# SOME INVESTIGATIONS ON COCO-NUT DISEASES ASSOCIATED WITH SOIL CONDITIONS IN NEW GUINEA.

(*Continued.*)

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In the previous instalment of this article (*New Guinea Agricultural Gazette*, Volume 5, No. 3, December, 1939) an account of some investigations and observations on occurrences of physiological disorders of coco-nut palms was presented. Particular attention was paid to investigations of maturation wilts of young coco-nut palms recorded from various parts of the Territory of New Guinea.

A further contribution on the subject is now presented. Some physiological derangements of mature coco-nut palms, particularly from those plantations situated on the deltaic and estuarine deposits on certain areas of the New Guinea mainland, are described, together with the contributory causes. These occurrences are compared with similar diseases recorded from other countries. The chemical and physiological changes, especially as regards moisture requirements and potash movements, which occur on coco-nut palms at various stages of growth are indicated and discussed in relation to the diseases described. An account of several other diseases and derangements of coco-nut palms, associated with unfavorable soil, moisture and nutritional relationships, are also discussed. The employment of proper cultural methods in the control of coco-nut diseases, especially those of physiological origin, is indicated.

## CHEMICAL AND PHYSIOLOGICAL CHANGES IN THE COCO-NUT PALM RELATED TO MATURITY.

According to Sampson[24] who furnishes the most complete analyses on the coco-nut from this point of view:—

In the case of *nitrogen* the heaviest demands are made on the resources of the tree quite late in the development of the fruit, i.e., within the last six weeks or eight months. Nearly 75 per cent. of the nitrogen removed from the tree when the ripe fruit is harvested is to be found in the meat of the nut. Analysis shows as regards *potash* that the demand for this commences early in the development of the fruit. The quantity of potash in the meat seems to be greatest at the time when the meat is being laid down after which it seems to be reduced, when no longer required for this work. The supply of potash seems to be readily forthcoming when it is required. It is probable that this being a more soluble salt than most other plant foods, there is much more elasticity in the supply, it being taken away from other parts of the plant, resulting possibly in the retardation of growth for the time being, and brought to where its presence is essential. (The significance of this in relation to a maturation wilt is self-evident, when the potash is transferred from the fronds to the developing fruits.) Potash is required in large quantities by any rapidly growing part of the palm. Such growing parts are always present. The bud or "cabbage" is continually forming new leaves and these leaves are all the time expanding. In the axis of each leaf a flowering branch is normally formed, and this in its turn has to grow very rapidly until the flowers expand. Even after this it continues to grow rapidly as the fruit which it carries are swelling and the meat within the fruit is forming. All these places show a concentration of potash. In the leaves also large quantities of potash are required especially in the young plant. The plant, however, is able to remove a large part of the potash from any working part of the plant, as this gets past work. Thus in the young tree not yet in bearing, it is seen that there is 41 per centum of potash in the ash of the tender leaf which is growing. In the fully developed green or working leaf there is only 18 per centum.

It has been shown by numerous investigators with temperate fruits and other crops, that the proportions of carbohydrates (sugars, starch and cellulose) to nitrogen (i.e. the carbohydrates/nitrogen ratio) greatly changes at the time of blossoming and fruit setting. How far this is true of coco-nuts does not appear to have been determined, but the indications are that great changes do occur at the first fruiting phase of young coco-nuts.

In most plants the daily rate of water utilization is low in the vegetative stages of growth, but increases rapidly as the plants reach maturity.

The "cabbage" on a young palm, six years old, has easily the lowest percentage of dry matter, but practically double the percentage of ash found in any part of the plant at that age.

In the young palm, of the same age as above, the percentage of dry matter is low in the trunk; about 9 per cent. according to Sampson and increases to 49.30 per cent. in the bearing palm. There is an increase of dry matter also in the leaves but this is not nearly so marked between the two stages as for the trunk.

There is a significantly higher percentage of phosphoric acid in the ash of a young palm than in that of a bearing tree and apparently this element has most use in the young developmental stages. Experiments in this country have shown that it must be seldom that phosphoric acid deficiency symptoms develop in a coco-nut palm here. On some of the western islands, however, where phosphate deposits occur, very high yields of coco-nuts are obtained. In spite of this, single applications of phosphatic manures on old palms here have given no results, which appears to conform with the experiences elsewhere.

Many coral-derived soils under tropical conditions are low in lime content, due to excessive leaching of the surface layers. This is one factor which leads to their stickiness and liability to water-logging. In some places, applications of quick-lime, freshly slaked lime, or coral sand often give excellent results in increasing the yield of coco-nuts. In addition to its direct effect on the texture of the soil, this element has use in replacing potash in the soil and thus liberating this for the use of the crop. The probable significance of this fact in connexion with the disease at Namatanai (New Ireland) is thus clear, if it is known that there is heavier demand on the potash supply at the time the palms are coming into bearing. The soils there are of coralline derivation being acid or lacking in lime, until the actual limestone layer is reached, in addition to having low values for actual potash content.

In Bangalore, India, studies and analyses[33] to determine the plant food requirements of coffee at the bearing stage gave some very valuable results, which may be applicable to the coco-nut palm. A known number of coffee spikes, blossoms, set-buds and berries was collected, month by month, over a period of thirteen months and analysed for the essential plant foods, organic matter and carbohydrates, especially sugars. It was found that a large amount of potash was required and stored in the spike and blossom, prior to setting, and that this potash became distributed as the berry developed after setting.

The phosphorus requirements of coffee seem to be very steady and uniform, being about one-fifth the nitrogen content throughout the course of its development.

Coffee seems to require a steady and increasingly available supply of nitrogen throughout the course of its growth, not only to supply the ordinary nitrogen requirements, but, also, to maintain the nitrogen/carbohydrate ratio, which influences, in no small measure, the successful ripening of the fruit. This shows that the practice of applying complete fertilizers in certain stipulated proportions is well supported by physiological reasons. These experiments, although more specific in their objective, bear a close resemblance to Sampson's results from detailed analyses of different parts of the coco-nuts at varying stages of maturity.

## Symptoms of Potash Deficiency.

Eckstein, Bruno and Turrentine[12] in their book on *Potash Deficiency Symptoms* state, " a characteristic of potash hunger signs is that they usually first become noticeable after a certain period of growth of the plant is reached (*see* page 6). After a certain time, where potash is lacking, the plant attains a stage in which its potash content becomes so low that a normal functioning of metabolic (building up) processes is no longer possible and pathological phenomena develop. The symptoms of potash hunger are, therefore, variable with the different ages of the plant. Since the metabolic processes of the plant are also dependent on the weather, light, temperature and humidity, the signs of potash deficiency under otherwise equal conditions will be manifest in variable form and extent under different conditions of climate. Since potash has a very high degree of efficiency, typical potash starvation signs occur only after an extreme degree of potash deficiency is reached."

It will be seen that bronzing, yellowing, leaf spotting and die-back (similar to the appearance of leaf scorch in fruit trees) may represent extreme conditions of nutritional disturbance, whether due to actual manurial deficiency or to insufficient water and contained nutrients reaching the growing portions of the plant.

It is only possible to give a very brief *résumé* of the findings that potash deficiency exerts an unfavorable influence on the water utilization of the plant. This is due to this element causing both impairment of water absorption through the roots and increased loss of water through transpiration, which decreases the ability of the plant to withstand drought.

According to the authors quoted above, " in plants suffering from lack of potash the shoots develop at the expense of the roots; the latter are usually more seriously damaged than the aerial part of the plant. The production of secondary roots and lateral growth of the roots are materially injured. The relationship between transpiration and potash nutrition (supply to the plants) are the biggest factors in the impairment of the water economy of the plant, when potash is deficient. The presence of potassium tends to reduce the loss of water by transpiration and increase absorption. Lack of potash causes greater loss of water and wilting typical of potash starvation results."

Wallace[31] has shown that potash deficiency has a greater influence on the root development of biennial and perennial plants than on annuals. It has also been demonstrated by several workers that the relationship between " potash deficiency " and " parasitism " (disease attack) is especially pronounced in perennial plants.

The general symptoms of potash deficiency in plants are that the leaves lack substance, hang down limply and the general appearance gives an impression of weakness and feebleness. Thus it is seen that such deficiency can lead to a condition closely approaching "leaf droop" without the appearance of outside organisms. It is a curious phenomena that plants suffering from potash deficiency at first go a darker green than in the case of a healthy palm, a phase which lasts for some time.

In more advanced stages, "leaf scorch", "necrotic and dark spotting", with leaves hanging down limply are common symptoms observed. There is collapse of supporting tissues in the leaves, and the root system is reduced. Finally, there is increased susceptibility to diseases, pests and climatic factors.

This discussion on potash deficiency symptoms only touches on the subject, as it has long been known that there must be a proper balance between the manurial constituents present, both in the soil and in the plant. As may be expected, the potash/nitrogen ratio is of the utmost importance in the nutrition of the plant. It is for this reason mostly that the results obtained from the use of balanced and complete fertilizers (applied in certain definite proportions) are much greater than those where single fertilizers only are used.

The degeneration of the midrib cells of the coco-nut fronds showing streaking, at Namatanai, may be due to cell dissociation caused by manurial deficiency (potash relatively low according to analysis), exaggerated by unfavorable water and nutritional relationships at the time the palms were coming into bearing.

Wallace[31] has shown that the nitrogen-potassium ratio is of the utmost importance. A wide ratio increases leaf scorching, while a narrow ratio reduces it.

Bain[2] as a result of analyses of very young palm leaves, from palms growing on both healthy and wilt areas, stated that "any differences which showed up were considered to be secondary to the seemingly more important water factor."

His general conclusion was that there was a high nitrogen status in wilt areas shown by leaf analyses, particularly in relation to phosphate or potash according to soil type. It was important to note that Bain found in some wilt areas that the percentages of potash in the young leaves were greater than in those from the healthy area.

Soil analyses or leaf analyses, considered by themselves, do not give anything like a full picture of the problem. The percentage amounts of potash and other nutrients found in various parts of the palm (especially when it is switching from the vegetative to the productive phase) are not nearly so important as the total amounts required for new growth and fruit production at critical periods. It is the sudden demand for water and nutrients normally required by a young palm, coming into bearing, not being met under unfavorable conditions of soil and climate, which leads to pathological symptoms.

There may be lack of balance of nutrition between nitrogen, potassium, phosphoric acid, and lime (or calcium) and magnesium. It is pointed out that there may be plenty of potash present in the soil, but it is not available to the plant, owing to lack of balance with the other nutrients present, unfavorable water relationships (which may be seasonal), or other causes. The largest proportion of the plant is built up with water, from the soil, and carbon dioxide, found in the air, through the action of sunlight on the green colouring matter or chlorophyll (photosynthesis). In this manner, starches, sugars, celluloses, fats, oils, plant acids and other compounds are synthesized. The direct nutritive effect of the water on the building up of carbohydrates (carbon compounds) and the necessity for respiration is not often stressed in relation to wilting and cell break down. Without recourse to actual figures it is absolutely certain that there is a tremendous increase in the total amounts of carbohydrates (starches, sugars, &c.), and oils synthesized at the time a coco-nut palm is coming into bearing, hence, there is a greater demand for water.

It is obvious that as far as coco-nuts are concerned there is plenty of room for research on the subjects indicated.

