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THE ROOT DISEASES OF CACAO IN PAPUA AND NEW GUINEA

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Summary

A GENERAL account is given of the mode of distribution and the action of the fungi which cause root diseases of cacao in Papua and New Guinea. Methods of control are discussed and recommendations are made.

A key is provided for the identification of four root diseases; by means of a second key the fruiting bodies of root-disease fungi and some related saprophytes may be identified. Symptoms of the diseases and representative fructifications are illustrated with photographs.

A short glossary is provided and some terms are explained also by line drawings.

Introduction.—

Most tropical tree crops are subject to attack by several species of root-rotting fungi. These fungi, and the diseases that they cause, have been investigated fairly thoroughly in several parts of the world so that the more important features of their biology are well established. Accounts of this work have been given by Sharples (1936) and Garrett (1944); the root diseases occurring in Papua and New Guinea have been discussed briefly by Henderson (1954).

In addition, a number of related species of fungi are able to grow upon moribund or dead trees and may thus be mistakenly supposed to have caused their death. The object of this article is to present information which will enable planters to distinguish between the two groups of fungi and to identify the commoner species of each; in addition the biology and control of root diseases will be discussed.

Although cacao is the crop with which this account is primarily concerned, some of the pathogens attack rubber and tea as well as shade trees such as *Leucaena glauca.*

Parasites and Saprophytes.—

Unlike green plants, fungi are unable to photosynthesize and so are dependent upon external sources of energy; one such source is living or dead plant material. The organisms that obtain their food from living tissues are called "parasites", while those that live on dead tissues are termed "saprophytes". These two groups are not absolutely distinct from one another, for there are organisms of intermediate type. Thus the following classes can be distinguished :—

(*a*) Obligate parasites: organisms that can exist only on a living host.

(*b*) Facultative saprophytes: organisms which are usually parasitic in habit, but which may exist saprophytically.

(*c*) Facultative parasites: which are normally saprophytic, but which may become parasitic under certain conditions.

(*d*) Obligate saprophytes: which can grow only on dead tissues.

The fungi that cause root diseases of cacao are all members of groups (*b*) and (*c*), whereas the fungi that may be confused with them belong to group (*d*).

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Action of Root-disease Fungi.—

When a fungus invades the tissues of a root, it usually penetrates to the water-conducting elements of the wood. This tissue consists largely of vessels which traverse the length of the tree and are interrupted by relatively few cross walls; the presence of the fungus blocks the vessels and reduces their efficiency in conducting water.

Simultaneously, the fungus secretes substances (enzymes) which destroy the structure of the wood. Wood is composed of two main components: cellulose and lignin. Under the action of the appropriate enzymes, these complex substances are converted into simpler compounds which can be absorbed by the fungus and used as a source of energy; in this way the wood is rotted. The colour of the rotted wood depends upon the type of enzyme that has been secreted. When the wood is rather lighter in colour than healthy tissue ("white rot") the lignin has been destroyed while, in wood that is darker than normal ("brown rot") the cellulose has been attacked.

Because the development of the parasite occurs internally to the host and below ground-level its presence is often not noticed until the fungus is thoroughly established, and the tree displays obvious symptoms.

Root Diseases of Cacao.—

Four important root diseases have been recorded on cacao in this Territory. The common names of these diseases and the names of the fungi associated with them are as follows:—

(*a*) White root disease—*Fomes lignosus*, Klotz.

(*b*) Brown root disease—*Fomes noxius*, Corn.

(*c*) Wet root disease—*Ganoderma pseudoferreum* (Wakef.) Ov. et Stein.

(*d*) Collar rot or dry root disease—*Ustilina deusta* (Hoffm. ex Fr.) Petr. [Syn. *U. zonata* (Lev.) Sacc].

These four root diseases may be divided into two groups depending upon the behaviour of the casual fungus: the Fomes group, comprising the first three members of the list, and Ustilina. Members of the Fomes group possess a pored fruiting body which produces spores in immense numbers. However, infection by means of wind-borne spores is probably a rare occurrence. Usually a cacao tree becomes infected by the fungus spreading underground from the stump of a forest tree or from pieces of wood in the soil. Fungi of this group are normally present among the roots of the forest trees and, when the jungle is cleared, they establish themselves in stumps or logs at the expense of which they derive their energy. However, unless they quickly invade the newly-felled tree, it will be colonized by saprophytic fungi so that the root-disease fungi are unable to establish themselves.

Eventually, the food reserves of the log or stump are exhausted and the root disease fungus must find a new source of energy. Migration is achieved by means of rhizomorphs, which are strands of fungal filaments or hyphae. Although capable of penetrating for short distances through root-free soil, the rhizomorphs can grow more readily and for longer distances along a series of solid surfaces such as roots or pieces of buried wood. It is during the migratory phase that the fungus is most likely to attack the roots of cacao trees. Furthermore, the food reserves of a small stump are exhausted more readily than those of a large one so that, generally, small stumps or small pieces of wood represent a more immediate source of infection than do larger ones.

Similarly, spread of the pathogen from a diseased to a healthy cacao tree occurs by the rhizomorphs growing from the roots of the diseased plant and along those of the healthy tree.

In contrast to the situation found among fungi of the Fomes type, Ustilina does not produce well organized rhizomorphs and the fungus can spread underground only when the roots are in contact. The fungus is able to colonize dead logs and stumps upon which its fruiting bodies are sometimes found. Infection of cacao may occur to some degree through the agency of wind-borne spores, but it is likely to occur more frequently by the healthy tree being wounded with an implement carrying spores or other infective material which had been picked up by slashing a fructification of Ustilina or the bark of a diseased tree.

Control of Root Diseases.—

Attention to cultural practices can help to reduce the number of trees which are attacked by root diseases. Such practices include care of drainage and shade manipulation in addition to eradicating all obvious sources of infection, such as logs and stumps, that it is practicable to remove. Despite all precautions some trees will be lost through the agency of root rots, and the number of trees that are attacked will vary with the type of soil and other environmental conditions. However, constant attention to measures of control will decrease the number of trees that are killed and will prevent the loss of large patches of trees.

The essential features of controlling root diseases are the removal of diseased trees and all of the infected material with which they were in contact, thus preventing the disease from spreading to adjacent healthy trees.

In a previous section is was stated that, in young plantations, the stumps and buried wood may act as centres of infection from which pathogenic fungi can attack the cacao trees. Consequently, the only way to eliminate root diseases would appear to be clean clearing including the removal of all roots from the soil; such a practice is not feasible.

Instead, attention should be given only to the areas of the plantation where root disease is definitely present. If a tree dies in an immature plantation it should be dug out promptly and the cause of its death determined. The root system should be traced out and the source of infection, together with all other buried timber, should be removed. All of this infected material should be burnt in the hole. Simultaneously, a check should be made to find whether the roots or surrounding cacao or shade trees may have become infected. If this has occurred, a trench about two feet deep should be dug to surround a complete row of healthy trees, the soil being thrown inward on to the infected area. The trench may be filled in again fairly promptly but should be reopened at intervals of twelve to eighteen months in order to cut the roots which would have grown through the soil to re-establish contact with the clean part of the plantation; simultaneously, these roots can be inspected for fungal infection. This practice should be continued until the area has been free from disease for six months. It will be seen that the basis of this procedure is to use the young cacao trees to locate foci of infection and to concentrate attention upon these areas. Logs and stumps that have been colonized by purely saprophytic fungi are not a source of danger, and may be left to rot.

In mature plantations, the root system of adjacent trees probably form a fairly continuous network. Thus, when a tree dies from a root disease it is advisable to dig a trench enclosing a ring of apparently healthy trees. During this process the cut roots should be examined for signs of infection and, if necessary, the trench extended to enclose another row of trees. Removal of the diseased tree and other operations should be carried out as described above.

Where isolated trees have been killed by members of the Fomes group of root-disease fungi replanting should be delayed for about six months. Where infection is more extensive and had to be limited by means of a trench, replanting should not be attempted until the area has been free from disease for a similar period.

With respect to replacement of trees killed by collar rot there seems to be little reason why immediate replanting should not be practised provided that no infected wood is left in the hole when the soil is replaced. Experiments are in progress to obtain more information on this topic, but, meanwhile, it would be well to follow the procedure advised for trees killed by the other root diseases.

Identification.—

The identity of the fungus causing a root disease can be determined by the symptoms that it causes in the host, or by its fructification. However, the fruiting bodies of root-rotting fungi are found more frequently on dead stumps than upon the standing host. Thus it is nearly always necessary to dig up the affected tree in order to discover the identity of the pathogen that killed it; simultaneously an important source of infection is removed from the plantation.

Accordingly, a key is given by means of which the identity of root diseases may be determined; it is based on the appearance of the diseased root system. A second key, which depends upon the type of fruiting body, includes several of the commoner saprophytes that could be confused with the parasites. The method of using the latter key is simply to choose the particular alternative that fits the specimen at hand, always starting from the beginning, then proceed until the name of a fungus is reached. In Figure 1 are illustrated some of the terms used in the key. It will be noted that most of the fructifications described in the second key have a pored layer. When such a fungus is cut across it will be seen that the upper layer is solid and usually homogeneous, while the lower layer consists of closely-packed tubes within which the spores are produced. A hand lens giving a magnification of about ten times would be found useful for the examining of these fructifications.

