PHYTOPHTORA PALMIVORA OF COCOA AND ITS CONTROL [1]

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SUMMARY

Phytophtora palmivora causes pod losses, die-back, defoliation, trunk and flower cushion canker, "sudden death" and chupon wilt of cocoa ; it also affects many other perennial crops. Sporophores are only produced on pods, which are therefore the only substratum for multiplication by spores. Spore infection is transmitted via water as well as air. Fruit in all stages is susceptible to infection. When conditions are favourable (high humidity, especially when combined with a temperature of 20° C and lower) pod infection leads to new production of spores after only 5 days (life cycle). Control should therefore be concentrated on preventing pod infection (by covering the pods with an effective fungicide) and on removal of diseased pods (harvesting in short cycles, burying the shells or transporting the crop outside the plantation). As pods are the only substratum for multiplication by spores, this explains why disease incidence increases with high pod production. High-yielding plantations should therefore be laid out in such a way that they can easily be treated with small automatic mist-blowers. With rising costs of labour the only effective and economic way of control will be with automatic mist-blowers. Good control can be achieved by means of specially designed types of mist-blowers (the Kiekens cocoa mist-blower) and with a specially manufactured cuprous oxide (Caocobre-Sandoz). Cycles of 3—6 weeks during the wet season will be sufficient when approx. 2½—3 kg Caocobre is used (in 100—200 litres) per cycle and hectare. However, a good effect is dependent on many small details such as drop size, size of cuprous oxide particles in the suspension, surface tension of the liquid, velocity and penetration of the air stream ; in the control of pod rot the fungicide must be effectively directed on to the crop region ; when also defoliation occurs the leaf canopy has to be treated in addition.

1 INTRODUCTION

This fungus is widely distributed throughout all cocoa-growing countries; it also affects rubber, citrus, cocoa-nuts, coffee and many other plants. On cocoa it was reported as early as 1727 in Trinidad.

Under favourable conditions it is able to affect the pods in all stages (causing pod rot and cherelle wilt), the flowers and flower cushions, the main trunk (canker), which sometimes leads to the death of the tree („morte subido"), the chupons (chupon wilt), the young growing twigs and young leaves of old trees (sometimes leading to repeated defoliation, die-back of the tree and its death), the petiole and afterwards the lamina of old leaves, and the young seedlings.

The literature on the subject and visits to various cocoa-growing countries show that in certain areas trunk canker is serious, whereas defoliation causing die-back is unknown (Java); in other areas, however, pod losses are extremely heavy, whereas defoliation and canker seem to be unknown (Br. Cameroons), and in other cases defoliation and die-back are disastrous, whereas canker is unknown (Costa Rica). These differences are partly due to different climatic conditions, but they might also be partly connected with different strains in the cocoa varieties as well. VAN HALL (1914) mentioned that Criollo types in particular were affected by canker, but not the Forastero types. Canker was serious in both Ceylon and Java at the beginning of the century, but since Criollo has been replaced by Forastero types canker is no longer a menace in these countries.

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In most countries the main trouble is pod rot; moreover, in certain areas defoliation plus die-back are serious, such as in Costa Rica, in the Bahia area, and on the island of Sao Tomé at an altitude of 400–600 metres above sea level. Although in these cases production is also badly affected by the poor condition of the leaf canopy, direct losses by pod infection are the most common cause of the trouble. *Since the spreading of the disease by spores is dependent on the pods, it is the latter which are chiefly important.*

2 Life cycle of the disease

The main features as described by Rorer (1910) from Trinidad have later been confirmed in other countries and by other phytopathologists such as Orellana (1953b), Thorold (1953b) and Gregory (1952). Pods are the only substratum on which the fungus multiplies through spores, whence they are distributed by wind, rain or insects (ants). In addition,, oospores and chlamidospores are produced inside the rotten tissue, and can tide the fungus over long unfavourable periods.

After a period unfavourable for the fungus (e.g. a dry season) when there are no diseased pods and no sporulating conidia, there are two possible ways of initiating the infection of a few pods, viz. by splashing soil particles to which mycelium is adhering, or by mycelium entering from old infected cushions. Once a few pods have been infected, spores are produced within a week, after which infection can start on a large scale through the air.

