# 5

# Rational Chemical Control and Cultural Techniques

*Dominique Berry*

In the two preceding chapters we saw that in some cases at least a partial solution had been found through the selection of plant material with varying degrees of disease resistance and that in a number of other cases a genetic solution could be provided for a more or less long term. It was also stated that control of insect vectors was often possible and efficient. Nevertheless, for several diseases chemical control is still indispensable until plant material that is sufficiently resistant, or tolerant in the case of viral diseases, is made available to planters. It will be seen that the efficacy of pesticides can sometimes be reinforced by practising cultural techniques that are simple but sometimes exigent in terms of manpower, difficult to implement in the absence of land management or which may have certain unfavourable effects.

## TELLURIC DISEASES

### Rots

The fight against rots is essentially based on preventive measures using appropriate cultural techniques complemented by local applications of pesticides for curing the disease.

#### ROTS IN FOREST PLANTATIONS

##### Preparation of land

Forest plantations are generally established on land earlier occupied by natural forests where floristic diversity is very high. An equilibrium exists between the microflora and the tree stands in these soils. Although a large number of species are susceptible to fungi, only some are found to be very susceptible.

Field observations have helped to establish that the method of forest clearing and preparation of land is very important for the sanitary state of the future plantation. This depends mainly on the amount of infested wood debris such as stumps and roots—which are contaminating (or healthy) foci relaying propagation—remaining in the soil. Clearing methods commonly used are: partial or total felling of trees followed by burning (slash and burn method); mechanised felling of standing trees by bulldozers which enables extirpation of stumps and roots, followed by swathing and burning of the residual wood (most of the commercial plantations were established by this method); poisoning of standing trees by applying arboricides on the trunk. Large areas have been replanted and managed in this way (Mallet *et al.*, 1985).

Fungal infections are restricted if the uprooting and destruction are done very carefully. In practice these jobs, which can be done manually by farmers, are done quite well considering the time and energy they demand. The cost is about $350 to $400 per hectare when done mechanically (in the Ivory Coast in the 80s).

Nevertheless, several techniques help to limit the rots before and after clearing.

Two methods are practised before clearing: poisoning and girdling. Poisoning of forest trees (with arsenic or 2-4-5-T) makes the root system unsuitable for colonisation by the parasite although this phenomenon cannot be explained (Catinot and Leroy-Deval, 1960). Girdling, which is done on the tree trunk, results in a gradual disappearance of starch in the roots and deprives the parasite of the carbohydrates necessary for its growth.

Removal of very large tree stumps is facilitated by using a machine which pulls out the heart of the stump by boring, leaving only a crown of wood a few cm thick, which decomposes very quickly. This technique is better adapted than uprooting for very big trees.

It is advisable to cultivate herbaceous plants that are not susceptible to rots (for example, rice) during the first two or three years after forest clearing so as to sanitise the land before setting up a plantation.

This practice, which favours the breaking up of residual ligneous masses after clearing and consequently the exhaustion of foci, is not always favoured by planters. Nevertheless it merits more attention because it is likely to preserve the productive capital in zones at risk.

## Control of disease foci

A number of methods are practised to control the spread of the foci of rot causing pathogens: digging deep trenches around the infected trees constituting the disease source in order to prevent the advance of rhizomorphs and scraping off the soil around the collar to clear the lateral roots.

However for a more effective control of rots, these methods are complemented by one or more chemical treatments (Table 1).

As armillarias are fungi which grow very slowly, using saprophytic fungi

**Table 1.** Pesticides used to control rots in forest plantations

| Etiological agents | Pesticide | Application method |
|---|---|---|
| *Armillaria mellea* | hexaconazole | Spraying the ground at the foot of infected trees and their neighbours at the rate of |
| *Phaeolus manihotis* | | 150 g active ingredient/ha. |
| *Phellinus noxius* | propiconazole + carbendazime | Spraying the ground at the foot of infected trees and their neighbours at the rate of |
| *Rigidoporus lignosus* | | 125 g active ingredient/ha. |
| *Ganoderma* sp. | | |

may help in thwarting the growth of the pathogen. Laboratory tests have shown that the Basidiomycetes species, *Lentinus squarrulosus*, hinders the growth of *Armillaria mellea*.

### White root rot of hevea

#### *Rigidoporus (Fomes) lignosus*

As in the control of rots of forest plants discussed above, a well prepared land helps to considerably reduce losses caused by white root rot of hevea whose agent is *Rigidoporus (Fomes) lignosus* (Tran Van Canh, 1996).

The main operations to be followed are felling, burning, subsoiling and removal of plant debris. Felling of the forest is accompanied by uprooting of all the trees one or two years before planting so as to expedite burning. The maximum number of trees and their stumps are burnt. Subsoiling of the plantation lines is done to a depth of 80 cm and all the debris is removed from the sowing pits in the plantation.

In crops less than four years old, all dead and infected trees are eliminated and the taproots and lateral roots are removed and taken out of the plantation.

In older crops, the taproots of dead and infected trees that are not being tapped are isolated in the following way: the trunk is cut about 20 or 30 cm above the collar; all the lateral roots up to a depth of 80 cm are sectioned and destroyed and an isolation pit 50 cm wide and 80 cm deep is dug around the taproot.

Latex yielding trees, where infection is detected by the presence of yellow mycelium of *Rigidoporus* at the collar and necrosis of the bark of the taproot, are isolated by digging circular trenches 25 cm wide and 80 cm deep, with a radius of about 1 m from the taproot. All the lateral roots beyond this trench are cut and destroyed. Stumps of forest trees infected by *Rigidoporus* and still remaining after the establishment of the plantation are isolated by a trench 50–60 cm wide and 80 cm deep and all the lateral roots are removed.

Tapping latex from hevea trees begins when they are between 5 and 7 years old and agriculturists often intercrop during a part of this unproductive period. The choice of the crop to be planted is important. Tapioca (cassava), with a long cycle (1.5 to 2 years), is not advisable because this plant is a veritable trap for *Rigidoporus*. It could later contaminate young hevea trees. When tapioca plants were uprooted, a large number of them were found to be infected (Delabarre, pers. comm.). However, this drawback was not observed when tapioca with a short cycle (1 year) was planted (Delabarre, 1997).

In plantations, the application of cultural techniques and chemical control methods depends on sanitary supervision. It helps to neutralise the infection sources. The first sanitary inspection should be made as early as possible and generally from the first year. Inspection rounds must be undertaken once or twice a year, depending on the degree of infection observed. Inspection of the root system near the collar of all the trees enables detection of infected ones which are then marked.

Chemical treatments are applied twice a year—once immediately after the infection is detected and the second after 6 months—to all the diseased trees and their neighbours by spreading fungicides in the form of granules all round the taproot. This is followed by a light second dressing to incorporate the chemicals in the soil. The following fungicides can be used:

— Atemi S (8 g cyproconazole and 800 g sulphur) at the rate of 50 g per tree;
— Bayfidan 1 GR. (10 g triadimenol/kg), 50 g per tree;
— Vectra 1.5 GR. (15 g bromuconazole/kg), 35 g per tree;
— Sumi8 1 GR. (10 g diniconazole/kg), 30 g per tree.

### *Armillaria* of hevea

As in the case of *Fomes*, control of *Armillaria* of hevea is first of all preventive while preparing the land through removal of as many tree stumps as possible when the plantation is to be established in a forest. Curative control, by scraping off the infected parts with or without brushing with a fungicide, was not found to be effective (Guyot, 1997).

### Coffee rot

Coffee rot is found under very diverse conditions, the preceding vegetation (particularly forest) and kind of crop (presence of shade trees) playing a decisive role in the presence of this malady. Injuries caused to subterranean parts by living organisms (insects, nematodes, etc.) and particularly by tools used for the mechanical maintenance of plantations, favour the entry of the causal organisms into the roots, especially their spread from plant to plant. The infection spreads as spots from well localised foci mainly through mycelial strands, the rhizomorphs, which go from root to root. It is generally slow except when tractor-drawn tools are used, as they disseminate infected root fragments carrying the mycelium, leading to the rapid advance of the disease in the coffee lines.

The disease can be controlled in a preventive way while preparing the land. Removal of all forest trees and destruction of their stumps and all ligneous debris and dead wood, which are the primary potential sources of infection, should be done carefully.

Once the plantation is established, the plots should be carefully surveyed in order to avoid the formation of large infection spots, so that the infected zones can be circumscribed by digging trenches. This survey should particularly take into account the presence of forest stumps that may have escaped destruction and, if the case arises, of shade trees.

When the disease is detected, curative treatment is generally limited to restricting the spread of the infection. Spread of a disease spot could then be checked by digging a pit at least 60 cm deep all around it. This pit prevents the advance of rhizomorphs by removing the continuity between the roots of infected plants and those of neighbouring plants that are still healthy. From a practical point of view, the diseased plants and associated shade trees are uprooted, taking care to extirpate the maximum number of woody roots. This uprooting is facilitated by using hoisting gear mounted on goats. The trunks, branches and roots should be burnt then and there. The pits are dug by throwing the soil towards the interior of the spot to be circumscribed and not outwards.

After the diseased areas are thus treated and while awaiting replantation, a herbaceous crop should be planted in order to protect the soil from erosion and leaching, for example, Gramineae, herbaceous food crops, etc., that are immune to the diseases under consideration, which are strictly restricted to woody plants. However, the cleansing effect of fallow land is slow. Blaha (1978) studied this phenomenon in the case of *Clitocybe elegans* attacks on Arabica coffee plants at high elevations in Cameroon by using bait sticks. He observed that after 2 months there was no more than 41% infection at 40 cm depth and 56% at 80 cm.; after 12 months there was still 34% decontamination at 40 cm and 35% at 80 cm. Hence it is recommended that replanting be done only after two or three years.

According to the investigations carried out in Central America, this long delay for replantation can be reduced to just a year by treating the soil left in the holes after uprooting with an appropriate fungicide such as Pcnb or Basamid or methyl bromide. Still, with respect to *C. elegans* on Arabica coffee at high elevations, it was demonstrated that deep and diffuse fumigation of the soil with methyl bromide is very effective in killing the mycelial fragments and appears to hasten their destruction by *Trichoderma* (Blaha, 1978). From an economic point of view, this method is interesting only for small disease foci and can be suggested if the latter are identified quite early. Once the disease source is located and treated, its spread can be monitored by planting sterilised bait sticks of a susceptible plant species such as *Hevea* or *Leucaena* in the soil.

Girdling of healthy trees along the entire boundary of the infected area is another method, already recommended while preparing the land in forest plantations, which can be proposed to stop the spread of rot areas. This girdling should be done only on the bark to enable the ascending sap to circulate in the xylem vessels left intact and to prevent the phloem sap from flowing down to the base of the trunk and roots. The stumps of trees thus treated are not only deprived of starch reserves, but are also emptied of their reserves and hence prevent the development of rot pathogens since they can only live at the expense of starch and not lignin. However, application of this method means sacrificing a very large number of healthy trees making it rather impractical.

