Epidemiological Consideration of Plant Diseases in the Tropical Environment

Donald S. Meredith

Professor of Plant Pathology, Department of Plant Pathology, University of Hawaii, Honolulu 96822.
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The term "epidemiology", in relation to plant disease, is self-explanatory. However, the term "tropical" is more difficult to define. Strictly speaking, it applies to crops which are grown between the Tropics of Cancer and Capricorn. Some, such as cotton and tobacco, originated and are still grown in the tropics, but now have their major centers of production in the subtropics and warm temperate countries. Conversely, other crops, the Brassicas for example, originated in the temperate regions but are now grown extensively in the lowland tropics. More crops are grown in the tropics than in temperate countries (49). Some, for example cacao, coffee, rubber, and most spices, can only be grown in the tropics, and temperate countries are dependent on these regions for their production. It is with these crops that the present discussion is chiefly concerned.

There is excellent justification for giving special consideration to the epidemiology of diseases of tropical crops. First, the wide range of products from them (food, fibers, vegetable oils, latex, dyes, etc.) is far greater than that supplied by crops in temperate countries (49), and there is an urgent need to reduce losses caused by diseases. Second, a considerable amount of phytopathological research has been and continues to be done in the tropics but, with few exceptions, the results rarely appear in major works on plant pathology. I hope that this symposium will stimulate future authors to delve more deeply into tropical aspects and include them in their works. The reason for this is that tropical studies have elucidated several phenomena and principles which are rare, sometimes unique, in plant pathology as a whole. I wish to dwell particularly on these aspects today. Finally, any course in plant pathology is incomplete if examples from the tropics are excluded. The student from Kansas or Nebraska may discover that his first assignment is in, say, Malaysia or Ghana, and that some basic training in tropical crops and their diseases would be invaluable to him.

Disease distribution and spread.—H. Marshall Ward may well be regarded as the father of tropical plant pathology because of his pioneer studies in Ceylon between 1880 and 1882 on the coffee leaf rust fungus, *Hemileia vastatrix*. He was the first to point out that exclusive cultivation of a crop over unbroken areas is one of the chief prerequisites for an epidemic (23, 69). He was also the first to note that copper fungicides act as *protectants* against endophytic fungi by causing destruction of the delicate germ tube and preventing penetration of the host.

Coffee leaf rust is still very much in the forefront of phytopathological interest. It was recorded in the New World (Brazil) for the first time in 1970 (71), and has subsequently continued to spread from the initial focus. There is considerable alarm because all coffee varieties cultivated in Central and South America, including the most outstanding selections, are highly susceptible to the most widespread of all races (I and II) of *H. vastatrix* (55). Coffee is a very important export for several Central and South American countries: Brazil (50% of total exports), Colombia (80%), Costa Rica (56%), El Salvador (90%), Guatemala (75%), and Mexico (70%). Almost 75% of all coffee production is from Central and South America (17).

The spread of *H. vastatrix* to Brazil has once again raised the controversial subject of long-range spore dispersal. The best known example of distant air dispersal of spores is the annual northward migration of *Puccinia graminis* uredospores from Mexico and the southern United States, to cause wheat stem rust in the wheat belt (63). In this case, proof was obtained by trapping migrant spores. In other cases, strong circumstantial evidence for distant, overland transport of spores has been presented in detailed maps illustrating the spread of pathogens from the point of their first introduction. Examples are the spread of tobacco blue mold (*Peronospora tabacina*) in Europe (51), and maize rust (*Puccinia polysora*) in Africa (8). In the case of coffee leaf rust, it was assumed until very recently, probably by analogy with the cereal rusts, that uredospores of *H. vastatrix* are dispersed by wind currents. Rayner (50) thought it highly probable that the fungus was blown to Ceylon from Africa and cautioned that spread and intensification of leaf rust in West Africa in the 1950s was a threat to the New World because uredospores might be carried there by the northeast trade winds. However, extensive epidemiological work by Nutman et al. (43) in Kenya showed that uredospores of *H. vastatrix* are not released by wind currents of up to 19 km/hr. Further, very few spores were detected when highly efficient traps were operated among infected bushes, even when bushes were mechanically disturbed. On the other hand, spores are easily released by water drops as they run over pustules. Dispersal in water drops is over relatively very short distances, that is, from one part of an individual leaf to another or from one leaf to another on the same bush. Consequently, disease outbreaks are usually highly localized (5, 31, 40, 42).

