Chemical Control of Plant Diseases in the Tropical Environment

Robert H. Fulton

Tropical Crops Pathologist, Tropical Agricultural Products Development, Marketing Department, International Division, Rohm and Haas Company, Philadelphia, Pennsylvania 19105

Tropical climatic adaption and the economics of the world food market have prompted intensification and specialization of crop production as exemplified by extensive plantations of banana, cacao, coffee, and rubber, to name a few. Many characteristics basic to plantation agriculture also favor the rapid and widespread development of diseases. In this unique model of susceptible hosts, optimal ecoclimates, and shifty pathogens, fungicides have been a keystone to economic stability of regions or countries by averting epiphytotics which would disrupt annual crop production outputs. This has not been without its heartaches because the control of plant diseases by fungicides under tropical conditions challenges the aspiring and experienced pathologist alike. On the one hand you are faced with extremes in climatic conditions, heterogeneity in soil types and genetic stock, variations in flushes of new unprotected growth, and crop areas requiring treatment ranging from several to many thousands of hectares. On the other hand, a scarcity of biological, climatic, and pesticide knowledge coupled with deficiencies in spray equipment technology, as measured by the needs of plantation agriculture, in turn has set the pace for the inception of fungicide control programs.

A review of all facets of chemical disease control programs in the tropics is not within the scope of this paper, but it will focus on fungicide utilization in selected tropical crops to typify the unique advances made and hopefully to generate new ideas for developing practical solutions to pressing problems. On the whole, this presentation reiterates that spraying is not simple, but a melding of disciplines to pinpoint the targets, to improve biocidal performance, and to time spray applications more precisely to achieve economic control.

Transfer of knowledge.—A common shortcoming in temperate as well as tropical climates has been our inability to quantify the economic significance of a disease and thus chemical control practices. This was strikingly illustrated in the "1971 Fungicide and Nematicide Test Results" in which only 25% of the reports on fruits and vegetables alluded to increased marketable crop yields through fungicide utilization and where only *one* cited cost production benefits (3). This form of routine testing and unimaginative reporting is in turn emulated by tropical researchers; an indirect transfer of knowledge.

For over two decades the notion persisted that attacks on African oil palm by *Cercospora elaeidis* Stey in the nurseries were of little consequence after the first year or two in commercial plantations since affected transplanted seedlings recovered. This alleged recovery did not occur (13). This was shown by Duff (6) through a critical field assessment that showed a relationship between destruction of leaf area and reduced fruit bunch weight during the first 7 years in commercial plantings. He found that even light infection by *C. elaeidis* caused an annual loss of 998 kg (1.1 tons) of fruit bunches per hectare (valued at $120/hectare), quite significant where planting units average more than 500 hectares. Thus, there is valid economic reason for research on control and for seeking resistance to *Cercospora* in the African palm breeding program. New emphasis has now been placed on chemical protection in the nursery, and upon further studies of the host-pathogen relationship in commercial fields, to determine whether the *Cercospora* spp. involved will lend themselves to chemical control.

Importantly, the oil palm produces new leaves singly as tightly folded leaflets with initial infections and seasonal spotting intensity following a pattern similar to banana leaf spot (23). Thus, the documentation on epidemiology and control procedures adopted for banana are now serving to pinpoint leads in control of *Cercospora* on oil palm (28).

Aside from *Cercospora, Phytophthora* spp. also rank high as "economic feeders" on tropical crop production, and scientific principles laid down for *P. infestans* epidemics were used as research stepping stones in several tropical disease situations (25). Noteworthy was the work of Peries (20) in Ceylon on the abnormal leaf fall of rubber caused by *P. palmivora* Butl., a malady common to rubber throughout the world. Peries established that the mature green seed pods were the most susceptible to infection and that their infection resulted in profuse formation of sporangia. Then, he observed a close relationship between pod set on individual trees and leaf fall; the pods became infected first and provided secondary inoculum for subsequent leaf petiole infection and abscission. Attendant to these observations, was a critical study of the environmental requirements of the pathogen which provided the basis for a disease forecasting system for leaf fall epidemics. Given conditions of temperature not above 29 C; relative humidity above 80%; and at least 2.5 mm (0.1 in) of rain and less than 3 hr of sunshine per day for 4 consecutive days when infected mature green pods are present on the host, the first disease wave will occur within 14 days. Further compilation of weather and disease records delimited such weather-infection cycles to a 10-week period for Ceylon. With these facts in hand, protectant sprays amenable to production costs were within reach. The answer to this was close at hand.