These curative practices can be justified on the economic front only in small areas which are the foci identified quite early. They therefore require great vigilance on the part of farmers.

All that has been said above for coffee is also valid for cocoa and tea plantations.

## Vascular wilt of oil palm

In the fight against the fungus responsible for causing vascular wilt (*Fusarium oxysporum* f. sp. *elaeidis*), chemical control is quite impossible because the fungus is dispersed in the soil and hence very vast areas would have to be treated. We saw that genetic control (see the chapter on Varietal resistance) has made available plant material with a high degree of resistance to vascular wilt.

Nevertheless, several series of experiments have helped to show that the impact of the disease on material with moderate resistance can be modulated by certain cultural techniques (Renard and Franqueville, 1991), being understood that they will not enable a susceptible material to escape the disease. Elimination of genetically susceptible sources from the parents used in breeding programmes of plant materials destined for Africa is therefore an imperative.

Among the factors studied, we will retain the plantation site, mineral nutrition, mulching with empty bunches and plant cover.

### Plantation site

Replantation on land that had been initially planted with susceptible crosses suffer greater infection than replantation done with resistant crosses. However, the percentage of fusariosis can be reduced by half if the young palms are replanted at a distance of more than 2 m from the old sources. It was also demonstrated that the maintenance of trees showing chronic wilt symptoms favours the development of the inoculum. It is therefore recommended to fell them in order to preserve the good health of later replantations (Franqueville and Renard, 1988).

### Mineral nutrition

Ollagnier and Renard (1976) showed that supplying potassium chloride

(KCl) slowed down the development of vascular wilt, confirming the observations of Prendergast (1957) in Nigeria. Calcium application, which has been studied in detail by agronomists under a programme on the restructuring of soils in palm plantations, does not significantly modify the incidence of vascular wilt (Franqueville and Renard, 1988).

### Mulching with empty bunches

Cobs are the remnants obtained from factories after the maize seeds have been stripped from them. They are commonly used in plantations to provide mulch at the base of the palm trees or on the interlines. A significant rise in the incidence of fusariosis was observed almost as soon as they were spread around young trees (Table 2; Renard and Franqueville, 1991).

**Table 2.** Effect of mulching with empty bunches on the incidence of fusarium wilt (as percentage) on two categories of hybrids (C1001 and C1401)

| | C1001 | | C1401 | |
|---|---|---|---|---|
| | Fc | Fe | Fc | Fe |
| First application | 16.1 | 1.8 | 34.1 | 7.1 |
| Second application | 22.6 | 6.0 | 38.9 | 13.5 |
| Control | 8.9 | 0.0 | 15.5 | 0.0 |

Fc: percentage of fusarium cumulated
Fe: percentage of fusarium wilt expressed over 5 years

On the other hand, cobs placed in the interlines of adult plantations does not have any effect on disease incidence but the consequences for future replantations are not yet known.

### Plant cover

Plant cover has an influence on fusariosis. The maintenance of bare soil, chemically or manually, reduces the percentage of fusariosis compared to the maintenance of leguminous plants such as *Pueraria javanica, Centrosema pubescens* and *Calopogonium caeruleum*, the last one being the most favourable for the expression of fusariosis (Franqueville and Renard, 1988). However, maintenance of bare land cannot be envisaged for obvious agronomic reasons.

These different factors may play an important role on the biotic and abiotic factors intervening in the receptivity of soils to *Fusarium oxysporum* f. sp. *elaeidis* or in maintaining its infective potential, the results of which determine the gravity of the disease. By correlating an inoculation test on linseed with an inoculation test on palm, Abadie *et al.* (1994) showed that different cover plants could induce modifications in the receptivity of soils to vascular wilts. The influence of bare soil is not of biotic nature, but rather the result of factors linked to moisture stress. On the other hand, measurements of receptivity have shown that the presence of empty bunches in pre-infested soil favours the development of a fusarian flora (Abadie *et al.*, 1996).

Many cultural techniques may be more or less favourable for the expression of the parasite; nevertheless, it is indispensable to use resistant plant material even when the most appropriate methods are practised.

## *Phytophthora* diseases

*Phytophthora* may provoke strictly telluric diseases when underground parts are specifically infected: this is the case with avocado wilt and citrus gummosis, which will be treated below. *Phytophthora* diseases of aerial organs such as brown pod rot of cocoa, will be treated further on. These two kinds of diseases dictate the specific modalities of control methods.

### Avocado wilt linked to *Phytophthora*

As wilt caused by *Phytophthora* is present in nearly all avocado orchards and subspontaneous stands, the search for effective control methods has been extensive and varied.

Among the preventive measures recommended is the use of uninfected plants in nurseries by taking the precaution of plucking the fruits meant for obtaining seeds and not picking them from the ground.

Next, the choice of location of the orchard should take into account factors that are favourable for the disease, especially high humidity, in order to avoid planting under these conditions.

Several fungicides are now available which can be used either for complete disinfection of the soil or for repeated soil treatments or foliar applications.

Total disinfection of the soil was found to be successful in nurseries and in substrates of soilless cultures before planting. Methyl bromide can be used at a concentration of about 50 g per $m^2$; various other fumigants can also be used but their application is onerous and is generally reserved for small areas in nurseries.

For periodic treatment of soils of planted orchards, various fungicides have been tried and then used, but the results were mediocre and this kind of treatment is quite onerous and constraining (Frossard and Bourdeaut, 1974).

A number of fungicides were experimented with, including metalaxyl (Ridomil) as soil application, in a dose of about 1 g active ingredient per tree of 5 years old, every 8 weeks. The results were excellent but this active ingredient is known to select resistant *Phytophthora* strains and hence its use cannot be generalised without warning.

Lastly, foliar applications of fosetyl-Al gives excellent results for protecting the roots against *P. cinnamomi* as much in the nursery (Mourichon *et al.*, 1984) as in the open field (Frossard *et al.*, 1997; Laville, 1980; Bertin *et al.*, 1983). In fact, fosetyl-Al has the property of migrating from the leaves to the roots and preventing the development of necrosis. It is applied as a periodic foliar spray, whose rhythm may vary depending on the climatic conditions of each region. The dose used is about 200 g active ingredient per hectolitre of water (about 10 to 15 litres of the formulation per tree of 5 to 10 years). For the best results, spraying regularly before the appearance of the first symptoms is imperative because any slow-down in the physiological activity of the tree compromises a good downward migration of fosetyl-Al and its efficiency. Good results were also obtained by injecting low concentrations of fosetyl-Al into the trunks, at the rate of two injections per year at the rate of 0.4 g active material per $m^2$ foliage (Gaillard, 1987).

### Citrus gummosis

#### Rational chemical control

A number of methods are available for controlling *Phytophthora* diseases on citrus, which can be used partially or fully, alone or in association, depending on the situation, economic imperatives and the parts that are infected (Boccas and Laville, 1978; Laville, 1984).

Until recently, chemical control was mainly by brushing with Bordeaux mixture or a copper formulation after scraping off the cankerous region. The immediate disinfection was satisfactory but onerous and besides, it was observed that cankerous activity often reappeared.

A number of more efficient fungitoxic compounds are now available. Metalaxyl (Redomil) is very effective against *Phytophthora* sp.

When sprinkled on the soil at the rate of about 0.2 g per litre, this active ingredient ensures good protection against attacks on the root system and its acropetal translocation also helps to cure the cankers on the trunks and low branches. It is also effective when painted on the trunks at the rate of 60 g active ingredient per litre of water. As indicated earlier, fungicides with a metalaxyl base should be used with great care because the risk of rapid selection of *Phytophthora* strains resistant to this ingredient cannot be ignored (Laville, 1984).

Fosetyl-Al (Aliette) has a different kind of fungitoxic activity. It is not directly active on *Phytophthora* but after entering and migrating in a susceptible variety, it would stimulate the resistance mechanisms present in this variety and thus ensure excellent protection for it (Frossard *et al.*, 1977; Laville, 1979; Laville and Chalandon, 1982).

The fungicide should be applied to the foliage and its basipetal translocation assures a good distribution in the low branches, base of the trunks and the roots. It helps to avoid insidious attacks on the roots, which affect the yield irrespective of the rootstock used. It completely arrests the development of cankers and helps their cicatrisation. The dosage used is 2000 ppm active ingredient. It is recommended to drench the foliage of treated trees and to apply it as a preventive measure to trees which are still apparently healthy or slightly infected and also during periods of intense physiological activity.

New techniques for fosetyl-Al application have been developed more recently, such as injection and collars (silicon impregnated with the active ingredient). These techniques are not only less constraining but they also provide an effective immunity over a period equivalent to that conferred by foliar applications (Chabrier *et al.*, 1995).

### Cultural techniques

To think that plantations on land free of *Phytophthora* will continue to be parasite-free for a long time is utopian; hence the permanent threat this parasite poses for orchards must always be kept in mind (Boccas and Laville, 1978).

Considering the impact of this disease, since it attacks standing trees of all ages, intensive research is underway to find appropriate counteractive cultural techniques. Some of these techniques are applicable whatever be the variety of rootstock or seeds. The less resistant the variety, the more imperative their use.

As a preventive measure, it is first of all recommended that grafting of plants in the nursery be done quite high so that the grafted variety, which is generally more susceptible than the rootstock, does not come too close to the soil after a few years when the tree has grown (Laville, 1984). For the same reason, it is desirable while setting up the plantation not to bury the young plant too deep in the soil and to anticipate a possible piling up of the soil in subsequent years by planting it on a slight mound.

Considerable attention should be paid to the selection of land and drainage of planted areas to avoid waterlogging due to abundant natural precipitation or untimely and/or poor irrigation, and to protect the base of the trunks from stagnant water by a double pan system.

It is recommended to remove all herbaceous plants coming into contact with the trunk and to facilitate aeration of the base of the trees by cutting the very low branches.

Precautions must be taken to avoid any injury to the bark of trunks and the base of low branches, irrespective of the origin of these injuries: rubbing of tethering ropes of animals, sickle or axe cuts, passage of vehicles, attacks by insects and worms.

## Nematodes of coffee plants

#### Chemical control

Curative chemical control of nematodes in adult coffee plantations has numerous limitations and inconveniences: efficacy, cost, toxicity, inadequate duration of the protective effect (Villain *et al.*, 1995). It is therefore recommended that prophylactic measures be complemented with chemical treatments in the nursery so that the nematodes do not get dispersed. Chemical control can also be used to reduce the inoculum in the field at the time of planting and to protect the plant during growth before it enters the productive phase. However, an experiment conducted in a site infested with *Pratylenchus* sp. in Guatemala showed the poor effect of nematicidal applications on production, both on ungrafted Arabica coffee as well as on plants grafted on *Coffea canephora* (Fig. 1; see Chapter 3: 'Varietal resistance'; Villain *et al.*, 1996).

