

VI. *On Polystelic Roots of certain Palms.* By B. G. CORMACK, M.A.
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(Plates XIX. & XX.)

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IT is a striking fact that throughout the vascular plants, however great the differences in the reproductive system and in the vegetative shoot, there is, nevertheless, a general sameness in the form and structure of the root.

This uniformity which characterizes the root is ultimately to be correlated with the uniformity of its function and environment. Botany and zoology alike afford many illustrations of the correlation between fixity in highly symmetrical environment and radial symmetry.

Van Tieghem made the root a starting-point for study of the symmetry of vascular plants, and has arrived at a new classification of tissues, involving the morphological conception of the *stele*. His views on the subject are now common property of botanists. His description of the polystelic condition of stems of *Pteridophyta* and of certain *Spermaphyta* has thrown a new light upon structures which were previously of a very puzzling nature. Roots, however, show, almost without exception, one normal central vascular cylinder or *stele*. Two exceptional forms are recognized and classed as polystelic, certain tuberous roots belonging to the *Cycadaceæ* and *Leguminosæ* respectively; and with polystelic roots must be classed certain abnormal Palm-roots now to be described.

The investigation was carried out on material from the collection made by Professor Bower in Ceylon, supplemented by specimens obtained during the re-potting of Palms in the Botanic Gardens of Edinburgh and Glasgow.

Thin normal roots of *Areca Catechu*, Linn., about 2 millim. thick, show a central *stele* of small diameter as compared with the thickness of the cortex. The proportions are indicated by Pl. XIX. fig. 1. The piliferous layer is, at least in places, cuticularized. The underlying cells of the cortex are sclerotic, forming an outer zone without intercellular spaces. From this there is a transition to an inner, thicker, more parenchymatous zone traversed by thick-walled sclerenchyma-cells. The rounded parenchyma-cells have the usual intercellular spaces between them; but in addition to these air-passages there are large radial rifts in the tissue, which extend between plates of cells twelve or even twenty deep radially. These rifts do not extend inward to the endodermis; thus the inmost layers of cortical parenchyma form a zone four or five cells thick, showing only the usual intercellular spaces. The endodermis is normal, a continuous zone of cells with stratified, pitted, lignified walls, thickened chiefly on the radial, inner-tangential,

and transverse walls. Thus most of the endodermal cells are thickened on five walls, but the usual thin-walled cells may be seen in the neighbourhood of protoxylem-groups.

The vascular cylinder is normal, central, and, proportionately to the cortex, small and concentrated, especially in comparison with thicker *Areca*-roots. Its conjunctive tissue is an uninterrupted mass of sclerenchyma; even the walls of the pericycle are mostly thick and woody.

The xylem- and phloem-strands have the usual radial arrangement. The xylem-groups are single and I-shaped or paired, and V- or Y-shaped, with a phloem-group in the fork; the significance of this variation will be subsequently referred to. The youngest vessels of the xylem-groups are large and constitute a conspicuous central ring.

Thicker roots of *Areca*, say about a centimetre in diameter, can be found, which are practically normal in structure. In these the cortical zone is relatively less bulky than in the thinner roots, and consequently the vascular cylinder is proportionately nearer the periphery. The piliferous layer and enclosed layers of the cortex are essentially the same as in the thinner roots. The cell-layers towards the periphery are thicker and more obviously sclerotic. The sclerenchyma-fibres of the deeper cortex are grouped in strong, definite strands, and the radial rifts are larger and more numerous.

With the large size and peripheral position of the vascular cylinder is associated the development of more numerous groups of xylem and phloem. These groups are larger than in thinner roots, yet the difference in size is not sufficient to bring the youngest vessels so near the centre. The conjunctive tissue is significantly different from that of the thin root just described. It does not extend to the centre as a continuous sclerenchymatous mass, but is so constructed as to leave a deeply-fluted central column, chiefly of parenchyma. Thus the arrangement of tissue is such as to show in transverse section sector-shaped masses of sclerenchyma united together and traversed by phloem and xylem proper, some of the phloem-groups being situated at the ends of the radiating arms of pith. In some sections, traversing the medulla there may be seen isolated strands of xylem surrounded by sclerenchyma, and sometimes accompanied by strands of phloem.

Thus far the structure of *Areca*-roots is seen to agree with Mohl's description of Palm-roots in general. At this point it may be noted that Mohl ('De Structura Palmarum,' Engl. transl. p. 49) wrote: "the cells immediately surrounding the central body contain on their inner side transverse fibrous thickenings like many anther cells," describing in these words the tissue now classified under the name endodermis.

A third type of section may be distinguished which differs from that just described only in that the vascular mass or stele is not a smooth cylinder or cone, but a longitudinally furrowed column; conformably with this the endodermis does not appear as a smooth circle in transverse section, but has a wavy outline; it is, however, perfectly continuous.