About the same time as studies were under way in Ceylon, industry representatives in India were coming to grips with improved copper formulations for leaf fall control that could be aerially applied in low volume to serve as a replacement for the laborious and costly task of spraying Bordeaux with ground rigs (5). After some trials, oil was selected as the carrier. Oil had been recognized earlier by investigators in temperate zones for its merits of nonevaporation, resistance to weathering, and improved surface coverage (8). These merits were confirmed in the tropics. Coverage of the waxy rubber leaves was excellent and spray deposit retention was superior during the monsoon season. A formulation of 1.8 kg metallic copper applied in oil at 37 to 47 liters/hectare soon served as the standard replacement for 10-10-100 Bordeaux. Since Peries has pinpointed the primary infection target in the upper canopy, this made aerial sprays a natural for strategic fungicide placement; also the inherent rapidity of such spraying permitted better timing to cope with forecasted leaf fall epidemics for large plantation areas. Today, tens of thousands of hectares of rubber are aerially sprayed for leaf fall control at varying cycles dependent upon local disease forecasts.

Cacao, neglected opportunities, a case in point.—Research technology has made great strides in increasing cacao production through the use of hybrid cultivars, fertilizers, and pest control programs. Not withstanding, black pod (*Phytophthora palmivora*) still accounts for annual losses in excess of $50 million. Ironically, evidence to date indicates that these losses will rise since the incidence of black pod apparently increases with yield.

Black pod studies are vigorously under way to make control more rational and precise. Nonetheless, additional research is needed because cacao possesses one genetic characteristic ideal for promoting epidemics, a prolonged flowering and cropping season. This, and the fact that the pathogen can attack all aerial parts of the cacao tree, increases the likelihood of an epidemic. A better understanding of the epidemiology of black pod may permit the use of timely sprays for reducing primary inoculum sources and forestalling epidemics.

Based on disease control studies, let us consider the potentially significant inoculum sources. At the onset of the rainy season, infected pods are predominantly found on the lower part of the tree trunk and this was held as proof that the soil was the source of primary infection. Weststeijn's detailed studies (29) verified this point, but also alluded to a more favorable microclimate for infection and a higher inoculum density in this zone because sporangia flow down from upper canopy sources. The higher inoculum density proposition has merit, since chemical soil treatments failed to prevent lower trunk pod infections, attributable to inoculum from canopy sources (17). On the tree, potential inoculum sources abound and extensive tests over the last 30 years have shown a great deal of local variation. In areas of high rainfall over a long season, leaf and shoot canopy infections predominate and spray programs are directed at pods in these areas. Conversely, in other areas of the world initial sprays are made to pods on the trunk because of splash dispersal of soil inoculum. Attendant to cankers, but not obviously associated, are flower cushion infections. It is my contention that these are the shifty sites that serve to initiate and maintain disease cycles. Position-wise on the tree, cushions are ideal sporangial springboards as compared to splash dispersal upward from the soil. Newhall et al. (18) pointed out that infected flower cushions were primary sites, especially so under heavy shading. Additionally, annual spray programs have shown that control is cumulative. Could this be the gradual elimination of infected cushion sites?

Today, as in the past, the most effective control method available is spraying. Researchers have shown that spraying should be made on the tree-to-tree basis since infection gradients are obscure in black pod due to the removal of infected pods during harvest. Furthermore, evidence for vertical disease movement is much better, with only small foci noted in a field rather than random distribution. Economics also fits into this scheme, trees with less than 12 pods are possibly not worth the cost of spraying (24). Bordeaux and fixed coppers are the present standards, usually applied on a calendar rather than a forecast basis. To date, organic fungicides have proved disappointing on cacao and this was attributed to poor residual persistency after rain. There has been little follow-up effort to develop persistent formulations of organic fungicides. In addition, spray equipment varies from knapsack to shoulder-mounted mist-blowers with severe limitations of throw and agitation not amenable to uniform coverage by presently available wettable powder formulations. Obviously, much remains to be done, not only on the mechanics of spraying but on epidemiology as well.