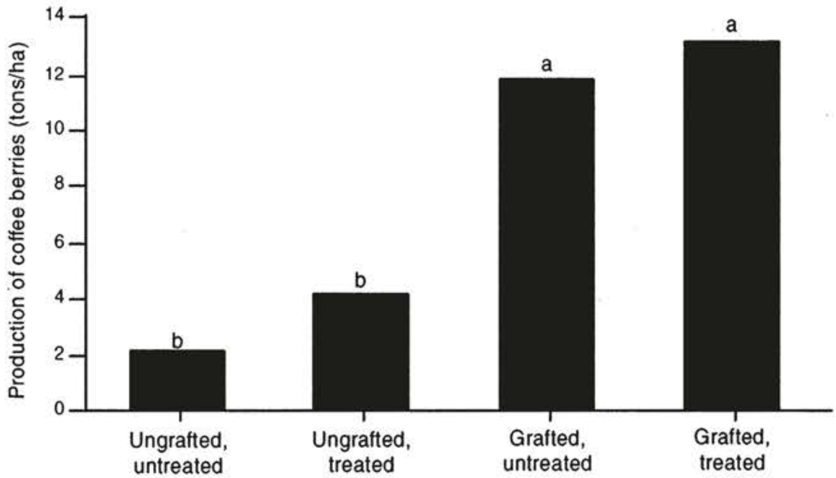



**Fig. 1.** Control of *Pratylenchus* sp. by grafting and nematicides (from Villain *et al.*, 1996).

## CULTURAL TECHNIQUES

### Management of soil fertility

Any cultural practice whose objective is to improve the nutrition of coffee plants helps to reduce the impact of nematodes (induced resistance and tolerance): application of fertilizers in the nursery and avoiding any mineral deficiency; correction of low pH, especially in soils of volcanic origin (common in Central America) which are often very acidic or acidified by frequent and localised nitrogen supply.

### Endomycorrhization in nurseries

Symbiosis between the coffee plant and endomycorrhizal fungi colonising its roots helps to considerably increase the capacity of soil exploration and absorption of nutrients. These elements, in particular phosphorus and the oligoelements, are transported by the external mycelium of mycorrhizae up to the roots where they are exchanged for the carbon produced by the coffee plant during photosynthesis.

In the field, the degree of this symbiosis varies with the age of the host coffee plant, ecological conditions and cultural practices. Endomycorrhization of the coffee plant in the nursery, by adding fungal inoculum at the time of replanting in bags, helps to effectively establish this symbiosis from a very early stage of seedling growth. This can be observed in the nursery by gains in growth ranging from 50% to more than 100% depending on the endomycorrhizal species. In the field it is expressed by a fall in the mortality rate in plantations, early start of the production phase and an increase in yield from 20 to 30% during the first few years.

Besides the beneficial effects on growth and nutrition, several experiments in the nursery have shown that symbiosis increases the tolerance of coffee plants to pathogens and telluric parasites, in particular nematodes, by means of several indirect mechanisms (Vaast, 1995).

Symbiosis helps to increase the tolerance of the host coffee plant by augmenting its vigour and improving its nutritional status, especially in phosphorus, thus enabling it to tolerate high nematode populations better by mitigating damage to the roots. Thus their absorption capacity is maintained by modifying the morphology of the root system (stimulation of branching and development of radicles, proliferation of mycelial hyphae), which enables it to compensate the losses in root biomass.

Symbiosis can also augment the resistance of plants by direct action on nematodes:

- by restricting, almost preventing, the entry and establishment of these nematodes in the region of the roots where endomycorrhizal colonisation has already been established;
- by reducing nematodal attraction to roots;
- by checking their growth and reproductive cycle by altering the root exudation (production of antibiotic and nematicidal substances) and modifying the rhizosphere flora (stimulation of *Rhizobacteria* and antagonistic microorganisms such as *Trichoderma, Bacillus* and *Pseudomonas*).

### Cultivation under shade

A common cultural practice in Central America, except in the central part of Costa Rica, is to grow coffee under shade. The main tree species used to provide this effect are *Erythrina* sp. and *Inga* sp., Leguminosae species which aid nitrogen fixation in the soil.

This shading helps to reduce the impact of nematodes in two main ways, especially in regions with a pronounced dry season: it creates a microclimate which maintains the coffee plants in a state of low stress, thus making them more tolerant to nematode attacks. It also generates litter which reduces the moisture stress of coffee plants during the dry season, which is generally five to six months in this region. This litter favours the growth of a microflora and microfauna antagonistic to plant parasitic nematodes and, by adding considerably to the organic matter, also improves the physical structure and chemical composition of the soil.

## DISEASES OF AERIAL PARTS

These diseases, which mainly affect the fruits and leaves, are related to the development of fungi or bacteria.

## Fungi

A large number of fungal species attack the aerial parts of plants. Some of them are typical pathogens that pass a major part of their life cycle in the soil, for example *Phytophthora*, but most have a purely aerial cycle.

*Phytophthora*

### Brown rot of cocoa pods (black pod rot)

As seen earlier in Chapter 1 'Symptomatology and Economic Importance', brown pod rot of cocoa is caused by various species of *Phytophthora*, of which *P. megakarya* may engender losses of more than 50% of fruits. Therefore, here we will study particularly brown pod rot caused by this species and compare it with rots caused by other species in order to distinguish the particularities of chemical control.

Considering the cost and intense manpower chemical control involves, selection of cocoa plants showing the least susceptibility in the field is a line of research currently favoured for controlling this disease. However, while awaiting a genetic solution, control of brown pod rot in countries most affected by this disease is necessarily through chemical control.

Initial infections take place after the dry season, with the onset of rains, which marks the beginning of a new productive cycle of the cocoa plant. Development of the disease is thus related to the intensity of rainfall. Hence it is generally from the beginning of the fruiting period that the first treatments should be undertaken.

Definition of the kind of treatment as well as application rhythms requires intensive epidemiological studies in the different ecologies of production zones in order to precisely specify the influence of rainfall distribution, duration of high humidity periods, tree architecture and modes of plantation over an infective cycle. Thus, in Cameroon where only the species *P. megakarya* has been identified, the largest production zone (central and south-central region) is characterised by an equatorial type of climate comprising two rainy seasons (April to June and September to November) and two dry seasons (Nyasse, 1997). During the first rainy season treatment of only the pods on the trunk (the ones mainly affected during this period) may sometimes prove to be adequate, thus helping to limit the consumption of fungicides (Fig. 2; Muller, 1974, 1984; Berry and Tafforeau, 1991; Table 3). However, this scheme cannot be generalised in production zones with a different climatic regime, as in the case of western Cameroon, where the rainy season is longer.

The most widely used control method is spraying of copper-based contact fungicides. In some countries such as Brazil, where the species *P. capsici* is predominant, the low incidence of the disease helps to control the epidemic with just two applications of cupric fungicides, but by using mixtures with high copper content (2% metallic copper). In countries where the species

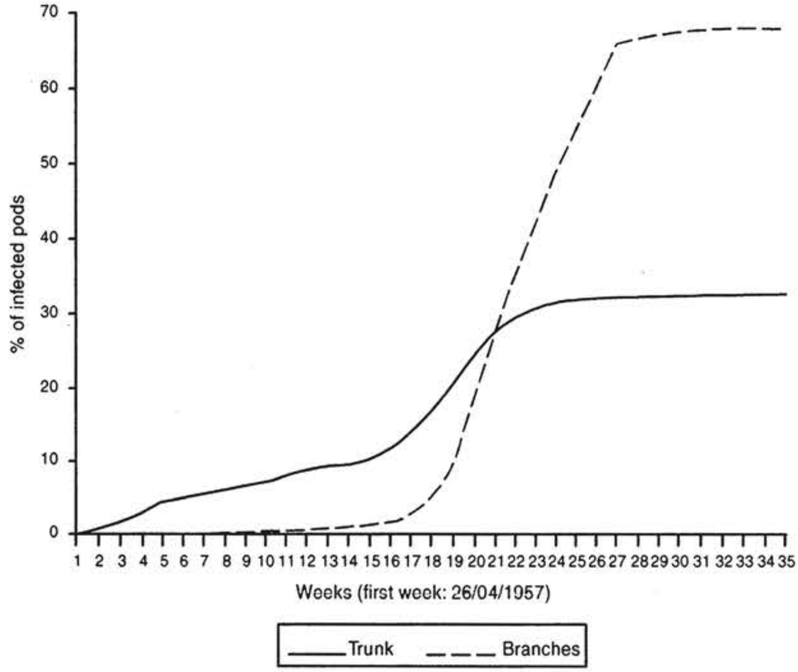



**Fig. 2.** Percentage of pods (cumulated weekly) infected by *Phytophthora* sp. at different levels of trees (from Muller, 1974).

*P. megakarya* is present, it is necessary to make several applications with contact fungicides or to use molecules with a more efficient systemic or penetrating character and showing greater persistence, which helps to space the treatments. Metalaxyl diluted with copper, such as Ridomil plus 72 wp, is often recommended (Davous *et al.*, 1984).

In any case, increasing the spacing of treatments using a single dose of Ridomil plus 72 wp may be limited during the first rainy season. This difficulty in increasing the interval between treatments up to the limit allowed by the active period of the fungicide is due to the fact that flowering is highly staggered in time and hence the pods are also formed in a staggered manner. Hence those which appear in the intervening period are not protected and can quickly get infected. This was demonstrated, particularly in Togo where the first rainy season, which is also the heaviest, makes the disease a very serious one right from the beginning, in contrast to the situation in Cameroon for example. Therefore, sometimes spacing of treatments is possible only during the second rainy season when all the pods have appeared and receive all the treatments. Considering the mode of action of metalaxyl, it seemed necessary to set up an anti-resistance strategy favouring an alternation of fungicides during the operation. This has been found to be perfectly effective until now.

**Table 3.** Chemical control of brown pod rot of cocoa in Cameroon using spraying or atomising techniques and a contact fungicide, alone or in combination with a penetrating type of fungicide.

| Techniques and fungicides used | Number of treatments | Concentration of mixture | Consumption of fungicide |
|---|---|---|---|
| 1: Spraying contact fungicides | | | |
| First rainy season (on the trunk) | | | |
| Interval of two weeks between treatments | | | |
| Copper (cupric oxide) (50% Cu) | 5 – 6 | 0.5% cp (75 g/15 l) | 80 l/ha/t (400 g/t) |
| Second rainy season (on the whole tree) | | | |
| Interval of two weeks between treatments | | | |
| Copper (cupric oxide) (50% Cu) | 5 – 6 | 0.5% cp (75 g/15 l) | 250 l/ha/t (1250 g/t) |
| 2: Spraying contact and penetrating fungicides | | | |
| First rainy season (on the whole tree) | | | |
| Interval of two weeks between treatments | | | |
| Copper (cupric oxide) (50% Cu) | 4 | 0.5% cp (75 g/15 l) | 180 l/ha/t (900 g/t) |
| Second rainy season (on the whole tree) | | | |
| Interval of three weeks between treatments | 4 | 0.33% cp (50 g/15 l) | 250 l/ha/t (830 g/t) |
| Ridomil | | | |
| 3: Spraying contact and penetrating fungicides | | | |
| First rainy season (on the whole tree) | | | |
| Interval of one month between the two treatments | | | |
| Copper (cupric oxide) (50% Cu) | 2 | 1.5% cp (225 g/15 l) | 180 l/ha/t (2700 g/t) |
| Second rainy season (on the whole tree) | | | |
| Interval of one month between the two treatments | 2 | 1% cp (150 g/15 l) | 250 l/ha/t (2500 g/t) |
| Ridomil | | | |
| 4: Atomising contact and penetrating fungicides | | | |
| First rainy season (on the whole tree) | | | |
| Interval of one month between the two treatments | | | |
| Copper (cupric oxide) (50% Cu) | 2 | 4.5% cp (450 g/10 l) | 80 l/ha/t (3600 g/t) |
| Second rainy season (on the whole tree) | | | |
| Interval of one month between the two treatments | | | |
| Ridomil* | 2 | 2% cp (200 g/10 l) | 140 l/ha/t (2800 g/t) |

cp: commercial product
t: treatment
*Ridomil: penetrating fungicide Ridomil plus 72 wp (Novartis), 12% metalaxyl and 60% Cu.