Nutman & Roberts (40) concluded that release and short-range dispersal of *H. vastatrix* uredospores by rain is inconsistent with the concept of intercontinental spread by wind. Short-range dispersal, combined with strict quarantine measures, were suggested to explain the long freedom of the New World from coffee rust. Possibly the disease reached Brazil on one or more undetected plant introductions or by insect or human agencies.

Recently Bowden et al. (7) reported that the terminal velocity of *H. vastatrix* uredospores was of the order of 0.6-1.2 cm/sec and not 7-10 cm/sec as stated by Nutman & Roberts (40). Bowden et al. argue that uredospores would, therefore, seem liable to be transferred over long distances by wind, and suggested the possibility of inoculum from Angola being transported at heights of up to 3,000 m in trade winds over the Atlantic to Bahia, Brazil, in 5-7 days. In a further communication, Nutman & Roberts (42) oppose this suggestion on the grounds that very few viable uredospores of *H. vastratrix* could be expected to survive the journey. Thus, the controversy continues.

Another fungus of interest in relation to long-range spore dispersal is *Mycosphaerella musicola*, the cause of banana leaf spot disease, or "Sigatoka" (35). It was first recorded from Java in 1902, and became epidemic in Fiji in 1912 and Australia in 1926. The first record from the New World was in 1933. Within a few years it had become epidemic in several widely separated areas in the Caribbean and Central and South America. Stover (65) postulated that the great Caribbean epidemic was due to the relatively sudden arrival of airborne ascospores throughout the area in the latter part of 1933. At the time of the Caribbean outbreak, the only large area in the world where Sigatoka was prevalent and epidemic was eastern Australia. Stover (65) suggested that large numbers of *M. musicola* ascospores were released in that region and carried upwards to heights of 2,100 m or more. Thence, they were supposed to have moved westward in the general direction of the southeast trade winds, at an average speed of about 27 km/hr, reaching the Caribbean in about 37 days.

This hypothesis brings several queries to mind. Can ascospores of this fungus survive the effects of radiation, desiccation, and low temperatures for at least 37 days? No convincing experimental evidence, one way or the other, is available. Dilution of a spore cloud during movement over a distance of some 25,600 km would be tremendous and only a few spores, particularly viable ones, might be expected to reach the Caribbean unless by some freak meteorological event. Also, a particularly fortuitous combination of down-draughts, rain, and other climatic factors throughout the entire Caribbean area would be required for almost simultaneous deposition and infection. As Hirst & Hurst (15) commented, Stover's hypothesis is reasonable but because the distances are so great and because the proposal is supported only bibliographically, it is not wholly convincing. An alternative explanation is that *M. musicola* was introduced to the New World on infected banana leaves. It will be of interest to trace the future spread, if any, from southeast Asia and the Pacific of the "new", more agressive form of banana leaf spot, black leaf streak, caused by *Mycosphaerella fijiensis* (26, 35, 37). Every effort should be made to prevent its introduction to Central and South America and the Caribbean on infected banana tissues.

Holliday (17) has given a useful account of important fungal pathogens of tropical crops that are not co-extensive with their respective hosts. Witches' broom disease of cacao caused by *Crinipellis perniciosa* is widespread throughout the Amazon-Orinoco equatorial region of South America on wild *Theobroma* spp. and also occurs in Colombia, Equador, Trinidad, and Grenada (1). It is absent from southeast Brazil, Central America, and the Old World. Blister blight (*Exobasidium vexans*), probably the major disease of tea, first attracted attention in Assam, India, in 1868. By 1951 it had moved out of Assam and was present in southern India, Ceylon, Malaysia, Vietnam, Laos, Cambodia, Taiwan, and Japan (16). It is important to prevent its spread to the smaller (but developing) tea industries of west Asia, Africa, and America. At present, *Microcyclus ulei*, the cause of South American leaf blight of rubber, is restricted to the mainland of tropical America and Trinidad. *Hevea* spp. are the only known hosts. The freely air-borne nature of conidia led Holliday (16) to conclude that if the fungus was introduced to the large rubber plantations in Asia, further spread would be rapid. This disease largely prevented the establishment of a viable natural rubber industry in America, hastened the development of the synthetic substitute, and indirectly contributed to the prosperity of southeast Asia.

