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Diseases of Tropical Tree Crops

Scientific Editor
Dominique Mariau

CIRAD

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CIRAD
Centre de coopération internationale en recherche agronomique pour le développement, France

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Foreword

Forty years of research and control of the most serious diseases affecting the major tropical tree crops are encapsulated here! Too long a period from the viewpoint of the evolution of socio-economic contexts, practices, methods and techniques, but the minimum or nominal for one or two crop cycles, rarely more. How to durably protect a resource essential for the economy of a number of developing countries from threats posed by diseases? This book deals precisely with this problem.

By compiling this impressive synthesis of studies, many of which are still unpublished, the authors have not only produced a compendium on diseases of tropical tree crops, but also provided an approach whose usefulness needs no demonstration: purposeful research proposing the scientific approach necessary for agricultural application, based on practical situations encountered in the field.

Moving clearly away from academic studies, D. Mariau and his collaborators do not propose an encyclopaedia of tropical pathogens. By avoiding the standard monographic presentation by species, they have shown how a thematic presentation can lead from a preliminary diagnosis to basic knowledge on the life-cycles of parasites, and implementation of protection strategies adapted to technical and socio-economic contexts in real situations.

The novel presentation, easy reading and willingness to consider application of the results are certain to attract protectors of perennial crops, be they researchers, technicians or producers.

Beyond the banal compilation of information on diseases and control methods, what struck me most while reading the manuscript was its comprehensive presentation of knowledge and methods, with hallmark beginnings of a reflection on integrated protection of perennial crops.

In this sense this book constitutes a reference base, similar to the one in insect pests* , on which new domains in the evolution of sciences can depend, be it cellular and molecular biology or sociology of agricultural practices, to obtain efficient and durable protection systems.

Michel Dron
Scientific Director, CIRAD

*D. Mariau (ed.). 1966. Integrated Control of Pests of Tropical Perennial Crops, Repères, CIRAD, Montpellier, France, 196 pp.

Preface

For several decades, plant pathologists of renowned research organisations (IRCC, IRFA, IRHO, IRCA, CTFT), amalgamated into CIRAD since 1985 (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), have been studying the major diseases of tropical perennial crops, viz., avocado, coffee, coconut, hevea, mango, oil palm, papaya and tea, sometimes in collaboration with entomologists and often with breeders. To these crops must be added citrus, which also grows in Mediterranean type of climate, and tropical agroforestry.

The results of all these studies, in both field and laboratory, have been published in a number of articles in CIRAD's publications, as well as in international journals. Vast amounts of data are contained in papers presented at scientific meetings or in reports that are not easily accessible and therefore forgotten. These results and information are of varied importance and the objective of this book is to bring together the most significant among them. For purely geographic reasons, some diseases have been little or not studied by CIRAD. To make coverage as exhaustive as possible, these diseases have nevertheless been listed at the end of the book along with some brief information and important bibliographic references.

Several presentation formats were considered. The one we have used, less classic than plant by plant study, appeared to be interesting for more than one reason. It helps to compare pathogen types, several of which affect different plants and could be the subject of similar control methods. This thematic presentation also enables a better demonstration of the great importance given by researchers to the characterisation of pathogens and selection of resistant plant material, which is an important control method for plant pathologists. To facilitate reading of this work, Chapters 1 and 4 ('Symptomatology and Economic Incidence' and 'Pathogens') contain recapitulative tables listing the major diseases of plants, their symptoms and causal agents, while a table summarising the control methods per plant and per disease and maps showing the global distribution of these diseases are given in the Annexure. Lastly, the general index can be consulted.

It is always salutary for researchers to review their work so that the reflection and investigations of tomorrow are based on a good synthesis of yesterday's studies. It is therefore for them, their successors and their colleagues in other scientific organisations that the authors have made their contribution here.

This book was also written for teachers, and hence for their students, in such a way that their teaching can be supported by concrete examples taken from the field of tropical agronomy.

Lastly, the authors have also given thought to users in the wider sense of the term, because the vocation of CIRAD is to take the results of their research up to the agriculturist. In this book they will find that in the great majority of cases, solutions are offered—even if they are sometimes only provisional—for solving their problems concerning protection of their plants against diseases.

In the field of chemical control, recommendations for use of various pesticides should naturally be adopted in accordance with the phytosanitary regulations of each country and adapted following the advances made in their knowledge over the years.

We cordially thank Dr. M. Dron, Professor of Phytopathology and Scientific Director (CIRAD) for writing the foreword. We wish to express our gratitude to Drs. R.-A. Muller and E. Laville (Honorary Scientific Directors of ex-IRCC and IRFA) for reviewing the book and offering suggestions. Their wide knowledge, especially in the domain of the pathology of the plants studied by these institutions, was an important input for this book. Dr. J. Meunier, Deputy Scientific Director of CIRAD, after a long career at IRHO, and Dr. J.-C. Follin, Plant pathologist at CIRAD, also reviewed the manuscript. We are grateful for their invaluable comments. We also thank Drs. M-L. Caruana, M. Grisoni, M. Delabarre, O. Pruvost, J-M. Thevenin and Tran van Canh for their contribution.

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Introduction

Dominique Mariau

ECONOMIC IMPORTANCE OF TREE CROPS

During the last few decades, the cultivation of tropical tree crops has expanded extensively not only in Asia, but also in Africa and Latin America, generating a substantial revenue for these countries. To mention just a few examples: in 1997, in the Indo-Malaysian peninsula, about four to five million hectares were under oil palm cultivation, representing ten times the area planted in the early 60s. In 1996, the Ivory Coast produced more than one million tons of cocoa beans, i.e., twelve times more than the production thirty years earlier. In 1990, with a production less than the current production, cocoa represented 40% of the agricultural exports of this country. During the same period, coffee production in Colombia was nearly one million tons, representing almost 50% of the agricultural exports of the country. With a citrus production of one million tons, Morocco can expect a revenue of 1.3 billion dirhams corresponding to 20% of the food exports of this country. All these crops constitute the basic resources of tens of millions of families throughout the world.

In the majority of the cases, the wide expansion of these crops is at the expense of forests which have been too extensively and too rapidly exploited. In the last few decades, tens of millions of hectares of forests have disappeared in the tropical zones, and the reconstitution of a forest park, similar to that which could be done in some European countries in the twentieth century, would require considerable input from specialists. These pioneering fronts are being abandoned in several countries. It would be advisable to engage in replantation with plant materials which are more productive and more resistant to such and such disease, as has been done, for example, for oil-palm, instead of going in for new land clearing for cultivation. Moreover, the carrying capacity has often led some planters to embark on an intensification programme, enabling them to improve the competitiveness of their plantation.

IMPORTANCE OF PLANT SANITATION

At the global level, it is very roughly estimated that about 30-50% of the plant production managed by man is destroyed before or after harvest by insects, diseases and weeds. Data are available for some major annual crops. To cite just two examples: 30% of the global production of rice, i.e., the equivalent of 300 million tons, is lost and we are quite aware of the impact of diseases and weeds on this crop. Similarly, the wheat lost is around 150 million tons, corresponding to three times the production of France.

Similar statistics are not available for tropical tree crops. However, we can cite a few figures which show the magnitude of the havoc caused by certain diseases. The lethal yellowing disease of coconut destroyed more than 5 million trees in Jamaica, while the *cadang-cadang* disease destroyed 12 million trees in the Philippines. Also, 150 million cocoa trees affected by the swollen shoot disease had to be uprooted in Ghana.

Ravaging insects can kill a tree, especially when it is young, as is sometimes the case with *Oryctes* (Coleoptera, Scarabaeidae), one of the major destroyers of coconut. However, most often the impact of insects as ravagers is only on production, either directly by attacking the fruits, or indirectly by reducing the foliar surface or weakening the plant. The situation is quite different when it comes to insect vectors of diseases, but that is a special case.

The effects of diseases are much more harmful. They may directly affect the fruits which, at the global level, is the case with the brown rot disease of cocoa pods, or they may affect the foliage, as in the case of *Phaeoramularia* cercosporiosis of citrus, with direct or indirect incidence on the production or plant growth.

In a large number of diseases, the irreversible evolution of symptoms leads to the death of the tree and these losses may extend over vast areas. Such is the case of the disease called heart rot of oil palm in South America which has wiped out, or greatly endangered, a large number of plantations over several thousand hectares in at least five countries. Before the development of tolerant plant material—most probably the only solution to this problem—this disease greatly restricted the development of oil palm cultivation in many regions as investors could not take ill-considered risks. The same is true in the case of citrus greening which is a major problem in Asia and continues to spread in Africa.

Similarly, large rubber (*Hevea*) plantations were rapidly eliminated in South America after the Second World War. The cultivation of rubber is confined to zones that are often marginal and represents only a few thousand hectares in the whole of South America compared to the millions of hectares in South-East Asia. Such vast areas could have been planted in the greater Amazon region (which is after all the area of origin of *Hevea*), but the presence of the fungus *Microcyclus ulei* has prevented such expansion until now. This example shows that the presence of a disease can also have an indirect effect on production by limiting or even prohibiting the development of a crop.

Lastly, implementation of pioneer fronts and sedentarization of crops have resulted in stronger disease pressure, which often becomes a limiting factor at the time of replantation.

IDENTIFICATION OF PATHOGENS

Development of a control method first of all requires very good knowledge of the causal organism which has to be characterised precisely, first by its taxonomic position and knowledge of its life cycle, and then in a more detailed manner by using biochemical techniques such as enzyme electrophoresis, as well as molecular biology techniques for studying the genome. Species which cause a disease showing the same or almost the same symptomatology in all the countries, could exhibit an extremely variable degree of aggressiveness. This is the case, for example, with *Phytophthora* disease of cocoa: the losses resulting from the disease caused by *P. megakarya* in Cameroon is unacceptable, whereas the damage caused by the fungus *P. palmivora* in the Ivory Coast is more tolerable. Similarly, for developing an appropriate control method it is important to know if the *Phytomonas* species observed in coconut trees affected by hartrot disease are the same as those detected on euphorbias growing in the same coconut plantation, and which should be eliminated if they act as storage hosts.

A consequence of the stopping of pioneering fronts and the sedentarization of crops is greater disease pressure, which is often a limiting factor during replanting.

VARIETAL SENSITIVITY TESTS

For a good number of diseases, we have recourse to the selection of tolerant or resistant plant material, which means conducting tests that are as quick, simple and precise as possible. Hence these researches often require good knowledge of host-parasite relationships. Considering the wide variability that can be observed among pathogenic organisms, it is very important that these tests are conducted outside cultivated zones in order to study the virulence of strains of different origins, operations that are naturally prohibited in producing countries. The results of these tests should of course be confirmed later in the field under natural environmental conditions, all the more because we are sometimes obliged to perform a test on a plant part which is not normally affected by the pathogen.

CONTROL METHODS

Whenever we speak of control methods, we think first of chemical control, and until very recently the use of chemical pesticides was widely favoured. Without ignoring the usefulness of these precious tools, researchers are striving very hard to restrict their spread in time and space and to retain only the least toxic and most specific active materials in the most appropriate doses in order to limit their impact on the environment as much as possible. The recommendation of a rational chemical control is now widely accepted.

With or without the support of chemical control, agronomists have worked a great deal on cultural techniques with the constant aim of limiting the impact of pathogens or modifying the environment in such a way that the physical conditions of the environment become unfavourable for the development of the pathogen.

In the domain of biological control, the means available to entomologists are much more varied than those available to plant pathologists. They can, for example, use indigenous or introduced parasitoid insects in order to regulate the populations of a ravager, favour the development of an entomopathogenic disease as specifically as possible, disturb insect behaviour by using certain substances, etc. In plant pathology, and especially in Mycology, we can envisage using a hyperparasitic fungus, but application of this method is still very limited. Nevertheless, it offers a path that should not be ignored.

The royal path of plant pathologists remains, with the cooperation of geneticists, the selection of more or less resistant plant material. However, this involves long term researches which, as we have seen, require good knowledge of the pathogens and perfecting tests to evaluate behaviour. Moreover, this material will be available only for future plantations and in the meantime the existing crops have to be protected, even if it is by means of provisional control techniques, without forgetting that in the domain of tropical perennial crops what is provisional could last a few decades. For some diseases, this selection process is obligatory, for example, fusarium wilt of oil palm in a number of cases in Africa, but tolerant plant material is available. It is the same for the foliar disease (leaf blight) of *Hevea* caused by *Microcyclus* in Latin America, but in this case planters have to still wait for some more years.

Due to the length of the vegetative cycle of tree crops, researches have to be conducted over a long period of time. Development of tests meant for measuring the resistance of varieties to pathogens should often be made on plant parts in order to avoid cluttering, which are not necessarily affected under natural conditions. Furthermore, the permanence of the crop leads to a quasi-constant selection pressure of the pathogenic organisms which could theoretically circumvent resistance more quickly than with an annual crop. The stability of resistance is therefore of very great importance. Acquiring it necessitates long and delicate studies on the genetic determinism of host resistance as well as on the diversity of pathogen populations.

Plant pathologists thus have a certain number of means at their disposal for controlling the numerous diseases affecting tropical tree crops. Perfecting the most appropriate method requires very long and extensive researches in the field as well as in the laboratory, which should be carried out in perfect harmony.

1

Symptomatology and Economic Importance

Jean-Luc Renard

The term disease applied to a plant expresses an abnormal state of the whole or a part of the plant due to the influence of the environment. Parasitic diseases, in contrast to physiological diseases which are caused by physical factors (especially soil and climate), are caused by the aggression of an organism which is both parasite as well as pathogen. This change, which may be temporary, permanent or fatal depending on the case, has the potential of becoming contagious and developing into an epidemic. This phenomenon is the result of direct contamination, gradually getting closer and closer, or through the mediation of a vector of the pathogen. Fungi, bacteria, phytoplasmas, trypanosomas, viruses, viroids and nematodes are responsible for causing the diseases presented in this work.

The tropical environment, with its hot and humid seasons, which may be more or less prolonged depending on the regions, is favourable for the development of parasites, especially fungi and bacteria. These organisms go into the resting stage in various resistant forms (chlamydospores, oospores, cysts, etc.) during dry periods. When the conditions become favourable again, the parasite resumes its activity and sporulates profusely. These spores are easily disseminated by wind and rain at a time when the plant is also extremely susceptible to infection (liquid water on the surface of the leaves, open stomata, etc.). In contrast to annual crops which are absent during a part of the year, perennial crops remain standing and constitute a permanent storage host of the parasites, which serve as the primary inoculum when infection recommences with the onset of rains, Regions without a real dry season are particularly favourable for the development of pathogens.

Symptoms of parasitic diseases are of various kinds: necrotic spots, rots, wilts, blights, etc. They depend on the type of parasitic activity and the part that is infected. Disease incidence on the production is variable. It depends on the part that is affected, intensity of the symptoms and the pathogenic ability of the causal agent organism. Death of the tree is the ultimate stage in the evolution of symptoms. It may be sudden or result from a slow and general decay. In both cases the damage caused to the productive capital is irreparable. Infection of fruits results in low yields and often changes the quality of the produce. Diseases of leaves and branches reduce the vigour of the plant and affect the yield. In some cases, repeated infections on the leaves weaken the plant and ultimately lead to its death.

Thus, the heavy investment made by the agriculturist by planting a tree crop, whichever it may be, could be quickly compromised or even wiped out.

This is why a planter should be specially vigilant with respect to the health of the crop, so that he can do everything possible to arrest the development of an epidemic at the right time. Moreover, he should ensure that the plant material selected by him has, as much as possible, all the characteristics for resistance to a disease present in the region under consideration.

The first part of this chapter will be devoted to the description of the various symptoms caused by pathogenic organisms on tropical tree crops. The consequences of the disease on the vegetative growth of the plant and on its production will be indicated in function of the symptoms expressed. Because of the diversity of the pathogens as well as of the concerned crops and for a coherent presentation, the affected plant parts are presented in the same order throughout this chapter.

GENERAL DECAY

These diseases inevitably lead to the death of the plant more or less quickly. All kinds of pathogens may be responsible for general decay.

Diseases caused by fungi

In the quasi-totality of cases, the pathogenic organism grows in the soil. It attacks the plant through the roots or is transported through the vessels which get blocked; nevertheless, it can still be transported to different parts of the plant.

Rot diseases

The causal pathogens have similar life-cycles and attack the roots and then the trunk of a large variety of trees.

White root rot of rubber tree

The name of this disease is derived from the white mycelium filaments or rhizomorphs which the fungus, *Rigidoporus lignosus* (Klotzsch) Imaz (Basidiomycetes, Polyporaceae), commonly called *Fomes*, produces in the form of a network on the roots and collar of rubber trees. It is possible to see this on an infected tree by clearing the roots and collar of the soil covering them. When the parasite is already well established in the woody part of the roots and base of the trunk, the rubber tree shows yellowing and shrivelling of the leaves (photo 1). The leaves turn reddish-brown before falling off. These symptoms are accompanied by unseasonal flowering. Sometimes the tree gives out new leaves which are smaller and lighter in colour than the leaves of a healthy tree. Defoliation is followed by a gradual wilting of the branches and death of the tree. Fruiting bodies of *Fomes* can be seen at the base of the trunk before the shrivelling of leaves and wilting of branches (photo 2).

These fructifications are in the form of semi-circular brackets, yellow to orange on the upper side and lighter in colour on the lower side. At this stage, the taproot and base of the trunk are partially or completely rotten and the tree falls down with the slightest wind.

Fomes is a root parasite on a large number of forest tree species. As soon as the forest is felled, the conditions become favourable for the growth of *Fomes* which invades the stumps of the felled trees. These constitute the primary sources of infection which infect the roots of the rubber tree. Infections by *Fomes* appear from the end of the first year of the plantation. The disease then gradually spreads from a diseased tree by the transmission of *Fomes* from infected roots to healthy roots. Once again, primary sources could be formed when the roots come into contact with infected stumps of forest trees.

Mortality increases every year, attaining a maximum towards the sixth year (6% annual mortality). A regression in the disease rate is then observed and the evolution of the disease becomes stabilised at about 1-2% mortality per year. The development of disease centres creates a clearing in the plantations, as a result of which the trees are easily broken by wind leading to considerable losses (Tran Van Canh, 1996) At the age of about twenty years, some infested plantations have no more than 200 trees per hectare, i.e., less than 50% of the trees planted initially.

Crack rot of rubber

Attacks by *Armillaria* on rubber are manifested by the flow of latex through deep cracks in the bark on the collar and base of the trunk (photo 3). The cortical epidermis becomes grey and dry and shows shallow cracks. Superficial scraping reveals black spots due to necrosis of the primary epidermal cork layers. The bark is reddish brown in colour and encloses a white mycelial mass intermixed with filaments of coagulated latex (photo 4). A white mycelial mass is also seen on the cortical layer.

When the infection is at an advanced stage, the foliage becomes yellow and takes on a reddish copper-red tinge. Defoliation follows and the branches become dry, eventually leading to the death of the tree (Guyot, 1997).

The disease is caused by *Armillaria heimii* (Basidiomycetes, Agaricales) which grows on the roots and taproot of the tree. The tree reacts to the infection by producing a mantle of irregular black rubbery substance that grows around the roots, amalgamated with the mycelium of the parasite. It is possible to detect the early stage of the disease by removing the soil covering the roots at the base of the tree (Michels, 1990; Petit-Renaud, 1991).

The economic impact of *Armillaria* on rubber cultivation is known only in the commercial plantations in Gabon, where the sanitary situation is regularly supervised. The annual infection rate between 3 and 5 years does not exceed 2.5% of the trees present and the mortality rate is only 2.1 trees per hectare per year. This represents just 10-30% of the total mortality due to rots, the most destructive causal organism being *Rigidoporus lignosus* (Guyot, 1997). In village plantations this rate seems to be higher but no precise data is available.

Basal rot of oil palm

Rot disease in oil palm is caused by a Basidiomycete fungus, *Ganoderma lucidum* (Leyss. ex Fr.) Karst. Depending on the advancing stage of the parasite at the base of the trunk, the palm exhibits a slackening in growth which is expressed by an accumulation of unopened leaves and sometimes the petioles of the lower still green leaves break, thus forming a kind of 'skirt' around the trunk. This disease can be recognised as soon as brown carpophores appear at the base of the trunk (photo 5). In the young stage, these fructifications are characterised by white protuberances on the surface of the trunk and evolve into brown brackets. The upper surface of these brackets is shiny and more or less dark, while the lower surface is white to whitish with a porous aspect. At this stage, the interior of the trunk is invaded by the mycelium of the parasite; the tissues have a more or less spongy consistency and become whitish or yellowish in colour.

The disease is found mainly in oil palm plantations in Indonesia and Malaysia. It also devastates plantations in Africa, the Democratic Republic of Congo, Cameroon and Nigeria. Symptoms have been observed in plantations established in forest clearings. The palms suffer considerable damage in the second and third generations. Under these conditions, the first manifestation of the disease could take place from the second year after replanting and the damage becomes devastating from the age of 10 years, sometimes with 50% of the palms infected or dead. An infected tree can survive and continue to yield for two to three years after the appearance of the first carpophores. However, it eventually falls down when the entire base of the trunk is invaded by the parasite. Umar Akbar *et al.* (1971) have reported the influence of mineral nutrition and plant material on the behaviour of oil palm faced with the presence of *Ganoderma*.

Besides field observations and their cartographic representation, the occurrence of *Ganoderma* can be estimated by remote sensing. By calibrating radiometric measurements, in liaison with agronomic parameters from the field and appropriate interpretation of Spot images, a satisfactory relationship can be shown between the percentage of dead trees and leaf area index

(LAI) and reflection measurements expressed as vegetation index (Naert *et al.*, 1990).

By eliminating as much dead wood (stumps, large roots) as possible before planting, preventive control against this disease is largely inspired by that which is practised in rubber plantations.

Rots on coffee, cocoa and tea

Several rots affect the roots of coffee, cocoa and tea plants.

Decaying symptoms on coffee plants, due to rot caused by *Clitocybe (Armillaria) elegans* Heim, are characterised by cracks in the collar and base of the trunk accompanied by longitudinal splitting of the roots. Mycelial fan-shaped patches develop under the bark and the cracks in the wood are invaded by thick xylostroma which are responsible for the splits observed. The fruiting bodies of the fungus arise mainly from the xylostroma at the base of diseased trees (photo 6). Shade trees such as *Albizzia malaccocarpa* are also infected by *C. elegans* (Muller, 1959).

On cocoa trees, white rot *(Leptoporus lignosus* or *Fomes)* has been observed in the Ivory Coast, whereas *Armillaria* attacks are seen in the northern (Blaha, 1982) and central (Blaha, 1989) parts of Gabon. Trees with infected taproots collapse suddenly; others show the characteristic radial fissures in the collar region preceding a general wilting of the foliage (photos 7 & 8).

As in all afflictions of this type, these attacks lead first to a fall in yield and then to the death of the sick trees. This results in the loss of the productive potential and investment.

A number of authors have reported the presence of rot disease on coffee plants in Africa. Blaha (1978) has proposed the measures to be adopted to reduce the incidence of rot on coffee cultivated at high elevations in Cameroon, viz., regular disinfection of the disease centres.

The polyphagic nature of these fungi complicates their control: before planting, it is suggested that a crop called "cleansing" crop be cultivated for several years, for example, a herbaceous species capable of completely decomposing the woody debris. It is also recommended that coffee and cocoa should not be planted after a rubber crop, nor in association with cassava.

Rot diseases are also common on tea (Bonheure, 1988). *Armillaria mellea* (Vahl) Pat. causes radial and longitudinal cracks near the collar and base of trunks, which are responsible for splitting of the wood and hence the name "collar crack" given to this disease.

White mycelial forming fan-shaped patches develop between the bark and wood and on the surface of the roots. The fungus is propagated mainly through the black rhizomorphs which can spread in the soil.

Rosellinia arcuata (Petch) can be recognized by the presence of a mycelial veil on the surface of the collar. The tea plant reacts by excessive growth of the bark forming a cushion-like structure and produces a large number of adventitious roots.

Other parasitic fungi such as *Phellinus lamaensis* (Murr) Heim, *Poria hypolateritia* (Berk), *Ustulina deusta* (Fr. Petrak), *Sphaerolstilbe repens* (B. Br.), are among the organisms responsible for root diseases of tea plants.

Phthiriasis or false rot of coffee, which presents itself in the form of a thick tube of crusty mycelium enveloping the collar, should not be confused with the "true" rot infections described earlier. This disease, which is linked to the development of bugs, is treated in the chapter on insect vectors.

Rots of tropical forest trees

Teak (*Tectona grandis*) is one of the most susceptible species to rot diseases. Attacks by *Rigidoporus lignosus* observed in teak plantations in the Ivory Coast are difficult to detect. The diseased trees usually fall down following a gust of wind or after a clearing done to accelerate the growth of the still standing trees (Mallet *et al.*, 1985). It appears that the tree, whose taproot is seriously infected by *R. lignosus*, strengthens its anchorage by developing lateral roots, which enables it to conserve its foliage. Nevertheless, when the infection of the root system becomes generalised and despite the protection provided by neighbouring trees against wind, the tree ultimately dies standing. Prior to this stage, a careful observation will help to detect the presence of rhizomorphs as whitish fan-shaped patches under the bark in the collar region. The first symptoms of attack by *Armillaria* and *Phellinus* on one or several large roots (photos 9 & 10), are expressed by a yellowing and premature but progressive leaf fall. *A. heimii* and *P. noxius* (Corner) G.H. Cunn. are the species most commonly implicated in basal rots. *Phellinus* can be recognized by the presence of cylindrical blackish rhizomorphs in contact with the roots. In the case of *Armillaria*, the yellow to whitish rhizomorphs, which look like a spider's web, grow on the roots. *Phellinus* (and sometimes *Armillaria*) forms a blackish and granular crust under the bark of the roots; on the other hand, *R. lignosus* is characterised by whitish fan-shaped patches. These parasites cause the wood and roots to rot. The rots which are spongy in a humid environment and fibrous in drier conditions (Lanier *et al.*, 1976), disturb and completely block the water and nutrient uptake of the tree.

In the forest, rots develop on the roots and collar of trees and gradually destroy the root, bark and wood. Disease symptoms vary depending on the parasite involved and the plant species infected.

Under natural conditions and in forest plantations, the first signs of rot infection are not easy to spot because the crowns are at a great height and overlap one another. Moreover, in moist forests the trees lose their leaves and replace them throughout the year. When the parasites spread to all the roots and go up the trunk, the bark cracks and peels off the trunk. At this stage there is a generalised leaf fall, followed by drying up of the branches. The tree dies one to three years after the onset of the attack (Arbonnier, 1995). Diagnosis is not always easy and other factors should always be taken into consideration (*Phytophthora* infection, influence of drought and root asphyxiation, attacks by xylophagous insects) to identify the cause of decay with a certain degree of certainty. Baiting with sticks of tender wood (*Hevea, Gmelina...*) embedded near the foot of diseased trees or girdling the collar of trees with a mantle of grass facilitates identification of the rots implicated in the decay (Samasserou *et al.*, 1981).

The economic impact of rot infections on tropical forest trees is generally considered to be low, considering the mode of exploitation practised. Management of plantations involves the removal (during their growth and hence spaced over time) of a majority of the trees planted as they are growing. For example, in a teak plantation in the Ivory Coast, the trees are planted with a density of 2000 plants per hectare and by the end of twenty to thirty-five years they are gradually brought to a final density of 100 to 125 stems per hectare. If the infection takes place at a young age, the contaminated trees are cut down and integrated in the quota of trees that have to be felled during the clearing operation following the date of observation of the attacks. If the attacks take place at a time when the trees are almost mature, the loss is generally less than 10%.

Treatment of the damages caused in plantations involves the implementation of large-scale and costly measures in terms of labour (necessary for drawing up inventories to localise and quantify the attacks, estimate the quantity of fungicides required...), materials (tractors with tanks and trailers) and chemicals. Treatments against rots are therefore rarely undertaken because the expenses are generally higher than the amount of losses.

In natural forests, the distribution of commercial and exploitable trees is from one to a few trees per hectare. They are very rarely accessible except on foot. In a forest of several thousand hectares, the loss of a few trees is generally considered to be negligible and the difficulties in accessing them make it almost impossible to treat them.

Systemic diseases

Vascular wilt of oil palm caused by *F. oxysporum* f. sp. *elaedis*

Fusarium wilt of oil palm is the most serious disease of this crop in West and Central Africa. The causal organism is *F. oxysporum* f. sp. *elaedis* (Schlecht) Toovey, which enters through the roots and then invades the vascular system.

Expression of the disease varies depending on several factors, including the age of the palm, the place it occupies in the crop cycle, stage of infection and degree of susceptibility of the tree itself (Renard and Franqueville, 1989). Three categories of symptoms can be distinguished schematically.

At a young age, fusarium wilt is expressed by a yellowing, often unilateral and then browning and drying of the middle leaf of the crown (photo 11). This symptom spreads to the neighbouring leaves and then to the lower leaves. Death may occur by a general drying up of the plant two months after the appearance of the first symptom. However, we sometimes come across trees of resistant progenies with partial or even total remission of symptoms, the initial symptom of yellowing remaining localised without further evolution. A section of the trunk shows brown vascular fibres which are characteristic of the disease, whether or not there is remission (photo 12).

On bearing palms, the typical (or extreme) symptom of the disease is characterised by the yellowing of a middle leaf, followed by the sudden drying of the middle and lower leaves and breaking of the rachis at about one-third distance from the petiole (photo 13). This drying may be generalised or may affect only a section of the palm. Death of the tree may occur three to four months after the appearance of the first symptoms.

In case of remission, the dry lower leaves fall, the tree gives out two, three or four spear leaves which open very slowly. The trunk becomes narrow and pointed and looks like a pencil (photo 14). A few bunches may be produced sporadically. The tree often dies many years after the appearance of the symptoms when the occasion presents itself, for example, when there is a drought. These palms always contain brown fibres which are evidence of the presence of the parasite. Besides, observations have shown that there are palms which seem to be perfectly healthy while they actually harbour the parasite.

Disease incidence varies depending on the region. Sandy soils are favourable for the development of vascular wilt, but the disease is also found in soils of volcanic regions, for example in Cameroon.