Initial infection. Dade (1928, 1930a and b) studied the importance of old cushion canker on the transmission of the disease to newly-developed flowers and fruit. It has been said that cherelle wilt and premature ripening may sometimes be caused in this way, but Dade came to the conclusion that old cushion canker caused few black pods, because a cushion either recovers from the disease or is completely killed and produces no more flowers (e.g. out of 201 infected cushions only 4 were not destroyed and produced flowers next year). Recently w.a.c.r.i. [1]) (Annual Report 1955/56) established that 9–12% of such black pods originated from diseased cushions. In some areas (where cushion canker is serious) this may be important for the initiation of a new epidemic; in most cases the initial infection will be caused by splashing soil. Thus Giraldi (1957) observed in the French Cameroons that the pods first attacked were situated only 15–30 cm. above the surface of the ground. In the first 4 months of the rainy season 98% of the infected pods were situated below 2 metres above the surface. During the first 2–3 months it therefore proved sufficient to concentrate on spraying the pods only on the lower 1–1½ metres of the main trunk. No better results were obtained when the rest of the trunk and branches were also sprayed. This concentrated spraying halved the spraying time and liquid consumption.

The mycelium remains alive in the soil for a long time. Wright (1930) succeeded in infecting sterilized pods with soil and pod debris even 4 and 6 months after the latter had been buried in sterilized soil. In the long run *Ph. palmivora* is wiped out by other saprophytic micro-organisms. If no new infected material (shells) is added to the soil, the disease will be gradually

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eradicated. *Fungicidal spraying should therefore be combined with field sanitation.* Unless well buried, no shells should be left in the plantation. The experience in many countries has been that with such measures *Phytophtora* control becomes increasingly easier and more effective (see under point 3).

Spreading and intensification of the disease by spores. The incidence of the disease starts to build up rapidly with sporulation. There is no evidence of the production of spores on any other parts of the cocoa tree than the pods, so that it is on the latter that the spread and control of the disease is focussed. Under favourable conditions development is vast and multiplication very rapid.

Flowers artificially sprayed with a conidial suspension wilted and abscissed within 20–30 hours; on inoculated pods appressorial structures and hyphae were observed 3 hours after infection and discoloration of the inoculated tissue first arose 24–30 hours after (ORELLANA, 1953b). Only 5 days after inoculation of pods new spores could be produced from their surface. THOROLD (1953a), working in Nigeria, observed clearly visible symptoms 3 days after infection, and sporangia were formed during the night following the second day of visible symptoms; within 10 days the whole pod may be black. Newly-set fruit up to fully mature pods are susceptible to infection.

It is remarkable that in the case of rubber also the fruit is the chief factor in the spread of *Phytophtora* leaf-fall disease. The following statement occurs in the standard work on rubber diseases (WIERSUM, 1955) (translated from the Dutch):

"Affected leaf is always preceded by fruit rot. The affected fruit does not open, but dries out during the wet season and remains on the trees. It is from these old pods that leaves are infected under favourable conditions. It is therefore advisable to remove and burn all dry rubber fruit in good time."

THOROLD (1952) proved that spreading can take place through the air by placing disks ½ and 2 cm. above the pods for 12 hours (with no free water in the air), after which spores were found on the vaseline. That spreading through the air is important was also shown by THOROLD (1953a) in an experiment in which pods showing the first symptoms of infection were harvested every other day and placed in a single large heap in the centre of a farm. The incidence of infection then showed a black pod percentage decreasing with increasing distance from the heap, viz. from 17.9 % at 0–20 metres distance to 2.9 % at 161–180 metres. In another case THOROLD (1952) found 33 % black pods at 0–10 metres and only 13 % at 51–60 metres from a heap.

3 FACTORS INFLUENCING THE SPREAD AND INCIDENCE OF THE DISEASE

The following factors are of importance:

a The number of pods (pod density).

b The infection intensity of the pods in an area.

c The climatic conditions, viz.

a high humidity, especially when combined with
a temperature of 20° C. and lower.

d The condition of the plantation (such as shade) and its influence on microclimatic conditions.

a *Number of pods.* As the pods are the substratum for multiplication by sporophores, it is clear that everyone who has studied this connection came to the same conclusion. THOROLD (1952) found a positive correlation of + 0.867 between disease intensity and number of pods. High-yielding trees had more black pod than low-yielding ones, most of the latter escaping infection. As regards control methods he therefore concluded that regular removal of diseased pods would only be effective when cocoa yielded less than 12 pods per tree. Hence in high-yielding clonal plantations *Phytophtora* will become an even more pressing problem than it was in old low-yielding plantations.

b *Infection intensity of pods.* When the incidence is high, such an abundance of spores is produced that it is much more difficult to control the disease than when the incidence of pod infection is low. As early as 1930 DADE proved that in the Gold Coast there was a positive correlation between the percentage of infected pods and the disease incidence 4 days later (incubation period). THOROLD obtained satisfactory results with the removal of black pods on alternate days in areas where the disease incidence was low, but in the Ondo Province, where the disease incidence was extremely high, the results of sanitation were entirely unsatisfactory, viz.