Trachysphaera fructigena is of special interest because of its very restricted distribution in a few tropical west and central African countries (32). The fungus causes mealy-pod disease of cacao and coffee, and a serious fruit rot (cigar-end) of bananas. It is highly infective, grows rapidly through tissues, and sporulates abundantly on all hosts. It is difficult to explain why it has not spread widely throughout Africa since the first report from Ghana in 1923.

The advent of universal jet air transport is probably the most serious threat to attempts to exclude plant diseases. Although *Peronospora tabacina* on tobacco was kept out of Europe, west Asia, and north Africa for 68 years (1890-1958) and *Puccinia polyspora* on maize took 70 years (1879-1949) to cross the Atlantic eastward (17), the future spread of plant pathogens may be accelerated unless quarantine measures are intensified. Once a pathogen is introduced, the task of eradicating it is very difficult, if it is possible at all. However, a notable exception was the successful eradication of coffee leaf rust from Papua (58). Soon after the pathogen was detected in 1965, all infected bushes were destroyed, together with possible contacts. Apparently the disease is still absent.

Disease control.—In the tropics there have been some major successes in controlling disease on a vast scale. In Queensland and New South Wales, bunchy top disease of bananas was almost completely eradicated in the 1930's as a result of epidemiological studies by Magee and cooperative eradication and quarantine measures by growers and state agricultural organizations (29, 34). Simmonds (61) commented that this magnificent achievement is one of the most striking examples of disease control by purely phytosanitary methods in the whole history of plant pathology.

In the 1930's, the entire banana industry in Central and South America was threatened with extinction by Sigatoka (*Mycosphaerella musicola*), and no completely satisfactory control method was known at that time. Preliminary trials showed that spraying with Bordeaux mixture held some promise (70). Consequently, central mixing and pumping stations were built and pipelines laid in the plantations to convey the fungicide to flexible spray hoses. By 1940 more than 40,000 hectares of bananas were being sprayed with Bordeaux mixture at rates of up to 2,400 liters/hectare/cycle every 2-4 weeks in Central America alone. Wardlaw (70) stated that control of Sigatoka on such a massive scale was one of the greatest achievements in the history of phytopathology and was the salvation of the major fruit companies in Central America. In 1953, Cuillé & Guyot (10) discovered that low-volume mist-spraying with mineral oil (6-16 liters/hectare/cycle) gave excellent control of Sigatoka. Oil had an unique therapeutic and fungistatic effect against established *M. musicola* infections. By 1963, costly high-volume Bordeaux spraying from the ground had been largely replaced by cheaper and more effective aerial oil sprays. In tribute, Ordish & Mitchell (44) stated, "It is doubtful if the world's growers and the world's eaters of bananas really appreciate the immense debt they owe to these two men" (Cuillé & Guyot). Various oil-fungicide-water emulsions are now being used commercially to effectively control Sigatoka in Central America and elsewhere, and black leaf streak disease in the Philippines and Taiwan. Particularly promising results have been obtained using benomyl (1-butylcarbamoyl-2-benzimidazole carbamic acid, methyl ester) as the fungicide component (Meredith, *personal observations*, 1971-1972). The evolution of low-volume aerial spraying techniques in bananas is probably the best example of advancement in fungicide utilization in the last 15 years.