In the first generation, vascular wilt is a disease of adult plants in savannas as well as in forests. The first symptoms appear only on palms which are 6 or 7 years old. On the other hand, in replantations, vascular wilt appears from the first year itself on susceptible progenies. It has a tendency to become stabilised in the fourth or fifth year, when it begins to develop by spreading. These phenomena are due to differences in the infective potential in these two situations.

In the Ivory Coast, for a long time it was thought that the incidence of vascular wilt of palm on a savanna antecedent was higher than that observed on a forest antecedent (Renard and Quillec, 1984a). Franqueville (1991) observed that large infection centres developed in old forest zones, the percentage of infected palms increasing from 2 to 20 from 1984 to 1987. Initially confined to Africa, fusarium wilt is now found highly localised and without economic incidence in Latin America. The Asian continent remains unscathed by the disease.

It is difficult to assess the loss in yield caused by vascular wilt considering the compensation phenomenon observed in a healthy palm standing near a dead tree. Nevertheless, Renard and Ravise (1986) have shown that these losses are in the order of 0.9% by weight of fresh **fruit bunches** for 1% of the palms showing external symptoms of fusariosis. The fall in yield may reach 30% in 15 to 20 years.

This assessment was specified recently by Renard *et al.* (1993) thanks to a study which took into account the different kinds of symptoms, whether or not they were expressed, as the trunks of healthy looking palms had been bored in order to look for the eventual presence of brown fibres in them . Two categories of plant material, C1001 and C1401 (the former more tolerant than the latter), reproducing known crosses and representatives of a widely distributed material, were analysed. Figure 1 shows that in the case of the C1001 category, the yield of palms with remission of symptoms (R) and of trees infected but without symptoms (f) is the same as that of healthy palms (H). The yield of palms, showing symptoms (F), is significantly lower. In the case of Category C1401, palms whose symptoms have disappeared (R) and those showing symptoms (F) have a significantly lower yield than healthy trees (S) and trees with latent infection (f), the yield in the last two being more or less equivalent. The phenomenon of remission of symptoms thus varies in function of the tolerance of the category under consideration, especially in proportion to the duration of the expression. For category C1001, the evolution of the yield of trees where the symptoms were only temporary is traced in Fig. 2. These yields are expressed in relation to that of healthy palms, which thus constitute the base 100 of the results. Class R1 represents palms which showed symptoms in only one survey, R2 in two successive surveys and R3 in three surveys. It is quite evident that the fall in production is proportional to the duration of the manifestation of symptoms and that this effect is more evident in susceptible than in resistant material.

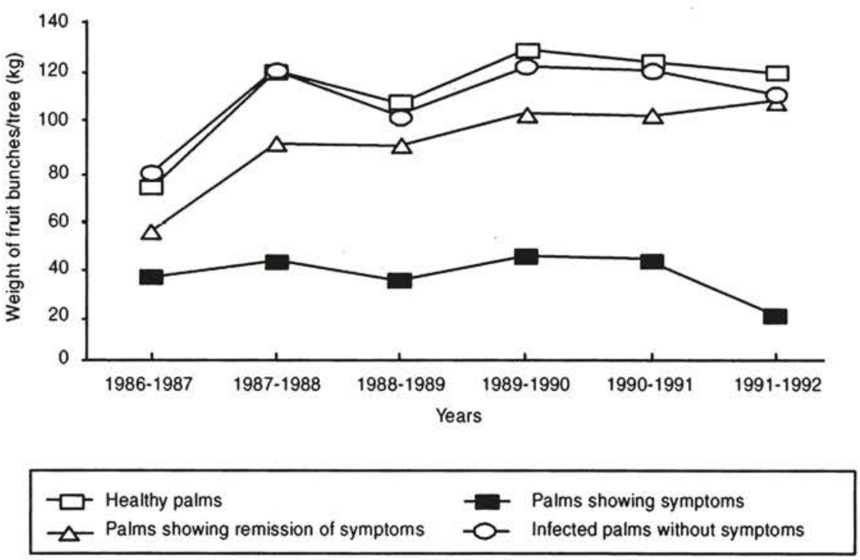

Fig. 1. Incidence of fusarium wilt on the yield of oil palm. Category C1001 (from Renard *et al.*, 1993).

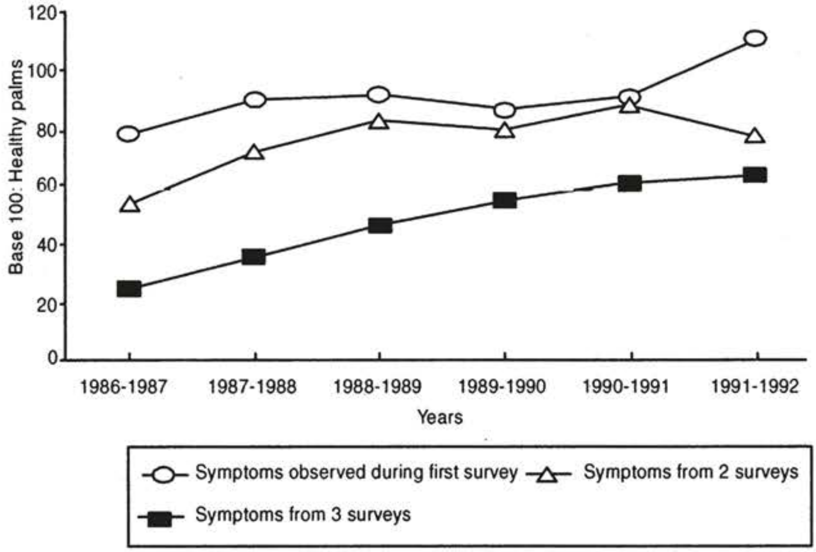

Fig. 2. Incidence of the intensity of fusarium wilt on the yield of oil palm. Category C1001 (from Renard *et al.*, 1993).

The bayoud of date palm, caused by *Fusarium oxysporum* f. sp. *albedinis*, shows several similarities with the vascular wilt of oil palms. This disease, for which inoculation tests on young seedlings were performed with success (Laville, 1962), is coming increasingly closer to oasis (Laville and Lossois, 1963).

Tracheomycosis of coffee

Tracheomycosis of coffee (carbunculariosis), caused by *Fusarium xylarioides* (Stey.) Gordon or *Gibberella xylarioides* (Steyaert) Heim et Saccas, is characterised by a sudden wilting of the plant due to the invasion of the vascular vessels by the pathogen.This decline may be limited to a part of the plant before becoming generalised and ultimately leading to its death. The presence of black to purplish-brown bands on the central column when the bark is removed and in the bark itself, is evidence of the fruiting bodies of the fungus. These fructifications are in the form of small balls (perithecia) which are first brown and then turn black , thus enabling a positive identification of tracheomycosis in the field.

This disease on coffee plants appeared for the first time in the 20s on *Coffea excelsa* in the Central African Republic where it may have at first been confused with a rot disease. In 1949, the disease affected *Coffea neo-arnoldinia* in the same country (Saccas, 1951). In 1970, the disease was reported on *Coffea arabica* in Ethiopia.

During the same period a coffee disease appeared on *Coffea canephora* in the Ivory Coast, mainly affecting two local varieties, Kouilou Bandama and

Kouilou Touba, as well as *Coffea abeokutae*, Indénié, and led to the destruction of tens of thousands of hectares. Similarly, in the Democratic Republic of Congo (ex-Belgian Congo), a similar disease was discovered on *Coffea robusta* of Ineac causing the death of 30-40% of the plants. Lastly, in Cameroon, in the 50s the disease affected *Coffea excelsa* in the eastern part of the country.

Curiously, the disease disappeared almost completely during the years 1960-65. This disappearance is certainly not very surprising because of the change in the plant material used during the same period, when Robusta replaced the other varieties. However, this conversion does not explain all because tracheomycosis reappeared in the Democratic Republic of Congo in the 80s and in East Africa in the 90s. Should we not therefore think that aging of the plantations and poor cultivating conditions are among the most important factors for the development of the disease? We know that the parasite makes its entry through injuries caused on the aerial parts of the plant or on roots, and several authors acknowledge the role played by environmental factors in the spread of the disease. Considering the behaviour observed in plantations, there is no doubt that selection of resistant coffee varieties is the method best adapted for controlling tracheomycosis. Behaviour tests, through artificial inoculations, have helped to bring out differences in varietal susceptibility (Saccas, 1956; Meiffren, 1961). A more intensive search in this domain should also take into account pathogen variability, given the diversity of the species and varieties affected in the different regions.

Citrus decline caused by *Ceratocystis fimbriata*

A serious decay caused by *Ceratocystis fimbriata* Ellis et Halst. has been observed since three or four years in citrus orchards in the coffee growing zone in Colombia (Mourichon, 1994). The spread of this disease is rather disturbing as it has infected an average of 10% of the citrus in the affected zone. This disease is also found on lime trees in Cuba. It is favoured by the severe pruning of these trees done without disinfecting the wounds or the pruning tools.

Tahiti lime and orange trees are particularly affected. The very first symptom is a yellowing followed by a more or less severe wilting of the foliage which is often localised in parts.

A transversal section of the trunk or low branches reveals a necrosis of variable colour in the woody tissues of the central column (photo 15). A longitudinal section shows that the necrosis can be continuous from the base of the trunk above the graft line up to the upper part of the tree. The necrosis spreads centrifugally, the whole looking like a flame with a characteristic black colour, especially on lime, or orange coloured with serrated edge lesions. These lesions may be visible on the trunk. Symptoms of foliar decay correspond to intensive internal necrosis. Microscopic examination of woody tissue taken from just behind the growing edge revealed a large number of chlamydospores characteristic of *C. fimbriata*. On the other hand, very few mycelial elements and endospores were observed. The conidial stage of the fungus, corresponding to the genus *Chalara*, can be easily obtained as a pure culture on a nutritive medium.

Ecofungal wilt of cocoa

In 1985, a wilting of cocoa branches was observed in Uganda. This dieback was first attributed to *Botryodiplodia theobromae* Pat. (Snowden, 1920). The high incidence of this disease in plantations later planted with material of the Amelonado type and hybirds of the Upper Amazonian type, enabled researchers (Leakey, 1965) to identify the causal agent of this wilt as *Verticillium dahliae* Kleb.

The symptom, characterised by the hanging position of leaves in the process of wilting, which is moreover known in cases of extreme drought, is the first manifestation of the disease. The edges of the lamina and veins become brown and this colour quickly spreads throughout the leaves. As the foliage withers, a generalised yellowing of the lamina may in some cases be a transitory symptom before the wilt. The symptoms begin at the tips of small branches and then spread to all the branches. The dry leaves remain attached to the branches for a long time before falling off.

These external symptoms correspond to light brown elongated aligned spots on the twigs and branches. They are accompanied by distinct thin black lines located in the extension of the spots or next to them. The brown spots are also found in the trunk but are rare, almost non-existent, in the roots. Generally speaking, the concentration of internal symptoms increases from the roots towards the tips of branches.

These elements were determinant for reserving the name branch dieback for this disease of cocoa (Trocmé, 1972). Although artificial infections have demonstrated the pathogenic character of *Verticillium dahliae*, Trocmé has shown that the manifestation of symptoms is greatly dependent on environmental factors. In Uganda, the absence of shade in particular predisposes the cocoa plant to drying of branches and hence it is also known as ecofungal wilt of cocoa, the name given by this author for the disease. According to him, adequate attention was not paid to the special climatic conditions in Uganda for developing the cultivation of cocoa crops, which would have required adaptation of cultural techniques.

DECAYS CAUSED BY *PHYTOPHTHORA*

Avocado wilt

Several species of *Phytophthora* and more particularly *P. cinnamomi* Rands, cause considerable damage in avocado orchards. These diseases are found in almost all the cultivated areas and none of the varieties, grafted or used as rootstocks, can be considered to be totally resistant. Two kinds of symptoms are distinguished, depending on the site of attack by the parasite.

The development of *P. cinnamomi* on roots results in the formation of small leaves that are greenish-yellow and often withered (photo 16). These leaves ultimately fall off and are not replaced. The foliage becomes very sparse and the tips of branchlets are bare and dry. The infected trees sometimes have a large number of small fruits. These symptoms are due to the growth of *P. cinnamomi* on the radicles and medium size roots. These roots become dark brown in colour while the cortex is destroyed and crumbles (Assas M'Billaut, 1978): the roots are not renewed, the tree can no longer nourish itself and it withers and dries up. The development of *P. cinnamomi* at the base of the trunk is manifested by large water-soaked spots on the bark, irregular in shape and dark brown in colour. A light brown, slightly gummy liquid oozes from the cracks in the bark (Brun, 1975). When the infected bark is removed, we can observe a browning of the underlying wood, which is generally more extensive than can be supposed from the external necrosis. The branches corresponding to the necrotic zone of the trunk dry up. The tree dies when the necrosis has girdled the whole trunk (photo 17). *P. cinnamomi* dominates these cankers, but *P. cactorum* (Lebert and Cohn) Schröter and *P. citrophthora* (Sm. and Sm.) Leonian may also be isolated.

Citrus gummosis

Phytophthora attacks almost all the parts of the citrus plant and at all stages too. In seeed-beds, *P. nicotianae* var. *parasitica* (Dastur) Waterh. causes damping off disease which is, however, not a big constraint (Boccas and Laville, 1978; Laville, 1984).

Phytophthora species are capable of infecting the elongation zone of *Citrus* and *Poncirus* roots and in susceptible varieties the parasite establishes itself in the cortical zone where it induces necrosis. Root decay causes yellowing of leaves which fall off. The tree which cannot regenerate its root system is not nourished adequately and hence it vegetates and eventually dies. This fatal outcome is more rapid if the parasite reaches the large roots.

The large roots are attacked following contamination of the fibrous roots. These insidious attacks on the root system may be common (for example, in Corsica) even with grafted varieties of root stocks (sour orange, citrange) that are generally considered to be resistant (Laville, 1974).

Phytophthora infections are most common at the base of the trunks (photo 18) and on low branches. Different species of *Phytophthora* induce necrosis and cankers of variable intensity depending on the citrus variety and scion-rootstock combination.

The first symptoms appear on the bark in the form of irregular, water-soaked dark brown spots about the size of a small coin. The bark then splits and exudes an amber-brown gum, more or less abundant depending on the variety attacked and the vegetative state of the tree. It must be stated that this gummy water soluble exudate of pectic origin cannot be easily observed when rainfall is heavy and is therefore difficult to record. While the bark dries up, the cambium remains moist and takes on a light brown stain, a colouring which also develops in the underlying wood. The necrosis spreads upwards and encompasses the trunk. At this stage the foliage begins to yellow in parts, the tree flowers out of season and bears small, immature fruits. The tree dries in proportion to the spread of the canker, the leaves fall in their turn and the fruits remain on the tree for a longer time but ultimately fall down as well. The rate of development of the canker varies depending on the climate and the physiological state of the tree. In Corsica, spring and autumn are favourable periods for the rapid development of cankers, the low winter temperatures limiting the development of these cankers as do high temperatures.

Bud rot of coconut

In coconut trees, *Phytophthora* rots are manifested on the meristems and nuts (Quillec and Renard, 1984). Only meristem rot will be examined in this section. The first symptom is the withering and drying up of the spear leaf and loss of turgidity of the first leaf, followed or accompanied by a slight yellowing of a central leaf (about the 3-6 position) of the crown (photo 19). The yellowing becomes generalised in the upper leaves and then gradually the leaves become brown from the tip to the base and finally dry up completely, break and hang down between the petioles of older leaves which are still green. This evolution is the fate of all the leaves from the middle to the periphery of the crown. It reaches the oldest leaves by the end of a year. All that is left of the tree is the pollard trunk. The coconut bunches continue to grow as long as the leaves supporting them are green. The persistence of green leaves and bunches can be explained by the fact that the roots of the coconut tree are still healthy and continue to nourish it. Dissection of a coconut tree showing the first symptoms reveals advanced internal rot in the young growing leaves (photo 20). At this stage the rot has completely invaded the merismatic zone and the base of the spear and the young leaves. The infected tissues become purple to pinkish in colour. The rot spreads downwards in the central part of the trunk, softening the tissues which become yellow with a brown edge, doubled by a salmon pink margin at their border with healthy tissues. When the rot is in an advanced stage, the decomposed tissues become creamy and give off a foul smell. Often, particularly in the case of *P. katsurae* Katsura et Uchida, small oily looking rot centres evolving towards a brown colour develop inside the petioles of old leaves, these symptoms becoming visible only after cleaving the petiole longitudinally. There may be variations in the colour of the infected tissues, as well as in the rate of development of the symptoms, depending, on the cultivars or the species of *Phytophthora* involved, but the stages in the evolution of symptoms remain the same.

Symptoms caused by *Phytophthora* have been reported in a number of countries in the intertropical zone. Renewed outbreaks of this disease seem to have occurred during the 70s. In 1977, a large centre of bud rot appeared in the Ivory Coast (Quillec *et al.*, 1984). Within a few years 50% of the West African Tall palms were dead in this centre.

In Indonesia, the disease which was initially confined to the local Tall cultivars and on the whole without any major economic impact, appeared in the 80s in new plantations planted with Nias Yellow Dwarf × West African Tall hybrids. The disease can cause the mortality of 40% of the trees within a few years (Thevenin *et al.*, 1994). The disease is known in the Philippines and the Caribbean (Renard, 1992) where more than 25% of the trees could die in less than 15 years.

Diseases transmitted by insect vectors

By stinging the plant, insects are capable of transmitting a large number of organisms: virus, phytoplasma, trypanosoma and bacteria. In the chapter on insect vectors, it will be seen that insects can be carriers of other types of pathogens as well, viz., fungi and nematodes.

Phytoplasma diseases

Only diseases affecting oil palm and coconut are dealt here. However, citrus plants can also be affected by this type of pathogen (see the table in the annex for diseases not treated in this book).

Lethal yellowing of coconut

All lethal yellowing type diseases, whether in America or in Africa, begin by a premature fall of mature and immature nuts. The leaflets at the tips of the lower leaves become yellow at the same time or immediately after the nut fall. The yellowing spreads to the whole leaf and then gradually extends to the increasingly younger leaves (photo 21). From the onset of yellowing, there appears a browning of the rachillas of ready to open or newly opened inflorescences (photo 22). The flowers, both male and female, also exhibit a more or less deep brown or grey-brown to black colour. The initial stages of lethal yellowing are similar to those of hartrot. In the final stage, when the oldest leaves have fallen, all that remains is a bouquet of yellow erect leaves (photo 23) which are shorter than the leaves of healthy trees. Secondary infections cause a rot in the upper part of the stem which sways and then falls down. All that is left of the coconut tree is an upright pollard trunk.

Lethal yellowing of coconut was recorded for the first time in the Cayman Islands in 1830. It then spread to the Caribbean (Haiti and Jamaica) and then to Florida and in the 80s to the Yucatan peninsula in Mexico. In was reported in the Honduras in 1996 by Ashburner *et al.* (1996). In Africa, it appeared in Togo in 1930 where it is called Kaïncopé disease (Bachy and Hoestra, 1958) and in south-east Ghana it is called St. Paul wilt. It is known as Kribi disease in Cameroon (Dollet *et al.*, 1977), Akwa disease in Nigeria and fatal yellowing or lethal disease in Tanzania. In the early 60s, the disease appeared in the Cape Three Point region in Ghana, after having almost disappeared in an endemic manner from the region of Cape St. Paul and Togo (Mariau *et al.*, 1996). In less than thirty years, it is estimated that a million coconut trees were destroyed by this disease in Ghana—all around Cape St. Paul on the Ghanaian coast. Lethal yellowing is transmitted by insects and is capable of completely annihilating a coconut plantation in one or two years (photo 24).

Blast of oil palm and coconut

Blast is the most important disease in oil palm nurseries in Africa. Although etiological studies have still not been able to demonstrate the role of an insect vector *(Recilia mica)*, it was observed that in the absence of shade, 80% of the trees could die of this disease (Bachy, 1958). The term blast, designated to characterise this malady, expresses the rapidity with which the symptoms evolve and lead to the death of the plant. The first symptom is blackening of the base of the spear leaf. At this stage, the spear leaf can be easily pulled out. Almost simultaneously the lower leaves of the plant begin to fade, quickly followed by browning of the leaf blade. This symptom evolves within one or two weeks, from the lower to the upper leaves, leading to a generalised wilting of the plant (photo 25). With the appearance of the first symptoms the roots exhibit cortical rot. A longitudinal section of the pseudo-bulb shows a brownish-yellow colouring. Remission of symptoms has been observed. However, when it occurs it is recommended not to plant these apparently cured palms (Franqueville *et al.*, 1991). Older plants are more tolerant than young nursery seedlings. Very exceptionally, cases of blast have been reported in the field in the year following planting. Blast may also affect coconut plants in nurseries. The symptoms are similar to those observed on oil palms (Quillec *et al.*,1978).

Trypanosoma diseases of oil palm (marchitez), coconut (hartrot) and coffee

Marchitez of oil palm and hartrot of coconut are two similar diseases which were of great concern during different periods: from the end of the nineteenth century on coconut in Surinam and in the 60s on oil palm when this crop began to be cultivated in countries such as Colombia and Peru. They are known only in Latin America. These two diseases with a common syndrome are associated with the presence of an intraphloem flagellate protozoan, recognized and identified well after the damage caused by them was described for the first time. The ascending wilt of the foliage characterises these two diseases. In the case of marchitez, the first symptom of the disease is a browning of the tips of the terminal leaflets of the lower leaves (photo 26). At this stage the roots may look normal and healthy. All the leaflets of the first affected leaf turn brown, and the colour then quickly spreads to all the leaves, from the bottom to the top. As the browning becomes generalised, the leaves become proportionally dry and turn ash grey in colour (photo 27). Rot may set in more or less quickly in the spear leaf depending on the environmental conditions. The young developing inflorescences get aborted and the bunches rot and dry up. At this stage the cortex of the primary and secondary roots become brown and the roots rot. It takes about three to six weeks from the appearance of the first symptom to the death of the palm (Lopez *et al.*,1975).

The evolution of hartrot of coconut is quite comparable to that of marchitez. The difference lies in the colour of the foliage. The first symptom is a yellow to light brown colouring of the leaflets depending on the cultivars (photo 28). Yellowing often precedes browning which becomes quickly generalised throughout the foliage. These foliar symptoms are accompanied by a premature fall of immature nuts and browning of the rachillas of the ready to open inflorescences (Renard, 1989; photo 29). The interior of the female flowers becomes brown and the male flowers are easily detached from the spikelets (photo 30). As in the case of oil palm, the roots become rotten. The tree generally dies about three to five weeks after the appearance of the first symptoms.

These symptoms are associated with the presence of an intraphloem flagellate protozoan (Dollet and Lopez, 1978). It is possible to confirm the presence of these protozoans as soon as the first symptoms appear by taking a drop obtained by pressing the still young root tissues of the oil palm or the peduncle of a ready to open coconut inflorescence and examining it under a light microscope.

These diseases are found in the northern part of South America, Peru and the State of Bahia in Brazil, up to Costa Rica. Hartrot has been known in Surinam since the end of the nineteenth century. Later it was also identified (and called cedros wilt) in Trinidad, where 15,000 coconut trees died within three years. It has caused sporadic destruction in small farming plantations in Latin America, particularly in Colombia, Brazil and French Guyana. It has devastated vast areas in commercial coconut plantations within a period of a few months.

In the case of oil palm, especially in some large commercial plantations, hundreds of hectares were infected by marchitez and thousands of hectares were, and still are, threatened. Treatment with insecticides along with regular maintenance of the plantations and their access helps to limit the damage to some extent. In the absence of preventive measures, the two diseases pose a serious threat for oil palm and coconut cultivation in Latin America.

A decaying disease of coffee has also been attributed to *Phytomonas* in Surinam and Guyana (Stahel, 1931). It must be noted that the symptoms are found in very humid, poorly drained zones where asphyxiation phenomena may superimpose a weak parasite or may favour it.

VIRUS DISEASES

Foliar decay of coconut

Coconut foliar decay is manifested by the appearance of diffuse orange-yellow spots and/or brown necrotic spots, depending on the cultivars (photo 31) on the leaflets of the upper third of the crown, from leaves 7-11 beginning from the unopened leaf (Calvez *et al.*, 1980). The yellowing on these leaves becomes generalised at the same time as the appearance of lateral necrosis on the petioles, symptoms which are very typical of this disease (photo 32). These leaves become dry and then fall off, leaving a gap between a tuft of yellowing leaves above and still green leaves below, giving the crown and X appearance. When the lower leaves have fallen, all that remain are 6 to 10 scraggy yellowish leaves, similar to the last stage of lethal yellowing disease caused by phytoplasmas.

The rot in the petiole of the middle leaves is perpetuated in the corresponding inflorescences, which become brown and necrotic. The inflorescences situated at the base of the young scraggy leaves remain healthy and it is this feature which distinguishes coconut foliar decay from lethal yellowing. The root system is normal until a very advanced stage of the disease. Susceptible cultivars (Malaysian Red Dwarf) remain for at least twelve months before dying. Remission is possible in some cultivars such as Rennell Tall (Calvez *et al.*, 1980). With the manifestation of the disease, the coconut tree stops yielding. The yield becomes normal only several years after it is completely cured. This disease is known only in Vanuatu (New Hebrides).

Citrus tristeza virus (ctv)

Tristeza disease of citrus is a very destructive virus disease in the majority of the citrus growing regions of the world. It has destroyed more than 25 million trees in South America and 3 million in California. Only some regions in Mediterranean Africa, Saharan Africa and Central America are still free of this disease, although recent data show that it is advancing in the Caribbean arc through the vector (Aubert *et al.*, 1992).

The disease is expressed by a rapid and generalised wilting (or decline) of trees grafted on Seville orange, accompanied by necrosis of the phloem tissues along the graft line and anomalous cambial growth causing invagination of the bark into the wood, a symptom called stem pitting (photo 33). This stem pitting reduces the vigour of the tree considerably, leading to a reduction in the size of the fruits as well as a fall in the yield in the case of lime and pomelo.

Swollen shoot disease of cocoa

Swollen shoot disease of cocoa is a virus disease known since 1992 in Ghana. It is characterised by the appearance of mosaic symptoms on the leaves, followed by swellings on the stems. When the swelling takes place at the tips of branches, it looks like a club and the apical meristem becomes nonfunctional (photos 34 & 35). Wilting may follow and in the most serious cases the tree dies. The virus is transmitted by several species of bugs.

The most consistent sign of the disease is leaf mosaic. Several kinds of symptoms have been described by Partiot *et al.* (1978) in Togo. Form Agou 1, which is similar to the one found in Ghana, is the most typical of the disease. It exhibits a 'feathery mosaic' along the veins and swelling of the shoots and roots. The pods produced are small and rounded. An attenuated form has been identified; in this case, the mosaic symptom is not pronounced and the shoots are not swollen. The yield of the tree is not affected by this weak form. The third kind of symptom is characterised by a slight defoliation and a few swollen shoots. The yield is not affected by these symptoms.

Variations of these symptoms are found on leaves. Depending on the case, they are characterised by intervenal mottling, without swellings, or by a stippled mosaic which begins along the veins and then spreads throughout the lamina. Swelling of shoots was not observed in this case. Totally, about thirty forms have been described. The disease causes wilting of the leaves and branches and a general and gradual weakening of the plant with a fall in its productivity. The ultimate stage of the disease is the death of the tree.

Swollen shoot disturbs the formation of cocoa seeds, which is responsible for the fall in production. Thresh (1958) considers swollen shoot to be one of the most important factors limiting the production of cocoa trees and one of the plant diseases responsible for the most serious economic losses in the world.

The virus is also found on several plant species growing near cocoa trees: *Cola chlamydantha, C. gigantea, Erythropsis barteri, Sterculia chinopetala, S. tragacantha, Adansonia barteri, Bombax brunuopense* and *Ceiba pentendra*, as well as a few herbaceous species such as *Corchorus* sp.

This disease was described in its serious form in Africa: in Sierra Leone (Attafuah *et al.*, 1963), Ivory Coast (Alibert, 1946), Nigeria (Murray, 1945) and Togo Partiot *et al.*, 1978). In Ghana it was responsible for the uprooting of 163 million trees (Legg, 1979) and continues to be the objective of a new eradication programme. Curiously, in the Ivory Coast where two virus strains had been identified (as Kongodia and Sankadiokro forms), the disease has remained localised in these two sites for more than fifty years. Faced with such situations, are we not right in questioning the interest of eradication campaigns?

Bacterial diseases: Huanglongbin or citrus greening

Huanglongbin or greening is a bacterial disease on citrus plants and is transmitted by insects.

The symptoms of this disease are similar to symptoms of mineral deficiency (photo 36). The disease can be identified with certainty only when the various sequences of the pathological stages following infection are taken into consideration. Greening is characterised by three kinds of abnormalities: chlorosis of leaves, disturbed phenology and abnormal fruits (Aubert, 1988).

Foliar chlorosis assumes varied aspects. In the island of Réunion, the most common symptom is the appearance of green spots on a yellow background which could be confused with zinc or iron deficiency. A second symptom which is often observed is that of small, pale yellow, spoon-shaped leaves, which is also similar to zinc deficiency. A third symptom corresponds to a mottling of the lamina, similar to that caused by manganese deficiency. Some old leaves may become thick and coriaceous and a network of protuberant veins may appear on their upper surface, sometimes with traces of suberisation resembling boron deficiency.

In contrast to deficiencies which induce general yellowing, chlorosis caused by greening appear in parts and are irreversible.

A disturbed phenology is expressed by the fall of chlorotic leaves, interspersed with vegetative growth and out of season flowering. The most chlorotic branches eventually dry up (photo 37). The fruits are asymmetrical and do not become coloured on maturity. The columella is deformed and the seeds are aborted. The juice and sugar content is low, making the fruits commercially unviable.

Besides these directly visible symptoms, anatomical disorders are also seen in the sieve elements, with the formation of secondary phloem, thickening of the cell walls and deposition of lignin in the sclerenchyma. All the disturbances in the phloem are particularly traumatic for the plant, as much for the leaves as for the reproductive organs, branches and roots. All these contribute more or less quickly to a progressive wilting and ultimately the death of the plant.

Greening is a serious problem in Asia and is also responsible for considerable destruction in sub-Saharan Africa.