Coffee berry disease control, the fungicide square pays off.—In the Americas the intensive coordination of research on banana leaf spot within the last decade served as a prime example that effective chemical control under the vagaries of the tropical environment became a reality only when all the facets of epidemiology, spray targets, formulations, and forecast timing were unraveled (23). Concurrently in Africa, similar studies culminated in the effective chemical control of coffee berry disease (CBD), caused by *Colletotrichum coffeanum* Novack. This, too, was achieved by applying low-volume rates either with aircarft or especially designed overhead boom sprayers.

Historically, CBD gradually spread through all high-altitude (above 1,800 m) coffee producing areas of Kenya, and by the sixties was reducing yields by 20%. Early studies showed that inoculum was produced by the pathogen on the bearing wood after the onset of rain. Pre-rain copper sprays were sometimes successful in reducing sporulation, but continued sporadic control results lead to a reevaluation of inoculum sources.

Flowering of coffee is regulated in part by rainfall, and the crop derived from flowers produced during extended periods of rain were the most severely affected. Gibbs (9) placed inoculum sources for this period into their true perspective. At the beginning of the rains the bark is the primary source of inoculum for berry infection, but subsequently diseased berries serve as the source of inoculum for the explosive secondary infection. Correspondingly, berries vary in degree of susceptibility to CBD depending upon their stage of development. Furthermore, field inoculations elucidated that stage of berry development conditions susceptibility to CBD and that berries are most susceptible 6 to 10 weeks after flowering (15). Such epidemiological data are keys to regulating spray schedules.

A series of sequential spray schedules using bark sporulation and berry expansion as benchmarks showed that early sprays only delayed the epidemics with losses equal or more than the control. But supplementing the early sprays with three extra cycles to coincide with berry expansion increased healthy berry production fourfold (10). Copper and Difolatan were the CBD control agents in these trials and both performed equally well. Nonetheless their success, besides biocidal efficacy, was attributed to residual persistency since spray intervals varied from 20 to 28 days.

Today several of the recommended chemicals for CBD control are benomyl, Difolatan, and copper with the coffee areas divided into zones based on the degree of CBD incidence as well as that of coffee leaf rust, caused by *Hemileia vastatrix* Berk.and Br. In this manner, varied spray schedules are suggested as well as combined organic-copper sprays to effect coffee leaf rust control (16).

Formerly, coffee was sprayed by hand-directed equipment using volumes of 1,850 liters/hectare, but this system has changed to the use of aircraft and multi-row, over-the-top spray equipment (19). Trials on coverage, redistribution, and control verified that sprays directed over the top of the foliage canopy at rates as low as 94 liters/hectare achieved good control. There are limitations, especially in high density plantings; no doubt this will be resolved by the adoption of new production systems now under intensive investigation.

A lesson in flexibility.–Leaf diseases of rubber have become more severe in the last two decades through extensive monoclonal plantings of more susceptible but higher yielding latex clones: the success of increased production has been in part at the expense of resistance to diseases. Thus, without chemical control, planters could not maintain the canopy necessary for maximum growth and latex yields on specific clonal lines.

The unique growth habit of the rubber tree plays an important role in disease control. The rubber plant develops through two basic growth phases. The juvenile phase, which lasts 4-5 years, is characterized by successive leaf flush cycles throughout the year. The second, or wintering, stage commences with maturity and is typified by the deciduous characteristic. Each year, all the leaves are shed uniformly with the onset of drier weather; this is immediately followed by refoliation. Depending on the weather conditions at the time of refoliation and clonal susceptibility, fungal invasion by one of several pathogens at this time incites a subsequent defoliation termed "secondary leaf fall" (SLF) - the primary fall being the shedding of wintering leaves. Repeated SLF defoliation prolongs the interval required to produce a satisfactory canopy, thus extending the period of low latex yield, reduced growth, and high weeding costs. The latter, a side effect of a thin canopy, allows increased solar radiation to penetrate the lower story which promotes growth of grasses and other weeds.