The problem of resistance, so long known against bactericides, insecticides, and acaricides, has not hitherto been important in the use of fungicides (19, 62). In 1969 Bent (3) suggested that "with the shift from the nonspecific surface fungicides, which are general enzyme inhibitors, to systemic compounds, which probably have more subtle mechanisms of action, fungicide resistance may well become more serious". This was borne out by the discovery that forms of powdery mildew, resistant to benomyl, developed on leaves of cucumber grown on benomyl-drenched soil (57). Resistance to benomyl and other benzimidazole fungicides has also been reported in a strain of *Botrytis cinerea* on cyclamen (6), and it is likely that other examples will arise. Returning to nonsystemic fungicides, Taylor (66) collected spores of *Physalospora obtusa* from several apple orchards and found greater tolerance to Bordeaux mixture in spores from sprayed orchards than in those from unsprayed ones. Tropical plant pathology has provided a more striking example of a similar phenomenon. This is a recent report from Kenya by Griffiths (14) working on coffee berry disease (CBD) caused by *Colletotrichum coffeanum*. CBD almost destroyed the Kenya crop a few years ago and recovery is still not complete (2, 39). It was found that routine spraying with coffee fungicides alters the relative proportions of various strains of the pathogen in the bark. Immediately after spraying in March, the spore population was drastically reduced, but 9-12 months later the population increased again. This increase was 10-12 times greater on sprayed plants than on unsprayed ones (2). Thus the chances of berries ultimately becoming infected are considerably greater on sprayed plants and, no doubt, this accounts for many earlier reports of apparent breakdown of control in sprayed plantations. This discouraging experience in Kenya should be borne in mind in Central America, since a coffee berry necrosis similar to CBD has been reported there (56).

Any discussion of the epidemiology and control of root diseases in plantation crops must chiefly be concerned with diseases of tropical crops (13, 53). More is known about root diseases of rubber and tea than about those of almost any plantation crop of temperate countries, probably because of the greater value of the former crops. An excellent example of how field observations and fundamental work on a root-infecting fungus have indicated possible control methods is provided by *Armillaria mellea* on tea in Malawi and Tanzania. Leach (24) observed that *A. mellea* readily invaded the roots and stumps of certain virgin forest trees (especially *Parinarium mobola*) soon after felling. The fungus then spread rapidly to the roots of young tea bushes planted at the cleared site. Leach (24) further discovered that for its growth *A. mellea* required roots with a high starch content. If *Parinarium* trees were completely ring-barked when in full leaf a year or more before felling, then their roots soon became depleted of starch, died quickly, and became invaded by harmless saprophytes instead of *A. mellea*. Thus the tea crop escaped infection. The method was put into effect and has continued to provide a simple and effective means of reducing losses from *A. mellea*. Ring-barking of indigenous forest trees prior to planting tung (*Aleurites montana*) has also reduced the incidence of *A. mellea* on this crop in Malawi (72). Unfortunately the method was not successful in England in preventing the spread of *A. mellea* from felled woodland tree stumps and roots to roots of young hardwood plantation trees (52). Thus, a control measure that works well against a pathogen in one region or country may fail altogether in another.

Another novel control method has been developed against the white root rot fungus *Rigidoporus lignosus* on rubber in Malaysia (11). This fungus, like *A. mellea*, also passes onto roots of the new plantation crop from stumps and roots of felled jungle trees, or a previous rubber planting. It was found that if the epiphytic advance of *R. lignosus* was arrested by removal of rhizomorphs at weekly intervals, then internal infection of the rubber root was also halted. Fox (11) found that a fungistatic preparation containing 15-20% pentachloronitrobenzene (PCNB) also arrested epiphytic growth and halted internal infection. In practice, the protectant is applied to the tap root in a band extending from a few inches above to a few inches below the point of junction with surface lateral roots, and around the proximal 23 cm of the laterals. The soil is then replaced and tamped down. The method gives excellent control of *R. lignosus* and is recommended by the Rubber Research Institute of Malaya for standard plantation practice (13).