Black pods, when harvested every month	Black pods, when removed on alternate days	
96.7 %	71.7 %	1951/52
88.2 %	59.5 %	1952/53
83.8 %	39.4 %	1950/51

The higher the disease incidence, the more difficult it was to reduce the disease by removing diseased pods on alternate days.

For the same reason disease control becomes gradually easier in an area where this control has been executed systematically year after year. MIRANDA AND DA CRUZ (1953) mention for the Bahia cocoa area that systematic field sanitation leads to "a progressive reduction in the disease from year to year". In experiments on field sanitation in French West Africa RENAUD (1953) also observed the after-effects in the following years; he says: ".... ces traitements semblent avoir une action résiduelle indirecte appréciable pendant une ou deux années au moins: ils augmentent la production en diminuant les sources de contamination." At the beginning of the century VAN HALL (1914) reported the same feature from Java, and also mentioned the progressive effect of field sanitation from an area in Ceylon: in the successive years 1902–1905: 38.6 %, 8.8 %, 4.8 % and 2.5 % of black pods were harvested (in 1902, field sanitation started). HAMMOND (1957) also reports from Ghana that combined spraying and field sanitation in the four years 1953/54–1956/57 led to a regular decrease, viz. 35.2 %, 17.4 %, 6.2 % and 2 % of black pod. On the islands of Fernando Poo and Sao Tomé, where the disease was serious, it has been treated continuously for 25 years by almost universal Bordeaux spraying in the main cocoa areas. As a result it is now possible to keep the black pod under control by only 2–5 spray-cycles per annum. THOROLD (1954) reports the same experience with Bordeaux spraying from Nigeria. In 1953 an untreated area had 42% black pods, as against 8% black pods in the area sprayed for the first year, and only 4% in the area that had also been sprayed in 1952. Hence the system in Nigeria is now to spray in the first year during the wet season at intervals of 3 weeks, and in the next and subsequent years at intervals of 6 weeks. WOODS (1957) mentions that in Costa Rica it is recommended to spray every two months in succeeding years. The first year there is no full control, but it is cumulative over 3–4 years. All this experience is of great practical importance, as it shows that the disease is gradually eradicated from year to year by reducing pod incidence.

c *Climatic conditions.* Everywhere it has been observed that production of sporosphores and chances of infection are favoured by high humidity. During dry periods there is no infection. In wet years and in humid areas, e.g. along rivers and in low wet parts, the incidence of the disease can be high. Quite recently LELLIS (1952) proved that in Brazil temperature is also of prime importance. PARK (1953) and also BAKER (1953) confirmed this for West Africa and Trinidad respectively. If the temperature is 20° C. or lower the incidence increases. Thus a combination of high humidity and low temperature during the crop season will lead to severe losses. This combination may have various causes, e.g. cloudy mountain slopes at 400–600 metres above sea level (Tombel, Br. Cameroons; certain mountain areas of islands like Sao Tomé and Trinidad), low lands of Bahia that have the main crop in the wettest and coldest winter months (July/August, 15° southern latitude), low lands of the Atlantic Coast of Costa Rica with an annual rainfall of approx. 4000 mm. and cool nights with clear sky. Nowhere are the defoliation and die-back caused by *Phytophtora* both in cocoa and rubber so serious as they are in Costa Rica.

d *Condition of plantation.* VAN HALL (1912) reported from mountain areas in Java and Ceylon that the disease incidence was increased by bad drainage and interplanting with other trees and shrubs, as well as low branching of the cocoa (all these cause humid conditions). Cutting away the interplanted

FIG. 1 COMPLETE DEFOLIATION OF COCOA TREES, CAUSED BY *Phytophtora*. SAO TOMÉ, ON CLOUDY MOUNTAIN SLOPES AT AN ALTITUDE OF 400 METRES.