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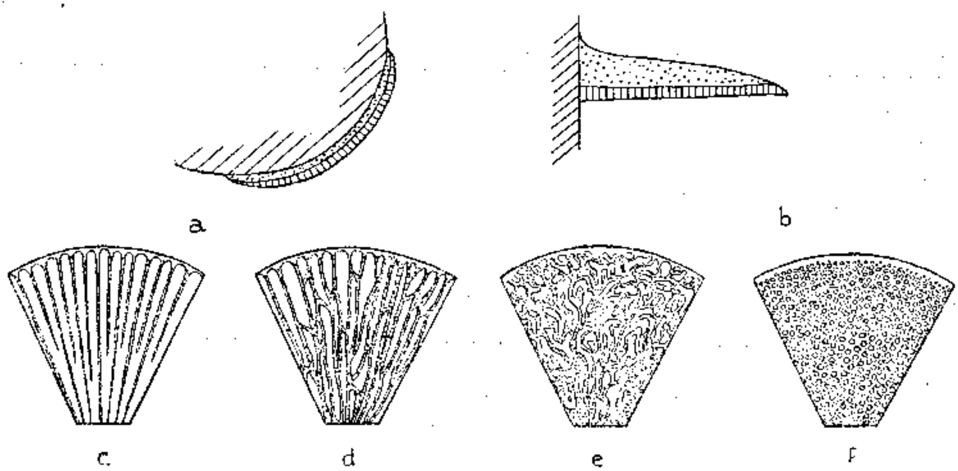


Fig. 1.—Explanation of terms used in the text: (a) and (b)—Type of fruiting body: (a) Resupinate. (b) Bracket-shaped. (c) to (f)—Lower surface of fructifications: (c) Gilled. (d) Lamellate. (e) Daedaloid. (f) Pored.

GLOSSARY.

Collar: The trunk of a tree at the region of ground-level.

Fructification: A fruiting body. The structure in which the spores of a fungus are formed.

Hypha: A thread of fungal material. Fungal structures, including the fruiting bodies, are composed of interwoven hyphae.

Mycelium: A mass of hyphae.

Parasite: An organism living upon and getting its food from another living organism (its host).

Pathogen: A parasite able to be the cause of disease.

Photosynthesis: The process by which green plants synthesize carbohydrates from water and carbon dioxide with the aid of energy absorbed from sunlight.

Rhizomorph: A cord-like structure composed of hyphae.

Saprophyte: An organism using dead organic material as food and causing its decay.

Sessile: Refers to a fructification which does not have a stalk.

Spore: A general name for a reproductive structure in fungi. Conidia are spores which are produced asexually.

KEY TO ROOT DISEASES OF CACAO

Disease	Appearance of Root System	Appearance of Wood of Root	Abundance
White Root Rot	No soil adhering to roots. Rhizomorphs and white fans of mycelium on surface of roots	Wood remains firm. Paler colour than healthy tissue	Common, especially in Popondetta District.
Brown Root Rot	Soil adhering, with inclusion of small stones, to surface of roots. Layer of brown or white mycelium beneath the soil is seen when the root is scraped. Brown crust often formed at the collar of affected trees	Pale colour; soft but dry. Fine brown lines run through the wood in fairly advanced stage of disease	Common. Encrustation at collar is often found in the Gazelle Peninsula.
Wet Root Rot	Tendency for some soil to remain attached to the roots. Redish membrane often present on surface of root beneath layer of soil	Pale colour; soft and spongy so that water can be squeezed from it. Lower surface of laterals usually attacked first	Occasional.
Collar Rot	Often attacks at the collar, where a black, plate-like fructification is formed. Roots may appear healthy for some time	Black lines in the wood when disease is in advanced condition	Occasional.

KEY TO FRUCTIFICATIONS OF ROOT DISEASE FUNGI AND RELATED FUNGI

1. Fructification smooth on lower surface .... Fructification with gills	Saprophytes and epiphytes.
or Fructification consisting of black or dark brown incrustation	2.
Fructification not corresponding to any of above	3.
2. Fructification consisting of smooth, hemispherical black lumps	*Daldinia concentrica.*
Fructification consisting of flat plates or incrustations, often in the collar region	*Ustilina deusta.*
3. Fructification resupinate and with pores	*Poria* spp.
Fructification bracket-shaped and with pores or some modification of them	4.
4. Lower surface of fructification lamellate	*Lenzites* spp.
Lower surface of fructification daedaloid	*Daedalea* spp.
Lower surface of fructification not so	5.
5. Pores drawn out at lower ends to form "teeth"	*Irpex* spp.
Pores very large and hexagonal or angular	*Hexogona* sp.
Pores simple, circular or angular	6.
6. Fructification woody in texture; upper surface covered with a brown varnish-like crust; lower surface white	7.
Fructification fleshy, leathery or corky in texture	8.
7. Fructification sessile, varnish-like layer extending over almost entire upper surface	*Ganoderma applanatum.*
Fructification sessile, varnish-like layer restricted to margin	*Ganoderma pseudoferreum.*
Fructification with a long, brown, shining stalk	*Ganoderma lucidum.*
8. Pores readily visible to naked eye	9.
Pores minute with a hand lens	10.

Key to Fructifications of Root Disease Fungi and Related Fungi—*continued*.

9. Pores shallow; entire fructification a bright orange-red colour	*Polystictus cinnabarinus*.
Pores shallow. Centre of fructification dark red, with a white margin of variable width	*Trametes corrugata*.
Pores deeper (to half thickness of fruiting body). Upper surface hirsute and concentrically zoned in yellow-brown shades	*Polystictus occidentalis*.
10. Upper surface of fructification orange-yellow and concentrically zoned. Pores dark orange. When cut, the fructification shows an upper white layer and a bright orange lower layer	*Fomes lignosus*.
Upper surface of fructification dark brown with a yellow margin; pores dark brown, often with a greyish bloom. Woody in texture	*Fomes noxius*.
* Several other genera of pored fungi also form resupinate fruiting bodies in addition to their normal bracket-shaped fructifications, e.g., *Fomes lignosus*.	

Fig. 2.—Tree killed by root disease. Note that the dead brown leaves remain on the tree and hang vertically.

Fig. 3.—White root rot. The root system is free from encrusting soil. (Compare with Fig. 6 Brown root rot.)

Fig. 4.—White root rot. The infected wood of the tap root is a lighter colour than that of the trunk.

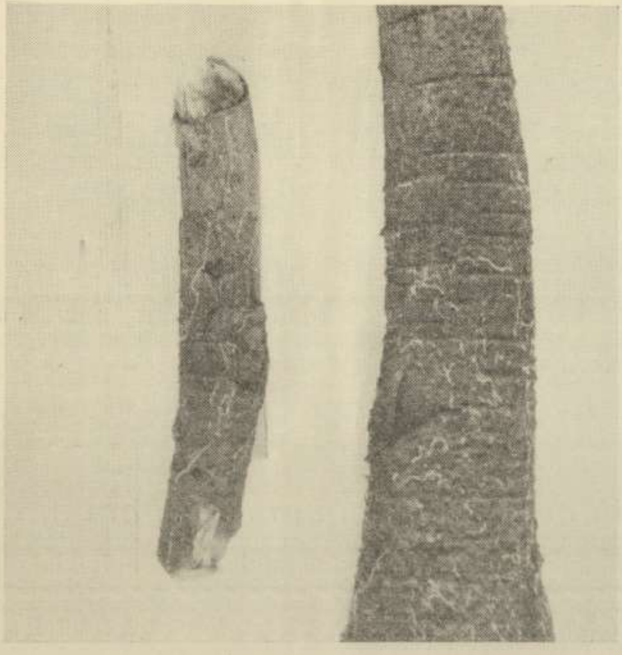


Fig. 5.—Rhizomorphs on the surface of cacao roots; they consist of white cords of mycelium.

Fig. 6.—Brown root rot. Note the crust of soil which adheres closely to the root system; beneath this crust is a layer of brown mycelium.

Fig. 7.—Brown root rot. In the northern Gazelle Peninsula, where the soil is derived from pumice, "Fomes noxius" often forms a brown encrustation at the collar of the affected tree. Sometimes a similar structure may be formed around a wound in the trunk.

Fig. 8.—Wet root rot. Sometimes trees that have been attacked by wet root rot show a marked develIopment of adventitious roots parallel to the tap root. This represents replacement of the diseased tap root by adventitious roots.

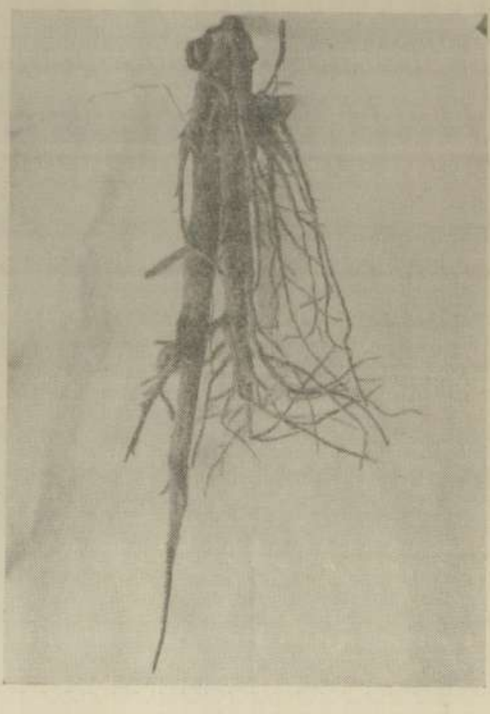


Fig. 9.—Collar rot. The conidal stage of "Ustilina deusta", consisting of plates of fungus, each with a grey centre and a white margin. In this example the fructification was situated in an uncommon position, just below the point of ramification.