In China greening, which is commonly called cgd (citrus green disease), caused the death of about 12 million trees in the 50s, mainly because of the divulgation of contaminated material. In 1960 and 1970, in Indonesia where the disease is known as cvpd (citrus vein phloem degeneration), the loss was estimated to be 3 million trees, to which should be added the plants infected in the nursery (Tirtawidjaja, 1980). The best commercial variety of Keprok tangerines has disappeared almost completely in Java. In the Philippines it is estimated that 5 million trees have been affected by greening (locally called leaf mottle disease) since the early 70s, reducing the area planted by 60%. In Africa, greening is responsible for the mortality of several million trees and the disease, which was initially localised in South Africa, has now spread to East Africa, up to Ethiopia, Cameroon and Madagascar (Aubert, 1992).

Diseases of unknown etiology

Dry bud rot of oil palm and coconut

Dry bud rot (or heart rot) of oil palm and coconut, which had remained undiscovered for a long time, spread with the generalisation of nurseries without shading following the results of researches conducted on blast disease. It is also found during the initial years of plantations, especially in areas where a vegetation dominated by Gramineae has become established in place of a homogenous cover of *Pueraria*. The etiological agent of the disease is not known but we know that it is transmitted by two insects.

The appearance of small yellow and white spots on the spear or first leaf is the most typical expression of the disease (photo 38). Sometimes this symptom is localised on the lower part of the leaflets of the still white spear leaf, in which case the spots are brown. At an advanced stage the base of the spear leaf is completely brown. These symptoms are accompanied by a pronounced stunting of the young leaves. Lenticular or elongated brown zones develop on the petioles of the middle leaves. Sometimes there is a variation of these symptoms. It is manifested by the appearance of a large number of small white spots on the young leaves and a reduction in their size. In this case, there is no rotting of the spear leaf nor of the bud, nor is the pseudo-bulb coloured. The plants remain stunted and sometimes remission of symptoms may be observed. In the nursery the symptoms on oil palm and coconut are almost identical. In the case of coconut the pseudo-bulb is brown in colour with a corky aspect (Renard *et al.*, 1975), while purple is the dominant colour in the oil palm (Renard and Quillec, 1984b; photo 39). In the case of coconut these symptoms are the same in plantations, whereas in the case of oil palm the most characteristic symptom in plantations is expressed by fairly deep yellowing of the young leaves.

The leaflets of the spear leaf are scattered with round, oily looking spots. The most typical symptom of the disease is still the wine purple colour which appears in the trunk in the first year of planting. All these symptoms gradually lead to the death of the tree, in the case of both oil palm and coconut: the leaves becomes yellow and then dry up, from the youngest to the oldest. The root system, which remained healthy for a long time, begins to rot from the tips of the roots, which in their turn become brown and dry up.

The damage caused is varied. The diseased plants are either scattered or grouped together depending on the environment (weeds, forest border, topography). The disease rate is about 2-3% on the average, but can go up to 10-25% of the plants in restricted areas or even more in certain parts of oil palm plantations.

Ring spot disease of oil palm

Symptoms of this disease are allied to those of dry bud rot of coconut because they also appear on the spear and young leaves. The disease begins with a slight chlorosis of the young leaves, concomitant with the appearance of a large number of elongated or ring-shaped spots (Dzido *et al.*, 1978) that are lighter in colour than the rest of the leaf blade (photo 40). These initial symptoms are followed by a generalised and intense yellowing of the young leaves and then of the older leaves. At this stage rot sets in the spear leaf and spreads towards the meristem. The lower leaves become brown, the fruit bunches and roots also rot and the plant ultimately dies. In the trunk, a large number of necroses can be observed in the vascular bundles. From the onset of the first symptoms to the death of the tree it takes about three months.

The damage caused by this disease is mainly during the initial years of the plantation and is generally not very serious. However, some small plantations have been devastated to the tune of 95%. Ring spot symptom has been reported only in Latin America, especially in Ecuador and Peru, and to a lesser extent in Colombia and Brazil.

Viroid diseases

It is believed that some of these diseases, like that of coconut, are transmitted by insects, but no formal demonstration has been possible until now.

COCONUT CADANG-CADANG DISEASE

Coconut cadang-cadang is a debilitating disease of coconut palms, which gradually leads to the death of the tree. It gets its name from gadan-gadan, which means dying in a Philippine dialect. Appearing in the late 20s in the island of Juan Miguel in the Philippines, this disease has killed about 30 million coconut trees since its appearance (Bigornia, 1977). Luzon province, situated in the north of the Philippine archipelago, is the only region affected by cadang-cadang. Mindanao island, the major copra-producing region in the south, is free of it.

Coconut trees infected by cadang-cadang can be recognized by the reduced number of leaves and bronze-yellow colouring of the foliage (photo 41). This colour is due to the presence of a multitude of small yellow, more or less circular, translucent spots which look oily and olivaceous when viewed against light (photo 42). This stage, which is already advanced, is due to an extremely slow evolution of the following process. The first stage of the disease corresponds to the appearance of more or less round nuts with brown equatorial scarifications. The first small yellow spots are scattered on the leaf. The next stage is characterised by the persistence of stipules at the base of the rachis of the leaves, as well as reduced production of nuts as the inflorescences begin to rot. The leaves given out are short and the large number of yellow spots gives the crown a chlorotic appearance. In the last stage, nut production ceases, the tree is fully chlorotic and the apical part of the trunk is narrowed. The plant stops producing flowers. It may take about ten years (from 8 to 17 years) from the appearance of the first symptoms to the death of the tree (Zelazny *et al.*, 1982). For a long time the disease was considered to be a malady of old coconut trees. We now know, by inoculating a viroid, that young coconut trees can show slight symptoms eighteen months after inoculation.

This disease may also attack oil palms. The symptoms are manifested by a cessation of flower production, reduced emission of leaves and the leaves given out becoming smaller and smaller and chlorotic. Orange coloured spots develop on the entire foliage (Randles *et al.*, 1980).

Exocortis and cachexia of citrus

Exocortis and cachexia are two diseases of citrus plants in which the causal organisms are transmitted through grafts and mechanically through the sap transported on the tools. Transmission of these diseases by insect vectors has not been reported. Expression of the symptoms is favoured by high temperatures.

Exocortis is manifested on *Poncirus trifoliata* rootstock and on most of its citrange hybrids, as well as on some lime trees (Rangpur, sweet lime) and certain citron clones. Scaling and cracking appear on the rootstock about four years after grafting of infected material (photo 43). The tree thus infected is more or less stunted and its production is reduced (Vogel and Bové, 1986).

Species susceptible to cachexia are mainly *Citrus macrophylla*, Mandarin-orange trees and their hybirds (tangelo, tangor). Small more or less deep pits appear in the wood above the graft line. At the same level small spots can be observed on the inner side of the bark, which are extensions going deep into the wood. This symptom is called stem pitting by Anglo-Saxons. Gummy impregnations are visible in the thickness of the bark (photo 44). Highly infected trees remain underdeveloped, become chlorotic and may perish (Bové, 1993).

A number of citrus varieties are tolerant to one or the other of these diseases and the symptoms are manifested when plant material from these healthy carriers is grafted on a susceptible rootstock. The disease can be prevented by using scions free of these viroids.

Diseases caused by nematodes

Coffee decline

Nematode pathogens of coffee belong to two genera, *Meloidogyne* (gall-causing nematodes) and *Pratylenchus* (nematodes causing lesions). These two nematodes are found throughout the coffee-producing region in Latin America causing heavy losses (Campos *et al.*, 1990). Despite its seriousness, the problem of coffee decline caused by nematodes was taken up in Central America only in the 60s (Schieber and Sosa, 1960; Salas and Echandi, 1961).

Nematodes of the genus *Pratylenchus* grow on the roots of coffee plants, inducing a separation of the cortex from the central column of the root. These nematodes are capable of leaving the roots if the conditions become unfavourable to go and colonise new roots (photo 45). They grow at the expense of the cortical parenchyma cells causing large lesions that are often accentuated by secondary pathogens, especially fungi. These infections are expressed by a general chlorosis of the foliage of the coffee plant, followed in severe cases by a progressive wilting of the primary branches which could lead to the death of the plant within a few years (photo 46). The symptoms evolve slowly, growth of the plant slows down and the yield is reduced. Any treatment to cure the disease is then impossible. According to a survey conducted by Anacafé in Guatemala, the loss in production was estimated to bc 20% in some coffee growing regions. A special study (Villain *et al.*, 1996) showed that the losses cumulated over several seasons could exceed 75%.

Nematodes of the genus *Meloidogyne* are sedentary endoparasites which attach themselves to the pericycle of the root. The plant tissues react to the infection by producing galls (photo 47). These galls may invade the entire root system. Severe symptoms are similar to those described for nematodes of the genus *Pratylenchus*. However, the symptomatology and damage caused are varied depending on the species involved. The species, *M. exigua* Goeldi, induces large galls without destroying the roots. This species is not very pathogenic on adult coffee plants. On the other hand, it can cause severe symptoms on young plants or when the soil is not very fertile and also under drought conditions (Campos *et al.*, 1990).

M. arabicida n. sp. (Lopez and Salazar, 1989), a species described recently in the Juan Vinas region in Costa Rica, is associated with a very serious wilt, corchiosis. This disease is manifested by very large corky galls on the taproot as well as on large roots, leading to the death of the plant within two to three years. Fungi belonging to the genera *Fusarium, Cylindrocladium* and *Phialophora* are associated with this decline (Calderon-Vega, 1989).

Red ring of oil palm and coconut

This disease, caused by the nematode *Rhadinaphelenchus cocophilus* (Cobb), affects oil palm as well as coconut trees in Latin America and the Caribbean. Despite some small differences, the general symptoms of this disease are similar on these two plants. They are manifested by a slowing down of the growth of the tree, visible in the shrinking of young leaves which become light green to yellowish in colour. This discoloration spreads throughout the foliage with the yellowing becoming more intense concomitant with wilting of the middle leaves. This wilting then gradually spreads throughout the crown, from the top towards the bottom. We often observe a rotting of bunches of oil palm and nut fall on coconut.

In very typical cases, a section of the trunk shows a pink to light brown coloured ring in coconut (photo 48) and brownish-grey in oil palm (photo 49). Depending on the stage of the disease, this ring is more or less complete and its location in the trunk is variable. It may be continuous from the base to the top of the trunk or may be present only at the top or only at the bottom of the trunk. Grey or brown necrotic spots are sometimes visible at the base of the petioles of young leaves (photo 50).

At an advanced stage of the disease, the infected tissues of the trunk rot, giving rise to a large cavity. As long as there is no rot at the top of the trunk, the palm tree does not die and gives out a succession of very short leaves making the tree totally unproductive. Total remission of the disease is unknown and death always ensues after a fairly long period.

Disease incidence varies depending on the regions. Some plantations may be badly affected, as observed for example in Venezuela where 70% of the palms died of red ring disease at the age of 15 years (Mariau, 1978). In Bahia State in Brazil, several plantations were severely affected with a mean annual disease rate of 1.5 to 3.4%, and some plots could be eliminated within a year (Renard, 1985).

Disease of unknown origin: heart rot of oil palm

Among the oil palm diseases present in Latin America, the one commonly called heart rot is the most devastating and constitutes a limiting factor for the cultivation of oil palm in several regions (Mariau *et al.*, 1992).

The first symptom of the disease is the chlorosis of young leaves (leaves 4, 5 and 6, starting from the spear leaf), quickly followed by browning and necrosis of the tips of leaflets (photo 51). Spotting, or yellow mottling, is also common on these leaflets. Asymmetrical rots appear on the leaflets and spear leaves. Often a wet deteriorating rot of the tissues is observed at the base of the spear leaves, which advances towards the terminal bud (photo 52). Transverse necrotic cracks appear on the inner side of the petioles and rachis of young leaves (photo 53). These symptoms generally develop rapidly which causes the central part of the crown to wither and sway. The remaining leaves yellow slowly, from the tip towards the base and from the middle leaves to the basal ones. The slow progress of symptoms is due to the absence of severe rot and momentary emission of small atrophied leave. In almost all cases, death of the palm is inevitable, from a few months to eighteen months after the appearance of the first symptoms.

The hanging production on the plant is not directly and immediately affected and matures in most cases. On the epidemiological front, this disease evolves slowly, even very slowly, with an arithmetical progression of 0.1 to 1.3 per year during the first few years following planting. Suddenly, the progression becomes geometrical (Fig 3) with the formation of large infection centres, this progression being more or less related to environmental factors such as soil and climate depending on the region. However that may be, the destruction is always heavy and spectacular.

In the early 70s, a 2000-hectare plantation in the region of Turbo in Colombia was completely destroyed in a few years. Similar symptoms were observed in small palm plantations on the Pacific coast. A disease showing some features in common with the heart rot disease of palm was described in the Llanos region in Colombia by research workers of that country (Nieto Paez, 1993). A fungal hypothesis was advanced to explain this type of heart rot for which a large number of more or less long lasting cures are available.

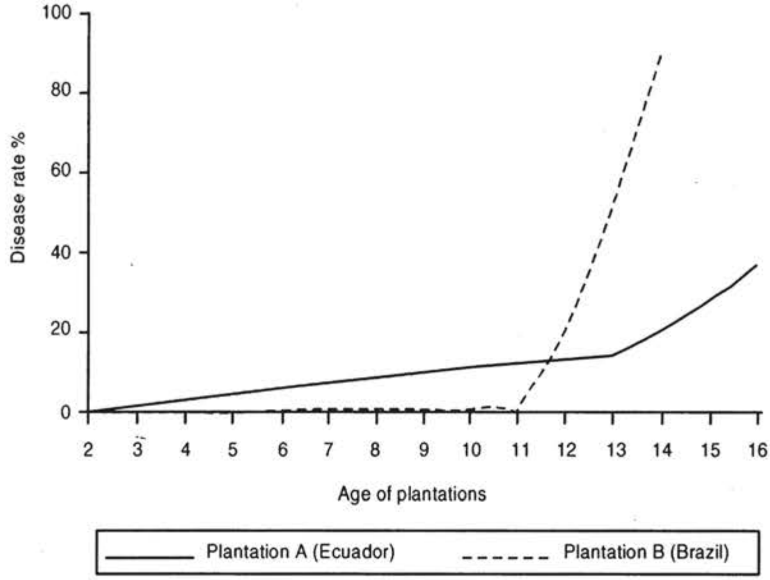

Fig. 3 Evolution of bud rot disease (from Mariau *et al.*, 1992).

In Ecuador, plantations situated in the Amazonian part of the country were seriously affected and in the end appeared to be highly endangered. Plantations situated on the Pacific side were less affected and the disease does not assume epidemic proportions as in the Amazonian region. In Brazil, an oil palm plantation in the Belem region was also destroyed by heart rot at the same time as a plantation in the Téfé region, several hundred kilometres west of Manaus. In Surinam, the disease was manifested when the palms were only four years old in the largest plantation in the country (1700 hectares). Disease centres have reduced the area planted by more than 500 hectares in six years and almost completely destroyed it in the following years. In Panama, a plantation of *Elaeis guineensis* was also destroyed.

DISEASES OF LEAVES, BRANCHES AND TRUNK

All foliar diseases are related to the development of fungi. The plant becomes weak as a result of such attacks and may even die in the most serious cases. The causal organisms of diseases of the trunk and branches are fungi and bacteria.

Diseases caused by fungi

Fungal diseases that affect leaves cause them to fall or render them incapable of photosynthesis. Other fungal diseases attack the trunks and branches.

South American leaf blight of rubber

Generally called Salb (South American leaf blight), this South American leaf disease is caused by *Microcyclus ulei* (P. Henn.) Von Arx. Repeated infections of this fungus induce successive defoliation (photo 54) accompanied by a decaying of the tips of branches and in extreme cases may lead to tree mortality. Symptoms caused by the asexual form (conidia) of the parasite vary depending on the age of the leaf at the time of infection. When the leaves are in the reddish-brown stage, i.e., four to nine days after their formation, dark grey lesions (bearers of conidia) make their appearance deforming the lamina and this is followed by leaf fall. Generally, slightly older leaves (ten to fifteen days) do not fall and laminal deformation is not severe. Lesions are formed on the lower surface and may enlarge up to 2 cm in diameter. Conidia are produced on these lesions which are grey to olive green with a downy aspect (photo 55). On the upper surface of the leaflet, each lesion gives rise to a chlorotic translucent spot. With the hardening of the leaf, the lesions lose their velvety aspect and become brown in colour. The centre of the lesion may become dry and even fall off (Chee and Holliday, 1986; photo 56). At an advanced stage of the infection (one month), black pycnidia can be observed on the upper surface of the leaves. They increase in size and number, forming black masses arranged in small circles a few mm in diameter (photo 57). Normally the leaf does not fall at this stage; it becomes rough to the touch. By the time the leaf reaches maturity (three months after its sprouting), the stromatic masses have become large and black; perithecia have replaced the pycnidia. They are situated at the margins of the necrotic spots, almost always on the upper surface of the leaf, giving it a sooty appearance.

This succession of the three stages of the disease may also take place on the petioles, green shoots, inflorescences and green fruits. The first symptom is a small swelling on which the conidia are produced. The infected petioles and stems become deformed, curve and may roll into a spiral. The lesions become corky and may disappear. The injured tissues become hypertrophied. The flowers may also be infected (Rivano, 1992).

Since the beginning of the century South American leaf blight, which is strictly confined to Latin America, has been the main factor hindering the development of rubber cultivation in this part of the world. Between 1908 and 1948, the disease was found wherever rubber was cultivated, irrespective of the size of the plantation—whether a plantation of a few thousand hectares or a small bud wood garden of one hectare.

M. ulei is present in Colombia, Bolivia, Ecuador, Peru, Venezuela, the Honduras, Guatemala and even in Mexico, which extends its distribution area up to 18°N.

In the south, the disease has spread to Brazil, first in Bahia state (in 1930) and later up to the state of Sao Paulo state (in 1960), soon after the establishment of the first plantations at latitudes quite uncommon for rubber, i.e., 24°S (Holliday, 1970).

M. ulei has been detected in Trinidad and Haiti, but is not found in Guadeloupe. This island has a quarantine station for rubber plant material transiting from America towards Asia and Africa (see the chapter on Healthy plant material and certification). Figure 4 shows the distribution of *M. ulei* as given by Holliday (1970) and Chee and Holiday (1986).

Rubber companies had to abandon their projects for establishing rubber plantations in Brazil, Surinam and Panama following very severe attacks by *M. ulei*.

Leaf anthracnose of hevea

Although leaf anthracnose of hevea rubber is present in all the continents, it is rampant mainly in Central Africa and Asia. It is caused by a fungus *Colletotrichum gloeosporoides* Penz., whose sexual form *Glomerella cingulata* (Ston.) Spauld and Schr. is almost never found on the rubber plant.

On very young leaves the disease is manifested by small red spots with a black border on the major part of the leaf blade. The tip of the leaf becomes soft, black and curled up. At this stage the leaf falls with the slightest gust of wind. On older leaves the symptoms appear at the edge of the lamina which may fall off (photo 58). The remaining part of the leaf shows large necroses around which the lamina is deformed. The parasite sporulates in the necrotic

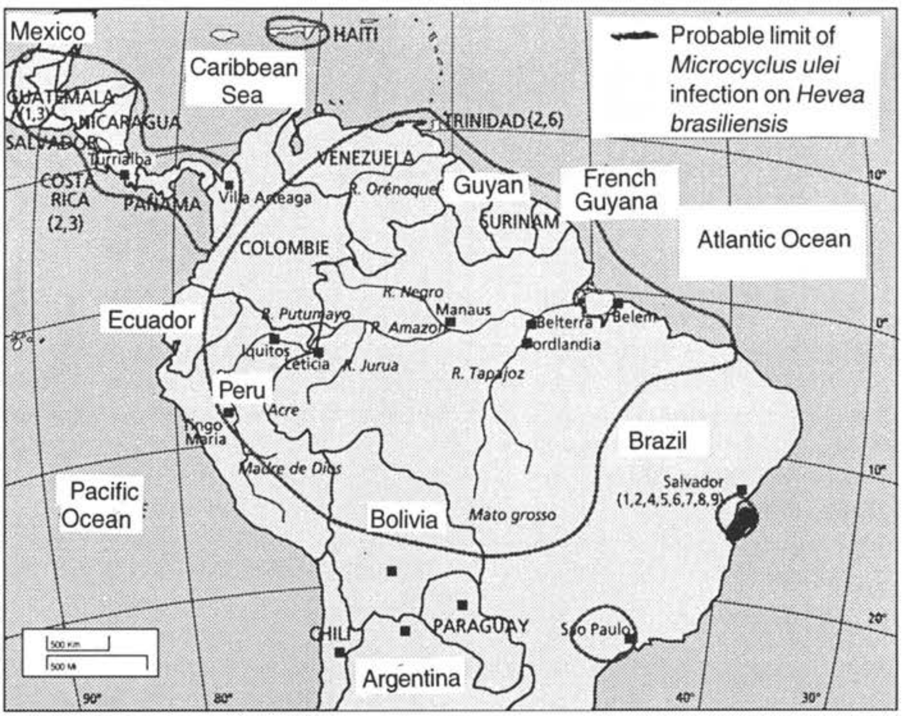

Fig. 4. Distribution of *Microcyclus ulei* (from Holliday, 1970).

areas by producing orange acervuli. Symptoms of anthracnose are also observed on the green branches as necrosis from which latex exudes. On the petioles of leaves and floral parts the symptoms are limited to small black spots. Sometimes the fruits are aborted and dry up and become areas of prolific spore production (photo 59).

The fall of young leaves and deforming necrotic spots on adult leaves lead to a reduced leaf surface and in some cases to the death (or dieback) of the terminal branches. It is difficult to make an accurate estimate of the economic loss but it is acknowledged that severe and repeated attacks slow down the growth and tire the plant due to repeated emission of new leaves (Peries, 1966; Senechal, 1986). In a plantation in Gabon planted mostly with susceptible clones, foliar density diminished by half in a span of six years (Guyot, pers. comm.).

This general weakening of the plant opens the door to other parasites such as *Botryodiplodia theobromae.* By allowing in more light and favouring the growth of grasses, it imposes frequent and prolonged maintenance of the plantations.

Corynespora leaf spot of rubber

Hevea leaves are susceptible to *Corynespora cassiicola* Berk and Curt. for about the first four weeks after the sprouting of leaves. The parasite causes brown foliar lesions which enlarge in an irregular manner. A browning of the veins characterises most of the lesions, giving rise to the expression 'fish-bone' symptoms (Breton *et al.*, 1997; Chee, 1988) (photo 60). The infected leaves gradually become yellow and then fall off. As in the case of *Colletotrichum*, repeated attacks by *Corynespora* weakens the tree. Differences in susceptibility to the parasite have been observed. This foliar disease is of great concern in Africa and also in Asia where its spread is favoured by the presence of susceptible clones. Genetic control through tolerant plant material is possible but it should take into account the extreme variability in the pathogenicity of *Corynespora cassiicola* (Breton *et al.*, 1997).

Helminthosporiosis of coconut

Helminthosporiosis of coconut, caused by *Heliminthosporium halodes* (Dresch.), is characterised by the presence of brown, usually elongated foliar spots, which are initially isolated and then become coalescent (Quillec and Renard, 1975; photo 61). The parasite sporulates on the lesions on the lower surface of the leaves, giving the symptom a dark brown and velvety appearance. These fragile spores are washed off by rain water and so well dispersed by wind that on older symptoms it is difficult and even impossible to identify the parasite when hyperparasites have invaded the necrotic tissues. The more the parasite spreads on the leaf blade, the more the centre of the spot becomes necrotic and grey and breaks up, the leaflet and the leaf assuming a laciniate aspect.

Reduction in the leaf surface, which may be considerable in susceptible cultivars, slows down the growth of plants in the nursery as well as in the field. The coconut plants thus look stunted. Coconut trees of Polynesian origin and certain coconut populations from Indonesia are susceptible to helminthosporiosis. Nevertheless it was possible to identify Polynesian cultivars that are more tolerant than others, which could be used for producing disease tolerant Dwarf × Tall or Tall × Tall hybrids tolerant to the disease. The West African Tall is particularly tolerant to helminthosporiosis and exhibits a hypersensitive reaction towards the parasite. In the case of susceptible material, standard fungal treatments are necessary in the nursery; chlorothalonil (Daconil) is particularly effective.

Coconut leaf diseases in Brazil

The warty disease of coconut, known by the Brazilian name of *lixa pequena* (small rasps), is caused by a fungus called *Phyllachora torrendiella* (Bat.) nov. comb. It is first manifested by the presence of black, slightly prominent stromata structures on the upper surface of the leaf, rachis and midrib of the leaves. These stromata become increasingly prominent on leaves of 8-10 whorls starting from the summit of the crown; they are made up of spherical, black, rugose perithecia with a dome opening through an ostiole ornamented with radial stripes (Irho, 1989). In case of severe infections, the leaflets dry prematurely, first on both sides of the midrib of the leaflets and then the necrosis spreads gradually leading to a generalised wilting of the leaf (photo 62). The middle and lower leaves lose about one-third of their assimilating surface.

Foliar damage is often aggravated by the intervention of *Botryosphaeria cocogena* n. sp., a parasite which generally grows on lesions caused by *Phyllachora torrendiella* (Subileau, 1993). Light brown necrotic areas showing a darker zonation are characteristic symptoms of *B. cocogena* (photo 63). When these necroses reach the midrib of the leaf, they lyse the tissues and a brown gummy exudate oozes out. This lysis accelerates the wilting of leaves. When primary infection begins at the tip of the midrib, wilting of the leaflets progresses from the tip towards the base of the leaf, giving the symptom a V shape (photo 64). A gummy exudate is seen at the point of insertion of the leaflets. Both the symptoms, which are often seen on the same leaf, are called *queima das folhas,* the Brazilian name for 'leaf burn' or coconut leaf blight (Warwick *et al.*, 1991). The combined action of *lixa pequena* and *queima das folhas* lead to a generalised wilting of the leaves situated below leaf no. 12. Weighed down by the fruits, the fragile leaves collapse at the point of insertion on the trunk. The peduncle of the fruit bunch breaks and is often accompanied by the fall of immature nuts, leading to loss in production which may reduce the potential yield of the coconut tree by 20-40%. These diseases are present in varying degrees in all the coconut-growing regions in Brazil. They have also been reported in French Guyana.

In Brazil, especially in the state of Para, a fungal hyperparasite, *Septofusidium elegantulum*, invades the perithecia of *P. torrendiella*, thereby interrupting the life cycle of the parasite and contributing naturally to control of the incidence of *lixa*.

CERCOSPORIOSIS

Cercospora disease of oil palm

Cercosporiosis of oil palm is a common disease in Central and West Africa. It is a foliar disease that is manifested in prenurseries and nurseries and on young palms in plantations.

Cercosporiosis caused by *Cercospora elaeidis* Steyaert is expressed by the appearance of yellow spots marked by a brown point in the middle. These spots spread, become brown and surrounded by a yellowish halo. They later assume a brown mottled aspect, scattered on the leaflets of the palm frond. A fine brownish down may cover the spots on the lower side of the leaflets. The spots spread and coalesce; the leaf blade becomes yellowish-brown, then brown and begins to dry from the tip towards the base and from the edge of the leaflet towards the midrib (photo 65). The leaf becomes grey and brittle (Renard and Quillec, 1979). The disease is propagated by conidia, which are disseminated by wind and rain. Under favourable conditions (especially when there is dew) the conidia germinate, the germinating tubes entering the leaf through the stomata. The incubation period is about 25 days (Renard and Quillec, 1977).

In the nursery, the assimilating surface of the leaf may be reduced by half and the global mass of the plant by 25-30% (Quillec and Renard, 1977). In the field, the disease is responsible for a reduction of 10% of the average number of leaves given out, 15% of the length of leaf no. 4 and 25% of the girth of the collar. Flowering is delayed in diseased plants and female inflorescences are less abundant than on healthy plants. However, we do not have precise estimates of the influence of cercosporiosis on the production of bunches.

Cercospora disease of citrus

Once called *Cercospora angolensis*, the fungus responsible for cercosporosis of citrus was recently described under the name *Phaeoramularia angolensis*. The sexual stage of the fungus is not known and there is no information available to help resolve its variability. This disease is not specific to leaves and also develops on fruits (Brun, 1972; Kuate *et al.*, 1994). The first symptoms on the leaf appear as small discoloured specks. These small lesions become bigger and are concomitantly surrounded by a yellow halo (photo 66). The spherical lesions enlarge to a diameter of 3-4 mm and then their centre dries up and the necrotic tissues break, leaving a hole in the lamina. The infected leaves fall prematurely. The damage is severe especially in the cultivation zones of medium and high elevations. Although not negligible, the damage to leaves is less than the damage to fruits (photo 67). The disease is found in Angola, where it was described for the first time in 1952 (De Carvalho and Mendes, 1953), and in a number of African countries and also in Yemen.

COFFEE RUST

Orange rust

Orange rust of coffee, caused by *Hemileia vastatrix* Berk. et Br., which actually affects only *Coffea arabica*, is characterised by the appearance of small discoloured spots on the lower surface of the leaf (photo 68).

In one to two weeks these spots are covered by uredospores from the centre to the periphery, forming a powdery orange-coloured mass (photo 69). These spots grow bigger, coalesce and form large lesions on the leaf blade and become necrotic in the middle as they age.

Photosynthetic activity is reduced and leaf fall follows. Massive defoliation leads to wilting of the branches. If defoliation is successive, the coffee plant loses its vigour and may eventually die. Several important works have been carried out by CIRAD research workers in several coffee-growing countries in Africa, Latin America, South-East Asia and Papua New Guinea. Rust attacks are more severe at medium elevations than at high elevations. Other factors such as rainfall, structure of the plantation, berry load, alternation in production from one year to another, govern the development of the epidemic and impact of the disease on the yield (Avelino *et al.*, 1991; see chapter on Rational chemical control and cultural techniques). Moreover, studies under controlled conditions (Berry *et al.*, 1987; André *et al.*, 1989) have shown that strong light favours the development of rust and intensifies its influence on the physiology of the coffee plant in terms of susceptibility of the plant and lower gas exchange between the plant and environment. This is why rust disease has repercussions on the yield of the coffee plant. Although it can be said that very severe attacks result in nil or almost nil harvests, we do not have accurate data to enable us to correctly predict the damage based on the intensity of attacks observed in the field. Recent researches conducted in the Honduras have attempted to forecast the damage by integrating the influence of all the biotic and abiotic factors comprising the environment of the coffee plant.