The kind of structure referred to as type three has been described for the roots of *Iriarteia*. Mohl (*loc. cit.*, Engl. transl. p. 50) wrote: "In the upper parts of many palm-roots, e. g. *Phœnix*, *Cocos*, fibrous bundles are scattered through the rind, while no trace of them is found in others. But the rather thick root of *Iriarteia exorrhiza* exhibits

more important deviations. A cross-section of it presents to the naked eye a star composed of brown lines, with obtuse, mostly bifid, rays. The microscope shows that this star is formed of crowded vascular bundles. Besides these, scattered vascular bundles occur singly in the centre of the star, but a central cord, like that of the other palm-roots, is wanting."

To this Hermann Karsten, who also gives a figure of the root (Die Veget. Palm., plate iii. fig. 3, and p. 63), replied that on comparing the structure described with the roots of the other Monocotyledons he should not have expected to find a central strand.

De Bary, grasping the relationship, wrote (Vergl. Anat., Engl. transl. p. 362) thus:—

"The roots of *Iriarteia*, finally, which are an inch in thickness, are distinguished from those last described, first by the fact that their bulky vascular mass is not cylindrical, but deeply furrowed, having in cross-section the form of a star with about ten blunt and usually bifid rays; further by the fact that the radial ring also is divided up into sclerenchymatous bundles, enclosing the vessels and phloem-groups, and radial bands of parenchyma, which are sometimes narrow, 1–2 layers in thickness, sometimes many-layered, and which separate the bundles from one another. The middle of the star also consists mainly of thin-walled parenchyma, often with lacunæ, which is directly continued into the radial bands of the ring, and in which bundles of sclerenchyma, each containing one or more vessels and phloem-groups, lie scattered. Inside each sclerenchymatous bundle the vessels are surrounded by 1–2 layers of parenchymatous cells, those of them which belong to the ring standing in direct connection with the many-layered pericambium. An endodermis, which is thickened here and there, appears according to Mohl's figure to surround the star. Finally, in the entire parenchyma, both of the star and of the cortex which surrounds it, numerous small bundles of sclerenchymatous fibres lie, each enclosing in its centre 1–2 thin-walled elongated elements (perhaps sieve-tubes?). The xylem-plates in the ring appear short and irregular in cross-section; their radial arrangement and alternation with the phloem-plates is according to Mohl's figure often indistinct, though in general to be recognized. The development of the elements, both in *Iriarteia* (Karsten) and in the roots of *Pandanus*, begins at the periphery of the ring, and in general proceeds centripetally. According to all these phenomena, the series of large roots just described are immediately connected with the type of monocotyledons as special cases, in which the anatomical differentiation becomes more varied, with the more considerable size."

A fourth type of transverse section of *Areca*-root may be recognized, in which the xylem, phloem, and appertinent sclerenchyma do not constitute an undivided column, but, on the contrary, form distinct masses having the structure and position of the outer parts of a series of steles, small in diameter. Conformably with this arrangement the endodermis is discontinuous, and shows as arcs of small circles (Pl. XIX. figs. 3, 4, 5).

In a fifth type, in place of some of the portions of small steles, there are entire steles surrounded by a complete endodermis; and thus, in transverse section, complete circles of endodermis, corresponding with the arcs of small circles seen in the fourth type. The type is, in fact, polystelic (figs. 6, 13).

Between these five types there is continuity of transition. In fact, figs. 2, 3, 4, 5 are diagrams representing transverse sections taken from one somewhat tapering root.

Fig. 5 represents a transverse section cut at a distance of 150 millim. from the apex. The incomplete endodermis appearing as small arcs indicates that the structure is that of type four.

Fig. 4 shows a stage in the transition as seen in a section cut 115 millim. from the apex.

Fig. 3 illustrates that at 77 millim. from the apex the structure is simpler and approximates to that of type three, which has a single endodermis complete and wavy in its outline.

Fig. 2 was drawn from a section cut 15 millim. from the apex, where the structure is another stage in the transition, being practically that of type two.

The root from which fig. 6 was drawn had not attained sufficient length to illustrate fully the transition between complex and simple structure. However, between two transverse sections from parts not far separate considerable difference in degree of complexity could be seen. With a wider field for search a single root might well be found exhibiting at successive points examples of each of the five structural types which have just been distinguished for convenience.

This raises the question as to the nature of the histological changes associated with morphological differences in successive parts of an individual root. Two explanations offer themselves for examination :—

1st. Secondary changes may have produced the complex abnormality.

2nd. The apical meristem may have undergone continuous change in its mode of differentiation. According to the first view an abnormal part was once normal: according to the second it never was.