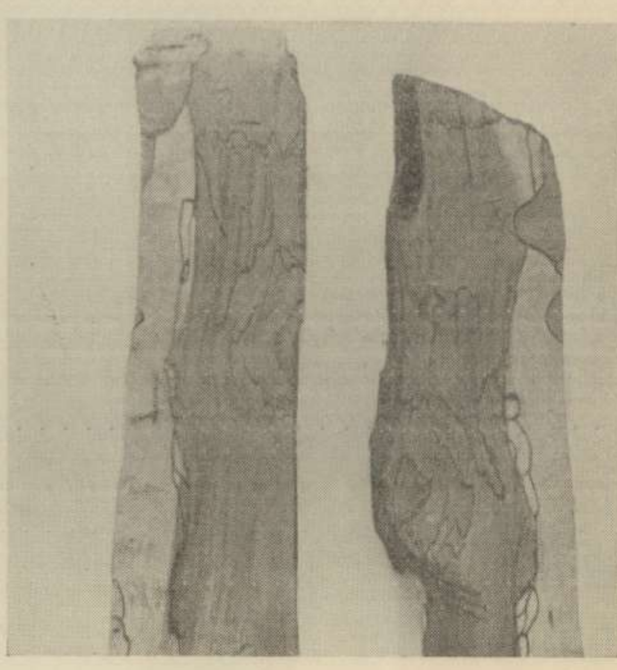


Fig. 10.—"Black lines" in wood. These are produced by "U." "deusta" and related fungi.

Fig. 11.—Fructification of "Daldinia concentrica", consisting of hard, hemispherical, black structures. When a fructification is cut across, a pattern of concentric circles is seen. Common on dead logs.

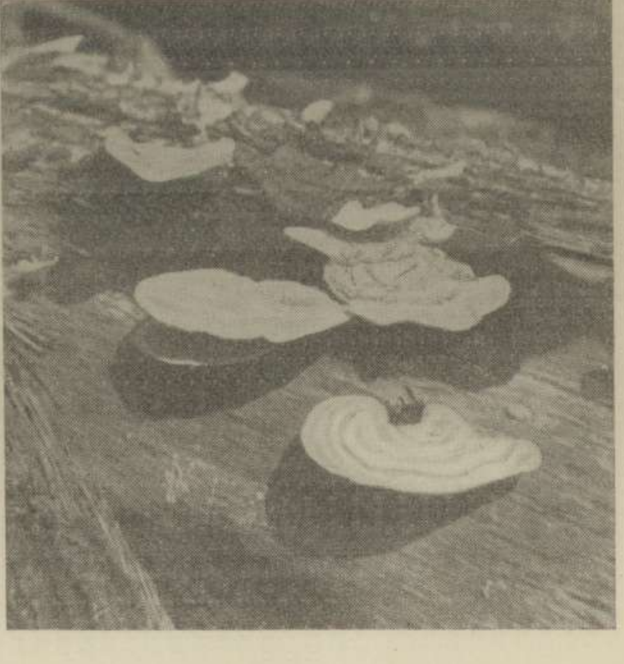
Fig. 12.—Fructifications of "Schizophyllum commune". This is a small, grey, gilled fungus which is common on recently-felled timber. In dry weather the fruiting bodies collapse as shown in the photograph, but after rain they revive.

Fig. 13.—Fructification of "Fomes lignosus". A fairly rough, bracket-shaped, pored structure. When fresh, it has zoned, orange-yellow upper surface with a yellowish-white margin. The lower, pored surface is bright orange. (Scale is six inches long.)

Fig. 14.—Fructification of "Fomes noxius". The actively-growing fruiting body has a dark brown upper surface and a very distinct yellow margin. The older fructifications are completely brown and may be two or three inches thick; apparently they can persist for several years.

Fig. 15.—Fructification of "Ganoderma applanatum". A bracket-shaped, woody structure with a zoned, cinnamon-brown upper surface which is partly covered by a varnish-like coating. In young specimens the margin and pored lower surface are white, but become brown when bruised or with age. (Scale is six inches long.)

Fig. 16.—Fructifications of "Polystictus occidentalis". A leathery, bracket-shaped fungus with a felt-like upper layer zoned in shades of brown. Very common on dead logs.



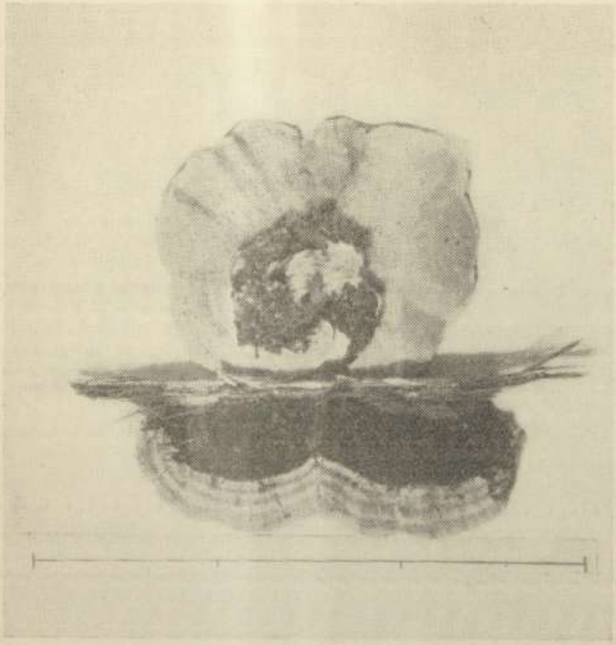


Fig. 17.—Fructification of "Tram etes corrugata". This structure thin and leathery in texture; the pore are shallow and visible to the nake eye. The upper surface has a whit margin of very variable width, an a dark red inner region. (Scale six inches long.)

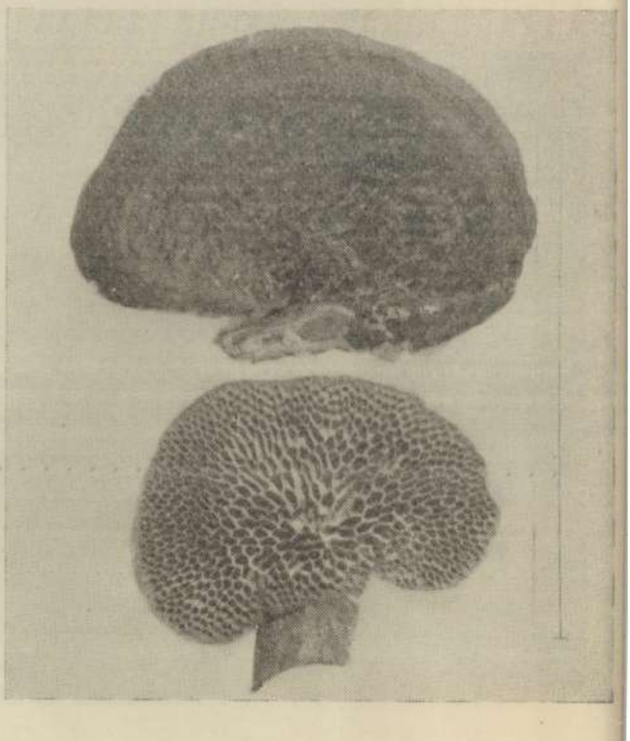


Fig. 18.—Fructifications of "Hexagona sp.". Note the large, angular pores. (Scale is six inches long.)

SMALL MESH TRAWLING IN PAPUA

A. M. Rapson *

RESULTS from forty hauls with small mesh trawl nets are described. The sea bottom of the Gulf of Papua is remarkably free of logs and debris. Records of nine different penaeid species of prawns are given of which five have commercial possibilities. Three species of carid shrimps which are not of commercial value by Australian standards were also obtained.

Greatest quantity of prawns was taken off the Fly River Mouth while largest were from Caution Bay and off Jokea. Small fish 6-8 inches long were most abundant off Kerema Bay while the largest fish were found off the Fly River. Salinity and quantity of phytoplankton of the area are described briefly.

I.—*Introduction.*

The Gulf of Papua comprises an area of more than 6,000 square miles under 100 fathoms deep, a large part of which is muddy or sandy bottom under 70 fathoms. To the south-east, extending from the vicinity of Caution Bay, the areas of mud bottom are much less because of the smaller rainfall and drainage area, with consequent smaller quantity of silt brought down by the rivers. Only in a few places such as Hood Lagoon and Milne Bay are there areas of soft bottom on which it is safe to haul a trawl net. The following account gives the result of forty small mesh trawl net hauls in shallow water in Papua. Details of the hauls are given in Appendix 1 and Chart 1 shows the positions in which the trawls were made.