## Potash Movements Only.

SAMPSON'S FIGURES[24] (CONDENSED AND TABULATED).

*"Analyses of the different Parts of a Coco-nut Palm about Six to Seven Years Old (not yet bearing) compared with a Bearing Palm".*

| —— | Root. | Stem. | Stipules. | Petioles. (Leaf stalk). | | | Leaflets. | | |
|---|---|---|---|---|---|---|---|---|---|
| A. Young Palm % $K_2O$ .. .. | .14 | .50 | .051 | av. 74 (.12 old, 1.78 tender) | | | av. 1.08 (.55 old, 2.01 tender) | | |
| B. Bearing Palm % $K_2O$ .. .. | .29 | .21 | .034 | av. 26 | | | av. .56 | | |
| Percentage of $K_2O$ (Potash) in the ash | | | | Old. | Green. | Tender. | Old. | Green. | Tender. |
| A. Young Palm .. | 3.33 | 10.89 | 2.68 | 3.92 | 4.24 | 34.60 | 13.75 | 18.13 | 40.94 |
| B. Bearing Palm .. | 8.27 | 3.91 | 3.50 | av. 4.17 | | | av. 13.08 | | |

In comparing analyses of an inflorescence about to open with a similar inflorescence after the kernel of the fruit is formed, it is found that there is more than double as much potash in all parts of the young inflorescence, as compared with the older one.

The percentage of potash in the inflorescence (Spathe about to open) is, on a "barren" palm, 15.80 per centum, compared with 20.46 per cent. in a bearing palm.

## Physiology of the Root System.

In order to give a better idea of the problem a very brief account of the root behaviour of coco-nuts is given. Copeland[5–6] and other authors have dealt with such physiological problems in detail.

All roots of the coco-nut palm have an impervious, rigid shell called the "hypodermis" which protects their structures, and gives them a very strong anchorage in the soil. The main horizontal spreading roots are like stout cords and both they and their larger branches bear numerous fine, much-branching roots which, in turn, may branch into much finer roots. The coco-nut palm has no root hairs, but the life history of their finest roots, like the root hairs of other plants, is very transitory.

The zones through which absorption of water and nutrients takes place is usually limited to the young growing part of the root, which has thinner epidermal or outer layers and thus allows the moisture and soil nutrients to be absorbed by osmosis. This zone is relatively short and is usually seen extending for just a few inches behind the hardened root-cap.

When the new growth of the roots is checked by dryness or other causes, the hardened, rigid shell (hypodermis) present on the older part of the root, tends to grow right up to the root cap and, thus, naturally limits the absorbing zone under unfavorable conditions.

As soon as the soil becomes wet again the roots revive, new root elongation occurs and absorption begins anew, through the thin, epidermal layers of the new portions or replaced roots.

The numerous, raised, light-coloured, outgrowths seen on the surface of all coco-nut roots are breathing organisms ("pneumatophores", really specialized reduced roots), through which the air supply to the roots and low internal system of the plant is maintained. These cannot function below the free water surface or in water-logged soils and, consequently, roots, growing under such conditions, either cease functioning or die altogether.

No roots will grow any distance into water, nor into a level of the soil where free water stands, also a rise in the water-level ultimately kills submerged roots. Sandy soils or pumice soils are naturally drier than heavy clay soils, and, in such free soils, the roots tend to grow deeper and maintain a deeper level than in stiff soils.

Duthie[(8)] says that, "as coco-nuts normally grow on poor soils (e.g., on sea-shores and coral atolls), it cannot be argued that potash and phosphate are the limiting factors present". This statement refers to a description of coco-nut wilt found on an acid clay soil, markedly deficient in available potash and phosphate, but with adequate nitrogen and organic matter.

It must be argued, however, that where the root system is restricted, manurial deficiencies, such as those indicated, must behave as important contributory, or inter-acting, limiting factors. Where palms are growing on poorer soils and are flourishing, it is because the proportionately greater and deeper root development in the loose sandy soil gives the roots access to a greater "total" of nutrients than where root growth is limited by heavy clays, or a high water-table. Further, in such free, sandy soils, found at the seashore, it is usual to have plenty of water available to the palm, which is charged with nutrients derived from the higher foothills and soil formations further inland. Under all circumstances, lack or exhaustion of nutrients will be felt, but it will have a much more pronounced effect where a restricted root system limits the total amount of moisture and nutrients available in an already deficient soil. That the nutrient content of the soil is most important in maintaining the healthy production of coco-nut palms is well illustrated on Witu Island, where the volcanic soils are very rich. There coco-nut palms are heavy yielders in areas where the soil is no more than 12 inches to 15 inches deep and rests on new volcanic rock which entirely restricts the root-growth below that level. This would not be possible in a soil deficient in nutrients.

Copeland[6] investigated, in detail, the water relationships of the coco-nut palm during drought conditions. It was found that after a prolonged drought in one district of the Philippines, it took palms two years to recover. He commented that "the injury to the palms' vitality during a prolonged drought is so severe that the return of favorable weather conditions is but slowly followed by resumption of normal activity. When adequate rains come the roots must awaken from a defensive rest, in which a prompt response cannot be expected. A constant supply of water must be at the disposal of the coco-nut, or it will protect itself against injurious desiccation by a partial suspense of vitality".

### Rooting of the Palms and the Necessity for Root Adjustment.

Soil conditions, such as those described in this article, undoubtedly lead to shallow rooting, except where the soil is well drained by creeks or main drains. Whether the roots go deeper or not they can only take up limited supplies of nutrients below the water surface, also the fibrous roots and smaller roots tend to die off in zones of poor aeration, as aeration is necessary for water and nutrient absorption. Thus, although plenty of water is present, conditions of physiological drought and reduced nutrient supply may occur, even though there are plenty of manurial ingredients present in the soil. If, by any chance, previous cropping with exhausting crops or lack of the main essential ingredients (nitrogen, phosphate, calcium and more particularly potash) is in evidence, this effect may be increased. It is seen that soil analyses are of great assistance in solving disease problems associated with soil nutrition.

Such causes as those indicated above can lead to cell collapse and breakdown, as for example some forms of bud-rot caused by unfavorable soil and moisture relationships, mainly, have been recorded from many sources. In the change-over period from wet to the dry season, where soils are liable to waterlogging and compaction after drying out, there is decided necessity for root adjustment. This often has marked physiological effects which are reflected in the behaviour of the palms. There is too much moisture in the wet season which leads to reduced nutrient intake and loss of roots. It is likely that in the dry season (particularly in abnormal periods), there is too little moisture present which, owing to compaction of the clay and the fact that the clay does not give up water quickly, would also lead to upset of the palms. The roots could be expected to grow and function better as soon as more rains are received, hence, in a plantation subject to a seasonal bearing, the best yield should be obtained from the beginning to the middle of the wet season.

It is feasible to believe that some form of seasonal adjustment is the natural behaviour of all coco-nut palms, excepting where the water-table exists at a relatively constant depth in a friable soil.

This root adjustment only leads to pathological symptoms becoming apparent under abnormal climatic conditions (e.g. too much or too little rainfall), where the soil and water-table do not favour normal root development.

It appears likely that seasonal bearing, nut-fall, leaf-droop, and often loss of palms (such as is found in coco-nuts growing on the Madang coast) may be due to fluctuating climatic and soil conditions affecting the behaviour of the roots and thus the water and nutrient supply to the palms.

### Moisture Requirements of Coco-nut Palms.

No work has been done on this problem in New Guinea, but a good deal of investigation has been carried out in the Philippines.[6-11]

In making injection experiments the writer observed when introducing culture solutions through numerous ¾-in. auger holes, which were about 4 inches deep and sufficient to hold 50 C.C. of water at one time, that hundreds of grammes of water were taken up, almost as quickly as they were introduced, on bright, sunny days. In the early morning and on rainy days the rate of absorption was very slow.

During a long wet season, when there are numerous consecutive cloudy days, moisture absorption and utilization by the plant are greatly reduced, despite the abundance of water present. In the dry season the rate of absorption is greatly increased, as is the transpiration. The palms have natural adaptation in the leaves for regulating transpiration to some extent.

The pinnae (leaflets) are adapted for folding longitudinally and thus lessen transpiration by protecting the stomata (breathing organs, found in the leaves) from undue evaporation. There are no water storage organs found in the coco-nut palm, such as are found in numerous other plants.

Espino and Juliano[11] carried out detailed investigations on the absorption of culture solutions by coco-nut palm roots. They showed that the rate of absorption was 233.33 per centum more rapid during rainless days than during rainy days. The wind makes a decided difference in the transpiration of the leaves, but makes a much greater one when the leaves are in full sunshine, as is more usual in the dry season.

Copeland[5-6] reports that a coco-nut palm can absorb 24 litres (54 lb.) of water per day, from root absorption experiments, but from determinations of evaporation from the leaves, he is inclined to place the figures at from 28-45 litres.

Espino and Juliano (*loc. cit.*) from a different set of calculations place the water requirements as 16 litres (36 lb.) per day.

Whatever figures are correct, they are all of a high order and explain why palms flourish so well at low levels (sea-shores and islands) in the tropical zones.

The annual requirements of a coco-nut palm requiring 36 lb. per day would be 13,140 lb. and for one requiring 54 lb. per day would be 19,710 lb. Thus the requirements per unit area (acre or hectare) are constantly very high.

All investigators agree that there is a very close correlation between absorption and transpiration. The absorption of nutrients by the palm depends on two sets of factors—those that occur inside the plant (physiological) and those that occur outside the body of the plant (environmental). Among the important factors determining absorption are the age, the health of the plant, and all of the factors which govern the rate and amount of transpiration.

The amount of transpiration depends upon the temperature and humidity of the air, rain, wind-velocity and the growth activities of the plant.

Where unfavorable moisture conditions occur, and in times of severe drought, the older leaves fall off or die back with unusual rapidity. It has been proved that the older leaves are the ones which would lose the most water; the tree cuts down its water requirements in this way, to a very considerable extent.

In several instances here, when the palms were growing under unfavorable conditions, or during abnormal weather periods, one has seen the ground literally littered with leaves. There is a tendency for this fall of leaves to occur within a very short space of time under certain conditions.

When root growth and absorption are greatly reduced, as usually follows physiological droughts, or dry periods, then the whole of the top growth is reduced proportionately. It may happen that the growth slows up completely or is reduced to such a degree that the fronds fall off altogether. If the conditions are permanently unsuitable, premature ageing of the palms may result, unless the soil conditions are improved.

It seems feasible that "leaf-droop" occurs where the moisture and nutrients supply of the palm are greatly reduced, so that the palms tend to shed a high proportion of their leaves to balance the absorption to the supply available. Where the palms are not sufficiently vigorous to shed their leaves, or where their vigour has been further reduced by other contributory factors, e.g., fungus attack, then these leaves remain attached to the palm in the familiar manner already described in the previous article on coco-nut diseases.(9)

Duthie(8) compared the soil moisture relationships in soils from healthy beds and those carrying palms liable to wilting . In the case of the heavy, clay soils under investigation he concluded that the slow lateral movement and availability of the moisture in compact, clay soils were key factors leading to the appearance of the diseases. It is not the gross moisture present in the soil, but the amount of available moisture which is most important. The wilting point in a clay soil may occur when there is more than 13 per centum moisture present in that soil, especially where there is a high percentage of salts (sodium, magnesium).