The fact that greater complexity is found in the basal older parts, less complexity in younger apical regions, with continuity of transition, is not at variance with either view.

The histological evidence obtained in the examination of these views is illustrated in part by Pl. XIX. figs. 7, 8, 9, 10, 11, 12.

Figs. 7, 8, 9 are diagrams showing the disposition of tissues in the neighbourhood of the points indicated by the arrows in the diagrams 3, 4, 5 respectively. Xylem and sclerenchyma are shaded dark; phloem and parenchyma, light. Larger vessels of the wood are shown unshaded and with double contour lines; large intercellular spaces, unshaded and with dotted contours. Endodermis is represented by a dark line.

Figs. 10, 11, 12 are drawings illustrating in greater detail tissues round the points indicated by the arrows in figs. 3 and 7, 4 and 8, 5 and 9 respectively.

If, according to the first view, increased complexity results from secondary changes, modifying dispositions which were simpler when younger, careful observation should detect histological evidence of such change; but the only peculiarities noticeable are such as might be expected from the development of sclerenchymatous masses in the neighbourhood of parenchyma.

Against this view, then, there is the negative evidence that, hypothetically, changes of great complexity, seemingly without parallel in any shoot, have been accomplished without leaving any trace of the process.

Further, there is evidence of a more positive character. The transverse section repre-

sented in fig. 3, cut 77 millim. from the apex, shows about one hundred groups of protoxylem; while a section 150 millim. from the apex (fig. 5) shows more than one hundred and twenty distinct groups; and cases more extreme could be cited. It is scarcely conceivable that secondary changes could accomplish this increase of a tissue like protoxylem-groups.

Thus the first explanation seems to be inconsistent with the evidence from anatomy and to have no parallel in any shoot. The second view, on the contrary, is consistent with both lines of evidence. Developmental studies have made familiar the idea of the apical meristem of a shoot altering its mode of differentiation while forming successively younger parts. For example, as regards vascular bundles with their protoxylem-groups, there is a numerical increase, as the plumule of a monocotyledon undergoes development; and there is numerical decrease in later-formed portions of an axis of *Equisetum*. Further, as regards steles, Leclerc du Sablon has shown that in many ferns, such as *Pteris*, a series of transverse sections of the same stem shows a change in number. It is true that in this case the number of steles increases in successively younger portions; but there is ultimately reduction to a single stele in *Nephrolepis*, and also in *Gunnera* and in *Primula Auricula*, as recorded by Van Tieghem and Douliot.

The following account of the changes in the mode of development of successively younger portions of complex *Areca*-roots is true also of roots of certain Palms to be mentioned afterwards. The changes are in part illustrated in the figures just referred to.

As regards the structure of the apex of these roots seen in longitudinal section, thin normal roots conform to the triacrorhize type usual in Monocotyledons; thicker roots show a structure which would doubtless be described by Van Tieghem as an "enchevêtrement de trois sortes d'initiales," a condition which, from Sachs's standpoint with regard to the disposition of walls in apical meristems, might well be expected.

In the transverse section of the older part of a root there may be several perfect steles, each surrounded by a complete endodermis, showing as circles; and also imperfect steles showing as arcs. These perfect steles are continued into younger parts in the form of imperfect steles with incomplete endodermis. Further, the imperfect steles are continuous with the single central stele of still younger portions, which includes for some distance isolated vascular strands in its pith.

In the course of the gradual transition to simplicity of structure, Y- or V-shaped groups of xylem become I-shaped, as a limb may cease to be developed in the younger portions, and correlatively the two phloem-groups that flanked the suppressed limb are, in the succeeding portions, represented by a single strand.

Further, two I-shaped groups of xylem with their surrounding sclerenchyma may be convergent in the younger portions, thus forming Y- or V-shaped groups with one surrounding mass of sclerenchyma.

Vascular groups forming the edges of imperfect steles are continued towards the apex as isolated strands traversing the pith; these strands consist of xylem and sclerenchyma, accompanied sometimes by phloem; they gradually cease to be developed, phloem earlier, xylem later; see isolated strand, *i.str.* in figs. 9, 8, 7.

The endodermis accompanying each imperfect stele is incomplete as such, merging

into sclerenchyma; and corresponding with the continuous change to the single large stele, there is a gradual change to the complete endodermal system of the normal root.

The changes just described seem best explained by assuming that in successively younger portions of the root the apical meristem has continuously changed its mode of differentiation.

With regard to other Palm-roots examined, roots of *Cocos nucifera*, Linn., were found showing, in all essential points, correspondence with the roots of *Areca* just described; the sclerenchymatous development was even stronger than that of *Areca*.