The disease originated in Africa but appeared for the first time in Ceylon (Sri Lanka) during the years 1860-1870 and later in Java in 1876, resulting in the almost total disappearance of Arabica in these regions. From Sri Lanka the disease quickly spread to all the coffee-growing regions in Asia. It was reported in Kenya in 1890 and is getting closer and closer to East Africa. It was detected in West Africa in 1960 and then in Brazil in 1970, from where it spread to South and Central America within a few years. It varies in intensity in all these countries and is often less serious than what was feared before it arrived. At present there is no economically important coffee production zone that has been spared by the rust.

Mealy rust

Mealy rust of coffee caused by *Hemeleia coffeicola* Maublanc et Roger is characterised by the presence of large lesions on the lower surface of the leaf on which the yellow-coloured fructifications of the parasite are found scattered. In contrast to orange rust symptoms, there is no discolouration of the lamina preceding the appearance of the spores. This is why mealy rust is not as easily detectable as orange rust. However one should not minimise the gravity of its incidence where it exists, even if defoliation is not heavy and is delayed. Studies conducted in Cameroon have shown that it disrupts photosynthesis and assimilation of phosphorus (Muller, 1980). Heavy losses in production following severe attacks of mealy rust have been reported in Cameroon.

In contrast to orange rust which is now widespread in all the coffee-growing countries, mealy rust is confined to a few countries in Africa. The disease was reported for the first time in Cameroon, on Arabica in 1929 and then on Robusta (Muller, 1954). Saccas (1951) reported it in the Central African Republic on Excelsa and Nana coffee plants. It is found mainly in Central Africa (Cameroon, Central African Republic, Nigeria, São Tomé and Angola), but has also been reported on Robusta in Togo and on wild *Coffea* in the Ivory Coast. Humidity favours its development but in contrast to orange rust, mealy rust is found at high as well as low elevations. This absence of ecological specialisation poses a threat for coffee cultivation throughout the world.

American foliar disease of coffee leaves

The American disease of coffee caused by *Mycena citricolor* (Berk. et Curt.) Sacc. was detected for the first time in Colombia in 1880. It is now found in several countries of Latin America at high elevations. The parasite induces different kinds of lesions on the leaves. The disease can be recognized by the large number of round, light to dark brown coloured spots on the leaf blade (photo 70). The tissues of these spots dry and fall off leaving holes in the leaves and eventually nothing is left of them. Other kinds of spots which are reddish in colour and angular are also found. This variability in symptoms could be due to genetic variability. Other parts of the coffee plant such as stems, branches and fruits may also get infected (photo 71).

M. citricolor, a Basidiomycetes of the Order Agaricales (Dennis, 1950), produces two kinds of fruiting bodies: gemmae, which are produced by vegetative propagation and basidiocarps, resulting from reproduction. The gemmae are lemon yellow in colour and made up of a mycelial pedicel with a globular head at its tip (which is itself mycelial) giving them a pin-head like appearance. They are 5-10 mm high and a few mm in diameter and constitute the infective component of the fungus. The pin-head (or large spore) gets detached on maturity. Basidiocarps are less common. They are found mostly on lesions of fallen leaves and are more than 5 mm high.

The disease is found in old plantations which have never been pruned and in shaded coffee plantations. *M. citricolor* has a large number of hosts (more than 500). Among them, there are many self-propagating fruit trees such as orange and cocoa. Avelino *et al.* (1995) reported that the disease is capable of causing considerable damage in coffee plantations, especially above elevations of 1200 m in countries near the equator: firstly, a direct loss due to the fall of fruits at the end of the period of physiological fall considered as normal and secondly, an indirect loss induced by defoliation which affects the production of the following year, i.e., a total loss of 36% of coffee berries in two years.

As its name indicates, the disease is found only in the American continent and in the Caribbean. In Costa Rica, growing coffee without shade has helped to reduce the damage caused by this malady. However, in the last few years American coffee disease has once again become very serious in Costa Rica and in some parts of Guatemala where the plantations are without shade.

Black stripe disease of hevea

The black stripe symptoms on hevea are caused by the growth of *Phytophthora palmivora* on the tapping panels. The disease begins with the appearance of cankerous changes on the bark accompanied by exudation of latex above the tapping cut (photo 72). The black stripes appear a few days after the beginning of the infection. The bark peels off from the wood and the intervening space gets filled with latex. This latex ferments without coagulating and oozes out as a thick brown foul-smelling liquid. If the bark is removed at this place a series of thin black parallel lines can be observed extending across the tapping panel above the notch. These black lines extend up to the wood in the form of blackish scales. From the point of infection, the infection spreads downwards to areas which have not yet been tapped and upwards in the young regenerated bark (Delabarre and Serier, 1995).

This disease is found in all the rubber-growing regions. The abundance of infection points on the same tapping panel destroys vast areas of regenerating bark, disrupts the normal functions of the tree and reduces the yield and quality of the latex. In the absence of preventive measures, the disease completely destroys the tapping panel resulting in the loss of the tree for exploitation.

Witches' broom disease of cocoa

The organism responsible for causing witches' broom disease of cocoa is a Basidiomycetes fungus called *Crinipellis perniciosa* (Stahel) Singer. The characteristic feature of this pathogen is that it attacks the vegetative tips of the plant, especially the shoot primordia, flower buds and cambial layers. The pathogen induces anomalous growth and hypertrophy of the tissues, giving the characteristic witches' broom appearance (photo 73). It also infects the young developing cocoa fruits and pods, sometimes resulting in heavy loss of pods (Thorold, 1975). A broom may be composed of a large number of infected shoots with short internodes and bear malformed leaves.

The parasite may also produce swollen lesions on the stems, without forming brooms, which are comparable to cankers. The infection causes a hypertrophy of the cushion flowers which give out vegetative shoots and abnormal star-shaped flowers, or star blooms, the whole looking like a cushion broom (photo 74). These infected floral cushion flowers produce abnormal young fruits that look like strawberries, or *chirimoyas,* which do not contain any beans and degenerate very quickly.

The spectacular nature of the infections on stems and formation of brooms have sometimes masked the intensity of infection on the young fruits and pods, which suffer the most. The symptoms on the pods are often confused by growers with those produced by *Phytophthora* or *Moniliophthora,* thus diminishing the actual impact of witches' broom disease (Evans, 1991). The infected pods are poorly developed and do not mature resulting in the total loss of yield.

This disease was reported for the first time in Surinam in 1880. It was responsible for the abandonment of cocoa cultivation in this country as well as in Guyana (South America). It is now the main limiting factor for cocoa production in many South American countries. Very little precise data is available to estimate the losses caused by witches' broom disease. Nevertheless an infection rate of 68% of pods reported from Trinidad gives an idea of the magnitude of the problem (Baker and Holliday, 1957). The death of branches and banchlets due to the disease also intervenes in the productive potential of the tree.

Losses of 80% of the pods were reported in Ecuador in the 50s and 60s. In the state of Rondonia in Brazil, high-yielding clones suffered 90% infection of the pods (Evans, 1991).

Witches' broom disease made its appearance in the late 80s in Bahia State in Brazil, the traditional cocoa-growing region of the country, causing extensive damage. The production fell from 300,000 to 180,000 tons of cocoa in 1997, leading to the abandonment of some plantations. Witches' broom disease is therefore a very serious threat for cocoa cultivation in Latin America, for which only varietal breeding can provide a satisfactory solution.

Stem bleeding of coconut

The first sign of stem bleeding is manifested by a blackish, more or less extensive spot on the stem. A blackish-brown liquid oozes out from the middle of this spot, blackening the stem over a length which may exceed 50 cm (photo 75). These irregular trails correspond to a light brown to black rotting of the stem tissues. This rot may affect a large portion of the stem as much in depth as in height. On aging the rot becomes fibrous and the cavity formed sometimes contains a clear liquid under pressure which spurts out in a jet if, for example, the bark is cut with a knife. In case of extreme dryness, we often observe the drooping leaves hanging along the trunk and premature nut fall. In extreme cases of extensive internal infection, the stem may break. In most cases, the internal rot dries up and the infected walls get cicatrised, which is a prelude to healing. However this internal cavity weakens the stem of the coconut tree. Variations of this symptom have been observed. They are seen as swellings on the stem containing brown gummy and granular concretions. This kind of symptom was considered to be the dormant symptom of stem bleeding.

In Indonesia, two mineral nutrition experiments demonstrated the important role of chlorine deficiency in the appearance of stem bleeding symptoms (Renard *et al.*, 1984), especially during periods of extreme drought. A good supply of chlorine to the coconut tree is an effective approach for controlling stem bleeding and dryness. Lastly, stem bleeding, which is often associated with the presence of *Thielaviopsis paradoxa* (de Seynes), appears more like a physiological disorder, favouring the establishment of weak parasites, rather than being a disease per se.

Bacterial diseases

Black spot disease of mango

Although the symptoms on leaves and fruits are by far the most commonly observed symptoms, *Xanthomonas* sp. *mangiferaeindicae* may cause lesions on all the aerial parts of the mango tree. The first visual signs on the leaves are small angular oily-looking spots measuring 1-3 mm and delimited by the veins. They then turn black and appear in relief on both sides of the leaves (photo 76). Most often young lesions have an oily-looking margin and are surrounded by a chlorotic halo. Old foliar lesions are brown and then become ash grey.

X. sp. *mangiferaeindicae* does not cause tree mortality but reduces the yield of susceptible cultivars, sometimes drastically, due to very heavy defoliation. Disease incidence is acute on these cultivars in all regions with concomitant hot and humid periods. The global distribution of mango black spot disease is given in Fig. 5. The disease was first observed on herbarium specimens collected from India in 1880 (Pruvost, 1989; Pruvost and Manicom, 1993; Pruvost *et al.*, 1995).

Bacterial canker of citrus

Symptoms of bacterial canker caused by *Xanthomonas axonopodis* pv. *citri* have been observed on leaves (photo 77), stems (photo 78), spines and fruits. Their morphology is quite similar on all these parts. The lesions become visible a few days after infection during the dry season. They are seen as water-soaked spots which evolve into small, white, slightly raised specks. The lesions then grow radially and become beige in colour with a corky texture and are

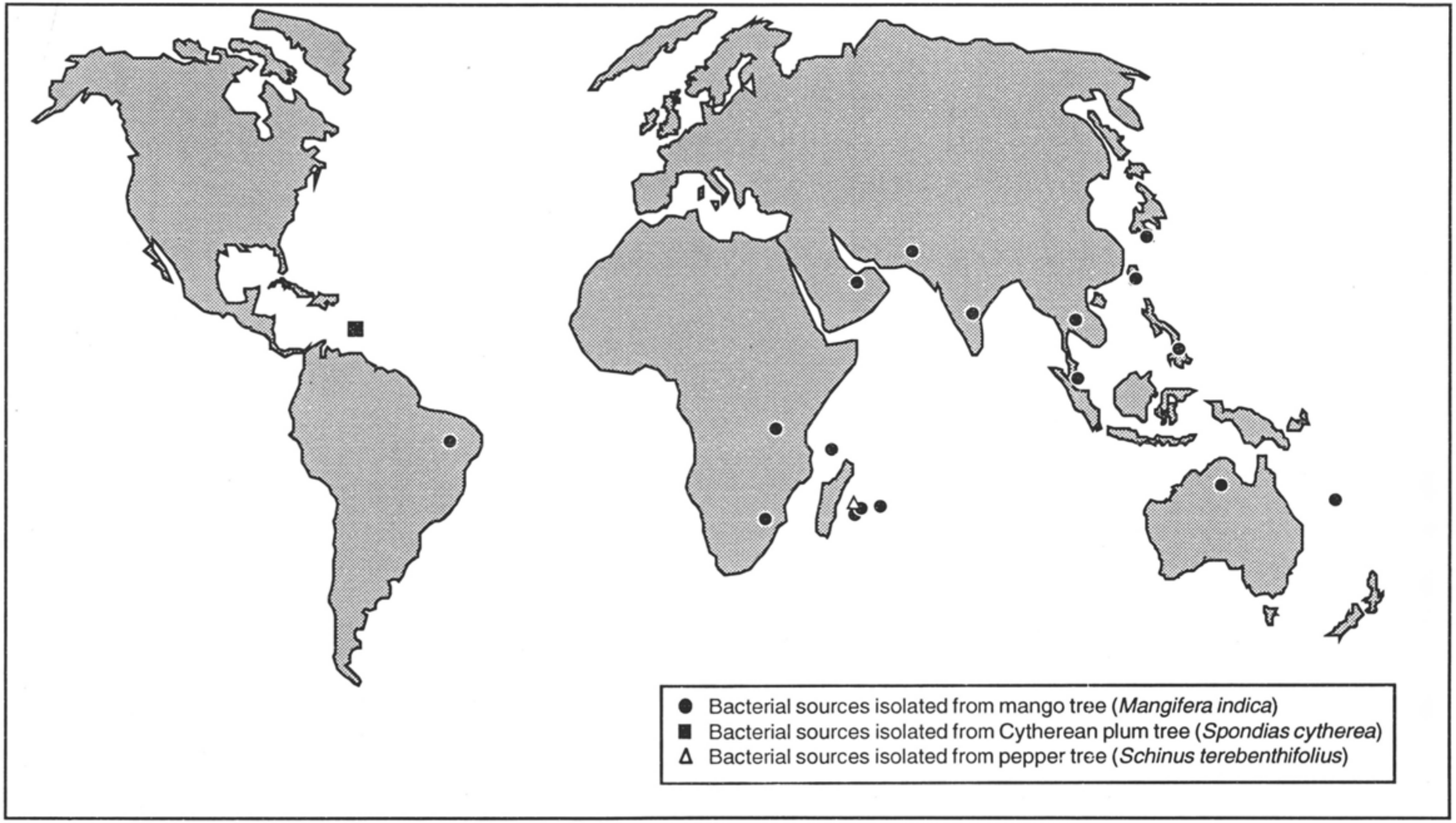

Fig. 5. Global distribution of *Xanthomonas* diseases on Anacardiaceae.

slightly raised (hypertrophy, hyperplasia). Young lesions are most often bordered by an oily looking margin. A chlorotic halo is usually visible around these lesions. Old lesions may be 1 to 1.5 cm in diameter. The symptomatology is quite characteristic and there is not much risk of committing mistakes in the visual diagnosis (Vernière, 1992).

Xanthomonas axonopodis pv. *citri* does not kill the trees but it can cause fairly severe defoliation in susceptible hosts. Generally speaking, the incidence of citrus bacterial canker on these citrus cultivars is high in all regions where the hot and humid seasons are concurrent. The potential gravity of this disease has led some countries (United States and member countries of the European Union) to impose strict quarantine regulations (Vernière, 1992). The global distribution of bacterial canker is given in Fig. 6. This disease was first observed on herbarium specimens collected in India in 1830. It is most probably of Asian origin.

FRUIT DISEASES

Although these diseases do not affect the life of the tree, the yield may be partly or almost completely destroyed. Most of these infections are caused by fungi.

Phytophthora rots

Brown pod rot of cocoa

Brown rot of cocoa pods is curiously called black pod rot by English speaking authors, which may lead to a confusion with the black rot of cocoa pods. It is caused by several species of *Phytophthora*, but for a long time it was believed to be only one species, viz., *P. palmivora* (Butler) Butler. Many other species are also responsible for brown rot. *P. citrophthora* is found in the Ivory Coast, *P. capsici* is abundant in Brazil, *P. megakarya* (Brasier et Griffin) is found only in Central Africa (Cameroon, Gabon, São Tomé and equatorial Ghana) and West Africa (Nigeria, Togo and Ghana). *P. megasperma*, which is confined to Venezuela, causes a soft rot. Brown rot is one of the most serious diseases of cocoa because of its economic impact, the fruits alone getting destroyed whatever may be the stage of their development (photo 79). It is also one of the most spectacular because of its sudden and inevitable appearance with rainfall. The infection generally begins at the distal or peduncular end of the fruits. A necrotic spot with a translucent halo delimits the infected zone which becomes brown more or less rapidly depending on the varieties (Blaha and Lotodé, 1976). The beans are affected even before the fruit rots fully, which takes about 3 to 10 days. The sporocysts which are produced on the necroses are powdery and greasy to the touch. They liberate the zoospores which

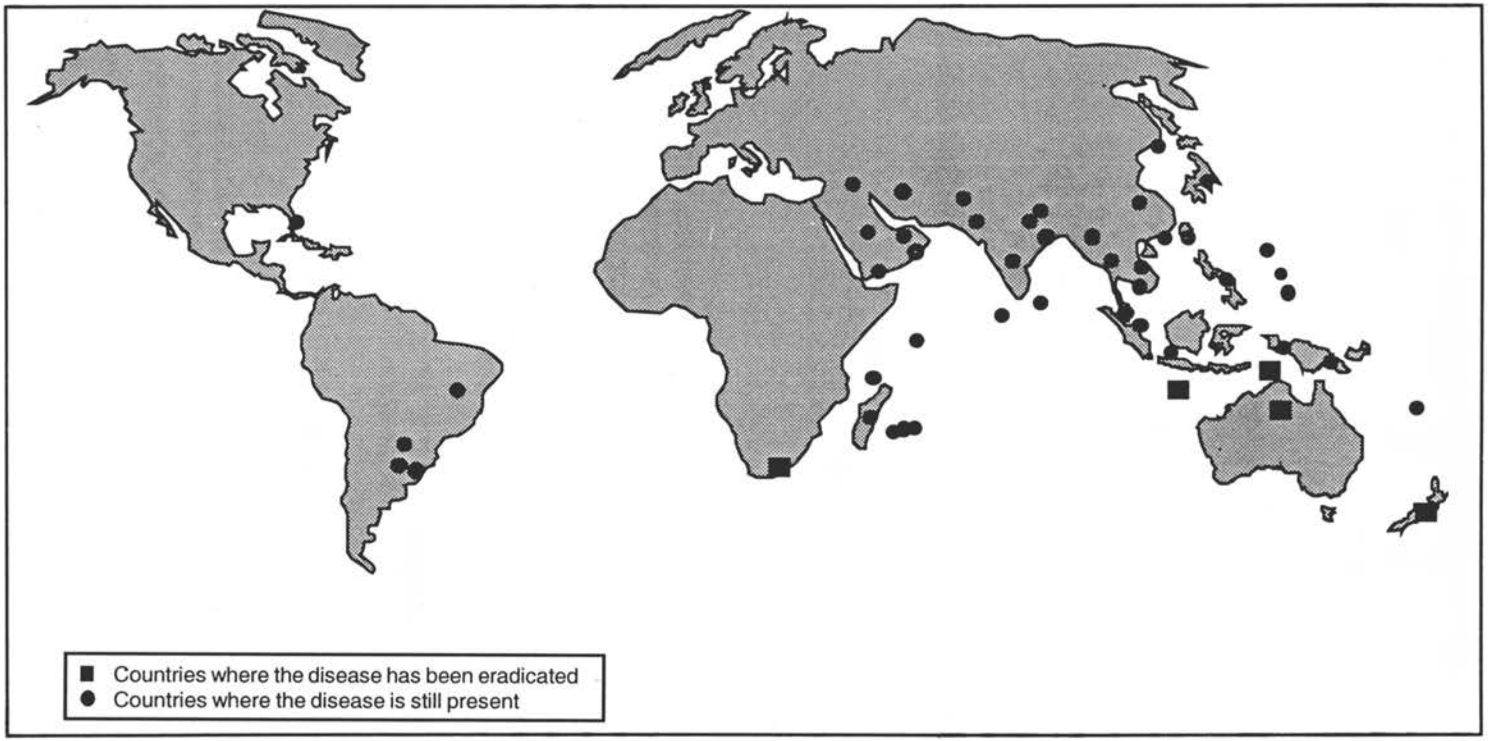

Fig. 6. Global distribution of Asian citrus canker.

infect the neighbouring fruits. The intensity of autoinfection by pod to pod contamination is related to the density of fruits on the trunk. Cauliflory makes the pods on the trunk more vulnerable to infection than those on fronds where the different spatial position may delay the epidemic kinetics by one to two weeks (Costa Deus Lima *et al.*, 1994) .

Although the symptoms of infection induced by the different species conform globally to the description just given, they can nevertheless be distinguished. For example, the infection front is a regular line in the case of *P. palmivora* while it is very sinuous with isolated diseased areas in front of the general infection line in the case of *P. megakarya* (photo 80). The habit of citing brown pod rot as a pathological entity may be eventually changed in order to attribute a specific disease to each of the species involved.

At the global level, the losses may be as high as about 30% of pod production. They may vary from one country to another: 15-20% in West Africa, Ivory Coast and Ghana; 30-75% in Nigeria; more than 50%, even 80-95% in cocoa farms in Cameroon and *P. megakarya* dominated areas in Gabon and equatorial Guinea (Jouve and Milly, 1990). In Latin America, the losses could be equally severe on the economic scale: 20-30% in Brazil, 20% in Venezuela, 20-40% in Mexico (Ortiz-Garcia *et al.*,1994). In South-East Asia (Malaysia and Indonesia) and the South Pacific (Papua New Guinea), the steep increase in the area under cocoa cultivation during the last fifteen years and counter-selections have now made the impact of *Phytophthora* diseases much more perceptible (Blaha, 1996).

PHYTOPHTHORA ROT OF COCONUT

Phytophthora rot of coconut is characterised by mottling which is light brown in the middle, yellow at the periphery and oily in appearance (photo 81). The infection generally begins around the floral parts or in the equatorial part of the coconut, particularly in the region of contact between the nuts. On the surface the rot extends towards the apex of the nuts and in depth towards the shell. The infected husk turns form brown to black. The rot may enter through the germinating pores of the coconut, killing the embryo and lysing the albumen. At a more or less advanced stage of the infection the nuts fall down and their kernel cannot be used for preparing copra.

Nut rot is independent of bud rot and, depending on the place and cultivars, the two kinds of rot may or may not coexist on the same tree. It may cause the premature fall of 20 to 25% of the immature nuts in some village plantations of Yellow Dwarf × West African Tall hybirds in the Ivory Coast (Franqueville and Renard, 1989). In some seed-gardens of Yellow Dwarf coconut in Indonesia, 50% nut fall has been recorded (Thévenin *et al.*, 1995).

Black pod rot of cocoa

Black rot of cocoa pods is generally attributed to *Botryodiplodia theobromae* Pat.

Necrosis caused by *B. theobromae*, which affects the cortex of the fruits (photo 79) and then the pulp and beans gives rise to a characteristic soft rot and hence the term soft pod rot often used to designate this rot. In the final stage, the pod is completely covered by a black powder which looks like soot and so there is no room for confusion with any other kind of rot. Considered a parasite of wounds or a weak parasite (Blaha, 1989), the fungus generally causes very little damage to the pods. On other parts this fungus may be found associated with other microorganisms such as *Calonectria rigidiuscula*, which it accompanies in the descending trachaeomycosis of cocoa capable of causing the death of the tree. This fungus enters through wounds caused by bug bites.

Moniliosis of cocoa pods

The symptoms of moniliosis are observed mainly on the pods. The first signs of the disease are manifested by the appearance of oily specks. Deformation of pods (photo 82) follows the intracellular growth of the parasite fungus (*Moniliophthora roreri* Cif. et Par.), which stimulates cambial activity. Brownish-black irregular lesions then appear and quickly invade the entire surface of the pods. A white mycelium grows on the surface, followed by a profuse production of spores which form a thick creamish to greyish-brown coloured felt. The internal tissues become disorganized. A wet rot develops and the cocoa beans cannot be used (Thévenin and Trocmé, 1996; photo 83). The perfect stage of this fungus is not known. Reproduction is by means of conidia produced in basipetal chains from the mycelium. *M. roreri* is a semi-biotrophic fungus because its life cycle passes through two phases: one is the germination of conidia at the time of intercellular invasion of the pods, and the other is the necrotic phase when the fungus invades the cells. One of the important characteristics of the disease is the very long incubation period, which is 3 to 6 weeks depending on the age of the fruit. The long incubation period of the spores and their transport over long distances are the important elements which govern the formulation of strategies for controlling this disease.

The disease was reported for the first time in Ecuador in 1914 (Desrosiers *et al.*, 1955) and was responsible for a steep fall in production in the 20s (Petithuguenin and Roche, 1995). The disease then spread to Peru and later to Colombia and Venezuela. In 1956 it appeared in Panama (Orellana, 1956) and in 1978 in Costa Rica (Enriquez and Suarez, 1978). For a long time confined to the west of the Andean range, the disease was reported in the zone east of Peru in 1988 (Hernandez *et al.*, 1990). Losses are always heavy and may affect 90% of the harvest. An average of 15 to 50% is common in many countries (Evans, 1986).

Anthracnosis of fruits

ANTHRACNOSIS OF MANGO, AVOCADO AND PAPAYA FRUITS

Anthracnose of mango, avocado and papaya fruits is the term commonly used to describe the disease caused by *Colletotrichum gloeosporioides* (Penzig) Sacc., a parasite common to these three fruits. In many regions this infection is considered to be one of the most important limiting factors affecting the quality of the fruits and making them either unsuitable for export or unmarketable when they reach the distribution circuits (Mourichon, 1987).

Although the characteristic symptoms of this disease appear only at a late stage in the development of the fruits and generally after harvesting, the contamination may have taken place at the time of fruit setting and during the months following it. This infection takes place by means of conidia issuing from cankers on stems or from foliar necroses and transported by rain water (droplets, streaming). The conidia germinate on the surface of the fruits and produce a special penetrating structure called the appressorium. The fungus then stops growing at this stage and undergoes a latent period which may last several months, depending on whether the variety is of the early or late type.

ANTHRACNOSIS OF ARABICA COFFEE BERRIES (COFFEE BERRY DISEASE)

Colletotrichum kahawae sp. nov. (Waller *et al.*, 1993) is responsible for causing anthracnose of Arabica coffee berries. The disease is manifested on fruits at all the stages of their development, but only the symptoms on young fruits enable an accurate diagnosis. Two kinds of lesions may be observed.

Lesions called 'active', are brown and slightly shallow, which coalesce and give rise to a wet rot of the pulp and seeds and ultimately fruit fall (photo 84). When atmospheric humidity is high, pink coloured acervuli of the parasite appear in a concentric manner on the surface of the spots and liberate the conidia which are the dispersal organs of the disease.

Lesions of the scab type generally increase in number during the prematuration period. These spots are slightly shallow with irregular edges, light brown in colour and have a slightly corky aspect. They do not have a serious effect on the yield nor on the quality of the seeds.

The damage caused by *C. kahawae* may be confused in South America, especially in Brazil, with the blackening of berries resulting from the anthracnose of leaves and branches (dieback) caused by another *Colletotrichum* sp.

Anthracnose of coffee berries, or coffee berry disease, is strictly restricted to *Coffea arabica* and is specific to fruits. When infection is severe the leaves and branches remain free of lesions. This particular feature should be considered as one of the important elements for a correct diagnosis (Muller, 1980). The disease, which was discovered in north-west Kenya in 1922 (MacDonald, 1926), gradually spread to eastern Kenya in 1939 and then to most countries in East and Central Africa: to the Democratic Republic of Congo in 1937, Cameroon in 1955, Rwanda in 1957, Uganda in 1959 and Tanzania in 1964.

The disease was reported in Ethiopia only in 1971 and in Malawi, Zimbabwe and Zambia in 1985. This disease confined to the African continent and only to the coffee-growing regions at high altitudes, affects only a small part of the producing regions at the global level. However, it is a formidable scourge which can destroy more than 80% of the production when conditions are favourable for the parasite (Aubin *et al.*, 1993). This is why active research is being continued as it still represents a serious potential threat for Arabica-producing countries outside Africa. Very often the presence of black berries borne on wilted branches lead inexperienced observers to think that it is this disease whereas it is only dieback.

The coincidence of climatic factors favourable for the development of the parasite with the optimal susceptible phases of the fruit determine the gravity of the disease (Berry *et al.*, 1991), as well as the strategy for the application of phytosanitary treatments.

Bacterial diseases of mango and citrus fruits

Bacterial diseases found on the leaves also develop on the fruits.

In the case of black spot of mango caused by *Xanthomonas* sp. *mangiferaeindicae*, the first symptoms on the fruits appear in the form of small water soaked lesions concentrated around lenticels or wounds. They then become black with a crater-like appearance (photo 85). They are most often 8 to 10 mm in diameter but can attain 15 mm. The lesions extend to a depth of about 8 to 10 mm inside the flesh. Very often a highly infectious gummy substance is exuded, causing secondary infection along its flow (Pruvost *et al.*, 1995). This disease induces a heavy fall of young fruits and even if they mature it is impossible to market them.

Bacterial citrus canker, caused by *Xanthomonas axonopodis* pv. *citri*, induces small lesions on the fruits (photo 86), which are quite similar to those observed on the leaves. Only the superficial tissues of the fruits are affected. This disease greatly depreciates the external quality of the fruit. In susceptible cultivars the yield may also be considerably reduced due to the fall of unripe fruits.

CONCLUSION

The study of plant diseases has been presented first by an analysis and detailed descriptions of the symptoms, which are summarised in Table 1, followed by the identification of the causal organism.