Such salts when present in high concentration hinder absorption through the roots. Physiological and chemical analyses of the New Guinea soils are very lacking as far as such data is concerned. It is pointed out that as the percentage of water to dry matter in a young palm is much greater than that in an older palm, the water requirements of a young palm, in proportion to its size, are greater. This helps to explain the greater susceptibility of young palms to drought conditions. Copeland(5) maintains that proper physical composition of the soil is of a great deal more importance than its chemical composition, if only the palms are able to secure sufficient water. It appears that both are important but the physical relationships of the soil are not usually given sufficient prominence.

### Restriction of Water Supply Due to Disease and Injuries.

Waterlogged soil and fluctuating climatic conditions which are often not optimum for the growth of the coco-nut palms favour insect and fungus attack.

The bleeding fungus (*Thielaviopsis paradoxa*) does most damage in wet situations and often causes hundreds of lesions to develop on the trunks, some of which become large and deep seated. Even though the palms recover from such attacks a good deal of conducting tissue is destroyed, which naturally reduces the water supply to the palms.

Thread Blight (*Corticium penicillatum*), as a general rule, only assumes serious proportions under wet conditions, in wind-locked areas. This fungus destroys the fronds and reduces water absorption under conditions where maximum leaf area is required for the palms to flourish.

"Frond-fall" and "leaf-droop" which are usually most prevalent in waterlogged and deficient soils, both lead to a reduction of the total number of fronds and reduce the water supply to the palms. Where the fronds fall off prematurely the soft tissues are exposed to beetle attack. After severe beetle attack half the diameter of the trunk may be destroyed and, although the palms recover, the water and nutrient supply to the palms are reduced for all time.

Severe burning off, such as is practised on some plantations here when the undergrowth is out of control, in addition to burning the humus from the soil, destroys the superficial layers of the palm trunks. This greatly reduces the water conducting tissues. The influence of such diseases and injuries as those outlined, greatly aggravates the effects of adverse climatic and soil conditions on the general health of the palm.

## MATURE PALM WILTS AND OTHER PHYSIOLOGICAL DISEASES.

There are mature palm wilts and other physiological derangements of coco-nuts present in New Guinea which are due to palms growing on soils with unsuitable profiles, which are subject to waterlogging in the wet season and to drying out and compaction in the dry season. In mentioning instances of this, some very good examples are to be seen on the mainland of New Guinea, in parts of the Markham Valley, near Lae, and in the plantations around Madang, located on estuarine formations. Similar occurrences have been noted in the Kavieng districts, also in Manus, and the Admiralty Islands, on varying classes of soil, but more especially where stiff, clay-soils overlying coralline limestone are present. The question is whether these mature palm wilts are to be classed in the same category as "maturation wilts" where the particular stage of growth and the change in the chemical composition of the plant itself comes so much into play.

The late Dr. H. R. Briton-Jones has clearly recognized the difficulty in classifying wilt diseases of coco-nuts in his second treatise on the subject.[4] He remarked that "the causes of the unsuitability of the conditions for coco-nuts in different soils may be entirely different. In one case, it might be due primarily to the physical texture of the soil, whereas, in another, it might be due to the chemical composition of the soil or even to a combination of certain physical and chemical factors".

This appears to indicate the crux of the position, and, further, it indicates how this problem of wilt diseases is so closely related to deficiency problems as a whole and to the retrogression of coco-nut areas, which is becoming more and more common in plantations here.

It seems a safe deduction that the soil profiles, the climatic environment and the cultural conditions in New Guinea would seldom duplicate those found in the West Indies, hence we may expect different responses from the coco-nut palms under the particular circumstances prevailing here.

It would appear that coco-nut wilts of the "bronze leaf" type are not nearly so severe or prevalent in this country as in the West Indies. Certain of the external characteristics of the diseases described in this article do not seem to correspond with those described by Briton-Jones,[4] Bain,[2] Duthie,[8] and others.

The possible explanations as to why coco-nut wilts are not common here are many, as, for example, most parts of New Guinea are classified amongst the wettest tropical countries in the world. Except on some areas of the mainland, the soils are all geologically new where coco-nuts are grown.

Culturally, in New Guinea, sugar-cane is never intentionally replaced with coco-nuts or vice versa, and interplanting coco-nuts with sugar-cane is not done. In very limited areas coco-nuts planted here may have replaced small areas of native-grown cane for edible purposes or patches of wild canes.

Briton-Jones, in 1928,[4] decided that there were two forms of the root disease (wilting) of coco-nuts recorded by Stockdale[28] and Nowell[17] in Trinidad, which he named, respectively, "bronze leaf wilt" and "yellow leaf" or "tapering stem wilt". In the former the leaves are a highly-coloured yellow to bronze or may assume a reddish-brown colour. The latter is distinguished by a yellow discolouration of the leaves progressing from the tip backwards, while all the leaves, including the central ones, become dwarfed, and it is a chronic malady whose history and effects have not been worked out. His observations in Trinidad and some of the other West Indian islands led to the opinion that the onset of "bronze leaf wilt" is in the majority of cases due to physiological drought, which does not need a prolonged period, but may become evident after a short, dry period under certain soil conditions, especially where the soil is heavy, badly drained, and subject to desiccation in the dry season.

The soils on which the disease is serious were said to be generally heavy, in very bad tilth and constitutionally such that they do not drain well, but dry out rapidly and crack in the dry season. The very definite correlation between lack of drainage and the incidence of the disease indicated that any organism present was a secondary factor, and the primary cause is suggested very strongly as a soil factor.

The general wilting of coco-nut palms often seen after a long spell of dry weather in portions of New Guinea (e.g., the Gazelle Peninsula, New Britain), with usually a subsequent recovery when the rains occur, shows some features in common with the above occurrences. It is, however, usually seen on light, porous soils with poor water-holding capacity. The lower leaves do brown off and wither, but these palms immediately respond to good rains. This browning off after a drought and subsequent recovery is not the same as bronze wilt and does not explain the conditions met with at Kokopo and Namatanai and elsewhere in New Guinea.

Park[19] refers to the effects of "drought" on coco-nuts in Ceylon. He first suspected bud-rot infestation, as one estate of 100 acres contained 600 dead or dying palms. The standard of cultivation on the estate was poor, and it was found that the condition was due to the effects of drought, while the buds fell off from mechanical causes only. He stated that "the condition was comparable with 'bronze leaf wilt' disease recorded by Briton-Jones, in Trinidad".[4] The condition was worst on low-lying land, liable to water-logging in wet weather, due to this water-logging causing the palms to become shallow-rooting. The effects of good cultivation were marked under these conditions, and drainage to induce deep rooting was advocated.

Patel[20] says that, "in the red soils of India, palms suffer through drought in the summer. It is possible that some mineral nutrients available in the soil may not be absorbed by the palms, because of some limiting factors such as moisture".

Briton-Jones[4] experimentally reproduced bronze leaf symptoms in healthy palms, under suitable conditions, by digging trenches around them. Another very interesting experiment was where he induced some leaves on one side of a palm to turn to a bronze-yellow colour by cultivating on that side to a depth of 3 inches, thus cutting the root system within the cultivated area.

According to Bain,[2] "bronze leaf wilt" is considered to be a physiological die-back of the palm, as a result of water deficiency in the plant. After a long investigation, he concluded that "the 'Trinidad wilt' was due to the curtailment of root growth by a high water table at certain times of the year, followed by dry seasons, which the restricted root system could not withstand and function properly".

The close approximation of the soil conditions described and the development of this type of root-growth in palms growing in certain areas of the Madang coast, as described elsewhere, are worthy of note.

It is seen that certain soil factors, particularly water-logging, which militate against the plant producing an effective root system, operate in wilt areas, and it has been clearly indicated that bronze wilt may occur in several types of soil. It would appear, therefore, that the factor to be particularly stressed in this disease is a water deficiency in the plant, the differences in nutrient status being considered as contributory factors. The disease should be extra prevalent in a dry period, following an abnormally wet season, and apparently field observations have confirmed this. It will be shown elsewhere in this article that many other disease symptoms found in coco-nut palms in New Guinea are worst under the particular conditions mentioned, as one may naturally expect.

It was been recorded that,[2-8] "in all plantations where 'bronze leaf wilt' was noted in Trinidad, the palms were planted generally at what appears to be just about half the proper distances apart (about 15 feet and in some cases 20 feet)". The range of spacing of coco-nut palms on the main plantations in New Guinea is from 25-36 feet, and is usually about 30 feet.

Curiously, the occurrence in young palms at Namatanai was on areas where the spacing was rather wider than usual, at about 36 feet. The only places where close planting is resorted to here are on the native groves, where frond choking does occur owing to light competition, but wilting appears to be very rare.

Bain[2] says that "the usual age at which palms die from the disease is from 15 to 18 years". If this is the period at which palms come to the bearing stage there, it seems that the palms come to this stage much later than in this Territory, probably owing to the late planting and the different soil conditions, &c.

Duthie, writing on "Coco-nut Wilt, in the Essequibo and Pomeroon Districts of British Guiana",[8] says that "Bain's findings explained the puzzling fact that trees grow normally for several years, as even a relatively small root system is sufficient to keep young trees in good health, but the strain of bearing is usually the critical point. Trees 15 to 25 years old are affected on the Essequibo coast and the symptoms are almost identical with those in Trinidad. The disease occurs both on clay and sandy soils."

His investigations were confined to the clay soils and he found the wilt occurring on an acid clay, markedly deficient in potash and phosphate, but with adequate nitrogen and organic matter. It was shown that the accumulation of saline substances (magnesia and soda) in the subsoil of the wilt area indicated lack of aeration and drainage, even though the soil was not waterlogged.

The following conditions were listed as leading to wilt in British Guiana:—

The widespread cultivation of sugar-cane led to large areas being changed from bush to sugar-cane—a shallow-rooted grass crop which exploits the top 18 inches of the soil and leaves the lower layers free from roots. The wilt disease of coco-nuts on the heavy, clay soils of the Essequibo coast is probably caused by planting coco-nuts on old cane beds where the sub-soil is too compact and saline to allow easy root penetrations, with the result that the top soil becomes a mass of roots and the percolation of water is greatly hindered. The trees are thus living on the verge of drought, and the effects of physiological drought were also important owing to the high content of moisture and soda even in the top soil. When evaporation from the soil surface is increased by 'clean cultivation' or by the death of a few trees, wilt appears and spreads slowly in the direction of the prevailing winds.

The type of soils in which this wilt occurs, the chemical status and, further, its occurrence after the growing of the exhausting crop sugar-cane should be carefully noted for comparison with New Guinea conditions. Duthie's description also largely conforms with the conditions found in Trinidad.

## Mature Palm Wilt on the Huon Gulf.

The nearest approach to an extreme case of "mature palm wilt" resembling the "bronze wilt", such as one has seen depicted from Trinidad, was seen recently on a plantation situated in the Huon Gulf area, on a plain apparently representing the old delta of the Markham and Adler Rivers. The areas planted with coco-nut palms, ranging from 21-27 years old, were covered by a dense undergrowth of grasses and weeds, such as Kunai, *Imperata arundinacea*, *Saccharum spontaneum* (wild sugar-cane), and many other grass-types, also bananas and cassava, *Manihot utilissima* (which had been previously planted and run wild).

