel element length decreases from February to May and June to August, while in remaining months it increases and decreases alternately (Table 13). In SF, fluctuations in the length of vessel elements are insignificant in relation to fusiform cambial cell length. Minimal length of vessel elements (143 µm) coincide with that of cambial cells in April. The length decreases from February to April and increases or decreases alternately from May to December (Table 13). Yearly average of vessel element length is reported minimum (188 µm) in SF while maximum (239 µm) in MDF (Table 33).

During the development, vessel element undergo radial expansion almost 5-16 times (Fig.19B) which results the larger lumen compared to its length. In MDF, the width of vessel elements ranges from 188 µm to 275 µm and remains more than that of its length from February to May and July. The width remains less than length in rest of the months. No correlation has been observed between increase and decrease in the length of vessel elements. Its width occurs minimal (188 µm) in January and maximal (275 μm) in July (Table 13). In DDF, vessel element width occurs less than its length from February to May, July to August. It remains more in June and September to December. However, minimal and maximal width of vessel elements are noticed in April and December (184 μm) and September (272 μm) respectively (Table 13). In SF, vessel elements width occur more than the length from March to September and it is found less from October to December. However, vessel element width increases and decreases alternately from January to April and October to December and decreases from June to September (Table 13). The yearly average width remains more than the length of vessel elements in DDF and SF. The width is found to be maximum (227 μm) in MDF and minimum (208 μm) in SF (Table 33).

Vessel lumen diameter:

Average vessel lumen diameter ranges from 105 μm to 197 μm, 104 μm to 210 μm and 98 μm to 198 μm in MDF, DDF and SF respectively (Fig. 28A). However, it remains minimal in June (105 μm), December (104 μm) and October (98 μm) and maximal in October (197 μm), September (210 μm) and August (198 μm) in MDF, DDF and SF respectively (Table 13). Yearly average lumen diameter remains maximum (158 μm) in MDF and minimum (150 μm) in SF (Table 33).

Number of vessels:

The number of vessels per 0.5 mm^2 of xylem is studied in transverse section of xylem. Increase in vessel lumen diameter leads to the decrease in the number of vessels and vice-versa in all the three forests. In MDF, maximum number of vessels are reported in May and December (20) while minimal (Fig.18G) in October (6). In DDF, vessel number is found to be more from February to May (13-19) and maximal in December (26) while number ranges from 7-12 per 0 5 mm^2 during the rainy season (Fig. 18H) with minimal in September (7) In SF. vessels are more from October to December with maximal number (Fig. 18I) in January (28). Among all the three forests yearly average vessels are more (17) in trees of SF and less (13) in DDF. The number of vessels in 0.5 mm^2 transectional area of xylem of the trees growing in MDF, DDF and SF are represented in Fig.28B and Table 13.

Xylem structure:

The xylem is diffuse porous with indistinct growth rings (Fig. 18G, H) and is composed of vessel elements, axial and ray parenchyma and fibres In transverse sections, vessels appear oval to oblong (Fig. 19C) angular (Fig. 19D) They are mostly solitary but radial multiples of 2-4 vessels are also encountered in the trees of all the three forests. However, compared with MDF and DDF occurrence of radial multiples and clusters of vessel elements (Fig. 19D) is more common in SF

Axial parenchyma are aliform to confluent (Fig. 19C) in MDF and DDF, while in SF they are sparsely vascicentric (Fig. 19D). However, wide tangential bands of axial parenchyma alternating with xylem fibre bands is common feature in SF which is not observed in the trees of other two forests types. Another interesting feature in the xylem of trees growing in SF is the occurrence of G-fibres (Fig 19F) which is observed almost throughout the year. G-fibres are rarely noticed in a few months in MDF and remain normal (Fig. 19E) in the remaining months

Growth ring width:

Being an evergreen tree there is no sharp distinction between the two adjacent xylem increments. But the extent of xylem produced in each year can be discernible with the help of abruptly narrow elements, thick walled cells and ray noding pattern (Fig. 18F). The extent of xylem added during the current year's and previous year's cambial activity measures 5.2 mm and 5.6 mm in MDF, 7.8 mm and 8.2 mm in DDF and 6.8 mm and 6.3 mm in SF respectively. The amount of xylem produced is more in DDF and less in MDF.

HISTOCHEMISTRY

Starch:

Starch grains are absent in both the fusiform and ray cambial cells throughout the year (Fig. 20A,B). However, differentiating xylem elements are seen containing reddish brown small starch grains while mature elements away from cambial cells are rich with darkly stained starch grains for the major part of the year. In MDF, starch grains in xylem derivatives are fusiform shaped (Fig 20D) and in phloem parenchyma they are oval and simple (Fig. 20C). Starch grains are oval to oblong in both the xylem and phloem derivatives (Fig. 20G, I) in DDF and SF.

In MDF starch deposition extends gradually towards the cambium in both xylem and phloem tissues and by March abundant starch accumulation is encountered in axial and ray parenchyma of xylem and phloem and even close to the cambial zone. Starch is found only in mature elements and absent in differentiating elements in April. Starch deposition in May is similar to that of March (Fig. 20E,F) Depletion of starch begins with the initiation of cambial cell division in June and it is observed only in mature xylem and phloem parenchyma in August (Fig. 20H). With the decline in cambial activity starch accumulation increases and by December abundant starch is observed in xylem and phloem derivatives except in differentiating elements.

In DDF, similar to that of MDF, abundant starch is observed away from cambial zone in xylem and phloem derivatives in January. Starch deposition increases slowly and by April-May heavy accumulation of starch is encountered when the activity is very sluggish. Depletion of starch begins in June in xylem fibres (Fig. 20G). Ray parenchyma of both xylem and phloem are found devoid of starch grains in August when rapid divisions take places. Starch deposition increases from September onwards, starting first in mature ray parenchyma and axial parenchyma formed in the begining of activity and spread towards cambium In December, abundant starch is noticed in xylem and phloem except in recently formed derivatives.

In SF, starch is present only in axial parenchyma of xylem and phloem and absent in ray parenchyma of both the tissues in January. However, abruptly abundant starch is observed in May and remain same until September (Fig. 20I). In September starch in ray parenchyma of xylem and phloem close to cambial zone is relatively less than that of previous months. From October, decline in starch deposition coincides with second flush of cambial cell division. In December, starch distribution remains restricted only to axial parenchyma of both xylem and phloem away from the cambial zone.

Lipids:

Lipids occur as minute globules in both the fusiform and ray cambial cells of Acacia growing in all the three forests. However, these globules are uniformly distributed along cambial cell walls during dormant condition while during active period it shows localised distribution either along the cell walls or around the nucleus.

In MDF, fusiform and ray cambial cells are rich in lipid globules in March and May (Fig. 21A) when the cambium is found inactive. With the initiation of cambial cell division in June (Fig. 21D) it decreases and by August cambial cell contain sparsely distributed lipids in the form of minute droplets. With the decline of cambial activity, lipid distribution increases and remains more or less similar in rest of the months.

In DDF, cambium is found to be active throughout the year. In May when the cambial cell divisions are sluggish fusiform and ray cambial cells exhibit lipid bodies (Fig. 21B). Lipid droplets are fairly larger than those in dormant cambium of MDF in March and May. Lipids are sparsely distributed as minute globules in August-September (Fig. 21E) when the cambial cell division reaches peak while in rest of the months their distribution is similar to that of MDF.

In SF, lipid globules are uniformly distributed in January in both fusiform and ray cambial cells. Their distribution decreases concomitantly with the increase in cell divisions in the following months. The cambium is fairly active in April when the cambial cell contain sparsely distributed lipids in the form of minute globules (Fig. 21C). Cambial cells are rich in lipids when the cell divisions are suspended between May and September. The distribution declines with the initiation of cambial cell divisions in October.

Proteins:

Proteins appear in the form of small granules in both the fusiform and ray cambial cells. They are distributed in cell lumen along the cell walls and around the nucleus.

Cambial cells are seen with sparsely distributed (Fig. 21F) protein bodies when the cambial growth is suspended in MDF (March and May). Protein distribution is less in May in DDF and May to September in SF. With the initiation of cell division protein deposition starts declining in cambium of all the three forest types (Fig. 21G). Protein bodies appear as small granules around the nucleus and along the cell walls of both the cambial cells, when the cambium is active in all the three forests (Fig. 21H). However, compared to fusiform cambial cells, ray cambial cells show more protein granules in all the forests. The accumulation of protein bodies increases slowly with the decline of cell divisions in the cambial cells of MDF and DDF. But in SF, they are sparsely distributed (Fig. 21I) even after the cessation of cambial activity.

TABLE: 8

Data on phenology, average number of cambial layers and differentiating xylem and phloem elements in the main trunk and branches of <u>Acacia</u> <u>nilotica</u> growing in MDF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Sprouting of new leaves, drying of fruits.	10 ±1.15	4 ±0.75	24 ±2.92	4 ±1.10	4 ±0.50	-
FEB	Sprouting of new leaves, drying of fruits	9 ±1.20	4 ±0.80	14 ±4.27	4 ±0.64	5 ±0.42	2 ±0.61
MAR	Sprouting of new leaves, fruits dispersal	5 ±0.49	3 ±0.61	-	8 ±1.68	-	2 ±1.02
APR	Full foliage .	9 ±1.12	5 ±0.85	20 ±2.07	12 ±1.92	4 ±0.60	3 ±0.81
MAY	Full foliage	5 ±1.08	3 ±0.66	-	7 ±1.87	-	2 ±0.95
JUN	Full foliage, flowering	10 ±1.25	4 ±1.18	17 ±1.60	4 ±0.86	4 ±0.38	2 ±0.38
JUL	Full foliage , development of flower buds	6 ±1.06	4 ±1.35	15 ±3.22	3 ±0.79	2 ±0.51	2 ±0.68
AUG	Full foliage, flowering , fruit setting	16 ±1.55	5 ±1.21	17 ±3.53	2 ±0.48	4 ±0.58	2 ±0.50
SEP	Full foliage, flowering , fruiting	13 ±1.69	4 ±1.18	24 ±2.97	3 ±0.52	4 ±0.58	2 ±0.48
OCT	Full foliage, fruiting	10 ±0.95	3 ±0.46	18 ±2.13	3 ±0.50	5 ±0.80	-
NOV	Full foliage, fruiting	6 ±1.24	3 ±0.50	10 ±2.00	-	5 ±0.82	-
DEC	Full foliage, maturation of fruits	11 ±1.50	4 ±0.49	8 ±1.95	-	4 ±0.54	-

TABLE : 9

Data on phenology, average number of cambial layers and differentiating xylem and phloem elements in the main trunk and branches of Acacia nilotica growing in DDF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Sprouting of new leaves, development of floral buds, drying of fruits .	13 ±1 56	4 ±0 74	15 ±1 90	4 ±1.32	4 ±0 73	2 ±0 48
FEB	Maturation of leaves, flowering, fruit dispersal	13 ±1.29	4 ±0 57	5 ±1.26	3 ±0.71	3 ±0.78	2 ±0 51
MAR	Full foliage, flowering ,fruit dispersal	9 ±2 10	6 ±2 00	5 1 68	2 ±0 73	4 ±0 98	2 ±0 64
APR	Full foliage, fruit setting	9 ±1 95	6 ±2 10	5 ±0 75	2 ±0 78	3 ±0 67	2 ±0 64
MAY	Full foliage, fruit setting, maturation	12 1 35	7 ±1 25	9 ±1.05	5 ±0.95	4 ±0 74	2 ±0 61
JUN	Full foliage, fruit maturation, dispersal	12 2.45	7 ±2.00	15 ±2.38	4 ±0 71	3 ±0 87	-
JUL	Full foliage	13 ±1 82	6 ±1.75	25 ±1.35	4 ±0. 84	5 ±0 80	3 ±0 78
AUG	Full foliage	13 ±2 12	7 ±2 06	26 ±3 00	4 ±0 84	5 ±0 78	-
SEP	Full foliage , flowering.	12 ±1 91	6 ±1 32	30 ±1.57	4 ±0 74	3 ±0 76	-
OCT	Full foliage, flowering	14 ±2 37	6 ±0.79	26 ±3.66	6 ±0 17	4 ±0 68	3 ±0 70
NOV	Sprouting of new leaves, fruit setting	8 ±2 37	3 ±1.02	10 ±1.15	-	5 ±0 73	-
DEC	Sprouting of new leaves , fruit maturation.	13 ±2.35	3 ±1 78	20 ±1.46	-	3 ±0 75	-

TABLE : 10

Data on phelonogy, average number of cambial layers and differentiating xylem and phloem in the main trunk and branches of Acacia nilotica growing in SF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Full foliage, fruit maturation, development of flower buds	6 ±0.56	3 ±0.46	6 ±1.10	4 ±0.83	-	2 ±0 52
FEB	Full foliage, fruit dispersal, flowering	10 ±1.41	4 ±1.05	6 ±1.48	-	3 ±1.00	-
MAR	Sprouting of new leaves, flowering.	7 ±1 14	4 ±0.96	16 ±1 08	7 ±1 66	4 ±0 63	3 ±0 58
APR	Sprouting of new leaves, fruit setting	16 ±3.28	5 ±1 12	26 ±3 92	3 ±0 69	4 ±0.49	2 ±0 39
MAY	Maturation of leaves, fruit maturation, dispersal	7 ±1.37	3 ±0.46	6 ±0.72	4 ±0 43	3 ±0.48	2 ±0 48
JUN	Full foliage, flowering	6 ±1.68	3 ±0.87	-	6 ±0.48	-	2 ±0 56
JUL	Full foliage, flowering, fruits setting.	6 ±1.52	5 ±0.76	-	8 ±0.32	-	3 ±0 76
AUG	Full foliage, flowering, fruit setting.	6 ±1.39	3 ±0.68	-	5 ±0.61	-	3 ±1 02
SEP	Full foliage, maturation of fruits.	7 ±1.53	3 ±0.82	-	3 ±0 58	-	2 ±0 68
OCT	Sprouting of new leaves, flowering, maturation of fruits.	8 ±1 69	7 ±1.10	15 ±3 12	-	3 ±0.51	2 ± 0 35
NOV	Sprouting of new leaves, flowering, fruit setting	9 ±1.85	5 ±0.78	12 ±2.71	3 ±0.66	2 ±0 20	2 ±0.49
DEC	Maturation of leaves, fruit setting.	7 ±1.77	4 0.65	5 ±2.36	2 ±0.48	2 ±0.39	2 ±0 29

TABLE : 11

Dimensional details of fusiform cambial cells (μm) in the main trunk of Acacia nilotica growing in MDF, DDF and SF.

Month	Length			Tangential width			Radial width		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	278 ±6.52	282 ±5.36	282 ±5.36	17 ±1.38	17 ±1.40	19 ±2.38	5 ±0.21	5 ±0.41	5 ±0.32
FEB	273 ±6.24	256 ±8.46	288 ±6.38	15 ±1.03	18 ±1.50	19 ±2.11	6 ±0.52	5 ±0.48	5 ±0.61
MAR	283 ±5.86	274 ±6.33	297 ±5.54	17 ±2.18	15 ±1.28	18 ±1.71	5 ±0.56	6 ±0.64	6 ±0.49
APR	340 ±8.07	295 ±9.64	267 ±8.52	21 ±1.56	12 ±1.34	16 ±1.55	5 ±0.28	6 ±0.46	4 ±0.45
MAY	279 ±6.17	291 ±9.12	309 ±10.91	17 ±1.43	15 ±1.25	24 ±2.32	6 ±0.66	6 ±0.40	5 ±0.46
JUN	356 ±9.50	262 ±6.86	291 ±5.14	24 ±3.70	15 ±1.31	16 ±1.01	5 ±0.50	5 ±0.50	6 ±0.58
JUL	357 ±6.80	293 ±8.35	307 ±6.60	22 ±1.89	18 ±1.43	19 ±1.94	6 ±0.45	5 ±0.38	7 ±0.44
AUG	359 ±8.94	301 ±7.99	303 ±5.38	23 ±2.30	21 ±1.49	16 ±1.63	4 ±0.56	4 ±0.40	7 ±0.59
SEP	374 ±6.53	361 ±5.46	302 ±5.38	20 ±2.68	18 ±1.61	16 ±3.02	6 ±0.62	6 ±0.41	5 ±0.51
OCT	398 ±8.75	367 ±7.93	308 ±11.14	22 ±1.55	17 ±1.27	23 ±2.31	5 ±0.85	7 ±0.59	6 ±0.41
NOV	346 ±8.62	327 ±7.48	384 ±10.65	22 ±1.18	19 ±1.54	22 ±1.54	6 ±0.50	7 ±0.82	5 ±0.64
DEC	314 ±5.48	297 ±8.17	380 ±6.19	19 ±1.53	24 ±2.09	23 ±2.18	4 ±0.55	5 ±0.77	6 ±0.45

TABLE : 12

Dimensional details of cambial rays (µm) and their population in 1 cm tangential width of cambium in the main trunk of <u>Acacia</u> <u>nilotica</u> growing in MDF, DDF and SF.

Month	Height			Width			Ray cell diameter			Ray population		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	381 ±19 81	393 ±22 48	382 ±15 10	55 ±0 94	59 ±1 90	56 ±1 10	16 ±1 90	15 ±1 90	16 ±1 11	54 ±22 62	52 ±20 12	56 ±12 20
FEB	419 ±21 43	249 ±20 64	375 ±18 30	67 ±1 22	54 ±2 12	60 ±1 98	18 ±1 90	14 ±2 07	17 ±1 92	65 ±28 28	75 ±29 69	72 ±33 94
MAR	362 ±18 70	288 ±17 35	412 ±16 38	50 ±1 69	47 ±1 33	54 ±1 41	14 ±1 78	14 ±1 61	16 ±1 37	66 ±27 35	72 ±24 04	63 ±24.74
APR	430 ±19 28	308 ±19.22	425 ±21 83	75 ±2 15	47 ±1.64	83 ±1 97	17 ±1 15	14 ±1 96	19 ±1 96	49 ±22.62	68 ±21.21	50 ±20 62
MAY	382 ±18.33	310 ±12.16	399 ±27.78	49 ±1 62	59 ±2 16	69 ±1 89	15 ±1.39	16 ±1.461	19 ±1.34	58 ±31 11	75 ±32 52	41 ±21 31
JUN	344 ±20.27	264 ±15 75	480 ±32 69	66 ±6 66	45 ±1.40	66 ±2 05	17 ±1 83	14 ±1 94	16 ±1 54	61 ±32.52	79 ±33.23	49 ±21 92
JUL	292 ±10 71	333 ±20 61	308 ±6 60	53 ±1 89	49 ±1.61	58 ±1 28	16 ±2.23	13 ±1 90	15 ±1 54	54 ±30.18	49 ±21 92	55 ±22 62
AUG	365 ±10 52	346 ±13 20	323 ±4 54	85 ±3 12	50 ±1 40	60 ±1 71	23 ±2 64	15 ±1 67	14 ±1 21	41 ±11 31	62 ±24 74	51 ±12 72
SEP	361 ±9.45	379 ±8 75	349 ±15.51	60 ±1 73	43 ±1 51	67 ±1 41	17 ±1.92	16 ±1 89	15 ±1 57	57 ±21 92	71 ±23 18	52 ±24 04
OCT	294 ±15.01	383 ±26 39	384 ±15 11	74 ±1 96	67 ±1 46	68 ±1 45	16 ±2 24	17 ±2 08	17 ±2 00	50 ±22.65	54 ±19 79	50 ±22 62
NOV	380 ±19 81	388 ±18 40	392 ±11 47	73 ±2 15	56 ±1.24	67 ±2 09	19 ±2.79	17 ±1 92	20 ±2 33	52 ±24.30	65 ±23 33	60 ±24 12
DEC	363 ±21 33	395 ±17 35	259 ±7 82	60 ±2 06	84 ±1 81	65 ±1 87	16 ±1.53	20 ±1 53	22 ±2.66	50 ±18 36	55 ±24 74	70 ±22 35

TABLE : 13

Dimensional details of vessel elements (μm) and average number of vessels per 0.5 mm^2 in the main trunk of Acacia nilotica growing in MDF, DDF and SF.

Month	Length			Width			Vessel lumen diameter			Number of vessels		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	248 ±7 25	224 ±9 73	165 ±6 32	188 ±5 55	224 ±10 24	158 ±9 03	148 ±3 66	130 ±5.46	108 ±4 23	11 ±1 60	8 ±3 47	28 ±2 83
FEB	192 ±7 79	237 ±10 69	248 ±7 12	227 ±7 14	215 ±9.45	240 ±5 49	147 ±5 32	124 ±4.87	108 ±7 61	10 ±1 88	16 ±1.12	10 ±2 00
MAR	203 ±8 91	229 ±7 82	190 ±6 11	203 ±7 00	219 ±12 86	218 ±8.63	130 ±5 79	111 ±6.67	156 ±7 14	11 ±1 25	16 ±2 00	12 ±2 37
APR	196 ±9 51	212 ±12 25	143 ±6 00	209 ±6 27	184 ±8 29	251 ±5 00	176 ±570	143 ±7 71	181 ±3.00	12 ±2 96	19 ±1 28	11 ±1 74
MAY	193 ±6 23	200 ±6.01	193 ±12 85	194 ±6 96	189 ±8 58	222 ±4 92	143 ±5 54	150 ±6.72	186 ±5 41	20 ±2 39	13 ±1 48	12 ±1 51
JUN	225 ±9.27	218 ±8 56	179 ±5 70	206 ±4 25	251 ±8 45	243 ±7 33	105 ±2 23	180 ±7.61	167 ±7 71	18 ±2 22	10 ±2 17	11 ±2 83
JUL	229 ±7 67	210 ±8.02	195 ±4 15	275 ±6 40	198 ±5 00	240 ±5 20	174 ±6.873	186 ±9.04	159 ±8 36	19 ±1 74	10 ±2 20	11 ±1 60
AUG	268 ±7 87	202 ±9 98	180 ±8 70	258 ±8 93	202 ±6 61	241 ±10 81	192 ±7 63	186 ±5 45	198 ±7.99	10 ±2 94	12 ±1 52	17 ±1 49
SEP	277 ±7.47	225 ±9 77	182 ±9 56	232 ±10 17	272 ±8 45	220 ±6 47	180 ±8 50	210 ±7 23	158 ±3 10	8 ±1 66	7 ±1 39	12 ±2 35
OCT	291 ±13 61	201 ±7 478	193 ±6 60	251 ±7 17	227 ±7 46	155 ±9 23	197 ±5 81	195 ±7.23	98 ±6 18	6 ±0 92	8 ±1 20	23 ±2 71
NOV	217 ±7 05	225 ±9.50	173 ±7 54	212 ±6 13	235 ±10.34	147 ±5 98	144 ±4 97	156 ±6 05	120 ±3 35	19 ±1 44	12 ±1 45	26 ±1 41
DEC	238 ±10.10	177 ±6 63	214 ±7.89	218 ±7.19	184 ±6.38	167 ±8 17	164 ±9 12	104 ±2 76	112 ±4 23	20 ±2 518	26 ±2 27	25 ±3 45

TABLE:14

Dimensional details of vessel lumen diameter (μm), average number of vessels per 0.5 mm^2 in the branches and length of fibres in the main trunk of <u>Acacia</u> <u>nilotica</u> growing in MDF, DDF and SF.

Month	Vessel lumen diameter			Number of vessels			Fiber length		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	63 ±2 91	54 ±3 15	53 ±2 55	19 ±1 80	14 ±1 77	15 ±2 00	1420 ±22 10	1388 ±32.07	1061 ±27 22
FEB	56 ±1.66	96 ±3 97	81 ±2 80	12 ±1.60	10 ±1 26	15 ±1 13	1431 ±29 98	1309 ±29 21	1500 ±27 77
MAR	64 ±2 84	81 ±2.83	87 ±2.95	16 ±1 93	15 ±1 78	9 ±2 11	1343 ±26.16	1457 ±24.00	1196 ±27 54
APR	92 ±3 15	82 ±3.13	81 ±3 10	8 ±1.86	12 ±1 43	15 ±1 63	1396 ±25.97	1382 ±28 96	1054 ±20 50
MAY	67 ±3 03	78 ±2.83	78 ±2.63	12 ±1.63	14 ±2 00	14 ±1 63	1154 ±7 73	1261 ±23 05	1746 ±43.14
JUN	74 ±2 86	70 ±2 96	77 ±5.73	7 ±0 89	11 ±1.62	16 ±1 82	1159 ±25 71	1426 ±17.88	1234 ±17 57
JUL	73 ±2 80	81 ±4 91	80 ±5 62	8 ±1.80	14 ±1 80	15 ±1 80	1386 ±16.19	1385 ±18 05	1330 ±27 32
AUG	71 ±2 55	83 ±3.10	66 ±5 58	9 ±1.93	11 ±1.85	15 ±2 31	1468 ±18 89	1300 ±25.00	1236 ±27 76
SEP	81 ±2 06	76 ±5.73	84 ±9.14	9 ±2.31	11 ±1.74	15 ±2.41	1398 ±22.80	1378 ±22.22	1254 ±17 87
OCT	76 ±2 11	80 ±5.44	82 ±2.10	10 ±1 70	16 ±0.28	13 ±1.87	1666 ±25.00	1503 ±20.67	1238 ±22.62
NOV	61 ±2 93	58 ±2.58	58 ±2 58	16 ±0.26	12 ±2.50	11 ±1 80	1341 ±32.62	1471 ±26.69	1257 ±28.73
DEC	83 ±2.08	55 ±2 23	64 ±3 68	12 ±1.67	14 ±1.76	13 ±2 31	1277 ±14 94	1297 ±8.38	1042 ±23.89

TABLE :15

Dimensional details of sieve tube elements (µm) in main trunk of <u>Acacia</u> <u>nilotica</u> growing in MDF , DDF and SF.

Month	MDF		DDF		SF	
	Length	Width	Length	Width	Length	Width
JAN	306 ±6.02	24 ±2.74	310 ±6.82	30 ±1.59	278 ±10.67	27 ±1.94
FEB	294 ±6.54	23 ±1.82	284 ±7.79	28 ±3.20	284 ±7.79	16 ±2.83
MAR	285 ±4.71	25 ±2.29	280 ±4.75	27 ±2.00	289 ±5.69	23 ±1.66
APR	344 ±9.69	25 ±1.89	299 ±5.74	23 ±1.73	269 ±4.47	25 ±2.00
MAY	276 ±4.90	25 ±1.80	308 ±7.05	27 ±1.73	275 ±5.82	26 ±1.70
JUN	331 ±7.00	30 ±2.65	288 ±4.59	24 ±1.74	280 ±3.82	26 ±2.50
JUL	387 ±5.84	25 ±3.94	289 ±9.75	29 ±2.21	265 ±5.09	28 ±2.46
AUG	314 ±10.22	29 ±2.94	294 ±6.11	29 ±1.83	288 ±7.12	27 ±2.19
SEP	349 ±7.63	30 ±2.12	293 ±5.14	28 ±1.84	280 ±5.06	31 ±3.78
OCT	403 ±7.69	32 ±2.84	334 ±7.18	29 ±1.84	357 ±8.25	29 ±2.73
NOV	340 ±9.40	29 ±2.20	348 ±6.42	28 ±2.18	396 ±6.98	26 ±1.68
DEC	296 ±5.66	28 ±2.63	327 ±6.97	26 ±2.83	392 ±5.31	28 ±1.80

Fig.16. A-H : Transverse section of cambium and adjacent xylem and phloem of <u>Acacia nilotica.</u>

A Dormant cambium in March surrounded by mature xylem and pholem elements in MDF. Note the anticlinally divided cells in one of the radial rows of cambial zone (arrows). X 650

B Wide cambial zone in April with actively dividing cambial cells in MDF. X 470

C Dormant cambium in May surrounded by mature xylem and phloem in MDF. Note the thick radial walls of fusiform cambial cells (arrows). X 550

D Initiation of cambial cell division in January in SF. The narrow cells in the middle of cambial zone (arrow) indicate the dividing cell. Arrow head shows differentiating vessel elements. X 294

E Dormant cambium in August surrounded by mature xylem and phloem in SF. X 310

F Initation of cell division in October. Note the fusiform cambial cell in the middle of cambial zone undgergoing swelling (arrows) which is followed by cell division (arrowhead) in SF. X 360

G Cambial zone showing newly formed thin tangential walls (arrows) in October in SF. Arrowhead indicates dividing cell with phragmoplast which is shown in the previous photograph. X 675

H Cambial zone showing loss of fusiform cambial cells (arrows) in a radial row in SF. Note the tangential expansion of cambial cells (arrowhead) due to narrowing of adjacent cells . X 600

CZ : Cambial zone, V : Vessel

Fig. 17 : Transverse (A-C) and tangential longitudinal sections (D-I) of cambium in <u>Acacia</u> <u>nilotica.</u>

A Peak activity of cambium in August in MDF. The wide cambial zone is surrounded by differentiating xylem and phloem. X 400

B Peak activity of cambium and differentiating xylem elements from cambial zone in September in DDF. X 300

C A wide cambial zone in April in SF. X 500

D Periclinally dividing fusiform cambial cell. Arrows indicate phragmoplast on either ends of cell plate. Note the origin of phragmoplast ring (arrowhead). X 775

E Newly formed thin pseudotransverse wall (arrow) in June in DDF. X 300

F Nonstoried nature of cambium in April in DDF. X 96

G Fusiform and ray cambial cells in April in SF. X 96

H Swelling of fusiform cambial cells in September in SF. X 150

I Twisting of fusiform cambial cells in DDF. X 150

CZ : Cambial zone, DP : Developing Phloem, DX : Developing xylem

Fig. 18. Tangential longitudinal (A-E) and transverse (F-I) sections of cambium, phloem and xylem of Acacia nilotica.

A Intrusive growth of fusiform cambial cell into a cambial ray. X 163

B, Fusion of cambial ray. Note the development of ray cambial cells (arrow) from fusiform cambial cell . X 163

C Loss of intervening fusiform cambial cell (arrow) between two rays. X 163

D Bending of fusiform cambial cell due to intrusive growth (arrows). X170

E A compound sieve plate (arrow) in a ray sieve element. X 800

F Xylem growthring boundary. Note the radially narrow (arrows) axial parenchyma cells. X 128

G Xylem structure in August in MDF. Note the predominantly solitary vessels. X 20

H Xylem structure in August in dry DDF. Note the density and radial multiples vessels. X 20

I Xylem structure in January in SF. Note the relatively more number of vessels compared with other two forests types. X 20

Fig. 19 · Transverse (A-F) sections of differentiating and mature xylem of <u>Acacia nilotica</u>.

A Periclinally dividing xylem mother cell. Arrows indicate phragmoplast in xylem mother cells . X 600

B A differentiating vessel. X 200

C Distribution of axial parenchyma in MDF. Note the aliform confluent parenchyma around the vessel. X 92

D Distribution of axial parenchyma in xylem of trees growing in SF. Note the vascicentue sparse parenchyma around the vessels. X 92

E Xylem fibres free of gelatinous layer in dry DDF. X 600

F Xylem with Gelatinous fibers (arrows) in SF. X 575

V : Vessel

Fig 20 · A-I : Radial longitudinal sections of cambium, xylem and phloem of <u>Acacia nilotica</u>.

A Starch free ray cambial cells in May in MDF. X 360

B Ray cambial cell devoid of starch grains in August in DDF. X 362

C Starch grains in axial ray parenchyma of phloem in MDF. Note the oval to circular shape of the starch grains. X 575

D Xylem ray parenchyma filled with fusiform shaped starch grains in MDF. X 625

E Heavy accumulation of starch in phloem ray parenchyma in May in MDF. X 157

F Distribution of starch grains in axial and ray parenchyma of xylem in May in trees growing in MDF. X116

G Starch grains in the lumen of xylem fibers in June in DDF Note theape of starch rains. X 144

H Xylem axial and ray parenchyma cells with fusiform shaped starch grains in August in MDF. X 144

I Heavy accumulation of starch in axial parenchyma of xylem in August in SF. X 157

Fig.21. A-I : Radial longitudinal sections of cambium of <u>Acacia nilotica</u>.

A Distribution of lipid bodies in ray cambial cells (arrows) in May in MDF. X 600.