The very thick root of *Verschaffeltia splendida*, H. Wendl., available for examination showed an extraordinary degree of complexity represented diagrammatically in Pl. XX. fig. 14. The diameter of the diagram is twice that of the root. Fig. 15 shows one of the perfect steles—the stele indicated by *st.* in fig. 14; the magnification and scheme of lettering and shading are the same as in figs. 7, 8, 9. Fig. 14 indicates, so far as the very small scale will admit, the result of observations made under the same magnification as figs. 7, 8, 9.

Roots of other Palms were examined with the following result :—

- Type Four. *Seaforthia elegans*, R. Br. (*Ptychosperma elegans*, Blume).
- Type Three. *Dypsis*, sp.
Euterpe edulis, Mart.
- Type Two. *Ptychosperma filifera*, H. Wendl.
Ptychosperma Cunninghamii, H. Wendl.
Hyophorbe Verschaffelti, H. Wendl. (*Areca Verschaffelti*, Hort.).
Kentia Fosteriana, F. Muell.
Caryota sobolifera, Wall.
Geonoma pumila, Lind. et H. Wendl.
Corypha australis, R. Br.
Livistona chinensis, R. Br.
Phœnix dactylifera, Linn.
Phœnix sylvestris, Roxb.

As the range of specimens available for examination was very limited, it by no means follows that the degree of complexity just noted is the maximum for each species in question.

With regard to the physiological aspect of these various types of root-structure, reference has already been made to the correlated prevalence of uniformity in structure, function, and environment among roots; there remains for consideration the problem of adaptation in a few of its aspects interesting from the present standpoint.

As a living organ, the root respire and fulfils the special functions of absorption, conduction, insinuation, fixation. The root of a young plant must perform these and other subsidiary duties; and the problem of adaptation is most complex, involving a combination of delicacy, slenderness, and strength.

A root-system of an older plant, especially one with marked secondary changes, shows

greater differentiation and integration; and the problem changes as some of the functions become chief duties of the older parts.

A young root is long and slender, exposing a relatively large surface favourable to absorption and respiration; the cylindrical form exhibits this surface on all sides, and gives the concentration of bulk, which combines strength with a slenderness and flexibility that facilitates insinuation.

Length of root necessitates an efficient system of transport, in which the passage alike of crude and elaborated materials is protected from interruption due to bending or to pressure from without. The pressure which must sometimes act on roots is considerable, and it is the deeper-lying younger portions that will be most affected; the growth of the root itself sets up pressure, and consequent caking of the surrounding soil has been recorded. Against such pressure the relatively thick cortex provides a cushion at once efficient and flexible. The xylem, by its peripheral position in the vascular cylinder, and by its centripetal development, is placed as near the absorptive system as is consistent with safety; at the same time the phloem-strands obtain additional protection from their sunken position in grooves between the xylem-groups. As regards avoidance of pressure on the phloem, the advantage afforded by an arrangement in which the phloem is hidden between plates of woody tissue, as compared with the disposal of the phloem in a sheath round the xylem, is well illustrated in the structure of many climbing stems, where, as in the case of roots, the risks arising from lateral pressure are serious; thus, for example, in several *Asclepiadaceæ* and *Apocynaceæ* the phloem-strands are sheltered in peripheral grooves of the wood.

This advantageous arrangement is seen even in some of the abnormal roots of *Lycopodium* and of *Ophioglossum*, where the xylem takes the form of a crescent enclosing a phloem-group; but it is most apparent in polyarch roots.

Simultaneously, this arrangement safely and inexpensively meets strains due to tension; for there is a concentration of the more resistant tissues into a central strand; thus also the centripetal development of the xylem affords the further advantage of adding more woody tissue as greater demands are made on the young root. This tendency to concentration of woody tissue is seen in the rarity of a parenchymatous pith: either the xylem-plates approximate towards the centre, or the conjunctive tissue is largely a sclerenchymatous matrix for the vascular strands.

Such is the scheme of construction in a normal root unaffected by secondary changes, which attains a compromise between such incompatible conditions as exposure of surface with concentration; slenderness, flexibility, and delicacy with strength; together with due prominence of structures requiring shelter.

In plants having a secondary thickening, the function of mechanical support is undertaken by fit increase in older parts which no longer require to perform the duty of insinuation.

Loss of liquid in transport is hindered by the relative decrease of surface consequent on increased diameter, and further by the development of cork, the duty of absorption now devolving on younger parts of the root. The concomitant loss of facilities for respiration is compensated by the formation of pneumatodes, such as lenticels.

Schwendener and his school have shown that, while concentration of the mechanical tissues into a central strand adapts an organ to withstand tensions, a more peripheral position is advantageous in resisting bending; and Warming and G. Karsten have illustrated this by showing the correlation between stem-like function and stem-like structure in adventitious roots of Rhizophoraceæ.