This observation phase accompanies the development of the disease, over time (on the plant) and space (in the plantation or in a cultivated or natural population of the species). Furthermore, the incidence of the parasite on the

Table 1. Major diseases of tropical tree crops and their symptoms

Plants	Roots, collar	Trunk, stems, branches	Leaves	Fruits
Citrus	Gummosis (*Phytophthora*)	Gummosis Tristeza (virus) Stem pitting Decay (*Ceratocystis*)	Greening (bacteria) Tristeza (wilt) Wilt (*Ceratocystis*)	Greening (bacteria) Bacterial canker (*Xanthomonas*)
Fruit trees	Avocado wilt (*Phytophthora*)		Avocado wilt (secondary) Black spot of mango (bacteria)	Anthracnose of fruits (*Colletotrichum*) Black spot of mango
Oil palm	Marchitez (trypanosomatids) Basal rot (*Ganoderma*)	Heart rot (pathogen?) Fusarium wilt (*Fusarium*) (in section) Red ring (nematodes)	Marchitez (secondary) Ring spot Fusarium wilt (secondary effect) Cercosporiosis	Marchitez (secondary)
Coconut	Hartrot (trypanosoma)	Heart rot (*Phytophthora*) Dry bud rot (virus?) Red ring (nematode)	Hartrot (secondary) Helminthosporiosis Dry bud rot Lethal yellowing (phytoplasma) Cadang-cadang (viroid)	Hartrot (fall) *Phytophthora* Lethal yellowing (nut fall)
Coffee	Wilt (*Armillaria*) Wilt (nematodes)	Trachaeomycosis (*Fusarium*) (visible in section)	Trachaeomycosis (secondary effect) Decay (secondary effect) Orange rust (*Hemileia*) American disease (*Mycena*)	Berry anthracnose (*Colletotrichum*)
Cocoa		Witches' broom (*Crinipellis*) (*shoot tips*)	Swollen shoot (virus)	Brown pod rot (*Phytophthora*) Moniliosis (*Moniliophthora*)
Hevea	Fomes (*Rigidoporus*) Armillaria (*Armillaria*)	Black stripe (*Phytophthora*)	South American leaf blight (*Microcyclus*) Anthracnose (*Colletotrichum*) *Corynespora*	

vegetative growth has also been noticed, as also the consequences on the production in order to assess the losses in yield.

During the last fifty years a lot of information has been acquired regarding diseases of tropical tree crops. Considerable progress has been made in combating these diseases, through the selection of tolerant or resistant varieties, agronomic methods and chemical control strategies.

Despite the spectacular results, the spread of these diseases remains a reality. The parasites can overcome resistance factors learnedly incorporated into new varieties, can adapt to the new chemical molecules developed and reach new territories and new continents till then untouched by the disease. Diseases, hitherto unreported, have appeared and the etiology of some of them is still not known.

This general situation is partly due to the extraordinary development of agriculture and its intensification in the tropical zone. It is also the consequence of the formidable power of almost all the causal organisms to adapt thanks to their extreme genetic diversity. Finally, the plant and its pathogen carry on a relentless battle in the centre of which the plant pathologist and other specialists have a preponderant place. At present descriptive studies are increasingly giving place, out of necessity, to extensive researches on the structure of pathogen populations, their variability and host-parasite relationship. The second part of this work presents the knowledge acquired in these domains by CIRAD during the last twenty years with respect to the most important pathogens of the tree crops studied.

By giving preference to integrated control methods, researches on the causal organisms help to envisage the development of tolerant varieties adapted to different ecological situations. With the development of in vitro culture and new genetic techniques used for obtaining resistant varieties, the agriculturist will have a wide array of control methods at his disposal in the third millennium.

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2

Pathogens

Michel Dollet

The indispensable phase of describing abnormal or decaying symptoms of cultivated plants is necessarily accompanied by an etiological investigation. The first step is to determine whether the origin of the anomaly is biotic or abiotic. This work deals only with abnormalities resulting from infections. This diagnosis is not always easy and requires the close collaboration of agronomists and plant pathologists. For this, the pathogen presumed to be infectious should not only be isolated, but its pathogenicity must also be proved by satisfying Koch's postulates.

Pathogenic fungi were the first organisms to be recognized as responsible for causing diseases in plants. There are a large number of them causing diseases of leaves, roots and fruits, or systemic diseases leading to general decay. For a long time the identification of fungi was based on morphological criteria, which are found to be increasingly imperfect, finer criteria enabling a better separation of confused species: this is the case, for example, with two species of *Phytophthora* on cocoa, which are distinguished thanks to karyological observations. Physiological criteria and sexual compatibility have also helped to refine the distinction between fungal species. More recently, cellular and molecular biology techniques have become valuable tools for this identification. However, although the identification of fungal species is primordial, we observe that genetic variability (including variability of pathogenicity) within a species is of increasing interest to the pathologist and geneticist.

Bacterial diseases were discovered much later—at the end of the 19th century—and in the world of tropical tree crops, the cause of citrus greening disease, after several controversies, was attributed to phloem-restricted bacterium only in the 1970s.

Lethal yellowing of coconut, known since the end of the 19th century in Jamaica, could be associated with the presence of phytoplasmas (MIO, mycoplasma-like organisms), organisms whose discovery in the plant world dates back to only 1967, thanks to the availability of electron microscopes in plant pathology laboratories.

Virus infections constitute a group of diseases, knowledge of which is relatively recent. The advent of the electron microscope, which helped to visualise some viruses, and the development of biophysical and biochemical purification techniques as well as molecular biology techniques for their identification and characterisation, have helped to demonstrate the viral origin of certain diseases.

The world of viroids was discovered only recently, during the period 1970-1975. Despite their small number, viroids—about twenty have been identified—are responsible for some of the diseases of tropical tree crops.

Marchitez disease of oil palm and hartrot of coconut have led to the discovery of a new kind of plant pathogen: trypanosomatids, organisms which had nevertheless been reported since the 1930s on coffee plants in Surinam.

Nematodes are also included among the pathogens causing diseases in tropical tree crops. They are often responsible for lethal diseases in oil palm, coconut and coffee.

Lastly, the etiology of wilts—and there is every reason to think of them as a disease because of their symptomatology and their method of propagation—is still completely unknown. In such situations, the techniques available for identifying the causal agent have not been successful up to now. Are we to think that there are still some bioaggressors waiting to be discovered at the borders of the world, already very vast, of known pathogens? The demonstration of prions in animals during the last decade permits us to answer in the affirmative.

Despite the importance accorded to environmental factors and plant materials, we realize increasingly that the pathogen, taking into account its variability, constitutes one of the important elements intervening in host-parasite relationships. This is why researches are focused on the study of the genetic diversity in a good number of fungal parasites. The genetic diversity of the host cannot be dissociated from such studies (the case of orange rust of coffee with its rather numerous races is a very typical example). The use of enzyme markers and molecular biology techniques has helped to refine studies on the structure of pathogenic fungal populations irrespective of the host. This has resulted in a better management of integral control methods using resistant sources, a better comprehension of the development and forecasting of epidemics, increased efficacy of phytosanitary measures and quarantine regulations. These new methods of investigation have opened encouraging prospects towards solving the problems posed by diseases.

FUNGI

Numerous are the plant diseases caused by fungi in the tropical world. Temperatures that are often high, together with a quasi-permanent humidity, present optimal conditions for the growth of parasitic fungi, telluric as well as aerial. Most often, the major pathogens responsible for the most serious diseases have spread rapidly thanks to the intensification and expansion of crops, thus giving rise to epidemics. Pronounced and transitory alternations in the climate making the plant highly susceptible to a latent pathogen (for example, *Verticillium dahliae* on cocoa and *Thielaviopsis paradoxa* on coconut) also lead to the development of characteristic disease syndromes.

TELLURIC DISEASES

Rots

The term rot expresses a pathological syndrome characterised by an alteration in the cortical and ligneous tissues of roots leading first to wilting and eventually to the death of the tree. The fungi responsible are the Basidiomycetes, *Rigidoporus lignosus* (Klotzsch) Imaz. (white rot), *Phellinus noxius* (Corner) G.H. Cunn. (brown rot), *Ganoderma philipii* or *pseudoferreum* (Bres. and P. Henn.) Bres. (red rot), *Helicobasidium compactum* (Boedijin) Boedijin (purple rot) and *Armillaria heimii* (crack rot), as well as an Ascomycete, *Sphaerostilbe repens* Berk. and Broome (collar and root cankers). The importance of the works undertaken by CIRAD in West Africa enabled it to pay special attention to the havoc caused by *R. lignosus* (*Fomes lignosus*) (Kl) Bres., agent of white rot of rubber (*Hevea*), and *A. heimii*.

Rigidoporus lignosus

Rigidoporus lignosus, a fungal parasite of the roots of a large number of forest and cultivated tree species, belongs to family Polyporaceae of the Class Basidiomycetes. When the forest is felled, the conditions become favourable for the development of *Fomes*, which quickly invades the stumps of the felled trees. They thus become the infection sources, threatening rubber trees in a radius of sometimes more than 40-50 metres. Propagation is generally by mycelial filaments of the rhizomorphs, which spread either through the roots of the colonised hosts, or freely through the soil.

Armillaria heimii

The fungus obtained from extracts taken from four sites in rubber plantations in Gabon shows homogeneous morphological characteristics that are different from those of European *Armillaria*. The species was identified as *Armillaria heimii* (Michels, 1990). This species, earlier described under the name *Clytocybe elegans*, is a Basidiomycetes belonging to family Agaricaceae. Comparisons of colonies showed tetrapolar sexuality (Petit-Renaud, 1991) as in the European species. It is thus related to species of the genus *Armillaria* of temperate regions.

Clitocybe elegans

An abundance of fructifications of an Agaricales is found growing at the base of diseased coffee plants. The analysis of these carpophores has helped to remove the taxonomic ambiguity of this fungus (Blaha, 1978). There is no annulus or, when there is one, it is not characteristic of *Armillaria*. Moreover, the wide variability in dimensions, such as the diameter of the pileus and length of the stipe, is similar to the description of *Clitocybe (Armillariella) elegans* (Heim.). New molecular techniques used nowadays to characterise microorganisms will enable us to confirm these data. As seen earlier, other agents cause different kinds of rots on coffee and cocoa.

FUSARIUM OXYSPORUM F. SP. *ELAEIDIS* (SCHLECHT) TOOVEY

The organism responsible for causing wilt in oil palm is a filamentous fungus specific to this plant: *Fusarium oxysporum* f. sp. *elaeidis*, which belongs to Class Hyphomycetes of the Division Deuteromycetes (Fungi Imperfectii) without known sexual reproduction. It is one of the most common *Fusarium* species in the soil, where it can survive several decades thanks to its resistant form, viz., the chlamydospores.

It is characterised by three kinds of asexual spores: chlamydospores are the resistant forms; microconidia are uninucleate spores produced in the phialides borne on aerial mycelia; and macroconidia are small spores produced either on branched conidiophores in the sporodochia, or directly on the aerial mycelium.

The last two types of spores may be produced in the vascular bundles of infected plants; microconidia are the dominant type there.

The only way of differentiating the strains of *F. oxysporum*—whether they belong to the same special form or not—is generally by the inoculation test on host plants. Fraselle (1951) reproduced the disease symptoms by inoculating oil palm seedlings with this strain. *Fusarium oxysporum* f. sp. *elaeidis* is the only special form capable of causing wilt in oil palm (*Elaeis guineensis*). Its biological and ecological characteristics are the same as those of other *F. oxysporum*.

The genetic diversity within *Fusarium oxysporum* f. sp. *elaeidis* populations was investigated by studying vegetative compatibility groups (Vcg), enzyme polymorphism analysis (Dossa *et al.*, 1991; Dossa, 1993) and by using molecular markers (Mouyna *et al.*, 1996).

Mouyna (1994) isolated a molecular marker which enables the differentiation of *Fusarium oxysporum* f. sp. *elaeidis* strains from all other strains of *F. oxysporum*.

A wide diversity was demonstrated by the characterisation of 21 vegetative compatibility groups. No relationship was observed between the groups obtained and their geographic origin or pathogenicity. On the other hand, a particular group contained strains from Benin, Ivory Coast, Brazil and Ecuador, which was confirmed by enzyme polymorphism analysis. The molecular study not only showed that the strains of *Fusarium oxysporum* f. sp. *elaeidis* are subdivided into several subpopulations corresponding to geographic boundaries, but it also confirmed the affinity between Latin American strains and those from the Ivory Coast.

Verticillium dahliae Kleb.

Since 1960, eco-fungal wilt of the branches of cocoa trees has been attributed to *V. dahliae*. In 1968, a closely related species, *V. albo-atrum* Rke and Berth (Trocmé, 1972), was isolated in Uganda. The pathogenicity of these two species of *Verticillium* can be demonstrated at the level of the root system, or with a pure culture of the fungus or with a spore suspension. We can also infect a tree by making a notch in the bark up to the wood and then applying a culture of *V. dahliae* on it. The degree of infection is almost 100% near the base of the trunk. However, such intense pathogenicity is expressed only under stress conditions.

Diseases of aerial parts

Phytophthora

In the vast majority of cases, *Phytophthora* species are soil organisms. Because of their development on aerial parts such as coconuts, cocoa pods and tapping panels of rubber trees and the influence of aerial factors (rainfall, hygrometry, wind, temperature) on their growth and on the epidemiology of diseases, *Phytophthora* have been placed among aerial pathogens. Root and collar rots of citrus and avocado linked to *Phytophthora* are strictly telluric diseases. Nevertheless, here they will be treated along with other phytophthoras.

Phytophthora disease of cocoa

Brown rot of cocoa pods (also called black pod of cocoa) caused by *Phytophthora* is considered to be the most harmful disease of cocoa from the economic point of view. The extent of losses depends on the environment, the type of cocoa cultivated, as well as the species of *Phytophthora* responsible for causing the disease. The characterisation, for a long time based on the morphology of the organs in their life cycle (Babacauh and Partiot, 1976), was mired in numerous controversies. The hegemony accorded to *P. palmivora* Butler was often challenged because of its association with other forms. Physiological and especially karyological criteria (presence of 6 large chromosomes in *P. megakarya* whereas *P. palmivora* has 12 small chromosomes) have helped to improve the identification keys and led to the emergence of the new species, *P. megakarya*.

Between 1984 and 1996, isoenzyme profiles made it possible to identify representative genotypes as much from gene flows as from the evolution within a genus (Tooley *et al.*, 1985; Blaha, 1988, 1994, 1995; Oudemans and Coffey, 1990; Ortiz-Garcia, 1996). Among the systems studied in 17 species of *Phytophthora* at CIRAD, 21 enzyme systems were found to be active, 8 showed a good resolution and 6 had very good resolution (Fig. 1). Moreover, the

Locus used: *Idh-2*, *Pgi* and *Mdh-1*

I	*Idh*-2, if allele C	*P. katsurae*
II	*Idh*-2, if allele D	*P. megakarya*
III	*Idh*-2, if allele E	*P. palmivora* (*P. arecae*)
IV	*Idh*-2, if allele F	*P. meadii*
V	*Idh*-2, if allele G	*P. parasitica*
VI	*Idh*-2, if allele H	*P. botryosa*
VII	*Idh*-2, if allele I	
	a. *Pgi*, if allele A	*P.* MF4 typical
	b. *Pgi*, if allele B	*P. citrophthora*
	c. *Pgi*, if allele C	*P.* MF4 typical
	d. *Pgi*, G	
	d. 1 *Mdh*-1, if allele B	*P.* MF4 atypical
	d. 2 *Mdh*-1, others	*P. capsici**

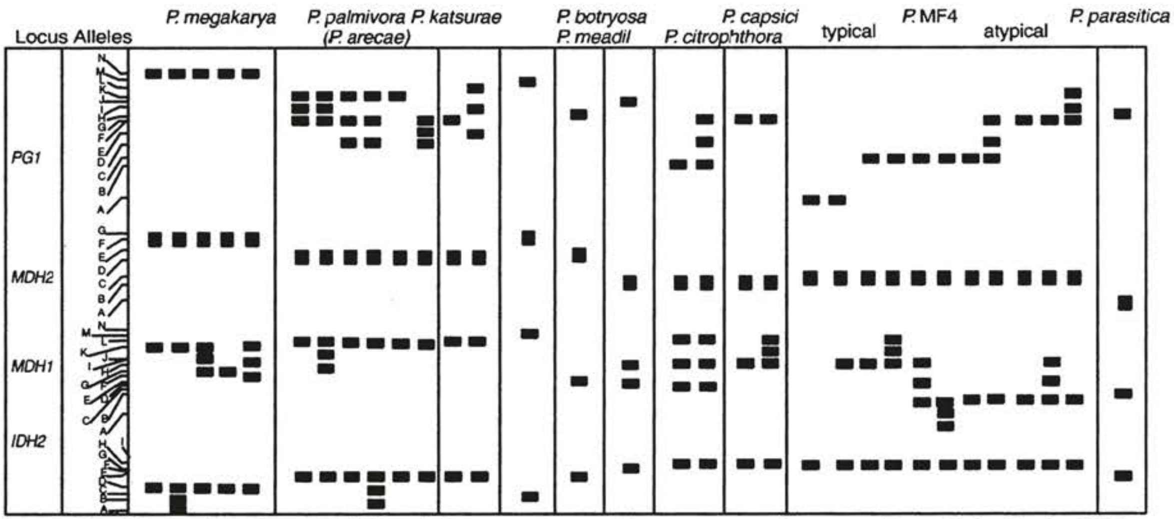

Fig. 1. Biochemical key for the identification of *Phytophthora* species parasitic on cocoa and coconut (from Ortiz-Garcia, 1996).

diploid cycle and heterothallism of *Phytophthora* parasites on cocoa emphasize—by the presence of heterozygotes or homozygotes—the recombinants or allelic segregations which are not only evidence of the presence of a locus (or loci) capable of coding a given enzyme, but also of genetic links between morphologically distinct species (Blaha, 1994).

The genetic diversity of *Phytophthora megakarya* isolates from some countries of Central Africa (Cameroon, Gabon and Sao Tomé) and West Africa (Nigeria, Togo and Ghana) was studied using biochemical (isoenzymes) and molecular (RAPD) markers. Two groups were identified, corresponding to the biogeographic distinction observed in other plants and organisms in Africa. This suggests the existence of two populations of *P. megakarya* (Nyasse, 1997).

As *Phytophthora* species have a mobile phase—the zoospores which are also responsible for infection—attacks are linked to the presence of water in which these zoospores swim before they get attached to the epidermis of the pod and penetrate it. This is the reason why most often the infections begin in places where rain water persists. Several observations have shown that in the case of *P. megakarya*, soil is the most important effective source of primary inoculum. Consequently contamination takes place first on the lowest pods which are in contact or in close proximity with the soil, through raised mounds of infested soil caused by rain splash, and the infection advances increasingly closer to the pods which are higher and higher (Muller, 1974).

On cocoa (Ortiz-Garcia *et al.*, 1994), *P. palmivora* is found in all the tropical zones; *P. arecae* in Indonesia, the Philippines and the South Pacific; *P. megakarya* in West Africa (Cameroon, Gabon, Equatorial Guinea, Sao Tomé, Nigeria, Togo and Ghana); *P. capsici* and more rarely *P. parasitica* in Africa (Cameroon), Central America (Costa Rica and Mexico), South America (Brazil), Caribbean (Cuba, Trinidad and Tobago) and South-East Asia (Malaysia and Indonesia).

Phytophthora disease of coconut

A network research programme has helped to specify the role played by the various species of *Phytophthora* associated with bud rot and nut rot diseases. The results were obtained from observations of morphological characters and isoenzyme analysis (Blaha *et al.*, 1994).

The studies clearly indicated the predominance of two species: *P. palmivora* in Indonesia and the Philippines and *P. katsurae*—earlier identified as *P. heveae*, a closely related species—in the Ivory Coast (Brasier, cited by Quillec *et al.*, 1984). Moreover, it was shown that the two species coexist in Jamaica (Steer and Coates-Beckford, 1990). *P. arecae* and *P. nicotianae* are also present in Indonesia, but seem to be less involved in the etiology of the disease.

Phytophthora disease of citrus

A number of species of *Phytophthora* have been reported on citrus plants, the most important ones being *P. parasitica, P. citrophthora, P. citricola* and *P. syringae*. A study of the distribution of *Phytophthora* species specific to clementines was carried out between 1978 and 1980 in Corsica (Vallavieille, 1983). More than a hundred isolates were collected from different levels of the tree. The morphology of the sporocysts of the majority of these isolates indicated that they belonged to group II (Waterhouse classification). A study of the maximum temperatures for growth helped to distinguish a majority of sterile *P. citrophthora*, a few heterothallic *P. nicotianae* f. sp. *parasitica* (A1 or A2) and finally some rare isolates belonging to group III that were identified as homothallic *P. citricola*.

The *Phytophthora* population in citrus orchards therefore appears to be well adapted to the climatic conditions in Corsica. Nevertheless we may suppose that the selection of *Phytophthora* species is not guided by climate alone but is also influenced by the physiology of citrus, and hence the whole pathosystem constituted by the host and its parasite. Thus an isolate of *P. citricola* was found to be particularly active on Seville orange trees while some isolates of *P. citrophthora* showed very pronounced pathogenic activity on Citrange Troyer. It is evident that *Phytophthora* isolates capable of growing on grafted rootstocks considered as resistant are now quite rare in Corsica, but their presence indicates that an adaptation phenomenon is slowly underway (Vallavieille and Perrier, 1981).

Phytophthora disease of avocado

P. cinnamomi, which causes avocado wilt, like other species of the genus *Phytophthora*, produces three kinds of spores: zoospores that are liberated from sporocysts under certain conditions, chlamydospores and oospores. The production of sporocysts is stimulated by various bacteria of the *Pseudomonas* type and depends greatly on the climatic conditions and pH of the soil. The zoospores are liberated in groups of about thirty and play an important role in the dissemination of the disease by contaminating irrigation water and streams. Chlamydospores represent the resistant forms of *P. cinnamomi*. Oospores are produced following the crossing of heterothallic strains of complementary A_1 and A_2 strains, or directly by homothallic strains. These crosses give rise to wide variations in the morphology, physiology and pathogenicity within the *P. cinnamomi* species (Huguenin *et al.*, 1975).

Phytophthora disease of rubber

The disease symptoms of bark stripes are caused by *P. palmivora*. The infection is propagated when the spores come into contact with the deep tissues of the bark following tapping. The spores germinate when humidity is high and enter the cambial cells killing them. The infection then spreads to the neighbouring tissues of the bark and wood only if atmospheric humidity is high. On the other hand, a dry climate arrests the infection and favours the formation of scar tissue. The asexual reproductive organs are sporangia, which are generally produced on the surface of the infected parts. They are varied in shape and produce zoospores that are liberated in the presence of water. These zoospores then germinate on the surface of the tissues of the rubber plant.

COLLETOTRICHUM

The genus *Colletotrichum*, with its perfect stage *Glomerella*, includes fungi causing diseases on a large number of plants in temperate and tropical countries. These diseases, manifested as dark spots on the fruits and leaves, are called anthracnoses. They are characterised by the presence of asexual fruiting bodies, the acervuli, which are initially subepidermal but open on maturity to liberate a large number of spores (conidia).

Colletotrichum gloeosporioides on *Hevea*

C. gloeosporioides Penz. (Melanconiales) causes anthracnose of the leaves. Its sexual stage is *Glomerella cingulata* (Ston.) Splaud et Schr. (Pyrenomycetes, Sphaeriales) and is almost never found on *Hevea*. The disease is severe on young leaves only during the rainy season. Fungal attacks are the points of entry for other parasites such as *Botryodiplodia theobromae*.

Colletotrichum coffeanum

The nomenclature of this pathogen, which causes anthracnose of Arabica coffee berries (coffee berry disease), has been revised several times. Mac Donald (1926) identified the causal agent from infected berries and differentiated it from the *Colletotrichum* borers from small branches. This distinction was confirmed by Rayner (1952) who reserved the name *C. coffeanum* Noack variety *virulans* for pathogenic strains on berries to distinguish them from saprophytic strains.

Hindorf (1970) took up the description of *C. coffeanum* and identified five species of *Colletotrichum* and one perfect form, *Glomerella cingulata*, capable of causing disease symptoms on coffee plants. He demonstrated the pathogenic form only in the berries. It is characterised by the absence of the perfect stage, a greenish-grey or olive green mycelial colony with poor growth, the absence of acervuli and conidia which are larger than those of other forms of *C. coffeanum* Noack. This strain was identified as *C. coffeanum* Noack *sensu* Hindorf.

According to Waller *et al.* (1993), the nomenclature of the pathogen responsible for causing coffee berry disease was confused and its taxonomic position continued to be debated. Hence, based on a large number of earlier works and their own research, these authors proposed the introduction of a new species, *Colletotrichum kahawae*, on the basis of morphological characters, pathogenicity and carbon nutrition of this pathogen. They have largely adopted the criteria defined by Hindorf (1970) and Mac Donald (1926).

The study of pathogenic diversity at the level of the African continent (Bella Manga *et al.*, 1997) using the vegetative compatibility group technique has demonstrated the presence of two subpopulations corresponding to two geographic zones: one group representing East African strains and the other representing strains originating from the Cameroon zone. Nevertheless, isolates showing genetic compatibility between the two subpopulations have been identified, which leads us to suppose a common origin for these two groups which may have become locally diversified. Until now, analysis of the pathogenicity of these populations has never clearly demonstrated the presence of interactions between the host and the pathogen. On the other hand, a variability in the aggressiveness of the pathogen has been regularly observed in studies under controlled conditions (Berry, 1997).

Colletotrichum gloeosporioides of fruit trees

Anthracnose of mango, papaya and avocado trees is a disease caused by *Colletotrichum gloeosporioides*. Although the disease often appears after harvesting, the contamination could have taken place at the time of fruit setting and in the following months through the conidia issuing from cankers on the stem or from foliar necrosis. These conidia germinate on the surface of the fruits and produce penetrating structures called appressoria. The fungus then stops growing at this stage and a latent period of varying duration follows.

The appressorium stage is the latent form in the *C. gloeosporioides*-avocado association, whereas in the *C. gloeosporioides*-mango or -papaya associations the appressoria give out a penetration hypha (mechanical action associated with fungal cutinase activity) which grows in the subcuticular cell layer before being momentarily stopped.

Coffee rusts

Hemileia vastatrix Berk. et Br.

The fungus responsible for causing orange rust of coffee*, *H. vastatrix*, was identified in 1869 by Berkeley and Broome (Saccas and Charpentier, 1971). This parasite belongs to subfamily Hemileia of family Pucciniaceae, Order Uredinales. All the possible stages in the life-cycle of fungi belonging to this group have not been observed; only the uredial, telial and basidial stages have been described. Dissemination is ensured by vegetative propagation, by means of uredospores.

In India, Mayne (1932) experimentally demonstrated the presence of physiological races in Coorg and Kent varieties. He described four different races by their virulence spectrum corresponding to specific reactions observed on a range of hosts.

The works of CIFC (Centro de Investigaçôes das Ferrugens do Cafeiero) in Portugal (Rodrigues *et al.*, 1975) have helped to further our knowledge on the relationships between *Coffea* spp. and *H. vastatrix*. The interactions are governed by a specific type of genetic system in which 9 host-specific susceptible genes, named SH1 to SH9, correspond gene for gene (according to Flor's theory) to 9 virulent genes, v1 to v9, of the pathogen. Race II (v5) is the one that has been most commonly detected up to now. The reaction is compatible when the

* leaf rust

fungus has all the virulent genes corresponding to the susceptible genes of the host. In the opposite case, the reaction is incompatible. The SH genes are dominant except for SH4 (Eskes, 1989), which confers total resistance only when in the homozygote state and under strong light conditions.

Discovery of the SH genes was gradual. The presence of these SH genes, alone or in association, determined the creation of differential coffee groups for the pathogen races. From 1980, the genetic structure of *C. canephora* for resistance to *H. vastatrix* began to be described through the analysis of the progeny of natural interspecific crossings such as the Timor hybrid or artificial crossings with *C. canephora*. Thus, *C. canephora* has a series of specific resistance genes: SH6, SH7, SH8 and SH9, defining the five differential coffee groups, A, R, 1, 2 and 3. These genes can be overcome by rust races having the virulence genes v5, v6, v7, v8 and v9, associated in various combinations. In contrast to that which was observed in the case of the virulence genes v1 to v5 (Lombardo Gil Fagioli *et al.*, 1987), the accumulation of *C. canephora* specific virulence genes in the same genotype does not seem to reduce its aggre-ssiveness (Holguin Melendez, 1993). The analysis of virulence genes based on the classifications proposed by Cifc led Eskes (1989) to separate the races into four groups.

Group 1 includes two pathogen races which are exclusive to universal differential plants (*C. excelsa* Longkoi 168/2 and *C. racemosa* 369/3).

Group 2 contains 14 pathogen races in the Arabica differential and universal differential groups. They have the v5 virulence gene in common, combined in various ways with the v1, v2, v3 and v4 genes.

Group 3 is constituted by 8 pathogen races in the Arabica, interspecific hybrid and universal differential groups. They have the v5 and v6 virulence factors in common, which may be associated with other virulence factors.

Group 4 comprises 7 pathogen races in the Arabica and universal differential groups, as well as in at least one of the interspecific hybrid or diploid coffee groups. They are characterised by the absence of the v5 virulence factor.

Forty physiological races, designated from I to IL, have been distinguished to date.

Hemileia coffeicola Maublanc et Roger

The life-cycle of *H. coffeicola*, responsible for causing mealy rust disease of coffee, is still not fully known. Experimental infections are possible, as in the case of *H. vastatrix*, but they are more delicate, especially because of the difficulties in preserving the spore-producing strain. In contrast to *H. vastatrix*, the production of uredospores in *H. coffeicola* seems to cease after one or two extractions. Like *H. vastatrix*, *H. coffeicola* also enters through the stomata, the germinating filaments of the uredospores being incapable of directly piercing the cuticle. Roger (1953) has emphasized that the peculiar aspect of the mycelium and its distribution in the leaf raises a question on the mode of infection and growth. As the sori, together with the few filaments which give rise to them, are isolated from one another, it appears that each of them results from the germination of a single uredospore.

OTHER AERIAL PATHOGENIC FUNGI

Microcyclus ulei (Henn.) V. Arx.

The causal organism of the South American leaf blight of *Hevea* was found for the first time in its perfect state in 1900: on *Hevea* in Brazil. However, it was only in the 1960s that it was given a specific name which is recognized even today: *M. ulei*, an Ascomycetes species belonging to Order Dothideales. *Fusicladium macrosporum* Kuyper represents the conidial stage and *Aposphaeria ulei* Henn, the pycnidial stage.

The fungus exhibits three morphologically different stages corresponding to three types of spores: conidia, pycnidiospores and ascospores (Fig. 2). The perfect form is characterised by a sooty stromatic mass, especially on the upper surface of leaves. These structures produce conceptacles which may become laterally fused. The asci are clavate and contain 8 elongate ascospores. The pycnidia are grouped in stromatic masses at the periphery of necrotic tissues or at the edge of the lamina. They are black and contain the pycnospores, which are small in size and bulging at the two extremities. The imperfect form (conidia) is characterised by green spots on the lower side of young leaves. Germination of conidia often begins in the apical cell. Liyanage (1981) observed that the pycnidia could be colonised by a hyperparasite of the genus *Botrytis*. There is also another hyperparasite which attacks the perfect form of *M. ulei*: *Dicyma pulvinata* (Berk. et Curt.) Arx.