B Distribution of lipid bodies in fusiform cambial cells (arrows) in May in DDF. X 540

C Distribution of lipid bodies in fusiform cambial cells (arrows) in April in SF. X 370

D Scanty distribution of lipid globules in ray cambial cells (arrows) in June in MDF. X 600

E Minute lipid globules in ray cambial cells (arrows) in August during the grand period of activity in DDF. X 540

F Distribution of protein bodies in fusiform cambial cells (arrows) in May in MDF. X 600

G Distribution of proteins (arrows) in June in DDF. Note the darkly stained phragmoplast (arrowhead). X 650

H Ray cambial cells showing minute protein bodies (arrows) in April in SF. X 700

I Scanty distribution of proteins in ray cambial cells (arrow) in May in DDF. X 650

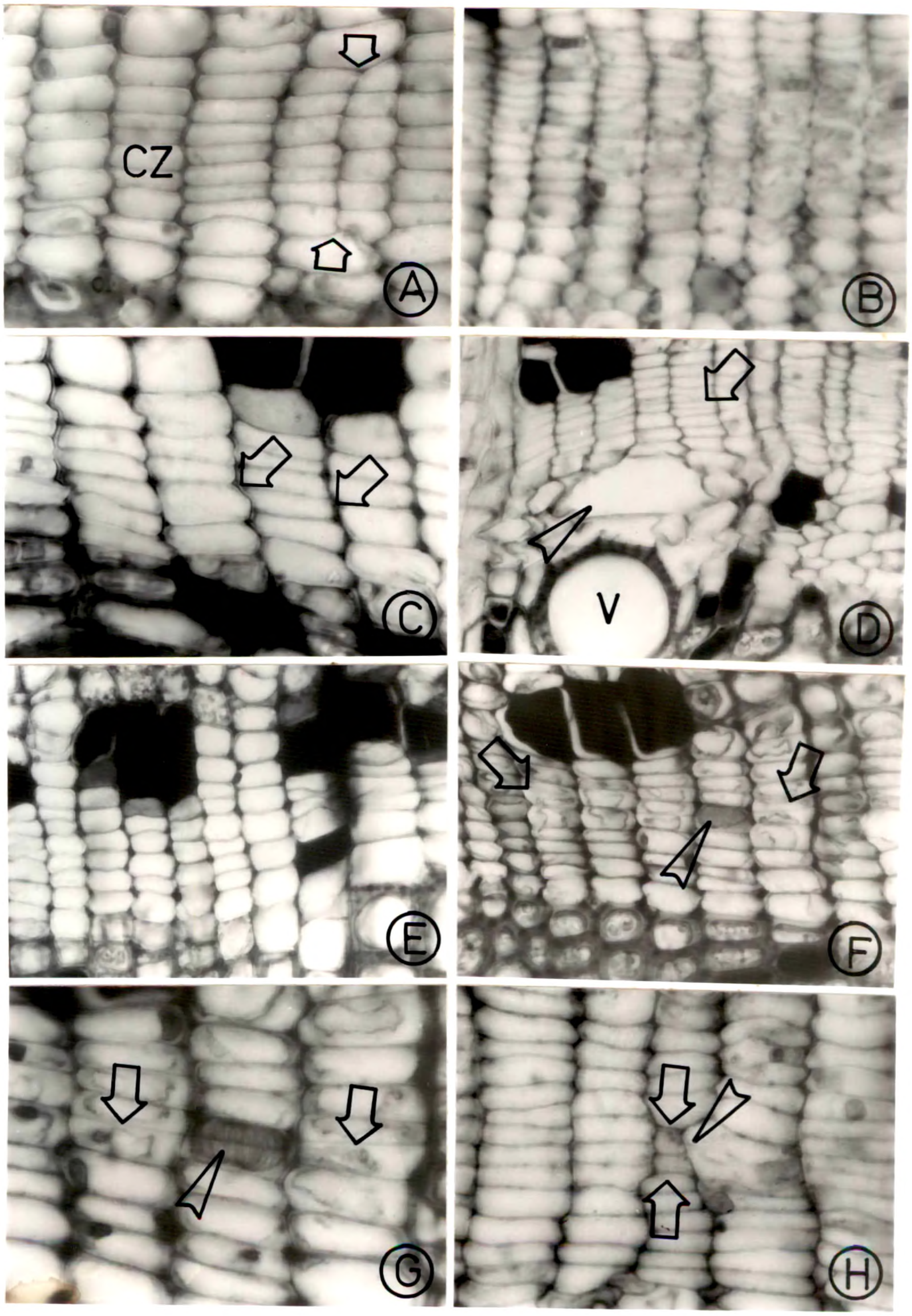


FIG. 16

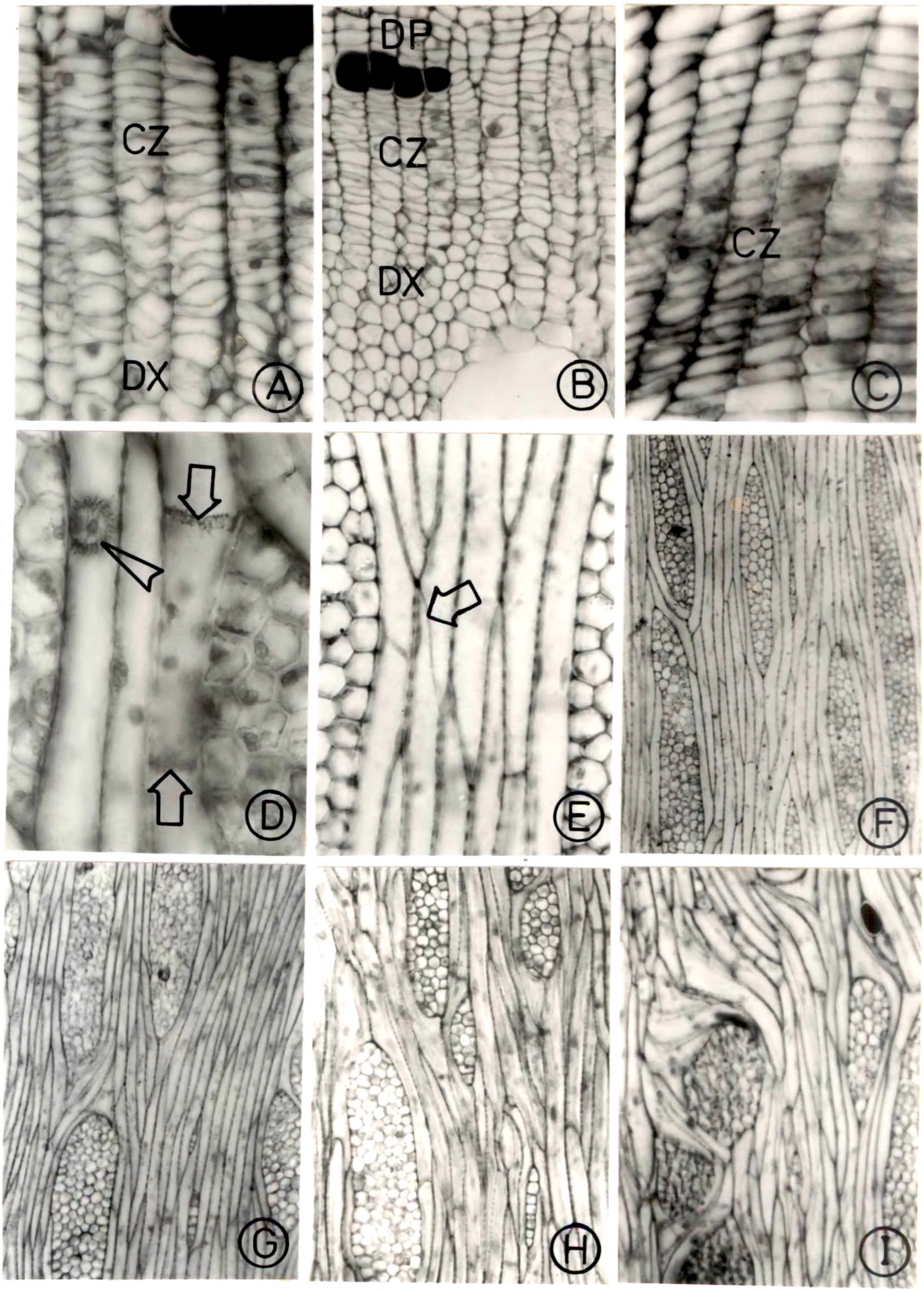


FIG. 17

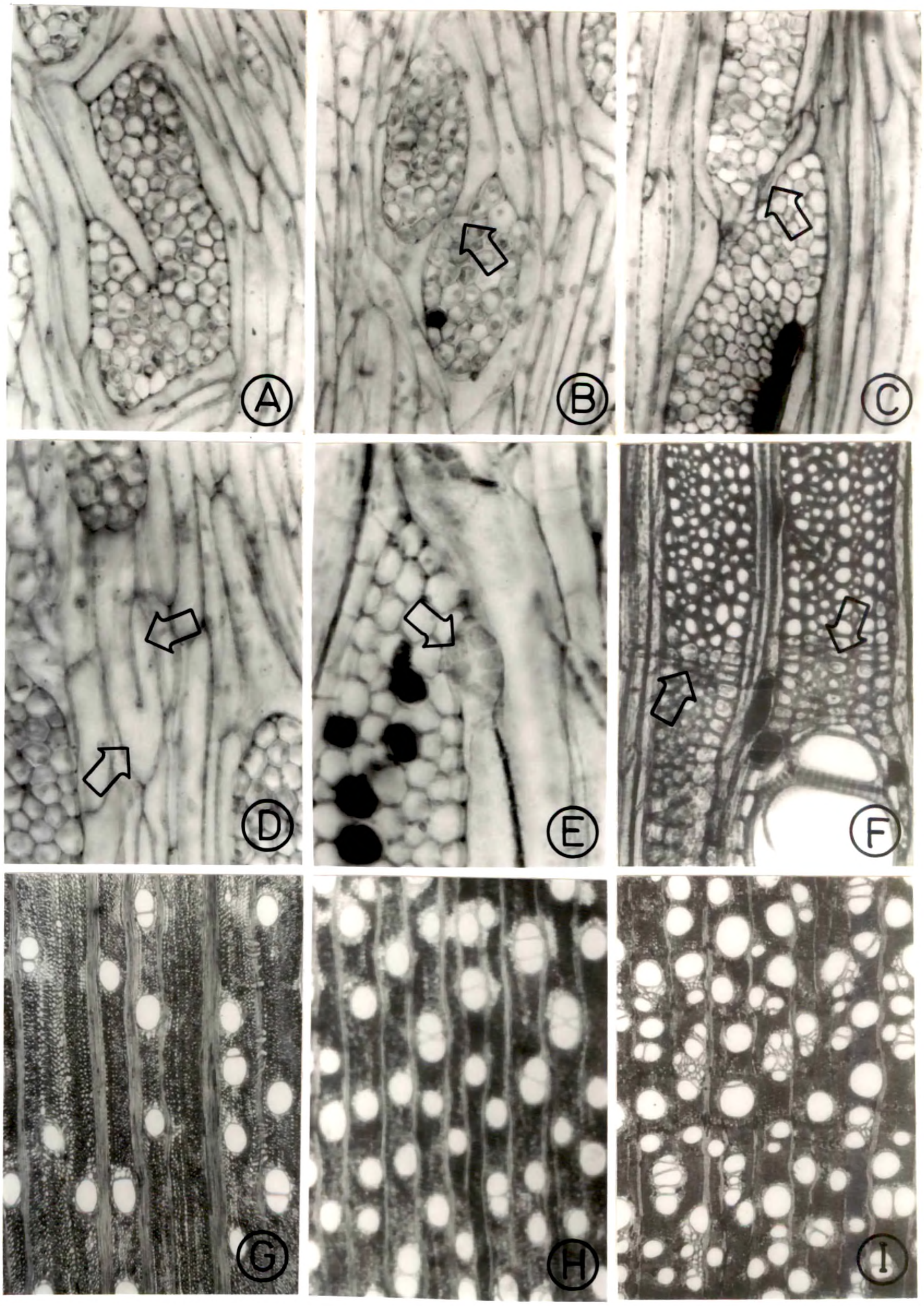


FIG. 18

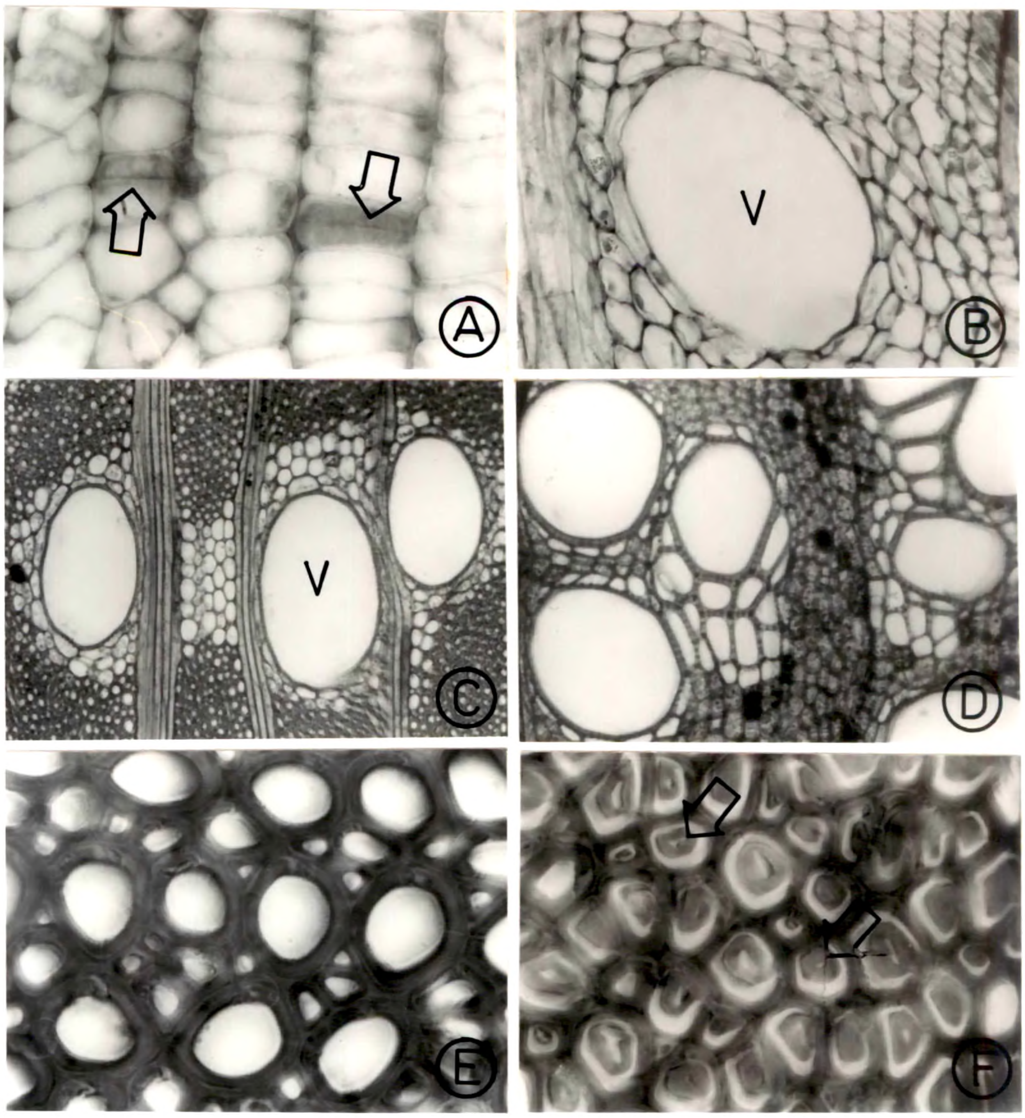


FIG. 19

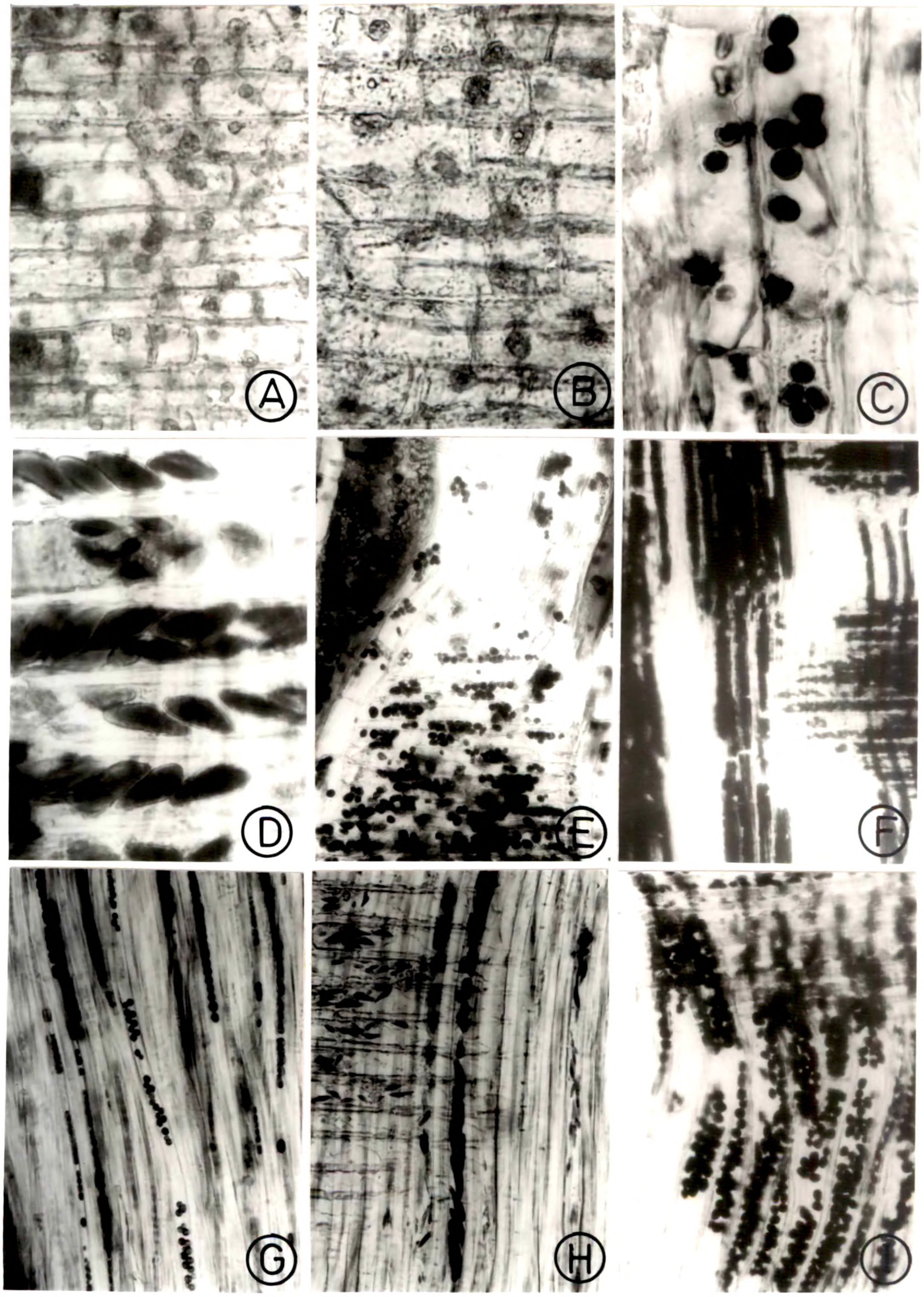


FIG. 20

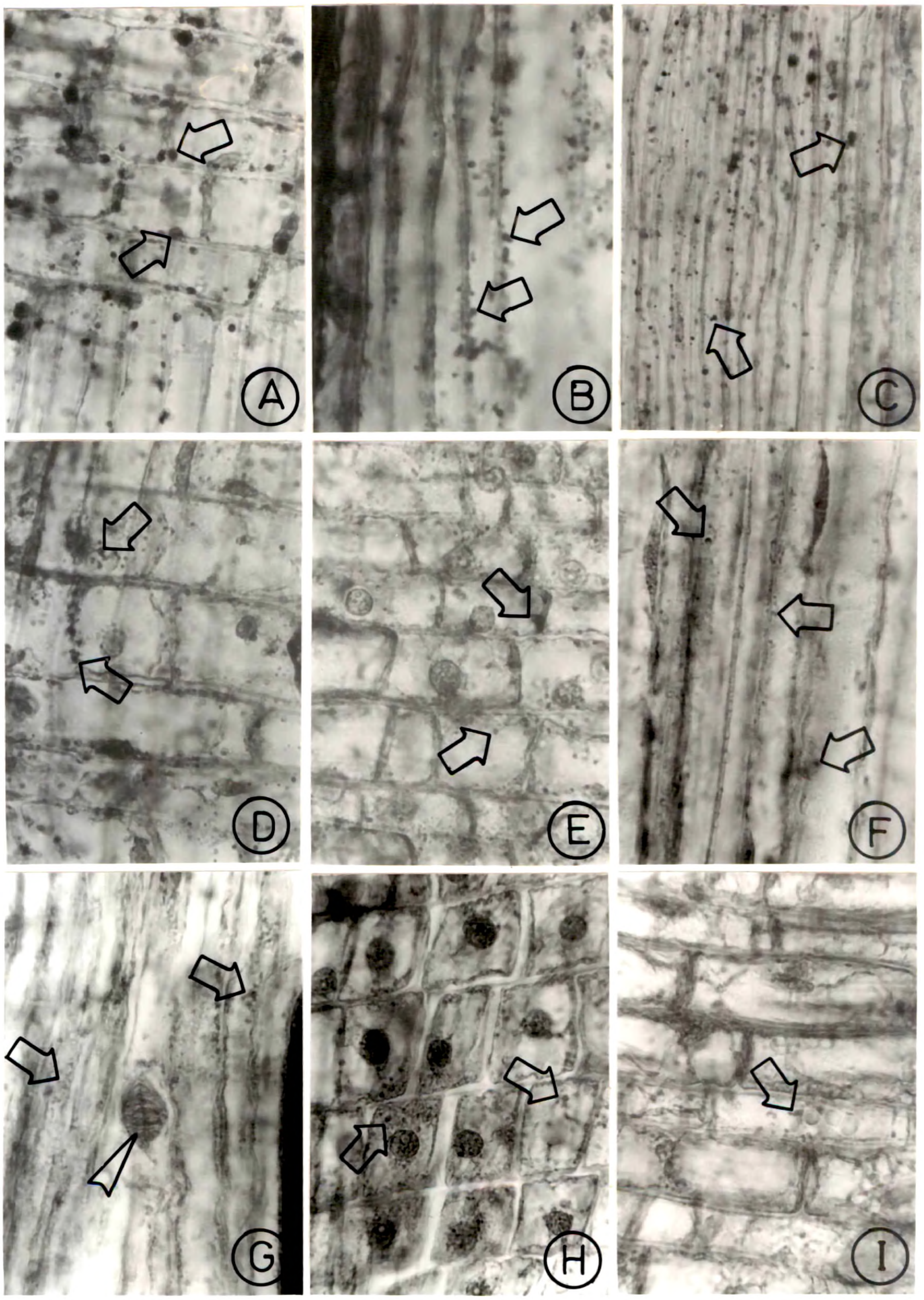


FIG. 21

Fig 22

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Acacia nilotica growing in MDF.

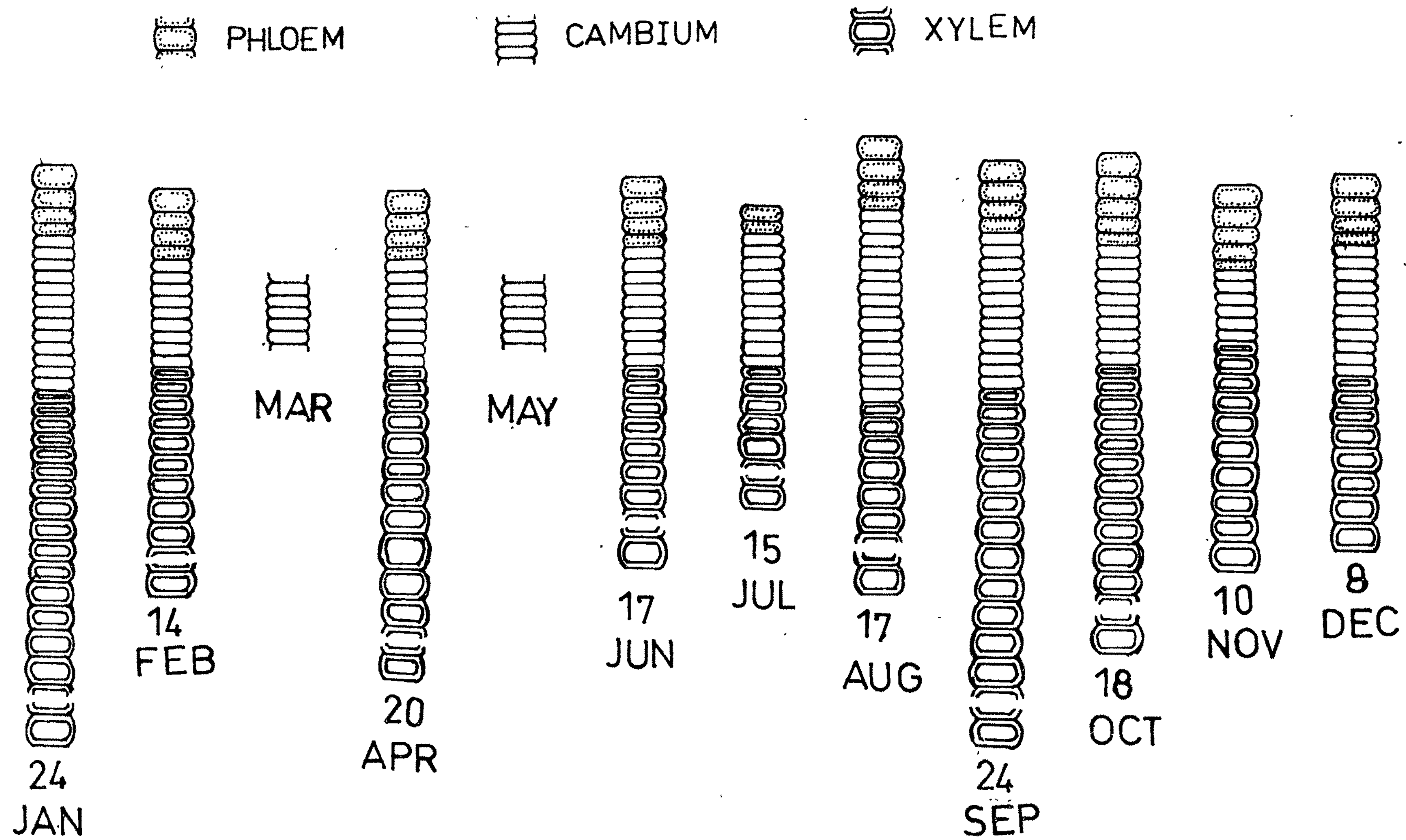

PHLOEM
CAMBIUM
XYLEM
24
JAN
14
FEB
MAR
20
APR
MAY
17
JUN
15
JUL
17
AUG
24
SEP
18
OCT
10
NOV
8
DEC

FIG. 22

Fig. 23

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of <u>Acacia</u> <u>nilotica</u> growing in DDF.

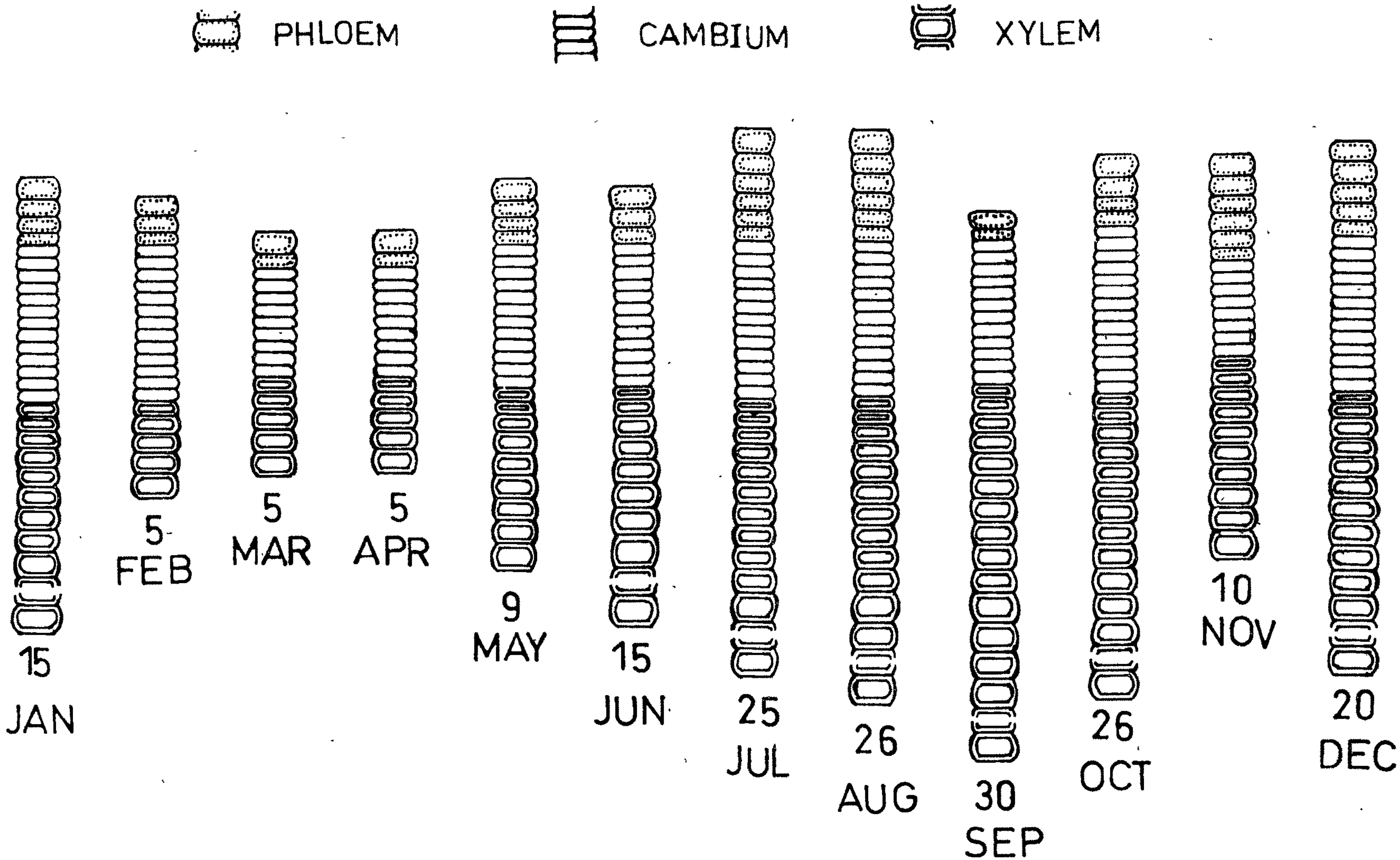

PHLOEM
CAMBIUM
XYLEM
15
JAN
5
FEB
5
MAR
5
APR
9
MAY
15
JUN
25
JUL
26
AUG
30
SEP
26
OCT
10
NOV
20
DEC

FIG. 23

Fig 24

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Acacia nilotica growing in SF.

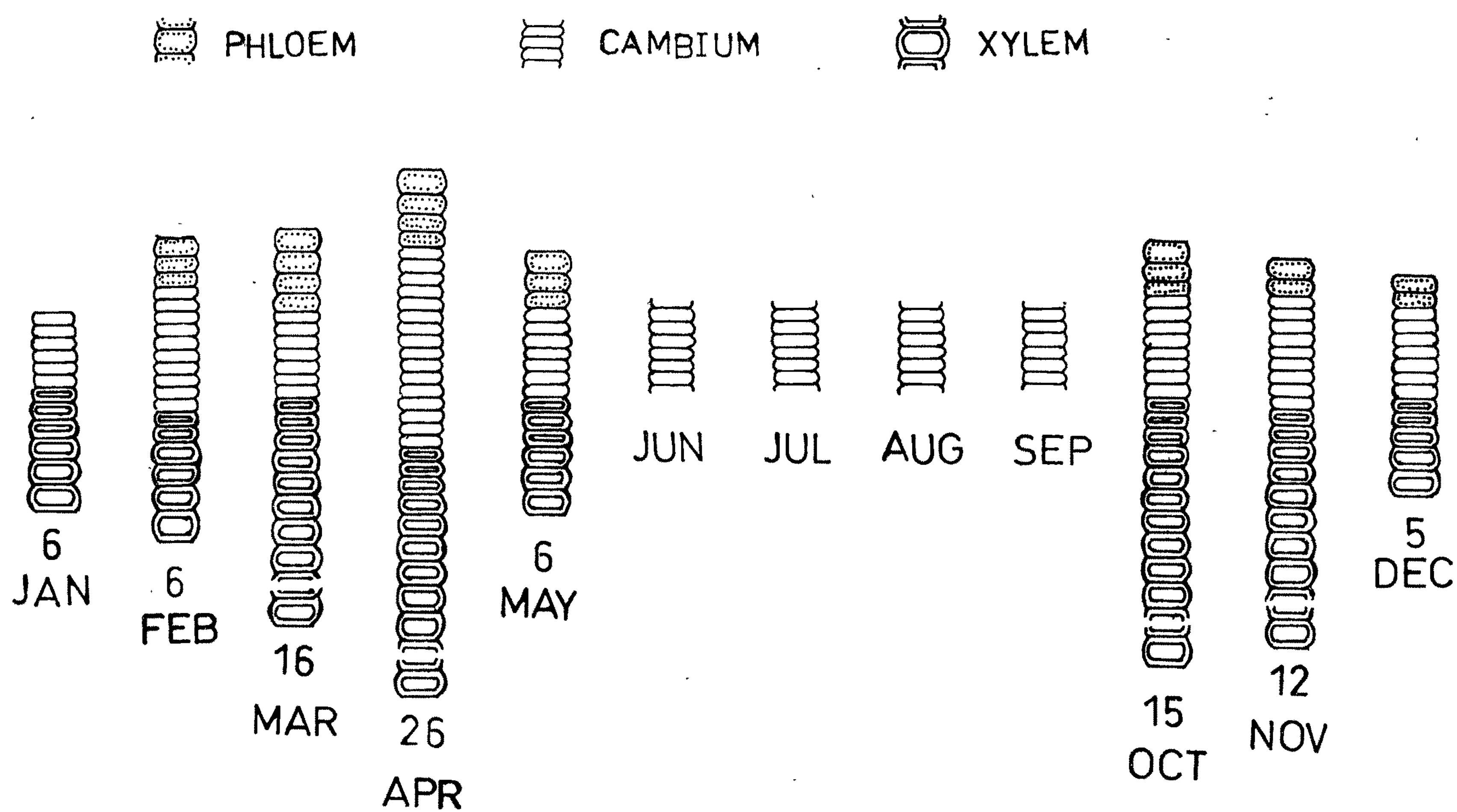

PHLOEM
CAMBIUM
XYLEM
6 JAN
6 FEB
16 MAR
26 APR
6 MAY
JUN
JUL
AUG
SEP
15 OCT
12 NOV
5 DEC

FIG. 24

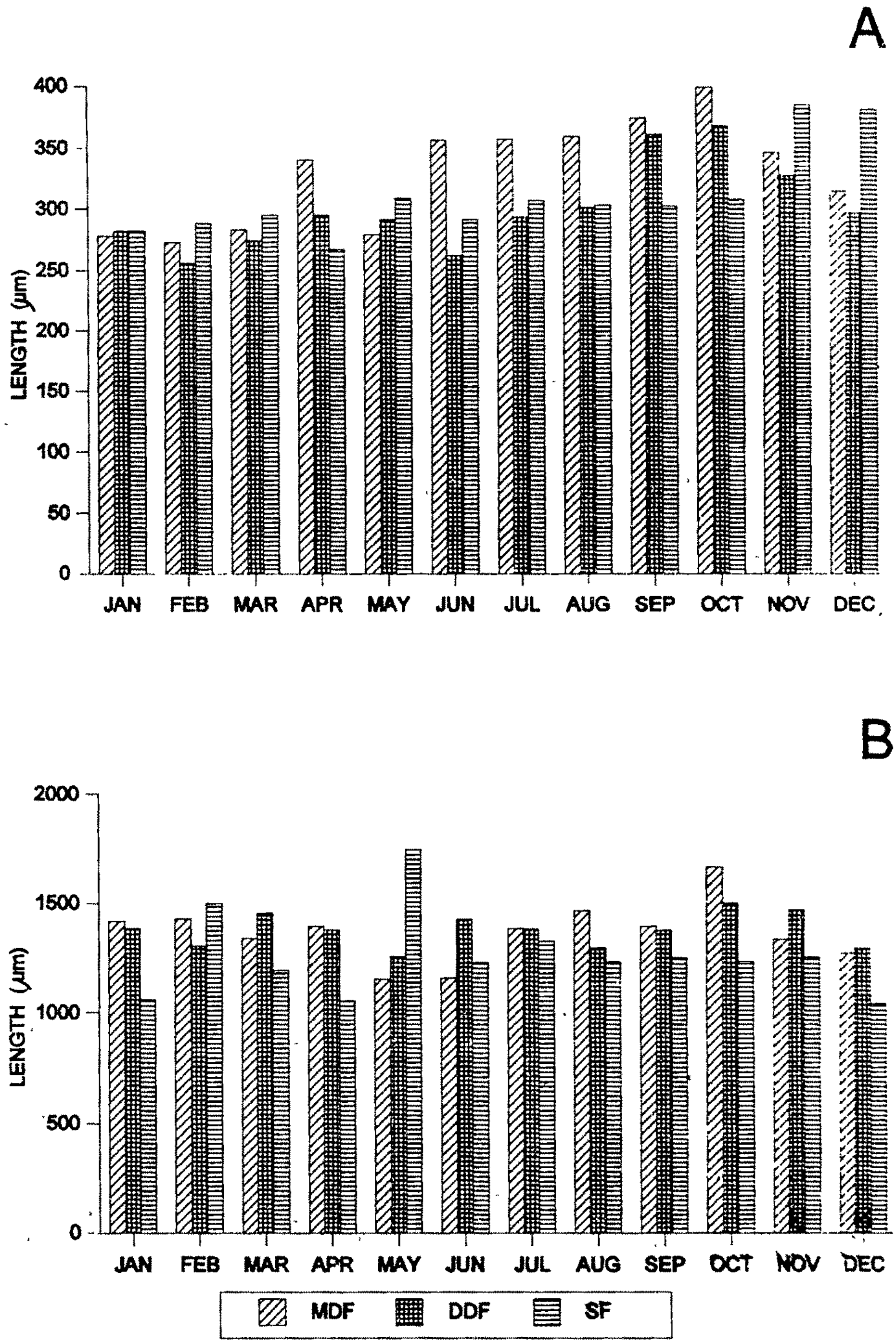


Fig. 25 Histograms showing seasonal variation in mean length of fusiform cambial cells (A) and xylem fibres (B) in Acacia nilotica.