II.—*Species of Prawns and their Size.*

The following species† were obtained at representative localities where collections were made. Common names refer to field identifications used in Table 1 :—

1. Off the Fly River Mouth.—
   - *Metapenaeus demani* (Roux)—Rainbow prawn.
   - *Parapenaeopsis sculptilis* male—Long spined prawn, female—Short spined prawn.
   - *Atyopenaeus formosus*—Spiny backed prawn.
   - *Palaemon (nematopalaemon)* sp.—White or pink shrimp.
   - *Leander* sp.—Hunchback prawn.
2. Eastern Gulf (principally off Jokea).—
   - *Penaeus merguiensis* (de Man)—Rainbow prawn or greasy-back of Australia.
   - *Metapenaeus monoceros* (Fabricius) —Speckled prawn.
   - *Trachypenaeus fulvus Dall*—Rough skin prawn.
3. Caution Bay.—
   - *Penaeus merguiensis* (de Man)—Rainbow prawn.
   - *Metapenaeus endeavouri* (Schmitt)—Banana prawn.
   - *Trachypenaeus anchoralis* (Bate)—Rough skin prawn.
4. Milne Bay.—
   - *Penaeus semisulcatus* (de Haan)—Rainbow prawn.
   - *Metapenaeus monoceros* (Fabricius).

Following are the Papuan species of penaeid prawns of possible commercial value, based on Australian standards. Sizes given are the largest recorded in the survey :—

Metapenaeus demani 5½ inches.

Penaeus merguiensis 8¾ inches.

Penaeus semi sulcatus 7¼ inches.

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† For common and scientific names of Australian Prawns, see W. Dall, 1956, Fisheries Newsletter, Vol. 15, No. 2, p. 5, in which there are differences from the names given for Papuan species.

Parapenaeopsis sculptilis 4 inches.

Metapenaeus endeavouri 6½ inches.

Over 90 per cent. of these species exceeded 3 inches in length and more than 40 per cent. were over 4 inches (Table 1).

The spinyback prawn, *Atyopenaeus formosus*, although fairly plentiful at times, is usually too small to be considered of commercial value.

The two carid species, *Paleomon* and *Leander* which were taken in the trawl and a third form *Heterocarpus*, taken from a tuna stomach to the south of the Gulf may be of use as a meal. *Leander* was taken in the greatest numbers but was also of smallest size; a considerable proportion being under 2 inches long.

The river prawns from Port Moresby to the Eastern Gulf which sometimes occur at a small size, in the sea, are *Macrobrachium lar* (Fabr) and belong to the palaemonid group.

Twenty per cent. of the prawns and shrimps measured were under 3 inches long. This, however, by weight is less than eight per cent.

III.—*Quantity of Prawns.*

Results from the Gulf of Papua showed that this area has commercial possibilities, and should be further tested. The best haul off the Fly River Mouth (south entrance) produced twenty-two pounds of medium sized prawns and shrimps of five species, and in the eastern Gulf off Jokea four pounds were taken, mostly of large prawns. Prawns were taken in all localities fished and, while shallow waters may not have been the best fishing grounds, the series of hauls made give comparable results throughout the area fished.

Caution Bay to Yule Island.—

First tests made here with a small net produced a few prawns, however, when a larger net was tested only a slight increase in quantity was taken with also increased quantities of fish. Although bottom and conditions generally appeared better in the vicinity of Yule Island and considerable numbers of flatfish were taken, results were not so good as in Caution Bay.

Jokea to Kerema.—

In a depth of 7-9 fathoms the best haul in the Eastern Gulf was made in a small channel off Jokea. The mud was found to be very soft and the trawl net dug deeply. Four pounds of prawns were taken in a haul of 30 minutes. Other hauls in the vicinity did not produce such satisfactory results. The next best results off Jokea being one pound in 5-6 fathoms, while in deeper water only several large prawns were taken. One hundred pounds of fish were taken off Jokea; they were mostly small *Gerres* and *Leiognathus* neither of which kept in the freezer. The greatest haul was obtained off Kerema Bay where 150 lb. of fish were taken including 60 lb. of small jew fish, several species of anchovy, including *Thrissocles* and *Engraulis*. The common sprat (patu) *Dactylolepis* is also found and blind sole—3½ lb. of prawns were taken.

Keakea Creek to Port Romilly.—

Off Keakea the hauling was heavy inside reef; the net with a large quantity of mud, brought up only about two pounds of prawns.

Off the Purari River was the only place where difficulty was experienced in hauling the net aboard the ship, a large quantity of small pieces of wood and palm seeds which was taken contained mixed with it, four pounds of prawns. Three "Bombay duck" (*Harpodon*) were taken here, the furthest east they were met in this region and with anchovy (*Thrissocles*) identify the head and western Gulf waters. Goat fish *Upeneus* were also taken in this haul and it is evidently near the limit of their distribution into the influence of fresh waters.

In the Panaroa River trawling in 1½-5 fathoms was unproductive, although Natives —by blocking backwaters of the river with woven cane barriers—get considerable quantities of prawns. It seems that in the region of the head of the Gulf there is an extensive area of mixing of salt and fresh water where conditions, particularly with reference to catches of fish and prawns, are very variable.

South of Port Romilly the greatest quantity of heavy mud was found and difficulty was experienced in freeing the net in this locality where it was found to have become buried to a depth of more than a foot (haul 22).

Off the Fly River.—

An almost entirely different fish population was found off the Fly River, and the principal prawn was also different. The variety of prawns and shrimps also was greater with, at least in shallow water, small prawns being more abundant in numbers. The area fished was confined to water 4-8 fathoms deep, and was over a region traversed by channels in which the bottom was of fine silt with shallow parts between the channels of sand and mud. The strong currents carried considerable quantities of this sandy mud which does not make ideal conditions for fish or prawns and water deeper than 10 fathoms may be more productive. Mixing effects of the tidal current is so strong that in no position fished off the Fly River Mouth was the net on the bottom, outside the limit of range of fresh water, and a depth of 10-15 fathoms may be more productive of greater quantities and larger prawns. It is significant that prawns do occur in the shallow water. Hauling in the gutters as off Jokea, produced no large catch and no big prawns, and the principal catch made was probably of small travelling shoals moving over the sand-banks where the trawl did not dig.

Hood Lagoon and Milne Bay.—

There are extensive areas of mud bottom inside the Barrier Reef to the east of Port Moresby but trawling tests were made in only two localities, Hood Lagoon and at the head of Milne Bay. Although prawns were found in these places results were poor and it is probable that on this type of coast, Native methods will prove more satisfactory than trawling. Small waterways draining swamps produce many prawns in some localities, and at Mogubu (north of Anioro or Lupon Island) scoop nets are used to catch prawns during minor floods, when at high tides sand-bars are broken down and the swamps then empty into the sea carrying good quantities of prawns; these are a penaeid species and although *Macrobrachium* is the common river prawn attaining a weight of 12 oz. it is not taken under these circumstances.

IV.—*Water Analyses and Prawn Distribution.*

Chart 1 shows the positions in which the inshore trawlings were made and in addition, gives the positions in which water samples and phytoplankton hauls were made with a 7-inch diameter net of 200 mesh per inch bolting silk. It was thought that the quantity of phytoplankton recorded over large areas would give some guide to productivity and consequently to the best areas to search for fish or prawns and while further work may show the soundness of this hypothesis, the results from the Gulf of Papua and the Coral Sea, with reference to prawns are inconclusive, they are briefly summarized below.

Quantity of phytoplankton is given as c.c. settled volume per 5 minute haul which is equivalent to a column of water 7 inch diameter representing 135 cubic feet of water through which the net was towed. Number of hauls is given in parentheses.

Head of Gulf, Kerema Bay to Kiwai Island, Fly River—0.5 (10).

North of Australian Barrier Reef, Daru to East Cay—1.5 (8).

Portlock Reef to Yule Island—1.7 (9).

Eastern Fields to Port Moresby—3.7 (2).

Yule Island to Hood Lagoon (60 miles south-east of Port Moresby)—10.5 (6).

Yule Island to Hood Lagoon (excluding two lagoons)—2.5 (4).

In the enclosed lagoon with small water drainage phytoplankton production was high but inshore in the Gulf where there is much fresh water phytoplankton production is low. It is considered, however, that the increasing phytoplankton in the regions—

(1) Daru to East Cay;

(2) Portlock Reef to Yule Island;

(3) Eastern Fields to Yule Island;

is attributable to the effects of land drainage. There is, however, after the North-West season a possibility that upwelling of deep water will have had some effect.

There are indications that to the east of Port Moresby, although there is a high phytoplankton concentration inshore in low drainage areas outside the reefs, phytoplankton production is comparable to that at the head of the Gulf of Papua.

Salinities in the Gulf of Papua and Coral Sea can be related to the prawn collection only to the extent that in the low saline area, off the Fly River Mouth, greater quantities of small prawns and shrimps were taken than in other localities. At a distance of 10 miles east of Kiwai Island the waters from surface to bottom are completely mixed when the tide flows strongly. Fine sand is found in the surface water and the influence of the river is felt at least 35 miles to the east of Kiwai. The following resume of the Western and Central Gulf gives average salinity in parts NaCl per thousand, number of analyses in parentheses :—

4½ to 10 miles off Kiwai Island—29.8 (3).
35 miles off Kiwai Island—35.2 (1).

Eastern Fields and Portlock Reefs—36.9 (8),

to 100 fathom line off Papuan Coast.