The fungus is isolated by means of its conidia or even ascospores. *In vitro* sporulation is obtained by a daily exposure to ultraviolet radiation for 30 minutes for 14 days or by incubating at 24°C in alternating light. The conidia germinate in less than 12 hours in water, the ascospores in 4 hours.

The conidia may be preserved for 3 months in dry conditions. The infected leaves of *Hevea* produce ascospores after 21 days and over a period which may continue until defoliation, i.e., around 9 months. In young plantations, survival of the fungus during the dry season is assured by the perfect form on adult leaves. In older plantations, the heterogeneity of the natural defoliation-refoliation phenomenon contributes effectively to the maintenance of large quantities of the inoculum (Rivano, 1992).

Since 1960, it has been observed that the resistance acquired in materials obtained from interspecific crossings was overcome by *M. ulei*, which was able to develop new pathotypes or new physiological races.

Study of the variability of the fungus began in Brazil and was continued in Guyana. Inoculation of a range of 10 differential clones with 16 isolates of *M. ulei* revealed the presence of 7 virulence factors and 12 races of *Microcyclus*, which gives the fungus a high capacity to diversify when faced with the host population (Rivano, 1992, 1997).

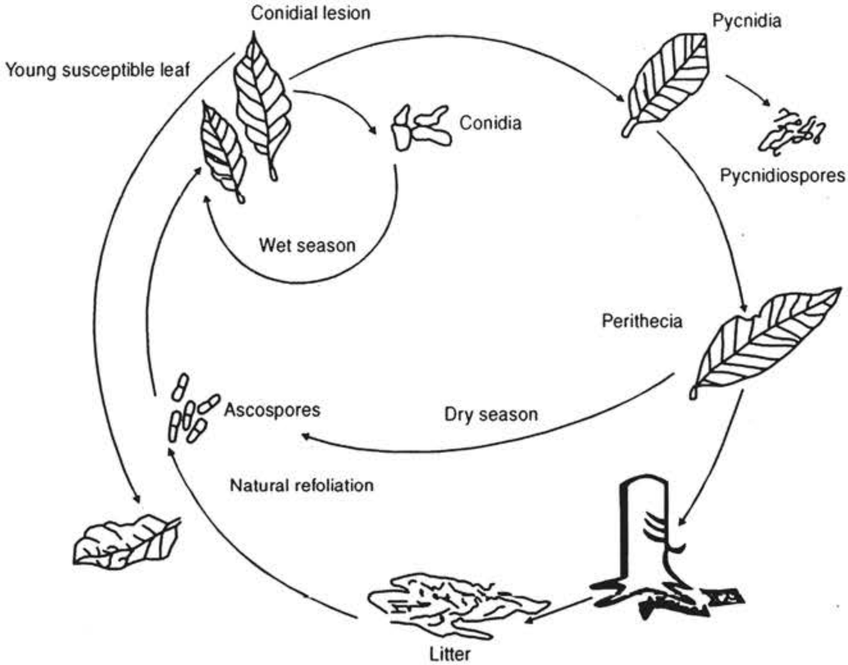

Fig. 2. Life cycle of *Mycrocyclus ulei* (from Rivano, 1997).

Phyllachora torrendiella (Batista) comb. nov.

The coconut warty disease, known by the Brazilian name of *Lixa pequena*, is caused by an Ascomycetes species whose taxonomic position remained controversial for a long time. The study of this pathogen undertaken by Renard (1989) and Subileau (1993) established the existence of two kinds of structures. The first type is subcuticular, black, lenticular in shape, and on maturity liberates unicellular spores which play the role of spermatia. These spores do not produce symptoms. The stromata, corresponding to spermagonia, produce lozenge-shaped symptoms in the initial stages of the disease. The second type of structure, which is superposed on the former, is made up of prominent black, spherical, rugose stromata with a dome opening out through an ostiole. These stromata contain the perithecia which, on maturity, liberate a gelatinous whitish mass of asci and paraphyses early in the morning. The asci are enveloped in a thin mucilaginous sheath and enclose 8 hyaline fusiform ascospores containing granular cytoplasm. Disease symptoms can be reproduced by spraying a suspension of ascospores on the lower side of the leaflets. These characteristics led Subileau (1993) to identify the pathogen as *Phyllachora torrendiella*.

Botryosphaeria cocogena and *Botryodiplodia theobromae* (Pat.)

The causal agent of *queima das folhas* in coconut (or coconut leaf blight) is

Botryosphaeria cocogena. The subepidermal, slightly projecting perithecia are produced on the brown lesions. They enclose the asci containing 8 fusiform to ovoid ascospores. The pycnidia generally appear earlier than the perithecia on the same lesions; it is difficult to distinguish the perithecia with the naked eye. The pycnidiospores, or conidia, produced in the pycnidia are hyaline in the immature state and then become oval, brown and bicellular. Morphological studies, cultural aspect, isoenzyme analysis and inoculation tests led to this fungus being identified as a new species and given the name *B. cocogena* nov. sp. (Subileau, 1993; Subileau *et al.*, 1994). Control of in vitro culture from a culture of monoascospores or monoconidia helped to establish that *B. cocogena* is monothallic and monoecious.

Isoenzyme electrophoresis has demonstrated the diversity of *Botryosphaeria* and helped to reveal a group directly linked to a pathogenicity of coconut leaves (Warwick *et al.*, 1994). The parasite enters through a wound. In nature, coconut leaves have several injuries but the stromata formed by *P. torrendiella* offer an easy point of entry, so much so the two parasites constitute a perfect parasitic complex.

Black rot of cocoa pods is generally attributed to *Botryodiplodia theobromae*, conidial stage of the genus *Physalospora* belonging to Sphaeropsidales (Stevens cited by Roger, 1993), which has since been linked to the perfect form, *Botryosphaeria rhodina* (Subileau, 1993). The mature bicellular conidia, which show browning and longitudinal striation, help in identifying the anamorphosis.

However, the remarkable polyphytism of *B. theobromae*, observed on more than a hundred hosts, should prompt identification methods other than morphological and biometric diagnoses. These other methods now range from giving prominence to specialized races resulting from cross infections to searching for molecular markers (through isoenzymes).

It was in this way that parasitic specialisation of *B. cocogena (Lasiodiplodia theobromae)* on coconut was verified and *B. rhodina (B. theobromae)* recognized as a non-pathogen (Subileau *et al.*, 1994). Besides, for other species of *Botryodiplodia* and the perfect forms of *Botryosphaeria*, acidic phosphatases (Acp) on acrylamide gels were found to be more suitable for classifying the strains of *B. theobromae* and were at the same time more discerning than esterases (Est), malico-enzyme (Me) and isocitrate dehydrogenase (Icd) (Subileau, 1993). Identification of the different electrophoretic types obtained from *Botryosphaeria* isolates has not only confirmed the possibility of species characterisation with the help of isoenzymes, but also demonstrated that there could be a diversity within the same species (Warwick *et al.*, 1994).

Crinipellis perniciosa (Stahel) Singer

The organism responsible for causing witches' broom disease on cocoa is a Basidiomycetes fungus called *C. perniciosa*. This pathogen was earlier described as *Marasmius perniciosus*. This name is still often used although it was reclassified under the genus *Crinipellis* by Singer in 1942.

Evans (1980) divided the life cycle of the fungus into two distinct phases. There are two types of mycelia which are genetically and physiologically dissimilar. The first is found in swollen and hypertrophied green tissues and the mycelia grow between the cells but do not invade them. The second has hyphae of a different kind and penetrates the dead cells. In the first phase, the fungus is typically parasitic. In the second, it is saprophytic; this mycelium later produces white to slightly pink carpophores which give rise to basidiospores. It is only after the death of the plant's tissues that the fungus can complete its life-cycle. The basidiospores are capable of infecting all growing meristematic tissues of the cocoa plant, giving rise to various kinds of symptoms depending on the cultivar, type of tissue infected and its stage of development.

Two kinds of *C. perniciosa* populations are found on cocoa: population A, comprising isolates from west of the Andes (Ecuador, Colombia, Bolivia), provokes a severe reaction on the descendants of clone Sca 6. Population B, which is found east of the Andes (Brazil, Trinidad and Tobago, Venezuela), induces a limited reaction to inoculations. Andebrhan and Furtek (1994) have confirmed this distinction through molecular analysis: random amplified polymorphic DNA analysis (RAPD).

Bacteria

This section deals only with those prokaryotes whose walls are partly made up of glucopeptides. Most of the bacteria can be identified quite easily because they can be observed under a light microscope and grow rapidly on fairly simple culture media. Only a few intraphloemic and intraxylemic bacteria, earlier called Rickettsia-like organisms (RLO), are difficult or impossible to culture. Very widespread in the plant kingdom, they do not pose great dangers for the plants studied by CIRAD except for tropical fruit trees, especially *Citrus*.

Xanthomonas axonopodis pv. *citri*

Only in 1915 was it demonstrated that the canker disease of citrus, or Asian canker, was caused by bacteria. Several *Xanthomonas* species cause diseases in citrus plants. Until recently they were considered to be variants (called pathotypes) of the same causal organism, *X. campestris* pv. *citri*. A taxonomic study of the genus *Xanthomonas* led to a modification in nomenclature (Table 1). In some cases the different taxa could be differentiated on the basis of their host range in the family Rutaceae, their aggressiveness on indicator hosts and by the morphology of the lesions they cause.

On agar media (LPGA, SPA or equivalent), the morphology of the colonies is very characteristic of the genus *Xanthomonas*: they are yellow in colour, round and bulging with a shiny aspect. *Xanthomonas axonopodis* pv. *aurantifolii* strains grow more slowly than other strains.

Table 1. Characteristics of the various *Xanthomonas* species on citrus

Old nomenclature (*X. c.* pv. *citri*)	Hosts	Geographic distribution	Symptomatology	New nomenclature
Pathotype A	Very wide range among wild and cultivated Rutaceae	More than 30 countries	Eruptive lesions with rupture of the epidermis	*X. axonopodis* pv. *citri*
	Mexican lime tree (*C. aurantifolia*)	Middle East (Saudi Arabia, Oman, Iran) and India	Eruptive lesions with rupture of the epidermis	*X. axonopodis* pv. *citri*[2]
Pathotype B	Mainly on orange and lime trees, weakly aggressive on other citrus	South America (Argentina, Uruguay, Paraguay)	Eruptive lesions with rupture of the epidermis	*X. axonopodis* pv. *aurantifolii*
Pathotype C	Mexican lime tree (*C. aurantifolia*)	Brazil	Eruptive lesions with rupture of the epidermis	*X. axonopodis* pv. *aurantifolii*
Pathotype D[1]	Mexican lime tree (*C. aurantifolia*)	Mexico		*X. axonopodis* pv. *aurantifolii*[3]
Pathotype E	*Poncirus trifoliata* and its hybrids	Florida	Non-eruptive brown lesions	*X. axonopodis* pv. *citrumelo*

[1] The causal organism is a fungus of the genus *Alternaria*. The majority of *Xanthomonas* isolated are not pathogenic on citrus plants. Only one pathogenic strain has been isolated. It is phenotypically and genetically very similar to strains of ex-pathotype B.
[2] These strains constitute a new serogroup.
[3] This name is given for the only pathogenic strain isolated.

A number of techniques (biochemical, serological, lysotypic, genetic) help to identify the various *Xanthomonas* pathogens of citrus plants (Pruvost *et al.*, 1992a; Pruvost *et al.*, 1994; Vernière *et al.*, 1992; Vernière *et al.*, 1993).

Xanthomonas sp. pv. *mangiferaeindicae*

The real causal agent of the black spot disease of mango was identified only in 1948. It was called *Pseudomonas mangiferaeindicae*, and later *Pseudomonas campestris* pv. *mangiferaeindicae*. A recent study on the taxonomy of genus *Xanthomonas* did not include representatives of this taxon. As long as its taxonomic position is not specified, it is recommended that it be called *X.* sp. pv. *mangiferaeindicae*.

Non-pigmented (the most common case) and yellow pigmented (typical of the genus *Xanthomonas*) strains were isolated from lesions on mango (Pruvost, 1989) and other Anacardiaceae, such as the pepper tree, *Schinus terebinthifolius* (Pruvost *et al.*, 1992b) and Cytherean plum tree (*Spondias cytherea*) (Rott and Frossard, 1986). The cashew tree (*Anacardium occidentale*) has also been described as a host.

Analysis of the phenotypic and genetic diversity (assimilation profiles of carbon sources, sensitivity to a range of antibiotics and salts of heavy metals, RFLP) indicate that the non-pigmented strains isolated from mango trees in Brazil, the yellow pigmented strains isolated from mango trees in several countries and the non-pigmented strains isolated from Cytherean plum trees in the West Indies, are clearly distinct from the typical strains of *X.* sp. *mangiferaeindicae* (Gagnevin *et al.*, 1997). Experiments with other RFLP markers have demonstrated the existence of four groups of genomes within the typical strains of *X.* sp. *mangiferaeindicae.* Two groups (A and C) are constituted by strains isolated from mango trees and have a wide geographic distribution. Group B contains only strains isolated from mango trees and originating from Asia, while group D consists of strains isolated only from the pepper tree. The haplotypes describing the strains isolated from the pepper tree were never obtained from strains isolated from mango, not even in the case of mango trees growing in the proximity of infected pepper trees. The role of the pepper tree as a possible storage host of the inoculum should be specified through epidemiological studies.

PHYTOPLASMAS

It was not until 1967 that these microorganisms, which can be observed only under an electron microscope, could be demonstrated in plants. At that time they were designated as *Mycoplasma*-like organisms, or MLO, because they could not be cultured in vitro and hence could not be described. These plant pathogens were often associated with yellows-type plant diseases and until 1967 these yellows were believed to be caused by viruses. More than 300 diseases caused by Mycoplasma-like organisms have been recorded in the tropics. CIRAD undertook studies on this type of pathogen which is particularly devastating on coconut. It must be noted that IOM* recently adopted the generic term *Phytoplasma* for all *Mycoplasma*-like organisms of plants and insects that cannot be cultured in vitro and are not spiral (in contrast to *Spiroplasma*).

Phytoplasmas of coconut and oil palm

PHYTOPLASMAS CAUSING LETHAL YELLOWING DISEASE OF COCONUT

For long considered to be a disease of viral origin, all these lethal yellowing diseases were finally associated with the presence of intraphloemic *Mycoplasma*-like organisms (Beakbane *et al.*, 1972; Dollet and Giannotti, 1976; Dollet *et al.*, 1977b; Nienhaus *et al.*, 1982; photo 87). Molecular biology techniques (PCR, RFLP) now enable the characterisation of phytoplasmas even in the absence of in vitro culture.

* International Organization of Mycoplasmology

DNA amplification of the gene coding rRNA helps to distinguish the phytoplasmas causing various kinds of yellowing diseases. These techniques seem to indicate that the phytoplasmas causing lethal yellowing disease in Florida are very closely related to those causing the lethal disease in Tanzania, but it is nevertheless possible to distinguish them by at least one restriction enzyme (Harrison *et al.*, 1994).

The same molecular biology techniques have enabled the comparison of the various lethal yellowing diseases with one another. Thus, the phytoplasmas of coconut in Tanzania are identical to those found in Kenya. On the other hand, they differ from those associated with Cape St. Paul wilt (Ghana) and Akwa disease (Nigeria). Of all these phytoplasmas associated with lethal yellowing in Africa, the ones closest to those of lethal yellowing in the Caribbean are those of East Africa (Jones *et al.*, 1995). This variability in the phytoplasmas of coconut may be responsible for the differences observed in the varietal tolerance to lethal yellowing (see Chapter on 'Varietal Resistance').

PHYTOPLASMAS CAUSING BLAST DISEASE OF OIL PALM AND COCONUT

Since the works of Robertson (1959) and until the mid-1970s, it was generally accepted that blast disease was due to the combined infection of the fungi *Pythium splendens* Braun and *Rhizoctonia lamellifera* Small.

Ultrastructural studies of palms affected by the blast disease revealed a large number of bacteria with rippled walls similar to the *Rickettsia*-like organisms (Dollet, 1980) now called *Xyllela fastidiosa*. These organisms had been observed but never described and probably cause only secondary infections. In fact Renard (1982) showed that preventive treatment with tetracycline on hydroponic crops provided protection against blast disease, whereas controls without treatment or treated with penicillin showed a disease rate of 60-68%.

Ultrastructural observation in the initial stage of the blast disease enabled the detection of round organites about 200 to 800 nm in diameter, which could be phytoplasmas. Lastly, the insect vector of blast disease transmits a yellowing disease, which is associated with phytoplasmas, to the Madagascar periwinkle, *Catharanthus roseus* (Dollet, 1980, 1985). Although Koch's postulates have not been verified, everything points to the disease being caused by phytoplasmas.

VIRUSES

The absence of a cold season and the perennial nature of the plants studied at CIRAD are unfavourable for the development of a large number of viruses which are sometimes highly localised (swollen shoot virus of cocoa, coconut foliar decay) and sometimes very widespread (citrus tristeza virus).

Citrus tristeza virus

The virus responsible for causing tristeza disease on citrus (CTV, citrus tristeza virus) is a flexuous, filamentous virus (photo 88) measuring 12 × 2000 nm, confined to the phloem and transmitted by aphids in a semi-persistent way. It belongs to the closterovirus group (Bar-Joseph and Lee, 1989). Its genome is a monocatenary RNA of about 20 kd. The gene sequences of the capsid protein are known for a number of isolates. The CTV genome also codes a replica of the capsid gene with a molecular weight of 27 kd, expressed in vivo and which may be involved in transporting the virus inside the plant. The CTV isolates are divided into four groups based on their pathogenicity. The largest groups are those comprising isolates which cause wilting (decline-inducing isolates, D-1) and stem pitting (Sp isolates). Others may cause yellowing in young Seville orange, pomelo and lime seedlings. The last symptom (yellowing) is used for diagnosing the most harmful isolates.

Characterisation takes into consideration the biological indexing of five species (lime, Seville orange, pomelo, orange rootstock and orange grafted on Seville orange) and serology. The various monoclonal antibodies developed have helped to establish at least twenty serogroups. CTV can be detected in two ways. Biological indexing is based on the observation of a lightening of the nerves and the appearance of stem pitting after grafting on Mexican lime. This method does not enable the identification of CTV isolates of the K strain type (Bové *et al.*, 1988). Serological detection is by Elisa tests with polyclonal and monoclonal antibodies (Caruana and Chabrier, 1993). Finally, the DTBIA method (direct tissue blotting immuno assay) was found to be better adapted and as sensitive as the Elisa test (photo 89).

The technique of molecular amplification of a part of the viral genome by immuno capture RT-PCR enables detection which is a thousand times more sensitive. It helps to detect the virus on aphid vectors.

Cocoa swollen shoot virus

Purification of the cocoa swollen shoot virus put a considerable brake on its characterisation because of the mucilage present in the ground tissues which gets oxidised very quickly. It was not until 1964 (Brunt *et al.*, 1964) that this virus was described for the first time as a bacilliform particle. The collaboration of CIRAD with INRA in the 1980s enabled the actual identification of this virus.

The cocoa swollen shoot virus (CSSV) is a bacilliform virus measuring about 12 × 28 nm, and contains a double-stranded DNA (Lot *et al.*, 1991; photo 90). This virus belongs to the *Badnavirus* group. A complete copy of the CSSV genome was cloned and then sequenced (Hagen *et al.*, 1993). It contains 7161 base pairs and 5 open reading frames capable of coding proteins of more than 10 kd. Region 3′ contains matching sequences characteristic of pararetroviruses.

This virus sequence is responsible for the disease because a complete genomic clone of the virus reproduces disease symptoms when cocoa beans are bombarded with a particle gun (Hagen *et al.*, 1994). The plants that grow from these bombarded seeds react positively in serology and dot-blot tests, and viral particles could be observed in them under an electron microscope.

Coconut foliar decay virus

Coconut foliar decay virus (CFD) was often confused with lethal yellowing, but it had never been possible to detect *Mycoplasma*-like organisms and treatment with tetracycline did not have any effect (Julia *et al.*, 1985). An etiological hypothesis of a viroid having evolved separately from those of cadang-cadang (Philippines) and Tinangaja (Guam island) diseases was also considered, but such a viroid could not be identified (Dollet, 1985).

A single-stranded DNA specifically associated with the CFD syndrome was demonstrated in 1986 (Randles *et al.*, 1986). Later, icosahedral viral particles about 20 nm in diameter were detected, associated with this circular single-stranded DNA of 1291 nucleotides (Randles and Hanold, 1989). It was a new type of virus sharing similarities with both the geminivirus of plants as well as with the porcine circovirus.

VIROIDS

Several diseases presumed to be caused by viruses remained unknown for several years because it was not possible to purify the presumed virus. It was only in the 1970s that the concept of viroids was mooted in pathology. They are circular single-stranded RNA molecules closed by covalent bonds and containing regions with matching bases. They are the smallest pathogens known to date: 246 nucleotides in the smallest viroid, the one causing cadang-cadang in coconut and 463 in the largest.

Until now they are known only in plants and just about twenty have been described, classified into two main groups (A and B).

Coconut cadang-cadang viroid

Cadang-cadang disease, which is caused by a viroid (CCCVd), mostly affects coconut but also oil palm and, to a lesser extent, another palm, *Corypha elata*. The viroid has four forms: two base forms with 246 or 247 nucleotides and two forms with a repeated region, of 296 and 297 nucleotides.

A closely related viroid (64% sequence homology with CCCVd) called Tinangaja viroid is found in Guam island where it causes a debilitating disease, called the Tinangaja disease, on coconut but without any serious economic repercussions (Boccardo, 1985).

According to Hanold and Randles (1991), nucleotide sequences similar to that of CCCVd, called coconut cadang-cadang viroid-like sequences, have been demonstrated in various palms in several countries. On the basis of these molecular hybridizations, these authors estimate that a large number of palms, whether they show pathological symptoms or not and other plants from different families could be storage hosts of CCCVd strains. It was demonstrated that there could be viroid type molecules in oil palm, but these molecules are found in all the countries studied and are not associated with any pathological syndrome. They are, in fact, double-stranded RNA with a strong secondary structure and not viroids (Dollet *et al.*, 1994; Beuther *et al.*, 1992). Recent works have helped to show that several technical artifacts may give rise to false molecular hybridizations: nucleic acid extraction techniques, nature of the probe, stringent conditions, autoradiography time exposure hybridization technique, etc. (Muller and Dollet, 1997).

Citrus viroids

Eleven distinct viroids have been commonly recognized in citrus plants and regularly associated in a complex form in the same tree. These viroids have been classified into five groups based on molecular, structural and biological criteria: Citrus exocortis viroid group (CEVd), citrus viroid group I (CVdI), CVdII, CVdIII and CVdIV (Semancik and Duran-Villa, 1991). Of these viroids, two are responsible for causing serious diseases in citrus: exocortis (CEVd) and cachexia-xyloporosis (CVdIIB or CCaVd). Viroids are also suspected to be responsible for other infections and some have been described as attenuated strains of CEVd. The exocortis viroid, besides inducing cortical symptoms on susceptible hosts, also causes a diminution in their growth and a fall in production (Vogel and Bové, 1986).

TRYPANOSOMAS

Phytomonas spp. on palms

Any syndrome of marchitez disease of palms or hartrot of coconut can be associated with the presence of intraphloemic trypanosomatids (Dollet *et al.*, 1977a; Dollet and Lopez, 1978; Parthasarathy *et al.*, 1976; photos 91 and 92). Trypanosomas were discovered on latex producing plants in 1909 and the arbitrary generic name of *Phytomonas* was assigned to them. For the sake of convenience they are still identified by this generic name with no criterion other than that of living in a plant, whereas they also pass a part of their life-cycle in insects.

Trypanosomas are elongated protozoans, about 20 μ in length and have a single flagellum at their anterior end. They can be observed, live, under a light microscope using phase contrast, or fixed on a slide and stained with Giemsa (photo 93).

The virology laboratory of CIRAD succeeded in culturing these trypanosomes *in vitro* (Dollet *et al.*, 1982; Menara *et al.*, 1988). Obtaining these cultures helped to find characterisation methods which have now enabled the distinction of two major groups of trypanosomatids associated with these diseases. There are four methods, from the least sensitive to the most discerning: immunofluorescence, isoenzyme electrophoresis, study of kinetoplast DNA characteristics and random amplified polymorphic DNA analysis (RAPD).

Immunofluorescence helps to obtain a clear geographic segregation with the help of monoclonal antibodies. In the case of South American trypanosomatids, it helps to distinguish the intraphloemic types of palms from those of latex producing plants (Petry *et al.*, 1989; Marche, 1995).

Isoenzyme electrophoresis enables the observation of a wide heterogeneity among the trypanosomas of latex producing plants and two well defined groups in the intraphloemic trypanosomatids of South America (Muller *et al.*, 1994).

These organisms have a single mitochondrion at the base of the flagellum containing a very dense network of several thousands of mini-circles of DNA, the kinetoplast DNA (Ahomadegbe *et al.*, 1990). The size of these mini-circles enables the distinction of several classes based on their length. Those of palms belong to two classes and correspond to those which were discovered with the isoenzymes. The mini-circles of a given isolate can be used as radioactive probes and hybridized with the mini-circles of other isolates. These same two groups are found once again (Muller *et al.*, 1995).

With the last approach (RAPD) we can also distinguish two groups constituting an ensemble far removed from other plant trypanosomatids (Muller *et al.*, 1997).

Thus, in South America there are two groups of trypanosomatids responsible for marchitez and hartrot diseases alike. These groups are independent of geographic origin (in America where they are endemic) like the hosts (oil palm, coconut and even *Alpinia purpurata* infected by decay in Granada in the Caribbean) and like the vector species. We have still not been able to verify whether these different groups correspond to the symptomatological differences of these diseases described by several authors (presence or absence of symptoms such as premature nut-fall in coconut and early spear rot in oil palm, rate of evolution of symptoms, etc.).

Phytomonas on coffee

Phytomonas on coffee was demonstrated for the first time in 1931 (Stahel cited by Dollet, 1984). However, locally it could be seen that the affected coffee plants were located in very humid regions and hence under very unfavourable agronomic conditions. This infection is manifested by a general wilting and death of the plant due to the growth of a flagellate protozoan, *Phytomonas* sp., in the phloem vessels, inducing necrosis of the invaded tissues. This disease is known only in the northern parts of South America, Surinam and Guyana and also in Trinidad and Tobago.

NEMATODES

Nematodes on coffee

Standard taxonomic tools for classifying nematode parasites of plants mostly make use of morphometric studies. In the case of the genus *Pratylenchus*, these tools are inadequate for determining the species status of *P. coffeae* and *P. loosi* in some Guatemalan populations (Anzueto *et al.*, 1991, Anzueto, 1993). These two species are probably very closely related.

Electrophoresis of isoenzyme systems is a tool commonly used for identifications within the genus *Meloidogyne* (Dalmasso and Berge, 1978; Fargette, 1987).

A study conducted on four discriminating isoenzyme systems helped to demonstrate the wide diversity of the populations attacking coffee plants in Central America (Hernandez *et al.*, 1995 and 1996). The species and types of parasite populations found are given in Table 2.

The species *M. exigua* is found in Costa Rica, Nicaragua and Honduras. The phenotype of *M. arabicida*, a highly pathogenic species in Costa Rica, has been described, confirming that it is indeed a special species. *M. arenaria*, as well as two new types, were demonstrated in El Salvador.

Table 2. Characterisation of *Meloidogyne* populations of Central American and Brazilian origin.

Enzyme phenotype				Perineal pattern	Species	Origin
EST	MDH	SOD	GOT[1]			
A2	N1	JA2	N1	Ar	*M. arenaria*	El Salvador
VF1	N1	N1a	H1	Ex	*M. exigua*	Costa Rica
VF1	N1	N1a	H1	Ex	*M. exigua*	Honduras
VF1	N1	N1a	H1	Ex	*M. exigua*	Nicaragua
VF1	N1	N1a	N1a	Ex	*M. exigua*	Costa Rica
M1F1b	N1	N1b	N1	T1	*M. arabicida*	Costa Rica
F1	N1	N2	N1	In	*M. incognita ?*	Guatemala
F1	N1a	N1b	N1	In	*M. incognita ?*	Guatemala
M1F1a	N1	I2	N1	In	*Meloidogyne* sp1	El Salvador
Sa4	N1	N1b	N1	T2	*Meloidogyne* sp2	El Salvador
M1	N1	I2	N1	In	*Meloidogyne* sp3	Brazil

EST: Esterase, MDH: Malate dehydrogenase, SOD: Superoxide dismutase
GOT: Glutamate oxaloacetate transaminase

A species of Brazilian origin has been morphologically identified as *M. incognita*, but its esterase phenotype is peculiar.

Lastly, the case of the Guatemalan type(s) is interesting. The esterase phenotype F1 has been described for a large number of parasite populations on coffee in Latin America. It was recently and separately linked to the description of two new species which could be synonyms: *M. paranaensis* in Brazil (Carneiro *et al.*, 1996) and *M. konaensis* in Hawaii (Eisenback *et al.*, 1994).

Researches based directly on the study of genomes after PCR amplification (RAPD and AFLP analyses) should be able to provide new and efficient tools for the characterisation of nematode populations.

CONCLUSION

If the fungi thus constitute a large group of pathogens of tropical tree crops, we can state that the entire range of parasites known until now in plant pathology is represented in it (Table 3). It is even possible that the proportion of each group of pathogens is only a reflection of the difficulties in isolating and describing them, or of their antiquity. It is not surprising, for example, that we know fewer viroids than fungi, keeping in mind that the viroid concept appeared only in 1971-1975, and that these pathogens are the smallest known to date in biology, so much so they cannot be diagnosed even with the electron microscope.

Besides this diversity among the pathogens themselves, it is interesting to note the variability within every species, a biological (symptomatological), serological and molecular variability which is often expressed by variations in the degree of aggressiveness. This diversity within a species is a recent element—only about twenty years—and its study has become indispensable for developing the best strategies for integrated disease control. Thus, before launching into a genetic programme for finding varieties resistant to a given disease, it has become very important to study the variability in the causal agent.