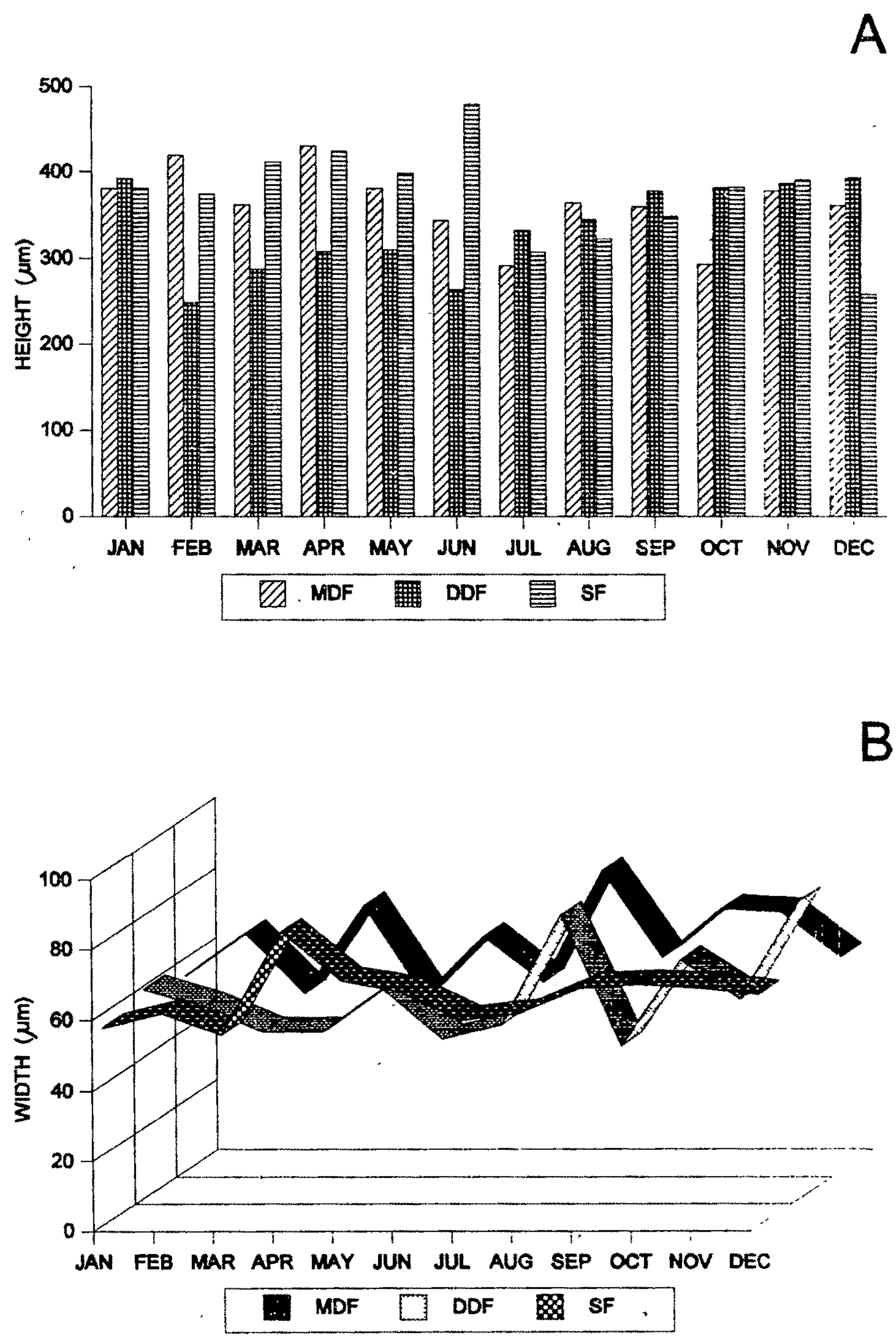


Fig. 26 Graphic representation of seasonal variation in cambial ray height (A) and ray width (B) in Acacia nilotica.

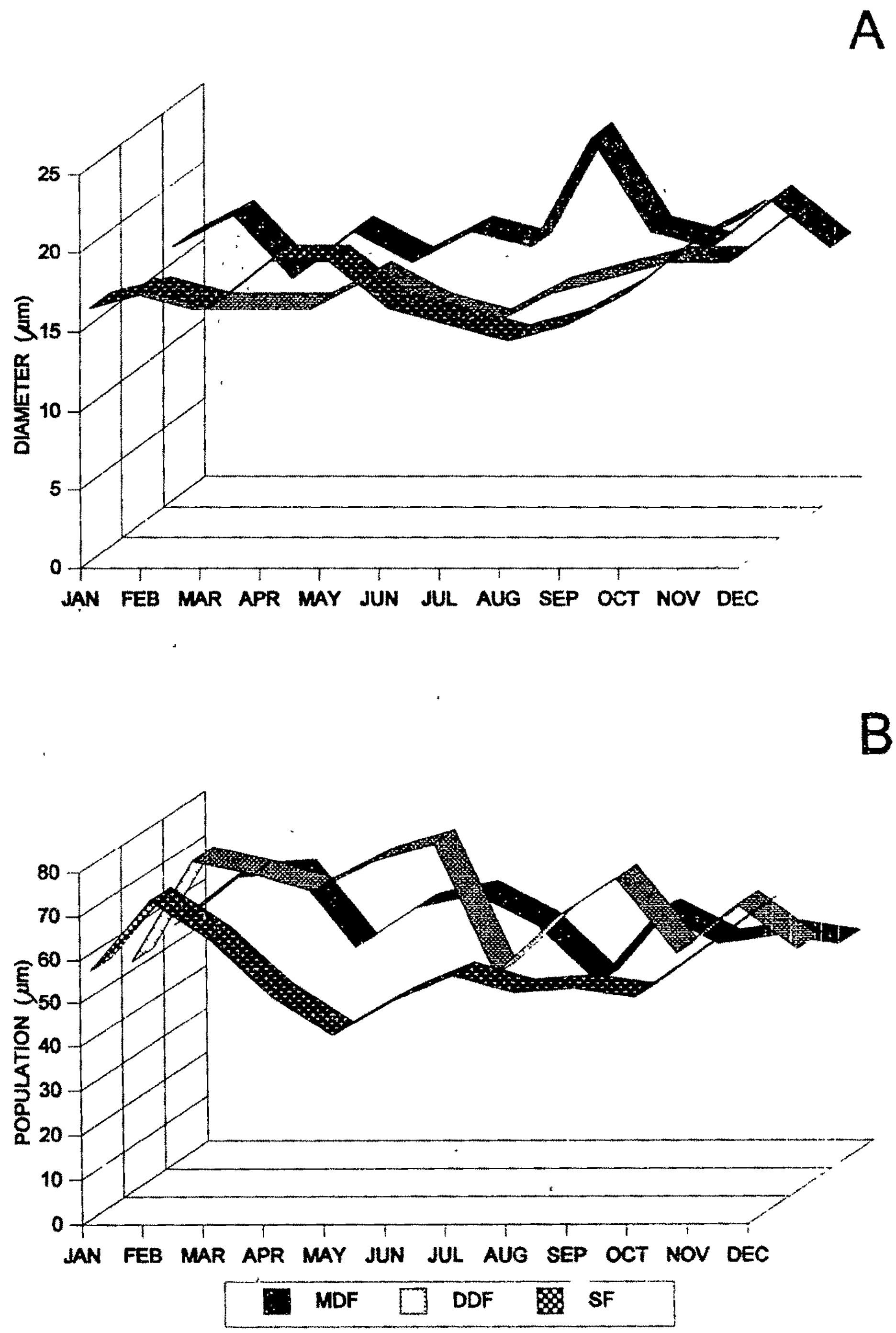


Fig. 27 Graphic representation of seasonal variation in ray cambial cell diameter (A) and ray population in 1cm tangential width of cambium (B) in Acacia nilotica.

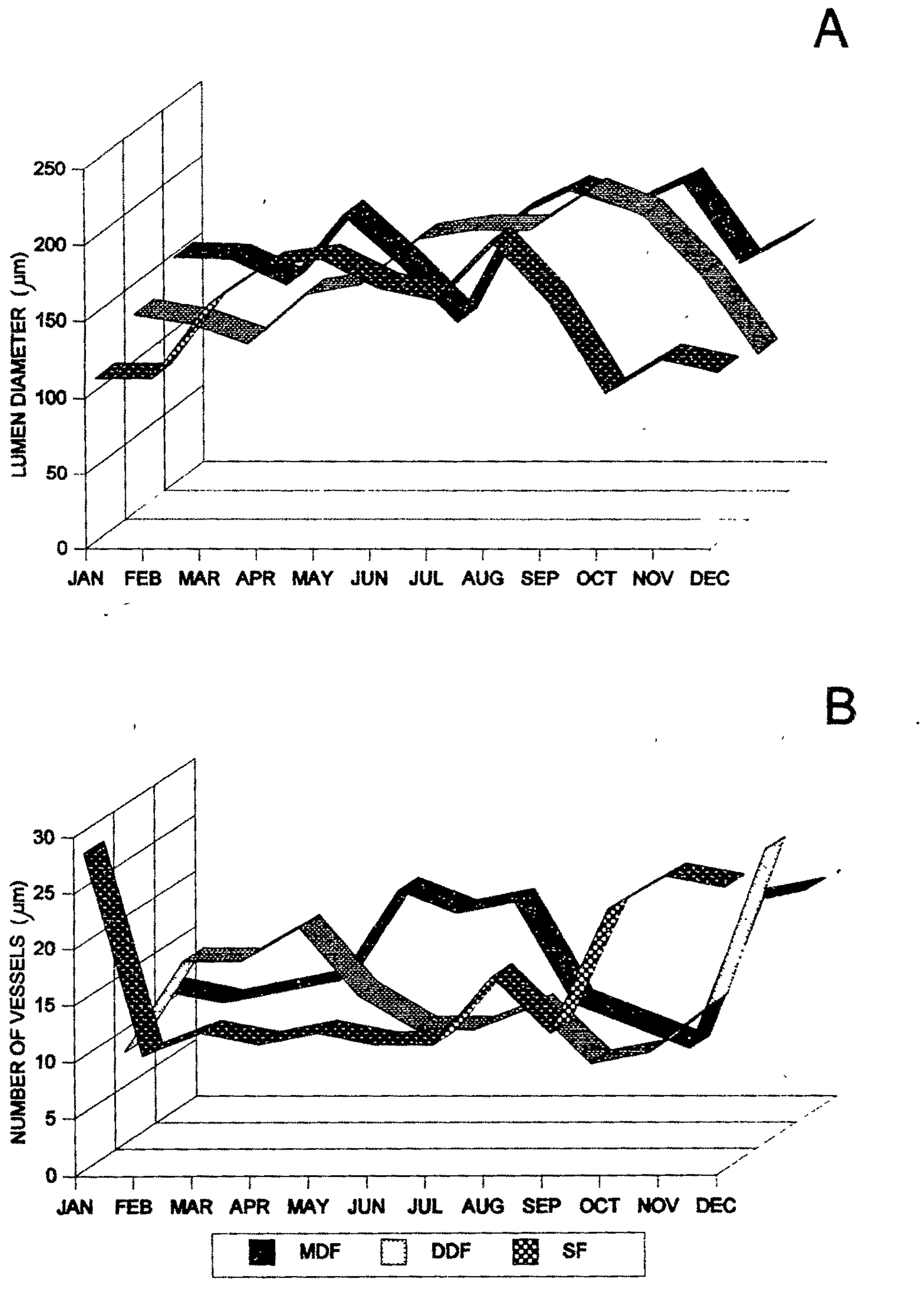


Fig. 28 Graphic representation of seasonal variation in vessel lumen diameter (A) and number of vessels per 0.5 mm2 (B) in Acacia nilotica.

<u>AZADIRACHTA</u> <u>INDICA</u> A. Juss

Family : Meliaceae

A large tree 40-50 ft. and higher with straight trunk, a broad rounded crown of dark green foliage. Leaves imparipinate 9-15 in. long, unequal sided, ovate-lanceolate, some time falcate, deep and sharply serrate, accuminate, glaborus. Flowers white with strong smell of honey, especially at night, pentamerous, short slender pedicels with shorter than leaf, bracts small, caducous, calyx small, flat with rounded, obtuse segments. Petals spathulate, obliquely imbricate in bud Anthers 10, linear, inserted opposite and below the teeth of staminal tube Ovary 3 celled. Drupe, ovoide-oblong size of olive, smooth dark yellow when ripe.

A common tree throughout the greater part of the India as far west as the Sutlej, planted or self sown but (in N.W. India) nowhere wild in the original forests. Sapwood yellowish white, heart wood red or brown, especially the inner part, fairly durable, bitter so that white ants or other insects will not touch it. Used for construction, cart building, ship building and agricultural implements. In south India it is much employed for furniture.

From the incision in the trunk near the base; made in spring issues a quantity of sap, often flowing for weeks, used as stomachic and cooling drink. A gum used as stimulant, exudes from the bark. From the fruit is extracted an acrid bitter oil (Margosa), which is deep yellow, with strong disagreeable flavour It is used medicinally, in dying, as an antiseptic and anthelmintic and is burnt in lamps. The seed is employed for washing hair and also to kill insects.

STRUCTURE OF CAMBIUM:

The cambium is nonstoried (Fig. 30D-F) with vertically elongated and randomly arranged fusiform cambial cells and horizontally arranged isodiametric ray cambial cells. The nuclei in the fusiform cambial cells are oval to oblong during active season and elongated fusiform shaped during dormant period. The radial walls of the cells are thick and beaded. The beaded walls are conspicuous due to the presence of numerous primary pit fields, when the cambium is inactive and the beaded pattern is less prominent when the cambium is active. Cambial rays are uni-multiseriate and heterocellular. However, ray cambial cells are turgid, polygonal and compactly arranged (Fig. 31I) in active cambium. When the cambium is dormant the cells become flaccid and lead to the formation of prominent intercellular spaces among the cells (Fig. 31H). Cambial zone is narrow during inactive condition (Fig. 29A) and wide when the cambium is active (Fig 29D).

CAMBIAL ACTIVITY:

Cambium of <u>Azadirachta</u> growing in MDF remains active throughout the year except for a brief spell of rest in April (Fig. 29A). Cambium is found active from January to March followed by cessation of cell division in April (Fig 29A)

Cambial cell division initiates in May (Fig. 29B, C) reaching peak in August-September with 12-19 number of cell layers in each radial file (Fig. 29D) Cell division then declines gradually in the following months. Cambial zone remains narrow with 4-8 cells in April (Fig. 29A). Periclinal divisions in the cambial zone of young branches begins in January reaching maximum in August and ceases in October. Cambium remains dormant from October to December in young branches (Table 16).

Cambial growth in DDF, occurs in two flushes. The first flush of cambial growth commences in January reaching peak in April with 9-14 layers of cells in transections. Then it declines suddenly ceasing in May. Inception of second flush of growth occurs in June reaching peak in September-October (Fig 29E) with 8-12 number of cells and ceases in November. In young branches it remains active throughout the year except in November when the cambial cell division and differentiation are found to be suspended (Table 17).

In SF, cambium remains active throughout the year. Cambium reaches peak activity in February, July (Fig. 29F) and October (Fig. 29G) with 8-14, 14-20 and 10-16 layers of cells in each radial file respectively. However, in young branches cambial cell division initiates in February reaching its vertex in June-July, declines gradually and ceases in November. Cambium is found dormant from November to January (Table 18).

Seasonal variations in the number of cambial layers in the main stem of trees growing in MDF, DDF and SF are presented in Figures 35,36 and 37 respectively.

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY

Similar to that of Acacia, Azadirachta does not shed all the leaves at a time. In all the three forests, defoliation starts first, immediately followed by sprouting of young leaves. Usually it occurs first on upper branches and spreads gradually downwards. Defoliation begins in December and by March entire old crown is replaced by new crop of young leaves. Development of floral bud occurs in March in MDF and SF while DDF it is noticed in February. In SF, second flush of flowering followed by fruit setting is encountered in June.

In MDF, cambium remains active throughout the year except in April when cell divisions are suspended in the cambial zone. Cambial cell division and differentiation of xylem and phloem tissues decline gradually in December when the leaves are completely matured and prior to yellowing of leaves and defoliation which occurs in January. Cambial cell division temporarily ceases in April when the tree beares full foliage with young leaves, flowers and fruits.

In DDF, the first flush of cambial cell division coincides with the sprouting of young leaves in January followed by flowering and development of full foliage in March. The cell division cease in November when the yellowing of leaves starts.

In SF, cambial cells divide throughout the year, even during leaf yellowing and defoliation between January to March. Cambial activity in relation to phenology of the trees growing in MDF, DDF and SF are presented in Tables 16, 17 and 18 respectively.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC CONDITIONS :

In MDF and DDF cambium is found to be dormant in April and May respectively when the air temperature is maximum of the year (MDF avg. temp. 37°C and DDF avg. temp. 40°C). Cambial cell division and differentiation of its derivatives culminate in August - September and Septmber - October in MDF and DDF respectively.

In SF, cambial cells divide continuously throughout the year, though the air temperature is maximum in May (40.3°C) compared with other two regions. Cambial growth attains peak thrice in a year i.e in February, July and October, but compared with February and October maximum activity is noticed in July when the rains have just started. However, cambial growth remains continuous throughout the year even in January when the average maximum temperature is lowest of the year (28.6°C). Fluctuations in meteorological data (maximum and minimum temperature, rainfall and relative humidity) are represented in Figures 1and 2A, B.

FUSIFORM CAMBIAL CELLS :

In all the three forests, fusiform cambial cells are axially elongated with overlaping cell tips resulting in nonstoried cambium (Fig. 30D). In transverse section, these cells are rectangular and arranged in radial files in between the xylem and phloem. Fusiform cambial cells are uninucleate with one to two nucleoli and less dense cytoplasm. The shape of the nucleus changes according to the physiological state of the cells. The nucleus is found to be oval to circular in active cells and remains eleongated and fusiform shaped in the dormant cells. In transverse section radial walls of dormant fusiform cambial cells appear thicker than those in active cambium. In tangential view beaded nature of radial walls is more conspicuous in dormant cambium due to the presence of numerous primary pit fields and it is inconspicuous with thin walls in active cambium (Fig. 30H). However, in MDF when the cambial growth is sluggish, fusiform cambial cell tips are abruptly ended with broader tip than the middle of the fusiform cambial cells (Fig. 30D). During the grand period of cambial growth, cell tips are gradually narrower and elogated (Fig. 30H). Intrusive growth of fusiform cambial cells into cambial rays (Fig. 31A) or development of ray cambial cells from fusiform cambial cells between adjacent ray leading to the fusion of cambial rays is noticed frequently throughout the cambial growth. Occasionally intrusion between the tips of neighbouring fusiform cambial cells is also observed (Fig. 31D) Some times intrusives growth of cell tips may result in the development of abnormal wall in the adjacent fusiform cambial cells (Fig. 31B). Loss (Fig. 31G) and deformation of fusiform cambial cells is also observed common throughout the year (Fig. 31C). In certain months abnormal fusiform cambial cells (Fig. 31F) are also observed in the cambium of all the three forest types.

Divisional activity:

Additive and multiplicative divisions in fusiform cambial cells leads to the radial increment of the trunk and circumferential expansion of cambial cylinder respectively (Fig. 30B, C). Periclinal division occur in the cells for major part of the year. In the telophase stage of mitosis, a fibrous structure, the phragmoplast develops in the form of ring in the center or close to the radial wall (Fig. 30A,B) of the dividing cell which extends gradually in opposite direction (Fig. 30B) towards the tips. However, width of cambial zone varies in the different months in all the three forests. Cambial zone is wider with 12-19 layers of cells in August-September in MDF, it is 9-14 layered in March and 8-12 layered in September-October during the first and second flush of cambial growth in DDF. In SF, periclinal divisions in cambial zone culminates thrice in a year i.e. 8-14, 14-20 and 10-16 layers of cells in February, July and October respectively. Along with periclinal divisions, anticlinal divisions are also encountered in the cambial zone throughout the year.

Dimensional changes:

Mean Length :

The mean length of fusiform cambial cells undergoes seasonal fluctuations. In MDF, it increases and decreases alternately from January to April (Fig 30D) and increases gradually from May to July and decreases from August to October (Table 19 and Fig. 38A). The average length of fusiform cambial cells is maximum in July (430 µm, Fig. 30H) and minimum in October (363 µm, Fig. 30G). Similar to that of MDF, in DDF, length of fusiform cambial cells increases and decreases alternately from January to June (Fig. 30E) and decreases from July to November with abrupt increase in December (Fig. 38A). The maximal and minimal length of cambial cells is encountered in July (415 µm) and November (326 µm) respectively (Table 19) while in SF, the average length decreases from January (Fig. 30F) to May and June to August (Fig. 30I) and increases from October to December with abrupt increase in September (Table 19). Length remains maximum (441 µm) and minimum (291 µm) in January and May respectively (Fig 30F, 38A). Yearly average of fusiform cambial cell length encountered maximal (394 µm) and minimal (369 µm) in MDF and SF respectively (Table 31).

Mean width:

The tangential and radial width of fusiform cambial cell do not show significant relationship with the seasonal behaviour of vascular cambium.

Tangential width is maximal (Fig. 30D) in January and May (23 µm), April (32 µm) and June (24 µm), while minimal in June (18 µm), October (21 µm), and September (20 µm) in MDF, DDF and SF respectively. It increases or decreases randomly or remain same in the intervening months in all the three forests (Table 19). The radial width of the cells remains relatively less during the peak cell division. The maximal and minimal radial width of fusiform cambial cells ranges from 4-7 µm, 5-7 µm and 5-8 µm in MDF, DDF and SF respectively. The variations in the mean width are presented in Table 19. Yearly average of tengential width measures relatively more (24 µm) in DDF compared with other two forests and radial width encountered same (6 µm) in all the three forests (Table 31).

Length variation in relation to xylem fibre length:

The average length of xylem fibres is 2.7-3.5, 3.4-3.9 and 3 6-4.7 times more than that of fusiform cambial cells in MDF, DDF and SF respectively. The mean length of fusiform cambial cells and xylem fibres is closely associated in MDF and SF (Fig. 38A,B). In DDF variation in the length of xylem fibre does not coincide with the fusiform cambial cells length (Fig. 38A,B). In MDF, length of xylem fibre increases and decreases alternately from January to March and increases from May to July. It again decreases from August to November (Table 22). However, xylem fibre length is maximal in July (1281 µm) and minimal (1006 μm) in November (Fig. 38B). In DDF, no significant correlation is observed between the length of fusiform cambial cells and xylem fibres. The length of xylem fibre increases or decreases alternately or randomly throughout the year (Table 22). It is maximal (1280 μm) in August and minimal (1122μm) in October (Fig. 38B). In SF, variations in xylem fibres length coincide with that of fusiform cambial cells throughtout the year. Fibre length decreases from January to May and June to August, while it increases from October to December (Table 22). Maximal (1368 μm) and minimal (1063 μm) length occurs in January and August respectively (Fig. 38B). Yearly average length of xylem fibre is relatively more (1235 μm) in MDF which coincides with that of fusiform cambial cells (Tables 31, 34).

RAY CAMBIAL CELLS:

Ray cambial cells are small isodiametric or radially elongated, uninucleate with 1-2 nucleoli. Cambial rays are uni-multiseriate and heterogenous with smaller procumbent and larger upright cells, but the multiseriate rays are found to be predominant. In tangential section, the ray cambial cells appear polygonal and compactly arranged (Fig., 31I), when the cambium is active. They appear oval to oblong (Fig. 31H) with intercellular air spaces when it is dormant. Fusion and splitting of cambial rays are observed in all the three forest types (Figs. 31E, 32A).

Divisional activity:

Ray cambial cells originate through the divisions of end or side of the fusiform cambial cells (Fig. 32B). The lateral anticlinal divisions may result in the origin of ray cambial cells at any position along the lateral walls. Ray cambial cells also increase in number by transverse anticlinal divisions. Biseriate rays develop through vertical or slightly oblique anticlinal divisions of ray cambial cells (Fig. 32C) in uniseriate ray cells.

Dimensional Changes

Cambial ray height:

In all the three forests, cambial ray height undergoes seasonal variations. In MDF, it increases from January to April and decreases from May to August and increases from October to December with sudden increase in September (Table 20). It's height is found maximal (323 µm) and minimal (165 µm) in September and August respectively (Fig. 39A). In DDF, the height decreases from January to March, April to August and September to December (Table 20). It remains maximum (325 µm) in September and minimum (260 µm) in August. In SF, the height increases from January to April and September to December while it decreases from May to August. However, cambial ray height is maximum (361 µm) and minimum (246 µm) in April and August respectively (Table 20. Fig

39A). The yearly average of cambial ray height is relatively maximum (298 µm) in SF and minimum (251 µm) in MDF (Table 32).

Cambial ray width:

In MDF, cambial ray width decreases from January to April, increases or decreases from May to September and increases from October to December (Table 20). Maximal width is noticed in June (70 µm) and minimal in April (53 µm, Fig. 39B). In DDF, it increases from January to March and July to October but decreases from April to June and November to December. The width remains maximal and minimal in October (84 µm) and December (47 µm) respectively. In SF, it increases from January to June and November to December and decreases from July to October. The minimal and maximal width of rays measures in January (49 µm) and December (79 µm) respectively (Table 20, Fig. 39B). The yearly average width is found relatively more (69 µm) in SF and less (61 µm) in MDF (Table 32).

Ray cambial cell diameter:

Ray cambial cell diameter increases or decreases randomly throughout the year in all the three forests (Fig. 40A). The minimum and maximum ray cell diameter is 19 µm and 27 µm in February and March in MDF, 19 µm and 23 µm in June and April in DDF and 19 µm in January-February and 25 µm in May and

September in SF respectively (Table 20). The average diameter remains same in MDF and SF (Table 32).

Cambial ray population:

The average number of rays passing for one cm tangential width of cambium ranges from 56-88, 66-96 and 59-100 during the annual growth in MDF, DDF and SF respectively (Table 20). In MDF, it increases from January to April, May to June and decreases from July to October and November-December In DDF, ray population decreases from January to March and June to December and increases in April - May, while in SF, it increases from May to August and October to December. It decreases and increases alternately in the intervening months (Fig. 40B). The yearly average of cambial ray population is found to be maximal (75) in DDF and minimal (56) in SF (Table 32).

The variations in average cambial ray height and width, average diameter of ray cambial cells and the average number of cambial rays per one cm tangential width of cambium are presented in Table 20.

DEVELOPMENT OF VASCULAR TISSUES:

Development of xylem preceds that of phloem (Fig. 29C) and phloem development ceases first followed by xylem development in MDF and DDF (Fig 29H) while in SF, the differentiation of both tissues is continuous throughout the year.

Radial growth in main trunk of Azadirachta growing in MDF starts in May culminating in August-September with 20-40 and 3-5 xylem and phloem elements respectively. Then it declines gradually and cell division ceases in April but maturation of xylem continues. However, cambial zone is found surrounded with mature xylem and phloem elements in May (Table 16). In young branches, maximal radial growth is observed in July-August which declines in the following months, ceases in April and maturation continues (Table 16).

In DDF, cell division and differentiation culminates twice. The first flush of cambial growth commences in January reaching its maxima in March-April with 9-23 xylem derivatives Xylem and phloem development remains suspended in May. Inception of xylem development during second flush takes place in June culminating in August with 10-20 and 2-4 developing xylem and phloem elements respectively and ceases in November (Table 17). Similar to main stem, in young branches also development of xylem culminates twice, in April and September (Table 17). The development of phloem remains suspended in November-December in both the main stem and young branches.

In SF, cambial cell division and development of xylem continues throughout the year. However, in December though the cambial cells divide, differentiation of xylem is not noticed. The growth of the xylem is maximal in March, July and October respectively. In young branches xylem development begins in March with maximal growth in April and July. Then it declines gradually and ceases in

November but maturation of xylem continues. Development of xylem in branches remain suspended until the initiation of cambial cell division in February (Table 18).

The phloem derivatives develop into sieve tube elements, companion cells, axial and ray parenchyma cells and fibres. Fibre bands are tangentially continuous except at phloem rays alternating with group of parenchyma cells and sieve elements (Fig. 32F). The vertically elongated narrow sieve tube elements are arranged in nonstoried manner. The endwalls of sieve tube elements are oblique to slightly transverse with compound sieve plate (Fig. 32E). The sieve areas on the lateral end walls are aggregate and linear (Fig. 32D). Each sieve element is associated with a single companion cell. Development of new sieve elements is followed by deposition of callose in older elements. Annual increment of phloem can be identified by phloem ray noding and obliteration of sieve elements produced in the begining of cambial activity (Fig. 32F).

Development, length and width of sieve elements:

During the course of development phloem mother cell undergoes periclinal division, elongation or may directly differentiate into a sieve element. However, in some months length of sieve tube elements is found to be more compared with that of fusiform cambial cells. Variations in the length of sieve tube elements and fusiform cambial cells do not show any significant correlation in the trees of all the three forests (Table 23).

In MDF, length of sieve tube element in March and October exceeds than that of fusiform cambial cells while in remaining months it is slightly less. Length decreases from March to June and increases from August to October. It increases or decreases in intervening months. Sieve tube element length remains minimal (327 μm) and maximal (400 μm) in February and April respectively (Table 23)

In DDF, sieve tube element length exceeds in June and November to that of fusiform cambial cells and found shorter than the cambial cells in rest of the months. The length of the sieve tube elements decreases from January to April and increases from August to November. In the remaining months the length increases or decreases randomly. However, minimal (331 μm) and maximal (408 μm) length is noticed in April and November respectively (Table 23).

In SF, length of the sieve tube elements exceeds that of fusiform cambial cells from April to October while it remains shorter than cambial cells in remaining months. It increases from February to April and May to July while increases and decreases in remaining months. However, maximal and minimal length is found in January (427 μm) and May (342 μm) respectively (Table 23).

Sieve elements in phloem rays:

Radially arranged sieve tube elements are noticed either solitary or in groups of 2-5 in uniseriate as well as multiseriate rays of secondary phloem (Fig. 32D). They are short and each one is associated with single companion cell. They have either simple or compound sieve plate on transverse to slightly oblique end walls. The structure and behaviour of these ray sieve elements are similar to that of axial sieve elements. Massive deposition of callose, obliteration and loss of cell contents are also noticed in ray sieve elements. These also showed accumulation of slime (p-protein) plugs against the sieve plate, cytoplasmic strands but no sieve areas are noticed on their lateral walls. The diameter of these elements was relatively more than that of adjacent ray parenchyma (Fig. 32D). Though they are observed in both uniseriate and multiseriate rays., They occur only at the extreme radial ends or at the margin of rays.

Development, Length and width of vessel elements:

Cambial derivatives towards xylem develop into vessel elements, fibres, axial and ray parenchyma. Xylem is diffuse porous with solitary or radial multiple vessels (Fig. 32I). Vessels are dispersed between the xylem fibres and axial parenchyma. Occurrence of tyloses in vessels is common. Vessel elements are elongated with oblique to transverse end walls and short tail with alternate bordered pits. Fibres are nonseptate and show thick lignin deposition in the inner secondary wall layers. Axial parenchyma are vascicentric and aliform to confluent (Fig. 32H). The developing vessel elements enlarge both radially and tagentially before the deposition of secondary wall (Fig. 32G). The mean length of vessel elements doesn't show any significant correlation with that of fusiform cambial cells. In MDF, vessel elements length decreases from February to June and July to

October. The minimal (229 μm) and maximal (311 μm) length occur in June and July respectively (Table 21). In DDF, the length decreases from January to April and increases from May to July and October to December and found fluctuating in the intervening months. Maximal (307 μm) and minimal (249 μm) length is noticed in July and October respectively. In SF, similar to that of DDF, it decreases from January to April. Length increases from May to July and August to November. It is maximal (306 μm) in January and minimal (232 μm) in December (Table 21). The yearly average mean length is maximal (275 μm) in DDF and minimal (253 μm) in SF (Table 33).

Compared with fusiform cambial cell vessel elements width increases 9-12, 9-13 and 7-11 times in MDF, DDF and SF respectively (Table 21). In MDF, it increases and decreases randomly throughout the year and is found maximal (259 μm) in March and minimal (175 μm) in September (Table 21). In DDF, it increases from January to April, May to July and increases and decreases alternately in rest of the months. The width is encountered minimal (199 μm) and maximal (273 μm) in August and September respectively (Table 21). In SF, width increase from January to March, April to June and July to September. It increases and decreases from October to December, and noticed maximal (230 μm) in June and minimal (151 μm) in July (Table 21). Yearly average width remains relatively more (241μm) in DDF as compared with other two forest types (Table 33).

Vessel lumen diameter :

Similar to that of vessel elements width, its lumen diameter doesn't show correlation with the cambial activity (Table 21). However, it is found maximal in July (170 μm), in October (176 μm) and July (193 μm) in MDF, DDF and SF respectively while minimal in November (113 μm), April (136 μm) and November (115 μm) in MDF, DDF and SF respectively (Fig. 41A). The variation in vessel lumen diameter is presented in Table 21. Yearly average lumen diameter is found maximal (150 μm) in DDF compared with other two forest types (Table 33).

Number of Vessels :

The number of vesels per 0.5 mm^2 of xylem ranges from 10-20 in MDF, 5-20 in DDF and 6-22 in SF (Table 21) while no relation exists between cambial activity and vessel frequency throughout the year in all the three forests (Fig. 41B) However, yearly average of vessel frequency is noticed maximal in MDF and minimal in SF (Table 33).

Growth ring width :

Growth rings in the xylem are discernible under the microscope. Growth ring boundary could be easily discerned by large lumen, initial axial parenchyma and ray noding pattern (Fig. 32H). The amount of annual xylem increment in two successive years (1993-1994) is 6.00 mm and 5.3 mm in MDF, 8.00 mm and 6.00 in DDF and 8.4 mm and 8.2 mm in SF.

HISTOCHEMISTRY

Starch

Strach grains are simple and spherical or oval and found only in ray cambial cells. Unlike Acacia no variation in the shape of starch grains is observed in Azadirachta growing in all the forest types. Ray cambial cells are found free of starch grains in April (Fig. 33A) in MDF and in May in DDF when the cambium is dormant. Group of 2-8 starch grains appear in all the three forests and their size and stainability increases in the following months. During the active period starch distribution remains same in all the three forests (Fig. 33B).

In MDF, starch is distributed in axial and ray paranchyma of xylem and only in axial parenchyma of phloem in January. Abruptly in February heavy deposition of starch is encountered in parenchyma cells of xylem and phloem. The depletion of starch begins in the succeeding months and by June it remains restricted to xylem ray parenchyma which are away from cambial zone. Similarly sudden accumulation of abundant starch is observed in July in cambial rays, axial and ray parenchyma of xylem and phloem. Then in the following months its depsoition declines and observed only in axial parenchyma away from cambial zone (Fig. 33E).