Thus, in Cameroon (Table 3) phytosanitary protection could be ensured by adopting spraying and atomising techniques using a contact fungicide (with copper oxide base) or a fungicide of the penetrating type (Ridomil plus 72 wp). It is possible to reduce the number of treatments, while still maintaining very good efficiency, by increasing the concentration of the fungicide in the mixture used (Fig. 3; Berry and Tafforeau, 1991). However, part of the manpower thus saved should be compared with the higher cost of the input. Therefore control methods using high concentrations of solutions and fewer treatments are to be employed only in potentially productive plantations where high disease pressure has been recorded.

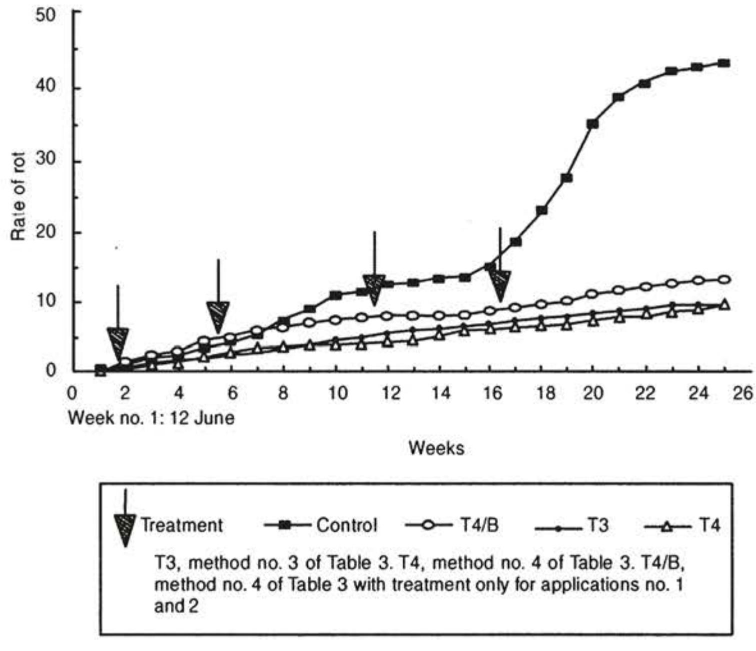



**Fig. 3.** Chemical control of brown pod rot of cocoa in Cameroon (from Berry and Tafforeau, 1991.

Another treatment technique is to inject fosetyl-Al into the trunk (10 to 20 g per tree per year). It has helped to reduce the disease incidence of *P. palmivora* by half (15% as against 30% in controls) in the Ivory Coast (Kebe, 1989). On the other hand, this type of treatment did not seem to have any effect in the short term on *P. megakarya* in Cameroon.

Considering the wide heterogeneity in the complex environment of cocoa plantations (variations in the shade, soil, imperfect clearing, mixture of several genotypes of cocoa, differences in disease pressure from one place to another, etc.), it was necessary to formulate an experimental strategy to complement traditional tests, which are based on the comparison of plots constituted by groups of trees. It was thus demonstrated that it is possible to reduce the size of the elementary plot up to the tree (Marticou and Muller, 1964).

Moreover, in order to have as homogeneous an environment as possible for evaluating the fungicide value of a formulation, this reduction of the elementary plot led to working on groups of pods of the same species borne on two trees close to one another and located in the same environment. An abundant supply of inoculum was provided by placing 5 pods infected in the crown region at the foot of each of these trees, i.e., following the miniaturised pairs method (Muller *et al.*, 1969).

Given the cost and intense workforce required for the chemical control of this disease, especially in the most infected productive zones, agronomic methods which create conditions unfavourable for the growth of the pathogen could complement chemical control for reinforcing the efficiency of the treatments.

Sanitary harvest is one of these agronomic methods. It consists of cleaning the trees at the beginning of the operation by removing the remains of earlier productions and regularly removing the diseased pods, which are potential sources of secondary inoculum. However, the impact of this measure is greatly dependent on climatic factors. Its effect is expressed mainly by a slowing down in the rate of evolution of the epidemic on the pods on branches, especially when infection pressure is moderate (Partiot, 1984).

The general ambience of the cocoa plantation can also be changed by reducing the ambient humidity in the plantation, which favours infection: lessening the shade or even removing it are good measures, but in return this requires increased vigilance with respect to insects, especially hemipteran borers such as mirids, psyllids and coccids, as well as appropriate mineral nutrition. Lastly, to facilitate chemical treatments, it is recommended that the cocoa trees be maintained at a height that makes them accessible to sprayers: a total height of 3.5 m should be the acceptable limit because beyond this the higher pods escape the treatments. Once infected, they become sources of contamination for the lower pods, thereby reducing the efficiency of chemical control measures.

To conclude, the choice of the control method to be adopted should take into consideration the nature of the plant material, the ecological requirements of the cocoa trees to be protected, degree of disease pressure and its potential level of productivity. Chemical control, which helps to reduce the heavy losses caused by brown rot, should in fact be able to give growers a return that is higher than its cost.

These treatments help to reduce the losses by 50 to 10% and their cost is equivalent to about 150 to 200 kg of cocoa trade. Calculating the feasibility of fungicidal treatment is complicated by the fact that brown pod rot is not the only factor limiting the production. In fact, Miridae hemipterans generally cause heavy losses and the yield can be improved only through treatments with both fungicides and insecticides.

## *Phytophthora* rots of coconut

On observation of the first manifestation of *Phytophthora* rot symptoms in a coconut plantation, the planter has no choice but to use chemical control methods to arrest or slow down the progress of the disease. Otherwise the infection will lead either to the death of the tree, as in the case of infection of the terminal bud (heart rot), or to premature nut fall.

The architecture of the coconut tree, with its unbranched trunk, comprises an assemblage of conducting vessels and a fasciculate root system made up of large primary roots (fairly superficial) that are particularly well suited for the absorption of systemic fungicide formulations.

A number of techniques have been envisaged. In the Ivory Coast, where the incidence of rot caused by *P. katsurae* on Malaysian Yellow Dwarf × West African Tall hybrids is more severe on nuts than on the bud, spraying the crown with 7.5 g fosetyl-Al was found to be totally ineffective (Fig. 4). The result was the same when the trunk, which had been punctured earlier, was injected with 3.2 g metalaxyl. On the other hand, an injection of 8 g Aliette (with 80% fosetyl-Al) per tree helped to limit nuts fall to less than 5% for at least two years (Franqueville and Renard, 1989).

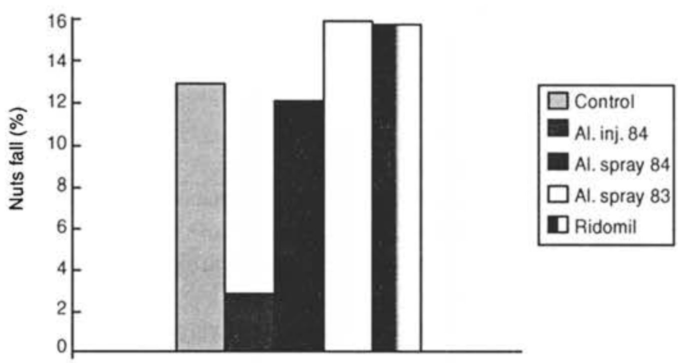



**Fig. 4.** Control of *P. katsurae* of coconut: nuts fall over harvests of two years (from Franqueville and Renard, 1989).

The most favourable period for treatment is between April and June, before the rainy season. Repeating the treatment in September reinforces its efficiency, the same as distributing the fungicide in two diametrically opposite pits (Fig. 5). In all the experiments, the effectiveness of the treatment was maintained for at least two years. It must be noted that this kind of treatment is not injurious to the coconut tree and neither mortality nor breaking of the trunk were observed. Furthermore, this treatment was successfully applied on a large scale in commercial coconut plantations of hundreds of hectares in the Ivory Coast.

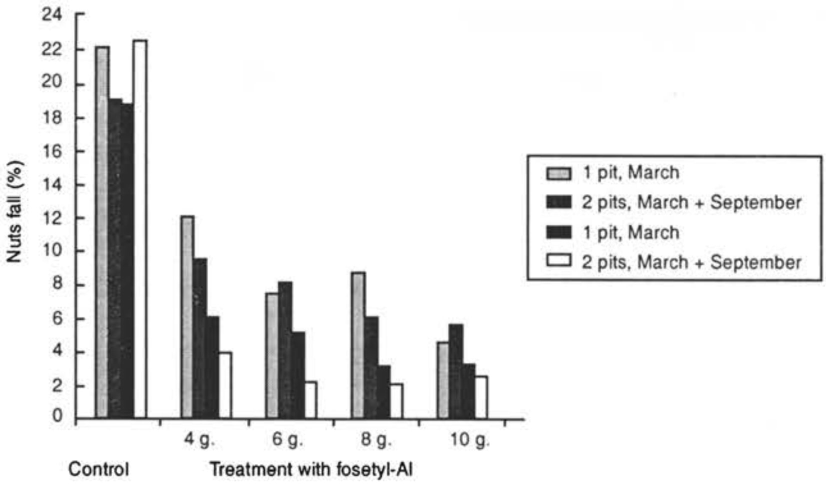



**Fig. 5.** Nuts fall of coconut over harvests two years after different types of treatments with fosetyl-Al injections (from Franqueville and Renard, 1989).