Thus in roots with cambial developments there are changes amounting almost to a reconstruction on a different plan, together with a redistribution of duties. On the other hand, the Palm-roots in question undergo no such reconstruction, and the plants depend on having their earlier root-system supplemented and replaced by an adventitious system. The older roots are not altered: they are replaced by new and suitable roots. Of this nature are the complex roots at present under consideration. While the root of an oak begins thin and gradually grows thick towards the base, the roots in question begin thick, and grow thin towards the apex. In general there is a correlation between the presence of cambial growth and the absence of polystelic increase; here there is a bulky primary polystelic development and a gradual return to normal root-structure.

The figures show that the vascular system lies proportionately much nearer the periphery than it does in a young normal root: with this may be compared the disposition, similar from a mechanical standpoint, attained in other plants through secondary thickening. But the mechanical tissue is disposed centrally as well as peripherally, after a fashion which Schwendener and Haberlandt have shown enables an organ to withstand either flexion or tension. The sclerenchyma-strands previously mentioned are well fitted to resist such tensions. The peculiar disposition of the tissues comes out very clearly in the root of *Verschaffeltia* previously referred to and illustrated diagrammatically in Pl. XX. figs. 14 & 15. While capable of resisting flexion, the structure seems best adapted for resisting tensions as a rope would. The roots seem, on the whole, more of the nature of stays than props; but at first, before they have firmly fixed themselves in the ground, they must be mainly props.

As successively younger portions of the root are developed, the mode of differentiation of the meristem continually changes; the root anticipates its entry on normal environment and duties, and assumes normal root-structure. In this condition there is the relatively thick cortex, more or less sclerenchymatous, and possessing the strong endodermis, one of whose functions Schwendener has shown to be mechanical. The main mass of sclerenchyma, however, is the conjunctive tissue of the vascular cylinder, including the large pith.

From the observations thus described it will be seen that certain roots may show the unusual condition of a polystelic structure: further, that in an individual root there is a transition from a polystelic condition, through various stages previously mentioned as types, to normal monostelic form, with concentration of the mechanical tissues into a central strand adapted to withstand the strains to which roots are usually subjected.

The large radial rifts previously mentioned form an aerating system; their presence and size are to be correlated with the large bulk and relatively small surface of the roots, together with the continuity of the peripheral zone of sclerotic tissue uninterrupted by such openings as lenticels.

Warming has described a system of intercellular spaces in the aerial roots of *Rhizophora Mangle*, Linn., to which he ascribes the function of helping to float the young plants; and shows that these spaces are kept distended by the presence in them of branched cells (*trichoblasts*), and that in this way collapse due to the heat of the sun may be avoided.

G. Karsten makes further mention of such intercellular spaces in the Rhizophoraceæ, and recognizing their function calls them "*pneumatophores*." In this he coins a word having analogy with the term "*pneumatode*," which Jost has applied to all openings of the nature of lenticels or stomata. G. Karsten mentions Palms also in which pneumatophores occur. In the case of the Palm-roots in question, there are no trichoblasts, and the duty of keeping the spaces open can scarcely be ascribed to the sclerenchyma-strands. On the other hand, it must be noted that the spaces are very much larger than those of the Rhizophoraceæ; and, further, the peripheral sclerotic ring previously mentioned guards against collapse. Similarly, as G. Karsten has shown, a woody ring aids in preventing obliteration by compression in the case of the Rhizophoraceæ. It may be that the development of sclerenchymatous strands or trichoblasts leads up to the formation of the intercellular spaces associated with them.

There remains to be pointed out the surprising increase of facility for movement of a body of air due to even a slight increase in diameter of a pneumatophore. Fluids, whether liquids or gases, have, owing to their viscosity, a different mode of flow in wide and in narrow channels. The speed with which a body of fluid can be transferred through a capillary tube increases as the fourth power of the tube's diameter. As it is evident from the work of Clerk Maxwell and others that this is true for gases as well as liquids, the advantage of increase of diameter of the pneumatophores is obvious.

In the Palm-roots examined nothing of the nature of pneumatodes was discovered. This finds a parallel in G. Karsten's observation that while other Rhizophoraceæ have pneumatodes in the roots, especially at places of branching, species of *Ceriops* have none in the root, but have them on the stem close to the ground.

It is not likely that, in the case of such roots springing from a monocotyledonous stem, the stem-system of pneumatophores could be separate from the root-system; but as the material for the present investigation did not include stem, it was not possible to test the continuity.

The foregoing considerations lead to the following conclusions:—

Aerial roots from several species of Palms are polystelic in their older thicker parts, and there is a continuous transition to normal monostelic structure in their younger thinner parts.