"Leaf-droop" and "leaf-break" were most abundant and were very prevalent, while the palms were stunted and bearing poorly. In many areas, tapering stem, yellowing and bronzing of the fronds, and reduction in the size and number of the fronds, were most noticeable. The erectness of the few fronds left, their feathery, open nature, and poor colour and vigour, showed conclusively that the soil and cultural conditions were at fault (*see* photographs).

Coco-nut Palms—Mature. Affected by unfavorable soil conditions ; non-bearing, also " leaf-droop " and " taper stem " present. Two palms with heads missing.

Coco-nut Palms affected by soil conditions.

N.B.—Palms—non-bearing. Fronds—feathery, reduction in size and number. " Leaf-droop "—present.

In some places the very strong-growing, soil-exhausting creeper, *Ipomœa robusta* (sweet potato type), was seen growing over the trunks and into the branches of the palms. Several palms were seen to be left as bare poles only, with the cabbages collapsed and fallen off. Stem-bleeding, due to the fungus *Thielaviopsis paradoxa,* was seen on many of the palms.

The frequent gaps in the plantation showed that the loss of the palms had been high in the past. The general appearance of the plantation suggested unsuitable soil conditions, and extreme manurial deficiency, which from the scorching and bronzing present on the palm fronds was apparently an inter-action of potash deficiency combined with physiological drought. The conditions were undoubtedly intensified by lack of care and attention, probably increased by

**Coco-nut Palms, showing dense undergrowth, such as *Ipomœa robusta,* climbing on trunk. N.B.—Stunted and poor condition of palms, also " leaf-break " present.**

burning off and the presence of so many strong-growing, soil-exhausting grasses and weeds, most of which have a heavy drain on nitrogen, but particularly on potash. The soil profile, however, showed the main reason for the state of the coco-nut palms here, when the inter-action with the other factors mentioned are taken into account. The surface-soil was a stiff clay loam, liable to waterlogging in the wet weather. The sub-soil was a very compact and small-grained clay, caused by deposition of the fine particles. At varying depths below this clay sub-soil, coarse rubble layers composed of water-worn pebbles were met. In the wet season there is a mass movement of water through these rubble layers from the high hills behind, so that almost a free water surface is presented. The surface layers were liable to waterlogging, with the presence of a superimposed water table in the wet season and to drying-out and cracking in the dry season. Obviously the rubble layers hasten the loss of water from the soil and sub-soil in the dry season. It will be seen that these conditions somewhat approximate the conditions seen in the Madang district. Owing to the presence of grasses, wild sugar-canes, native food crops, wild bananas, &c., which would not be present on a well-kept place, the chances of deficiency and unsuitable water-relationships causing severe symptoms are greatly increased. It is also apparent that this set of circumstances would more closely represent the extreme conditions found in the West Indies, where coco-nuts have been previously grown for several years.

Where unsuitable soil conditions exist, and the plantations are badly treated as concerns lack of drainge and the growing of exhausting crops, there is, in the future, considerable likelihood of many other areas showing " mature palm wilt ", some forms of " bud-rot ", and related symptoms.

## Particulars of Some Areas Where Physiological Derangements of Coco-nuts Occur.

All of the plantations where clay exists hold the surface water after heavy rains, except where creeks and running streams provide adequate natural drainage. The coco-nuts in the naturally-drained areas bear quite well, thereby showing that drainage is essential for all the undrained areas of similar soil type. Some typical soil profiles from waterlogged areas in the Astrolabe Bay area, where palms are very stunted and surface water is often found right to the surface, are now described.

When holes are first sunk, the water is seen at about 6 inches from the surface, but usually fills and runs over at various periods. The ground is very clayey down to 4 ft. 6 in., being slightly freer at the surface. At a short distance from the surface there is usually a hardened pan of deposited clay, blue-grey in colour, showing poor aeration and the presence of unoxidized iron. Even at the surface the clay was very puggy, but much more so in the compacted layers where the very fine-grained, colloidal particles are washed down and deposited. Such soil conditions are totally unsuited for plant growth, or nutrient intake. Under ordinary conditions heavy clay soils give up their nutrients slowly, owing to colloidal attraction. It is almost impossible for a coco-nut palm to take up its food from such a soil under water-logged conditions, or, conversely, when the soil has set very hard in the dry season.

Typical soil profiles in areas liable to forms of " mature palm wilt " vary somewhat as to actual depth of the deposits, but usually conform to the same type. In one water-logged area, the face of a creek showed first a shallow, dark humic layer on top, then a stiff clay loam (about 1 ft. 6 in. to 2 feet deep) overlying a very stiff, clay sub-soil, which reaches to a depth of 5 feet. Then, from the bottom of this clay to 15 feet down, alternating layers of pebbly gravel (rubble) with sandy layers intervening were seen. This type of deposition appears to be associated with the streams running from inland through the plantation, or, in other words, are estuarine deposits. In this particular case, it was derived from the shifting mouth of a comparatively large river.

## Underground Water.

The whole of the area subject to the palms dying off has an extensive underlying free water-table, at no great distance from the surface. The level of this main water-table usually corresponds with the level of the water in the running streams present, which are usually quite shallow in the estuarine areas. It seemed practically certain that there is a superimposed, secondary, water-table which is only in evidence in the wet season, or in periods of heavy rainfall. This secondary water-table is only a few inches from the surface, in the wet areas, and is held up by the compacted zone of deposited clay (which acts as a hard pan), assisted by the flatness of the land and the lack of drainage. This raised water-table lies near the surface during the whole of the wet season, but, in the comparatively short dry season, the ground dries up, sets very hard, and compacts. This is especially so in the case of the non-bearing areas, where the water tends to lie all over the place. In the dry season, under these particular conditions, even the grass and weeds stop their growth to a large extent. The change-over period from the wet to the dry season greatly affects the nutrition of the plant and plays a most important part in the development of deficiency symptoms leading to stunted growth, leaf-droop, nut-fall, and so on.

In the bad water-logged areas mentioned, the palms range from 10-20 feet high, while nowhere are they higher than 40 feet, even in the best areas, where the soils are so heavy. Numerous palms in these areas show constriction of the trunks at a few feet above the ground level with evidence of a later recovery of diameter to a limited extent, which illustrates the effect of neglect in the early stages. Where the palms are stunted, with tapering stems, and non-bearing, this is a direct reflection of the soil conditions and related root development.

The high water-table and water-logged state of the soils following heavy rains are very deleterious to the healthy growth of the root system, as this prevents air intake below the water level and interferes with it in the saturated zone. Because of this fact, and despite the excess of moisture present, it is impossible for it to be absorbed by the roots. Consequent on the reduced water supply to the palm is a reduced intake of nutrients and untimely death of the roots.

In many places the palms are reduced to getting their air and nutrient supply from the top 6 inches of soil during the wet period and after prolonged periods of stagnation either the roots die off or become sickly below the water level. In the dry reason the soil cakes and compacts, and the heavy clay soils give up their moisture very slowly to the reduced root system. The palms often show a partial recovery towards the end of the dry season, when new roots develop and cause more water and nutrients to become available from the lower sub-soil layers.

It is pointed out that the presence of the estuarine rubble layers underneath the soil layers assists the water getting away in the dry seasons and leads to a greater contrast, between the wet and dry seasons, of soil conditions than would otherwise occur. Extremely bad cases of unsuitable soil profiles such as those described above may mean that the ground is totally unsuited for coco-nuts, especially where drainage is impossible or uneconomic. The pronounced seasonal bearing in the plantations on this coast is closely related to the fluctuating soil and climatic seasons (*see* graph). The change-over periods from the wet to the dry seasons or vice versa are believed to be critical seasonal periods for the coco-nut palms, and to have a pronounced influence on both seasonal bearing and the occurrence of nut-fall in coco-nuts, where heavy, water-logged soils liable to drying out are present.

## Seasonal Variations In Yield.

It is not intended to discuss this problem for New Guinea as a whole, but to relate the seasonal fluctuations in yield of certain plantations with the moisture and nutritional status of the soils already described, and to indicate other reactions of the palms to these particular environments.

The monthly yield of one plantation, in particular, is discussed where the tendency to seasonal bearing is pronounced. In the three years considered November, December and January are usually peak months for production, while March, April, May and June are months of comparatively low yield of copra. If, for the three years, the total monthly yields as bags of copra harvested are compared, the following interesting facts are revealed. The total number of bags harvested in the three high yielding months are as follows:—November (902), December (914), and January (900), giving a total of 2,716 bags. In the three low yielding months the numbers of bags harvested were for April (680), May (624), and June (715), giving a total of 2,019 bags, which represents almost a third reduction in yield compared with the former three months.

This seasonal variation in yield is undoubtedly due to a seasonal inter-action between the soil, climatic factors and the nutrition of the plant, and is what one would expect under the conditions prevailing on most of the plantations around the Madang district, particularly on those properties which are situated on deltaic deposits in the extensive Astrolabe Bay area.

Under the particular conditions obtaining at Kasaragood, India, Patel has shown by mathematical calculations (regression, co-efficients, and significance of yield) that the rainfall of the year previous to and of the year of the harvest is significantly correlated with yield.

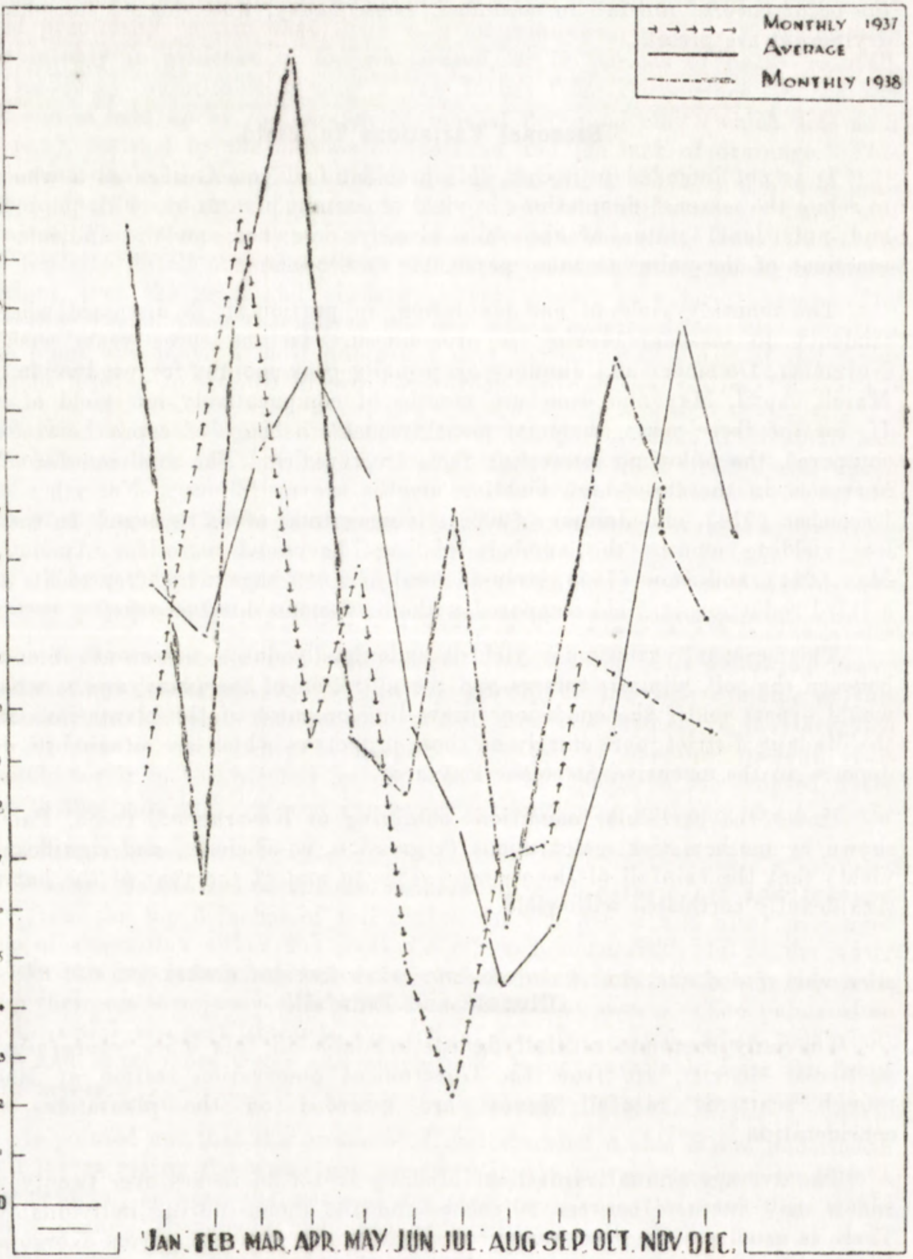
## Climate and Rainfall.