In Indonesia, bud rot due to *Phytophthora* is predominant and causes considerable losses from a young age in Nias Yellow Dwarf (or Malaysian YD) × West African Tall hybrids. Experimental treatments through root absorption showed variation factors linked to the rate of absorption, quality of the absorbed product, especially with a fungicide formula used as a wettable powder and the heterogeneity observed from one tree to another (Thévenin *et al.*, 1995). Injecting the trunk eliminates these uncertainties and ensures a better homogeneity of the results, besides being less expensive than treatment by root absorption. All said and done, these authors recommend treatment by injecting the equivalent of 8 g phosphoric acid (in the form of Foli-R-Fos or Aliette) into the trunk at the beginning of the rainy season, instead of dabbing with phosphoric acid which is very soluble but not registered. In this case, using injection syringes of the Chemjet ® type, whose superiority is yet to be confirmed, would be the most appropriate means of causing minimum injury to the trunk and for injecting a small volume of a strong dose of the active material. Although root absorption gives less reliable results, it is generally reserved for young coconut plants where the trunk tissues are still too tender for puncturing.

Researches carried out to control *Phytophthora* diseases of coconut have led to proposing methodologies that are simple and technically accessible to the planter, enabling him to preserve the capital invested and to conserve the production potential. Preventive treatments every two or three years are strongly recommended in regions that are potentially propitious for the development of heart rot and nuts fall epidemics.

## Black stripe disease of hevea

This disease caused by *Phytophthora palmivora*, which may lead to the destruction of the tapping panels, can be avoided by taking preventive measures. Several fungicides can be used: metalaxyl, folpel, cymoxanil, oxadixil or fosetyl-Al in solution varying from 1 to 2% depending on the climatic conditions and intensity of the infection. These treatments are applied mainly on the notch and tapping panel by painting them during the rainy season and generally after each tapping. The fungicidal solution is coloured with eosin to monitor the thoroughness of the work (Delabarre and Serier, 1995).

*COLLETOTRICHUM*

## Hevea leaf blight

*Colletotrichum gloeosporioides* Penz. infects young leaves less than three weeks old at the time of refoliation, which takes place during the rainy season, a period that is favourable for the growth of the fungus. Chemical control using fungicides proved to be very difficult because of the size of the hevea trees and the high frequency of these treatments necessary to check infection. Escape control consists of artificially provoking early defoliation of hevea so as to induce early refoliation of the trees before the rainy season begins, and hence during a period which is not favourable for the growth of the fungus. After experiments were carried out in Malaysia, the technique was implemented on a large scale from 1974 using various herbicides or sodium cacodylate (Yussof-Azaldin and Rao, 1974). The method was adopted in Cameroon by using ethephon, a precursor of ethylene (Sénéchal, 1986), and later in Gabon using several active ingredients including ethephon at the rate of 3 litres per hectare diluted in 37 litres of water (Anonymous, 1995, 1996).

Figure 6 enables the comparison of the results of defoliation obtained with ethephon with that obtained in untreated plots in the case of a 10-year old clone, GT1. Natural defoliation is gradual and does not actually begin until around 15 February. It is incomplete, leaving about 20% of the foliage. In contrast, ethephon application provokes a sudden and almost total defoliation about one and a half months in advance of natural defoliation.

Figure 7 shows the percentage of trees in the process of refoliation, or having completed it, in both cases. Natural refoliation begins between 15 and 20 February and is 50% by 15 March, the beginning of the rainy season. Refoliation after ethephon treatment begins a little after mid-January and reaches 50% of the trees by 4 February, i.e., more than a month earlier than natural refoliation.

Trees whose refoliation commences three weeks before the beginning of the risk period are protected at a level that is sufficient for a good reconstitution of their foliage. Artificial defoliation ensures protection for 60% of the trees, whereas in the case of a natural cycle almost all the trees are exposed to attacks by the pathogen.

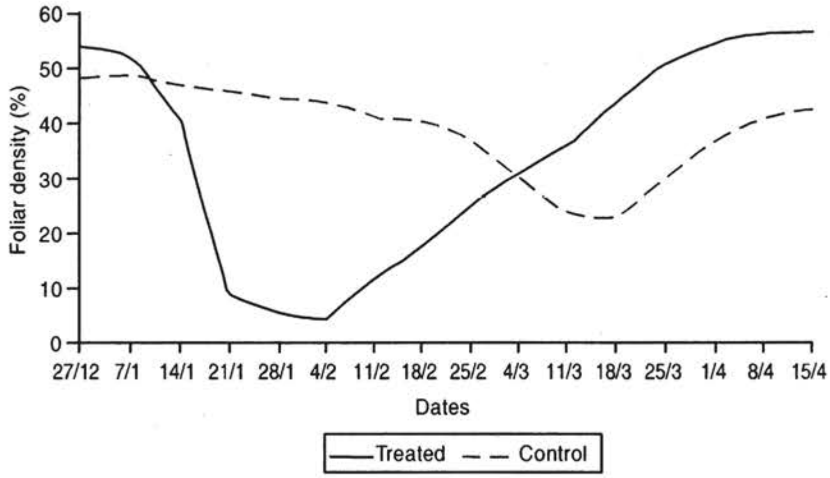



**Fig. 6.** Evolution of foliar density in hevea plots after artificial defoliation and without defoliation (from Guyot, unpublished)

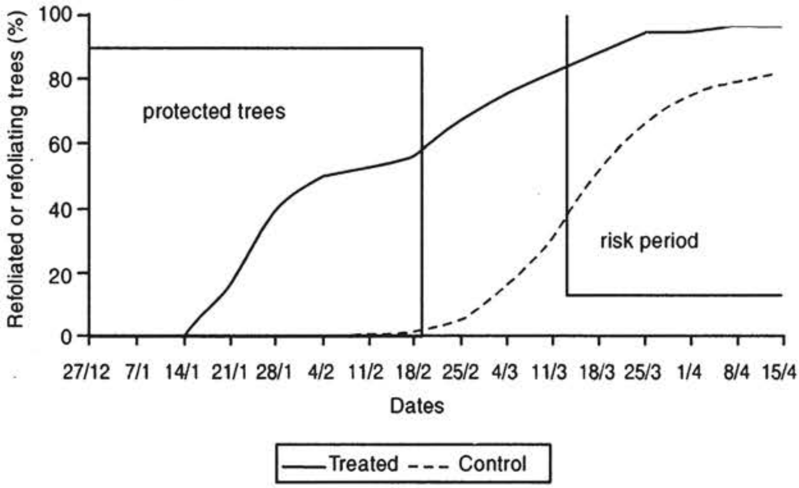



**Fig. 7.** Rate of refoliation in hevea plots after artificial defoliation and without defoliation (from Guyot, unpublished).

In the present case, evading the disease by early artificial defoliation enabled a gain of about 25% in the foliar density when compared to untreated controls in mid-April.

In some years the rains may arrive early, during the refoliation period of the treated zones, and may cause damage and reduce the effect of the expected escape. The variable behaviour of trees from one year to another also has an influence on the beneficial effect of the operation. Thus the example cited earlier corresponds to a period of poor natural defoliation. In 1994, natural defoliation was much more pronounced and the difference in foliar density between the treated and untreated was much more significant (60% compared to 25%).

The results also vary with the clones. Some lose their new leaves and give out new ones very quickly (PB235, PB217) and there may be a rapid increase in their foliar density in a single year. Others, such as GT1, have a much slower reaction and their foliar density improves only after several successive cycles (Fig. 8).

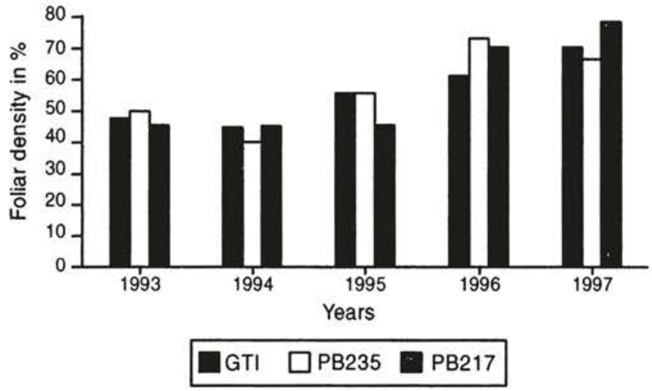



Fig. 8. Evolution of foliar density in a hevea plantation (from Guyot, unpublished).

Lastly, the age of the plots also exerts an influence in various ways, depending on the clones. GT1 is not very receptive to treatment in the immature phase while PB235 and PB260 respond very well to treatment with ethephon, even before they are exploited. However, in all these cases there is a significant gain in foliar density with repeated use of this method.

Escape control is therefore an original and effective solution to the problem of leaf anthracnose of hevea. At the same time it also provides protection against damage by *Oidium* which may erupt with great force in June and July on susceptible clones such as PB235 if refoliation is still underway during this period of the year.

In Malaysia, the results of this treatment have shown considerable gains in the short term and the technique is considered to be economically very viable (Yussof-Azaldin and Rao, 1974).

## Coffee berry disease

Anthracnose of Arabica coffee berries or coffee berry disease, caused by *Colletotrichum kahawae*, is found mainly in production zones at high elevations, where the climatic conditions are cool and humid (above 1000 m). Considering the important losses it causes and the fact that it is not possible to offer commercial varieties with satisfactory field resistance characters on a large scale, chemical control remains indispensable.

## Chemical control

The main fungicide currently used is copper, often associated with chlorothalonil, despite the risks of phytotoxicity during the first treatment with copper-based solutions (Muller, 1978). Other fungicides belonging to the dithiocarbomate, benzimidazole and triazole families are also available in the phytosanitary market.

In regions where only coffee berry disease is present, copper treatments were complemented by treatments with organic fungicides, which are more effective but also more expensive, for example, captafol (which has now been withdrawn from the market due to its toxicity to humans) and systemic fungicides such as benomyl, dithianon and carbendazime. However, the appearance of tolerance to large doses of benomyl and carbendazime, due to intensive use of these molecules in treatment programmes, has reduced the range of active ingredients and the possibilities of alternation or combination. The resistance acquired by the pathogen has been found to be very stable, even when there is no selection pressure by a fungicide.

In regions where coffee berry disease coexists with coffee rust, the organic fungicides are mixed with cupric compounds. Application of these mixed treatments is widespread in East Africa. In Kenya the main mixtures associate chlorothalonil or manebe with copper with an average consumption per treatment being 7 kg of the commercial product per hetare.

Whatever the type of fungicide used, the plan of action is an important factor that will dictate the efficiency of plant sanitary protection measures. In Cameroon, post-flowering treatments covering the period of susceptibility of the berries have been the basis for planning the calendar for treatments since 1959 (Muller, 1964; Muller and Gestin, 1967). Susceptibility of the fruit varies during its development; after a phase of low susceptibility, which extends until the sixth week after flowering, the fruit becomes very susceptible between the eighth and twelfth weeks. This susceptibility disappears after the enlargement phase of the fruit, i.e., about twenty weeks after flowering. Figure 9 shows the position in time and qualitative evolution of the infection (curve A), loss (curve B) and susceptibility index of berries (curve C) when flowering is natural (F2), which was on 1 March. For early flowering (F1) induced by irrigation in early January, the positions in time and evolution of the susceptibility index of berries are represented by curve D for normal growth and curve E for accelerated growth. It can be seen that due to the gradual production of the inoculum, it is very low when F1 berries are most susceptible and then becomes increasingly abundant, ensuring severe infection of F2 berries.