This difference in structure is due to a continuous change in the mode of differentiation of the apical meristem.

The whole structure of the older aerial parts is such as to fit them for withstanding both pressure as props or tension as stays; while the thinner subterranean parts are normal in conformity with the normality of their functions and environment.

In correlation with the bulk of these roots, and the absence from them of pneumatodes, there is a conspicuous formation of pneumatophores.

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EXPLANATION OF THE PLATES.

end., endodermis ; *i.sp.*, intercellular space ; *i.str.*, isolated strand ; *p.*, phloem ; *l.r.*, lateral root ;
scl., sclerenchyma ; *st.*, a complete stele ; *v.*, vessel of the wood.

PLATE XIX.

Figs. 1-6. Diagrams illustrating various types of transverse section of *Areca* roots ; these types are distinguished merely for convenience, as there is perfect continuity of transition. The lines *end.* represent the endodermis, and with the aid of figs. 7-9 give an indication of the general disposition of the vascular system. $\times 1\frac{1}{2}$ diam.

Fig. 1. From a transverse section of a normal subterranean root of *Areca*, showing continuous endodermis and concentrated vascular cylinder.

Figs. 2-5. From sections of the same, somewhat tapering, aerial root of *Areca*. The arrows indicate corresponding points.

Fig. 2. From a section 15 millim. from the apex ; the vascular cylinder is more bulky, and relatively nearer the periphery than in fig. 1 ; the endodermis is almost circular in outline and is continuous.

Fig. 3. From a section 77 millim. from the apex ; the outline of the endodermis is markedly not circular and is discontinuous at several places ; it is, however, continuous at the point indicated by the arrow \uparrow (see figs. 7 & 10).

Fig. 4. From a section 115 millim. from the apex ; the endodermis is more markedly abnormal in outline and more discontinuous ; at the point indicated by the arrow, the endodermis is almost discontinuous (see figs. 8 & 11).

Fig. 5. From a section 150 millim. from the apex ; the endodermis shows even more marked abnormality in outline and greater discontinuity ; it is quite discontinuous at the point indicated by the arrow (see figs. 9 & 12).

Fig. 6. Diagram of a transverse section of a thicker aerial root of *Areca*, showing greater complexity of structure ; a small complete stele (*st.*) is indicated by the continuous endodermal outline. This stele is drawn in greater detail in fig. 13.

Figs. 7-9. Diagrams to illustrate the disposition of tissues in the neighbourhood of the points indicated by the arrows in diagrams 3-5 respectively ; xylem and sclerenchyma are shaded dark ; phloem and parenchyma, light ; large vessels of the wood are shown unshaded and with double contour-lines ; large intercellular spaces, unshaded and with broken contours ; endodermis is represented by dark lines ; *i.st.* is an isolated strand traversing the pith. $\times 25$ diam.

Figs. 10-12. Drawings illustrating in greater detail the tissues in the neighbourhood indicated by the arrow in figs. 3 and 7, 4 and 8, 5 and 9 respectively ; dots in cells indicate that they belong to endodermis. $\times 200$ diam.

Fig. 10 shows the endodermis continuous ; the cells are young, and their walls not much thickened.

Fig. 11 shows the endodermis merging into sclerenchyma and almost discontinuous.

Fig. 12 shows the endodermis quite discontinuous.