FIG. 2 DIE-BACK (DEAD TOPS), CAUSED BY Phytophtora ; NEAR URUÇUCA, BAHIA (BRAZIL). TYPICAL FOR ALL COCOA AREAS IN BAHIA, WHERE SHADE HAS BEEN ELIMINATED.

shrubs, pruning of cocoa and removal of all low, bending branches had a favourable effect. For the same reason pod rot is usually unimportant in young plantations, but as soon as they have closed in, after 5 to 7 years, the disease becomes increasingly serious; see for example VAN HALL (1912). For the same reason the disease is serious on cloudy, sunless mountain slopes of Sao Tomé (fig. 1, pod rot, defoliation, trunk canker and morte subido), and the disease is then favoured by abundant shade, as this increases the humidity in an area that regularly has temperatures below 20° C.

On the other hand, in the humid low lands of Costa Rica, a not closed shade canopy has a detrimental effect, as it causes a drop in temperature during the night, thus often reaching the critical temperature of 20° C. and lower. In such low-land areas (e.g. Costa Rica, Bahia and Mexico), removal of shade leads to repeated defoliation and die-back (see fig. 2), such plants flower poorly, they do not set fruit and production is soon reduced to nil. Owing to the need of wood fuel, shade has been cut in considerable areas in Bahia along the roads and near the drying-houses, with the above disastrous effect.

4 LOSSES CAUSED BY THE DISEASE

The following information may be given concerning losses from black pod:

Country	Percentage of black pod	References
Bahia, Brazil	18 %–25 %, in some years 50 %	MIRANDA and DA CRUZ (1953)
Cameroons		
Moliwe Estate	56 %–67 %	VON FABER (1907)
Tombel Estate	90 %–95 %	SANDERS (1956)
Costa Rica	47 %	"La Lola" Estate, ORELLANA (1953a)
Mexico	25 %–40 %	Comalcalco, the author
do.	up to 40 %	WOOD (1957)
Nigeria	up till 58 %–74 %	in wet areas, THOROLD (1953b)
Trinidad	36 %	100 inches of annual rainfall, HOLLIDAY (1954)
do.	26 %	„Non Pareil" Estate, DALE (1952)
do.	1.7 %	Relatively dry area (I.C.T.A.), BAKER (1953)
Samoa	50 %	"Cacao", Vol. 3, no. 10 (1956)

Losses vary from year to year, according to humidity and temperature during the crop season. When infection takes place at a late stage, the beans can be partly used, although they are of a low quality (black beans). On the other hand, when defoliation and die-back occur production is reduced to a much greater extent than would appear from the black pod percentages only.

From all this information it is obvious that under certain conditions losses may be considerable and the same conclusion may be drawn from the fact that production was doubled in Costa Rica (McLaughlin & Bowman, 1952) and tripled in Br. Cameroons (Sanders, 1956), when effective control methods were applied by United Fruit Cy and the Cameroons Development Corporation respectively.

5 Older control methods. Removal of diseased pods; high volume spraying

Originally an attempt was made to control the disease by removing the newly-infected pods and burying them. As new spores are produced on pods within 2 days after the first symptoms are visible, removal should take place every other day. It is clear that at the present rate of wages this is an economic impossibility. Moreover, when there is a high disease incidence or a heavy crop, it is impossible to keep the disease under control (a few diseased pods are easily overlooked). Thorold (1953b) stated that regular removal of diseased pods can only be effective with less than 12 pods per tree and limited disease incidence. On the other hand, in Samoa (Smith, 1956) fungicidal control is, from an economic point of view, only advocated when there are more than 10 pods per tree and black pod is above 25 %. In any case, with rising wages pod removal becomes impossible as a general method of control.

High-volume spraying with Bordeaux mixture 1–1¼ %, 1000–1500 litres per hectare in 3–8 weekly cycles has been successful in experiments in Nigeria, in experiments and on a commercial scale in Costa Rica, and on a commercial scale in Samoa (Smith, 1956).

Thorold (1953), comparing 1 % Bordeaux spraying at 3-weekly intervals from April–December 1952 with removal of infected pods, harvested the following percentages of black pods from April 1952–February 1953: untreated 75 %; removal of pods 65.6 %; spraying 6.2 %.

In Costa Rica, Bordeaux proved to be more effective than Dithane and SR-406 (Siller, 1950 and 1954; NN, 1954a). On a United Fruit estate approx. 100 % more production was obtained with monthly intervals and 65 % with 60 days' intervals (when spraying with 1200 litres 1¼ % Bordeaux per hectare). Portable aluminium towers are connected to a pipeline system with Bordeaux under pressure and revolved; the Bordeaux is thus sprayed from above (fig. 3).