The only complete rainfall figures available in this office, concerning this particular district, are from the Government observation station at Madang, though scattered rainfall figures are recorded on the plantations under consideration.

The average annual rainfall at Madang is 136.36 inches over twenty years, and it may fluctuate between 90 inches and 165 inches during individual years. There is usually a long wet season of seven months duration, from November to May, with a short dry season, usually of only five months duration, from June to October.

# RAINFALL GRAPH, MADANG.

## MONTHLY RAINFALL (1938): AVERAGE FOR 21 YEARS (1917–38): MONTHLY RAINFALL (1937).



The appearances are that both the maximum and low yields are recorded at the beginning and end of the wet season respectively, but this may be misleading as to times at which the causes leading to the actual losses in crop occur. The peak months are March, April and May, while August and September are the driest months and, as seen, the lowest yields are recorded in April and May, which, however, ranges from five to six months after the rainfall season has begun. The fact that this reduction in yield is more apparent at the end of the wet season and lasts into the change-over period is worthy of note.

The period of maximum yield is where regular and moderate rainfall conditions are experienced immediately after the dry season. The high yields seem to commence immediately the dry season is over, when the soil is not water-logged, and sufficient rainfall occurs for the palms to set satisfactory crops.

There may be both immediate and long term effects (or seasonal and annual responses) to seasonal conditions. The effects of drought on reducing the following year's crop is well known. The fact, however, that poor, or optimum, fruit-setting conditions in a particular part of the season may not be evidenced till twelve months later is not often recognized. Where the seasonal effects on yield occur in the same crop, this may be due to either the full crop not being carried to maturity owing to nut-fall, or, conversely, to spathes and already mature nuts being carried down over on the palms and dropped together at a later date. This latter occurrence is not uncommon on poorly vigorous palms.

### Nut-fall of the Type Related to Soil Conditions.

Stockdale[29] has briefly described nut-fall from the Kurunegala district, Ceylon, where the rainfall was said to be rather excessive for optimum growth of the coco-nuts and the soils heavy. It was only under these conditions that "nut-fall" and "leaf-droop" proved serious in Ceylon, and under excessive and continuous spells of wet weather proved capable of considerable damage to palms and crops.

Gadd, in 1923,[13] stated that "in Ceylon it was shown that water deficit following on a prolonged drought caused greatly increased fall of the 'female flowers', or 'button nuts'. Such abscission of 'buttons' and youngest fruits may be caused by periods of drought as may the falling of larger nuts".

He indicated, however, that "nut-fall" in Ceylon occurs principally in the rainy season, and in the districts where it was particularly severe the soils were heavy loams which become hard during the dry weather, with a tendency to water-logging in periods of excess rainfall. These particular soil conditions, during heavy rains, become deleterious to the healthy growth of the root system by interfering with the air supply, which despite the excess of moisture present leads to reduced absorption of water, and untimely death of the roots, resulting in nut-fall.

The reader is referred to the New Guinea *Agricultural Gazette*, Vol. 3, No. 1, pages 58 to 70, for a detailed account of nut-fall in coco-nuts where the various kinds of nut-fall are described.[9] The purpose of the discussion included here is to show that nut-fall can be closely related to deficiency of water and nutrients in certain types of soil. The nut-fall problem in New Guinea is elucidated on page 62 of the same article, where it is stated that severe incidences of nut-fall have been recorded only at intervals on plantations in this Territory.

The fall of buttons and of large nuts up to 10 inches in diameter was noted in certain areas near Madang with soil horizons as described previously, and, also, in other plantations in the same district, where stiff clay soil rested on a loose foundation of decomposed coral. In these areas there was no great depth of soil on top, and, owing to an intervening zone of deposition, or probably due to an excessive lime status, the coco-nut roots did not extend far into the coral layers.

In the limestone soils of coral atolls in this Territory (e.g., in the Western Islands) there is generally deposition of secondary limestone hard pans due to the leaching action of the water. The lime is leached out by the water and deposited at certain depths, where it has a typical mortarising effect and firmly cements the fragments of sand.

Brackish underground water is present at relatively constant depths right throughout the coral atolls. The small difference in height from the surface to the water in the various places is more dependent on the slight irregularities of ground elevation present. On the higher ground on the margins it is rarely more than 5 ft. 6 in. to the free-water level, while it rises to the surface in the lagoons, and over wide intermediate areas the water is only at about 1 foot to 18 inches from the surface.

The holding up of the surface water by the lime-impregnated layer would lead to increased water-logging in very wet seasons.

In the lagoons and swampy depressions, however, it is the excess of free brackish rather stagnant water coming to the surface which restricts the root-growth and makes the areas unsuited for growth of coco-nut palms at any time, as is seen where they are dwarfed or lean over.

It was seen from soil profiles examined that underneath some areas it was no distance to a second lime-impregnated layer, below the free water surface of the true water-table, which was practically impervious to water. Below this at varying depths solid coral is usually met with its lime-infiltrated coating, which also prevents the free water level dropping far.

It would be thought that the presence of this underground free water should ensure that any water shortage would be unlikely. This, however, is not the case and the best coco-nuts on these atolls are very prone to seasonal bearing and are affected by seasonal conditions.

The yield of copra falls off badly after long dry seasons.

The shallow rooting of the palms in most areas here and the tendency for them to fall over and show flat plates of hardened mortar-like ground at their bases has been described in a previous article.[10] The superimposed limestone hard-pan mentioned does not entirely prevent root-growth, but below this layer the roots are usually constricted, gnarled and not well developed.

In addition to the restrictive action on the spread of the plant roots, it also causes retention of the surface rainfall, near the surface in the wet seasons, despite the fact that the surface soil is loose and sandy. It is also believed that this layer has the effect of limiting the amount of nutrients available. The loose, sandy, surface soil leads to a quick drying out in the dry season and reduces the water and nutrient supply to a restricted root system. Stunting, deficiency symptoms in the palms and fall of poorly developed and unfilled nuts is common under these conditions as is "leaf-droop" and seasonal bearing. The effect of the physical conditions mentioned are closely inter-related with soil exhaustion and lack of nutrients which has caused the palms on so many of the older areas to retrogress in vigour and production.

In the plantations of New Guinea, there is reason to believe that any physiological upset of the palms and nut-fall which occurs is worse in the change-over period from the wet to the dry season, although a certain amount may occur all the year round.

The occurrence of nut-fall as indicated is undoubtedly a question of unsuitable soil and water relationships. Few insects or fungi could be seen present on the base of the fallen nuts at Madang. It is fairly safe to conclude that physiological conditions are responsible, and the organisms present serve to increase the effect. It appears that a much heavier crop is set at flowering time than is carried to maturity, simply because under unfavorable circumstances the palms cannot carry a full crop.

It is the opinion of Dr. Tammes[30] of the coco-nut experiment station at Manado, Celebes, N.E.I., that "It seems that the number of fruits produced is not limited by the number of flowers nor by pollination, but is exclusively controlled by the physiological condition of the nutrition of the tree. A very important factor is the available quantity of water."

The present author does not entirely subscribe to the above conclusion, but there is no doubt that the water relationships do play a very big part as where there is too little water present, or where too much water in the soil leads to physiological drought owing to root restriction and reduction of water intake.

**Influence of Soil-exhausting Crops on Wilt and Disease Occurrences.**

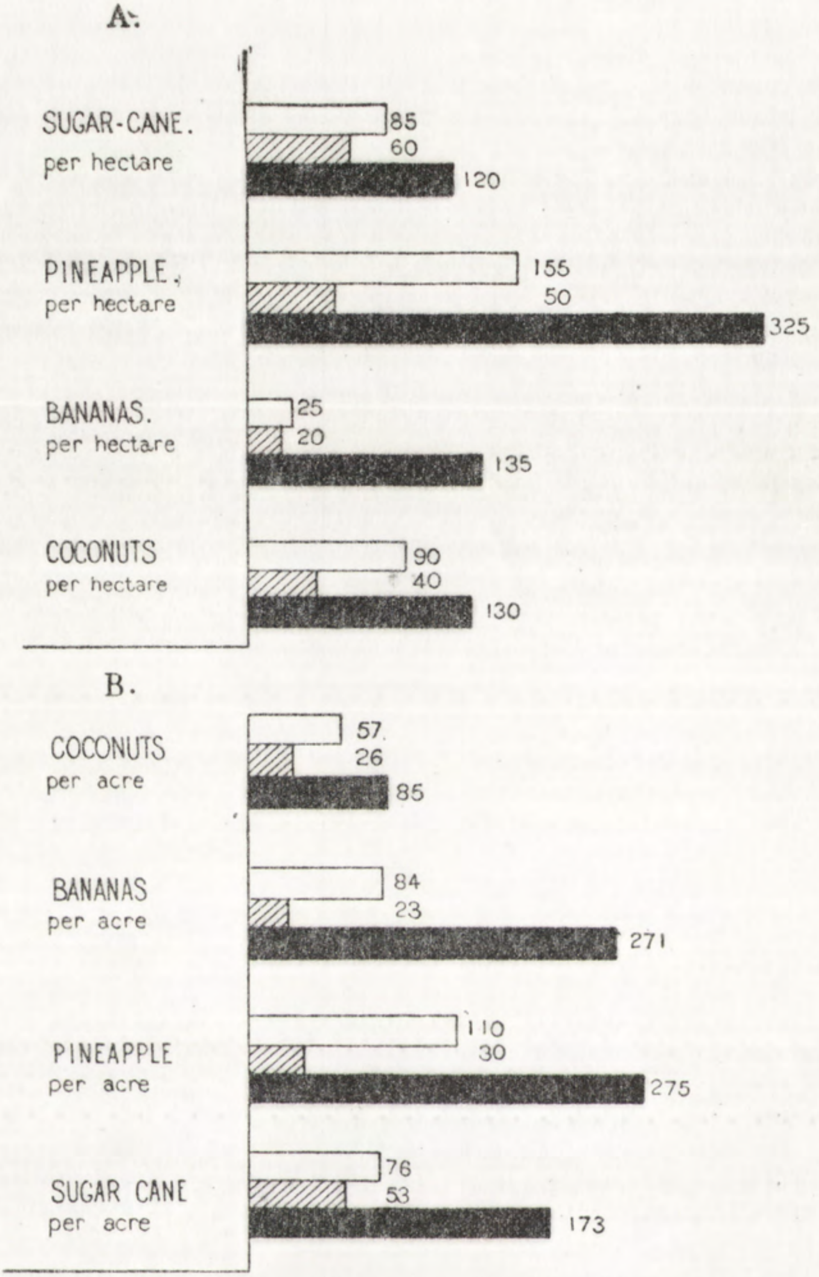
It has been pointed out that the worst manifestations of wilt in the West Indies occur where coco-nut planting follows sugar-cane culture. Reference to the graph, showing the approximate manurial requirements of this crop as compared with coco-nuts, will indicate that apart from the physical effects of this crop on the soil, sugar-cane has a much greater drain on the soil constituents than coco-nuts; this is particularly true of the potash requirements.