These etiological studies should be necessarily accompanied by research on the modes of propagation of the parasite, especially when the transmission is by an insect, nematode or even a fungus, because it is at this stage that new parameters will intervene. These parameters are essential for developing the best integrated control methods: relationships between the vector and the parasite on the one hand and relationships between the hosts, vectors and parasites, on the other. In fact, the same phenomenon of variability may be present in the vector, giving rise to a large number of combinations that would come into play in the propagation and intensity of the disease.

Table 3. Important diseases of tropical tree crops and their pathogens

Plants	Fungi				Bacteria	Phyto-plasma	Virus	Viroids	Trypa-nosoma	Nema-todes
	Rots	*Phytophthora*	*Colletotrichum*	Others						
Citrus		Gummosis		Cercosporosis *Ceratocystis* wilt	Citrus canker Greening		*Tristeza*	*Exocortis*		
Fruit trees		Avocado wilt	Fruit anthracnose		Black spot of mango					
Oil plam	*Ganoderma*			*Fusarium* wilt Cercosporiosis		Blast	Ring spot Bud rot Agent?		Marchitez	Red ring
Coconut		Bud rot and nut rot		Helminthosporiosis		Lethal yellowing	DBR[1] CFD[2]	Cadang-cadang	Hartrot	Red Ring
Coffee	*Clitocybe*		Berry anthracnose	Orange rust Trachaeomycosis (*Fusarium*) American leaf blight (*Mycena*)					Phloem necrosis	Decline
Cocoa		Pod rot	Witches' broom (*Crinipellis*) Moniliosis (*Moniliophthora*)				Swollen shoot			
Hevea	*Fomes* *Armillaria*	Black stripe	Leaf anthracnose	*Microcyclus*						

[1]Dry bud rot (?) in Africa, [2]CFD Coconut foliar decay

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3

Varietal Resistance

Hubert de Franqueville

The selection of plant material resistant to the various diseases that perennial tropical tree crops are confronted with is based on prior observations of the behaviour of this plant material under conditions of natural contamination. The differences in susceptibility among varieties or cultivars subjected to the same pathogen pressure help to establish the ground for this control strategy and at the same time conserve the agronomic qualities of the concerned crop.

Depending on the cases studied in this chapter, it could be a specific resistance system of a qualitative nature—where the reactions of the plant follow the 'all or nothing' rule—or a general or partial resistance system where the degree of susceptibility can be measured quantitatively. Ultimately it is varietal resistance which is the most satisfying procedure in a large number of cases. Its objective is to gradually obtain increasingly higher resistance levels so that the success of the crop depends less on other control methods, if at all they exist.

In most of the studies presented in this chapter, resistant plant material was selected by reproducing disease symptoms at an early stage in the vegetative growth on the seedling or on vulnerable parts in nature. Depending on the case, the symptoms were artificially induced by direct inoculation of the causal organism or by exposing the host to insect vectors (for example, swollen shoot of cocoa, coconut foliar decay, blast disease of oil palm). The pathogen can also be inoculated into plant parts that are easily accessible such as the leaf, which is not necessarily the targeted part. The reaction obtained should then be correlated with that of affected parts under natural conditions (brown pod rot of cocoa).

Furthermore, the search for resistant rootstocks is an interesting way, or even the only way, for crops which are amenable to it and obviously depends on the origin of the disease. Concrete results have been obtained with coffee and citrus plants and probably for some rot diseases of hevea.

COCOA

Swollen shoot

The swollen shoot virus (see the chapter on Insect vectors) can be inoculated into cocoa beans, thanks to the vectoring of scales (Legg and Lockwood, 1977). This test, which is used as an early test for resistance to the virus, initially gave extremely varying results. Improved knowledge on host-parasite relationships helped to demonstrate on the one hand the importance of the number of bugs and species and on the other that of the virus isolate and the efficiency of its transmission. Thus in Togo a study conducted by inoculating the larvae of *Planococcus citri* with the Agou isolate showed that the infection of a susceptible material (IFC5 × IFC5) was 28% with 3 scales per cocoa bean, 77% with 6 scales and 82% with 12 bugs. In the case of resistant material (T60/887 × IMC67), the infection rate varied from 4% with 3 scales per bean to 10% with 6 scales and 21% with 12 bugs (Dufour *et al.*, 1993).

Hence experiments were carried out in Togo with bugs of the species *Planococcus citri* at the rate of 6 larvae per bean on 13 hybrids popularised in the country (Paulin *et al.*, 1993). These hybrids were studied and compared with susceptible (IFC5 × IFC5) and more resistant (IMC67 × T60/887) controls. They showed varying degrees of infection, ranging from 3 to 65%, with an average of 33%. All the popularised hybrids showed lower susceptibility than the susceptible control (74%) and 2 hybrids showed lower susceptibility than the resistant control (12%). On the whole, the least susceptible hybrids came from Amazon Tall crosses. Moreover, a test-cross using a susceptible parent (IFC5) and a resistant parent (T60/887) showed transmission of susceptibility of the dominant type. Several plots situated in the zone infected by the virus and where the symptoms were detected were replanted with hybrids whose high resistance level had been demonstrated by the cocoa bean inoculation method. Field observations have confirmed the high resistance level of these selections (Paulin *et al.*, 1993).

Witches' broom disease

Selection of cocoa clones resistant to witches' broom disease caused by *Crinipellis perniciosa* is the only effective method for controlling this malady.

In Trinidad and Tobago the CRU (Cocoa Research Unit, University of West Indies) and CIRAD are jointly conducting researches to evaluate the resistance of nearly 2500 cocoa clones in the international collection of the IGC-T (International Germplasm Collection of Trinidad) to witches' broom disease. However, this evaluation can be made only for the B population of the pathogen, the only one present in the island of Trinidad. The clones thus selected should also be tested for their resistance to population A, which is the most aggressive; the second screening has to be developed in a country in South America where the disease is rampant, or at CIRAD in France.

Field observations on the 2500 clones helped to make a preliminary selection of plant material which did not show the infection in the field. In order to confirm this level of resistance, early evaluation tests were developed in the plant pathology laboratory of CRU. The leaf test has helped to evaluate more than 150 clones and to select a certain number of them showing high vegetative resistance to witches' broom disease such as TSH 919, Sca 6, P18 A, IMC 6, IMC 57 and IMC 67.

Furthermore, the selection of Gu clones obtained by CIRAD from a survey in French Guyana confirmed the interest of this wild material.

Within the framework of a preselection programme, the selected clones could be crossed among themselves with a view to cumulating the resistance genes. The descendants are being evaluated by the leaf test.

This test is also used to evaluate the vegetative resistance of seedlings obtained from the two crosses: IMC 57 (R) × Catongo (S) and Sca 6 (R) × Catongo (S). These progenies have also been biochemically mapped (by Rflp and Aflp) by CIRAD at CRU. The aim of this study is to further our knowledge of the genetic bases of resistance to witches' broom disease through QTL (quantitative trait loci) research.

An early test on cocoa beans has also enabled the selection of progeny showing good resistance: 92 from crosses between Thy and Ics clones and 125 from self-crossing of Ics clones.

Brown pod rot of cocoa (black pod rot)

Observations on naturally infested cocoa plants have enabled a preliminary classification of hybrid clones and families in terms of their behaviour towards brown pod rot of cocoa. The CIRAD selectors of cocoa lines have therefore veered, since the early 60s, towards direct experimentation on the fruits, in order to have a better understanding of the components of resistance and the hereditary mechanisms governing them, knowing that brown rot is a group of distinct diseases given the number of *Phytophthora* species involved and the nature of the reactions they induce on the cocoa plant.

The first breeding programme for tolerance was conducted by Besse (1964, 1969) in the Ivory Coast. He took into consideration the variations in the percentage of rot observed among clones and hybrid families the field, in collections and in comparative tests. Four years of observations, during which the fruits were harvested every 10 to 15 days, showed the susceptibility of Amelonado to be 30%, a susceptibility which is less thanks to the Amazon Tall (AT) in Amelonado × AT crosses (20 to 25%) and a more pronounced resistance in Trinitario × AT hybrids (less than 20%) and T38 × AT 605 hybrids (between 4 and 9%) hybrids. However, the heterogeneous nature of the distribution of the infection linked to climatic and environmental variations and to factors such as the density of the plantation and distribution of the production in time and space, led to the launching of a major programme of controlled evaluation of resistance in the early 60s. Various kinds of tests were performed on a pathosystem with *P. palmivora* in the Ivory Coast and later on another pathosystem with *P. megakarya* in Cameroon (Tarjot, 1964; Marticou and Muller, 1964; Lotodé and Muller, 1974).

TESTS ON PODS

Artificial inoculations with *Phytophthora* spp. were first performed in the Ivory Coast on detached injured or uninjured pods in the laboratory and then on the still attached pods in plantations (Tarjot, 1965, 1967, 1969). The method on attached pods was taken up in Cameroon and strictly standardised. About a hundred clones from local selections and around 20 from introductions were thus classified based on two susceptibility criteria: resistance to entry through the epidermis, which expresses the percentage of successful infections and the rate of progress of the parasite in the inner cortical tissues (Blaha and Lotodé, 1976).

The comparison of 28 clones tested in two different ecologies in Cameroon showed that under conditions favourable for the disease, the percentage of successful infections is not sufficient to evaluate varietal resistance. On the other hand, the speed of colonisation of the cortex in the clones in the two sites showed similar variations ($r = 0.65$), thus confirming the stability of the intrinsic clonal resistance in geographically distinct sites (Nyasse *et al.*, 1996).

TESTS ON OTHER PLANT PARTS

The pod test considerably delays the selection of plant material because of the time lapse of 4 to 5 years before the plants begin to yield fruits. The necessity of an early and non-destructive test led to testing on leaves. The abundance and renewal of leaves and especially the anatomical similarity of their lower surface to the epidermal surface of pods facilitated the selection of this part (Blaha and Paris, 1987). A simple recording of the severity of necrosis (from 0 to 5) twice successively (on the fifth and seventh day after inoculation) also makes this leaf test, which has been standardised to discs 15 mm in diameter, much faster. Only the age of the leaf has an extremely important influence on the expression of susceptibility and should be taken into consideration for obtaining a satisfactory reproducibility (Nyasse *et al.*, 1995). Moreover, this leaf test enables experiments to be performed outside the production zones.

CORRELATION BETWEEN RESISTANCE TESTS AND FIELD RESISTANCE

The leaf test reproduced categories of extreme reactions (i.e., very high susceptibility or very high resistance) when pods were artificially inoculated in Cameroon and Latin America (Table 1). The test also took into account the significant influence of the plant in accordance with the high intrafamilial variability in cocoa plants (Nyasse *et al.*, 1995; Nyasse, 1997).

Table 1. Classification of 13 cocoa clones of various origins after inoculating leaf discs with two *Phytophthora* species: *P. palmivora* and *P. megakarya* (degree of susceptibility of the reference clones of both species being known for the fruits).

Clone		Observation of symptoms*			
		P. palmivora		*P. megakarya*	
IMC47		0.35	a	0.17	a
SNK413	(R)	0.90	ab	0.28	a
T85/799		1.10	abc	1.10	b
CC231	(LR)	1.13	abc	1.52	b
GU333		1.27	bcd	0.85	b
SNK10	(S)	1.35	bcd	1.08	b
SPEC138/8		1.48	bcd	0.90	b
R13	(LR)	1.55	bcd	1.52	b
EBC/10/401		1.63	bcd	1.02	b
UF667	(S)	1.85	bcd	2.40	c
LCTEEN37		1.90	cd	2.20	c
VEN4/4		2.17	d	2.20	c
OC77	(LS)	3.25	d	2.50	c

* The scale of observation of symptoms is from 0 (symptomless) to 5 (true necrosis). Mean values within a *Phytophthora* species followed by the same letter are not very different from the Neuman and Keuls test with a 5% threshold.
The reaction of fruits to artificial inoculations is given in parentheses (R and LR for more or less resistant, S and LS for more or less susceptible).

The test on attached pods brought out the influence of the plant on the clone and showed more clearly the influence of environmental factors on pods of the same genotype. This phenomenon could be responsible for the discordance between the inoculation test on the fruit and the losses in the field (Nyasse *et al.*, 1996). The influence of the genotype nevertheless dominates over the influence of the plant as long as the cultivation or experimental conditions are sufficiently uniform and hence individual selection for resistance can be done by inoculating the pods or leaves.

Inheritance of intrinsic resistance and field resistance

A study of the transmission of intrinsic resistance was undertaken in Cameroon, thanks to the test on attached pods, on 56 hybrid families obtained from clones of known behaviour. By cumulating the data of five years, tree by tree, it was observed that on the one hand there was a strong intrafamilial disjunction on the fruit and on the other a statistically higher proportion of less susceptible individuals in R × R crosses than in S × S crosses.

Different kinds of crosses were made in the various zones affected by the disease in order to define the genetic effects of the two characters targeted for selection under natural conditions of infection viz., production and resistance to brown pod rot (Cilas *et al.*, 1996). It is a 6 × 6 diallele in Cameroon, a factorial plan between 16 female Amazon Talls (AT) and 4 male Amazon Dwarfs (AD) parents in the Ivory Coast and a triangular triallel among 12 parents in Togo. An analysis showed the strong influence of Gca (general combining ability) compared to Sca (specific combining ability), Gre (general reciprocal effect) and Sre (specific reciprocal effect). This analysis also showed that the characters are transferred mainly by additive gene action because of the influence of female parents, the main variation factors in the factorial programme in the Ivory Coast.

Towards a strategy for exploiting the effects of the interaction between genotypes and the environment

The resistance of some clones is constant, whether as a function of time in the same country or some other geographic location: Africa (Ivory Coast, Togo, Cameroon), America (Trinidad and Tobago, Brazil, Costa Rica) or the southern islands (Papua New Guinea). The polygene governance of resistance forms of the horizontal or partial type in cocoa plants should ensure this stability and durability of resistance to the disease. Besides, the obligate saprophytic phase in the life-cycle of *Phytophthora* spp. between two cocoa sites appears to be an additional guarantee for the perpetuity of this resistance in the host (Chevaugeon, 1973).

The absence of interactions between a range of clones and isolates of the same species in the case of *Phytophthora palmivora*, as with *P. megakarya* (Nyasse *et al.*, 1993), would moreover signify that a selection can be made irrespective of the isolate used (Nyasse *et al.*, 1996) and that the groups obtained in one country could be used in other countries (Cilas *et al.*, 1996).

The various crossing programmes have helped to obtain a selection index after estimating the desired genetic gains in each of the quantitative characters taken into consideration, i.e., the production and rate of rot (Cilas *et al.*, 1994). Genotypes (individual, family) are now used in breeding programmes either directly as elite hybrid clones after validation through confirmation tests or as new parents in backcrossing programmes with the aim of accumulating the alleles favourable for the desired characters (Clément *et al.*, 1996).

The leaf test is a tool that can be used on leaves of seedlings (uniform environment, orthrotropic vegetative axis) for the early selection of newly created progeny because of its reliability. Nevertheless direct access to the genome is still preferred and a selection aided by molecular markers closely linked to the genes controlling the targeted character(s) represents the best, the quickest and the surest screening method. Thus a map saturated with genetic links was established with the help of isoenzymes and molecular markers (Rapd, Rflp, Aflp and microsatellites). Aflp markers and microsatellites were used to establish the genotype of 144 individuals studied in the Ivory Coast. Characters resistant to *Phytophthora palmivora* were evaluated by means of the leaf test and through analysis of the losses in yield over several years. A few Qtl could be identified, thus opening the path for using these techniques to aid selection (N'Goran, 1994; N'Goran *et al.*, 1996; Lanaud *et al.*, 1997).

At present it is the phenotypic, genetic and environmental correlations between the potential production (total number of pods formed) and degree of rot in the three African countries compared, viz., Cameroon, Togo and Ivory Coast, which seem to provide the most interesting information on the interactions between the genotypes and environment and their effects (Cilas *et al.*, 1996). Phenotypic correlations are very different from one country to another, especially in Cameroon where the effect of Trinitario in crosses is distinguished from the effects of Amazon Tall × Amazon Dwarf crosses (Berry and Cilas, 1994). The variability of the pathogen should not be minimised either. Genetic correlations show that parents good for production are also good for resistance to brown rot, the families which are attacked the most bearing less pods because the infection can take place on the young fruits or flowers. Environmental correlations between the degree of rot and potential production are systematically positive, a fact attributed by authors to fruit-to-fruit infection, which increases with the number of fruits present and also to the increased proximity between the fruits which are more numerous and the infection sources (on the tree itself, on the bark and cushion flowers).

Breeding programmes through recurrent selection programmes using genetically distinct populations even end by cumulating the minor genes in new elite hybrid clones that are agronomically acceptable, particularly their resistance to pod rot (Paulin and Eskes, 1995). However, genetic control alone is not sufficient and should be associated with other measures, especially adapted cultural practices for managing a veritable integrated control programme.

Muller (1974) reported the existence of a kind of escape detected in some clones which have the peculiarity of out-of-season flowering in the most extreme cases. In many other cases flowering is simply delayed or highly staggered, enabling a certain number of pods to escape infection. This kind of escape may be counted among the numerous factors intervening in field resistance, which expresses the actual impact of the disease. Selection from this notion of escape, eventually supported by adapted cultural methods such as irrigation, should not be given up.

COFFEE

Orange rust

Because of the seriousness of orange rust of coffee caused by *Hemileia vastatrix*, as well as the financial and technical difficulties in initiating a chemical control programme, development of resistant varieties became a priority for a number of coffee-growing countries. Selection of coffee plants resistant to orange rust was carried out mostly with the species *C. arabica*, the main varieties cultivated in the world (Bourbon, Typica, Mundo Novo, Caturra) being very susceptible to the most common races of the pathogen. Many species belonging to the genus *Coffea* were used as sources for gene resistance.

Specific resistance factors in *C. arabica*

Resistance factors present in the species *C. arabica* were used for the first time in India, with the Kent variety and its derivatives such as the K7 selection which possesses the SH2 gene. However, the resistance was quickly overcome because of the appearance of new races (Muller, 1984). A similar situation was observed after the introduction of resistance factors in the Ethiopian coffee plants Geisha and Dilla and Alghe which contain the SH1 factor and later in the Agaro genotype possessing the SH4 factor. Similarly, in Brazil, resistance of the multiline larana variety, constituted by lines with gene combinations associating SH1, 2, 4 and 5, was quickly overcome by the appearance of complex races. The distribution of this variety was thus interrupted because most of the plants were found to be attacked.

Specific resistance factors in *C. liberica*

The SH3 resistance factor was identified in the species *C. liberica*. In the past, interspecific hybrids with *C. arabica* had been created and the progenies of these plants were then backcrossed with the Kent variety. Resistance of these selections, such as S795, was maintained in the field for nearly twenty years (Muller, 1984). Resistance of advanced selection S1934, distributed especially in Indonesia, no longer seems to be effective except in new cultivating zones. In Brazil, as well as in other regions of Latin America, the field resistance conferred by SH3 seems to be operational but in an experimental way, as a race capable of overcoming this resistance has been described (Eskes, 1989).

Specific resistance factors in *C. canephora*

The species *C. canephora* is the most important source of resistance up to now (resistance factors SH6 to SH9 and probably S10). It was used through natural (Timor hybrid) or artificial interspecific crosses with *C. arabica*. The Timor hybrid, discovered in the middle of the century in the island of the same name, has not been commercially exploited directly but at the CIFC (Centro de Investigação das Ferrugens do Cafeeiro) in Portugal, its descendants (CIFC 832/1 and CIFC 832/2 in particular), which are resistant to all the known races of the parasite, were crossed with different commercial varieties; crosses with the Caturra dwarf variety gave rise to the Catimors.

In Brazil, a breeding programme of artificial hybridisation between *C. arabica* and *C. canephora* with repeated backcrossings with *C. arabica*, led to the distribution of the Icatu variety from 1980. In Colombia, it was through hybridisations between the Caturra variety and the CIFC.1343 progeny of the Timor hybrid that the Columbia variety was created. It is a composite variety containing different advanced selections of similar agronomic values but with different resistance factors. A similar selection programme resulted in the creation of the Ruiru 11 variety in Kenya (Van der Vossen and Walyaro, 1980; Walywaro *et al.*, 1982; Nyoro and Sprey, 1986).

Breeding programmes were therefore mainly based on the exploitation of specific resistant genes found in various species of *Coffea*. The resistance introduced by using the genes SH1 to SH5 present in the species *C. arabica* was overcome by the appearance of rust races accumulating the different virulent genes v1 to v5 through successive monogenic mutations. This has led to an erosion of the resistance genes SH1 to SH5 and hence they can no longer be used alone in breeding programmes for creating resistant varieties.

Selection programmes are now directed towards the exploitation of the resistance genes of *C. canephora*. However a diversification mechanism of the parasite towards the resistance genes present in the species *C. canephora* has also been observed. Pathogen races for the different genotypes of the Timor hybrid have been described in Timor (Gonçalves *et al.*, 1977), India, Sri Lanka and Angola, as well as in Brazil (Eskes, 1989). More recently, Holguin Melendez (1993) reported the presence of isolates, collected from Catimor in Indonesia attacking some plants issuing from the Timor hybrid, as well as Catimors and several differentials of *C. arabica*.

These elements pose a problem for the stability of the specific resistance in *C. canephora* and its derivatives. In order to obtain varieties showing a more durable resistance, researches were undertaken to try and find a non-specific type of resistance showing a quantitative character.

Incomplete resistance of coffee to rust

In Cameroon, investigations on 127 progeny of *C. arabica* from Ethiopia helped to demonstrate a wide variation in the average percentage of infection in the field and a highly variable defoliation rate depending on the origin (Tarjot and Lotodé, 1979). At the CIRAD in France, Leguizamon (1983) proposed a methodology for the quantitative evaluation of the development of symptoms under experimental conditions, integrating the various components of resistance. The results obtained with race II, which is the most represented in the world, showed the existence of incomplete resistance in Ethiopian coffee plants which is expressed by a low rate of sporulation and a long latent period. Fagioli (1988) confirmed this quantitative resistance in several races and showed that the accumulation of virulent genes in the pathogen could lead to a diminution in its aggressiveness. These results prove the existence of a source of incomplete resistance in the species *C. arabica* as emphasized by Eskes (1989).

Perspectives

The selection of varieties resistant to orange rust has been a major concern ever since this crop was introduced in the second half of the nineteenth century. Selections aimed at accumulating the resistance genes of *C. arabica* and *C. liberica* were overcome more or less quickly. The resistance obtained by the introgression of genes inherited from *C. arabica* in the Timor hybrid and resulting in the creation of Catimor appears to be a promising path.

However recent observations on the Catimor lines distributed in Asia which had lost their resistance indicate that the accumulation of SH6 to SH9 genes inherited from *C. canephora* can be overcome by isolates possessing a wide spectrum of virulent genes and showing a high degree of aggressiveness. It is therefore very important to prevent the gradual erosion of resistance in Catimor. At present although the strategy used for composite varieties, which possess different resistance factors in the different lines, appears to be satisfactory, exploitation of the incomplete resistance present in the species *C. arabica* should enable the selection of coffee plants showing a more durable resistance (Muller, 1984, 1985). However, this path is still to be investigated. We may particularly think of studying the sensitisation of the plant with age: no doubt, cultural corrections at an adult age would enable the expression of a resistance observed at a young age (see the chapter on Rational chemical control and cultural techniques).

Powdery rust

Concurrent with the investigations carried out on orange rust in Cameroon, Tarjot and Lotodé (1979) observed that the percentage of leaves attacked by *Hemileia coffeicola*, responsible for causing powdery rust, was distinctly higher in the Java variety than in the Jamaican variety, these two varieties then being the most widely grown in Arabica plantations. The study of collections showed that the number of cultivars infected by mealy rust was higher than that of cultivars affected by orange rust. However, an early test for evaluating the susceptibility could not be done. Wide differences in clonal susceptibility were observed in Robusta coffee plants. The level of susceptibility does not vary significantly from one ecology to another but the degree of infection shows variations which could be considerable.

Anthracnose of Arabica coffee berries

Evaluation of resistance

The resistance of Arabica coffee plants to anthracnose of berries (coffee berry disease) caused by *Colletotrichum kahawae* can be evaluated in the field under natural infection conditions. This is done mainly through the observation of the percentage of infected berries on the branches. However, this evaluation should take into consideration the variability in the susceptibility of the berries over time and requires several repetitions in order to appreciate the influence of climatic conditions and also take into account other factors which could have an incidence on the expression of the disease, such as the structure of the plantation (shading, spacing of coffee plants) and productivity of the trees.

Following the appearance of the disease in Kenya in 1922, differences were observed among the varieties in the field. A higher level of resistance was observed in Blue Mountain (Mac Donald, 1926). Later high levels of resistance were also observed by Firman (1964) in a wild population of coffee plants of West Sudanese origin (Rume Sudan) and by Vermeulen (1966) in the Timor hybrid, the natural hybrid of *C. arabica* and *C. canephora*.

In Ethiopia, where the disease was reported only in 1970, differences in the level of infection were observed in wild coffee populations and cultivated varieties (Robinson, 1974; Van der Graaf, 1981). In Cameroon, field observations revealed coffee plants showing different resistance levels in collections composed mainly of introductions of material of Ethiopian origin. These constitute the best source of variability of plant material and a good reserve of genes resistant to both orange rust and coffee berry disease (Bouharmont, 1992, 1995).

Resistance to coffee berry disease can also be evaluated by performing the artificial inoculation test. This is done by applying (spraying, drenching) a measured volume of a conidial suspension on different parts of the plant (hypocotyles of young seedlings, young shoots, berries); the inoculations can be done in the field or in the laboratory under controlled conditions on detached plant parts.

The test on hypocotyles of seedlings was developed by Cook (1973) in Kenya. It is still used for the identification and selection of resistant plant material. However, the results may vary depending on the test conditions (hypocotyle with or without roots and inoculation by drenching or spraying). It is therefore important that this test be standardised (controlled and homogeneous conditions for inoculation and incubation) in order to have a tool which would enable a reliable evaluation of the level of resistance.

In Ethiopia, Van der Graaf (1992) used the test on attached berries on a large scale. However, this test seemed to be too dependent on environmental conditions. Tests on detached berries inoculated in the laboratory apparently gave good results in Ethiopia but the results obtained in other countries are controversial. Ongoing researches in Cameroon indicate the importance of ensuring very rigorous and homogeneous experimental conditions as the expression of symptoms is highly influenced by them.

Resistance sources and characterisation of resistance

Studies on resistance to coffee berry disease actually began in Kenya, Ethiopia and Cameroon in the early 70s. Although the majority of the cultivated varieties were very susceptible to the disease, it was still possible to spot the varieties or wild coffee plants showing varying degrees of field resistance. However, the nature of this resistance has not been clearly established.

Resistant genotypes were observed in Kenya, especially in the Pretoria varieties (mutant of Typica) and K7, as well as in populations of Rume Sudan and Timor hybrid (a particularly interesting parent produced by the natural crossing between *C. arabica* and *C. canephora*), discovered on the island of Timor. Besides resistance to coffee berry disease, the Timor hybrid is interesting because it is also highly resistant to orange rust as well as nematodes.

A study of these populations helped to demonstrate that the resistance observed is of oligogenic nature. The hypothesis of a control by three genes located on three different loci was put forward (Van der Vossen and Walyaro, 1980): the recessive gene *k* present in the K7 and Rume Sudan varieties, gene *T* in the Typica variety and Timor hybrid and gene *R* in the Rume Sudan variety. Histological studies (Masaba and Van der Vossen, 1982) have shown that the resistance conferred by these genes is essentially mechanical in nature: the formation of a cork barrier has been observed.

Considering the supposed oligogenic nature of this resistance, the study of its specificity towards the pathogen is now a priority for the ongoing research programmes on this disease. Although some works have mentioned the possible existence of races in *Colletotrichum kahawae* (Rodrigues *et al.*, 1992), studies carried out within the framework of a European project on resistance to coffee berry disease tend to indicate the presence of a quantitative and nonspecific type of resistance. Nevertheless, a wide variability in aggressiveness has been systematically observed in the isolates tested (Bella Manga *et al.*, 1997).

In Ethiopia, the region of diversification of Arabica species, the appearance of the disease helped to demonstrate different levels of infection in wild populations of *C. arabica*. Van der Graaf (1981, 1992) showed that this resistance was quantitative in nature as immunity was not observed at all; the hypothesis of a polygenic type of resistance was proposed. In Cameroon, resistance to coffee berry disease was also demonstrated in introduced Ethiopian material (Bouharmont, 1995). Until now it has not been verified whether the genes *k*, *R* and *T* were also present in the Ethiopian material.

Selection for resistance

Breeding programmes were undertaken simultaneously with the search for resistance sources in the various countries affected by the disease.

In Kenya, the selection programme was defined with a view to combining the resistance observed in several varieties such as Rume Sudan and K7 with the organoleptic qualities of the best commercial varieties (SL28), especially through repeated backcrossings. The introduction of diverse Catimor lines during the period 1975-1977 enabled crosses between those showing resistance to both coffee berry disease as well as orange rust with the best known hybrids. This selection programme resulted in the creation of the Ruiru 11 variety; this is a mixture of hybrids with dwarf character which is now being distributed to the farming community (Van der Vossen and Walyaro, 1980); Walyaro *et al.*, 1982; Nyoro and Sprey, 1986). The resistance appears to be stable even after more than 10 years of use, although symptoms have been observed under some unfavourable environmental conditions. However, distribution of this plant material is being slowed down because of the low production of seeds which requires setting up manual pollination programmes.

A programme was launched in Ethiopia in 1973 to exploit the field resistance observed in wild coffee plants. The genotypes identified were thus integrated into a varietal breeding programme through mass selection. In 1986, this breeding programme resulted in the selection of hybrid varieties combining vigour and resistance to coffee berry disease (Van der Graaf, 1992).

In Cameroon, resistant trees were identified from collections containing cultivated varieties as well as those introduced from Ethiopia. Among the varieties evaluated, the Java variety was notable for its productivity, good vigour and degree of resistance to both orange rust and coffee berry disease (Bouharmont, 1992). This variety shows similarities with the Abyssinian variety introduced by Cramer at the beginning of the century in Java in Indonesia. The Java variety was released in Cameroon in the early 80s. However, it does not seem to be totally fixed (Cilas *et al.*, 1998) and recent studies have shown a variability among the trees (Berry, 1997), which may help to locate individuals that are more resistant than the mother population.