Bowman performed the same task on a commercial scale using a special portable Bean sprayer fitted with 3 automatic spray systems, directed upward above the trees (photo NN 1954b); in this case also the spray drizzles down on to and through the leaf canopy. With 1000–1200 litres per hectare every 6 weeks an average increase of production of 150 % is obtained in commercial sprayings. According to private information received in 1957 from Bowman in Costa Rica, he obtains an 85 % control of the disease with a 6 weeks' cycle, 95 % with a 4 weeks' cycle and 99 % with a 2 weeks' cycle (1 % Bordeaux mix-

FIG. 3 OVERHEAD SPRAYING OF BORDEAUX MIXTURE FROM MOVABLE ALUMINIUM TUBES TO BE TURNED AROUND BY HAND, AND FIXED TO A PIPE LINE SYSTEM UNDER PRESSURE. UNITED FRUIT PLANTATIONS NEAR ZENT, COSTA RICA. FULL LEAF CANOPY OF COCOA HAS BEEN RESTORED BY THIS HIGH VOLUME SPRAYING.

ture, sprayed throughout the year). Spraying from above also results in a rapid improvement of the leaf canopy; it thus becomes possible to grow the cocoa without shade even under the conditions prevailing in Costa Rica.

As early as 1907 VON FABER (1907) reported successful control (only 22–24 % diseased pods, as against 56 % untreated) in the Cameroons after 3 sprays of 2 % Boredaux, 1½ litre per tree.

Recently HADLAND (1957) reported that cuprous oxide spraying had been such a commercial success against black pod in Nigeria, that it was now being carried out on an area of about 160.000 acres.

6 MIST-BLOWING

Mist-blowing is a technique in which droplets of 50–100 μ are directed by an air-stream of a certain velocity on to the object to be covered. This does not result in a complete coverage as with Bordeaux mixture, but a regular pattern of minor fungicide droplets has to be achieved; the drops should be deposited close together but without coalescing. The fungicide concentration should be 5–10 times higher than in the case of high-volume spraying.

SANDERS (1956) in Br. Cameroons was the first to use this method systematically in cocoa plantations of the Cameroons Development Corporation (since 1954). At first a semi-automatic Kiekens mist-blower was used (fig. 4); recently a fully-automatic Kiekens mist-blower has been introduced; the tractor used was a Ransom MG-6. Approx. 150 litres of cuprous oxide of 2 % per hectare are mist-blown at 3-weekly intervals during the wet season (coinciding with the crop season) from April–October. Every other row is treated twice by driving up and down in both directions. The average production has increased by more than 200 %; some production is still lost by black pod.

In 1956 BOWMAN in Costa Rica tried high-volume spraying with Bordeaux in comparison to mist-blowing with an automatic Kiekens, using Banacobre-Sandoz, a cuprous oxide especially developed for the mist-blowing of bananas. The result was that a 30 days' cycle with this Banacobre mist-blowing (100 litres 3 % per hectare) gave the same control as was achieved with a 6 weeks' cycle of high-volume Bordeaux spraying. The impression was that this shorter cycle with mist-blowing became necessary because the Banacobre was more rapidly washed off. In any case, this result shows that with mist-blowing 1½ x 100 litres of liquid the same control can be achieved as with approx. 1000–1200 litres of Bordeaux.

FIG. 4 MIST-BLOWING OF CUPROUS OXIDE WITH A KIEKENS AUTOMATIC MIST-BLOWER. TOMBEL ESTATE, CAMEROONS DEVELOPMENT CORPORATION, BR. CAMEROONS. PRODUCTION HAS BEEN TRIPLED BY THIS LOW VOLUME SPRAYING.