It will also be seen that this drain on manurial constituents (especially potash) is even greater in the case of bananas and pineapples, which are normally grown as native food crops in New Guinea. Cassava, taros, sweet potatoes, maize and other crops can be shown to have a similar effect. Some of the native non-leguminous creepers, commonly found in plantations, e.g. *Ipomoea robusta* (a very strong creeper of the sweet potato family), have a most exhausting effect on the soil. Such rampant-growing weeds as *Sida rhombifolia* and Blue Rat's Tail, *Stachytarphetum* spp., have much the same effect.

In ordinary native culture their normal shifting system of cultivation ensures that after one crop is sown it is a long interval before the same ground is utilized again. The exhausting effect of these native foods is thus recognized in a practical fashion.

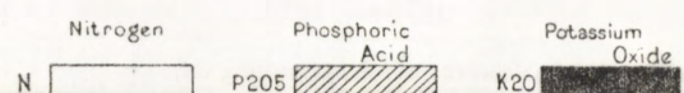
In the past, and even up to the present time, it has been the practice of planters when developing new places here to grow large areas of native crops to feed their native labour or for sale. In numerous instances here, where plantations are just coming to the bearing stage, it has been possible to distinguish the palms growing

## QUANTITIES OF PLANT FOOD REMOVED FROM SOIL BY TROPICAL PLANTS.




A. Figures given by Eckstein, Bruno, Turrentine, (12)
= Kilogram per hectare, kg/ha. 1 kg/ha. = 0·9 lb. per acre

B. Figures given by Jacob and Coyle (15)
= lb. per acre.



over old native gardens or on areas previously used for growing native crops. After growing such food crops, the sôil is often left without cover for some time, so that the ground is exposed to the scorching effect of the sun's rays and to erosion and washing by heavy rains.

The young palms growing on such exhausted and previously exposed areas usually appear stunted with a general appearance of debility compared with the surrounding palms. The fronds appear yellowish or yellowish brown in appearance, as contrasted with the healthy green colour of palms growing on normal bush soils. It is rarely that these palms reach an extreme wilted appearance as is apparently common in other countries; nevertheless, this is probably a manifestation of the same kind of growth reaction but in a lesser degree. It is seldom that the palms do not recover when the palms get older and the roots get a greater hold on the soil. There are few plantations in New Guinea where some areas of palms showing similar symptoms to those indicated above do not exist.

It is unfortunate that one cannot present general chemical analyses of the common grasses found in New Guinea plantations. As far as this country is concerned, "kunai" or "lalang" grass, *Imperata arundinacea,* has all the deleterious effects of sugar-cane on the physical texture of the soil. This ubiquitous grass occurs over the whole Territory and its dense growth has a most exhausting effect on the soil. It has a deep matted and intertwined strong fibrous root system which goes down to considerable depths. Analysis shows that this grass has a high percentage of ash which is rich in potash. It is small wonder that palms growing in competition with such a growing and soil-exhausting grass fare badly and become more liable to both fungus and insect attack, besides reacting immediately to unfavorable water-table and climatic conditions. The relationship of the previous strong growth of kunai to the poor appearance of the palms coming into bearing at Kokopo (and probably in Namatanai) is readily understandable.

## Coco-nuts Following Sisal Hemp: "Agave Sisalana".

Near Constantinchafen, Astrolabe Bay area, there were formerly old sisal plantations, planted by an old German company. These were later abandoned and coco-nuts planted instead. As would be expected the coco-nuts did not thrive. Over large areas the palms remained stunted, yellowish and poorly bearing; often their tops fell off. About three-quarters of the whole area had to be abandoned. The main reason for this was the shallow stony soil present with deep layers of rubble underneath, allowing the water to get away quickly to the free underground water flowing through the gravels. The conditions were exaggerated by the impoverishing crops of sisal hemp previously grown.

Sisal hemp is a most exhausting crop, as is seen from the analysis quoted, and unless the waste is returned to the soil and heavy manuring carried out the soil may be rendered useless for other crops.

The green leaves of sisal contain in their ash 18.8 per cent. potash, 3.29 per cent. phosphoric acid, .098 per cent. nitrogen (low), 33.40 per cent. lime and 15.37 per cent. magnesia.

As would be expected the palms following such an exhausting crop showed marked signs of deficiency.

In addition to the shallowness and lack of nutrient content in this soil, the prevalence of leaf-droop and yellowing was largely caused by the previous cropping and the attempts to control weeds by burning off.

Curiously the predominant native grass which has now grown over the abandoned areas is a most rampant-growing, soil-exhausting species. The planters in the district usually refer to this area as a "kunai" or "kangaroo" grass plain. In reality, the tall coarse grass present is *Ophiurus megalophyllus,* a common species in the tropics which has no common name here. There are several other species present including the kangaroo grasses, but very little kunai. Based on experiences elsewhere, it is under these extreme conditions that die-backs would be expected in the coco-nut palms.

In addition to kunai and the small areas of true sugar-cane, grown for native requirements, the following indigenous grasses are listed as being amongst those which may produce similar bad effects on coco-nuts to those already indicated for kunai and sugar-cane:—

*Saccharum spontaneum*—Native sugar-canes.
*Saccharum robustum*—Native sugar-canes.
*Chrysopogon aciculatus*—Love or seedy grass.
*Paspalum conjugatum*—Thurston grass.
*Themeda gigantea*—Giant kangaroo grass.
*Themeda australis*—Kangaroo grass.
*Ischaemum muticum*—Swamp grass.
*Sorghum nitida*—Native sorghum.
*Pennisetum macrostachymum*—A native grass, very like elephant grass.
*Ophiurus megalophyllus*—A very strong vigorous grass, common in certain areas, e.g., at Melamu.

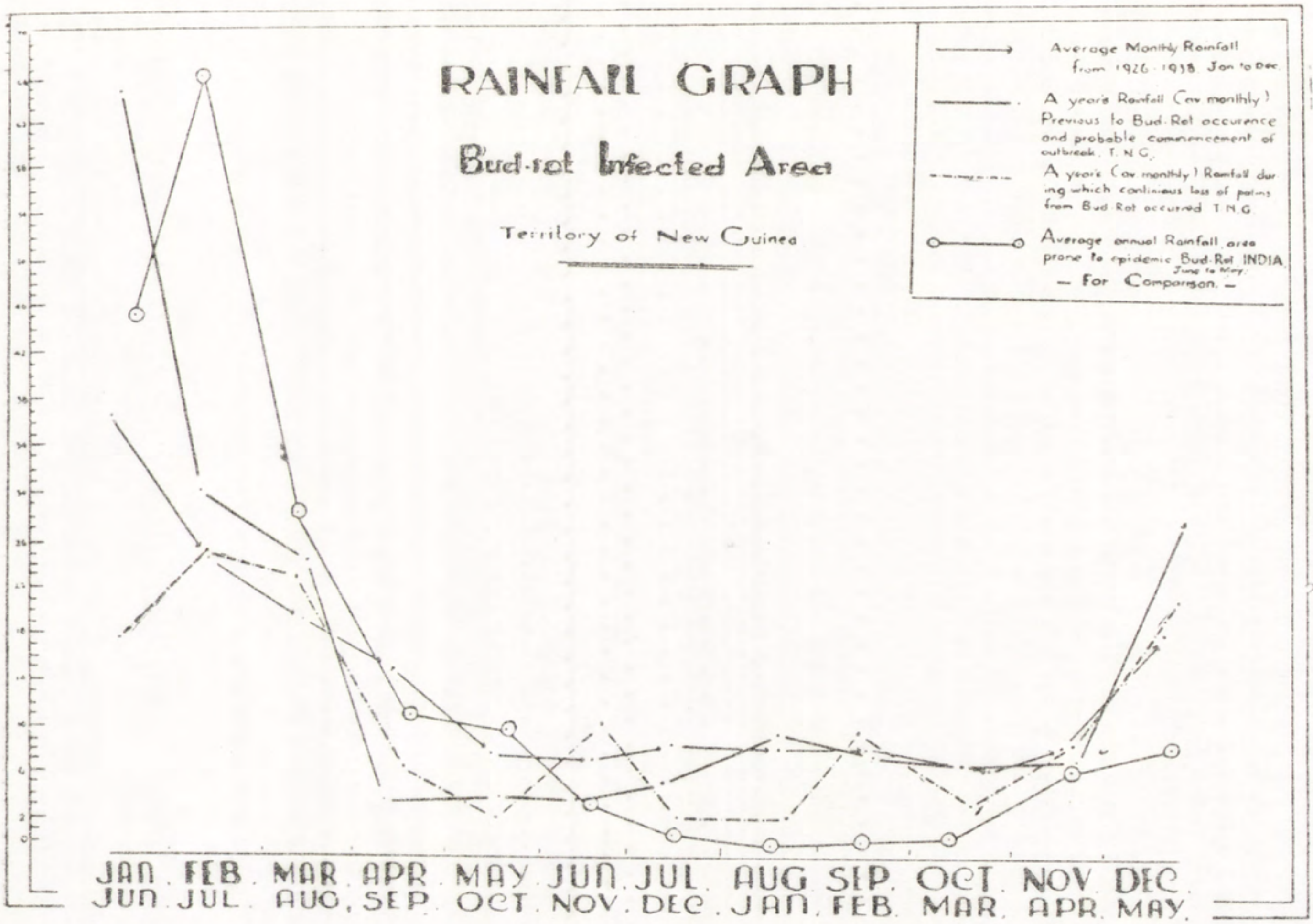
### Tobacco.

On the Madang coast and in various other parts of New Guinea, coco-nuts have been planted after extensive trials of tobacco-growing had been carried out. Some of the biggest areas grown in German times were planted at Bogadjim (Stephansort, the first German capital of this Territory), where numerous Chinese were engaged in tobacco production. This may be one of the contributory reasons, apart from soil and climatic conditions, why the later planted coco-nut palms have not flourished.

In recent years tests have been made on growing tobacco leaf for manufacturing native twist or trade tobacco and coco-nut palms do not appear to flourish so well on areas used for this purpose.