These two examples indicate the importance of infected stumps in serving as inoculum sources for plantation crops. How do the stumps become infected? One obvious and common way is by invasion from portions of root infected before felling. Petch (46), working in Ceylon, suggested another method, namely, infection of the freshly cut stump surface by airborne spores. However, no evidence was presented to support this suggestion. Several years later Rishbeth (54), working in England, showed that basidiospores of *Fomes annosus* can infect freshly cut pine stumps in this way. The fungus then colonizes the stump and roots and passes (through root contacts) into roots of healthy trees, eventually causing butt rot or death of the tree. The important problem was to devise means of preventing stump infection after thinning operations, because the removal of only one tree often led to the development of a large disease gap around the unprotected stump. Treatment of stumps with chemicals (sodium nitrite, borax, urea, disodium octaborate) was effective and has been carried out for several years both in Great Britain and the United States (13). Later, Rishbeth found that inoculation of stumps with oidia of *Peniophora gigantea*, the most common and most effective competitor of *F. annosus* in stumps, prevented infection by *F. annosus*. Spore inoculum of *P. gigantea* is now prepared and stored in the form of dehydrated tablets containing approximately 1×10^7 viable oidia, and having a storage life of at least 2 months at 22 C. Tablets are placed in water and the resultant spore suspension is applied to the stump surface immediately after felling. Garrett (13) commented that "this is the first example of successful biological control through inoculation to have been adopted in plant pathological practice . . .". It is now used by the Forestry Commission in Great Britain over some 24,000 hectares (13).

The importance of stump infection by spores of tropical plant pathogens is not so well understood. There is evidence that it sometimes occurs in *Rigidoporus lignosus* and *Armillaria mellea*, and frequently in *Phellinus noxius* (brown root rot of rubber, oil palm, and tea) and *Ustulina zonata* (root rot of rubber and tea) (13). Further studies are required to determine whether stump protection holds promise for the control of various tropical root-rot fungi.

In Hawaii, a "papaya replant" problem has for several years prohibited growers from economically replanting papaya in a given orchard after the previous crop had been affected by root rot caused by *Phytophthora palmivora*. Ko (22) found that 100% control could be obtained by growing seedlings in "virgin" soil (free from *P. palmivora*) placed in the planting holes. Normally, up to 50% loss can be expected after 3 months when seedlings are grown in infected soil.

Against certain vascular wilts of tropical crops, the main progress with control has derived from the breeding of new resistant varieties. Examples are wilt of cotton, caused by *Fusarium oxysporum* f. sp. *vasinfectum*, and wilt of oil palm caused by another strain of *F. oxysporum* (49, 68). However, breeding has not yet solved the problem of Fusarial wilt (Panama disease) of bananas (*F. oxysporum* f. sp. *cubense*). In the damage it has done, Panama disease ranks with the half dozen most catastrophic diseases, comparable in importance with wheat rust and potato blight (21, 64). By 1925 it was responsible for the destruction of over 40,000 hectares of the susceptible 'Gros Michel' variety in Central and South America, and the losses entailed and cost of treating the disease ran to millions of dollars each year. Because of the abandonment of large areas, the disease had a marked effect on the economy and sociology of several Latin American countries.

Intensive epidemiological studies have been carried out on Panama disease and enormous sums spent on research (34, 64). Initially, there was some evidence that phytosanitary methods checked spread of disease but they were ineffective in the long run, partly because of the failure of many growers to comply with recommendations. Attempts were made to improve soil conditions in the hope that increased soil fertility would render plants less susceptible to the disease; however, none of the treatments were effective. Chemical treatment of soil was sometimes effective in eradicating the pathogen in pot tests, but not in the field. Between 1945 and 1955 United Fruit Company used the method of flood-fallowing to eradicate the pathogen from certain areas in Central America. Banks were constructed around affected sites which were then flooded to a depth of 0.7-1.8 m for periods of up to 18 months. The pathogen, being strongly aerobic, died out together with most of the other soil microflora. Gros Michel replanted on such sites gave 3-5 years of economic production before disease once more became a limiting factor. The method was eventually abandoned because of increased material and labor costs.

Pioneer efforts to replace Gros Michel with a resistant cultivar were made in the West Indies in the 1940's. The changeover to 'Lacatan' converted a dying industry into a profitable one. In the 1950's Standard Fruit Company replanted Gros Michel in Central America with resistant 'Giant Cavendish'. The changeover was successful, and this clone is still cultivated by the Company, both in Central America and the Philippines. In the 1960's, United Fruit Company started to replace Gros Michel with resistant 'Valery' in Central America and elsewhere. Thus, Panama disease has ceased to be a problem in most areas where resistant Cavendish cultivars are grown. A notable exception is the Canary Islands where the supposedly resistant 'Dwarf Cavendish' cultivar is sometimes severely affected by Panama disease (Meredith, *unpublished data*). It remains to discover whether a "new" race of the pathogen is involved or if certain adverse growing conditions cause much reduced host resistance to an "old" race.