In hilly or broken areas, and in cocoa areas with a close or irregular planting distance, where small tractors and mist-blowing machines are unable to move, the only solution is to use portable, e.g. shoulder-mounted mist-blowing machines. The maximum load that can be carried by these machines is approx. 5 litres of liquid, so that high-volume spraying is impossible in practice. Mist-blowing with as little as 120 litres per hectare means 24 refillings in order to cover one hectare which limits the capacity to the spraying of only one hectare per man-day, assuming there is no disturbance by rainfall and that the liquid supply is well organized. The best mist-blowers for this purpose proved to be the Kiekens 60 cc. and 75 cc. In 1956 I was able to plan mist-blowing trials with the 60 cc. type during the crop season from April–September, using as cuprous oxide Cobre-Sandoz (= Banacobre) at Fazendas Mucambo, Bahia (Brazil). Because of the satisfactory results, in 1957 this mist-blowing was extended to an area of several hundreds of hectares. When visiting the area in May 1957 I found a marked increase of black pod moving only some 25 metres outside the treated area. VERMEER carried out the experiments in 1956, laid out in adjoining blocks of a few hundred trees. Each treatment and the control (untreated) were repeated four times. A comparison was made between crop region treatment and canopy treatment. In the first case 100 litres were applied and in the latter the amount was increased to 125 litres; in both cases 2½ % Cobre-Sandoz was used. With a 6 weekly cycle there were the following percentages of black pods on September 20th (on August 15th all diseased pods had been removed): untreated 7.58%, crop region treatment 2.80% and canopy treatment 2.87%. The same result was obtained in the following month as well, viz. canopy treatment did not produce less black pods than crop region treatment only.

Another comparison was made between 3, 4½ and 6 weeks' cycles of crop region mist-blowing with 100 litres 2½% Cobre-Sandoz per hectare. On September 30th the average black pod percentage was: 3 weeks' cycle 3.09%, 4½ weeks' cycle 3.25% and 6 weeks' cycle 3.29%.

In Trinidad a mist-blowing trial was commenced in 1954 at Perseverance Estate (MINUTES of monthly meeting Agr. Soc. Trinidad, 1956). Approx. 20 litres of 5% cuprous oxide solution was sprayed per hectare in 4 and 6 weekly cycles. Per tree there were harvested: untreated 1.66 kg wet cocoa, 6 weeks' cycles 1.84 kg and 4 weeks' cycles 2.42 kg.

Mist-blowing the crop region in order to control black pod reduces liquid consumption to such an extent that it will increasingly replace high-volume spraying. Even if it were necessary to treat the plantations at somewhat shorter intervals than with high-volume spraying, liquid consumption would be approx. 85% less.

Moreover it seems possible to increase the effectiveness of low-volume spraying to such an extent that copper will adhere as long as Bordeaux.

With Bordeaux we plaster the whole surface with a lime-copper emulsion; this suspension is sprayed so abundantly that a considerable excess runs to waste.

With mist-blowing the aim is not to cover the surface completely, but on the contrary the drops ejected from the air-stream, which should have a velocity of approx. 5 m/sec. at the moment the object is touched, should be deposited separately and remain separate. After drying out the object is to achieve a regular dense pattern of minute droplets; such a coverage will resist heavy tropical rains, whereas when water or dew wets the surface it will bring a sufficient number of copper ions into solution to kill germinating spores. Consequently when it is desired to achieve the same adhesion and disease control with small quantities of liquid, many details become important that can be neglected with high-volume spraying. The correct drop-size (50/100 u), an air-stream of the right velocity and penetration capacity (dependent on the type of mist-blower), the manner of directing the stream on to the plant (dependent on the machine and its handling), the fungicide (finest dispersion of copper particles and incorporation of an effective sticker) and the contact angle between droplet and object, are all details that will influence adhesion and disease control. The correct drop-size, air-stream velocity and penetration are obtained with the Kiekens machine and their nozzles. When using the 60 cc. Kiekens shoulder machine, it is necessary to blow from a distance of 3–6 metres, and the stream should not be directed too low because as little liquid as possible should be lost on the ground. It is less inefficient when some liquid is deposited too high in the canopy, because from this point the fungicide will gradually wash down along the tree.

An automatic mist-blowing machine for this kind of crop region spraying has been developed by the Kiekens factory.

As already pointed out, the contact angle between the liquid and the object is of great importance. If the surface tension of the spraying liquid is too high the droplets will bounce off when touching the object. On the other hand, if the surface tension is too low the droplets will immediately flatten on the object, leading to a confluence to larger drops which will flow out over the object more readily, accumulating along veins, leaf margins and on the tips of leaves and fruit and resulting in a poor uneven coverage. On checking the deposits of a cuprous oxide on cocoa pods after mist-blowing in Br. Cameroons, it transpired that the surface tension had been too low; much of the fungicide could be observed on the lower pod end, from where it had partly dripped off. In Ecuador spraying tests were made on cocoa and coffee leaves and in Belem (Pará) on rubber leaves with several cuprous oxide suspensions of different surface tension; these leaves were then exposed partly to artificial and partly to natural showers. The contact angle between droplet and object can be changed by altering the surface tension of the fungicide liquid. The less the droplet flattens before drying out, the better the cuprous