In DDF, starch is observed in axial and ray parenchyma of phloem in January. It decreases gradually in the following months and by April parenchyma of both, xylem and phloem are found completely devoid of starch. In phloem it accumulates near the sieve plate (Fig. 33 C). Distribution of starch remains same until August (Fig. 33 G). With the decline of cambial activity from September onwards it increases (Fig. 33 I) and by December axial and ray parenchyma of xylem and phloem are completely filled with starch grains.

In SF, January month showed heavy deposition of starch in parenchyma of both xylem and phloem. However, depletion of starch begins in phloem from February onwards. Starch accumulation is heavy between March and May (Fig. 33D) in parenchyma cells of xylem and phloem. In June, starch accumulates heavily in xylem and phloem. The depletion starts from July until November (Fig. 33 F,H) and remains restricted to parenchyma of xylem and phloem away from cambial zone. In December, starch in phloem parenchyma away from cambial zone diminishes and observed only in parenchyma cells close to the cambial zone

Lipids :

Lipids occur as a small globules in both the cambial cells. The globules are uniformly distributed along the cell walls and in the cell lumen during dormant condition. They rarely appear as minute globules around nucleus. Cambial cells and its derivatives contain lipids in all the months but their size and distribution vary with the seasonal activity of cambium.

In Azadirachta growing in MDF, cambial cells are rich with lipid globules in April (Fig. 34A) when the cell divisions are suspended. The distribution and size of globules decrease gradually with the initiation of cambial activity and diminishes completely in August and September when the cell divisions are maximal (Fig. 34D). Lipid glopbules increase concomitantly with the decline of cambial activity.

Cambial cells in DDF, are rich with lipid bodies (Fig. 34B) when the cambium is dormant in May and December. The increase and decrease of lipid distribution during cambial cell divisions coincide with that of MDF.

In SF, the deposition of lipid markedly decreases in the cambial cells (Fig. 34 C,E) when the divisions are active but they are prominent following the decline in the rate of cell division. In all the three forests, distribution of lipid globules is found similar during the period of maximal cell divisions.

Proteins:

Distribution of proteins in cambial cells remain similar to that of Acacia. Protein occurs as minute globules in cell lumen, along the cell walls and around nucleus of both the fusiform and ray cambial cells in all the three forests. Darkly stained protein granules are conspicuous in cambial cells of MDF (Fig. 34G) and DDF (Fig. 34F) when the cambium is dormant. However, protein deposition declines with initiation of cambial cell divisions from June onwards in all the three forests. Protein distribution is more in ray cambial cells compared to that of fusiform cambial cells. Distribution of protein increases with the delcline of cambial activity (Fig. 34H). Differentiating and mature vascular elements contain negligible amount of protein bodies (Fig. 34 I).

TABLE : 16

Data on phenology, average number of cambial layers and differentiating xylem and phloem elements in the main trunk and branches of Azadirachta indica growing in MDF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Leaf yellowing , defoliation terminal bud active	5 ±1.93	4 ±0.82	10 ±1.49	-	-	-
FEB	Defoliation, sprouting of new leaves .	9 ±1.30	4 ±0.78	9 ±1.12	4 ±1.61	2 ±0.75	-
MAR	Sprouting of new leaves, flowering.	10 ±1.70	3 ±0.97	5 ±0.79	6 ±1.30	-	2 ±0.72
APR	Sprouting, maturation of new leaves, flowering, fruit setting.	8 ±1.11	4 ±0.05	7 ±1.57	4 ±0.68	2 ±0.60	2 ±61
MAY	Sprouting, maturation of new leaves, flowering, fruit maturation.	5 ±0.78	4 ±0.65	-	-	-	-
JUN	Sprouting, maturation of new leaves, flowering, fruit dispersal	10 ±1.56	5 ±0.64	8 ±1.38	6 ±0.83	3 ±0.82	2 ±0.86
JUL	Full foliage, terminal bud active.	10 ±1.32	6 ±0.70	20 ±2.38	12 ±1.61	4 ±1.05	2 ±0.58
AUG	Full foliage, terminal bud active	12 ±1.69	6 ±0.35	28 ±3.72	10 ±1.28	4 ±1 10	-
SEP	Full foliage, terminal bud dormant.	16 ±2.51	4 ±0.85	32 ±3.11	8 ±1.38	4 ±0.89	-
OCT	Full foliage with mature leaves, terminal bud dormant.	8 ±1.12	5 ±0.89	20 ±2.00	6 ±1.49	3 ±1.03	-
NOV	Full foliage with mature leaves, terminal bud dormant	9 ±1.16	5 ±0.78	9 ±1.37	4 ±0.38	2 ±0.50	2 ±0.70
DEC	Full foliage with mature leaves; terminal bud dormant.	7 ±1.10	5 ±0.73	8 ±1.33	-	2 ±0.50	-

TABLE : 17

Data on phenology, average number of cambial layers and differentiating xylem and phloem elements in the main trunk and branches of Azadirachta indica growing in DDF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Partial leaf fall, sprouting of new leaves.	8 ±1.95	5 ±0.82	9 ±1.61	7 ±1.30	3 ±0.96	2 ±0 68
FEB	Sprouting of new leaves, flower buds.	7 ±1.69	6 ±0.69	10 ±3.00	6 ±1.18	3 ±0.73	3 ±0.83
MAR	Full foliage, flowering, fruit setting.	8 ±1.91	6 ±0.90	9 ±1.98	8 ±2.43	3 ±0.64	3 ±0.82
APR	Full foliage, maturation of fruits.	10 ±2.27	5 ±0.16	17 ±3.43	12 ±3.15	3 ±0.94	3 ±0.80
MAY	Full foliage, maturation dispersal of fruits.	6 ±1.32	6 ±1.10	-	8 ±1.62	-	-
JUN	Full foliage, dispersal of fruits.	8 ±1.67	6 ±1.44	3 ±1.17	5 ±1.12	2 ±1.23	2 ±1.09
JUL	Full foliage, terminal bud active.	7 ±0.75	7 ±0.99	9 ±1.52	10 ±2.15	3 ±0.78	3 ±0.87
AUG	Full foliage, flowering in some branches, terminal bud active.	9 ±1.45	6 ±0.84	15 ±2.87	9 ±1.68	3 ±0.77	2 ±0.81
SEP	Full foliage, terminal bud dormant.	9 ±1.63	6 ±0.84	9 ±1.50	12 ±2.05	2 ±0.50	2 ±0 80
OCT	Full foliage , yellowing of leaves.	14 ±2.68	4 ±0.82	12 ±1.92	11 ±1.75	3 ±0.70	2 ±0.72
NOV	Yellowing of leaves, initiation of defoliation , sprouting of new leaves.	8 ±1.32	4 ±0.50	-	-	-	-
DEC	Defoliation, sprouting of new leaves	5 ±0.72	6 ±1.42	-	5 ±1.00	-	-

TABLE : 18

Data on phenology, average number of cambial layers and differentiating xylem and phloem elements in main trunk and branches of Azadirachta indica growing in SF.

Month	Phenology	Cambial layers		Xylem		Phloem	
		Stem	Branch	Stem	Branch	Stem	Branch
JAN	Yellowing of leaves, initiation of defoliation.	8 ±0.72	4 ±0.75	5 ±0.83	-	2 ±1.10	-
FEB	Partial defoliation , sprouting of new leaves,flowering	10 ±0.74	5 ±0.69	10 ±0.88	-	2 ±0.92	-
MAR	Sprouting of new leaves, flowering, fruit setting.	9 ±1.50	5 ±0.98	16 ±1.67	9 ±1.37	3 ±0.77	-
APR	Sprouting of new leaves flowering , fruit setting.	9 ±1.35	6 ±0.63	13 ±1.54	10 ±1.50	3 ±0.73	2 ±0.72
MAY	Maturation of leaves , fruits.	11 ±1.98	5 ±1.03	8 ±1.11	4 ±0.73	2 ±0.68	2 ±0.59
JUN	Full foliage, fruit dispersal, Folwer buds development.	12 ±1.35	5 ±0.72	15 ±2.54	5 ±0.94	4 ±0.79	2 ±0.60
JUL	Full foliage, fruit setting.	17 ±2.30	7 ±1.00	25 ±2.38	12 ±1.55	5 ±0.96	3 ±0.90
AUG	Full foliage, fruit setting.	10 ±1.63	6 ±0.81	18 ±1.51	6 ±0.75	3 ±0.79	2 ±0.67
SEP	Full foliage,maturation of fruits, terminal bud dormant.	12 ±1.74	4 ±0.66	16 ±2.34	5 ±0.60	4 ±0.75	2 ±0 75
OCT	Full foliage, terminal bud dormant,	14 ±1.32	4 ±0.75	26 ±2.34	5 ±1.13	4 ±0.76	2 ±0.50
NOV	Full foliage, terminal bud dormant.	10 ±2.00	5 ±0.61	13 ±2.87	4 ±1.39	3 ±0.66	3 ±0 58
DEC	Full foliage, terminal bud dormant	11 ±2.17	4 ±0.83	8 ±2.19	-	4 ±0.63	-

TABLE : 19

Dimensional details of fusiform cambial cells (μm) in the main trunk of Azadirachta indica growing in MDF, DDF and SF.

Month	Length			Tangential width			Radial width		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	383 ±1.45	388 ±11.16	441 ±6.50	23 ±1.73	22 1.78	23 ±1.69	7 ±0.486	6 ±1.93	8 ±0.72
FEB	372 ±7.04	361 ±10.87	429 ±12.13	20 ±2.53	25 ±2.32	22 ±2.00	6 ±0.78	5 ±1.69	5 ±0.50
MAR	389 ±10.77	380 ±9.60	386 ±8.64	20 ±2.55	25 ±2.37	21 ±2.14	5 ±0.20	5 ±0.45	6 ±0 48
APR	403 ±8.63	339 ±7.15	361 ±9.96	22 ±2.29	32 ±3.71	21 ±2.70	7 ±0.50	6 ±0.46	6 ±0.50
MAY	392 ±1.79	412 ±10.26	291 ±9.68	23 ±2.09	24 ±2.98	23 ±1.98	7 ±0.65	7 ±0.46	5 ±0.36
JUN	403 ±7.14	351 ±6.37	358 ±8.81	18 ±2.41	24 ±2.62	24 ±2.83	6 ±0.63	5 ±0.49	5 ±0.48
JUL	430 ±9.11	415 ±8.77	349 ±12.89	22 ±2.09	22 ±2.36	23 ±2.94	4 ±0.52	6 ±0.50	5 ±0.20
AUG	418 ±10.31	400 ±10.12	343 ±8.63	21 ±2.11	25 ±2.34	22 ±2.93	5 ±0.35	6 ±0.45	5 ±0.50
SEP	380 ±8.53	398 ±9.30	372 ±6.90	22 ±2.56	22 ±1.70	20 ±2.56	4 ±0.47	5 ±0.15	6 ±0.41
OCT	363 ±9.19	384 ±12.75	339 ±8.67	19 ±1.86	21 ±1.56	21 ±1.62	5 ±0.53	5 ±0.47	7 ±0.46
NOV	402 ±7.67	326 ±9.73	373 ±7.80	21 ±1.83	22 ±1.63	21 ±2.38	5 ±0.74	7 ±0 64	6 ±0 70
DEC	368 ±8.05	410 ±6.00	393 ±8.25	20 ±2.12	23 ±2.41	21 ±2.56	6 ±0.37	7 ±0.45	5 ±0.45

TABLE . 20

Dimensional details of cambial rays (m) and their population in 1 cm tangential width of cambium in the main trunk of <u>Azadirachta</u> <u>indica</u> growing in MDF, DDF and SF.

Month	Height			Width			Ray cell diameter			Ray population		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	214 ±13 00	283 ±8 22	281 ±8 42	61 ±1 43	62 ±1 74	49 ±1 70	22 ±2 85	21 ±1 91	19 ±2 74	60 ±21 53	72 ±19 12	82 ±23 58
FEB	225 ±7 93	273 ±11 73	295 ±10 65	60 ±1 18	64 ±1 78	52 ±1.10	19 ±2 33	20 ±2 63	19 ±1 98	80 ±24.28	70 ±27 69	74 ±24 94
MAR	260 ±9.40	263 ±10 68	342 ±7 08	56 ±1.31	74 ±1 64	66 ±1.05	27 ±2 58	20 ±3 58	22 ±2.76	86 ±20.61	66 ±21 21	100 ±22 30
APR	308 ±15.06	292 ±12.99	361 ±9 86	53 ±0.95	65 ±1 57	68 ±1 39	21 ±1.83	23 ±2 12	22 ±2.28	88 ±21 31	70 ±31 11	74 ±32.52
MAY	255 ±11 46	288 ±5.52	298 ±12 81	55 ±1 78	62 ±1 50	70 ±2 58	20 ±2 14	20 ±2 05	25 ±2.30	80 ±21 92	80 ±32 23	59 ±13 48
JUN	249 ±6 89	272 ±11 00	261 ±7 30	70 ±2 10	60 ±2 10	75 ±1 51	22 ±1 83	19 ±2 65	23 ±3 29	85 ±28 69	96 ±30 85	82 ±27 20
JUL	239 ±7 40	263 ±8 62	257 ±8.34	57 ±2 36	56 ±1 25	74 ±1 98	21 ±2 36	23 ±2 04	23 ±3 00	80 ±19 36	81 ±24 37	86 ±22 75
AUG	165 ±7 98	260 ±9.25	246 ±10 49	60 ±1 33	64 ±2.10	64 ±2 19	23 ±2.94	21 ±2 10	23 ±2.91	75 ±23 48	79 ±24 60	97 ±24 63
SEP	323 ±7.77	325 ±13 65	284 ±9 53	87 ±1.37	66 ±2.13	62 ±1.29	22 ±2 56	22 ±1 96	25 ±2.66	67 ±22 65	75 ±19 92	73 ±22 83
OCT	247 ±8 49	309 ±9.86	293 ±13 82	61 ±1 31	84 ±1.79	71 ±1 86	22 ±2 06	21 ±2.75	21 ±1 79	56 ±20 04	73 ±22.18	70 ±21 92
NOV	249 ±8 06	303 ±14.50	311 ±19 43	63 ±1 19	78 ±1 74	77 ±1 51	21 ±3 00	21 ±1 92	23 ±2 47	67 ±18 34	72 ±20 07	75 ±20 96
DEC	285 ±14 32	287 ±9 57	355 ±8 64	66 ±2 12	47 ±1 34	79 ±1 50	22 ±2 34	20 ±2 10	21 ±2 32	64 ±81 21	71 ±20 52	80 ±21 58

TABLE : 21

Dimensional details of vessel elements (μm) and average number of vessels per 0\.5 mm^2 in the main trunk of Azadirachta indica growing in MDF, DDF and SF.

Month	Length			Width			Lumen diameter			Number of Vessels		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	280	284	306	194	246	187	137	147	132	16	8	17
	±9 36	±11 98	±9 48	±5 96	±9 85	±6 61	±5 79	±6 90	±6 06	±1 53	±1 54	±2 18
FEB	306	269	275	182	250	189	133	140	144	17	14	10
	±8 68	±8 64	±9 03	±6 49	±9 77	±7 37	±4 54	±6 50	±7 89	±3 42	±2 00	±1 36
MAR	289	264	250	259	259	194	134	143	134	16	13	16
	±10 19	±6 37	±8 91	±9 29	±7 41	±7 23	±6 85	±7 00	±4 59	±1.47	±2.61	±1 46
APR	257	257	238	214	271	180	144	136	126	14	13	6
	±12 22	±9 71	±10 37	±6 48	±7 07	±6 43	±6 72	±7 48	±4 90	±2 41	±2 69	±1 14
MAY	250	283	254	235	223	217	120	138	156	13	13	10
	±10 00	±10 20	±9 48	±6 91	±7 32	±6 00	±5 23	±5 12	±5 08	±2 06	±1 82	±1 64
JUN	229	296	263	176	236	230	143	166	128	14	14	12
	±11 73	±11 25	±9.68	±5 46	±6 16	±9 76	±4 79	±8 50	±6.63	±1.97	±2 27	±1 80
JUL	311	307	277	218	254	151	170	158	193	16	8	9
	±8 74	±12 22	±10 93	±8 18	±10 45	±2 64	±7 34	±4 50	±4 20	±1 27	±1 34	±1 03
AUG	284	254	235	201	199	162	137	170	121	15	12	12
	±9 42	±8 59	±6 80	±7 25	±6 65	±6 05	±4 76	±6 50	±4 72	±1 59	±1 38	±1 73
SEP	265	300	252	175	255	190	127	146	167	14	11	13
	±8 99	±11 75	±6 94	±6 08	±7 22	±4 50	±6 24	±6 99	±4 54	±1 32	±2.35	±1 55
OCT	239	249	258	228	222	172	125	176	144	13	13	7
	±10 00	±10 65	±8 74	±8 76	±9 90	±4 96	±5 58	±5 12	±3 88	±2 16	+1 89	+1 10
NOV	256	257	269	195	273	160	113	137	115	15	14	8
	±13 00	10.22	±9.00	±4 24	±8 25	±5 72	±4 52	±5 11	±5 59	±1 40	±1 83	±1 28
DEC	238	290	232	229	233	200	114	139	119	14	16	9
	±9 55	±11 82	±9.36	±5 93	±8 42	±5 56	±6 39	±6 36	±6 07	±1 93	±1 64	±1 12

TABLE : 22

Dimensional details of vessel lumen diameter (µm) and average number of vessels per 0.5 mm^2 in the branch and length of fibres (µm) in the main trunk of Azadirachta indica growing in MDF, DDF and SF.

Month	Lumen diameter			No. of vessels			Fibre Length		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	76	59	69	17	14	18	1277	1236	1368
	±3.59	±2 78	±2 62	±3 42	±2 00	±2.18	±24 66	±23 45	±18 81
FEB	69	78	65	18	14	14	1192	1135	1292
	±3.18	±4.38	±3.30	±3.18	±2.26	±1.70	±16.18	±22.83	±18 86
MAR	71	54	79	16	12	18	1253	1257	1214
	±3 57	±1.93	±3 42	±1 17	±2.32	±2.78	±17.90	±21.34	±16 74
APR	67	59	62	15	11	16	1270	1162	1162
	±3.13	±1 59	±2.22	±2.54	±1.63	±1 53	±19 38	±24 00	±21.94
MAY	64	60	66	15	13	15	1148	1219	1071
	±2 38	±1 72	±2.39	±2 53	±1 98	±2 23	±21 83	±17 30	±16 47
JUN	69	57	70	14	9	16	1156	1273	1182
	±2 28	±2 06	±2 23	±1 41	±0 49	±1 62	±14 59	±29 32	±23.44
JUL	68	59	81	14	12	16	1281	1167	1169
	±2 26	±1.85	±3.36	±1 14	±1 80	±1 59	±28 48	±26 26	±17 11
AUG	78	72	82	15	16	14	1171	1280	1063
	±3.70	±2 62	±2.99	±1 43	±2 93	±1 74	±22 55	±20 17	±17 16
SEP	78	83	63	15	15	19	1140	1152	1151
	±3.43	±2 93	±1 70	±1.68	±1.68	±2.94	±17.26	±23.37	±19 30
OCT	65	59	56	14	14	15	1062	1122	1119
	±2 06	±2 34	±2 35	±1.78	±1 71	±1 79	±11.58	±18 69	±21 71
NOV	72	61	72	10	14	11	1006	1250	1174
	±3 00	±2.25	±2 60	±1 59	±1.36	±1.88	±13.15	±23.68	±19 18
DEC	69	59	83	14	16	10	1106	1170	1183
	±2.05	±2 15	±3.53	±2.70	±1.64	±2.04	±12.62	±26 96	±18 49

TABLE : 23

Dimensional details of sieve tube elements (μm) in the main trunk of Azadirachta indica growing in MDF, DDF and SF.

Month	MDF		DDF		SF	
	Length	Width	Length	Width	Length	Width
JAN	365 ±6.71	30 ±2.05	379 ±9.58	35 ±3.40	427 ±9.71	37 ±2.92
FEB	327 ±7.17	29 ±2.11	365 ±10.00	30 ±7.00	346 ±8.86	36 ±3 21
MAR	400 ±8.82	30 ±4.70	357 ±8.45	35 ±2.72	360 ±9.431	34 ±2.47
APR	398 ±10.26	30 ±2.57	331 ±6.58	35 ±2.93	372 ±9.32	37 ±3.08
MAY	361 ±9.21	36 ±2.99	400 ±10.31	38 ±3.62	342 ±9.00	36 ±3.44
JUN	342 ±8.98	35 ±2.69	356 ±8.18	35 ±3.29	359 ±6.46	35 ±2.10
JUL	397 ±10.43	34 ±3.50	386 ±7.97	35 ±3.45	390 ±9.80	38 ±3.44
AUG	353 ±9.78	34 ±2.16	355 ±9.65	34 ±3.45	344 ±7.00	37 ±3.54
SEP	372 ±6.87	33 ±2.41	359 ±8.24	35 ±4.11	375 ±8.56	36 ±3.21
OCT	391 ±6.55	32 ±2.50	368 ±9.89	39 ±3.11	359 ±7.62	35 ±2.64
NOV	381 ±9.71	30 ±2.87	408 ±10.06	38 ±3.75	372 ±3.34	36 ±3.55
DEC	355 ±7.33	33 ±3.59	397 ±6.93	38 ±3.47	351 ±7.42	35 ±3.23

Fig 29 A-H: Transverse sections of cambium and adjacent xylem and phloem of *Azadirachta indica.*

A Dormant cambium in April surrounded by mature xylem and phloem in MDF X 470

B Initiation of cambial cell division in May in MDF. Note the newly formed thin tangential walls (arrows). X 230

C Wide cambial zone in June in MDF. Note the differentiating xylem elements. X 185

D Cambium showing peak activity in August in MDF. X 185

E A wide cambial zone in October in DDF. X 195

F Peak cambial activity in July SF. X 185

G Cambium showing peak activity in October in SF. X 195

H Cessation of phloem development in January in DDF. Note the differentiating xylem. X 230

CZ : Cambial zone, DX : Differentiating Xylem PH : Phloem, XY : Xylem V : Vessel

Fig 30: A-I: Tangential longitudinal sections of cambium of <u>Azadirachta</u> <u>indica</u>.

A A periclinally dividing fusiform cambial cell showing a phragmoplast ring (arrow). X 600

B Periclinally dividing fusiform cambial cells. Arrows indicates phragmoplast on either ends of developing cell plate. Note the origin of phragmoplast ring (arrowhead). X 240

C Newly formed thin pseudotransverse walls in fusiform cambial cell (arrow) following anticlinal division. X 150

D Structure of cambium in January in MDF. Note the swelling of fusiform cambial cells. X 96

E Structure of cambium in January in DDF. X 96

F Relatively long fusiform cambial cells with gradually tappered tips in January in SF . X 96

G Relatively short fusiform cambial cells with abruptly tappered tips in October in MDF. Note the wide rays. X 96

H Structure of cambium during the grand period of activity in July in MDF. Note the elongated fusiform cambial cells with gradually tappered tips. X 96

I Fusiform cambial cells in July in SF. X 96

Fig 31. A-I: Tangential longitudinal sections of cambium of <u>Azadirachta</u> <u>indica</u>.

A Intrusive growth of fusiform cambial cell into adjacent ray (arrow). X 150

B Intrusive growth of fusiform cambial cell tip into the lumen of adjacent cell (arrow). X 625

C A "U" shaped (arrow) fusiform cambial cell around one of the radial ends of a ray. Arrowhead indicates a short narrow fusiform cambial cell which is being lost from the cambial zone. X 240

D Forking at the tips of fusiform cambial cells (arrow). Arrowhead indicates a newly formed thin pseudotransverse anticlinal wall. X 150

E A fusiform cambial cell differentiating into a fibre. Arrows showing forked ends overlapping a ray following intrusive growth. X 150

F Abnormal arrangement of fusiform cambial cells between two adjacent rays. X 240

G Short and narrow fusiform cambial cells (arrows) which are being lost from cambium. X 500

H Large intercellular air spaces among ray cambial cells in May (arrows) in DDF. X 575

I Compactly arranged ray cambial cells with no intercellular spaces in active cambium in August. X 575

Fig. 32: Tangential longitudinal (A-D, G) and transverse (E-F, H-I) sections of cambium, phloem and xylem of Azadirachta indica.

A Development of ray cambial cells into fusiform cambial cells (arrows). X 150

B Development of ray cambial cells (arrow) from fusiform cambial cells (arrowhead) by transverse division. X 230

C Development of biseriate ray by radial anticlinal division of ray cambial cells (arrows). X 230

D A phloem ray sieve element showing a compound sieve plate (arrow). Arrowhead indicates aggregate and linear sieve areas on their lateral walls. X 230

E Adjacent sieve elements showing compound sieve plate. X 625

F Phloem ray noding (arrows) indicating phloem growthring boundry. Note the obliteration of last season's nonfunctional (arrowhead) sieve tube elements. X 150

G Differentiating vessel elements with a nucleus (arrow). X 290

H Xylem ray noding (arrow) and tangential band of axial parenchyma (arrowhead) indicating xylem growth ring boundry. X 98

I Structure of xylem in DDF. X 98

Fig. 33: A-I: Longitudinal sections of cambium, xylem and phloem of <u>Azadirachta indica</u>.

A Starch free ray cambial cells in April in MDF. X 380

B Newly formed lightly stained starch grains in ray cambial cells in August in MDF. X 380

C Distribution of starch in sieve tube elements in May in DDF. Note the starch free phloem ray parenchyma. X 108

D Heavy accumulation of starch in axial parenchyma of phloem in May in SF. X 150

E Starch distribution in phloem elements in August in MDF. X 108

F Distribution of starch in phloem elements in August in the trees of SF. X 169

G Starch free xylem in August in DDF. X 112

H Distribution of starch in July. Note the heavy accumulation of starch in mature xylem elements while scanty distribution in newly formed derivatives in SF. X 108

I Distribution of starch in axial and ray parenchyma of xylem in September in DDF X 150

Fig 34: A-I: Radial longitudinal sections of cambium in <u>Azadirachta</u> <u>indica</u>

A Distribution of lipid bodies (arrows) in ray cambial cells in April in MDF. X 600

B Distribution of lipid bodies (arrows) in fusiform cambial cells in DDF. X 600

C Distribution of lipid bodies in ray cambial cells (arrows) in April in SF. X 600

D Ray cambial cells devoid of lipid bodies in August in MDF. X 600

E Lipids free fusiform cambial cells in SF X 600

F Distribution of protein bodies in ray cambial cells (arrows) in May in MDF X 600.

G Distribution of protein bodies in ray cambial cells (arrows) in May in MDF. X 600

H Distribution of protein bodies in fusiform cambial cells (arrows) in May in SF. X 600

I Scanty distribution of proteins in fusiform cambial cells (arrows) in September in MDF. X 600