## SOIL CONDITIONS ASSOCIATED WITH BUD-ROT AND THEIR RELATION TO OTHER DISEASES

Association of unfavorable soil and climatic conditions with the development of true bud-rot, in which the fungus *Phytopthora palmivora* Butler was in evidence, have been recorded from certain New Guinea plantations. It is not intended that the sporadic occurrences of bud-rot be described in detail in this article. Certain contributory factors found in the situations where an outbreak occurred and which are of decided value in illustrating the conclusions of this present article are described. This is the first undeniable diagnosis of true *Phytopthora* bud-rot here and this was arrived at from investigations by the Director of the Department of a loss of several hundreds of palms. This fungus was at first definitely suspected from the macroscopic symptoms present (i.e., from



RAINFALL GRAPH
Bud-rot Infected Area
Territory of New Guinea
Average Monthly Rainfall from 1926-1938. Jan to Dec.
A year's Rainfall (av. monthly) Previous to Bud-Rot occurence and probable commencement of outbreak. T.N.G.
A year's (av. monthly) Rainfall during which continious loss of palms from Bud-Rot occurred T.N.G.
Average annual Rainfall, area prone to epidemic Bud-Rot INDIA June to May.
— For Comparison. —
JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC.
JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY.

the visible appearance and symptoms of the disease). This determination was backed up by the opinion of the Director of the Imperial Mycological Institute, based on the presence of fungus mycelium closely resembling *Phytopthora,* and from the descriptions and specimens forwarded to him. Unmistakable spore forms of *Phytopthora palmivora* were later isolated in Rabaul, from the tissue of a diseased coco-nut palm. In the future, a detailed article on the local occurrences of this disease will be presented.

The only losses of palms from bud-rot recorded here are from regions of heavy rainfall and usually occur under abnormal weather conditions. In the most recent records, it was noted that the first appearance of the disease coincided with a period when the rainfall was much wetter, in the wet season, and much drier, in the dry season, than was usual. This gives a much greater contrast of climatic conditions between the wet and the dry seasons (*see* graph). The loss of palms occurred on heavy soils under flat and foothill conditions. Significantly, it is under very similar circumstances that the scattered occurrences of bud-rot in Fiji have been recorded by Simmonds[26-27] and others.

The occurrences of this disease have been almost confined to the wetter portions of the Fiji group, being commonly found on the back portions of the estates, along the foothills. This comprises a region of continuous rainfall and frequently of poor drainage where the coco-nuts grow under unfavorable soil and climatic conditions which favour fungus development, but reduce the vigour of the palms. Palms growing close to the seashore with optimum water-table conditions are affected slightly as was found in the occurrences here.

The environmental conditions prevailing where bud-rot has been recorded here have many features in common with those obtaining where the other diseased conditions, described in this article, have been recorded, but are more extreme.

The heavy soils present are liable to water-logging in the wet season, and to drying-out and compaction in the dry season. This tendency is increased in areas of heavy rainfall and where poor drainage exists.

In a typical soil-profile of an affected area, it is found that there are proportionately large areas with very compact, almost impermeable hard-pan, or clay layers, present, which hold the water at the surface and restrict root-growth. In certain flat areas, where loss of palms, frond-fall and nut-fall were most in evidence, a stiff clay band was present, usually at a depth of 6 inches to 9 inches, but often almost to the surface. It is seen from water lying about in shallow depressions and from other signs that a superimposed water-table exists in the wet season which disappears in the dry season. The evaporation of this surface water continually adds to the humidity of the surrounding atmosphere.

Below the first clay zone there was, in several places, a sandy sub-soil layer present which was loose and porous and extended to a depth of at least 2 feet. Below this again a second impervious clay band is often met with, which is blue-grey in colour (showing the presence of un-oxidized iron) and represents a second zone where deposition of fine particles has taken place.

The root systems of coco-nut palms growing under these conditions are restricted by the relatively impervious layers near the surface, especially as the water stagnates there in the wet season.

Some root-growth does occur below the first clay layer, but is absolutely prevented where a second clay layer or other hard-pan exists.

In the dry season the loose sand, underneath the clay, is believed to reduce the water supply to the palms, which effect would be greatly increased in the dry season. The clay layers present hinder water movements and the access of the roots to the true water-table. It is obvious, without reference to the bud-rotting and other organisms present, that such conditions are not optimum for the growth of coco-nut palms, though they do favour most types of fungus development. The *Phytophora* bud-rot disease particularly can only be exceedingly destructive in a very moist atmosphere.

Where bud-rotted palms are found on the sides of low foothills, the water-table may not be so close to the surfaces, but the soil conditions may still lead to water-logging and restricted root-growth. On one typical area it was seen that the surface soil was a stiff chocolate clay loam, which was stiffer even than those soils found on the flats. The sub-soil was an extremely fine-grained and puggy clay, resting on a compacted layer of weathered parent basaltic rock. This weathered rock formation gradually merges into the unweathered parent rock at a comparatively shallow depth. The soil as described is very puggy in the wet season but sets like a brick in the dry season. Palms growing under these conditions do not flourish. This can be seen from the chlorotic leaves, reduced length and number of fronds, and the grass ground covers present showing a light overhead canopy. It is impossible to think that such climatic conditions, and soil and water-table formations, do not have a great deal to do with the development of bud-rot. Obviously, it is no coincidence that the type of bud-rot found here, and in Fiji, occurs under such conditions.

In the Philippine Islands bud-rot only assumes epidemic proportions in one of the most humid districts of the islands, where the soils are heavy and wet.

The late Dr. Sharples,[25] in 1924, enumerated several instances of where investigators had recorded outbreaks of bud-rot in various parts of the world which were associated with unfavorable soil and climatic conditions. It was resolved at the Imperial Botanical Conference of 1924[25] that the term "coco-nut wilt" be applied to such occurrences as were falsely designated bud-rot, for the reason that the bud, as a general rule, was the last portion of the crown to become affected.

It is the author's opinion that, whether the crown is affected first (as in the instances of true bud-rot given) or last, the soil conditions always warrant very close study wherever outbreaks of wilts and bud-rot occur.

It has been mentioned right throughout this article, that there are several other diseases and conditions of the palm influenced by related environmental conditions. In this regard, it is a significant fact that on some areas where true bud-rot was recorded here, the following series of diseases or symptoms were noted. Leaf-droop, leaf-break, nut-fall (bad), frond-fall (bad), leaf scorch, deficiency spotting, taper stem, *chlorosis*, stem bleeding, *Pestalozzia*, leaf-spotting, thread-blight (*Corticium penicillatum*), *Botryo-diplodia theobromæ* and a condition tentatively named "gummy leaf". It is plain that many of these conditions (especially the first nine listed) are symptomatic of the particular soil conditions prevailing, rather than distinctive diseases.

It is worthy of note that the dynastid beetles (especially *Xylotrupes gideon*) had caused considerable damage under these conditions and probably favoured the spread of the disease.

There may be a number of inter-related and inter-acting factors (working both from within and outside the palm) responsible for palms showing a series of pathological derangements such as those described.

It is very clear from the considerations outlined that cultural practices designed to keep up the vigour of the palms and remedy unfavorable environmental circumstances are of the utmost importance in disease control.

## Discussion.

It is necessary to refer to the well-known subject of optima and limiting factors to obtain a true idea of what occurs where there are a number of inter-acting conditions of nutrition and environment necessary for best growth of the palms. Optimum growth is impossible wherever one main limiting factor is present, as this will determine the maximum influence of any other factors present. In plant growth, there is no such thing as the influence of one factor without reference to the effect of other conditions present. It has been shown that water supply and available potash are two of the very important factors limiting the growth of coco-nut palms. Besides acting as simple, limiting factors, they also interact in many ways, as is indicated in various sections of this article. Regardless of the amount of potash present in the soil, only a certain total quantity can be absorbed by the palm if the water supply is checked in any way.

It is, however, reasonable to state that where the water and potash contents of a soil are both too low (or too high) much greater detrimental effects of malnutrition can be expected. Looking at this contention in another way, let us assume that by a series of pot culture or other methods, it is possible to maintain an optimum water supply to young palms all growing in a constant nutrient medium and to vary the potash supplied to them. Then some plants will be found to have lower than the minimum supply of potash necessary for the proper growth of the palms, so that pathological symptoms may result. Some palms will show lesser effects of the deficiency by being only a darker green than others then, within a certain range, other palms will appear quite normal. Other palms, with so much potash supplied as to upset the balance with the other nutrients and moisture present, will either show no increase in growth or else retarded growth.

If the supply was varied in another series of similar cultures, and the potash kept constant, then similar variations in growth responses would be expected. If both the potash and water supply to the palms was varied, it is likely that the palms receiving the larger quantities of water could do with less potash within certain limits. This is an attempt, in a simple way, to demonstrate how limiting factors may work and also indicate one type of experiment necessary to determine the nutrient requirements of coco-nut palms. Obviously, such pot culture experiments are relatively simple with annual plants, such as the tomato, but are difficult with long-lived and bulky perennial plants like the coco-nut palm. It might be mentioned here that annual plants, like the tomato, have been used as indicators as to the nutrient requirements of other plants, in pot experiments.

The subject is very much more complex, however, than is indicated here, when it is considered that such nutrients as nitrogen, phosphates, calcium, &c., all have their effect and that temperature and actual inherent vigour of the plant come into play.

It must also be recognized that the coco-nut palm has very great inherent capabilities of adapting itself to its environment and to varying conditions of moisture and nutrient supply. Sampson[24] and others have indicated that a coco-nut palm shows a much different analysis when grown on a good soil than on poor soil, which means that the plant can and does economize on plant food under unfavorable conditions.

It might be pointed out that there is a growing mass of evidence to prove that when the humus content of the soil is allowed to run down below a certain level, crops become increasingly subject to diseases of all kinds.

It must be stressed that the inter-action of many limiting factors has to be considered when investigating any physiological disease. The genetical constitution of the plant usually interacts with environment and it is found that weaker palms are much more affected by unfavorable soil and water relationships than strong ones.

One would think that when wilting of palms actually occurred, the end point of water or nutrient deficiency was not far away and that there may be several degrees of growth differences between this and a normal palm.

Thus, although palms do not show pronounced deficiency symptoms, they may have their vigour sufficiently reduced to render them liable to fungus attack. Though there are relatively few records of occurrences of severe palm wilts in New Guinea approaching those known as "bronze wilt" in the West Indies, how are we to classify the occurrences which are recorded here? Is the "maturation wilt" described to be classed in the same category as the more permanent "mature palm wilts", such as are described from the Madang coast? It seems that much more detailed work is necessary as regards the actual physiology and nutrition of the coco-nuts, through all stages, before complete understanding of the problems is possible.

It is no coincidence that similar unsuitable soils conditions to those described as causing coco-nut wilts elsewhere, are responsible for similar physiological diseases here. There appears to be a tendency to classify all pathological symptoms due to soil moisture and deficiency relationships as wilts. One should remember that complications are frequent where otherwise harmless organisms attack the plant, once its vigour is lowered. Wilts, bud-rot, nut-fall, leaf-droop and many other diseases are all symptoms which may be due to different causes, but it has been shown that they may be closely inter-related under certain conditions.

As mentioned before, it is probable that wilts are, as yet, not so prevalent in New Guinea, because the soils are newer and, secondly, because the land has not been cleared of its virgin jungle and been in cultivation with soil exhausting crops for so long.