The coincidence of the phase of maximum susceptibility of berries with the period of heavy rainfall, which is conducive for the growth of the fungus,

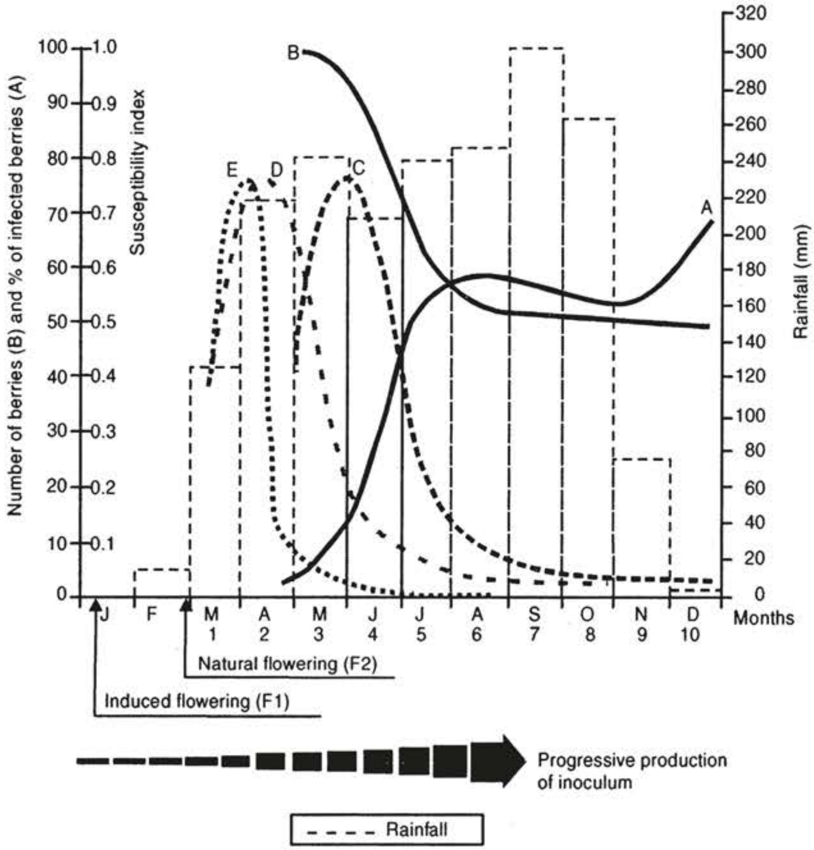



**Fig. 9.** Coffee berry disease: evolution of the infection (A), total number of berries (B), susceptibility of berries to flowering date (C, D, E) (from Muller, 1978).

makes this disease devastating. The first operation should be carried out after fruit-setting. Afterwards the number and rhythm of treatments would depend on the rainfall regime encountered: a single rainy season in regions with a tropical type of climate as in the Arabica-growing zone in Cameroon; or two rainy seasons per year in regions with an equatorial type of climate as in Kenya, each yielding a production and the two productions overlapping and mutually contaminating one another. Similarly, the nature of the fungicide used determines the rhythm of the applications. If copper fungicides have to be applied every two weeks in regions with heavy rainfall, systemic or penetrating organic fungicides help to space the treatments every three weeks under the same conditions.

In Kenya, the permanent presence of two populations of berries on the trees, each one the result of one of the two flowerings and a source of contamination for the other, gives rise to strong inoculum pressure. The number of treatments required is therefore more than twelve per year. This protection is provided by using a combination of organic and cupric fungicides.

In Cameroon, taking into consideration the annual rainfall regime encountered and the nature of fungicides used, the number of treatments required varies from five to seven per year (Table 4). A treatment calendar was determined experimentally. Irrespective of the type of fungicide used, the first treatment is fixed two weeks after the main flowering in order to provide preventive protection to the very young fruits before they reach the susceptibility stage. The second treatment should be carried out five weeks after the first and the third treatment four weeks after the second. Afterwards the rhythm of the treatments to be followed should take into consideration the nature of the fungicide used, becoming increasingly frequent with increase in the intensity of rainfall.

This treatment programme helps to provide protection until the twentieth, or even twenty-second week of fruit development, which corresponds to the end of its period of susceptibility. In regions with a high rate of infection, where losses of up to 80% have been recorded in the absence of treatment as in Cameroon, applications of organic fungicides following this calendar have helped to reduce the losses to about 30% (Berry *et al.*, 1991).

The most widely used mode of application is spraying a high volume. In fact, it is necessary to use 0.8 litre per coffee plant and per treatment. For one hectare of 1200 coffee plants, nearly 1000 litres of the mixture per treatment is therefore applied, which is about 5 kg of the commercial product. Considering the high cost of the fungicides required for chemical control, it can be implemented only in plantations that are sufficiently productive and enjoy a favourable economic situation.

At a cost of 1000 CFA franc per kg for the planter, it is estimated that five treatments with a penetrating fungicide would mean 200 to 250 kg of coffee for the market. Treatments are therefore viable only above a potential production of 500 kg per hectare.

## Control by cultural techniques

In order to optimise chemical control, elimination of identified or potential

**Table 4.** Treatment calendar for controlling coffee berry disease in Cameroon, depending on the nature of the fungicide used

| | Contact fungicide (7 treatments) | Penetrating fungicide (5 treatments) |
|---|---|---|
| First treatment | 2 weeks after flowering | 2 weeks after flowering |
| Second treatment | 5 weeks after the first | 5 weeks after the first |
| Third treatment | 4 weeks after the second | 4 weeks after the second |
| Fourth treatment | 3 weeks after the third | 4 weeks after the third |
| Fifth treatment | 2 weeks after the fourth | 3 weeks after the fourth |
| Sixth treatment | 2 weeks after the fifth | — |
| Seventh treatment | 2 weeks after the sixth | — |

sources of the inoculum, such as infected berries from earlier harvests, whether overlapping or not, can be envisaged (Table 5; Muller, 1978). In fact, harvesting is often imperfect and the quantity of unpicked fruits can be as much as 20%. Besides, in countries with a single annual harvest, sporadic out-of-season flowering may result in the presence of green fruits that could serve as relays for the parasite.

**Table 5.** Percentage of infected berries compared to the total number of berries in the plot

| Blocks | Plots in which interseasonal and infected berries had been removed | Control plot |
|---|---|---|
| A | 9.43 | 21.01 |
| B | 2.96 | 25.83 |
| Average | 6.20 | 23.42 |

Significant differences with P = 0.01.

In the case of family labour or low expenses and during a period when coffee harvest is good providing a good income, removal of these leftover berries could be a good prophylactic measure to adopt. Although some countries have encouraged this measure, its effect has been very limited.

Disease control through irrigation was experimented with in Cameroon (Muller, 1978; Fig. 5.9). This mainly involves supplying water to the plants one to two months before the onset of rains in quantities adequate to artificially induce flowering and then ensure normal growth of the young fruits with normal water supply. This shift in the production cycle enables these young fruits to grow during the dry season and thus reach their stage of maximum susceptibility during a climatic period that is unsuitable for the activity of the pathogen.

This method thus helps to delay the onset of the epidemic and to control the disease. Moreover, it also allows the expression of the productive potential of the plant and ensures increased growth of branches. All the advantages of this method combined ensure a consistently high level of production, avoiding the uncertainties of flowering (dropping off, failure of flower buds to open, etc.) and could be integrated into current agronomic practices. Unfortunately, this method also has the disadvantage of stimulating attacks by rusts, which can however be controlled by 2 or 3 applications of fungicides. Although early irrigation makes it possible to control coffee berry disease with a lesser number of chemical treatments, it has still not been adopted by planters, mainly because of the difficulties encountered in the context of poor economic viability.

Considering the agronomic challenge this technique represents, land management practices should be envisaged.

## Anthracnose of mango, avocado and papaya

Control of *C. gloeosporioides* is mainly through blockage of resumption of growth by the parasite following the latent period. This can be done in two ways.

The aim of pre-harvest treatments is to reduce inoculum pressure. Generally speaking, this is done between flowering and harvesting and is a pledge for the efficiency of post-harvest treatments (Mourichon, 1987).

Post-harvest treatments are obligatory to inhibit all the developmental stages of the fungus present on the fruits at different times during the course of their maturation: germination of conidia in the case of late contamination of fruits (just before harvest), formation of appressoria, formation of penetration hyphae, resumption of growth by the parasite at the end of the latent period. The work of Laville (1994) may be referred for this particular aspect of fruit conservation.

Data on pre-harvest treatments is very limited. The best active ingredients for mangoes as well as avocados were found to be: mancozeb (3.5 kg active ingredient in 1500 litres per hectare); maneb (3.5 kg of active ingredient in 1500 litres per hectare); chlorothalonil or Daconil (2.2 kg active ingredient in 1500 litres per hectare); copper oxychloride (2.5 kg active ingredient in 1500 litres per hectare); benomyl (400 to 600 g active ingredient in 1500 litres per hectare).

It would be interesting to add propiconazole (Tilt) to this list. It is not used much but has been found to be particularly effective in doses of 200 to 250 g active ingredient per hectare. Besides, in many cases the efficiency of treatments is improved with the addition of a wetting agent to the fungicide suspensions.

Treatments are carried out in a systematic manner right from fruit-setting on a monthly rhythm during the dry season and bi-monthly during wet periods. Among the contact fungicides, mancozeb appears to be the best active material at present and the most interesting results were obtained when it was used in rotation with benomyl, which is a systemic fungicide. The interest in using the latter, similar to using propiconazole, is that it reduces the risk of leaching during rainy periods. The economic importance of this control method has been well demonstrated in the case of anthracnose of avocado (Cottin, 1987).

Lastly, it must be borne in mind that the role of these pre-harvest treatments is to reduce inoculum pressure and to see if they can act, as stated earlier, on certain stages in the infection process after contamination. However, they will prove to be really effective only if they are associated with more standard cultural techniques aimed at reducing multiplication of the inoculum or facilitating the operations inherent to treatments: pruning the trees so that they do not grow too big in size and enabling treatment of all the vegetative parts; removing all necrotic twigs and branches, which are usually the bearers of primary inoculum, in the month before flowering; thinning to provide good aeration.

### Coffee rust

Development of a control method for coffee rust is based on thorough knowledge, to the extent possible, of the epidemiology and harmful nature of the disease. Various factors, favourable as well as unfavourable for development of the rust, were therefore studied.

#### Rainfall

It is considered that 5 mm of rainfall are necessary for the liberation of urediospores. Water is also necessary for their germination and entry into the leaf through the stomata. Hence it is after the onset of rains that the epidemic begins to develop and attains its peak at the end of the rainy season (Avelino *et al.*, 1991).

#### Temperature

The optimum temperature for the germination of urediospores is 22-23°C (Nutman and Roberts, 1963). If sunlight is strong, growth of the fungus inside the leaf may be totally inhibited. This link to temperature explains the inversely proportional relationship between disease incidence and altitude which has been reported in Mexico and Guatemala (Fig. 10).