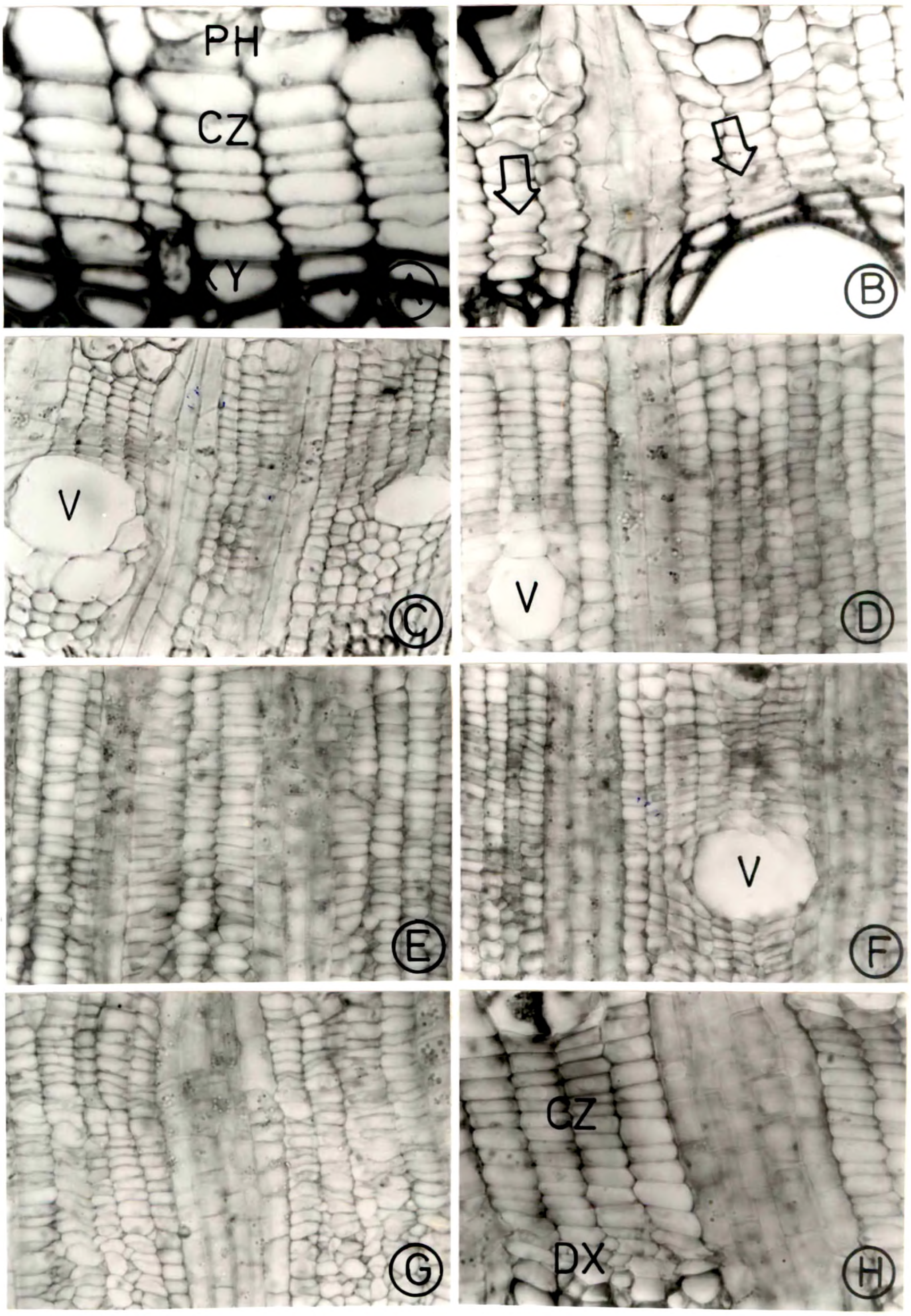


FIG. 29

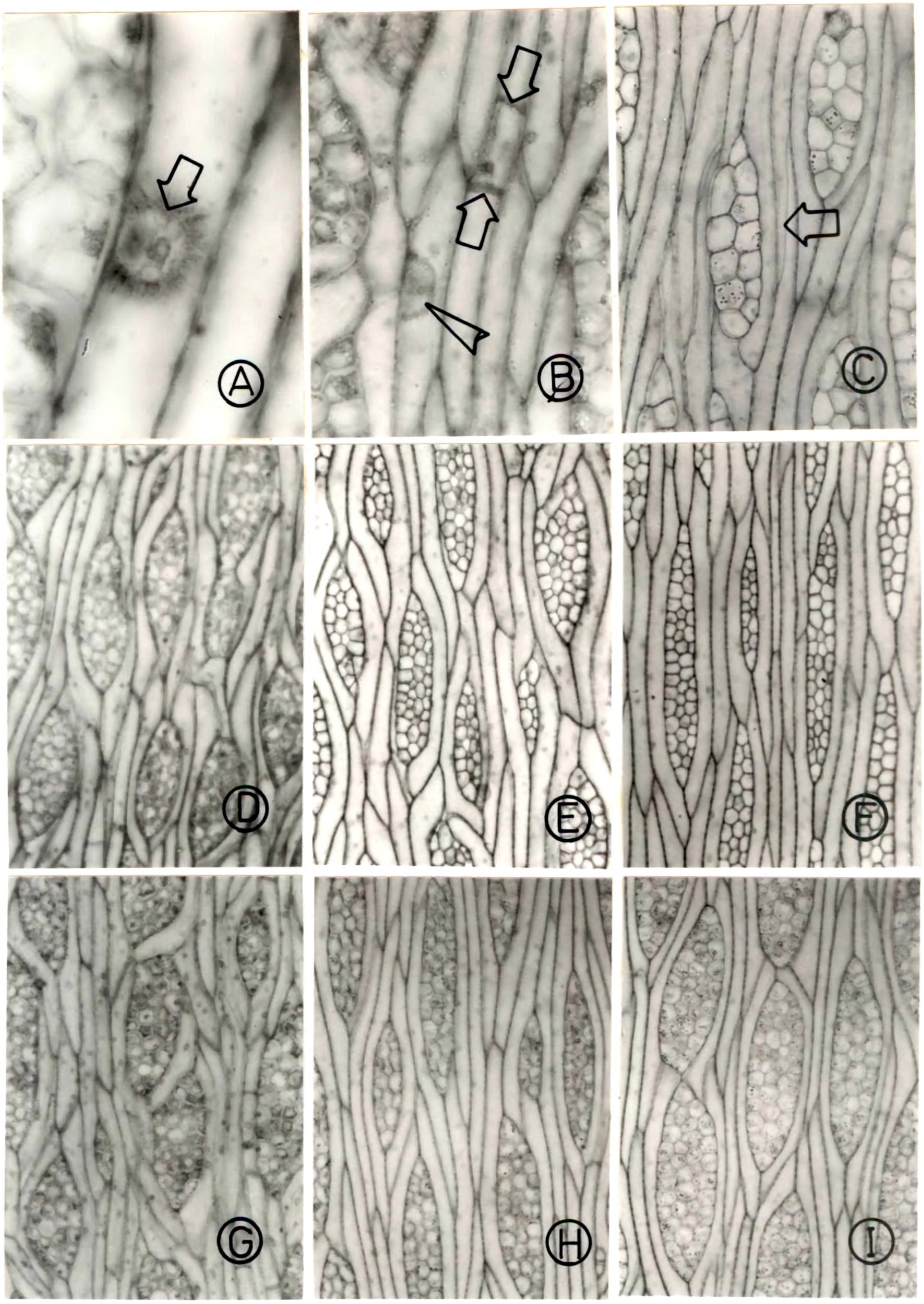


FIG. 30

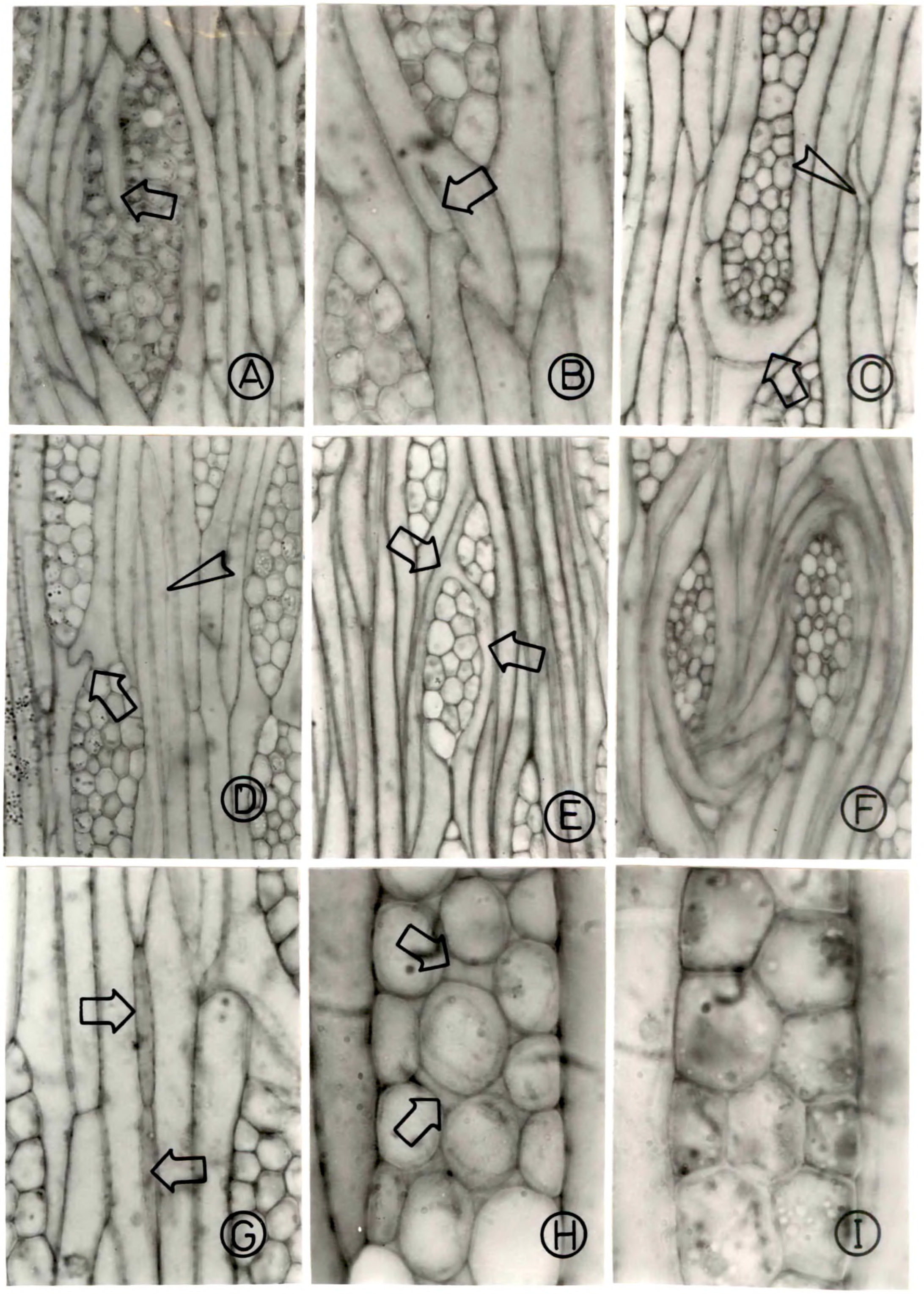


FIG. 31

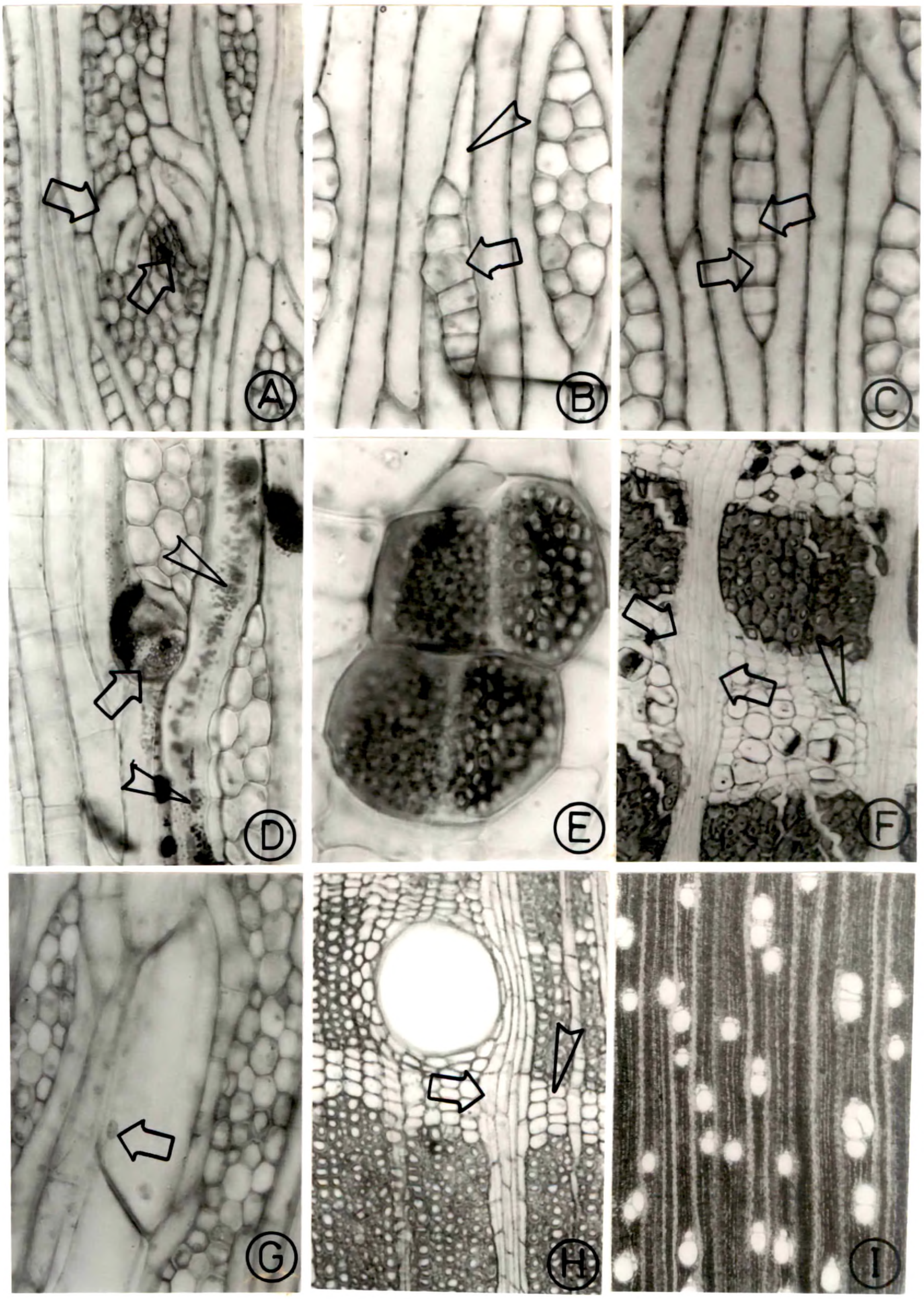


FIG. 32

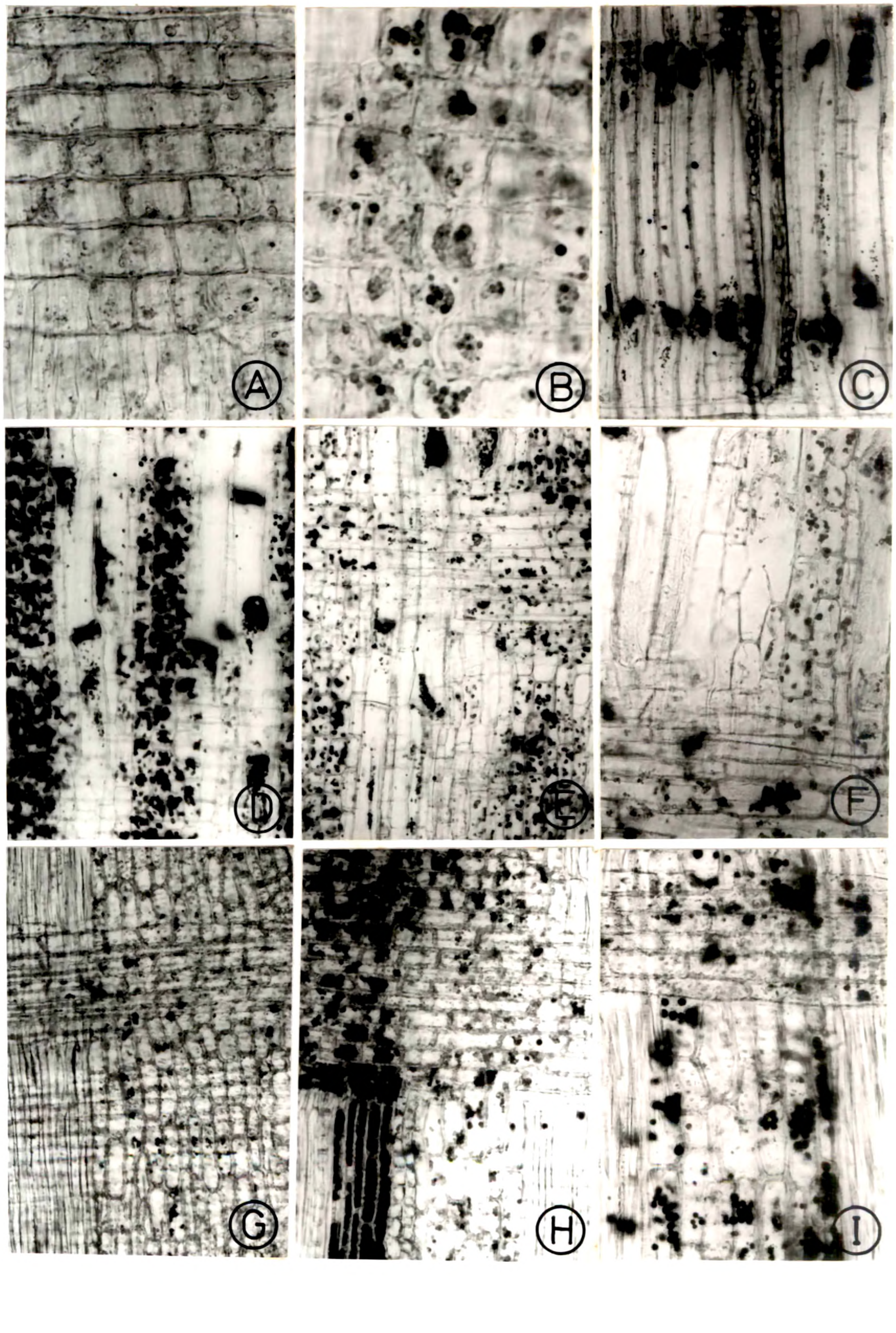


FIG. 33

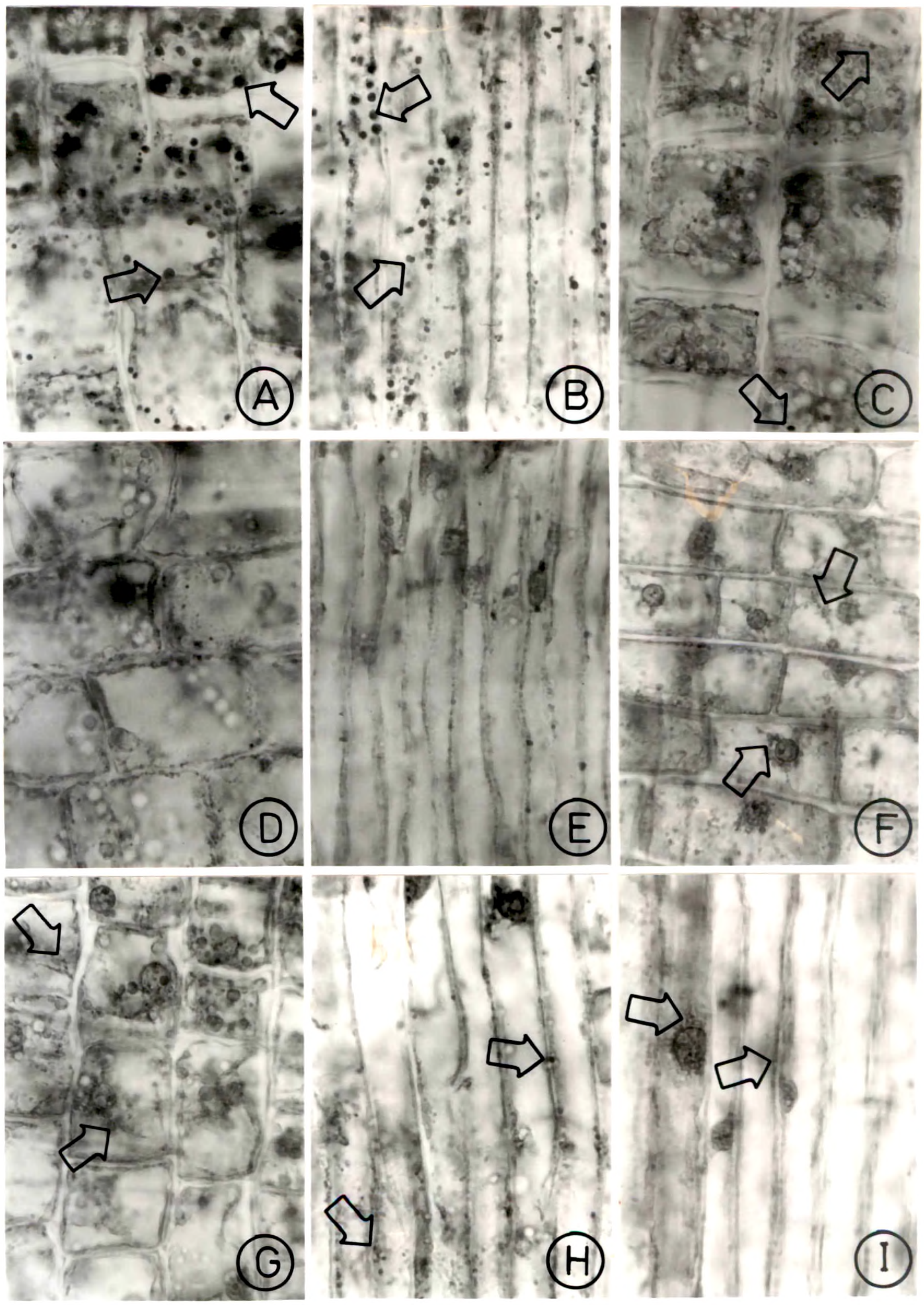


FIG. 34

Fig. 35

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Azadirachta indica growing in MDF.

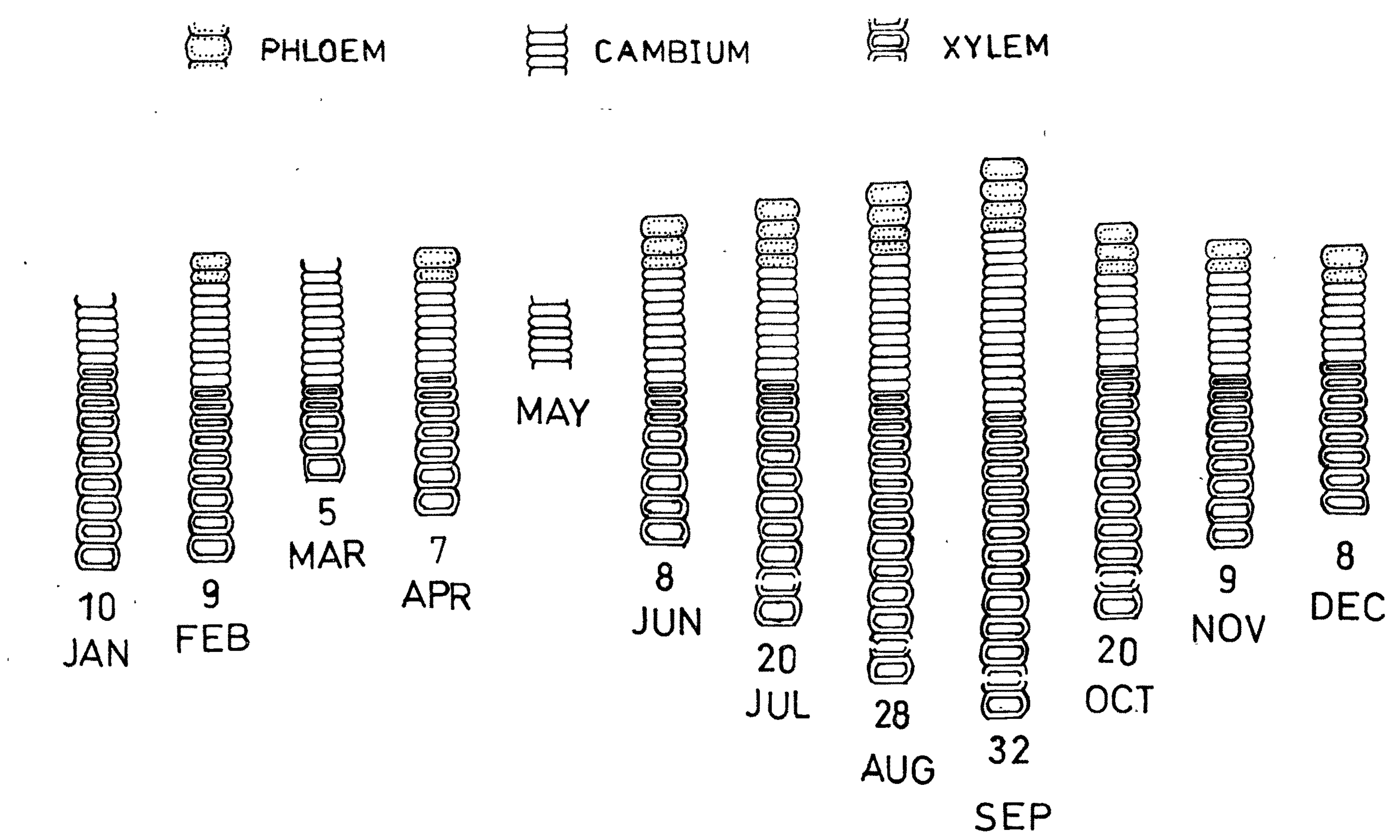

PHLOEM
CAMBIUM
XYLEM
10
JAN
9
FEB
5
MAR
7
APR
MAY
8
JUN
20
JUL
28
AUG
32
SEP
20
OCT
9
NOV
8
DEC

FIG. 35

Fig. 36

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Azadirachta indica growing in DDF.

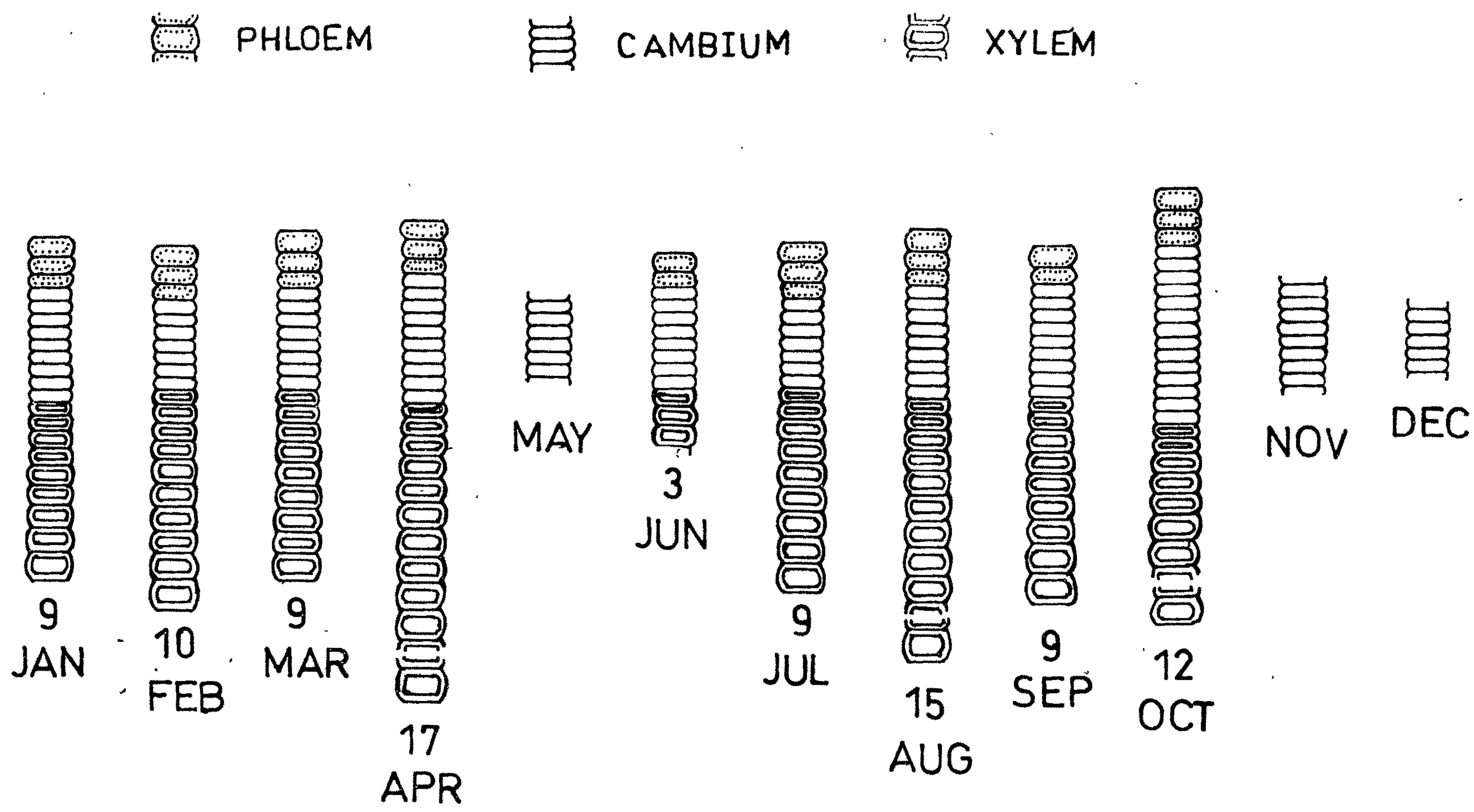

PHLOEM
CAMBIUM
XYLEM
9
JAN
10
FEB
9
MAR
17
APR
MAY
3
JUN
9
JUL
15
AUG
9
SEP
12
OCT
NOV
DEC

FIG. 36

Fig. 37

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Azadirachta indica growing in SF.

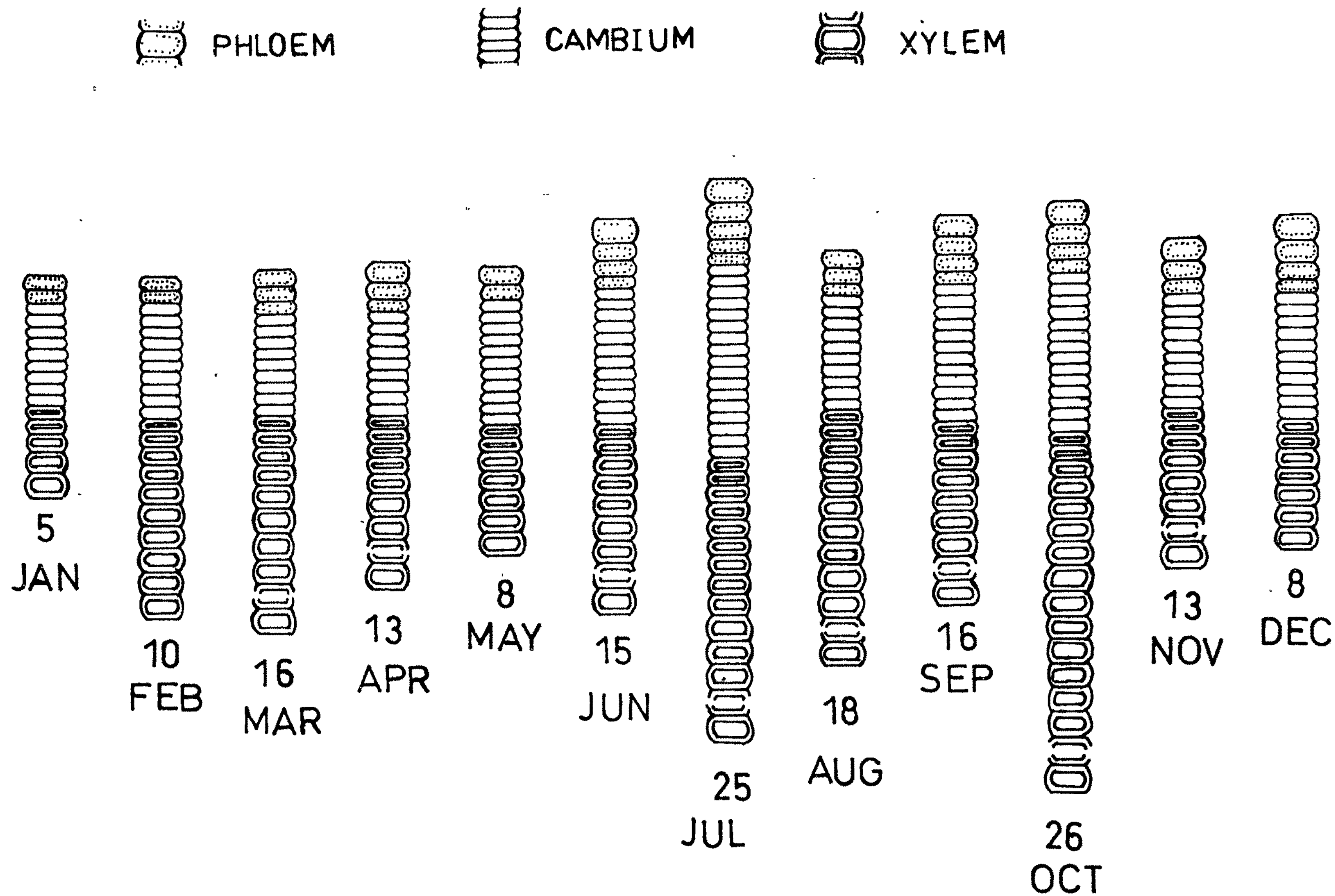

PHLOEM
CAMBIUM
XYLEM
5 JAN
10 FEB
16 MAR
13 APR
8 MAY
15 JUN
25 JUL
18 AUG
16 SEP
26 OCT
13 NOV
8 DEC

FIG. 37

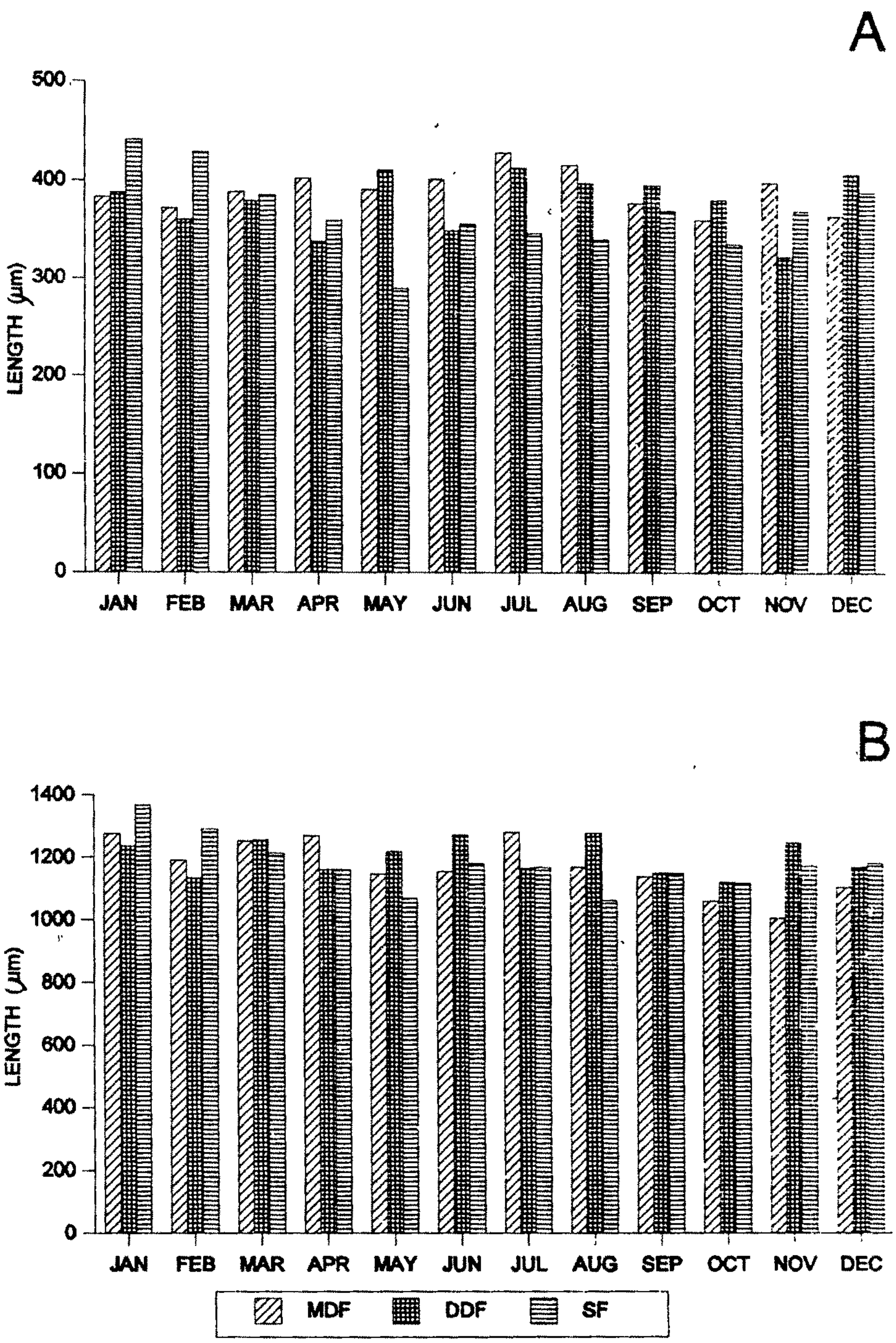
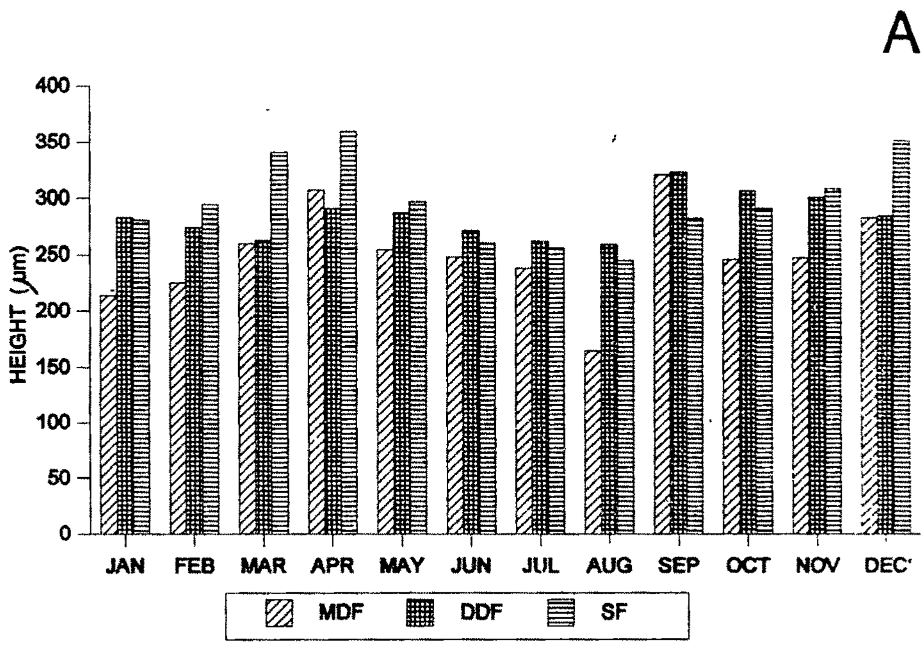


Fig. 38 Histograms showing seasonal variation in mean length of fusiform cambial cells (A) and xylem fibres (B) in Azadirachta indica.



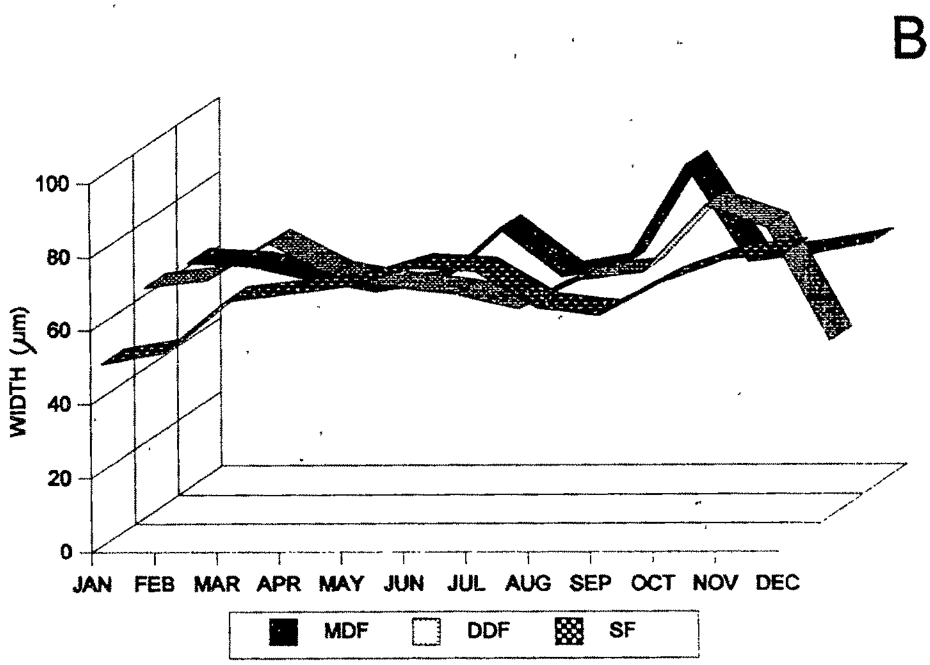


Fig. 39 Graphic representation of seasonal variation in cambial ray height (A) and ray width (B) in Azadirachta indica.