In Africa and Asia, two pathogens, individually or in combination, contribute to SLF; namely, *Oidium heveae* Steinm and *Colletotrichum gloeosporioides* Penz. Rubber leaves are highly susceptible to fungal invasion by these pathogens during the approximately 15-day period after bud break or until full leaf expansion. Leaves attacked during the early stage of this 15-day period rapidly wither and fall, but if infected later the internal resistance of the host usually prevents extensive damage and, though partly deformed and extensively spotted, the leaves do not readily absciss (26). The SLF, although severity depends on weather conditions, occurs in a rapid rhythmic cycle since refoliating leaf flushes are similar in age and susceptibility.

Chemical application at this stage in the life of the rubber tree are difficult since the trees are 9 to 21 m in height, the fungicide targets are at or near the crown of the tree, and the terrain is quite hilly in many instances. For *Oidium* control, sulfur dust applied at 5-day intervals was economic, based on improved tree girth and panel bark renewal (27). However, the frequent applications required and the logistic management of land-borne power dusters were disadvantages. Control of *Colletotrichum* on the other hand, required frequent spray applications of Daconil. To circumvent the problem of frequent applications, extensive testing of oil-borne fungicide formulations was conducted to improve coverage and extend residual persistency; to date, all such formulations have been found phytotoxic to the young leaf flushes (26). A further complication was the lack of reliable weather forecasting, which is basic to predicting which diseases may occur and to planning a spray program. Concurrently, it was also observed that early-wintering clones generally escaped the intense ravages of SLF. Therefore, could earlier and more complete wintering, artificially induced, be a mechanism to avoid severe SLF?

In 1950, Altson (2) suggested artificial defoliation of rubber as a plant protection measure to eradicate South American leaf blight (caused by *Microcyclus (Dothidella) ulei* P. Henn.) in the eventuality that this disease were to spread out of the neotropics to Malaysia. This idea for disease avoidance was crystallized and today a single spray of cacodylic acid is used as a safe defoliant for manipulating the time of wintering for complete mature refoliation prior to the onset of weather favoring SLF (21). This provides true flexibility in the modification of the host-pathogen-climate-fungicide square to achieve reduced production costs (25).

The jet age tropical twins.—Many visitors to the tropics have extolled the flavorful taste and texture of mango and papaya. Until now, however, the arrival of these fruits to consumer tables in the temperate zone free of rot and blemishes has been sporadic at best. A marketing approach has evolved from a series of in-depth studies on the field biology and control of their major fruit diseases coupled with jet air transport to distant markets.

Anthracnose, *Colletotrichum gloeosporioides*, has been the major limiting factor for large-scale orchard production of mango, the apple of the tropics. Early control methods employed copper fungicides with varying levels of success, no doubt related to the fact that in-bloom sprays were phytotoxic and had to be omitted (14). Splash-dispersed spores from oversummered cankers triggered the early primary infection cycle on the flowering panicles, which in turn reduced fruit set and caused the typical stem-end oriented anthracnose lesions. The latter also contributed to secondary latent infections on developing fruit. The key to clean fruit, as in apple scab control, was early spraying timed with the bloom period. This was verified by a series of sequential applications of captan, maneb, and zineb from pre-bloom through the cover sprays. These protectants were nonphytotoxic when applied during bloom, and all treatments significantly increased fruit set and production of blemish-free fruit (4). The incorporation of a surfactant was mandatory to assure uniform wetting and retention on the waxy plant surfaces. Anthracnose no longer constrains growth of the mango industry.