In addition to major nutrient deficiencies, several unfavorable circumstances are listed. These may, or may not, be present, but where found could be expected to produce outward visible symptoms in the growth of the palms, especially if several were found together in the one situation—

1. Stiff soils or soils too porous.
2. Class of subsoil and the presence of hard pans and superimposed water tables.

3. Shallow planting.
4. Poor seed nuts (inherent vigour of the palms).
5. Previous cropping with exhausting crops.
6. Presence of grasses and weeds.
7. Close planting.
8. Overshading.
9. Continuous burning off.
10. Exposure to heavy winds.
11. Excessive rainfall and continuous cloudy weather.
12. Drought.
13. Season of coming into bearing.
14. Cultural conditions, such as lack of cultivation or drainage.
15. Overstocking the plantation with cattle, especially where tramping over heavy soils.
16. Leaching and erosion of the soil.

If deficiencies of other minerals (e.g., rare metals) are involved in some New Guinea soils, as well as any major nutrient deficiencies, the palms would undoubtedly show other distinguishing symptoms. Theoretically, different combinations of limiting factors may lead to distinct types of physiological diseases.

Finally, it is necessary to decide where one is dealing with physiological wilts or with virus diseases caused by ultra-microscopic viruses carried by certain vectors such as sucking insects.

The influences of water relationships and nutrition on fruit setting, nut-fall and disease occurrence in coco-nut palms, show how closely related are soil problems (physico-chemical) and the functions of the plant (physiology). It is also shown how necessary it is to associate chemical findings with botanical studies and considerations. The determinations of the virus and other diseases present are the province of the plant pathologist.

It would be a most valuable contribution from physiological and chemical research to find out, in detail, whether there is a heavy drain on any particular elements, when the palms are reaching the bearing stage and just what changes do occur.

It is the sphere of the chemist to give us much more data on the nutrient status of the soils here, and to give us detailed chemical analyses of the plant itself. The future studies of our departmental chemist are expected to elucidate many of the problems outlined in this article.

## Remedial Measures.

A description of the correct agricultural practices in coco-nut cultivation would entail a separate article, hence some of the salient points only are indicated for New Guinea conditions in particular. It is necessary to consider most of the conditions which affect the nutrition and health of the coco-nut palms in determining any suitable methods of prevention or control of coco-nut wilts, or similar physiological diseases. References to suitable measures for control of maturation wilts have been made as the particular conditions were described.

The selection of the original plantation site is most important. When selecting areas for coco-nut planting avoid obviously unsuitable soils and situations by making preliminary soil surveys. Proper attention should be paid to the nature of the sub-soils present. This can be determined by digging deep holes at specified intervals and also studying the soil profiles in exposed banks of creeks, cuttings, quarries, &c., before the planting is proceeded with. Soils liable to watêr-logging, such as in low-lying, swampy areas, should not be planted, nor should those areas with hard-pans or wide stony layers present in the sub-soil strata.

Naturally unsuitable formations such as hard-pans, solid rock too close to the surface, clay belts and similar unfavorable profiles are usually unchangeable circumstances once the palms are planted. If coco-nut wilts occur-when the soils have an impervious hard-pan the condition is irremediable. Proper clearing and planting methods must be followed and it is necesary for the best growth of palms that planting at the right depths, in well prepared holes, be carried out.

Seed and nursery selection are most important procedures rarely followed in this country though commonly urged by this department.

Where it is necessary to plant coco-nuts in wet situations drainage is essential. Deep main drains following a proper fall should be constructed with plenty of smaller lateral drains leading into them. Levels should be taken with a dumpy level, row tracer, or suitable contrivance before the drains are made.

Cattle grazing over wet soils liable to compaction are injurious to the growth of coco-nut palms on such soils. It is not possible to drain soils when they are running in the plantation. They may be beneficial when rotationally grazed in properly sub-divided paddocks where the soils are friable and free working.

Strong growing grasses and other exhausting plants should not be allowed to take possession of the planted areas. Eradicate "kunai", or "lalang", *imperata arundinacea,* also seedy grass, *chrysopogon aciculatus,* particularly. Nothing does this better than where the palms are vigorous growing and provide a dense, overhead canopy, as grasses generally do not flourish under dense shade.

Do not grow soil-exhausting crops such as sugar-cane, bananas and native food crops prior to planting out coco-nuts unless a suitable rotation is used. The graphs showing the high manurial requirements of heavy feeding crops well illustrate the reasons for this. There is legislation in force in Malaya to prevent more than one crop of such plants as cassava, *manihot utilissima,* being grown prior to planting of permanent crops such as rubber.

The use of drier ash, composted refuse, &c., and the provision of complete chemical fertilizers and potash manures to increase the vigour of the palms and remedy deficiencies are indicated. There are economic and other considerations involved which require detailing in a separate study. The use of burnt coral and slaked lime is worthy of much greater trial on some of the stiffer soils in this country.

One of the most important problems on New Guinea plantations is the conservation of humus and organic matter which is very seldom given sufficient attention.

The effects of continuous burning off on the humus supply of most tropical soils is disastrous in the long run. Of course, where pests are bad, occasional burning off of accumulated rubbish is essential. Burning off is usually practised to try and kill off injurious growths and to revive the vigour of palms which should never have been allowed to get into such a state of decline.

The conservation of the humus involves various methods of assisting the dropped fronds, cut weeds and husks to decay without actually being lost from the soil.

Cultivation, ploughing, mulching, circle weeding, hoeing, rolling of dense covers, &c., are all subjects which need separate discourse. It is apparent that clean weeding, hoeing or ploughing should not be carried out in the middle of the dry season, or in times of drought, especially in shallow soils, where the fibrous roots are close to the surface. The palms may suffer badly and show wilting where the water and nutrient supplies to the palm are reduced by the cutting of these roots under such circumstances.

The uses of creeping covers on plantations have already been dealt with in an article by the Director.[34]

In soils greatly depleted of humus, the use of erect, cover crops such as *Leucaena glauca, Tephrosia candida* and *Crotalaria anagyroides,* is recommended. These are cut back at intervals and, if possible, the final objective should be to establish suitable creeping cover crops under them.

Among the great uses of cover crops is that they keep the soils cold and moist over the dry season, reduce severe fluctuations in soil moisture and thus greatly lessen the necessity for root adjustment.

On heavy soils, cover-cropping is recommended providing drainage is adequate. Under wet soil conditions less rampant growers like *Desmodium scorpiurus* or *Dolichos hoseii* are worthy of trial. Cover crops should be kept under control and slashing, hoeing or turning under the rampant cover periodically, say, once in every twelve months or two years, adds humus to the palms and increases their vigour. Where the palms are poorly vigorous circle weeding should be carried on where cover crops are used, as root competition may occur under such circumstances.

This Department recommends *Centrosema pubescens, Pueraria javanica* and *Calopogonium mucunoides* for normal coco-nut soils. It must be remembered that these covers show a high percentage of mineral nutrients on analysis which are returning to the soil in an available form when they are cut back or the leaves drop naturally. They also possess the faculty of adding nitrogen to the soil per medium of the bacterial nodules on the roots. Cost of plantation maintenance and weeding are greatly reduced where cover crops are established.

Phenomenal yield increases are the result often expected from the use of cover crops which are not realized in practice for various reasons which it is not possible to describe here. It is certain that if the plantations in this country had been cover-cropped ten years ago, and proper cultural practices followed, many of the older plantations here would not be approaching the stage of uneconomic production as is the case to-day. Increased yields per acre lessen cost of production and care and attention to the planted areas are usually repaid by the additions to the economic life of the property.

Obviously, the natural rainfall and climatic conditions cannot be changed and the soil profiles are also constant. It is usually possible to improve the vigour of coco-nut palms by methods which prevent water-logging, increase the available depth of soil and the water and nutrient supplies available to the palms. The profound importance of employing proper cultural methods for control and prevention of coco-nut diseases is consequently indicated.

## Summary.

An account of some further investigations and observations on occurrences of physiological disorders (wilts, die-backs, &c.) of coco-nut palms in New Guinea is presented.

Special attention is paid to "maturation wilts" of young coco-nut palms at the first bearing stage, recorded from various parts of this Territory.

The symptoms and pathology of the disease at Namatanai, New Ireland, and, also, the detailed investigations and identification of the organisms present by the Director of the Imperial Mycological Institute are given. His comments relating this occurrence to the "cadang cadang" disease of the Philippines, made it necessary to consider the possibility of virus causation.

Reports on soil analyses by the Waite Institute and the comments of their Chemist and Plant Pathologist on the nutrient status and water-relationships of the soils, associated with the occurrences at Kokopo and Namatanai are presented. They indicate the close resemblance between these occurrences and the "bronze wilt" described from Trinidad.

The evidence presented shows that this "maturation wilt" is most probably a physiological disease. During three years, the symptoms made a cyclic appearance in dry periods, and each time disappeared when the conditions became favorable.

Some pathological derangements of mature palms ("mature palm wilts"), particularly from those plantations situated on the deltaic and estuarine deposits of the Huon Gulf and Astrolabe Bay areas of the New Guinea mainland, are described, as are the contributory causes.

Most plantations in this Territory contain areas where palms grow poorly, nevertheless, severe coco-nut wilts are of relatively infrequent occurrence here, probably owing to special local conditions which are discussed.

The occurrences in New Guinea are compared with similar diseases recorded from other countries. These are "cadang cadang" disease, described from the Philippines as a suggested virus disease, "bronze wilts" from Trinidad and Jamaica, coco-nut wilts from Ceylon and derangements of palms coming into bearing described from Malaya.

The pathological symptoms displayed are of physiological origin, excluding possible virus diseases.

The chemical and physiological changes (especially as regards moisture requirements and potash movements) which occur in coco-nut palms at various stages of growth are discussed in relation to the diseases described. Particular attention is paid to the physiology of the root system and its natural adaptations and reactions to such unfavorable circumstances as water-logging and lack of aeration.

Several other diseases and derangements of coco-nut palms present in this country are described (*see* also previous article[9]) as being primarily associated with similar unfavorable soil, moisture, and nutritional relationships to those already mentioned, though the symptoms displayed are often complicated by fungus and insect attack. "Seasonal bearing", "leaf-droop", "frond-choke", certain types of nut-fall, "bud-collapse", "deficiency spotting" and "die-back" appear to belong to this category.

Selected soil profiles showing unsuitable soil, sub-soil, water-table and moisture relationships are described, both in relation to diseases present and their control.

The importance of proper cultural conditions in relation to the control of most coco-nut diseases, but particularly those of physiological origin, is stressed.

The relative importance of physiological disorders of coco-nut palms, as related to fungus diseases, or distinct from virus diseases, is not yet determined. The necessity for chemical and botanical research on the nutrition of the coco-nut palm in relation to the soil conditions obtaining here is clearly indicated.

## Acknowledgment.

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The soil analyses published in connexion with the investigations on maturation wilts were carried out through the kind courtesy of Professor Prescott, Director of the Waite Institute, South Australia.

The analyses were made by J. H. Hosking, Soil Chemist, who has since published an article (32) which includes a detailed comparison of the soils from Kokopo with the deposits from the Rabaul volcanic eruption of 1937. His comments and those of D. B. Adam, Plant Pathologist at the Waite Institute, in connexion with the occurrences described, are most valuable and gratefully acknowledged.

F. Henderson, Inspector and Instructor of the Department of Agriculture, New Guinea, carried out useful collaborative work on the disease in New Ireland, being detailed for this work by the Director.

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