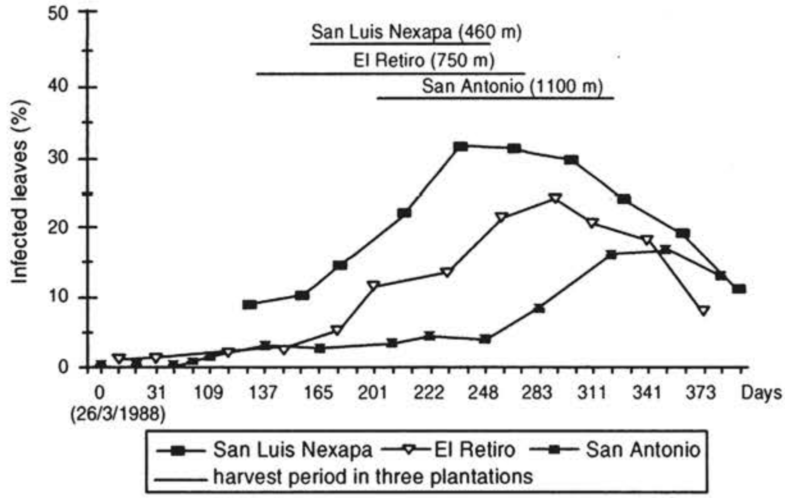
#### Fruit load

Eskes and Souza (1981) showed In Brazil that the receptivity of leaves varies depending on the fruit load. This relationship was verified in Guatemala by Avelino *et al.* (1993; Fig. 11). The influence of fruit load on the receptivity of leaves in the plot explains the biennial nature of coffee rust epidemics observed in a number of Central American countries, which keeps up with the distribution of production.

## Residual inoculum

The residual inoculum, conserved on infected leaves that have survived the dry season, is undoubtedly the main source of primary inoculum (Avelino *et al.*, 1991). In Cameroon, epidemics were more severe in irrigated lands because of the early resumption of sporulation from old lesions (Muller, 1978). Avelino *et al.* (1995) reported that in Guatemala plots, that received the best copper treatment in 1991, and hence retained more leaves than the control plots, were attacked earlier in 1992.

In production areas where a very pronounced dry season separates two operations, heavy defoliation was observed and consequently the disappearance of a large proportion of old rust-bearing leaves. The quantity of inoculum at the beginning of the rainy season is therefore considerably reduced, thus delaying the onset of the epidemic, which does not however greatly affect the year's fruit production because it reaches its peak very late. Defoliation therefore appears to be a true regulator of the epidemic.



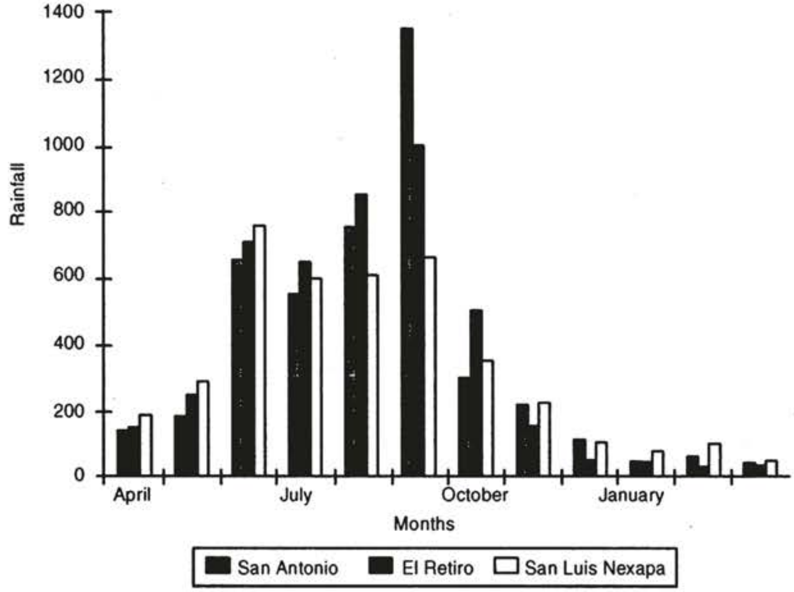




**Fig. 10.** Evolution of the percentage of young leaves of coffee plants infected by orange rust in three plantations in south-eastern Mexico (from Avelino *et al.*, 1991).

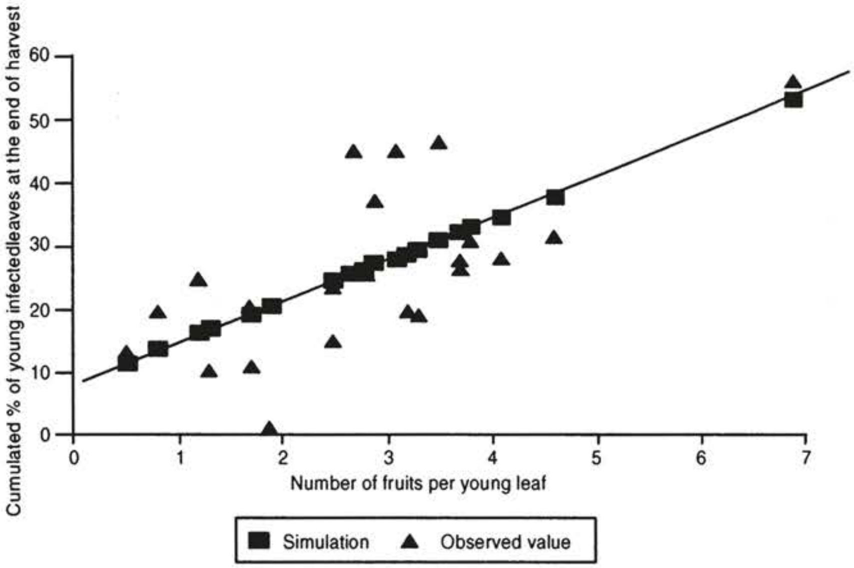



**Fig. 11.** Effect of fruit load on coffee rust (from Avelino *et al.*, 1993).

## Disease development inside the tree

An epidemic has been described as a centrifuge (Avelino *et al.*, 1991). The pathogen progresses gradually from old leaves and inside the plant towards the outer leaves and from lower parts to the higher parts (Fig. 12). It was shown that 60% of the physiological activity of the plant comes from the leaves at the tips of the branches, which represent just 25% of the total leaf area (Gaubiac, 1988). Attacks on these young leaves are mainly responsible for the severity of the disease.

## Harvesting period

In Mexico it was observed that the onset of the epidemic coincided with the beginning of the harvest and that it accelerated when the harvest was well underway, the infection reaching its peak at the end of the harvesting period (Avelino *et al.*, 1991; Fig. 10). In this case, the lateness of the epidemic explains the fact that the disease does not damage the yield of the current year. However, the disease generally peaks before harvesting and hence affects this harvest.

## Risk areas

To complete the factors mentioned above, other parameters such as soil, cultural practices, number of harvests, plant vigour, density of the plantation, etc., no doubt have an influence on the development of the epidemic. A study conducted in the Honduras helped to establish a preliminary hierarchy of all these factors according to their importance, for a better definition of the

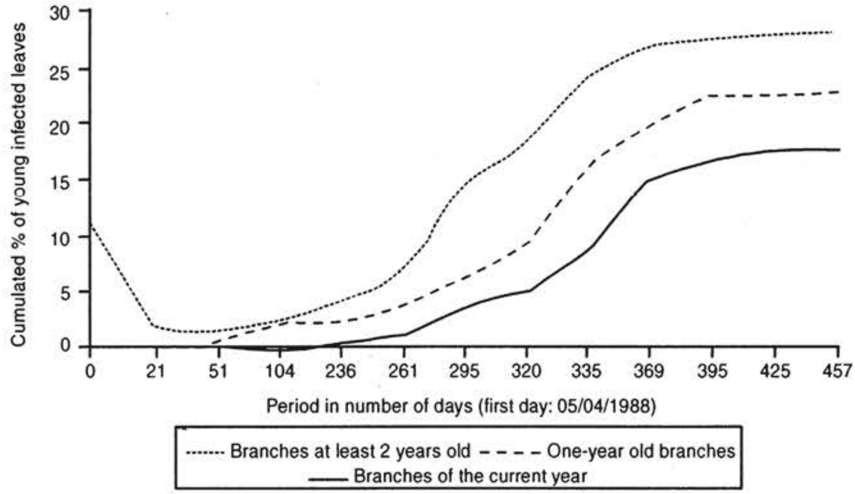



**Fig. 12.** Development of coffee rust over time according to the position of branches on the plant in a plantation situated at an elevation of 730 m (from Avelino *et al.*, 1991).

advice to be given to planters in terms of chemical control applications, which have still not been precisely formulated (Avelino *et al.*, 1997).

### Damage assessment and chemical control

The delayed action of disease incidence from one year to another and the large number of variables of a physiological nature involved in leaf-fruit relationships, make it difficult to assess the damage. Secondary losses due to the reduced growth of branches of defoliated coffee plants should also be taken into consideration. In Guatemala it was estimated that the loss in production in 1991, correlated with the infection and production of the preceding year, was about 20%, thus justifying the cost of chemical control (Avelino *et al.*, 1993). This consists of three sprayings at intervals of two months with a copper oxide based fungicide containing 50% metallic copper (0.35% concentration) for effective control in ecological zones favourable for the disease. Among the systemic fungicides, triazoles such as cyproconazole and hexaconazole are particularly efficient (Toledo *et al.*, 1995). Using such fungicides in the first spraying should limit the number of copper sprayings to just one.

## Conclusion

Although the appearance of coffee rust in Latin America did not have the devastating effect that one had feared, implementing a control method is indispensable in certain situations (Muller, 1971).

Studies are continuing but have still not been able to propose cultural practices that would enable passage from a high-risk domain to one of lower risk. Nevertheless, in the current state of our knowledge they are of great interest in determining the modalities for establishing chemical control methods.

### Coffee grey rust

Applications of copper fungicides (copper oxide titrating 50% of 0.5% metallic copper) were found to be efficient with three sprayings per year with a month's interval in between, the first one being done one month after the onset of rains (Muller, 1975).

### Other aerial parasites

#### Cercosporiosis of oil palm

Chemical control is found to be the most efficient method against cercosporosis of oil palm. Renard and Quillec (1983) showed that in the nursery chlorothalonil and fungicides containing maneb and methylthiophanate or carbendazime ensured very good protection against the disease, better than that of benomyl and methylthiophanate alone.

The efficiency of a treatment depends more on the frequency of applications than on the amount of fungicide applied.

Certain agronomic conditions may however favour disease development. Water stress predisposes the plants to cercosporiosis. In the nursery or in the field, the disease is aggravated by shocks suffered during transplantation and should therefore be avoided. Generally speaking, disease incidence is reduced as soon as good cultural practices are adopted (especially watering and fertilization).