In the latter area salinity varies from 35.8°/oo at 25 miles west of Yule Island where there is influence of fresh water from the head of the Gulf to 37.3°/oo at a position 20 miles east-south-east of East Cay.

Ten miles to the south-east of Daru on 23rd August, 1955, fresh water was present in considerable proportion and the salinity was 30.7°/oo while a few miles further to the east a definite area of mixing was found in which to the west the salinity was 32.1°/oo and a quarter mile to the east 34.9°/oo. At Bramble Cay 25 miles further east salinity was found to be 36.1°/oo.

V.—*Trawling Possibilities.*

Although quantities of prawns taken were small, the results show that the bottom is suitable for trawling in depths from 3 fathoms or more, over many hundreds of square miles. The small mesh trawl was used as it was expected that prawns would be found in quantity; it is possible that at a different season better results may be obtained. Although the greatest quantity was obtained off the Fly River the best class of prawns was found near Port Moresby from Caution Bay to Jokea. A large mesh commercial fish trawl may prove a more efficient method of taking fish than the various Native methods used in inshore waters in the Gulf of Papua where Native sea fishing techniques are poor.

Conditions change suddenly about 20 miles south of the southern entrance of the Fly where bottom fauna is typical of the open sea and comparable to that found off Jokea or in Caution Bay in the eastern Gulf. The specific differences in the area are shown by the results obtained in hauls 24-26 where over a short distance the population of prawns and *Harpodon*, *Engraulis* and *Polypenus* changed to *Upeneus* and *Platax*. The changing conditions off the Fly River Mouth, however, are shown in hauls 27 to 33 made eighteen days after the first series. The area bearing prawns was not rediscovered although the net fished part of the area on the second series of hauls. It is probable that in some hauls of 40 minutes towing with the tide, the net covered a distance of 7 miles.

Apart from the *Harpodon*, *Engraulis* and small *Polynemus*, the most striking catch in the net was two specimens of the Queensland King Salmon *Polynemus sheridani* Macleay (related to *P. indicus*?). These two fish weighed 20 and 22 pounds and their occurrence in the area of mixed salt and fresh water off the Fly River suggests the possibility of large commercial shoals either in the river itself or in deeper water in the sea.

VI.—*Conclusions.*

(1) Logs are not a serious problem for the trawl in the areas fished although for steaming at night they are a navigational hazard even far out in the Coral Sea.

(2) In shallow water fish were plentiful in several places including Kerema Bay and off Jokea where *Gerres* and *Leiognathus* predominated and off the Fly River Mouth where many *Polynemus* were caught.

(3) In the ten weeks of the survey prawns were not taken in commercial quantities but with a ship equipped with a special trawling winch and capable of hauling to 50 fathoms, better results may be obtained. At other seasons also different results could be expected.

(4) Largest quantity off the Fly River Mouth was obtained in 4½ fathoms in a strong current. The biggest prawns were taken on the eastern side of the Gulf off Jokea in a channel 12-15 fathoms deep.

(5) In the Panaroa River although few prawns were obtained in daylight trawling, some shrimps were taken; Natives fishing with woven nets blocking tidal arms of the river take good quantities of prawns and this is typical of prawn

fishing of the rivers of the Gulf area. Woven cane basket traps such as are used in the Sepik River are not seen in Papua.

(6) Natural runs of prawns in small rivers which are closed by sand-bars in the South-East season are effectively fished by Natives in a number of places.

VII.—*Acknowledgments.*

Mr. F. McNeill, Curator of Invertebrates of the Australian Museum, kindly identified the carid species and Mr. W. Dall of the C.S.I.R.O., Division of Fisheries, Cronulla, the penaeid prawns. Mr. P. Southern carried out the chemical analyses of the water.

List of Tables.

APPENDIX 1

TRAWLING RECORD

23rd March to 12th May, 1955

Station No.	Date	Locality	Depth fathoms	Bottom	TIME			Tide	Catch	Remarks
					Shot	Finish	Total Trawl. time			
1	23.3	Caution Bay	6½ to 10	Soft mud	5.15 p.m.	6.59 p.m.	60 min.	¼ F.	3 only prawns, 1 mantis prawn, 2 red mullet, 1 swimming crab, 2 silver bellies and 1 jew fish	Net appears to be digging but quantity of catch small, and believe net is not fishing correctly. Trawl 14 fathoms.
2	24.3	Caution Bay	6¾ to 9	Soft mud	8.30 a.m.	9.40 a.m.	60 min.	H.W.	2 flathead, 1 starfish, 1 beche-de-mer	Water possibly too deep for part of haul only 40 fathoms warp (coir). Trawl 14 fathoms.
3	26.3	Red Scar Bay	7¼	Soft mud	3 p.m.	3.40 p.m.	50 min.	¼ E.	10 small prawns, ½ bucket of sweep, 2 mantis prawns, 10 silver bream, 3 tongue soles, 5 whiting, 5 patu	Prawns milk white (banana) and reddish. Net hauled early as 1 board riding high. Trawl 14 fathoms.
4	26.3	Red Scar Bay	6 to 8	Soft mud	4.15 p.m.	5.40 p.m.	50 min.	¼ E.	1 *Trichiurus*, 10 sweep, 2 flounder, 1 round nosed sole, 3 Milky white prawns 3½ to 4 in., 9 red prawns 2½ to 3 in.	Net shot on return course but in shallower water. Trawl 14 fathoms.
5	27.3	Off Isiu	6 to 8	Soft mud	9.15 a.m.	10.25 a.m.	60 min.	¾ F.	1 large red prawn 7¼ in., 1 pale blue green and red tail 7¼ in., 10 white 5 in. and 6½ in. 4¼ to 2½ in., 11 mantis prawns	Only fish 15 sweep and 1 red mullet. The small quantity of prawns here suggests that the ground though poor is the best so far. Trawl 14 fathoms.
6	28.3	West side of Caution Bay	5 to 7	Sand to mud	9 a.m.	9.55 a.m.	55 min.	½ F.	Catch only fish. 15 *Gerres oblongus* and 2 G. *arglyreus*	Net towed at 4 knots at same engine speed as previously. The hard sand is not productive. Trawl 14 fathoms.
7	31.3	Caution Bay	7 to 9	Soft mud	1.55 p.m.	3 p.m.	50 min.	¼ F.	1 prawn 3 in., 36 lb. small fish 2½ to 4 in. long including 1 *Lutjanus sebae*	20 fathoms net.
8	31.3	Caution Bay	7 to 7½	Soft mud	3.40 p.m.	4.45 p.m.	60 min.	¾ F.	6 prawns, soft corals and sponges. 65 lb. small fish as previously. 18 large sea urchins 5 in. diameter	Net towing easily and fishing well. 20 fathoms net.
9	1.4	North of Yule Island	9½ to 9	Hard mud	3.10 p.m.	3.40 p.m.	30 min.	½ F.	1 small prawn, 45 small flatfish 3 to 5 in. long. Miscellaneous other fish and crabs, total 10 lb.	Several short lengths of chain used in front of trawl to disturb mud. Appears to move flatfish out. 20 fathoms net.

10	1.4	North of Yule Island	6	Hard mud	4.20 p.m.	5.5 p.m.	45 min.	$\frac{3}{4}$ F.	1 large red prawn, 120 small flatfish—4 different species; few other species	The quantity of small flatfish suggests that there may be commercial grounds. 1 flatfish 10 in. long. 20 fathoms net.
11	2.4	Off Jokea	7 to 9	Very soft mud	11.50 a.m.	12.20 p.m.	30 min.	$\frac{3}{4}$ E.	About 4 lb. of prawns, 4 kinds. 26.3.55 Red Scar Bay. 30 lb. fish	Very soft mud. The net digging deeply came up muddy. Prawns also muddy. Lead on sounding sunk its full depth of 8 in. 20 fathoms net.
12	2.4	Off Jokea	5 to 6	Mud	2.10 p.m.	2.40 p.m.	30 min.	$\frac{1}{4}$ F.	About 1 lb. prawns. As previous haul. 100 lb. fish	Mud harder and lead did not sink in it. Some of bottom fish (6 in. long) nearly large enough to eat. 20 fathoms net.
13	3.4	Off Jokea	14 to 15	Fine silty grey mud	8.45 a.m.	9.30 a.m.	45 min.	$\frac{1}{2}$ E.	6 prawns, 5 lb. fish	Foul haul. 20 fathoms net.
14	3.4	7 miles N.W. of Jokea	15 to 12	Grey silty mud	12.20 p.m.	1.5 p.m.	45 min.	L.W.	30 lb. fish, 1 lb. prawns	Very strong tide rip although low water by tables and net at one time almost stopped. 20 fathoms net.
15	4.4	Kerema Bay	$5\frac{1}{2}$	Fine black mud	9.5 a.m.	10.10 a.m.	45 min.	$\frac{1}{2}$ E.	About 300 lb., about $\frac{1}{2}$ leaves and logs, 60 lb. jewfish, catfish, anchovies, sprats, soles, 2 lb. prawns	Bay flat even bottom but much rubbish, leaves and logs caused difficulty in lifting aboard. 20 fathoms net.
16	4.4	$2\frac{1}{2}$ miles off Keakea Creek	$6\frac{1}{2}$	Fine black mud	12.49 p.m.	1.50 p.m.	59 min.	L.W.	8 lb. fish, $1\frac{1}{2}$ lb. prawns	Very heavy hauling inside bank on which sea was breaking. 20 fathoms net.
17	4.4	$2\frac{1}{2}$ miles off east head Purari River	$4\frac{3}{4}$	Fine black mud	4.10 p.m.	4.40 p.m.	30 min.	$\frac{1}{4}$ F.	Many small logs and seed heads of nipa palm, 20 lb. fish and 2 lb. prawns	Unsatisfactory haul; the large quantity of rubbish damaged fish and prawns.
18	5.4	Panaroa River tributary on west bank near mouth	$1\frac{1}{2}$	Grey fine silt	2 p.m.	2.30 p.m.	30 min.	L.W.	Many leaves about 2 buckets. 1 lb. prawns, few catfish and anchovies and jewfish (5 lb.)	The large quantity of leaves in the bottom of river had prevented prawns living here. They could be seen near surface close inshore. 20 fathoms net.
19	5.4	Panaroa River main channel near mouth	5	Grey fine silt	3.55 p.m.	4.20 p.m.	25 min.	L.W.	Little rubbish, 10 lb. fish, 1 lb. prawns	The strong tide clears the main river channel of rubbish and fish and prawns live in holes in the river bed which are difficult to fish and locate. 14 fathoms net.
20	6.4	5 miles off Urika River	$6\frac{1}{2}$ to 8	Grey silt	8.50 a.m.	9.30 a.m.	40 min.	$\frac{1}{4}$ E.	No catch	Towing warp set for 6 fathoms and dropped into gutter at 8. Not able to bring vessel into 6 fathoms again. 14 fathoms net.