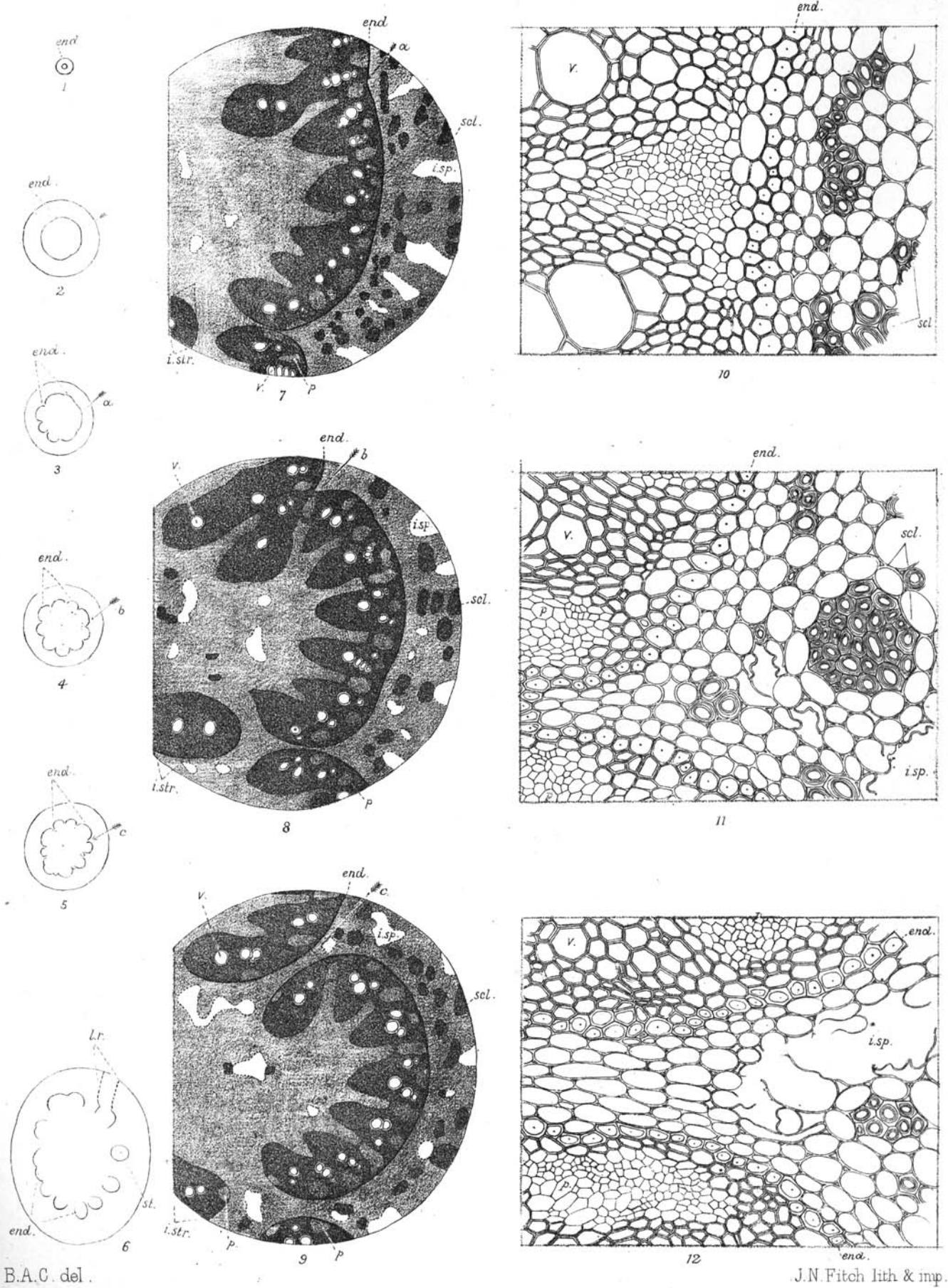
PLATE XX.

Fig. 13. Drawing from a transverse section of the small stele (*st.*) indicated in fig. 6; the cells of the endodermis are shown in their relation to the neighbouring cells of the cortex and of the pericycle; other features are indicated as in fig. 7. $\times 100$ diam.

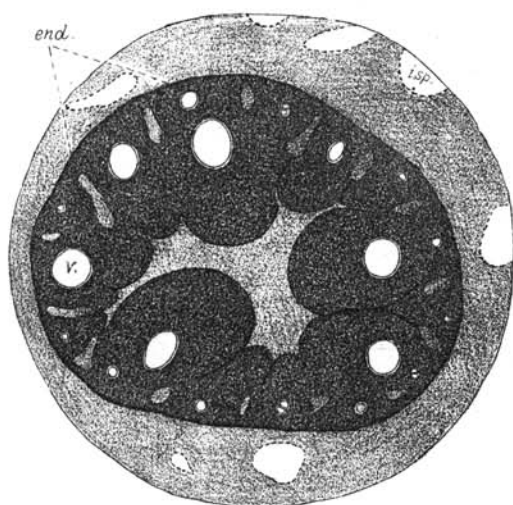
(In the absence of an objective possessing simultaneously field and magnification sufficiently great, this figure was obtained thus: a set of camera-lucida drawings was made under a magnification of 294 diameters; these sections were then accurately fitted together; a tracing was then made and the whole revised; that drawing has been reduced by the lithographer to a magnification of 100 diameters.)

Fig. 14. Diagram representing a transverse section of a thick root of *Verschaffeltia*; many incomplete and several complete steles are indicated; the complete stele (*st.*) is the one shown in fig. 15; large vessels of the wood are indicated by small circles. $\times 2$ diam. (The drawing was checked by observations under a magnification of about 60 diameters.)