#### Witches' broom disease of cocoa

It must be remembered that it is only through selection of resistant plant material that we can fight effectively against witches' broom disease of cocoa. Chemical control is not recommended at present because of the high cost and intense labour required. Fungicide applications have never given good results for controlling witches' broom disease in the field because it is difficult to effectively protect young expanding plant tissues and also because of the lack of a fungicide which can control the growth of mycelium within the tissues.

Experiments with monthly applications of copper based fungicides helped to reduce the loss in cocoa pods and number of brooms produced on the island of Trinidad. However, the same treatment in Ecuador did not have any significant effect on pod loss.

Within the framework of a project undertaken by CIRAD in collaboration with the Cocoa Research Unit (CRU) of Trinidad and Tobago, a method was developed for the disinfection of contaminated cocoa beans, especially for the preventive protection of the beans against witches' broom disease (Ducamp, pers. comm.). Two systemic fungicides gave 100% healthy seedlings from cocoa beans inoculated with *Crinipellis perniciosa*. The two fungicides are Moncut (active ingredient: flutolanil) and Bayleton (active ingredient: triadimefon).

Very encouraging results were also obtained in the nursery in experiments on protection of young seedlings using these two fungicides for a period of almost two years. None of the young plants was contaminated despite repeated periodic inoculations. It therefore seems possible to protect young cocoa seedlings from attacks by witches' broom disease by treating the cocoa beans, followed by periodic applications of these two fungicides (Moncut and Bayleton) before and after planting them. In this way the seedlings are protected from infections during the most critical stage of their development. In fact infection of the apical bud of a young seedling eventually results in disturbed growth, which could lead to death within a more or less short period of time. Moreover the transfer of cocoa beans treated with these two fungicides from a country contaminated by witches' broom disease to a country free of this malady appears to be possible, but after maintaining a period of observation in the country of arrival (see the chapter on Healthy plant material and certification).

Control of witches' broom disease during the first two years therefore seems possible but afterwards the use of these two fungicides in the field is no longer viable. Phytosanitary pruning may reduce the quantity of primary inoculum and the degree of infection, but it cannot by itself eradicate the pathogen; moreover, it is very expensive in terms of labour required.

A recent study has shown that for this pruning to be more effective, it should be done at the green broom stage. At this stage the fungus has not yet produced chlamydospores at the base of the broom the way it can at the necrotic broom stage. Pruning at the latter stage may leave behind tissues containing these chlamydospores at the base of the broom. These will germinate as soon as the meristems of new shoots grow, giving rise to a new infection. A highly infested tree should be pruned during the dry period so that the new shoots are not infected by the basidiospores of the fungus, as they are absent during this period.

## American leaf spot of coffee

Researches undertaken by CIRAD on chemical control of American leaf spot of coffee favoured the use of fungicides such as Bordeaux mixture (calcium hydroxide and copper sulphate) as a preventive measure, whereas earlier recommendations were essentially of a curative nature (Avelino *et al.*, 1992). Systemic fungicides such as triazoles, which are highly specific in their mode of action, run the risk (if they are used alone or improperly used) of selecting fungal strains that are resistant to them.

Studies carried out in Canada showed that the fungus enters the leaf thanks to a toxin, oxalic acid, which is inhibited by calcium (Tewari, 1990). In order to combine the properties of calcium with the fungistatic properties of copper, an alkaline mixture loaded with calcium hydroxide was prepared and successfully tested in Guatemala (Avelino *et al.*, 1992). The alkaline nature of the mixture also helps to increase the persistence of the fungicide on the leaf, a quality that is not evident when calcium hydroxide is used alone. At present it is this composition which is recommended and distributed throughout the country.

However, it must be stated that it is desirable to alternate systemic fungicides (cyproconazole and hexaconazole) in the first spraying and preventive fungicides in the following sprayings because of the influence of the residual inoculum.

The great dependence of the fungus on liquid water explains the fact that all cultural practices that lower the humidity in coffee plantations also result in reducing disease incidence. It would be difficult to cite all the cultural practices here, but the most common ones can be mentioned: regulating the shade (up to total elimination), line stumping, pruning, and weeding. The last practice also helps to eliminate the inoculum present on adventitious roots. The efficiency of these operations depends on the penetration of sunlight. For example, the success of cyclic stumping would depend greatly on the orientation of the coffee lines: east-west orientation is more favourable because it is this direction that enables maximum penetration of sunlight. The more favourable the climatic conditions for the parasite (heavy cloud cover, less daylight hours), the less useful these methods will be.

Although the efficiency of cultural methods is not absolute, it nevertheless helps to optimise chemical control. In Guatemala, it was observed that the rate of infected leaves was only 8 to 18% in coffee lines next to the lines that were stumped, while the maximum incidence reached 44% in coffee lines whose neighbouring lines had not been stumped (Fig. 13). Chemical treatments could therefore be applied only to these lines (Avelino *et al.*, 1992). It must be added that the technique of line stumping is favourable from an agronomic point of view and that it can be easily integrated with other methods practised by the planter. In places where American leaf blight is rampant, this method is preferable to selective stumping plant by plant which does not enable as good a penetration of sunlight, besides disorganizing the plantation.

## Moniliosis of cocoa

Some chemical molecules were found to be effective against the causal agent of moniliosis of cocoa plants, an important disease in Latin America. These are 0.75% chlorothalonil and 0.5% copper oxide (Trocmé, 1991). However, because of the tree's architecture, dispersion of pods and frequency of treatments, chemical control is still a difficult application. As with many other diseases, appropriate cultural practices help to either reduce the source of the inoculum (removal of infested pods as often as possible) or to modify the microclimate of the plantation so as to make conditions less conducive for the

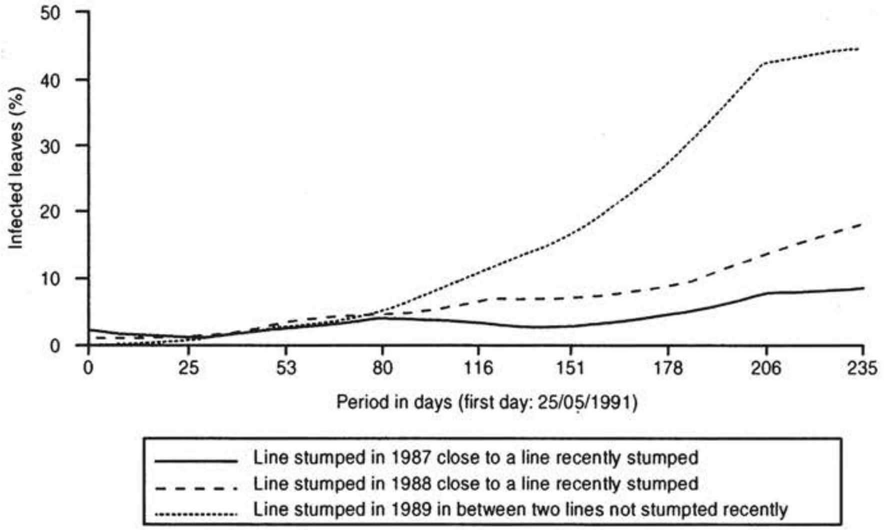



**Fig. 13.** Effect of line stumping on American leaf spot of coffee in a plantation situated at an elevation of 1200 m (from Avelino *et al.*, 1992).

growth of the parasite: drainage, weeding, frequent pruning, shade regulation (Barros, 1992, cited in Thevenin and Trocmé, 1996). However, these are only stopgap measures until such time as resistant plant material becomes available.

## Bacteria

Only bacterial diseases of leaves and fruits of citrus and mango are dealt with in this book.

BACTERIAL CANKER OF CITRUS

### Rational chemical control

*Xanthomonas axonopodis* pv. *citri* is capable of entering the tissues of citrus plants through natural openings (mainly stomata) and wounds under the influence of external conditions and physiology of the plant. Susceptibility of vegetative shoots to infection depends on their developmental stage. This variability in susceptibility is related to the structure of the stomata and development of the cuticle.

Shoots are most susceptible to *Xanthomonas* when the size of the leaves is 50-80% of the adult size. The presence of free water is essential for infection to take place and, in practice, infection through stomata can be produced with suspensions containing at least $10^4$ to $10^5$ cells of *Xanthomonas axonopodis* pv. *citri* per ml. Infection of fruits through stomata is possible 2 to 3 months after the fall of petals (Vernière, 1992; Vernière *et al.*, 1992). All these data on the relationship between the susceptibility of citrus to bacterial canker and their phenology have been used as the base for developing a programme for rational treatments.

Wounds enable infection by *X. axonopodis* pv. *citri,* whatever be the phenological stage of the organs. These injuries may be caused during maintenance operations in orchards and nurseries or by insects such as citrus borer (*Phyllocnistis citrella*) and wind.

Chemical treatments therefore include combinations of copper compounds with preventive anti-bacterial action and insecticides (diflubenzuron, deltamethrine, abamectine, flufenoxuron, imidaclopride and malathion) with a view to controlling attacks by borers in countries where they are present.

### Cultural techniques

Sprinkler irrigation is highly favourable for the development of bacterial canker. Moreover, dissemination of the bacteria is most often associated with certain climatic phenomena (rainfall associated with wind speeds of more than 7 to 8 m per sec) and maintenance operations in the orchard. These observations serve as the basis for defining technical methods that are less favourable for the development of the disease: setting up a localised irrigation system at the base of the trees; installing an efficient network of windbreak hedges all round the orchard; proscribing maintenance operations in the orchard as soon as the foliage of the trees becomes wet; regular phytosanitary inspection of the orchard; removal of infected twigs and branches by pruning (the cut parts should be burnt). All the implements used in pruning operations should be disinfected.

#### BLACK SPOT DISEASE OF MANGO

The above recommendations are also valid for black spot disease of mango (*Xanthomonas* sp. *mangiferaeindicae*).

## CONCLUSION

Cultural techniques as a preventive measure combined with the use of pesticides as local applications are very effective in controlling rots.

Preventive and curative chemical control is still indispensable in certain cases such as anthracnose of fruits and coffee berries and *Phytophthora* diseases in general.

It is generally recommended to complement these treatments with cultural control methods. At least in coconut and cocoa plantations, these methods involve reducing the source of inoculum by removing the infected fruits or by making the environment less favourable for the development of the pathogen, mainly by lowering the humidity.

For controlling the swollen shoot disease of cocoa in West Africa, an array of protection measures can be adopted to check the spread of the infection and the epidemic (destruction of the host plants of the virus and insect vectors as well as the infested cocoa trees, planting non-susceptible plant barriers around the cocoa plantation, anti-bug treatments).

Thanks to these control methods it is possible to considerably reduce the incidence of a number of diseases, but their application is usually difficult and onerous in terms of both material and labour. Considering the impact of diseases and poor cultural practices, these methods are preferred in plantations that are not very productive and in which the profits cannot offset the cost of chemical control operations. However, in many cases they enable us to wait until resistant plant material becomes available.

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