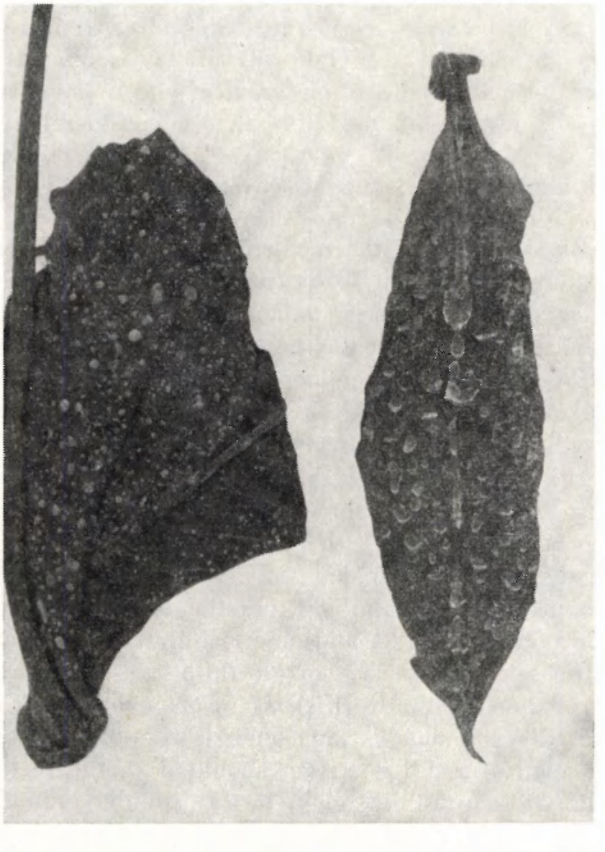

FIG. 5 TWO RUBBER LEAVES SPRAYED WITH SUSPENSIONS OF CUPROUS OXIDE OF DIFFERENT SURFACE TENSION. AT RIGHT: DROPS, THAT WERE TOO FLAT; AT LEFT: DROPS, THAT HAD THE RIGHT SURFACE TENSION FOR RUBBER LEAVES (CAOCOBRE-SANDOZ). ORIBOCA ESTATE, BELEM (PARÁ).

oxide particles are distributed over the droplet and the less copper is washed off by showers. Even when there is no coalescence of droplets the flattening is disadvantageous because it promotes washing off. Fig. 5 shows the difference between 2 cuprous oxide sprays having different surface tensions. The drops with the lowest surface tension show the phenomenon of accumulation of copper particles in the lower part of the drop. A tropical rain shower of, say 2 inches would remove most of the copper, leaving only crescent-shaped remnants. On the other hand, the round, unflattened drops with an even copper distribution had suffered little from the same shower, only the colour intensity being somewhat reduced.

Solutions of 2—3 % Banacobre giving round droplets on banana-leaves show far too flat droplets on cocoa pods and cocoa leaves. A cuprous oxide has now been manufactured by Sandoz that gives the right contact angle for cocoa, coffee and rubber in concentrations of between 1¼—2½ % (Cobre-Sandoz 884, also called Caocobre-Sandoz). The waxy banana leaf needs a liquid with a lower surface tension in order to show the same contact angle as cocoa-pods and leaves. This also indicates that we should be careful in adding other chemicals, e.g. insecticides containing oil, without examining whether the surface tension has been affected.

Adhesion and aggressivity are also considerably influenced by the size of the copper particles in the droplets. Fuchs, Stellmach and Vogel (1956) studied the effect of drop size on adhesion and on the anti-spore activity of *Alternaria tenuis*. The smaller the size of the particles, the better their resistance to rain and the larger their activity. With a particle size of about 1 μ the activity of cuprous oxide reaches the same level as Bordeaux. This may explain why our best mist-blowing results were obtained with Cobre-Sandoz of which a solution shows the Brown movement.

Lellis and de Matta (1956), comparing Cobre-Sandoz, copper oxychloride and Dithane in field studies in Brazil also conclude that Cobre-Sandoz gives the best control on account of its adhesive properties.