APPENDIX 1—*continued.*

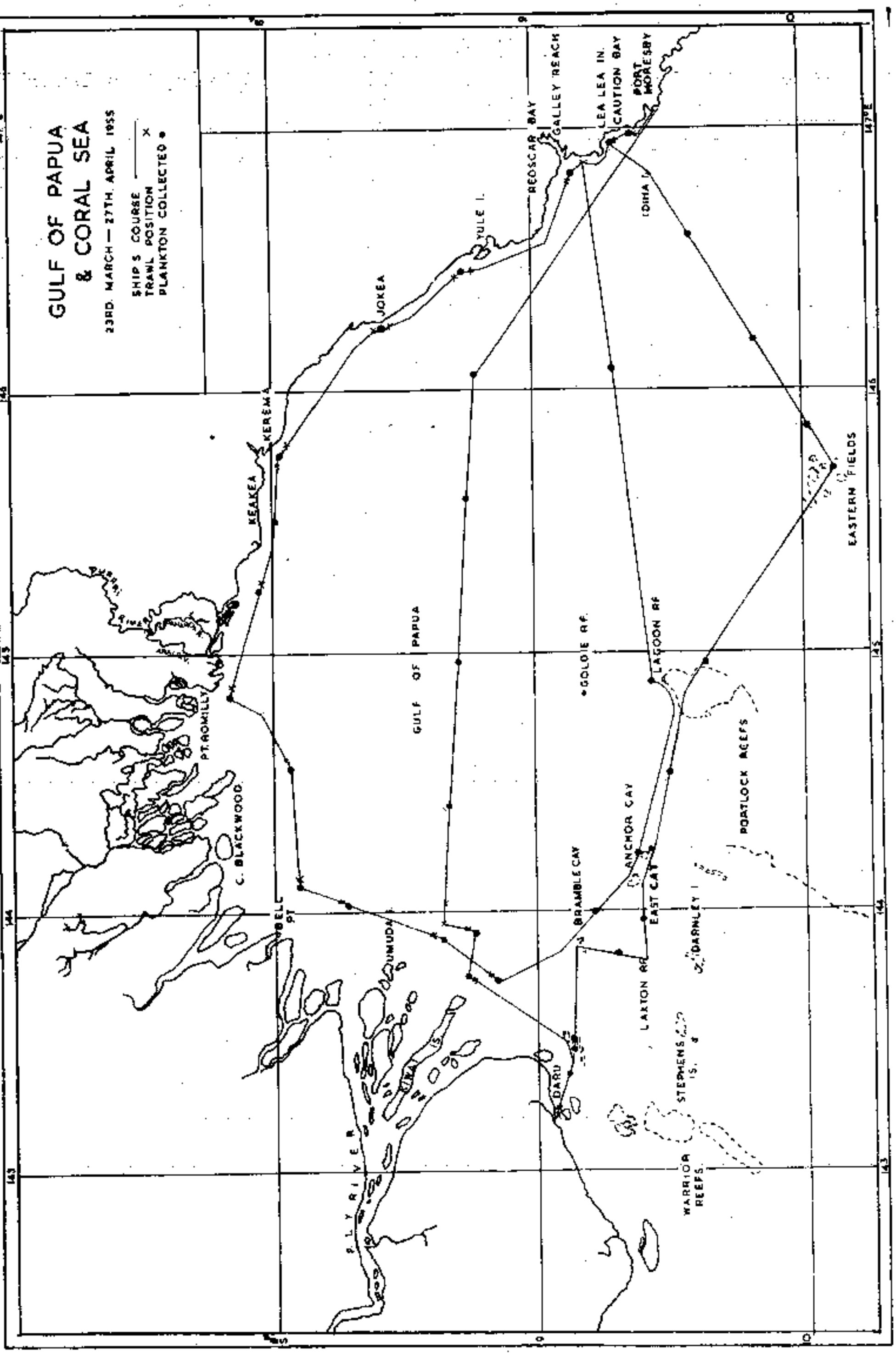
Station No.	Date	Locality	Depth fathoms	Bottom	TIME			Tide	Catch	Remarks
					Shot	Finish	Total Trawl. time			
21	6.4	Off Port Romilly 7° 55'S 144° 48'E	7	Hard grey mud	11.45 a.m.	12.25 p.m.	40 min.	½ E.	19 prawns, 3 lb. anchovy	Clean haul. 14 fathoms net.
22	6.4	8° 7'S 144° 35'E	11½ to 12	Fine grey silt	4.30 p.m.	5.10 p.m.	40 min.	¼ F.	17 prawns, 8 small fish	Heavy mud; hauling difficult, possibly too much warp (60 fathoms). 20 fathoms net.
23	6.4	8° 16'S 144° 12'E	6 to 6½	Fine grey silt	8.5 p.m.	8.45 p.m.	40 min.	¼ F.	2½ lb. prawns of 6 varieties, 12 lb. fish mostly *Polynemus*	Net hauled easily with 27 fathoms of warp. Tide running at about 5 knots to W. 20 fathoms net.
24	7.4	8° 40'S 144° 17'E	7¼	Fine mud	8.55 a.m.	9.35 a.m.	40 min.	¼ F.	2 lb. prawns as previous haul, 4 lb. *Harpodon*, few *Polynemus*	Tide strong, estimated at 5 knots. Net towed covered about 7 miles. Good bottom. 20 fathoms net.
25	7.4	8° 42'S 144° 5'E	4½	Fine silty mud	10.35 a.m.	11.10 a.m.	40 min.	H.W.	22 lb. prawns, 6 lb. *Harpodon* and few *Engraulids*	Water discoloured and certainly from tide strength is mixed to bottom. 20 fathoms net.
26	7.4	8° 50'S 143° 45'E	6½	Hard mud	12.20 p.m.	1.5 p.m.	45 min.	½ E.	2 only prawns, *Upeneus*, Batfish no *Harpodon* or *Engraulids*	Water nearly clear but still same evidence of Fly River at least on surface. 20 fathoms net.
27	25.4	Off south entrance of Fly 8° 59'S 143° 38'E	4½	Fine hard mud	1.5 p.m.	1.45 p.m.	40 min.	¼ E.	5 lb. prawns, 10 lb. anchovy, *Thrissocles* 14 large Scyphozoa, 1 king salmon, *Polynemus* 22 lb.	The bell-shaped Scyphozoa have tentacles with severe stinging cells. Bag rolled tightly. 20 fathoms.
28	25.4	8° 53'S 143° 42'S	5	Fine hard mud	2.25 p.m.	3.5 p.m.	40 min.	½ E.	3 lb. prawns, anchovies	Heavy swell shooting difficult. Turned into wind to haul, starboard wing of net twisted. 20 fathoms net.
29	25.4	8° 45'S 143° 47'E	6	Fine hard mud	4.20 p.m.	5 p.m.	40 min.	¼ E.	½ lb. prawns and anchovies	Heavy swell. The port warp had two twists in it and net had not been fishing. 20 fathoms.
30	26.4	8° 38'S 143° 54'E	6	Fine hard mud	8.15 a.m.	9 a.m.	50 min.	¼ F.	3½ lb. prawns, *Harpodon* 5 lb. and anchovies 6 lb.	Sea calm, 20 fathoms net.
31	26.4	8° 40'S 143° 51'E	6 to 4¾	Fine hard mud	9.30 a.m.	10.10 a.m.	40 min.	½ F.	3½ lb. prawns, 1 whiptail ray 3 ft. *Harpodon* and *Thrissocles*	Depth changed suddenly but maintained depth after change. 20 fathoms net.