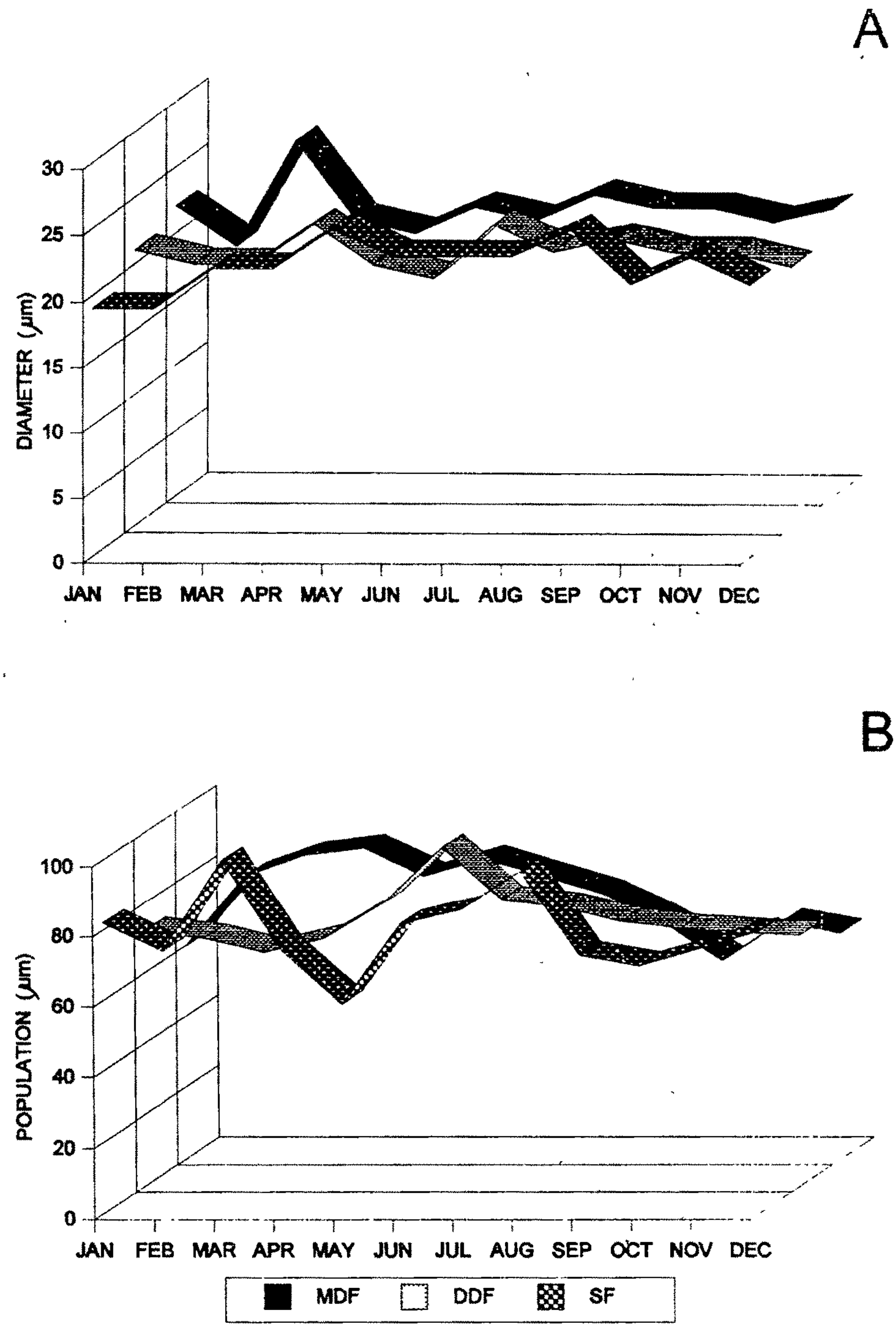


Fig. 40 Graphic representation of seasonal variation in ray cambial cell diameter (A) and ray population in 1cm tangential width of cambium (B) in <u>Azadirachta indica</u>.

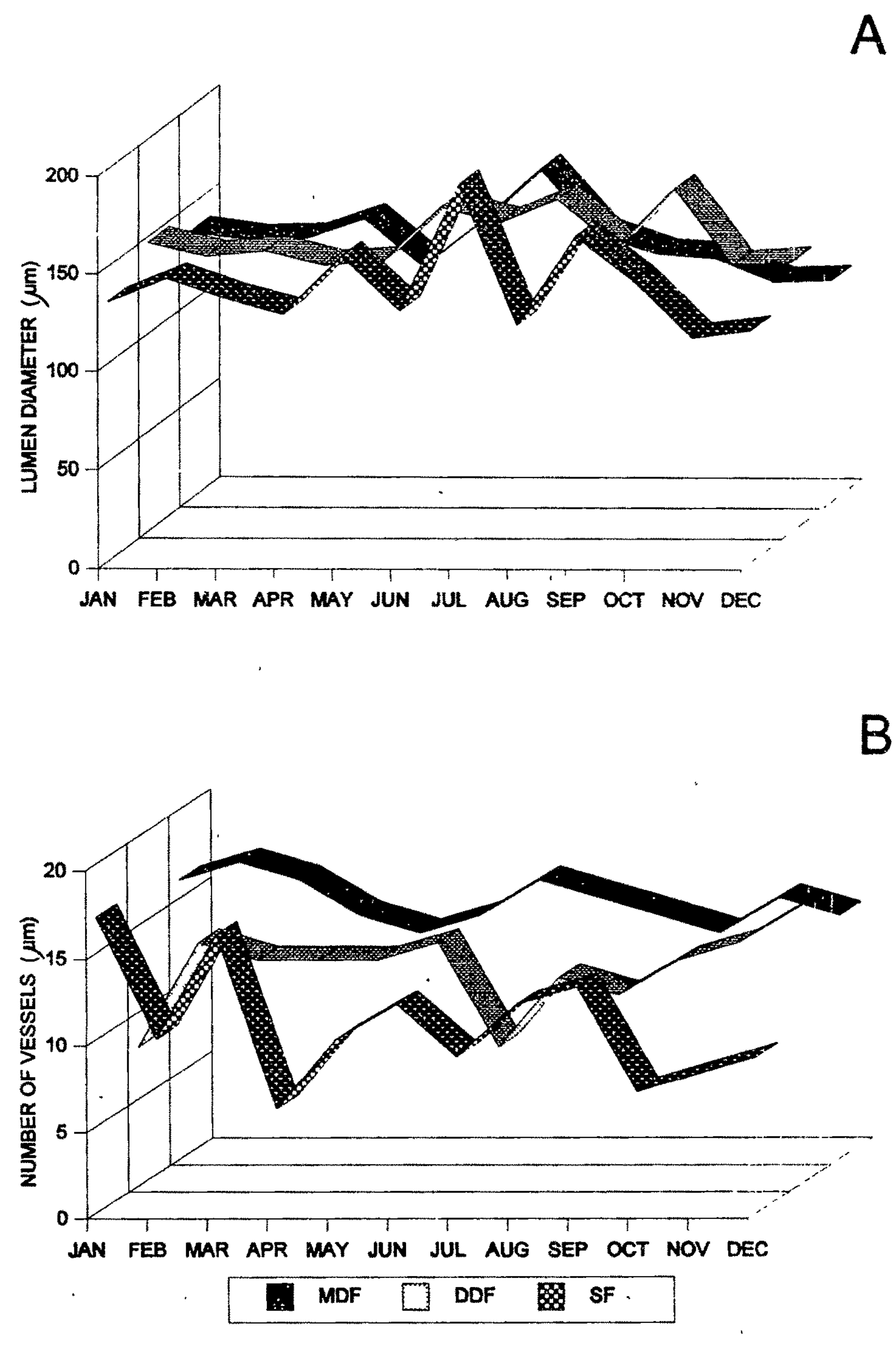


Fig. 41 Graphic representation of seasonal variation in vessel lumen diameter (A) and number of vessels per 0.5 mm2 (B) in <u>Azadirachta indica</u>.

TAMARINDUS INDICA Linn.

Family : Caesalpinaceae (Leguminoceae)

The name Tamarind comes from Persian Tamar-i-Hind means Indian date The specific name indica referes to the supposed Indian origin of the tree:. it is now commonly held that the tree is African in origin but cultivated in most tropical countries.

The Tamarind tree is handsome, evergreen and grows to large sizes. In young trees the trunk is straight and shapely, in old trees trunk may become abnormaly and irregularly thick, especially if the tree has been roughly treated. The leaves are compound consisting of many small leaflets and grow so densely on the tree that they cast unbroken and pleasent shade on the ground. Young leaves are light green, the older lose their brilliancy but remain still very pleasently green. The flowers are small, in small loose clusters among the leaves, the petals are variegated yellow and red, three of them being normal, two reduced to scales. Flowers come out in great abundance. The pod is curved, irregularly swollen, brown in colour and contains several seeds immersed in fibrous pulp. The timber is hard and difficult to work and used to make furnitures, mallets or rice pounders. The seed ground to powder and boiled with gum are said to be the strongest wood cement. Medicinally several parts of the tree are said to be tonic and astringent. Alcoholic beverages obtained by the fermentation of fruit pulp is famous in Java.

STURCTURE OF CAMBIUM :

Cambium in Tamarindus appears storied comprising of two types of cells i) Fusiform cambial cells and ii) Ray cambial cells (Fig. 44A). The former are vertically elongated and arranged in definite rows or tires while latter type of cells are more or less isodiametric, short and horizontally arranged. However, fusiform cambial cells lose their storied arrangement in certain months during grand period of activity (Fig. 44E). Cambial zone remains narrow with 3-5 layers of cells (Fig. 42A) when dormant and wide with 10-20 layers of cells (Fig. 42C) when active. During dormant condition, fusiform cambial cell's raidal walls are relatively thick and conspicuously beaded. The walls are thin and less beaded in active cambium. Cambial rays are exclusively uni-biseriate (Fig. 44A) and rarely triseriate.

Ray cambial cell appear polygonal and campactly arranged during active condition (Fig. 45D). However, during dormancy they are oval to oblong and leads to the formation of intercellular spaces at their corners (Fig. 45C). Nuclei in both the cambial cells are fusiform shaped in dormant condition.

CAMBIAL ACTIVITY

The initiation of cambial cell division, grand period of activity and cessation of radial growth in the main trunk of Tamaridus differ among all the three forests. In MDF, periclinal divisions in cambial cells initiate in May (Fig. 42B) reaching its vertex in October with 14-18 number of layers in each radial file (Fig. 42C) then declines gradually (Fig. 42D) ceasing in March. However, cambial growth remains suspended between March and April (Fig. 42A). During this period cambial zone is narrow with 4-7 number of cells in each radial file (Fig. 48).

In DDF, cambial activity commences in June (Fig. 42F) reaching peak in August with 12-16 number of cells (Fig. 42G) then declines gradually and ceases in January (Fig. 42H). The cambial zone is narrow with 3-7 layers of cells with no cell division untill May (Figs. 42E, 49).

In SF, radial growth occurs for major part of the year and cambium remains inactive between January and March (Fig. 43A,C). However, cambial cell division begins in April reaching peak in September - October with 8-15 number of cells in each radial file (Fig. 43B). The cambial zone is dormant and narrow with 4-6 number of cell layers in February (Figs. 43C, 50).

CAMBIAL ACTIVITY IN RELATION TO PHENOLOGY :

Being an evergreen tree sprouting of young leaves and defoliation occurs simultaneously in April and by June, the entire crown of old leaves is replaced by young ones. Development of flower buds also starts in May-June with fruit setting in August. Fruit maturation and dispersal occur in February and March respectively. However, no significant variations in phenology have been observed among the three forests. In MDF and DDF cambial cell division starts in May and June respectively though sprouting of young leaves occur in April. The cell division ceases in March and January respectively, when the tree bears mature leaves. In SF, cambial cell division commences in April with sprouting of new leaves and ceases in January when tree bears mature leaves. Cambial activity in relation to phenology in all the three forests is presented in Tables 24, 25 and 26.

CAMBIAL ACTIVITY IN RELATION TO CLIMATIC FACTORS :

The reactivation of cambium occurs in May and June when the mean maximum temperature is 34.9°C and 35.7°C in MDF and DDF respectively However, sprouting of new crop of leaves starts in April when the temperature is 35.3°C and 37.9°C in MDF and DDF respectively. Cambial growth in MDF reaches peak in October at the end of rainy season while in DDF the peak is in August when the rains are heavy. In SF, cambial cell division occurs in April (average temp. 38.8°C) reaching peak in September-October and ceases in January during the drier part of the year (Fig.1 and 2A,B).

FUSIFORM CAMBIAL CELLS :

In tangential section fusiform cambial cells are arranged veritcally with tappered cell tips. In nondividing cambium they are arranged in more or less definite horizontal rows forming stratified arrangement (Fig. 44A). However, during active condition their storied arrnagement is found to be disturbed due to the elongation of cell tips (Fig. 44E,G) beyond the limit of the storey and appear as semistoried (Fig. 44 B,E). Radial walls are beaded (Fig. 44C) due to the presence of primary pit fields. Compared with other three species studied, the beads appear larger in size in dormant cells. Elongation of cell tips by intrusive growth, which sometime leads to the forking of the cell ends (Figs. 44I, 45A,B). Intrusive growth sometimes leads to the intrusion of radial walls into the cell lumen (Fig. 44H). In transverse section the cells are arranged in radial rows and appear rectangular. The radial walls are more thicker than tangential ones (Fig. 42A,E). The nucleus is round in active cambial cells and fusiform shaped in dormant cells.

Divisional activity :

Periclinal divisions in cambial zone lead to the development of xylem and phloem derivatives and anticlinal division attribute to the increase in circumferance of cambial cells (Fig. 43D). Periclinally dividing fusiform cambial cell reveal phragmoplast on eitherside of tangentially growing cell walls (Fig 44D). Occurrence of phragmoplast bands are frequently observed in active cambium. Fusiform cambial cells increase in their number following radial longitudinal divisions. This division results in the formation of cell wall from one end of the cell tip to the other end (Fig. 44C). The newly formed adjacent cells give rise to stratified cambium. Loss of fusiform cambial cells are also encountered throughout the active period of cambial growth in all the three forests (Fig. 43D).

Dimensional changes :

Mean length:

Mean length of fusiform cambial cells undergoes seasonal variation in all the three forests. In MDF, mean length of the cells decreases from January to March, April to July and August to December (Table 27). It is minimal (334 µm) and maximal (388 µm) in March and August (Fig. 44E) respectively. Cell length in DDF is found to be maximal and minimal (Fig. 44F) in January (381 µm) and April (306 µm) respectively (Fig. 44F). However, it decreases from January to April, May to July and August to October (Fig. 44G) and in November - December (Table 27). In SF, it decrease from January to April and May to September (Table 27). Maximum (369 µm) and minimum (299 µm) length of fusiform cambial cells are encountered in May and September respectively (Fig. 51A). Yearly average of fusiform cambial cell length is observed maximum (354 µm) in MDF and minimum (334 µm) in SF (Table 31).

Mean width :

In all the three forests, tangential and radial width of fusiform cambial cells do not show any significant correlation with seasonal activity. However, tangential width of the cells remains maximum (21 µm) in June in MDF and DDF and March (22 µm) in SF. It is found minimal (15 µm) in December in MDF and DDF and in January (15 µm) in SF.

In MDF, maximal (8 μm) and minimal (3 μm) radial width of cells in March and August coincide with inactive and active cambium respectively. In DDF, maximal and minimal width are noticed in March (8 μm) and August - September (4 μm) respectively. In SF, it is minimal (4 μm) in June to September and maximal (8 μm) in December. Yearly average of tangential and radial width of cells remain more or less same among all the forests (Table 31).

Length variation in relation to xylem fibres :

The mean length of fusiform cambial cells and xylem fibres are closely related throughout the year. Compared to fusiform cambial cells, xylem fibre length increases 3 to 4 times in all the three forests. Similar to that of fusiform cambial cells, in MDF xylem fibre length decreases from January to March, April to July and August to November (Table.30). Maximal (1281 μm) length of xylem fibre coincides with that of fusiform cambial cells in August (Fig. 51A,B) The minimal (1110 μm) length of xylem fibre is encountered in November In DDF, it decrease from January to March, April to July and August to October and increases in November - December (Table 30). However, maximal (1200 μm) and minimal (1088 μm) length of xylem fibre coincide with that of fusiform cambial cells in January and April respectively (Fig. 51A,B). In SF, xylem fibre length decreases from January to April and May to September and increases from October to December. However, it remains maximal in January (1230 μm) and minimal in

September (1070 μm). Minimal length of fibres and fusiform cambial cells coincides in September (Fig. 51A,B).

Yearly average length is noticed maximal (1193 μm) in MDF and minimal (1152 μm) in SF (Table 34).

RAY CAMBIAL CELLS :

In tangential view ray cambial cells appear as isodiametric. In active cambium they are compactly arranged and polygonal (Fig. 45D). As the cambium approaches dormancy the cells lose their turgidity and become oval to oblong This leads to the development of intercellular air spaces (Fig. 45C) among the cells. The size of air spaces in ray cambial cells increases in all the three from MDF to DDF and from DDF to SF. Cambial rays are exclusively uni-biseriate and homocellular. They are in stratified manner (Fig. 44A) when the cambium is dormant. Triseriate rays are rarely encountered. During the grand period of activity rays lose their storied arrangement along with the fusiform cambial cells (Fig. 44B,C,E).

Divisional activity :

Ray cambial cell originates by division of fusiform cambial cells. A complete or a part of cell undergo division forming a ray cambial cell (Fig 45A) During the grand period of activity, ray cambial cells multiply by divisions or adjacent fusiform cambial cell divide and develop into bi-triseriate cambial rays.

Demisional Changes :

Cambial ray height undergoes seasonal fluctuations in all the three forests .The height varies from 186-259 µm in MDF, 177-249 µm in DDF and 180-275 µm in SF during the seasonal cycle of cambial growth. However, in MDF, the height increases and decreases alternately from January to April and decreases from May to July and October to December with sudden increase and decrease in August - September respectively (Table 28). Ray height attains maximum and minimum in August and September (Fig. 52A) respectively.

In DDF, it decreases from January to April, May to July, and August to December with maximal and minimal height in May and July respectively (Table 28, Fig. 52A). In SF, the height increases from January to March and April to June and decreases from July to December. Maximal and minimal height of cambial ray is reported in March and December respectively. Yearly average of cambial ray height remains maximal (213 µm) in MDF and minimal (200 µm) in SF (200 µm) Table 32.

Cambial ray width .

Cambial ray width does show significant correlaions with the seasonal activity of cambium. In MDF, it increases from January to April and decreases from May to August and September to November. In DDF, it increases from January to May, July to October and November - December. In SF, it decreases from March to August and September to November (Table 28, Fig. 52B) However, cambial ray width is found maximal in April (37 μm), May (31 μm) and March (39 μm) and minimal in August (20 μm), November (22 μm) and August (24μm) in MDF, DDF and SF respectively (Fig. 52B). Yearly average of cambial ray width is found maximal in SF while no significant difference has been observed in other two forest types (Table 32).

Ray cambial cell diameter :

Ray cambial cell diameter in MDF, decreases from March to August and increases and decreases alternately in remaining months. In DDF, it increases from January to March and increase and decreases alternately in rest of the months. In SF, it increases from January to March and April to July Ray cell diameter ranges from 17-21 μm, 13-20 μm and 16-20 μm in MDF, DDF and SF respectively (Table 28, Fig. 53A). Yearly average of ray cambial cell diameter is noticed more or less similar and ranges from 17-19 μm among all the three forests (Table 32).

Cambial ray population :

The average number of cambial rays per one cm tangetial width of cambium ranges from 158-200, 140-190, and 120-174 in MDF, DDF and SF respectively. In MDF and DDF cambial ray frequency decreases with initiation of cambial activity and increases gradually as the cambial cell division declines while in SF, it does not show any significant relation with cambial cell division. In MDF, number of cambial rays per one cm tangential width decreases from March to September and increases from October to December. In DDF, it decreases from March to May and June to September and increases or decreases from October to December. In SF, their number decreases from January to April, May to July and August to December (Table 28, Fig. 53B). Yearly average number of rays per one cm tangential width of cambium is found maximum (177) in MDF and encountered minimum (158) in SF (Table 32).

DEVELOPMENT OF VASCULAR TISSUES :

Periclinal divisions in cambial zone cells leads to the development of xylem and phloem on either side of cambium. In all the three forest types xylem and phloem development occurs simultaneously (Fig. 42 B,F) and phloem development ceases first followed by xylem development (Fig. 43E) However, rate of cambial cell division and differentiation noticed similar in all the three forests. Therefore, though differentiating xylem elements are observed more but cambial zone remains narrow for the major part of the year. Differentiation of vascular tissues from cambium always showed inclination towards development of more xylem than phloem in all the forests regions. In MDF, though cambial cell division initiates in May but differentiation of vascular tissues start in June. However, differentiation of xylem culminate twice during the cambial growth. In July, though the cambial zone is narrow, the differentiating xylem is found to be more with 30-38 elements in each radial file. Then the rate of differentiating derivatives decline in August but number of cambial layer reaches peak in October with 14-18 cells in transverse section. The cell division and differentiation cease in February, and maturation of xylem derivatives continues (Fig. 43E) until March (Table 24).

In DDF, differentiation of xylem and phloem elements begins in July though the cambial activity starts in June, cambial cell division and differentiation culminates in August with 27-35 xylem derivatives in each radial file. Then both, cambial cell division and differentiation decline in September-October. In November, again cell division and differentiation rate increase with 25-32 number of differentiating xylem elements in transection. Cambial cell division ceases in January but maturation of xylem continues even in February (Table 25).

In SF, periclinal divisions are noticed in April but development of xylem derivatives starts in May reaching peak in September and October (Fig. 43F) with 28-36 number of differentiating cells towards xylem. Then cambial cell divisions declines and cambium remains inactive in January with maturing xylem elements (Table 26). However, xylem differentiation and maturation are suspended in April-May, March to June and February to April in MDF, DDF and SF respectively.

Phloem derivatives develop into sieve tube elements, companion cells, axial and ray parenchyma. Discontinuous phloem fibre bands are distributed among sieve tube elements and axial parenchyma cells (Fig 45E). Sieve tube elements have simple sieve plate (Fig. 45E) with well developed sieve areas on their lateral walls. P-protein is copious and occur as a plug near the sieve plate (Fig. 45F). As they are derived from storied cambium, sieve elements maintain storied arrnagement.

Xylem derivatives from cambium differentiate into vessel members, fibres. axial and ray parenchyma. Xylem is diffuse porous with mostly solitary vessels (Fig. 45G) but radial (Fig. 45H), tangential or diagonal multiples of 3-4 vessels have also been encountered. Xylem parenchyma are vascicentric and aliform to confluent (Figs. 45G,H,I) forming distinct tangential bands. Vesels are interspersed among the xylem fibres. Vessel elements are short with transverse to slightly oblique end walls with simple perforation plate. Intervessel pits are bordered and arranged alternately Xylem fibres are nonstoried and nonseptate. Uniseriate rays which become trapped between two tangentially adjacent elements are also noticed in all the three forests (Fig. 45J).

Development, length and width of sieve elements:

Fluctuations in sieve tube element length do not show any correlation with seasonal changes in the length of fusiform cambial cells. In MDF, length of sieve tube elements increases from February to April, May to July and August to December (Table 30). In DDF, it decreases from February to April and May to

August while it increases from October to December with a sudden increase in september. In SF, it decreases from January to May and June to September while it increases from October to December. The length remains maximal in January (302 μm), May (304 μm) and December (308 μm) and minimal in February (252 μm). August (266 μm), and September (261 μm) iun MDF, DDF and SF respectively. Yearly average length of sieve tube elements is relatively more in MDF (287 μm)

No consistant seasonal changes are observed in the width of sieve tube elements. It ranges between 21-24 μm, 20-25 μm and 20-23 μm MDF, DDF, and SF respectively. The yearly average remains same (22 μm) in MDF and SF

Development, length and width of vessel elements:

During the course of development vessel element mothercell enlarges both radially and tangentially. Compared with fusiform cambial cells, it enlarges 6-11, 8-12 and 9-13 times in MDF, DDF and SF respectively. However, in all the three forest types, the length of vessel element remains shorter compared with that of fusiform cambial cells. In MDF, it increases from January to March and April to June but decreases from September to December. The average length remains minimal (193 μm) in January and maximal (262 μm), in March. In DDF, length of vessel elements decreases from January to April and May to September It increases from October to December. Minimal (198 μm) and maximal (283 μm) length of vessel elements are encountered in April and May respectively while in

SF, it decreases from January to March, April to June and increases in July-August and from September to December. Vessel element length remains maximal (252 μm) and minimal (200 μm) in April and June respectively (Table 29). Yearly average of vessel member length is observed maximal (239 μm) and minimal (231 μm) in DDF and SF respectively (Table 33).

Width of vessel elements does not show any significant correlation with the seasonal activity of cambium. In MDF, it decreases and increases alternately from January to April and increases from May to September and decreases from October to December. In DDF, vessel member width increases from February to May and August to December and noticed fluctuating in rest of the months. In SF, it increases from January to March and September to November but decrease from April to August while fluctuating in remaining months. However, vessel member width is highest in March (163 μm), January (187 μm) and March (190 μm) and lowest in February (113 μm, 115 μm) and August (130 μm) in MDF, DDF and SF respectively (Table 29). Yearly average of vessel width is maximal (150 μm) in SF and minimal (137 μm) in MDF (Table 33).

Vessel lumen diameter:

In all the three forests, vessel lumen diameter relatively increases with arrival of rains and decreases during drier part of the year. Except in SF, vessel lumen diameter is maximal in February during dry season In MDF, it decreases from February to May and October to December but increases in between June and September (Table 29). It is observed minimal in January (68 μm) and maximal (118 μm) in September. In DDF, it decreases from January to April and increases from May to July and August to November. It remains minimal (60 μm) in April and maximal (107 μm) in November. In SF, it decreases from February to July and increases from August-December. Vessel lumen diameter occurs maximal (106 μm) and minimal (70 μm) in February and July respectively (Fig. 54A). Yearly average of vessel lumen diameter remains same (85 μm) in MDF and SF (Table 33)

Number of Vessels:

Number of vessels per 0.5 mm^2 in transverse section of xylem is closely associated with its lumen diameter. In all the three forests number of vessels decreases with increase in diameter and vice-versa. In MDF, number of vessels increases from January to April and September to December and it decreases from April to September. The number is recorded heighest (22-30) in May and lowest (7-15) in September. In DDF, it decreases from April to October. The number is highest (14-22) in April and lowest (7-12) in October. In SF number of vessels decreases from February to May and June to November. Vessel number is found maximal (17-23) in February and minimal (7-13) in November (Table 29, Fig. 54B). Yearly average number of vessels is maximal (17) in MDF and minimal (13) in DDF (Table 33).

Growth ring width:

Xylem shows indistinct growth rings which are, however, visible when observed under microscope. The amount of xylem increment can be discerned by tangential bands of initial parenchyma (Fig. 45K) and narrow lumen elements with thick walls. The growth ring width increment in two successive years i e 1993 and 1994 is 7.8 and 8.2 mm in MDF, 6.3 and 6.5 mm in DDF and 5.6 and 6.3 mm in SF respectively.

HISTOCHEMISTRY:

Starch:

Similar to that of Tectona and Azadirachta starch grains in Tamarindus are oval (Fig. 46E) and found only in ray cambial cells. Size and distribution of starch grains differ strikingly with the seasonal cycle of cambial growth and development of young leaves. Starch grains in the parenchyma of xylem and phloem are large and darkly stained. In MDF, starch grain disappear from ray cambial cells between February and May when the cambium is dormant (Fig. 46A,C) and reappear in June with the sprouting of young leaves and development of flower buds. In the subsequent months, size and distribution of starch grains in cambial rays increase as the leaves become mature and they remain present until February.

Ray cambial cells are devoid of starch grains from December to May in DDF (Fig. 46B) and February to May in SF, while distribution of starch in rest of the months in ray cambial cells coincide to that of MDF (Fig. 46D)

In MDF, starch is negligible in xylem close to cambial zone but present in small quantities in the cells away from cambium in January (Fig. 46F) Accumulation of starch increases in the succeeding months and by May heavy deposition of starch is encountered in parenchyma cells of both xylem (Fig. 46 H) and phloem. However, depletion of starch commences in June with the initiation of cambial activity. Parenchyma cells of xylem and phloem are free of starch in August-September when the cambial activity reaches peak. In the following months, with the decline of cambial activity deposition of starch begins. Starch is observed in axial parenchyma of xylem and phloem away from the cambial zone in December.

Parenchyma cells of xylem and phloem are devoid of starch close to the cambium in DDF and SF in January . Deposition of starch increases from February with a heavy deposition in May (Fig. 46G) in parenchyma cells of xylem and phloem. In the remaining months fluctuations in starch content in xylem and phloem coincide with that of MDF and DDF (Fig. 46I).

Lipids:

Occurrence and distribution of lipid globules is similar to that of Azadirachta. In MDF, lipid content in cambial cells decreases with the initiation of cell divisions (Fig. 47C). When the cambium is fairly active in September and October, fusiform and ray cambial cells contain sparsely distributed lipids in the form of minute droplets (Fig. 47D). Lipid distribution appears relatively high in differentiating vascular elements. The cambial cell have higher deposition of lipids during dormant period and cessation of activity (Fig. 47A). Ray cambial cells usually comprises more lipid content than fusiform cambial cells and mature vascular elements commonly show large amount of lipid globules.

The occurrence and distribution of lipids in the cambial cells of trees from DDF is more or less similar with that of MDF. However, their size and distribution decreases with the initiation of cambial activity and they are sparsely distributed as minute globules in August-September (Fig. 47E) when the cambial activity reaches peak. Lipid deposition increases with the decline of cambial activity and the cells are rich with large lipid globules at the time of cessation of cell divisions and when the cambium is dormant between February and May (Fig 47B).

In SF, the size and deposition of lipid bodies in dormant cambial cells and vascular elements decrease as the cambium becomes active. The lipid bodies in ray and fusiform cambial cells and their derivatives show similar distribution to that of MDF during dormant period in January and February. Small globules of lipids sparsely distributed along the walls occur in ray and fusiform cambial cells in September and October when the cambium is fairly active (Fig. 47F).

Proteins:

Both the cambial cells possess protein bodies in the form of small granules which stain blue with Coomisie Brilliant Blue. These granules are distributed in the lumen of cambial cells in all the three regions. During the inactive period of cambium they are uniformly distributed in cell lumen and along the cell walls They occur in the form of very minute granules along the cell walls and around the nucleus of cambial cells when the cells are actively dividing. Both the cambial cells in May in MDF and DDF and in February in SF show sparse distribution of protein bodies (Fig. 47G). Then they decline (Fig. 47H) in actively dividing cambial cells and appear feebly stained protein bodies in September, August and September-October (Fig. 47I) in MDF. DDF and SF respectively However, in all the three forests distribution of proteins in actively dividing cambial cells is similar until the cessation of cambial growth. Differentiating and mature vascular elements show negligible deposition of small protein bodies in all the forest types

TABLE : 24

Data on phenology, average number of cambial layers and differentiating xylem and phloem elements in the main trunk of Tamarindus indica growing in MDF.

Month	Phenology	Cambial layers	Xylem	Phloem
JAN	Full foliage with mature fruits.	5 ±0.89	27 ±3.14	2 ±0.73
FEB	Full foliage with mature fruits.	9 ±1.49	26 ±3.70	1 ±0 78
MAR	Full foliage with mature leaves, dispersal of fruits.	5 ±0.94	15 ±2.92	-
APR	Full foliage sprouting of young leaves , dispersal of fruits	5 ±0.70	-	-
MAY	Young leaves , full foliage.	5 ±1.06	-	-
JUN	Young leaves, full foliage, flowering.	8 ±1.02	24 ±4.31	3 ±0 71
JUL	Full foliage, flowering	9 ±1.09	33 ±3.97	3 ±0 5
AUG	Full foliage, flowering, fruit setting.	13 ±1.79	11 ±1.63	4 ±0.75
SEP	Full foliage, young fruits.	14 ±0.95	33 ±4.27	4 ±0 8
OCT	Full foliage, maturation of fruits.	16 ±1.82	35 ±3.91	3 ±0 73
NOV	Full foliage, maturation of fruits.	6 ±1.24	25 ±3.49	3 ±0.72
DEC	Full foliage, mature fruits.	8 ±1.15	30 ±4.08	3 ±.70

TABLE : 25

Data on phenology, average number of cambial layers and differentiating xylem and phloem in the main trunk of Tamarindus indica growing in DDF.

Month	Phenology	Cambial layers	Xylem	Phloem
JAN	Full foliage with mature leaves, fruits.	5 ±0.74	11 ±1.16	2 ±0.62
FEB	Full foliage, mature fruits.	5 ±0.71	6 ±2.03	-
MAR	Full foliage, dispersal of fruits.	5 ±0.96	-	-
APR	Full foiage, dispersal of fruits	4 ±0.80	-	-
MAY	Sprouting of young leaves, full foliage	4 ±0.71	-	-
JUN	New leaves, full foliage, flowering.	5 ±0.82	-	-
JUL	Full foliage with flowers.	8 ±1.35	15 ±3.12	2 ±0.65
AUG	Full foliage, fruit setting	13 ±1.77	30 ±3.45	3 ±0.89
SEP	Full foliage, young fruits,	9 ±0.42	17 ±3.1	3 ±0.81
OCT	Full foliage, maturation of fruits.	6 ±1.33	21 ±4.15	3 ±0.78
NOV	Full foliage, maturation of fruits.	8 ±0.98	28 ±3.42	3 ±0.66
DEC	Full foliage with mature fruits.	5 ±1.15	13 ±1.04	2 ±0.75

TABLE : 26

Data on phenology, average number of cambial layers and differentiating xylem and phloem in the main trunk of Tamarindus indica growing in SF.

Month	Phenology	Cambial layers	Xylem	Phloem
JAN	Full foliage, with mature leaves, fruits.	4 ±0.76	3 ±0.84	-
FEB	Full foliage, young and mature fruits.	5 ±0.94	-	-
MAR	Full foliage, mature fruits.	6 ±1.16	-	-
APR	Sprouting of young leaves, dispersal of fruits	5 ±0.79	-	-
MAY	Full foliage, dispersal of fruits.	8 ±0.09	16 ±2.68	3 ±0.69
JUN	Full foliage, with young leaves, flowering.	6 ±0.94	18 ±4.20	3 ±0.69
JUL	Full foliage, flowering	8 ±0.92	23 ±3.86	3 ±0.56
AUG	Full foliage, flowering , fruit setting.	8 ±0.86	25 ±2.88	4 ±0.69
SEP	Full foliage, young fruits,	9 ±1.36	32 ±3.96	4 ±1.37
OCT	Full foliage, maturation of fruits.	9 ±0.36	32 ±4.64	3 ±0.90
NOV	Full foliage, maturation of fruits.	6 ±0.78	25 ±3.10	2 ±0.75
DEC	Full foliage, development of flower buds, mature fruits.	5 ±0.76	15 ±2.85	2 ±0.82

TABLE : 27

Diamensional details of fusiform cambial cells (µm) in the main trunk of <u>Tamarindus</u> <u>indica</u> growing in MDF, DDF and SF.

Month	Length			Tangential width			Radial width		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	360 ±3.83	381 ±5.95	341 ±5.07	16 ±0.98	18 ±0.82	15 ±0.82	7 ±0.75	6 ±0 72	7 ±0.71
FEB	338 ±5.71	357 ±5.52	334 ±6.03	16 ±1.86	16 ±1.21	19 ±1.37	5 ±0.85	7 ±0.63	7 ±0.68
MAR	334 ±5.69	342 ±6.96	321 ±7.19	20 ±1.19	20 ±1.71	22 ±1.32	8 ±0.76	8 ±0.60	7 ±0.58
APR	380 ±7.63	306 ±7.03	309 ±8.09	16 ±1.06	18 ±1.61	17 ±1.48	6 ±0.83	7 ±0.81	7 ±0.51
MAY	363 ±6.02	350 ±7.96	369 ±7.63	17 ±1.07	16 ±1.1	16 ±1.34	7 ±0.65	7 ±0.67	5 ±0 71
JUN	356 ±7.38	337 ±7.08	365 ±8.05	21 ±1.5	21 ±1.75	17 ±1.45	5 ±0.78	5 ±0.85	4 ±0 58
JUL	343 ±6.35	320 ±7.04	330 ±6.61	18 ±1.50	18 ±1.88	19 ±1.63	4 ±0.51	5 ±0.75	4 ±0 50
AUG	388 ±7.02	352 ±7.60	323 ±5.40	16 ±1.14	18 ±1.68	18 ±1.73	3 ±0.69	4 ±0.86	4 ±0.65
SEP	358 ±6.22	316 ±5.47	299 ±4.74	20 ±1.37	16 ±0.94	20 ±1.77	4 ±0.50	4 ±0.51	4 ±0.82
OCT	348 ±6.14	307 ±6.09	335 ±5.38	18 ±2.12	17 ±1.30	17 ±1.63	4 ±0.49	5 ±0 76	6 ±0.58
NOV	345 ±6.29	349 ±7.04	342 ±6.16	17 ±1.12	16 ±0.08	17 ±1.35	4 ±0.50	6 ±0.82	7 ±0 58
DEC	342 ±5.13	340 ±6.15	344 ±5.76	15 ±0.84	15 ±0.79	21 ±1.61	4 ±0.87	7 ±0.58	8 ±0.56

TABLE : 28

Diamensional details of cambial ray cells (µm) and their population in one cm tangential width of cambium in the main trunk of <u>Tamarindus</u> <u>indica</u> growing in MDF, DDF and SF.