When the canopy of cocoa has been badly damaged by *Phytophtora* it is advisable to give it a special treatment. At Fazendas Mucambo the shade in a certain area had been removed, and as a consequence *Phytophtora* had badly damaged the trees; they had dead tops, a very thin leaf canopy, there was hardly any flowering, and no fruit-setting at all. In May 1956 it was decided to give half this area a special canopy mist-blowing every month with 2½ % Cobre-Sandoz. In December 1956 the effect was already remarkable; the treated part was rapidly recovering and new shoots were developing. When I visited the site of the experiment in May 1957, the treated part had a healthy new leaf canopy and the trees were again producing pods; the untreated part continued to die back. A special high reaching mist-blower, the Kiekens 75 cc, is useful for this canopy mist-blowing. As soon as the canopy is brought back to a reasonably good state it is sufficient to continue with crop region mist-blowing only. A secondary favourable effect of such mist-blowing with Caocobre has shown to be the killing of mosses growing on trunk, twigs and leaves, which especially in humid high regions cause considerable damage.

7 Method of phytophtora control in modern cocoa plantations

In most areas, after modern high-yielding cocoa plantations have closed in, they will suffer so severely from black pod, that control will be an economic necessity. Low-volume spraying is preferable to high-volume spraying, because it is cheaper and requires less labour. For the same reason automatic mist-blowers are preferable to small mist-blowers carried by one or two men (such as shoulder machines). Twenty hectares can be treated daily with an automatic mistblower, whereas one to two men are needed per hectare per day in the case of a shoulder mist-blower. The life of an automatic mist-blower is some 5000 hours, whereas the life of a shoulder mistblower is not more than 750 hours. The liquid tank of a shoulder machine cannot be larger than 5 litres, otherwise it will be too heavy to carry; with an automatic machine the tank may hold several hundred litres.

Experience in European orchards leads us to expect that better results will be achieved with 200–240 litres 1½ and 1¼ % cuprous oxide respectively, than with 100 litres 3 % cuprous oxide per hectare. 200 litres per hectare means 40 refillings in the case of a shoulder mist-blower. We must therefore conclude that shoulder mistblowers are much more expensive and that their use involves a labour problem.

The only future seems to lie in automatic mist-blowers (such as the K.W.H. Cocoa-automatic), drawn by a small tractor (e.g. the Ransom). As systematic control of diseases and pests is a necessity in unicrop, high-yielding plantations, new plantations will have to be laid out in such a way as to be suitable for the use of such small automatic machinery. This means long rows of plantations (fewer turns for the machinery), a planting distance of at least 4 metres between the rows, plants in adjoining rows to be planted alternately (so that the mist is also blown on to the plants of the second row), and that drainage system and shade trees must not interfere with machines passing through every other row. The cocoa should preferably be of the chupon type, and not of the fan type (i.e. planted from seed or bud grafts, and not from cuttings).

Pods and shells being the only source of infection, they should be systematically removed from the plantation, either by burying the shells or by transporting the crop to be opened at the fermentation and drying centre. Harvesting in short cycles is preferable so that infected fruit can be removed more frequently.

8 Phytophtora canker paving the way for cocoa necrosis (caused by ceratostomella fimbriata)

In recent years a new serious threat has appeared in Venezuela, Columbia, Mexico and Ecuador, eradicating whole cocoa areas (especially Criollo types, but also ICS 1) within a short time (see e.g. Malagutti, 1956). It was found that this trouble is caused by a combination of a *Xyleborus* borer, carrying the fungus *Ceratostomella fimbriata,* which kills the tree (a case comparable to the Dutch Elm Disease). But the *Xyleborus* borer is usually only known to attack trees when they have been wounded or weakened. There are indications that in several areas some *Phytophtora* canker paves the way for the borer. This might explain why at Hacienda Clementina, Ecuador Banacobre plus Dieldrin painted on the cocoa trunk, was successful in combating the trouble (OECHSLI, 1957), although copper is ineffective against *C. fimbriata.* I now also believe it possible that the eradication of Criollo types in Ceylon and Java at the beginning of the century (VAN HALL, 1912 and 1914) was also caused by the combination of *Phytophtora-Xyleborus-Ceratostomella,* and not only by the former. *C. fimbriata* is still present in the cocoa areas of Java, at the present day causing mouldy rot in the surrounding Hevea plantations (a serious tapping panel disease caused by the same fungus). As no more Criollo or other types susceptible to *Ceratostomella* have been planted in Java, cocoa itself no longer suffers from this fungus.

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