Existing breeding programs in Honduras and Jamaica may eventually produce better commercial bananas than are now available. Certain tetraploids which are resistant to both Panama disease and Sigatoka have already been bred, but they have several commercial disadvantages (59). Banana breeding is a slow and complicated process and, therefore, the Cavendish era of banana production will probably last several years longer.

Disease forecasting.—In recent years, considerable emphasis has been placed on the need for accurate estimates of losses caused by plant diseases (9). An early study was that by Padwick (45) who first drew attention to losses in British Colonies. The study involved many tropical plant pathogens, and diseases were classified into three categories; viz., those causing over 10% loss, those causing important damage but under 10%, and those causing small or very small damage. The current FAO program for the development of reproducible methods for the assessment of crop losses (9) may enable more precise estimates to be made in the future in the tropics.

Losses from and the cost of controlling certain plant diseases have been greatly reduced by forecasts of probable seasonal incidence in Europe, the United States, Japan, and other temperate countries (38). These systems either give sufficient time for efficient control measures or indicate that such controls are unnecessary. Some of the diseases concerned are: late blight of potato (*Phytophthora infestans*), apple scab (*Venturia inaequalis*), grapevine downy mildew (*Plasmopara viticola*), tobacco blue mold (*Peronospora tabacina*), rice blast (*Pyricularia oryzae*), and bacterial wilt of corn (*Xanthomonas stewartii*). In the tropics, disease forecasting is largely in a developmental stage but good progress has been made for certain diseases. Of special interest is the system worked out by Kerr & Rodrigo (18) for blister blight of tea (*Exobasidium vexans*) in Ceylon. From epidemiological studies, it was found that a forecast of disease incidence 2-3 weeks *later* could be made by measuring (i) *current* level of infection in tea leaf brought to the factory, and (ii) the mean daily sunshine for the *previous* 7 days. A simple calculating device, similar to a circular slide-rule, was designed for the use of the planters in Ceylon. It is claimed that the accuracy of prediction is higher than for any other airborne plant disease. It is possible to predict both when an epidemic is likely to occur and what the approximate level of infection (expressed as no. of blisters/100 shoots) will be. The method can be safely applied to mature tea, 9 months or more from pruning, and can save many cycles of spraying each year.

In Kenya, studies on spore release and dispersal in *Hemileia vastatrix* provided a basis for improved timing of spray applications (40). Residual inoculum is usually at a minimum at the end of a dry season. It is at the end of this period and as precisely as possible before the onset of the first heavy rains that sprays have their maximum effect against coffee leaf rust. In South Africa, analysis of meteorological data and Hirst spore trap counts during a 3-year period showed that the first spray of the season to control black spot of citrus (*Guignardia citricarpa*) could be postponed by 4-6 weeks if temperature and rainfall between August and October were average or below average (27). This resulted in economy of spray materials and reduced labor costs. In the Philippines, continuous inspection of banana leaves in commercial plantations is currently done to assess the severity of early stages (streaks) of black leaf streak disease (*Mycosphaerella fijiensis*). Fluctuations in streak counts are a useful guide for programming spray cycles (Meredith, *unpublished*). A similar system was developed by Klein (20) for controlling *M. musicola* in Central America. Other workers have examined the possibility of using temperature, rainfall, and other climatic factors as bases for forecasting outbreaks of banana leaf spot diseases. However, no single factor appears to have universal value and the most reliable one has to be worked out for each area (35). In Hawaii, there is promise that rainfall data alone can be used to predict epidemics of leaf blight of taro (*Colocasia esculenta*) caused by *Phytophthora colocasiae* (R. R. Bergquist, *personal communication*).