Month	Height			Width			Ray cell diameter			Ray population		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	223 ±3.04	236 ±2 88	212 ±4.33	24 ±2.85	24 ±2.38	26 ±2.69	20 ±1 63	13 ±1 77	16 ±1.99	200 ±15 0	175 ±19.78	174 ±18 25
FEB	194 ±8 74	232 ±6.26	227 ±4.61	25 ±1.9	26 ±3.28	26 ±3.72	17 ±1.77	15 ±1.82	18 ±2.8	180 ±9.07	160 ±11 15	170 ±17 19
MAR	212 ±8.21	210 ±7.06	275 ±7 55	32 ±4 29	29 ±4 13	39 ±6 80	21 ±2.11	20 ±2.92	22 ±2.61	200 ±14 5	170 ±20.85	130 ±13 51
APR	199 ±8 45	200 ±7.69	196 ±8 94	37 ±4 21	30 ±5 20	36 ±5.77	20 ±2.26	17 ±1.73	16 ±1 85	180 ±10 8	160 ±20 46	120 ±10 80
MAY	228 ±7 06	249 ±7.21	202 ±8.15	31 ±4 75	31 ±3.71	31 ±5.17	19 ±2 78	16 ±1.86	19 ±2.52	170 ±13.1	140 ±11 16	170 ±15 83
JUN	213 ±8.73	197 ±8.91	210 ±7.95	23 ±2.90	30 ±3.99	30 ±3.98	19 ±2 03	18 ±2 09	19 ±2.65	166 ±9.07	160 ±11.73	160 ±14 15
JUL	212 ±9 93	177 ±7.10	205 ±8.52	22 ±2 96	23 ±3 15	28 ±4 27	18 ±2 26	17 ±1.58	21 ±2.62	162 ±12.4	150 ±16.12	150 11.21
AUG	259 ±9 26	223 ±8 36	196 ±3.80	20 ±4 33	26 ±2.56	24 ±3.83	17 ±3.35	19 ±3.22	19 ±2.11	160 ±13 1	150 ±15.30	170 9 92
SEP	186 ±5 21	186 ±5 52	193 ±8.80	29 ±4.96	28 ±5 12	37 ±4 34	20 ±2.18	16 ±1.62	17 ±2 56	158 ±9 57	149 ±13 31	162 ±10 00
OCT	232 ±3 68	185 ±10 88	190 ±3 61	26 ±2 54	30 ±3 16	27 ±3 11	19 ±1 66	18 ±2 03	20 ±2 09	180 ±11 5	180 ±14.80	153 ±12.38
NOV	208 ±3.12	184 ±6.79	189 ±4.26	23 ±2 95	22 ±3 55	25 ±3 92	20 ±1.87	16 ±1.47	17 ±1 82	188 ±13 6	195 ±9 88	150 ±18 85
DEC	192 ±9 09	180 ±8.82	180 ±5 31	23 ±3 37	25 ±1 89	32 ±5.72	18 ±1.67	14 ±1 35	20 ±3 01	195 ±9 35	188 ±11.80	147 ±7 81

TABLE : 29

Dimensional details of vessel elements (μm) and average number of vessels per 0.5 mm^2 in the main trunk of Tamarindus indica growing in MDF, DDF and SF.

Month	Length			Width			Lumen diameter			Number of Vessels		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
JAN	193 ±6 964	258 ±10 39	248 ±6 96	116 ±6.05	187 ±6 29	148 ±3 83	68 ±2 45	88 ±4 74	77 ±4 00	16 ±2 14	14 ±1 70	14 ±2 08
FEB	253 ±7 25	255 ±8 37	243 ±7 81	113 ±5 68	115 ±9 78	169 ±5 37	95 ±3 34	81 ±4 99	166 ±6 59	17 ±2 03	14 ±1 52	20 ±2 87
MAR	262 ±6 71	216 ±8 81	240 ±6 39	163 ±11 00	132 ±5 92	190 ±5 55	75 ±4 24	64 ±3 27	84 ±5 13	19 ±2 13	15 ±1 26	18 ±2.92
APR	215 ±8 80	198 ±7 54	252 ±8 80	140 ±3 21	143 ±3 59	149 ±4 49	71 ±2 43	60 ±2 91	82 ±3 23	28 ±4 26	17 ±1 56	17 ±1 46
MAY	230 ±9 78	283 ±6 42	230 ±6 88	138 ±3 49	162 ±5 92	145 ±4 68	67 ±4 84	73 ±4 48	77 ±3 6	23 ±2 40	15 ±1 87	15 ±2 82
JUN	235 ±7 21	250 ±9 55	200 ±6 70	142 ±5 45	152 ±8 89	135 ±3 30	89 ±2 72	76 ±4 33	73 ±3 08	15 ±2 13	13 ±1 72	16 ±2 15
JUL	214 ±10 16	239 ±7 52	227 ±6 92	146 ±2 35	140 ±6 58	134 ±2 36	92 ±2 13	80 ±3 63	70 ±3 40	13 ±2 86	12 ±1 41	14 ±1 90
AUG	203 ±13 68	227 ±10 89	230 ±7 85	149 ±6 32	132 ±8 92	130 ±5 85	96 ±4 26	70 ±3.24	75 ±2.89	10 ±2 76	11 ±1 55	13 ±1 77
SEP	259 ±9 01	217 ±5 63	213 ±9 88	156 ±9 96	135 ±5 68	143 ±2 18	118 ±4 00	76 ±4 22	82 ±3 02	9 ±2 77	10 ±2 20	12 ±2 52
OCT	243 ±7 49	234 ±5 60	224 ±8 1 3	131 ±2 63	136 ±5 52	139 ±4 21	89 ±3 50	94 ±3 50	96 ±3 08	11 ±1 91	9 ±1 33	11 ±1 59
NOV	236 ±7 97	245 8 38	229 ±9 08	124 ±2 16	148 ±5 59	166 ±5 31	86 ±2 93	107 ±3 72	97 ±4 79	12 ±1 55	12 ±1 96	10 ±1 39
DEC	235 ±6 88	250 ±8 55	235 ±7 05	121 ±2 6	150 ±4 26	146 ±3.20	84 ±2 67	80 ±5 16	98 ±3 39	14 ±1 17	15 ±2 01	11 ±1 48

TABLE . 30

Dimensional details of sieve tube elements (µm) in the main trunk of Tamarindus indica growing in MDF, DDF and SF.

Month	MDF		DDF		SF		Fibre length		
	Length	Width	Length	Width	Length	Width	MDF	DDF	SF
JAN	302	21	267	23	298	21	1176	1200	1230
	± 6 87	±1.62	±6 18	±2 12	±6 29	±2 83	±22 66	±14 66	±9.27
FEB	252	21	302	24	290	22	1162	1183	1182
	±6.13	±1.80	±5 66	±1 71	±5 03	±1 64	±18 71	±12 23	±8 87
MAR	287	22	289	23	289	21	1157	1094	1165
	±1.06	±1.77	±5 95	±2 97	±5 57	±3 25	±17 14	±12.32	±13.91
APR	298	22	286	20	277	20	1274	1088	1075
	±5.18	±1 42	±5 13	±1 47	±5 78	±1 09	±14 01	±9 47	±9 86
MAY	274	22	304	22	271	22	1252	1167	1180
	±4 94	±1 33	±5 33	±4 14	±3 83	±1 4	±14 41	±13 98	±14 62
JUN	289	22	285	25	283	22	1214	1136	1138
	±4 71	±1.58	±6 89	±1 76	±4 22	±1 58	±17 54	±14 83	±13 95
JUL	296	22	270	23	268	23	1139	1123	1135
	±6 00	±4.33	±5 70	±2 16	±5 46	±1 41	±11 29	±13 62	±12 24
AUG	280	23	266	21	263	22	1281	1193	1132
	±7.12	±1 51	±6 35	±1 56	±5.76	±2.09	±12.68	±9 52	±14 50
SEP	283	24	292	22	261	21	1197	1185	1070
	±6 11	±2 06	±5 25	±1 66	±6 85	±1 37	±11 51	±11 45	±9 86
OCT	286	21	259	23	274	23	1164	1152	1146
	±6 29	±2 24	±5 04	±1 72	±5 55	±2.98	±11.64	±15 09	±11 93
NOV	298	22	286	24	286	23	1110	1176	1181
	±4 78	±1 64	±5 04	±1 96	±4 75	±1 50	±12 19	±9 78	±12 05
DEC	299	24	295	22	308	21	1195	1186	1193
	±6 24	±1.92	±5 05	±1.50	±6 45	±2 31	±10 80	±16 93	±17 51

TABLE : 31

Diamensional details (yearly average) of fusiform cambial cells in the main trunk of (1) Tectona grandis ,(2)Acacia nilotica ,(3) Azadirachta indica ,(4)Tamarindus indica growing MDF, DDF and SF.

No	Length (μm)			Tangential width (μm)			Radial width (μm)		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
1	344 ±29.7	310 ±41.67	-	26 ±1.76	23 ±1.97	-	7 ±1.16	7 ±1.27	-
2	330 ±49.1	300 ±29.42	310 ±47.41	20 ±2.87	17 ±3.12	19 ±3.04	5 ±0.75	6 ±0.90	6 ±0.96
3	394 ±32.2	377 ±34.44	369 ±41.00	21 ±1.56	24 ±2.83	22 ±0.90	6 ±1.05	6 ±0.89	6 ±0.96
4	354 ±16.5	338 ±12.01	334 ±20.34	18 ±1.93	17 ±1 93	18 ±2.08	5 ±1.56	6 ±1.33	6 ±1.52

TABLE . 32

Dimensional details (yearly average) of ray cambial cells and its population in one cm tangential width of cambium in the main trunk of (1) Tectona grandis (2) Acacia nilotica, (3) Azadirachta indica and (4) Tamarindus indica.

Nos	Height (µm)			Width (µm)			Ray cell diameter (µm)			Ray population		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
1	443 ±56 68	351 ±61 20	-	66 ±9 93	67 ±9 24	-	23 ±2.00	23 ±1 51	-	63 ±5.39	64 ±7 87	-
2	364 ±41 28	336 ±49 75	374 ±59 68	64 ±11 21	55 ±11 49	65 ±9 84	17 ±2 53	15 ±1 93	17 ±2 43	55 ±7 15	65 ±10 20	54 ±10 62
3	251 ±45 11	284 ±20 53	298 ±21 00	61 ±9 65	66 ±9 71	69 ±12 92	22 ±1 95	21 ±1 24	22 ±1 92	68 ±9 23	75 ±7 92	56 ±9 34
4	213 ±20 34	205 ±23 08	200 ±9.19	25 ±3 35	27 ±2 74	29 ±4.56	19 ±1.27	17 ±2 02	19 ±1 92	177 ±16 08	164 16 24	158 12 84

TABLE : 33

Dimensional details (yearly average) of vessel elements (µm) and average number of number of vessels per 0.5 mm^2 in the main trunk of (1) Tectona grandis, (2) Acacia nilotica, (3) Azadirachta indica, and (4) Taramindus indica.

No	Length			Width			Vessel lumen diameter			Number of vessels		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
1	234 ±31 33	224 ±18 94	-	178 ±33 00	197 ±33 74	-	124 ±46 30	113 ±36 68	-	12 ±2 31	12 ±2 10	-
2	231 ±33 36	213 ±16 52	188 ±25 00	227 ±24 52	219 ±27 98	208 ±24 26	158 ±26 98	156 ±34 83	150 ±35.35	15 ±4 91	13 ±5 46	17 ±6 94
3	267 ±26 93	275 ±19 58	253 ±23 17	208 ±26 16	241 ±22 59	186 ±23.14	133 ±15 53	150 ±14 13	131 ±19 63	15 ±1 28	12 ±2 39	11 ±3 39
4	233 ±21.74	239 ±22 74	231 ±14.54	137 ±15 87	144 ±18.03	150 ±17 34	85 ±15.20	80 ±12 24	85 ±11 62	17 ±4.83	13 ±2.35	14 ±3.07

TABLE : 34

Dimensional details (yearly average) of vessels in young branches and fibre length (µm) in the main trunk of (1) Tectona grandis, (2) Acacia nilotica, (3) Azadirachta indica and (4) Tamarandus indica growing in MDF, DDF and SF.

No.	Vessel Lumen diameter			Number of Vessels			Fibre Length (µm)		
	MDF	DDF	SF	MDF	DDF	SF	MDF	DDF	SF
1	65 ±26 26	60 ±24 73	-	21 ±2 91	25 ±4 72	-	1202 ±96 82	1152 ±77 59	-
2	72 ±10 31	75 ±12 24	74 ±11 09	12 ±3 78	13 ±1 99	14 ±2 04	1370 ±137 45	1380 ±76 30	1353 ±198 65
3	71 ±4 70	63 ±9 12	71 ±8 87	15 ±1 96	13 ±2.06	15 ±2 69	1235 ±91 35	1202 ±56 52	1142 ±88 22
4	–	–	–	–	–	–	1193 ±53 45	1157 ±38 44	11 52 ±46 74

Fig. 42: A-H: Transverse sections of cambium with the adjacent xylem and phloem of <u>Tamarindus</u> <u>indica</u>

A Dormant cambium in April from MDF. Cambial zone is surrounded by mature xylem and phloem elements. Note the thick radial walls (arrows) of cambial cells. X 350

B Initiation of cambial cell division in May from MDF. The narrow cells in the middle of cambial zone show recently formed thin tangential walls (arrows). X 400

C A wide cambial zone in October from MDF. The cambial zone is surrounded by differentiating xylem and phloem elements. X 240

D A wide cambial zone with differentiating xylem and phloem elements from MDF in February. X 260

E Dormant cambium in May from DDF. Note the thick radial walls (arrows). X 400

F Swelling of fusiform cambial cells followed by periclinal divisions in June from DDF. Note the thin radial walls of cambial cells (arrows). X 370

G Peak activity in August from DDF. The wide cambial zone is surrounded by differentiating xylem and phloem elements X 240

H Cessation of cambial cell divisions in January from DDF. Note the completion of phloem development while xylem elements are still undergoing maturation. X 400

CZ : cambial zone, DP. Differentiating Phloem, DX : Differentiating Xylem

Fig 43 A-F : Transverse sections of Cambium alongwith adjacent xylem and phloem in Tamarindus indica.

A Swelling of cambial cells in March prior to the initiation of cambial cell division in SF. X 330

B A wide cambial zone in August surrounded by differentiating xylem and phloem elements in SF. X 280

C Narrow cambial zone in February surrounded bu nature xylem and phloem elements in SF. X 370

D Loss (small arrows) and addition (large arrows) of fusiform cambial cells in cambial zone. X 270

E Cessation of phloem development in February marked by occurrence of parenchyma with phenolic contents close to the cambial zone in MDF. Note that the development of xylem is continued. X 144

F Differentiating xylem fibres in October during the grand period of Cambial cell division in SF. X 244

CZ : Cambial zone, PH : phloem, XY : Xylem DX : Differentiating Xylem

Fig 44 A-I Tangential longitudinal sections of cambium in _Tamarindus indica_

A Cambial cells in February showing storied arrangement in DDF. X 96

B Cambial cells in January showing nonstoried arrangement in MDF. X 96

C A pseudotransverse anticlinal wall (arrow) in one of the fusiform cambial cells in May from MDF. Note the beaded nature or radial walls and the length of the anticlinal wall that runs almost the entire length of the cell. X 150

D A periclinally dividing fusiform cambial cell. Arrows indicate phragmoplast on either ends of a short cell plate. X 240

E Active cambium in August with thin radial walls and elongated cell tips in MDF. X 108

F Short fusiform cambial cells in April in DDF. Note the abruptly ended cell tips. X 96

G Active cambium in October with elongated cell tips and thin radial walls in DDF X 96

H Intrusive growth of fusiform cambial cell resulting radial wall intrusion into cell lumen (arrow). X 240

I Forking of fusiform cambial cell tip (arrows) following intrusive growth. X 600

Fig. 45: Tangential longitudinal (A-D. F, I, J) and transverse (E, G, H, K) sections of cambium, xylem and phloem of Tamarindus indica.

A Development of ray cambial cells (arrowhead) from a fusiform cambial cell tip. Arrows indicate the tips of intrusively growing fusiform cambial cells. X 260

B Pseudotransverse (arrowhead) wall and forking of tips (arrow) in fusiform cambial cells. X 270

C Intercellular air spaces (arrows) in March among ray cambial cells in MDF. X 625

D Ray cambial cells in June with no intercellular air spaces in MDF. X 625

E Structure of phloem. Arrows indicate dispersed bands of phloem fibres X 150

F Functional sieve elements with slime plugs (arrows) and accumulation of callose on lateral sieve areas (arrowheads). X 96

G Xylem showing aliform parenchyma around the vessels. X 92

H Xylem showing radial multiples of vessels. X 92

I Xylem showing arrangement of axial parenchyma strands between a vessel and fibres. X 96

J Uniseriate rays which have become trapped between two tangentially adjacent vessel elements (arrows). X 240

K A growthring boundry in xylem marked by biseriate layer of initial parenchyma. X 132

Fig.46: Radial longitudinal sections of cambium, xylem and phloem of _Tamarindus indica_.

A Distribution of starch in ray cambial cells in February in MDF. X 470

B Ray cambial cells devoid of starch grains in December in DDF. X 470

C Starch free ray cambial cells in May in MDF. X 400

D Distribution of starch in ray cambial cells in September in SF. X 430

E Xylem axial arenchyma filled with oval-circular starch grains in SF. X 240

F Xylem axial and ray parenchyma cells devoide of starch grains in January in MDF. X 150

G Heavy accumulation of starch in axial parenchyma of xylem in May in DDF. X 150

H Heavy accumulation of starch in axial parenchyma of xylem in May in MDF. Note that ray parenchyma are free of starch grains. X 100

I Distribution of starch in axial and ray parenchyma of xylem in September in SF. Note the xylem ray parenchyma free of starch grains. X 150

Fig 47: Radial longitudinal sections of cambium of <u>Tamarindus</u> <u>indica</u>.

A Distribution of lipid bodies in fusiform cambial cells (arrows) in February in MDF X 600

B Distribution of lipid bodies in fusiform cambial cells (arrows) in May in DDF X 600

C Distribution of lipid bodies in ray cambial cells (arrows) in May in MDF X 600

D Scanty distribution of lipid globules in fusiform cambial cells (arrows) in September in MDF X 600

E Minute lipid globules in fusiform and ray cambial cells (arrows) in september in DDF X 600

F Distribution of lipid bodies (arrows) in ray cambial cells in September in SF X 600

G Distribution of protein bodies (arrows) in ray cambial cells in May in MDF. X 600

H Distribution of proteins (arrows) in fusiform cambial cells in May in DDF. X 600