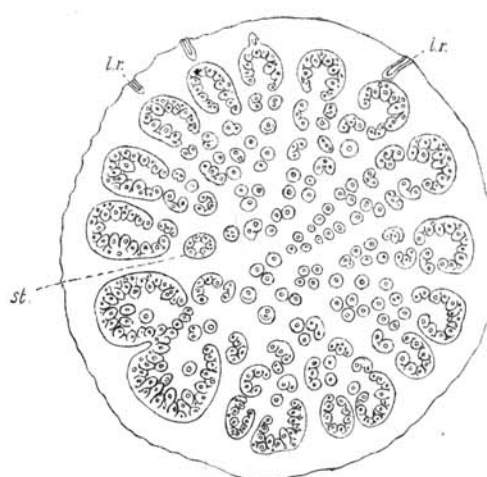
Fig. 15. Diagram to illustrate the disposition of tissues forming the stele (*st.*) in fig. 14; scheme of shading and lettering as in fig. 7. $\times 25$ diam.



POLYSTELEIC ROOTS OF PALMS.

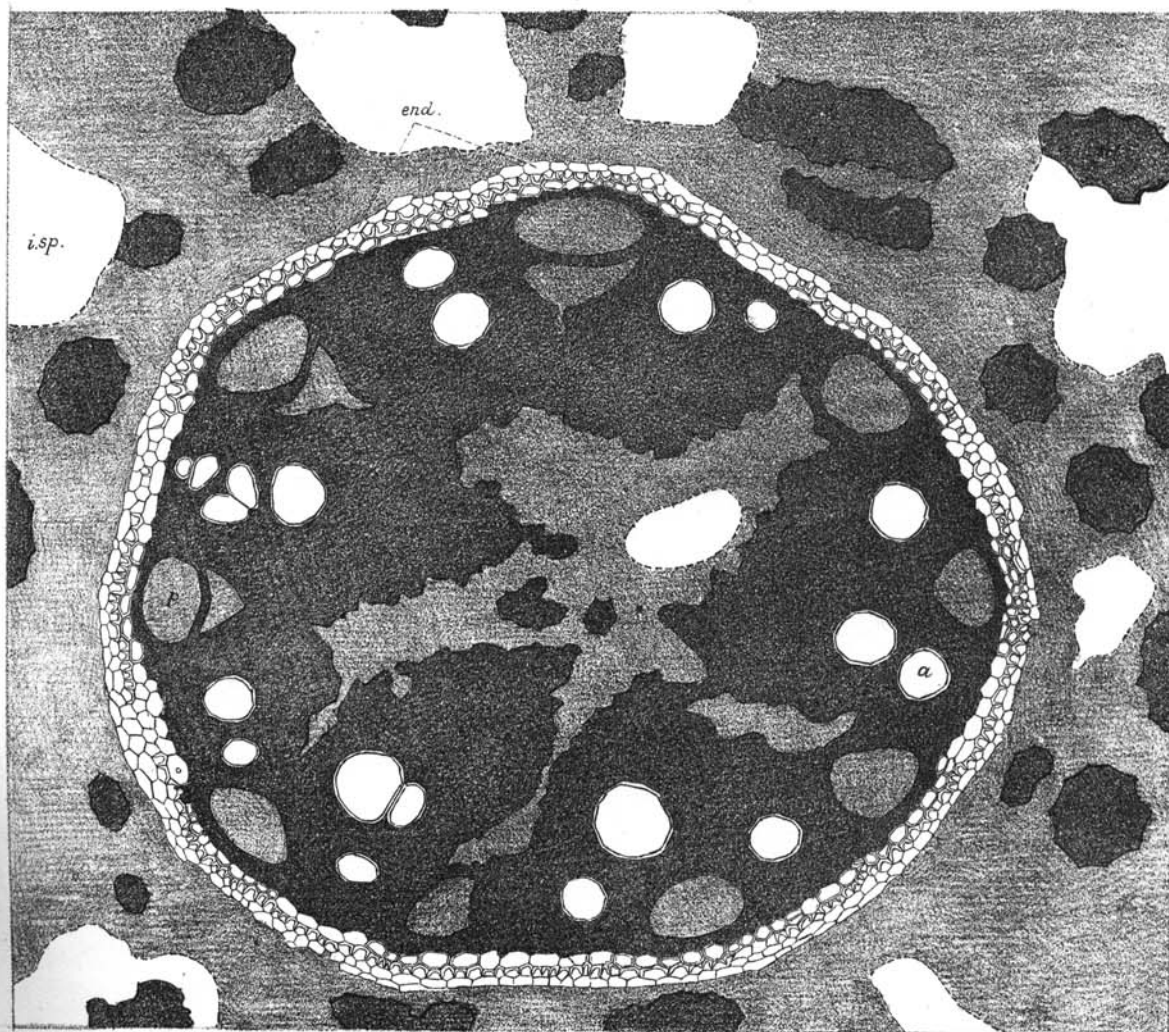


15



14

13



BAC. del.

J.N. Fitch lith & imp

POLYSTELIC ROOTS OF PALMS.