In Hawaii, papaya has increased in economic importance due to imaginative research. Briefly, fruit disease losses were grouped as to occurrence in the field or as post-harvest problems. Attack by *Phytophthora parasitica* Dastur, a major field culprit, was limited to epidemics that quickly developed during periods with weekly rainfall in excess of 50 mm; there appeared to be no correlation to temperature. Spore trapping showed that abundant sporangia were liberated from the mycelial mats on infected fruits only during wet weather. Thus, developing fruit was indicated as the primary inoculum source and the fungicide target in a control program. This was corroborated by a complete lack of *Phytophthora* fruit rot control when sprays were applied by aircraft because the papaya leaf canopy trapped descending spray droplets and coverage of the fruit was poor. In turn, extensive spray trials based on biweekly (dry period) and weekly (wet period) schedules with Difolatan or mancozeb produced economic control (11). Now to the next hurdle, that of postharvest rots.

In this area of investigation the researchers discerned abrupt week-to-week changes in the incidence of different types of fruit-rots. These changes were related to biological conditions during the periods of flowering and harvesting and to fungal contamination levels during storage. The controllability of these factors was ameliorated by an indirect approach. Since papaya fruit are produced acropetally, young fruit develop above older fruits on the trunk. Comparative sprays applied only to the upper portion or only to the lower portion of the fruiting area of the tree demonstrated significant control of postharvest fruit rots by only spraying the upper portion of the papaya tree fruiting area (12). Interestingly, copper sprays increased stem-end rots and were significantly less effective than captan or mancozeb in controlling other fruit-rotting organisms. Simply stated, application of scientific principles led to a workable solution accounting for modern, marketable, blemish-free papaya.

The systemic fungicides, a new tool for plant disease control in the tropics.—From a practical point of view, the systemics offer unique possibilities in the tropics since the active spray residues are not subject to tropical weathering, thus permitting fewer applications. The benzimidazoles have been exceptional in this respect for control of *Mycosphaerella* on banana and peanut, and their use as postharvest fruit treatments on citrus and mango, to name a few, has virtually eliminated *Penicillium* and *Colletotrichum* as important fruit-rotting organisms (7, 23).

Importantly, the systemics are effective against deep-seated pathogens due to their internal movement. Mouldy rot of rubber tree tapping panels is such an example. The practice of controlled wounding in rubber has provided a suitable site for *Ceratocystis fimbriata* Ell. & Hals. infection, which in turn stops normal regeneration of tissue and causes deep fissures. Mercury and quaternary ammonium compounds were the expedient prophylactic measures of yesterday. Today, the new weapon at the planters' disposal is benomyl. Even under conditions of high inoculum potential, benomyl panel applications brought the disease under complete control within a month (22).

Novel approaches to the host-pathogen-climate-fungicide square will be required to place systemics strategically and economically in disease situations and to realize the full impact of their potentialities (7). The nonsystemics will continue to serve in the defense bulwark on their own or integrated with systemics. The possibilities for both are boundless.

The opportunities ahead.—The magnitude of tropical disease problems necessitates that chemicals will be the major control tool in the foreseeable future. But control measures must also be ecologically sound. In specific cases, like downy mildew of maize or root rots of black pepper and avocado, there is a real need to compensate for rapid chemical loss by soil leaching. Effective controlled-release fungicides are needed. Controlled release of insecticides has been achieved under high rainfall tropical conditions by diffusion from polymeric encapsulation or by degradation release from polymers containing the active chemical as a pendent side chain (1). Obviously, the ecological and control implications would be extended periods of protection at minimal dosages in a reduced number of seasonal applications.

The semi-arid tropical regions where irrigation is essential for production and where root rots and mildew play havoc, present special challenges. Formerly, surface or sprinkler irrigation methods were standard, but now the trickle system could lend itself well to chemical placement in the target zone for root rot action or absorptive translocation for foliar protection. These hypotheses are no substitute for experiment, but nevertheless the opportunity exists.

Direct and indirect approaches to chemical control of diseases in the tropical environment have been woven into the fabric of this presentation. The unique advances made, as in the temperate zones, were based on sound biological principles using the fungicide square as the development keystone to arrive at effective and economical programs. This idea is not new, but warrants repeating to exemplify that chemical disease control is a melding of disciplines.

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