Some particularly "difficult" diseases in the tropics.—The coconut palm, valuable for its many products, is notorious for being affected by disorders of unknown or doubtful etiology. Lethal yellowing occurs in Florida, Jamaica, Cuba, Venezuela, Panama, and other parts of Central America, and the Bahamas (30). It has also been called "west end bud rot", and the "unknown disease", and may be the same as the "Kaincopé disease", "Awka wilt", and "Cape St. Paul wilt" of West Africa (30), and an abnormality in Surinam (28). The disorder accounted for the death of 100,000 productive palms/year in Jamaica alone in recent years, and has devastated plantations in Haiti, Cuba, Toga, Ghana, and Nigeria. Between 1955 and 1967 it destroyed many palms at Key West, Florida, before disappearing spontaneously. The cause of lethal yellowing has been variously attributed since 1905 to salt damage, strontium or other toxic materials, nutritional deficiency, nematode injury, bacteria, or a virus. The virus hypothesis was strengthened by reports of mechanical transmission of a filterable agent (48), although mechanical transmission was not confirmed in Jamaica despite repeated attempts using the same and other techniques. Recently, mycoplasma-like bodies (MLB) were detected in phloem elements from inflorescences of palms showing lethal yellowing (47). This suggests a mycoplasma etiology and is the first report of MLB in coconut palms.

The serious coconut disorder in the Philippines known as cadang-cadang is thought to be of virus etiology (30). Experiments are in progress to determine whether it can be mechanically transmitted (48). Yet another condition, coconut bronze leaf wilt, was considered to be due to environmental factors in Jamaica (30). In 1960 in the Philippines, a disorder known as "frond-drop" was recorded for the first time (4). It is similar to a disorder in Jamaica, originally named "false-wilt", and has been variously attributed to a genetic abnormality, environmental conditions, and a virus. In the Philippines, a rod-shaped bacterium and *Thielaviopsis* sp. have been isolated from petioles of affected palms, but pathogenicity is still unproven (4).

Another valuable tropical crop is the clove tree (*Eugenia caryophyllus*). A condition known as "sudden death" was present in Zanzibar in the mid 19th century but did not cause alarm until 1894. By 1953 more than half the mature cloves in Zanzibar Island had died of this disease or of die-back (see below). Physiological disturbance, virus, and other causes were suggested for sudden death, but extensive studies by Nutman & Roberts (41) showed that it is due to a root-invading fungus, *Valsa eugeniae*. Control of the disease in Zanzibar, so far as the present stand of trees is concerned, seems to present an insoluble problem. Complete replanting after destroying all infected trees, followed by a fallow period, is the only way to re-establish the clove industry (41). Die-back of cloves, caused by *Cryptosporella eugeniae*, is also contributing to the devastation of the clove industry in Zanzibar. The magnitude of the control problem is illustrated by the following example given by Nutman & Roberts (41): "In one block of 235 trees following heavy damage during harvesting, 7,105 separate infections were recorded. Of these 101 had reached the main trunk, some extending for several feet. Since spores are produced from the infected areas for at least nine months a very considerable source of inoculum is present. The spores can be distributed by water-splash and water-trickle down the trunk and branches of the same tree. In addition, as harvesting the flower-buds involves the pickers climbing the trees and handling most of the branches, they almost certainly, act as carriers". The obvious method of control is drastic pruning and wound-protection.

The breadfruit tree (*Artocarpus* sp.) is an important food source in the Pacific Islands. Since 1957, many trees have died from the so-called "Pingalap disease", so designated from the island where it first occurred. Zaiger & Zentmyer (74) thought it possible that a vascular wilt disease and/or a root-rotting pathogen are involved. However, Trujillo (67) concluded that the condition is nonpathogenic, and can be attributed mostly to unfavorable environmental factors, especially ground water salinity or drought, and typhoon damage accentuated by drought and old age. For the time being, it is impossible to make recommendations for effective control of the condition.