32	25.4	8° 44'S 143° 45'E	5	Heavy silty mud	11.5 a.m.	11.45 a.m.	40 min.	¾ F.	3 lb. prawns, *Harpodon* and *Thrissocles*	Hauling in a gutter the net left a trail of mud on surface distinct. 20 fathoms net.
33	26.4	8° 47'S 143° 47'E	5 to 4	Heavy silty mud	12.10 p.m.	1.5 p.m.	55 min.	H.W.	1½ lb. prawns *Harpodon*, *Thrissocles* and 1 king salmon *Polynemus* 20 lb.	Footline of net torn for 3 fathoms. In gutter as before. 20 fathoms net.
34	3.5	Hood Lagoon	8 to 1½	Soft mud	11.40 a.m.	11.48 a.m.	8 min.	¾ E.	1 *Gerres* 4 in., 2 Pecten, 1 swimming crab, Crinoids about 30 small fish 1½ to 2½ in. long Gerres	Depth shelved sharply on to bank north-east of village. 14 fathoms net.
35	3.5	Hood Lagoon	9 to 2½	Soft mud	12.20 p.m.	12.40 p.m.	20 min.	L.W.	1 tiger prawn, 1 Trachinocephalus about 3 *Leiognathus*; 4 *Upeneus*, *Aprion*; *Sillago* 10 lb. *Gerres*	Bottom of sticky mud but with some patches with shell. Free of snags, water with thick plankton. 14 fathoms net.
36	3.5	Hood Lagoon	8 to 1½	Soft mud	2.5 p.m.	2.30 p.m.	25 min.	¼ F.	Catch as above and 1 sprat about 10 lb. small fish, mostly *Gerres*	In hauling, net digging deeply and in 4 fathoms and less made a brown silt come to the surface. 14 fathoms net.
37	11.5	Milne Bay off Gamadodo	8 to 6	Fine silt	10.10 a.m.	10.40 a.m.	30 min.	H.W.	No prawns, 29 *Trachinocephalus* 13 Therapons 7 to 9 in., 40 anchovy flatfish including *Psettodes* and 60 edible scallops 2½ to 3 in. diameter	Athough no prawns taken and few fish this area appears to be good trawling ground. 20 fathoms net.
38	11.5	Milne Bay off Gamadodo	7	Fine silt	5.35 p.m.	6.5 p.m.	30 min.	L.W.	2 prawns 2 in. and 2½ in., 2 scallops, 1 Goby	Net fishing correctly, bottom poor. 20 fathoms net.
39	12.5	Milne Bay off Gamadodo	7	Fine silt	8.40 a.m.	9.12 a.m.	32 min.	H.W.	7 prawns 5 to 6¾ in., 2 flatfish *Platycephalus*, 1 Therapon, 1 anchovy	3 other species of prawns 9 specimens. Pistol prawn, spider crabs, scallops. 20 fathoms net.
40	12.5	North-west of Howell Is.	8 to 9	Fine silt	10.01 a.m.	10.31 a.m.	30 min.	3 E.	1 pistol prawn. Very small catch of bottom organisms, few *Gerres*	Scallops and sea urchins. 20 fathoms net.

TABLE I

LENGTH OF PRAWNS AND SHRIMPS—TRAWLING SURVEY, PAPUA
26th March, 1955, to 12th May, 1955

Length	Off South Entrance Fly River						Off North Entrance Fly River						Kerema to Port Romilly					Caution Bay to Jokea				Hood Lagoon	Milne Bay		
in.	Rainbow	Long Spined	Short Spined	White or Pink Shrimp	Hunchback Shrimp	Spiny Back	Rainbow	Long Spined	Short Spined	White or Pale Pink Shrimp	Hunchback Shrimp	Spiny Back	Rainbow	Banana	Short Spined	Speckled	White	Rainbow	Banana	Speckled Short Spined	Rough Skin	Rainbow	Rainbow	Rough Skin	Straight Spined
1¾	....	....	....	....	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....		....	1	....
2	....	1	....	1	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....
2¼	....	....	....	3	11	2	....	....	....	7	....	....	1	....	....	....	1	....	....	....	1	....	....	....	....
2½	....	....	....	2	8	7	....	....	....	4	1	5	4	....	....	....	4	....	1	1	2	....	....	3	....
2¾	....	....	....	3	5	10	....	....	....	4	4	22	5	....	....	5	7	4	1	1	....	....	....	1	....
3	1	....	3	3	3	10	1	....	....	2	1	15	4	....	....	4	6	9	2	4	....	....	....	1	....
3¼	6	....	5	3	2	2	2	1	4	....	....	1	2	....	....	5	4	12	....	1	....	....	....	....	....
3½	12	....	5	1	....	....	11	3	....	....	....	....	1	....	....	4	2	2	3	1	1	....	....	....	....
3¾	2	....	4	....	....	....	5	2	....	1	....	....	....	....	....	6	3	....	2	....	3	....	....	1	....
4	3	....	1	....	....	....	4	4	....	....	....	....	....	1	....	12	1	....	....	1	....	1	....	....	....
4¼	5	....	....	....	....	....	1	....	....	....	....	....	....	2	....	6	1	....	1	....	....	....	1	....	1
4½	9	....	....	....	....	....	3	....	....	....	....	....	....	7	....	....	....	....	1	1	....	....	....	....	....
4¾	6	....	....	....	....	....	2	....	....	....	....	....	....	5	....	....	....	....	1	....	....	....	....	....	1
5	11	....	....	....	....	....	3	....	....	....	....	....	6	8	....	....	....	....	3	1	....	....	....	....	....
5¼	3	....	....	....	....	....	1	....	....	....	....	....	5	1	....	....	....	....	3	....	....	....	....	....	....
5½	2	....	....	....	....	....	2	....	....	....	....	....	10	....	....	....	....	....	4	1	....	....	....	....	....
5¾	....	....	....	....	....	....	....	....	....	....	....	....	4	....	....	....	....	....	10	2	....	....	....	....	....
6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	10	....	....	....	....	....	....
6¼	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	7	1	....	....	....	....	....
6½	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	5	1	....	....	....	....	....
6¾	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6	3	....	....	....	....	....	....
7	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6	3	....	....	....	1	....	....
7¼	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....	....	....	....	1	....	....
7½	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....
7¾	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....	....	....	....	....	....	....
8	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8¼	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8½	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8¾	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....	....	....	....	....	....	....
Total	60	1	18	16	49	31	35	10	4	19	6	43	43	24	....	42	29	46	61	16	7	1	3	9	2


GULF OF PAPUA
& CORAL SEA
23RD. MARCH — 27TH. APRIL 1955
SHIP'S COURSE
TRAWL POSITION ×
PLANKTON COLLECTED •
REDSCAR BAY
GALLEY REACH
LEA LEA IN.
CAUTION BAY
PORT MORESBY
YULE I.
JOKEA
KEREMA
KEAKEA
PT. ROMILLY
C. BLACKWOOD
BELL PT
GULF OF PAPUA
GOLDIE RF.
LAGOON RF
EASTERN FIELDS
PORTLOCK REEFS
ANCHOR CAY
BRAMBLE CAY
EAST CAY
DARNLEY I.
LAXTON RF
STEPHENS IS.
WARRIOR REEFS
DARU
UMUDA
FLY RIVER

SHADE OR NO SHADE FOR ARABIAN COFFEE

A. E. HAARER, F.L.S.

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THROUGHOUT the world the question of shade for coffee has been the cause of controversy among coffee planters, and among the research or overall authorities who guide or control the various coffee industries. It is only in recent years that research has been able to simplify the problem and give guidance to those who plant coffee. Mr. Haarer lends some support for the theory for shading Arabian coffee, but at the end of this article we have printed a note, extracted from the Information Bulletin, Inter-American Institute of Agricultural Sciences, which advocates a no-shade theory for nursery seedlings, at least under the conditions that prevail at Turrialba, Costa Rica.

It is well known that Arabian coffee originated in the shaded, forest-clad valleys of Southern Ethiopia, where it is found fringing streams and in forest glades. It sprawls or grows into a tall and slender tree in its efforts to reach the light, and the more light it is given, up to a point, the heavier the bushes have appeared to yield. It is unfortunate that when cultivated coffee grows in full sunlight it often overbears its strength and afterwards suffers disastrously from exhaustion.

Research has shown that when the leaves are exposed to intense light the stomata or breathing pores close; hence assimilation and the manufacture of carbohydrates are seriously retarded. At low altitudes in East Africa the stomata of exposed leaves close on bright days as early as 9 a.m. and do not open again until late afternoon.

This accounts for much of the trouble. Intense light encourages over-bearing and then makes it difficult for the plant to manufacture enough food to maintain itself and mature its fruit at the same time. This knowledge helps to prove that the Arabian coffee tree is one that prefers a subdued light or, in other words, a partial shade in those regions where the sunlight is intense. Of course, the effects would be far greater if every leaf of the tree were exposed at the same time. In fact, only a proportion of the leaves are exposed at any time, for the foliage creates shade for the lower branches or for the eastern side of the tree as the sun moves west. Even so, the proportion of leaves affected are enough to tip the balance unfavourably when a tree is bearing its crop.

For those reasons the general advice in East Africa is to give shade below 5,000 feet and to grow coffee without shade above this altitude, except at the highest altitudes in special circumstances where shade is again necessary for another reason, i.e., to protect the coffee trees from the cold night air.