I Minute protein bodies (arrows) in ray cambial cells in September in SF. X 575

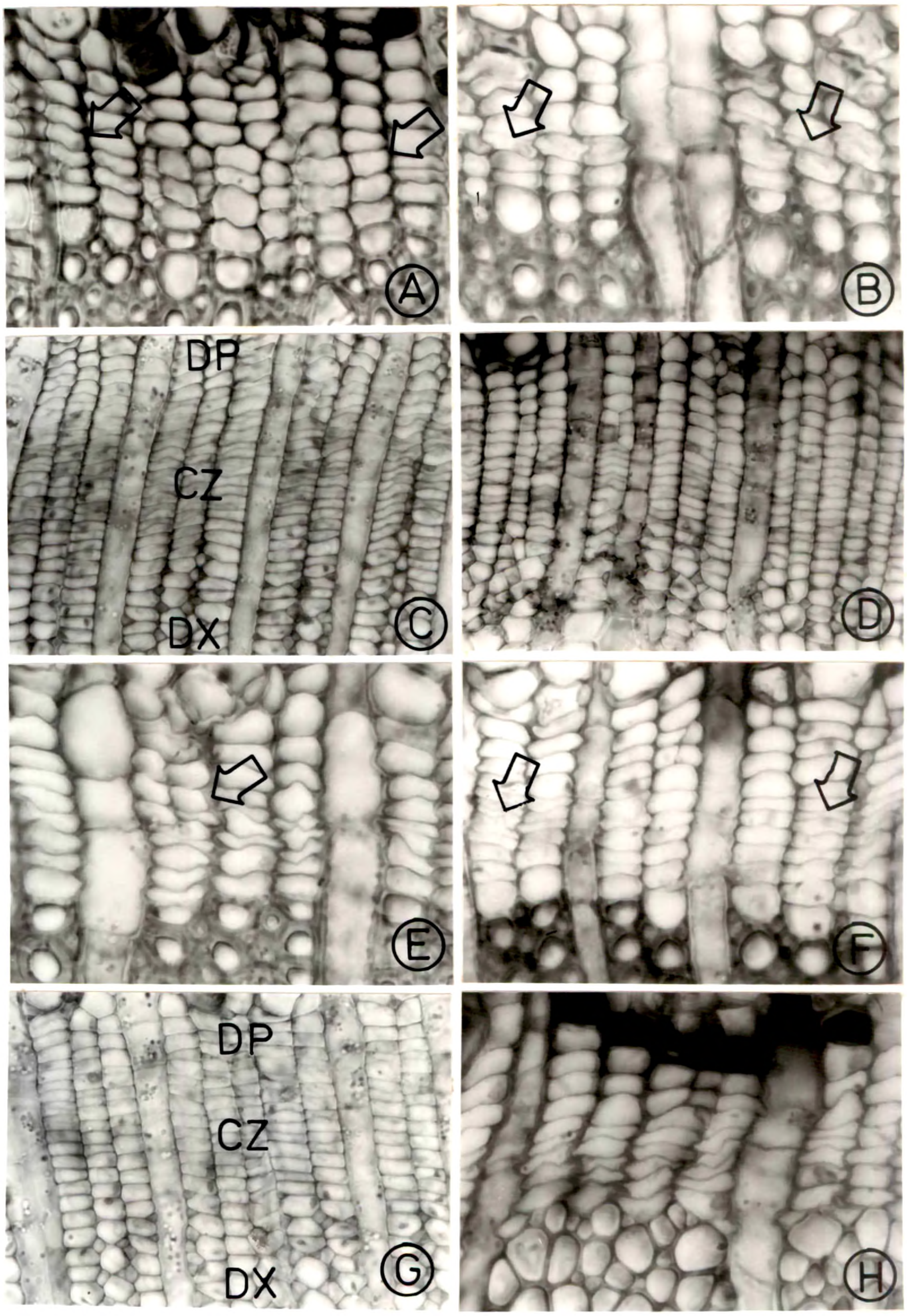


FIG. 42

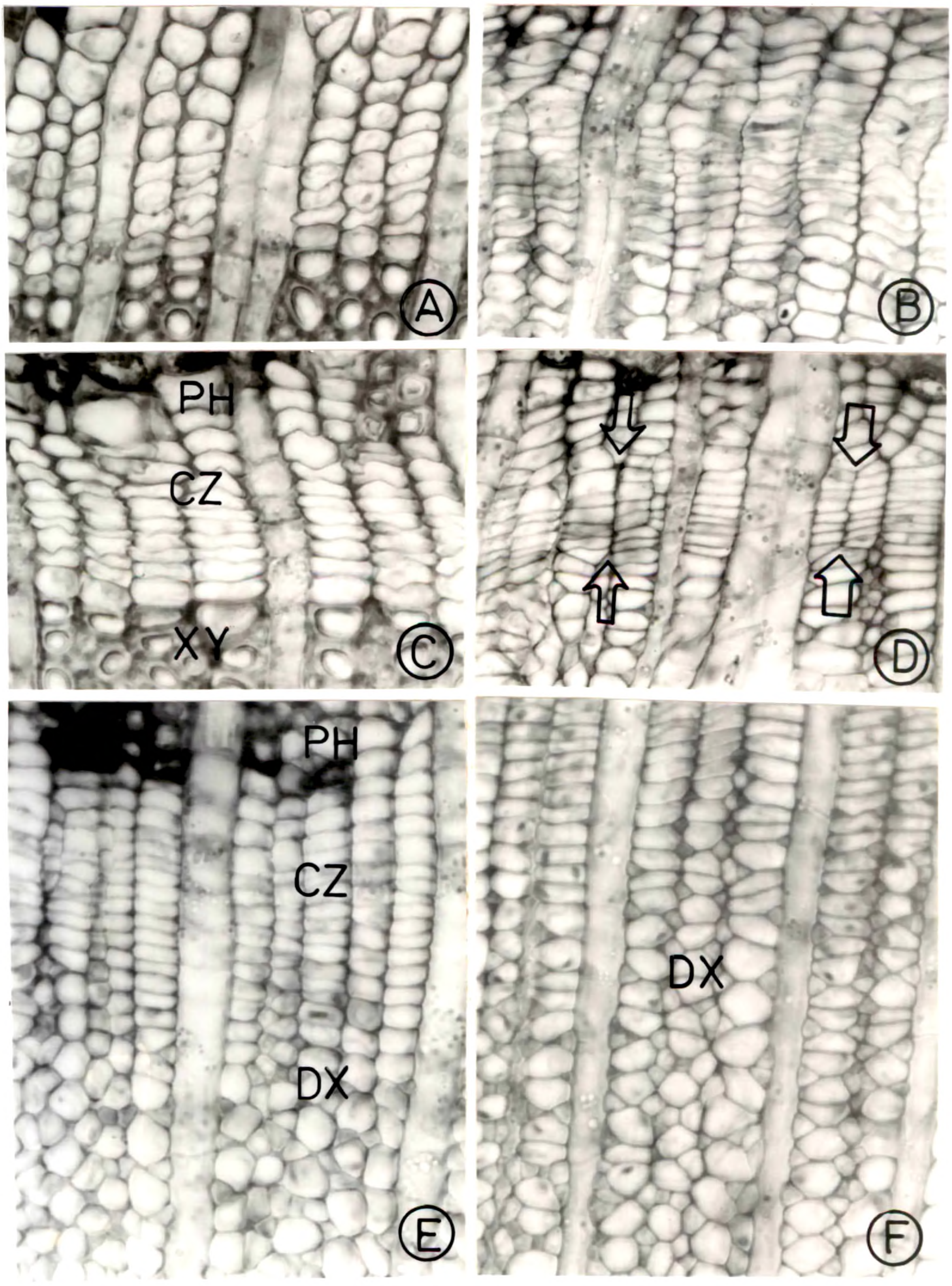


FIG. 43

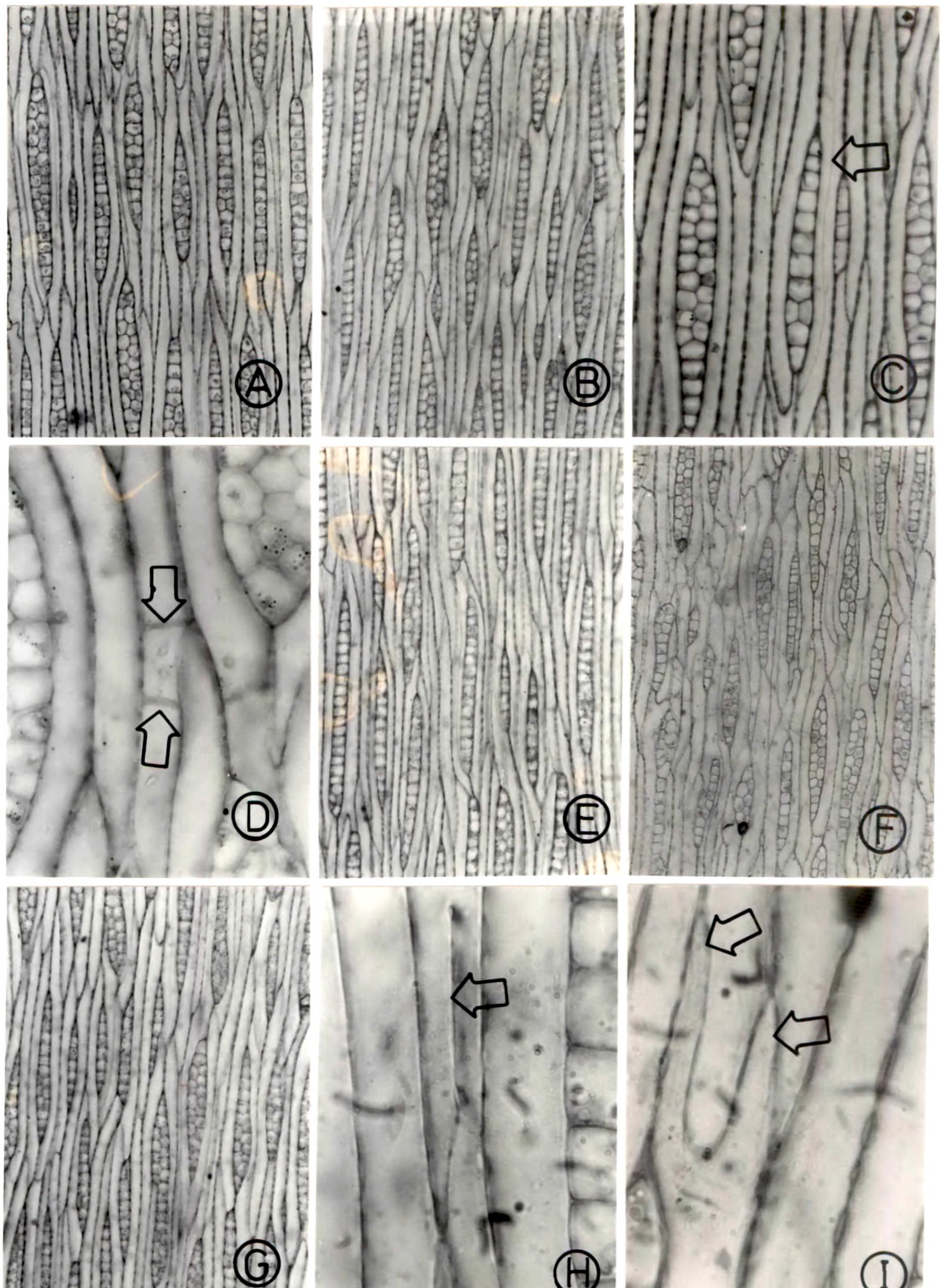


FIG. 44

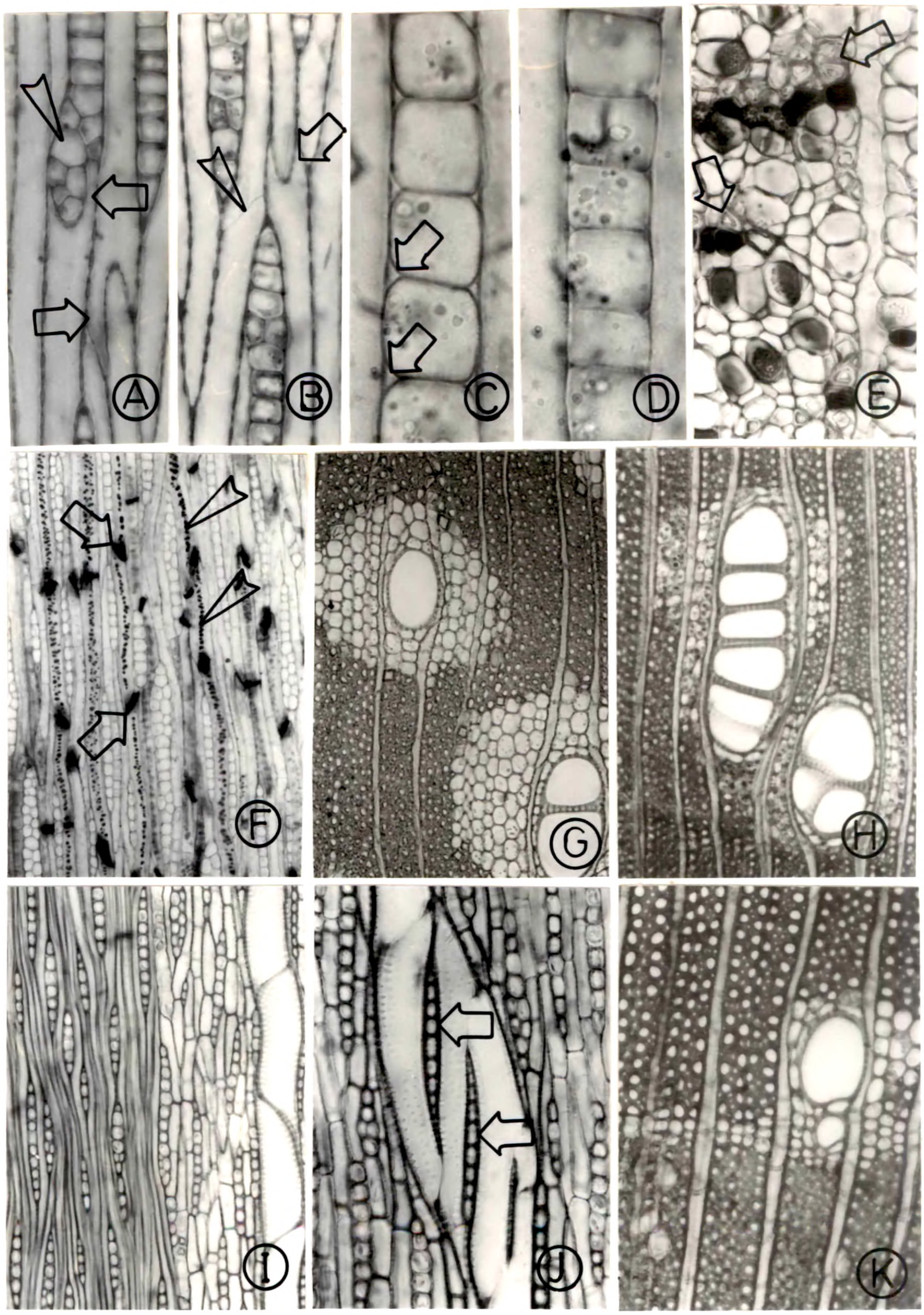


FIG. 45

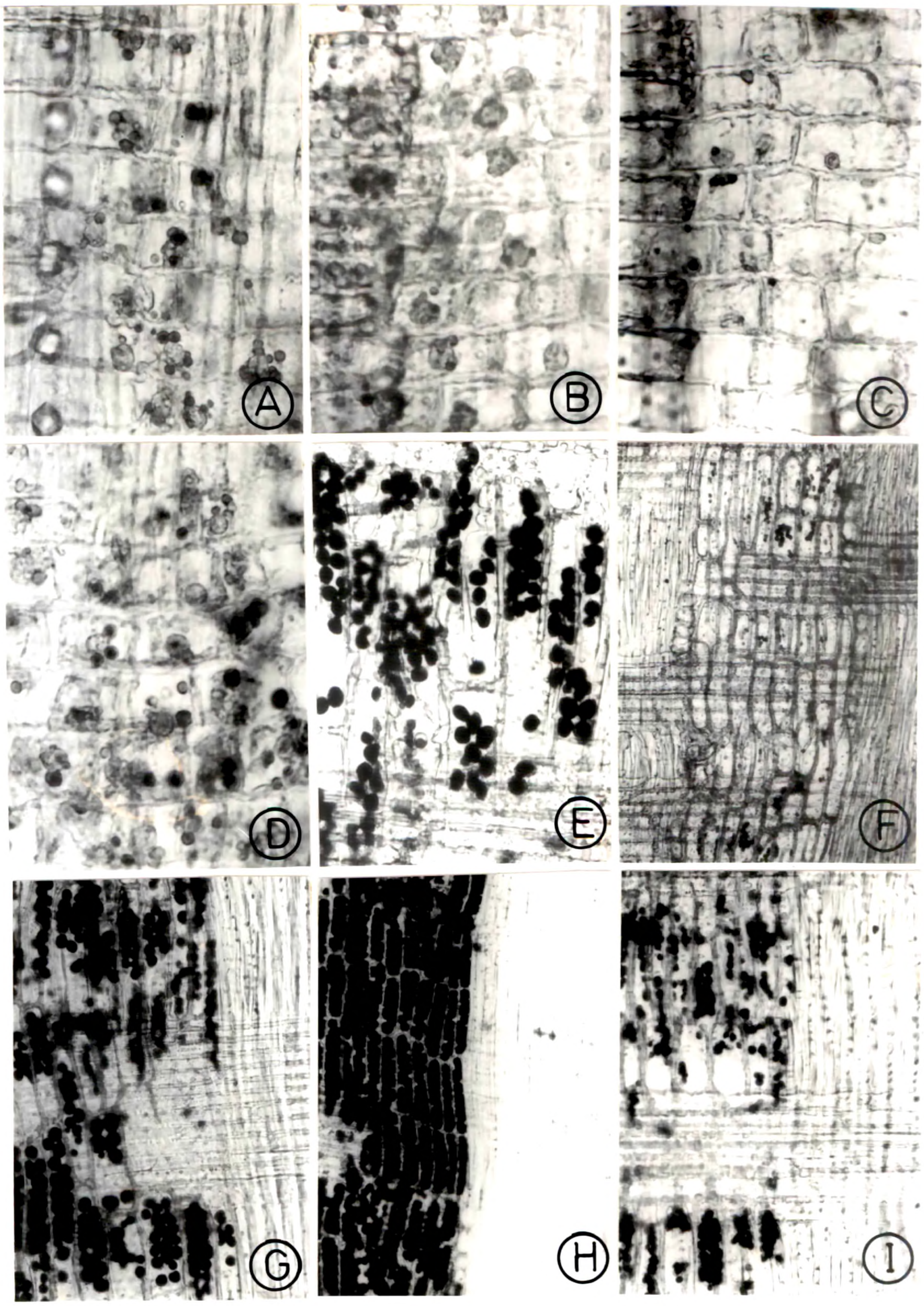


FIG. 46

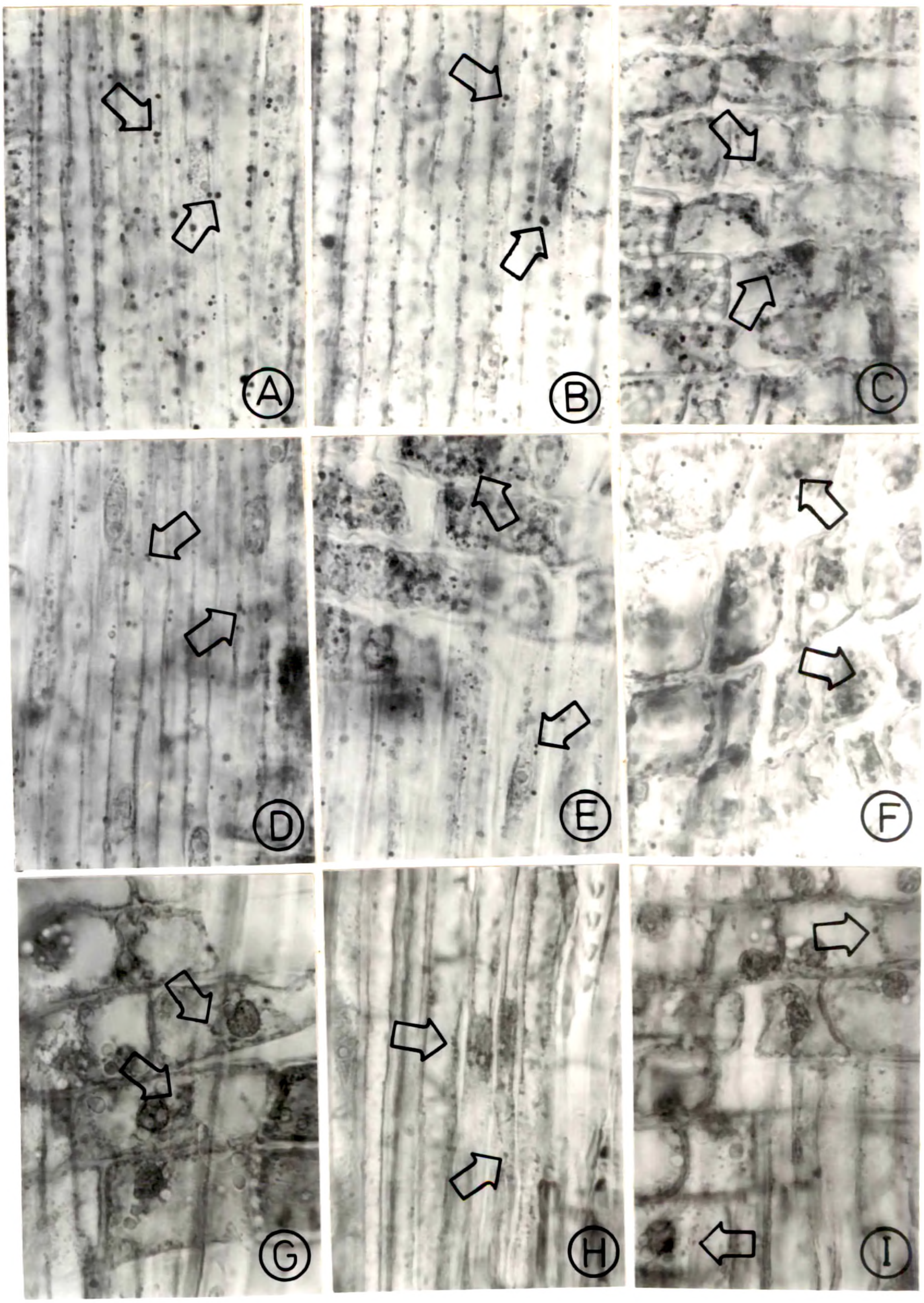


FIG. 47

Fig. 48

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Tamarindus indica growing in MDF.

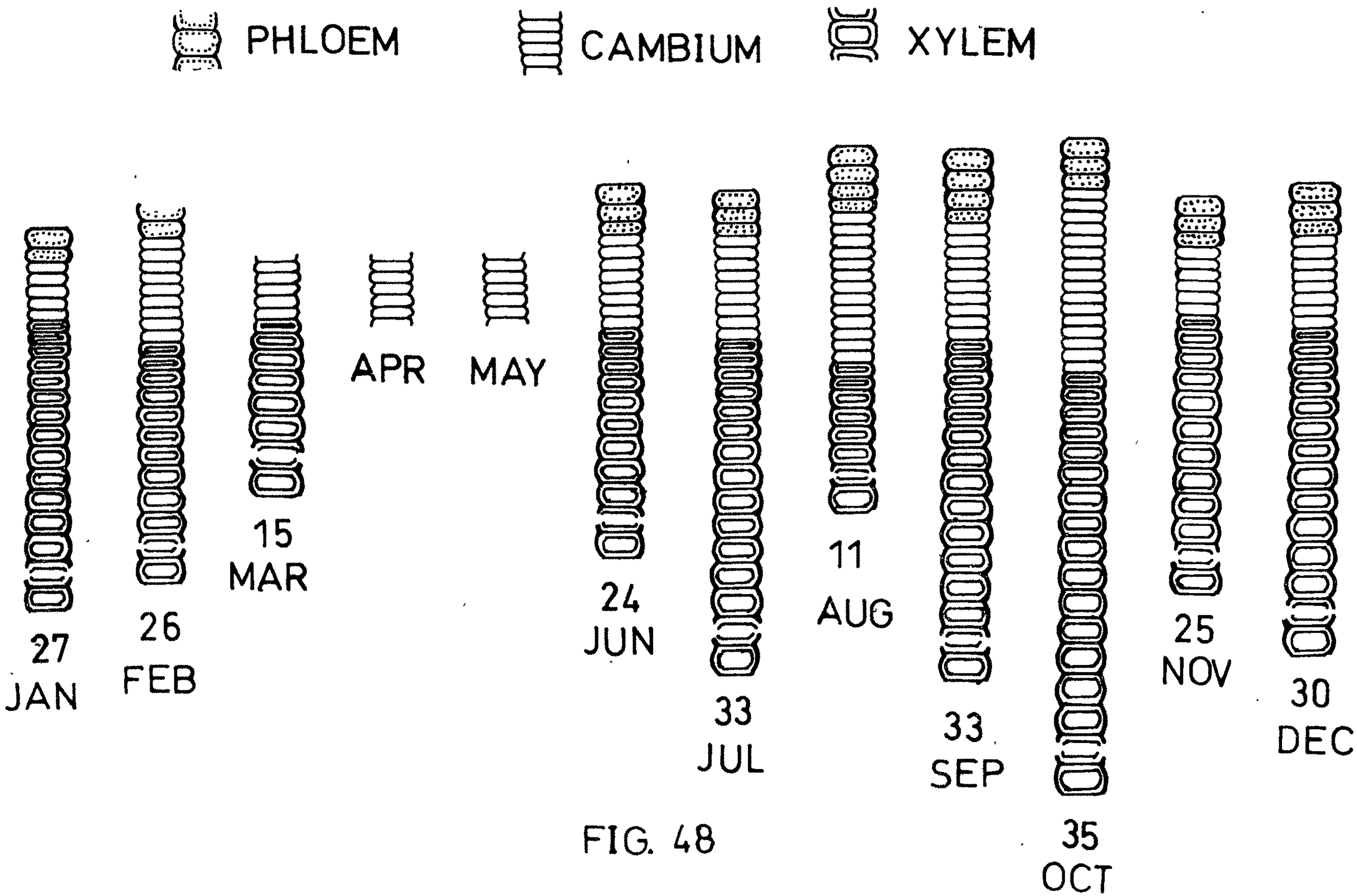
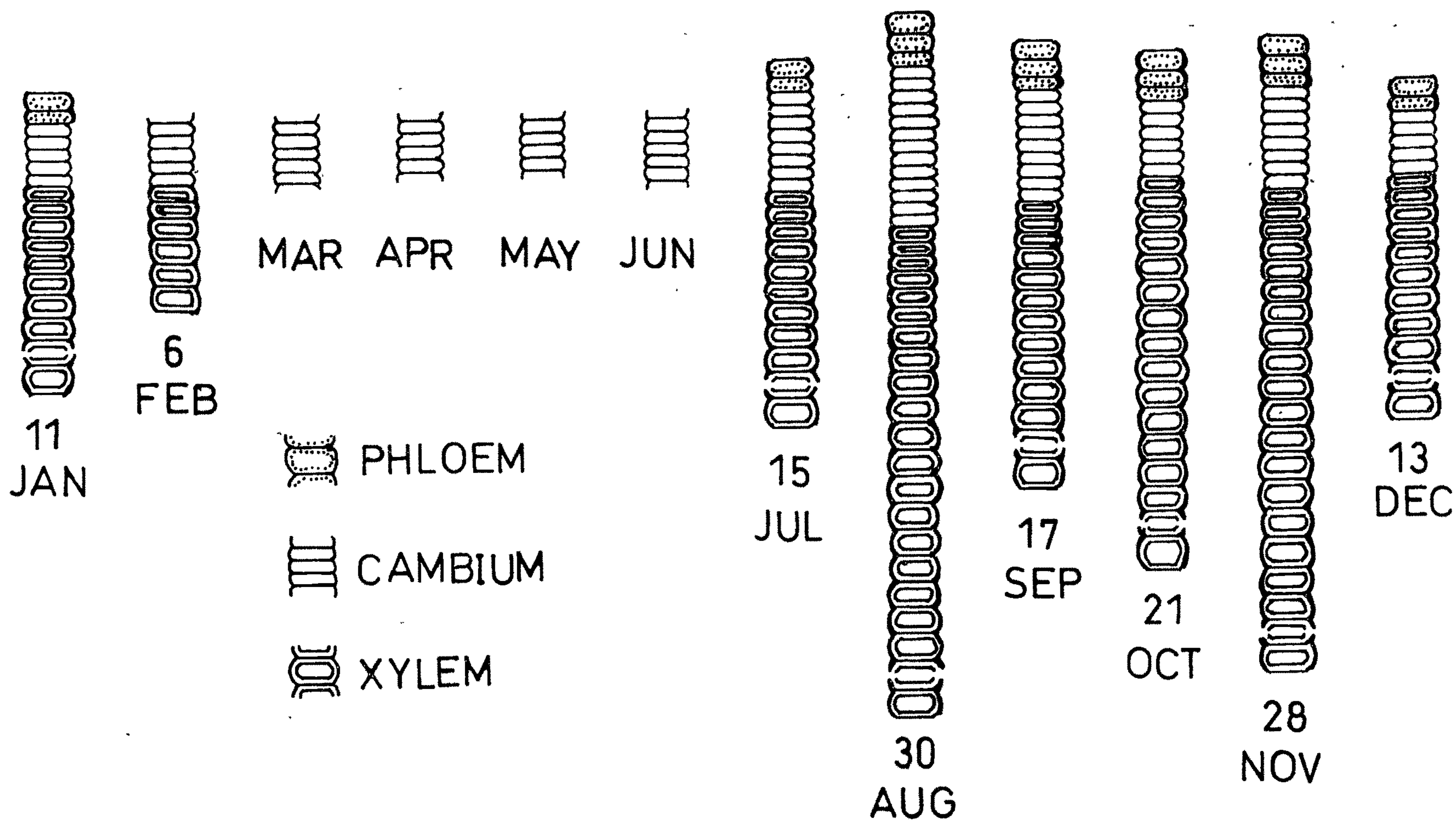

PHLOEM
CAMBIUM
XYLEM
27
JAN
26
FEB
15
MAR
APR
MAY
24
JUN
33
JUL
11
AUG
33
SEP
35
OCT
25
NOV
30
DEC

FIG. 48

Fig. 49

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Tamarindus indica growing in DDF.



11 JAN
6 FEB
MAR
APR
MAY
JUN
15 JUL
30 AUG
17 SEP
21 OCT
28 NOV
13 DEC
PHLOEM
CAMBIUM
XYLEM

FIG. 49

Fig. 50

Schematic diagram illustrating the seasonal variation in the mean number of cell layers in cambial zone and differentiating xylem and pholem elements in the main stem of Tamarindus indica growing in SF.

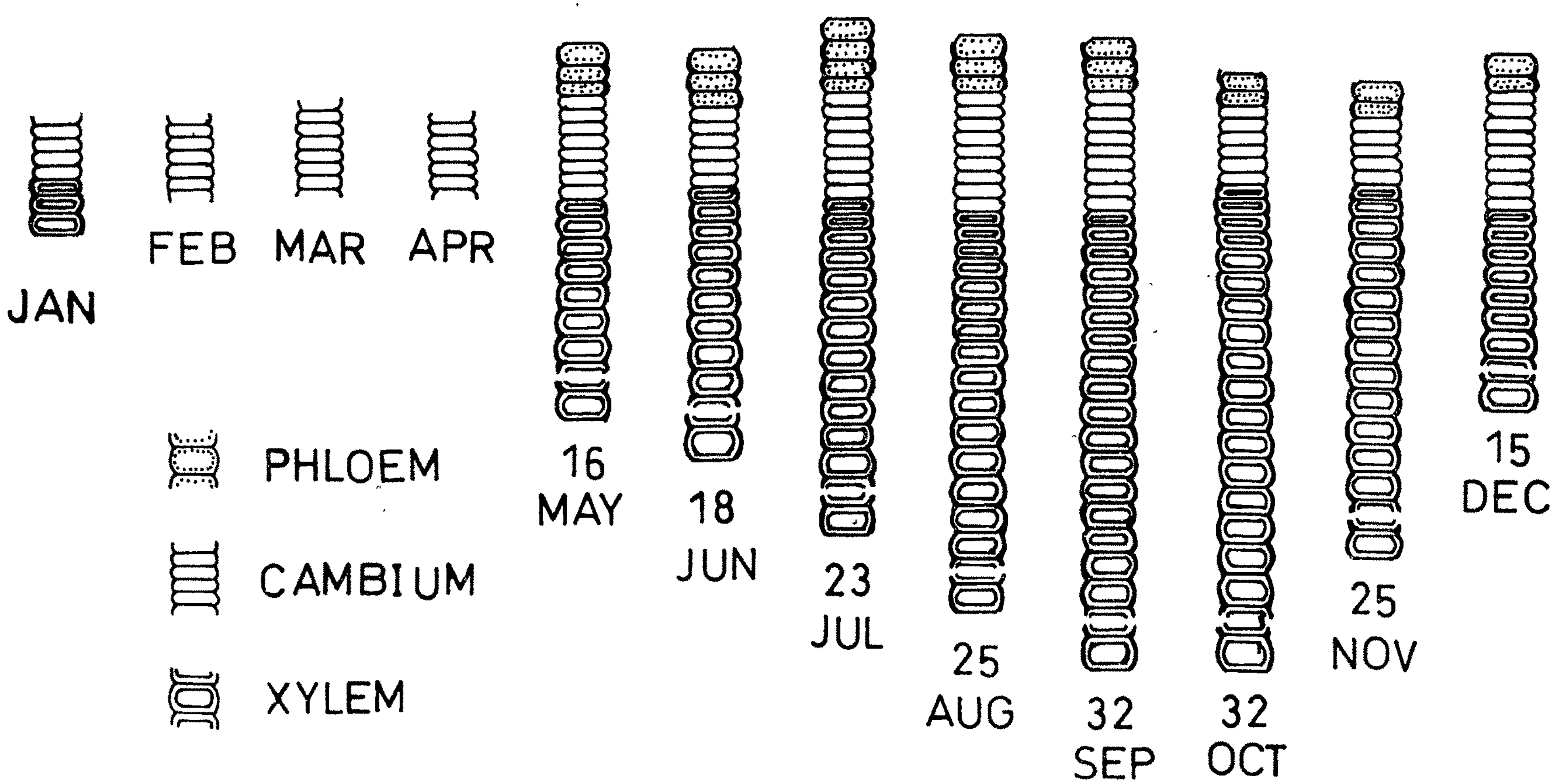

JAN
FEB
MAR
APR
16
MAY
18
JUN
23
JUL
25
AUG
32
SEP
32
OCT
25
NOV
15
DEC
PHLOEM
CAMBIUM
XYLEM

FIG. 50

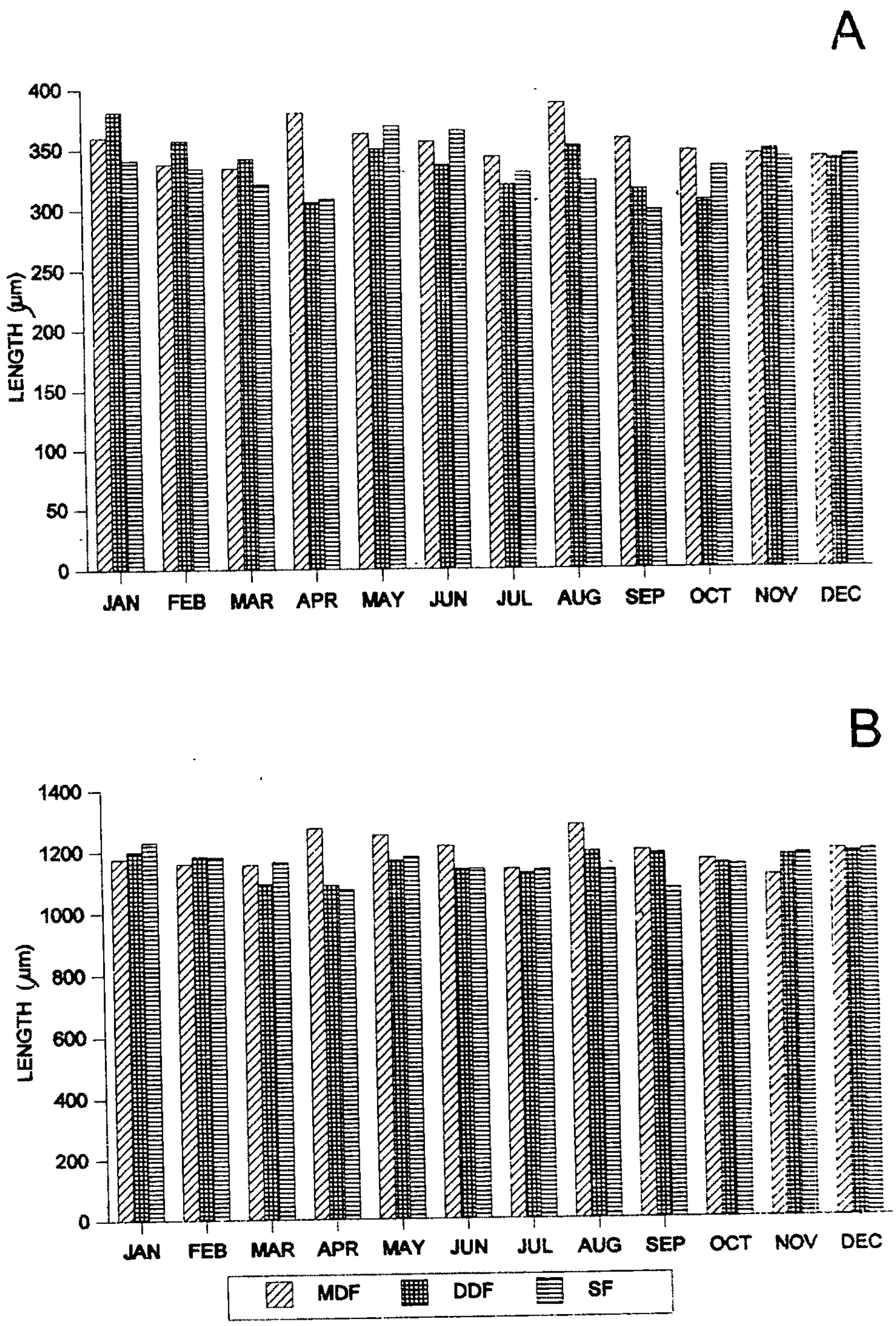
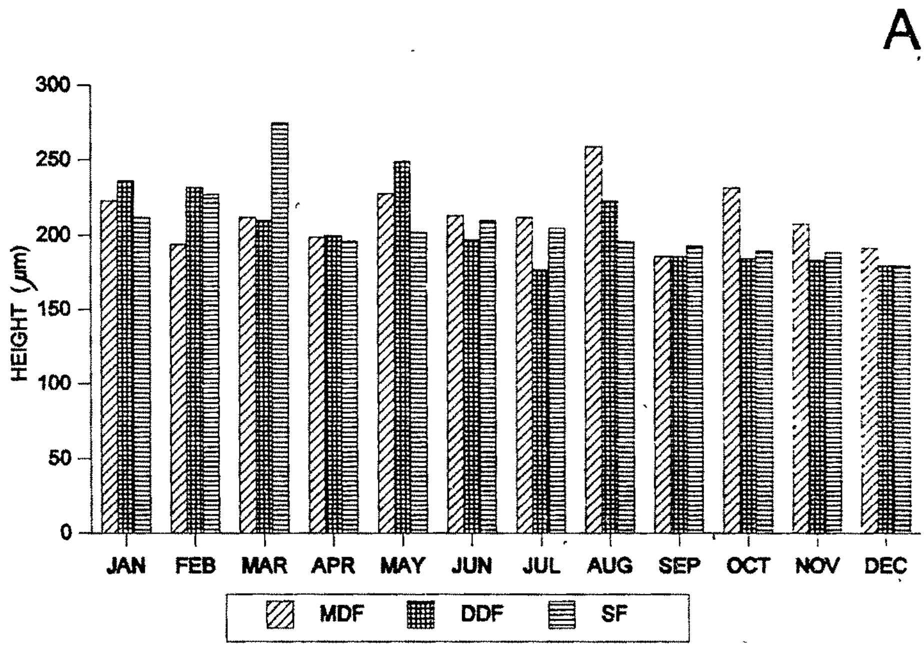


Fig. 51 Histograms showing seasonal variation in mean length of fusiform cambial cells (A) and xylem fibres (B) in Tamarindus indica.



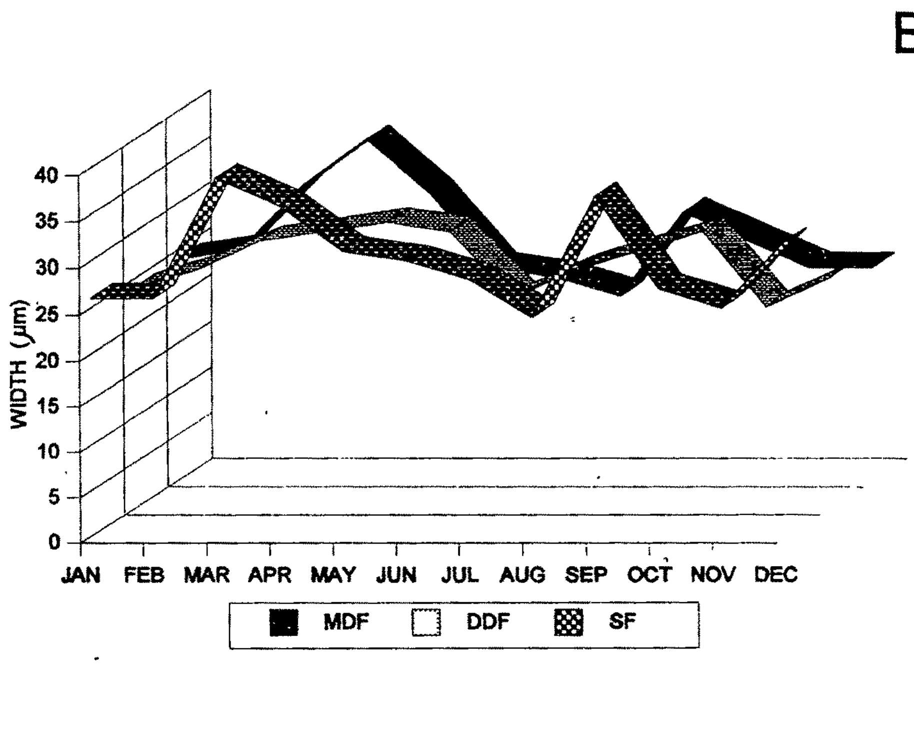


Fig. 52 Graphic representation of seasonal variation in cambial ray height (A) and ray width (B) in Tamarindus indica.

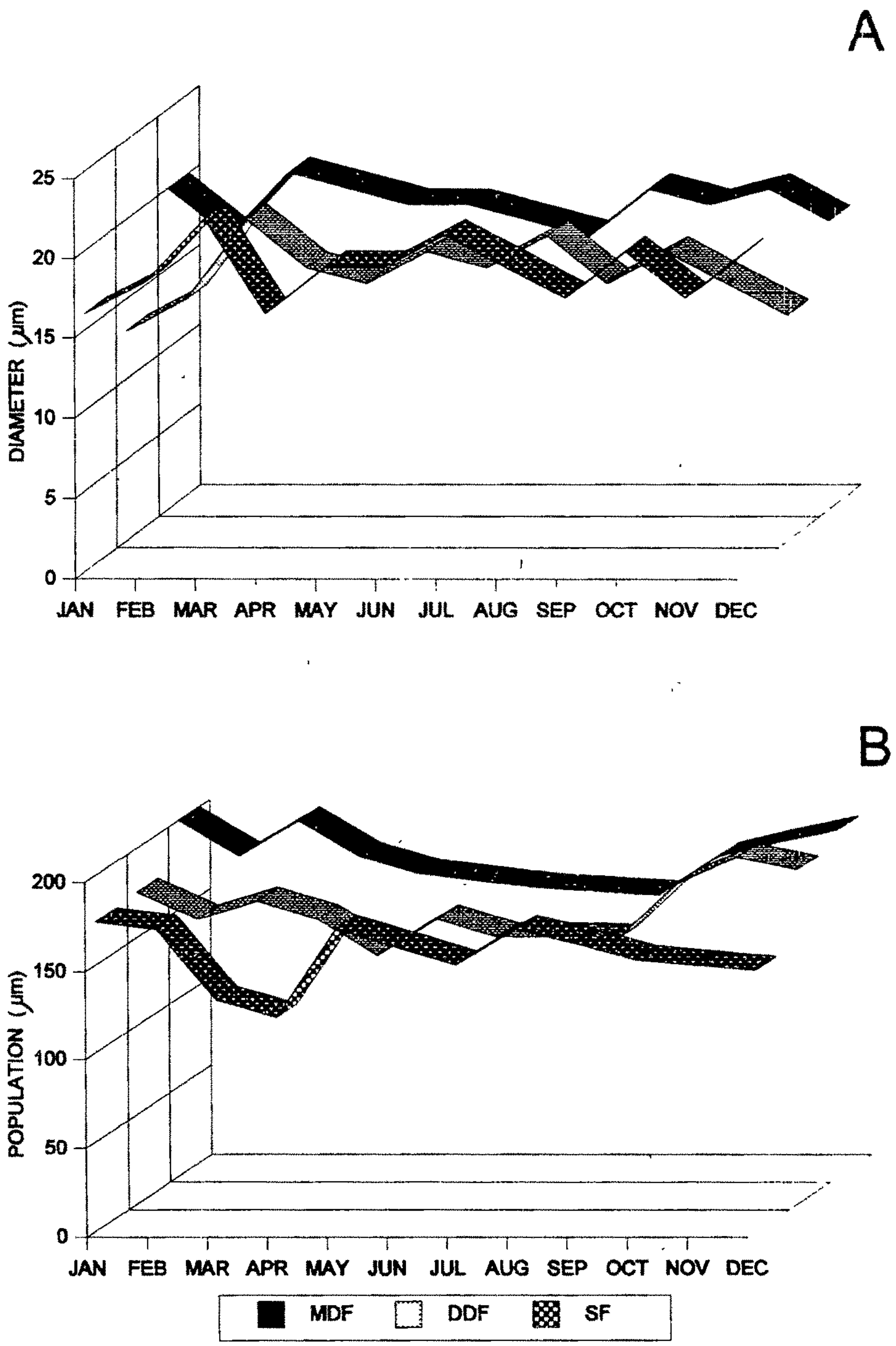
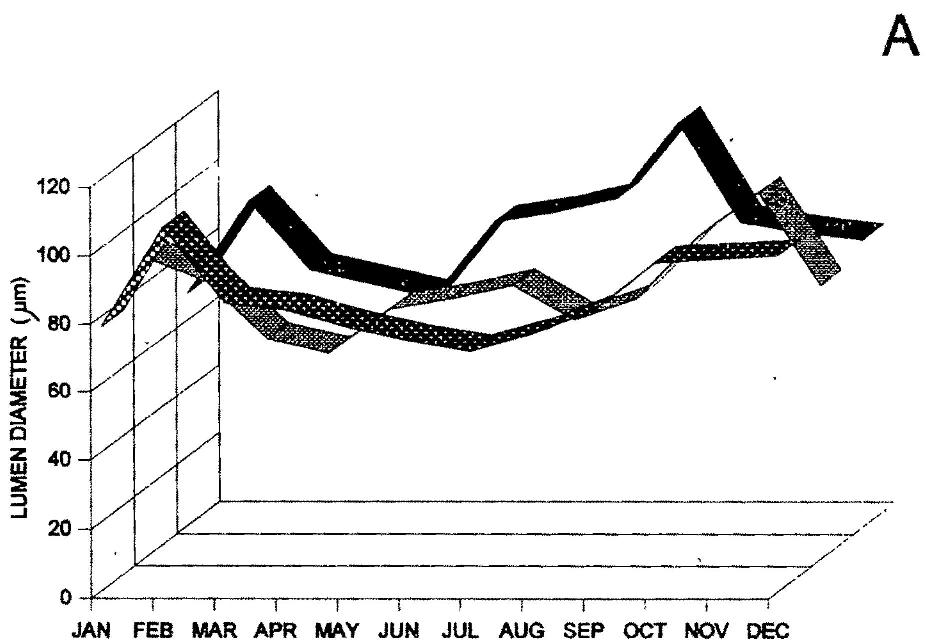


Fig. 53 Graphic representation of seasonal variation in ray cambial cell diameter (A) and ray population in 1cm tangential width of cambium (B) in Tamarindus indica.



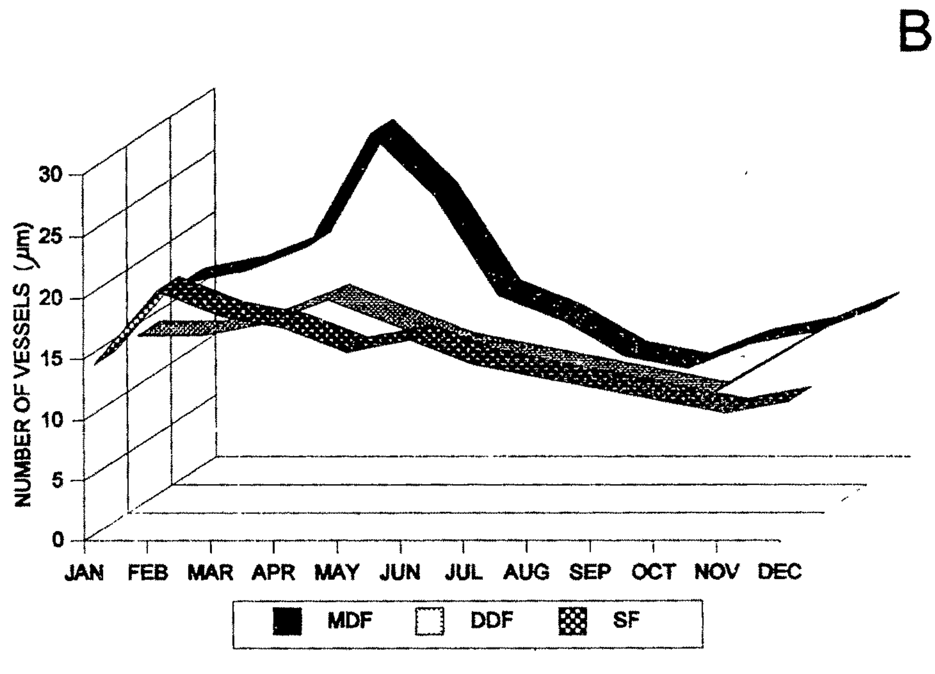


Fig. 54 Graphic representation of seasonal variation in vessel lumen diameter (A) and number of vessels per 0.5 mm2 (B) in Tamarindus indica.