Latent infections are particularly common and of considerable economic importance in certain tropical fruits; e.g., banana, papaya, mango, guava, and passion fruit. These infections can, and frequently do, become established in the field at an early stage of fruit development, but do not develop further until the fruit approaches maturity. Consequently, apparently healthy fruit may be harvested and transported to the market (often overseas) only to spoil in transit or during ripening. Species of *Colletotrichum*, causing various types of anthracnose, and *Pyricularia grisea*, causing a banana fruit spot, are good examples (33, 60). Simmonds (60) found that in *Colletotrichum* spp. the conidium produces a germ tube which then swells into an appressorium. From the appressorium a fine infection hypha penetrates the cuticle but stops growth before penetrating the epidermis cell wall of immature fruit. It is in the form of this subcuticular hypha that the fungus survives its period of latency. When the fruit approaches maturity, the subcuticular hypha resumes activity and penetrates both peel and pulp. The protected location of the subcuticular hypha explains the failure of protectant fungicides, applied after infection, to control latent infections. However, it is encouraging to note that benomyl, and to a lesser extent 2-(4′-thiazolyl)-benzimidazole (thiabendazole, TBZ), are effective against latent *C. musae* infections in bananas (36). Both appear to have systemic activity and act in a therapeutic manner. Even better control may be possible if the physiological basis of latency is elucidated.

Brief reference should be made here to the extensive crop losses caused by nematodes. The burrowing nematode, *Radopholus similis*, has been responsible for the near destruction of the pepper industry in Indonesia (73). It is also one of the major factors causing loss of fruit yield in bananas wherever they are grown (34), and causes severe damage to coffee, tea, pineapple, citrus, sugarcane, and sweet potato. The epidemiology of diseases caused by this and other destructive nematodes (*Meloidogyne, Heterodera, Ditylenchus*, etc.) is fairly well understood and the principles of disease control are simply stated, viz., the use of nematode-free planting material in nematode-free soil. However, achievement of the latter situation is often beset with considerable practical problems. The most important control measures, apart from preventive quarantine inspections, are: (i) heat (dry and steam) for soil, and hot-water treatment for many flower bulbs, runners, corms, stools, and banana setts; (ii) chemical (several excellent nematicides and soil fumigants are widely used); and (iii) crop rotation using nonhosts or resistant varieties. For successful crop rotations, the precise identity of the nematodes must be established, their host ranges (often extremely wide) must be known and checks made on the nematode population in the soil. In the tropics, especially, great care must be taken in the choice of crop planted to avoid the risk of crop failure due to the presence of an unidentified pathogenic nematode.

Conclusion.—There is no doubt that increasing effort in the future will be directed toward crop protection in the tropics. New major areas of crop production will be established and a continuous succession of disease problems can be expected. The banana industry has provided an excellent example, having suffered from Panama disease, bunchy top, Sigatoka, bacterial wilt ("Moko") caused by *Pseudomonas solanacearum*, nematodes, and black leaf streak; currently, several types of fruit rot and fruit spotting are common and adversely affect fruit quality (34). It is largely because of the efforts of phytopathologists that the industry has managed to survive at all. Unless strict quarantine measures are enforced, serious diseases of important crops may be carried by man to formerly disease-free regions. For example, it is possible that bacterial wilt ("Moko") of banana was taken on infected planting material from Central America to the Philippines during the last 5 years (C. B. Segars, *personal communication*).

During the past two decades in temperate regions, there have been several shifts in emphasis in phytopathological research, away from classical observational and experimental studies in the field. Because the tropical environment is less well known from a phytopathological standpoint, the classical approach, involving basic studies such as the satisfaction of Koch's postulates, will be necessary for some considerable time. Problems of identification and classification of fungi, bacteria, MLB, viruses, and nematodes are common. For instance, is coffee berry necrosis in Central America caused by the same fungus that causes CBD in Kenya (56)? Are *Mycosphaerella musicola* and *M. fijiensis* truly different species, or two forms of the same species (37)? And is bacterial wilt of banana in the Philippines caused by the B, D, SFR, or another strain of *P. solanacearum* (12)? Some pathogenic fungi are known only in their imperfect state. In the case of Sigatoka disease of bananas, the perfect state of the causal fungus was discovered some 40 years after the imperfect state (*Cercospora musae*). This discovery was vital to a full understanding of disease epidemiology and resulted in greatly improved control measures in the West Indies in the 1940's (25). The search for perfect states of other important pathogenic Fungi Imperfecti should continue.

The tropical environment presents a great challenge to the phytopathologist, and to the epidemiologist in particular. I hope that increasing numbers of workers will meet this challenge and, in turn, contribute an increasing bulk of information to phytopathological science as a whole.

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