The reason why coffee does not require overhead shade in East Africa at the higher altitudes is because the rainfall is more evenly spread, there is more cloud and mist, and hence, the light is not so intense. It is not, it seems, a question of air temperatures so much as light intensity, although shade at the lower altitudes does help to steady and lower the temperature of the air surrounding the coffee trees. This also is important because Arabian coffee grows best in a temperate climate without frost.

The questions of soil moisture and soil temperatures have their part to play, more particularly subsoil moisture, but first it is necessary to return to shade density. The fact that coffee grows so well in several other parts of the world without shade is undoubtedly due to the environment as a whole; to a light intensity which is less, or to a heavier rainfall and cloudy weather during the cropping and growth periods, which help to annul the effects of the brighter light during the resting periods.

Shade Density.—

Shade should never be dense and it does not seem to be necessary before a coffee tree begins to bear fruit, hence overhead shade can grow up with the coffee if it is planted at the same time. Except at planting time to prevent wilting, temporary shade should be dispensed with because several authorities have proved that competition for moisture during early growth is more harmful than exposure to sunshine. It is soil shade that is needed in the form of a mulch.

The shade trees should be of a kind that grow fast, have a long life, a feathery foliage and are easy to lop or prune. They should have a spreading growth, and they are best planted in lines across the path of the sun and so widely apart that their branches, when full grown, do not interlace. They are required to throw shadows across the field during the longer hours while the sun rises to its zenith and then declines in the afternoon.

Altitude is not a good guide, for an aspect facing the afternoon sunshine may require a little shade above the 5,000 feet level, whereas a plantation at a lower level facing the rising sun may not need shade at all. Common sense must be brought to bear on the question when the reasons for requiring shade are known.

Fig. 1.—An unshaded high altitude coffee plantation in Kenya. The soil between the coffee trees is mulched with grass and this is cut from every piece of land available on the outskirts of the coffee fields. An opportunity is given to apply fertilizers to the grass rather than to the coffee.

Shade can have an influence on flowering and yield. A light shade need not depress yields, but a little more shade will begin to have an effect. Flower initiation is not so plentiful, the coffee leaves grow larger and the internodes longer the more shade is used. Shade, therefore, can be a means of regulating the yield and, to a certain extent, the time of ripening. The pruning of shade trees should have almost as close and careful attention as the pruning of the coffee trees.

Pests, such as the berry borer and some species of leaf miner, are encouraged by too much shade and shade trees which are susceptible and act as hosts for mealy bugs and other pests which attack coffee should not be planted on an estate.

Since the shade trees must be of a kind, and planted at a distance apart so that they will not shade a coffee tree the whole time, a properly planted field, in actual fact, is open to a good deal of sunshine. On account of the constant movement of the sun and leaves overhead, and of the coffee leaves themselves disturbed by the movement of the air, no part of a leaf is shaded for very long or in sunshine for long enough to do harm.

Soil Shade.—

It does happen, therefore, that the soil of a shaded plantation still needs extra shade, especially when the plantation is young, and in those regions where the rainfall is short and there is likely to be a moisture deficit in the subsoil. The shade may be of a kind that will drop ample litter, but if it does not then a grass mulch will be beneficial.

A mulch becomes imperative to obtain best yields and maintain the health of the trees whenever coffee can be grown without overhead shade. Even where the light is not too intense, the soil temperatures can rise too high during sunny days. A mulch keeps the soil cool, it preserves the microflora and conserves moisture. By its gradual decay it helps to maintain the fertility of the soil.

Species of Overhead Shade.—

Not only must a shade tree have all the attributes already mentioned, but it must be one which harmonizes with the coffee in the environment where it is planted.

Some trees, even those of the legume family, appear to be antagonistic and harmful to coffee no matter what the environment happens to be, hence it is unwise merely to thin out a forest and leave indigenous trees for shade without exercising a choice and knowing beforehand what the result will be.

Moreover, having found a shade tree which harmonizes with coffee in one country, it may well be found that the same tree will not harmonize with similar coffee elsewhere. A shade tree that prospers in one country will not always grow healthily in another.

It is this, of course, that has led to such confusion and has heaped fuel on the controversies of the past. It is generally a question of soil moisture and temperatures, principally the former.

The ideal shade tree has a rooting system and make-up which does not rob the coffee trees among which it grows of too much soil moisture or soil nutrients. Yet, in a region where the rainfall is short and the soil of a particular kind, it may well do so. Or the tree may not prosper.

Fig. 2.—A shaded coffee plantation at low altitude in Kenya. "Cordia holstii" is the tree often favoured. Note the open shade. The trees are trained to the single stem method of pruning.

When it has been decided that overhead shade is necessary, it then becomes imperative to choose a tree which will succeed and agree with the coffee in the environment concerned. Guidance given by a local research station may not be sufficient if the plantation in question is sited on a different kind of soil, a different aspect of a mountain slope or where the conditions are not the same.

The author has seen unshaded unhealthy coffee at a low altitude in which odd specimens of the sausage tree, *Kigelia aethiopica*, and other indigenous trees stood. Against the trunks and beneath the dense shade of the heavily leaved sausage trees the coffee trees were healthy, but beneath the shade of the other trees the coffee was dead and dying.

Albizzia lebbeck appears to grow well as a shade tree in India, and the Lamtoro, *Leucaena glauca*, grows well in Indonesia, yet these trees are useless in most coffee regions of East Africa. They grow stunted with abundant seed pods and refuse to make good growth. Many of the *Erythrina* species do well in other parts of the world, whereas in East Africa they are attacked by grubs which bore into the young growths and prevent the trees attaining a suitable size.

The *Grevillea robusta* is not a suitable tree in shape and it competes too severely for the moisture supply in regions of short rainfall. Each tree must be decided upon according to its merits and behaviour in the differing environments of the coffee world. Many a planter has found that his coffee has done better without a particular kind of shade tree and he has assumed from this that his coffee did not require shade, whereas, had he tried another kind of tree or regulated his shade in the proper manner, he would have had a different tale to tell.

Doubtless in Brazil, despite the possibility that the light intensity may be less, the coffee there would be better with a light shade of the right kind, if only to aid in preventing the rapid deterioration of the soil and the premature ageing of the coffee trees. One would have thought they would give some protection from the frosts that do so much damage to coffee in that country.

Even though the guiding rules are known, there is still a lot to discover and argue about as to the best kind of shade for each locality. One is sorry for the planter who is opening up land in a new region where, on account of light intensity and warm temperatures, he is convinced that shade is necessary. One can only advise him to observe the effects on coffee of any local trees that appear suitable for shade.

Moreover, he may list the commonly used shade trees of the world and their attributes. Having decided to narrow his list he may then obtain all the information possible about the rainfall, temperatures and soils of the regions where these trees grow well and compare them with those of his own locality. In this manner he may improve his chances of success.

Generally speaking, where the rainfall is dependable and about 60-80 inches per annum, where temperatures do not rise much above 80° F. and the soil is fertile, well drained, but retentive of moisture, most of the best shade trees will thrive and grow well with coffee. It is where the rainfall is erratic and short, where temperatures are higher, and the soil easily dries out, that some of the best-known and more valuable shade trees are difficult to introduce among coffee. It is time that the requirements of each shade tree were listed along with attributes or shortcomings.

Summary.—

It is described how light intensity is a factor ruling the necessity for shade; also how shade may ameliorate conditions and assist in maintaining fertility in regions where intense light is correlated with erratic rainfall and warm temperatures. The density of shade is discussed and how this may regulate crops. Several reasons are given for the controversy about shade which has persisted for many years, and how shade trees of different species may harmonize or not with coffee in different environments. The attributes of shade trees are mentioned and of how a species may prosper in one country but not in another. It is pointed out that there is insufficient data about the environmental requirements for most of the shade trees commonly used in the world.

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But in Costa Rica.—

The cultivation of the coffee tree under shade is based, almost entirely, on empiric results rather than on scientific studies. The fact that the coffee plant, in its natural habitat, grows under shade is interpreted as a need for such a condition for its better growth. There has not been any careful study to demonstrate this necessity or to explain why the coffee plant cannot grow under direct sunlight.

These ideas have been exposed in the introduction of a thesis presented by Armando Huerta, Bolivian student who entered the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica, in 1952 and made studies of coffee physiology under Dr. Paulo de T. Alvim, Professor of Plant Physiology at the Institute. In his conclusions Huerta states that the physiological reaction of the young coffee plant to the stimulus of light was considered as one of a direct sunlight plant, inasmuch as photo-synthesis and the "proportion of relative growth" were gradually increased as light intensity increased. If the reaction was similar to that of the shade plant, the "efficiency of assimilation" and the "proportion of relative growth" should reach its maximum and then remain constant or decrease before the maximum light intensity is reached. The plants grown under direct sunlight had more dry weight, larger roots, more leaves and a larger number of stomata per leaf and per unit of leaf area.

The author considers that these results indicate that under the conditions at Turrialba the coffee nurseries should be maintained under direct sunlight, due regard being paid to the control of *Colletotrichum* and *Cercospora*, both of which seem to be intensified by sunlight.

NOTE:—Recommended nursery practice for the Territory of Papua and New Guinea includes removal of shade for "hardening" of the seedling prior to planting out—See *Papua and New Guinea Agricultural Gazette* Vol. 8, No. 2—Editor.

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