American disease of coffee

This disease is caused by *Mycena citricolor*, a highly polyphagous fungus. Moreover, it is of American origin and hence could not co-evolve with coffee. Consequently, the possibilities of finding specific resistance are practically non-existent. On the other hand there is a possibility, which cannot be ignored, of detecting a non-specific or incomplete resistance. Planters and some agronomists are of the opinion that Catimor is more susceptible than Catuaï.

Nuñez *et al.* (1995) have developed a methodology to estimate resistance in the laboratory: resistance to the entry of the pathogen and resistance to the fruiting bodies. The originality of this method is that the inoculations are done without causing injury. By using this methodology, it was found that Catimor appeared to be more resistant to entry but less resistant to the fruiting bodies than Catuaï. When these data are compared with field observations, it becomes evident that only resistance to the fruiting bodies could be responsible for the differences observed in susceptiblity. Later improvements in the methodology enabled evaluations under conditions very close to optimum for the fungus. Under these conditions, no difference could be observed between the susceptibility of Catimor and Catuaï. It therefore seems that incomplete resistance, if it exists, is useful only when environmental conditions are not exactly ideal for the fungus, i.e., when the disease is obviously not severe. Interest in this resistance is therefore quite diminished now.

Finally, it must be mentioned that differences in field resistance could also be due to architectural differences among the varieties. It is possible that certain architectures help to conserve a more humid ambience in the plantation and by the same token favour the disease. The capacity of water to adhere to leaves varies with the cultivars and this should not be ignored either.

Tracheomycosis

This disease is caused by the fungus *Fusarium xylarioides*. Observations made in the Republic of Central Africa in 1951 showed that Excelsa and neo-Arnoldiana were 100% susceptible to tracheomycosis (carbunculariosis), while the susceptibility of Robusta varied from 0 to 100% depending on the clones (Saccas, 1951). In the Ivory Coast, Kouilou (indigenous *C. canephora*) was found to be susceptible, Excelsa resisted better and Robusta showed clear resistance characterstics. Only Excelsa was affected in Cameroon. The disease was identified in Ethiopia in 1970. In future the selection of resistant clones or varieties should be done taking into account the wide diversity that the pathogenic species seems to be endowed with, since it does not attack the same varieties everywhere, and when they co-exist some may be more susceptible in one place and resistant elsewhere.

Nematode diseases

Grafting Arabica on Robusta

Highly pathogenic nematodes are very common in coffee plantations in Guatemala. Reyna (1968) therefore developed a grafting method in this country by using rootstocks of non-selected Robusta plants that had generally been observed to exhibit some resistance or tolerance to these pests. This hypocotyledonary type of grafting is done at the two-leaf cotyledonary stage using a bandage held in place by a thin plastic tape during cicatrisation. Cicatrisation and weaning are done in a seed-bed or directly in nursery bags. This technique is now commonly used by coffee planters in Guatemala, especially in regions with high nematode populations where nearly all the large plantations produce only grafted plants in the nurseries. Its success is due mainly to a good mastery of the technique: (*i*) 90 – 95% success in the nursery; (*ii*) a high degree of efficiency, as seen in Fig. 1, in controlling *Pratylenchus* sp., which is the most widespread nematode parasite of coffee in Guatemala and (*iii*) low cost compared to chemical control, which is more polluting and not very effective (Villain *et al.*, 1996).

This technique was introduced in Salvador where coffee plantations are also parasitised by highly pathogenic nematode populations (Hernandez *et al.*, 1995). Furthermore, major planters in Costa Rica also became interested in this technique. Lastly, it is very widely practised in Brazil.

Selection of *Coffea canephora* cv. Robusta rootstocks resistant to *Meloidogyne* spp.

Selection of plant material from the Robusta cultivar was done in Brazil. It

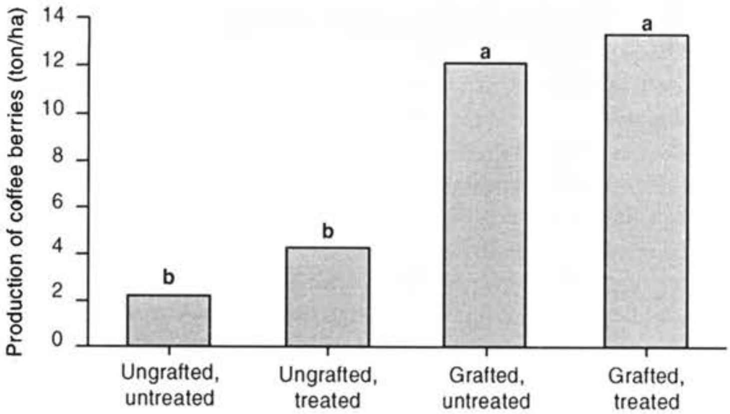


Fig. 1. Effect of grafting and Terbufos treatment to control *Pratylenchus* sp. on the average coffee production (from Villain *et al.*, 1996).

resulted in the creation of the Apoata variety (Fazuoli, 1986; Gonçalves and Ferraz, 1987) which is resistant to various pathotypes of *Meloidogyne incognita* that causes serious damage to coffee plants. On the other hand, in Central America no proper selection was carried out for resistance to nematodes. In the case of attacks by *Pratylenchus* sp. attacks, grafting on non-selected Robusta gave highly satisfactory results in Guatemala. However, it was necessary to make a selection for resistance to *Meloidogyne* spp. populations present in Central America, particularly for the populations in Guatemala and El Salvador which are highly pathogenic to coffee (Anzueto, 1993; Hernandez *et al.*, 1995). A project was therefore undertaken to evaluate and select genetic material for resistance to the important nematodes in Central America, with financial assistance from the European Union from 1993 to 1997. This search for resistance to nematodes has become one of the major criteria for selection in the regional coffee-breeding programme in Central America.

According to the studies carried out in several Central American countries (Decazy *et al.*, 1997), most of the Robusta lines tested were resistant to *M. exigua* populations in Costa Rica, a species which is also present in Nicaragua and the Honduras (Hernandez *et al.*, 1995). On the other hand, they are generally susceptible to the highly pathogenic *Meloidogyne* spp. populations in Guatemala and El Salvador. In fact, from this evaluation only two Robusta clones from the CATIE collection (Centro Agronomico Tropical de Investigación y Enseñanza) had transmitted a high level of resistance to *Meloidogyne* spp. populations collected from Central American countries (photo 94) to their progeny. These two clones are now being multiplied by CIRAD on a large scale through *in vitro* vegetative propagation in the CATIE laboratory. The vitroplants are being distributed to coffee establishments in the Central American countries to go through a phase of acclimatisation and weaning. They will then be planted in intercalation in isolated seedling fields with controlled fertilization in order to avoid contamination by pollen alien to these plots. The hybrid seedling resulting from the crossing of these two clones and constituting the rootstock of the Nemaya variety will be distributed to coffee growers from the year 2000 (Anzueto *et al.*, 1995). It must be pointed out that these two Robusta clones have also shown a good level of tolerance and resistance to the *Pratylenchus* sp. populations in Guatemala, which were found to be highly pathogenic to *C. arabica*.

SELECTION AND CREATION OF ARABICA CULTIVARS RESISTANT TO *MELOIDOGYNE* SPP.

A resistance to *M. exigua* populations was observed in some progenies of the Timor hybrid, Catimor and Sarchimor, but was not found in other varieties already distributed in Central America (Catuaï, Bourbon, Caturra), nor in the various varieties of Ethiopian origin that were tested (Decazy *et al.*, 1997; Hernandez, 1997). The IAPAR59 variety selected by the Agronomic Institute of Parana in Brazil was found to be resistant to the *M. exigua* populations in Costa Rica. Thanks to its good organoleptic property it is likely to be widely distributed in Costa Rica, as well as in the Honduras and Nicaragua where the same species seems to be present.

Tests carried out on a factorial hybridization programme with aggressive populations of *Meloidogyne* species from Guatemala (*M. incognita* or close to this species) showed that resistance was not transmitted by the two evaluated progeny of the Timor hybrid, viz., Catimor T8667 and Sarchimor T5296. On the other hand, two of the Ethiopian parents tested, ET59a2 and ET52a2, transmitted a good degree of resistance to all their descendants (Decazy *et al.*, 1997). Many other wild lines of Ethiopian origin also showed resistance to these Guatemalan populations (Anzueto, 1993; Hernandez, 1997), as well as to some of the *M. arenaria* populations from El Salvador and *M. arabicida* populations from Costa Rica (Hernandez, 1997). Hybridization using parents of Ethiopian origin therefore appears to be another interesting way of creating plant material resistant to certain populations of the genus *Meloidogyne* and could complement the selection of resistant rootstocks.

Hence, at present there are no commercial varieties that are resistant to the various species and types of nematodes at the regional level. Obtaining a universal resistant variety for the region appears to be very difficult because of the diversity of the pathogenicity (Hernandez, 1997). First of all, the plant material has to be selected in function of the populations present in each country. This solution would help to avoid grafting, especially in countries or regions where this practice is not common and where it increases the cost of production significantly, particularly in places where labour is expensive. Nevertheless, care should be taken to obtain a good organoleptic quality, which is now an important factor to be taken into consideration in genetic breeding programmes for coffee. The behaviour of these cultivars towards *Pratylenchus* sp. populations, which cause devastating economic losses in some countries, should also be studied. Lastly, transport of plant material should be strictly controlled in order to avoid the introduction of species which are pathogenic to the selected varieties.

COCONUT

At present varietal selection is not used much as a control method for coconut diseases. Nevertheless, often there are indications gathered from field observations that resistance or susceptibility appears to be linked to certain ecotypes. These indications are, however, fragile and can rarely be made use of by breeders.

Thus, in the case of foliar diseases in Brazil, the observation of the different ecotypes and hybrids of coconut present in this country helped to state that Dwarf coconut trees are less susceptible to *Phyllachora torrendiella*, causal organism of *lixa pequena*, than the Tall and hybrid coconut trees. The limited development of the perithecial stage of the fungus on the Dwarfs could be responsible for this better behaviour (IRHO, 1989).

Behavioural differences towards *queima das folhas* were observed among many coconut cultivars in Sergipe State in studies on the evolution of the size of lesions on the midrib of leaves, number of lesions and number of healthy leaves (Warwick *et al.*, 1991). When these criteria were considered, Equatorial Guinea Green Dwarf × West African Tall (EGD × WAT) and Cameroon Red Dwarf × West African Tall (CRD × WAT) hybrids showed the best performance under the studied conditions. These indices help to envisage using genetic diversity in coconut with a view to planting the best adapted plant material.

Coconut of Polynesian origin is susceptible to helminthosporiosis but it has been possible to identify cultivars that are more resistant than others and which could be used for producing Dwarf × Tall hybrids resistant to the disease. The West African Tall is particularly resistant and exhibits a hypersensitive reaction towards the parasite (Quillec and Renard, 1975).

On the other hand, neither hartrot nor cadang-cadang diseases seem to have been checked by the selection of such and such ecotype. Nevertheless, various fields screening trial towards hartrot have been planted and studied during the last twenty years, especially in French Guyana where four Dwarf varieties, eight Tall varieties and seven Dwarf × Tall hybrids were tested, but without success.

Better results were obtained for coconut foliar decay in Vanuatu (New Hebrides), lethal yellowing and *Phytophthora* rots.

Coconut foliar decay

All the varieties introduced in Vanuatu, whatever be their origin (Pacific, Asia, Africa), are susceptible to foliar decay of coconut. Only the local Tall, called Vanuatu Tall, is tolerant: the virus causing coconut foliar decay can multiply in it without affecting the growth or the yield of the tree (Calvez *et al.*, 1980).

Individual variations can be observed in some varieties. Although Rennell Tall can sometimes be quickly infected by foliar decay, it shows a high rate of remission. Besides, some trees of this variety seem to escape the disease even when they are situated in the middle of a focus. Isolated cases of remission could even be observed in one of the varieties reputed to be most susceptible to foliar decay, viz., the Malaysian Red Tall. In contrast, the local Red Dwarf (RD) is not very susceptible to the disease although it may sometimes show very strong symptoms leading to mortality. The VT × RD hybrid is very resistant.

It is possible to reproduce the disease on very young newly germinated coconut plants (one or two emergent-leaf stage) by introducing the insect vector *Myndus taffini* collected in the field from coconut trees, whether or not they are diseased. When insects were introduced at the rate of 200 per Malaysian Red Dwarf plant into a cage containing 25 of these young coconut seedlings, it resulted in 90–100% infection. These experiments help to quickly have an idea of the susceptibility of the varieties tested. They have helped to demonstrate a phenomenon of acquired resistance or resistance induced in certain varieties after being in a cage with *M. taffini* (Julia, pers. comm.). Some young coconut plants showed the typical symptoms of foliar decay after exposure to *M. taffini*. They harboured the virus but did not die and could be planted after they were taken out of the cage. This phenomenon is found in most of the varieties. Thus Brazilian Green Dwarf (BGD) crossed with Vanuatu Tall (VT) after passing through the cage with *Myndus* became tolerant to the disease. In an experiment on three rows of 25 BGD × VT trees including 8 controls which had not passed through the cage, the controls died or showed very strong symptoms followed by a long and difficult remission, whereas the trees exposed to *Myndus* in the cage survived. Experiments by reinfecting these trees with acquired resistance, at the rate of more than 10,000 vectors per tree, did not show signs of the disease. At present this property is not being used as a control method for fear of a high proliferation of the virus, but it could offer ways for disease control through genetic transformation of the coconut tree using viral genes.

Lethal yellowing

A high degree of resistance to lethal yellowing was observed in Malaysian Red Dwarf in Jamaica in the 50s. Later the Green Dwarf and Malaysian Yellow Dwarf were also found to be very resistant to these phytoplasma diseases and several fields screening trial were planted for evaluating varietal performance in various parts of the island during the 60s. In all these sites, an average survival rate of 96% after 10 to 18 years was obtained (Been, 1981).

However mortality rates of 10–11% were recorded for these Malaysian Dwarfs in some regions. Other ecotypes have been introduced since then. Some of them show good resistance, such as the Green Dwarf from Sri Lanka or the King coconut.

Some hybrids have been created: Malaysian Yellow Dwarf × Panama Tall (Maypan F1) hybrid has given good results with an acceptable level of resistance to lethal yellowing. By 1989, about ten million Maypan or Malaysian Dwarfs had already been replanted in Jamaica. However, after the hurricane of 1988, infection rates much higher than earlier were recorded (Been, 1995). The search for new resistant varieties has therefore been taken up once again.

In Tanzania, multilocation trials to evaluate varietal performance gave results that varied from one place to another, for example in Jamaica. On an average, the Dwarfs were more resistant than the Talls, and among the Dwarfs, the Cameroon Red Dwarf and the Equatorial Guinea Green Dwarf. On the other hand, it is quite surprising to see that some Local Talls of Tanzanian origin (from the Tanga region) seem to be quite resistant to the disease (Schuilling and Mpumani, 1990).

It was in Ghana that the CIRAD was particularly involved in setting up five fields screening trial, between 1981 and 1983 (Sangare *et al.*, 1992). For various reasons, especially with respect to the epidemiology of the disease, only two of these fields could be exploited for more than 10 years after their establishment. In fact the other fields, although situated in the disease zone or in its proximity, had not yet been affected. The results obtained in these two fields are summarised in Table 2 (Mariau *et al.*, 1996).

The results at present pertain to 10 varieties (5 Tall and 5 Dwarf) and 17 hybrids comprising 15 Tall × Dwarf and 2 Tall × Tall hybrids. Other causes for mortality were observed (infection by *Oryctes*, drought) and the missing plants were or were not replaced. Some of these replaced trees were affected by the disease, in which case they are placed in the 'mortality due to disease' column (M). Others had not grown enough to be affected by the disease and in such cases they remain in the R (replaced) column, giving rise to some heterogeneity in the results.

Despite the weakness of some plants, it was generally observed that the Dwarfs show greater resistance than the Talls, except for Vanuatu Tall whose level of resistance is, however, to be confirmed. All the other Talls tested were highly susceptible, especially the West African Tall. Among the Dwarfs, the Yellow Dwarf appears to be quite resistant. However, when disease pressure is strong, in other places it was observed that most of the trees ultimately succumbed to the disease. The apparent high resistance observed in the Sri Lankan Green Dwarf would probably be very interesting to use for crossing with a Tall, which could be the Vanuatu Tall. Other field resistance trials have been set up recently to test other varieties and hybrids. While waiting for the results, which will require many years, an initial regeneration programme for coconut plantations can be envisaged with the existing resistant material.

Table 2. Incidence of lethal yellowing disease on different varieties.

Varieties	Number of coconut trees				
	Initial number	Missing (M) or replaced (R)	Living	Died of the disease	Mortality rate (%)
WAT	37	7M + 5R	0	25	100
RLT	12	9M	0	3	100
MLT	12	6M	0	6	100
PYT	12	2M + 2R	2	6	75
VTT	6	1M	5	0	0
MYD	30	15M + 4R	10	1	9
SGD	36	11M	25	0	0
EGD	29	8M + 2R	10	9	47
MRD	36	16M + 1R	11	8	42
CRD	37	10M + 5R	6	16	78
MRD × WAT	35	4M + 3R	6	21	84
CRD × WAT	30	2M + 3R	4	21	84
MRD × PYT	28	0M + 1R	8	19	70
CRD × MLT	36	18M	7	11	61
RLT × WAT	48	8M + 2R	5	33	87
MYD × WAT	36	9M + 1R	4	22	84
MYD × PYT	9	4M	1	4	80
MYD × MLT	12	1M + 1R	6	4	40
MYD × RLT	12	7M	0	5	100
MYD × VTT	12	4M + 4R	1	3	75
SGD × WAT	11	5R	1	5	83
EGD × WAT	12	3M	0	9	100
EGD × VTT	12	3R	1	8	89
CRD × RLT	12	1M + 5R	0	6	100
CRD × VTT	12	3R	1	8	89
CRD × PYT	12	3M	1	8	89
VTT × MLT	12	4M + 1R	2	5	71

MLT: Malaysian Tall
RLT: Rennell Tall
SGD: Sri Lankan Green Dwarf
MRD: Malaysian Red Dwarf
VTT: Vanuatu Tall
WAT: West African Tall
PYT: Polynesian Tall
EGD: Equatorial Guinea Green Dwarf
CRD: Cameroon Red Dwarf
MYD: Malaysian Yellow Dwarf

Phytophthora rots

The most important works on the behaviour of coconut trees with respect to *Phytophthora* were carried out in the Ivory Coast, Indonesia and the Philippines (Renard, 1996). Characterisation of plant material is based on two kinds of information: the performance of cultivars planted in the field and the ability of nuts to develop lesions after artificial inoculation.

In the Ivory Coast, comparative tests on ecotypes and their hybrids under strong natural pressure of *Phytophthora katsurae* were performed for more than ten years for individual and systematic surveys of mortality due to bud rot and premature nutfall (Franqueville *et al.*, 1989). These observations enabled the classification of the various cultivars for each of these characters (Table 3; Renard, 1993).

Similarly in Indonesia and the Philippines, where parasite pressure from different species of *Phytophthora* is high, the results are most often from surveys made all over the country where numerous ecotypes and hybrids of coconut have been planted.

In Indonesia, among the most common ecotypes, the West African Tall, which is susceptible to bud rot wherever it is planted, confers a pronounced susceptibility to bud rot caused by *P. palmivora* to its hybrids. The local ecotypes (Bali, Tenga, Palu) are generally more resistant than the introduced ecotypes, except for Polynesian Tall and Rennell Tall which, moreover, show better resistance to bud rot than Bali Tall in northern Sumatra. These ecotypes, viz., Polynesian Tall and Rennell Tall, perform well in the presence of both *P. palmivora* and *P. katsurae*. In the Philippines the local ecotypes show a certain resistance: two hybrids, Camotes Green Dwarf × BayBay Tall and West African Tall × Rennell Tall, are unharmed by bud rot (Concibido-Manohar and Abad, 1994).

Table 3. Performance tests in Samo, Ivory Coast. Performance of plant material with respect to bud rot and nut fall caused by *Phytophthora katsurae*.

Plant material	Bud rot (%)	Nut fall (%)
MYD	5.0	1.3
MRD	28.3	2.4
CRD	13.3	4.2
MYD × WAT	8.3	21.5
MRD × WAT	20.0	14.2
CRD × WAT	20.0	36.6
EGD × WAT	31.7	37.2
MYD × RLT	5.0	11.2
MRD × RLT	15.0	6.9
CRD × RLT	6.7	11.0
WAT × RLT	8.3	7.7
MYD × VTT	6.7	2.0
VTT × VTT	5.0	1.9
MYD × MLT	0.0	4.7
CRD × MLT	8.6	12.8
VTT × MLT	5.0	1.9
MLT × MLT	1.8	3.3
MYD × PYT	0.0	2.3
MRD × PYT	3.3	5.3
WAT (Port Bouet)	25.0	8.8
WAT (Samo)	20.9	2.9

MYD: Malaysian Yellow Dwarf
EGD: Equatorial Guinea Green Dwarf
VTT: Vanuatu Tall
MRD: Malaysian Red Dwarf
WAT: West African Tall
MLT: Malaysian Tall
CRD: Cameroon Red Dwarf
RLT: Rennel Tall
PYT: Polynesian Tall

An attempt was made in Indonesia to detect resistant factors towards *Phytophthora* in the nut by artificially inoculating detached nuts (Kharie *et al.*, 1994). This method, in which an inoculum comprising a suspension of zoospores is deposited on the equatorial region of a large immature nut (in the 15-20 row), helped to establish a classification based on the size and rate of spread of the lesions, and also on the success of the infection. Among the Dwarf cultivars, the Bali Yellow Dwarf, Nias Yellow Dwarf, Malaysian Red Dwarf and Jombang Green Dwarf were found to be very susceptible to *P. palmivora, P. nicotianae* and *P. arecae* worldwide, despite some differences depending on the species of *Phytophthora* used. The nuts of Palu Tall and Bali Tall are also susceptible, as well as nuts of the Malaysian Yellow Dwarf × West African Tall hybrid.

Among the most resistant cultivars may be cited the Salak Green Dwarf, Tebbing Tinggi Green Dwarf, Rennell Tall, Polynesian Tall and Tall populations of Mapanget, KB 1, 2, 3 and 4.

These results have to be validated by their performance in the field; this was not always possible considering the low representation of some cultivars in the field. The field trials conducted within the framework of a programme funded by the European Union, set up in the central part of Balitka in northern Celebes (Indonesia), should be able to provide a solution in the future (Thévenin, 1994).

The precaution of comparing laboratory results with field performance becomes all the more important as the results obtained in the Ivory Coast with *P. katsurae* is an example of the pronounced differences in the response of the nuts depending on whether they were artificially inoculated or naturally contaminated in the field (Franqueville and Allou Kouassi, 1994). Such is the case, in particular with nuts of the Malaysian Yellow Dwarf × Polynesian Tall hybrid, which are not greatly affected by nut fall in the field, whereas detached nuts inoculated artificially are highly susceptible to *P. katsurae* and nuts of the Rennell × West African Tall hybrid to a lesser degree.

All the existing data on coconut behaviour should therefore help the concerned managers to make a rational selection of the plant material to be planted, i.e., material suitable for the region under consideration.

OIL PALM

All progeny of oil palm (*Elaeis guineensis*), irrespective of their origin, are very susceptible to the trypanosomas causing palm wilt (marchitez) from the age of two years. The *E. guineensis* × *E. oleifera* hybrid is also susceptible to it. Thus, at present there is no genetic solution for the intraphloem trypanosoma diseases, as in the case of hartrot disease of coconut. There do not seem to be any genetic solutions for dry bud rot, red ring and ring spot diseases either.

In the case of cercosporosis, a selection programme for resistance to it has not been developed, although it appears that certain genotypes are more susceptible to the disease than others. This is all the more true in the case of clones where a wider range of susceptibility was observed than in the commonly used sexual material. *Elaeis oleifera* and the *E. oleifera* × *E. guineensis* hybrids are much more susceptible than pure *E. guineensis* . Some cases of mortality may be recorded in this type of plant material, in the nursery or in the plantation. In any case the response that can be obtained against this disease, thanks to a rational chemical control strategy, does not justify considering this selection criterion.

On the other hand, three lethal diseases of oil palm illustrate the competition genetic control can give in varying degrees: blast disease, whose incidence on clones may be a limiting factor; bud rot in Latin America, against which selection strategies have to be formulated; and fusarium wilt, which is one of the most convincing examples of the efficacy of genetic control.

Blast disease

Blast disease was for long considered to be a disease whose development was not actually imputable to plant origin. This position was invalidated by the culture of oil palm clones, which showed a wide range of susceptibility under natural conditions. The disease symptoms can be easily reproduced by introducing *Recilia mica* Kramer, insect vector of the disease (see the chapter on Insect vectors), into insect-proof cages containing nursery stage oil palm seedlings (IRHO, 1992). During the course of an experiment conducted in cages, five clones selected for their performance (susceptible, resistant, intermediate) in the nursery were subjected to a high pressure of *R. mica* in the cage. The results, which conform to those observed in the nursery, are given in Table 4.

Table 4. Differences in the performance of oil palm clones with respect to blast disease.

Clone	Blast (%)	Remission (%)
LMC 104	96.0	27.0
LMC 051	74.0	32.0
LMC 056	70.0	44.0
LMC 096	20.0	100
LMC 044	16.0	100

These results show that a method for evaluating the performance of clones against the disease is now available. It has not been used in selection strategies, but the susceptibility of a given clone can be taken into consideration for the management of control methods practised in nurseries or at a young age in plantations.

Bud rot in Latin America

Environmental factors have an influence on the spread of the disease, which enables the application of some cultural practices destined to limit their impact. However, it is only through genetic control that this disease can be cured, thus considerably limiting the cultivation of oil palm in Latin America. Some variability in the susceptibility to this disease exists within the species *E. guineensis*, but it is probably weak. In contrast, *E. guineensis* × *E. oleifera* hybrids exhibit a high level of resistance. In a commercial plantation, in a 10-year old plot planted with a mixture of hybrids of this type, the percentage of diseased trees was observed to be 0.2%, whereas in neighbouring plots of the same age planted with *E. guineensis*, the disease rate was 15 to 20% (Mariau, 1992). Moreover, it could be observed that in almost all cases the infected hybrids did not die but re-established themselves after a few months. This kind of healing is quite exceptional in *E. guineensis*. Perhaps there is a variability even among these hybrids, but many research workers think that it is here that the solution to the problem can be found.

Fusarium wilt

When fusarium wilt began to spread in African oil palm plantations in the 1950s, it very quickly became apparent that like the other fusarium wilts, especially that of date palm (Pereau-Leroy, 1954), selection of plant material resistant to the disease could help to limit its spread (Bachy and Fehling, 1957). In fact, data collected on identified progenies from the field and from sampling plots in plantations have helped to show important differences in their performance which can be directly attributed to the origin and ancestry of these crosses.

Prendergast (1963) proposed conducting an early test to help evaluate the behaviour of plant material towards fusariosis by following an experimental process similar to the one carried out on the date palm (Laville, 1962). This test is based on the inoculation of *Fusarium oxysporum* f. sp. *elaeidis* into nursery seedlings. Renard *et al.* (1972) later improved this by passing from the nursery stage to the prenursery stage with a view to getting a quicker response on a larger number of crosses. Breeding for general resistance to fusarium wilts has become attractive since then.

Oil palm seedlings are about 1.5 to 2 months when they are inoculated with the pathogen. This is done in the collar region which has been cleared earlier to expose the base of the roots and the most superficial radicles. The inoculum is obtained by grinding a 5-day-old culture of *Fusarium oxysporum*. Each seedling receives 20 mm of this inoculum containing an average of 3.5×10^6 propagules. The crosses or clones are represented by 160 seedlings divided into 8 replications.

The test results are evaluated after 5 months by dissecting the pseudobulb of every seedling. Browning of the vascular fibres confirms the external symptoms.

The result of a cross or clone is expressed by an index representing the ratio between the percentage of wilted plants recorded for the cross or clone with the mean percentage of all the crosses represented in the inoculation series. An index of 100 is assigned to this average and the lower the index, the more resistant the cross.

A parent represented in several crosses will be characterised by the mean of the indices of the crosses where it is involved and also by the number of crosses with indices higher or lower than 100, which is the mean value of a series. Similarly, a type of determinant plant material can be characterised by grouping either the different crosses or the different trees belonging to this type of plant material.

The plant material tested for its reaction to the disease belongs to different selection programmes and particularly to the general oil palm breeding programme, which is based on the principle of recurrent reciprocal selection (Meunier and Gascon, 1972). Resistance to fusarium wilt constitutes an important selection criterion for material destined for Africa. Renard *et al.* (1980) have described resistance sources obtained from inoculation tests through a recurrent reciprocal selection programme on the one hand, and from new introductions such as those of Latin American origin derived from *Elaeis oleifera* and its hybridization with *E. guineensis* on the other. These results led Renard and Meunier (1983) to define the categories of plant material to be conserved or eliminated in regions affected by fusarium wilt.

The general validity of the tests has been demonstrated in the Ivory Coast (Renard and Meunier, 1983) as well as in the Democratic Republic of the Congo (Franqueville, 1984) under extremely varying conditions and with different genetic origins, by comparing the performance of young plant material with that expressed by the same material at an adult age, in replantations on fusarium wilt affected antecedents.

In-depth confirmation of the validity of these early tests was provided by Franqueville and Renard (1990) thanks to the study of the evolution of fusarium wilt in the 4000 hectare Robert Michaux experimental plantation in the Ivory Coast (Fig. 2). On an average, 20 to 30% of the oldest crops were infected by fusarium wilt, this percentage gradually diminishing during successive programmes until the incidence became almost negligible, despite the conditions of replantation confronting the plant material continuously with a high risk of fusarium infection. This evolution is directly related to the improvement in the level of resistance of the plant material discovered thanks to the introduction of the inoculation test.

The last is not limited to the characterisation of sexual material. Numerous clones of oil palm—about a hundred—have been introduced in early tests. The most promising were retained and have been planted in fusarium wilt infested zones since 1989 (Renard *et al.*, 1991). Evaluation tests were also

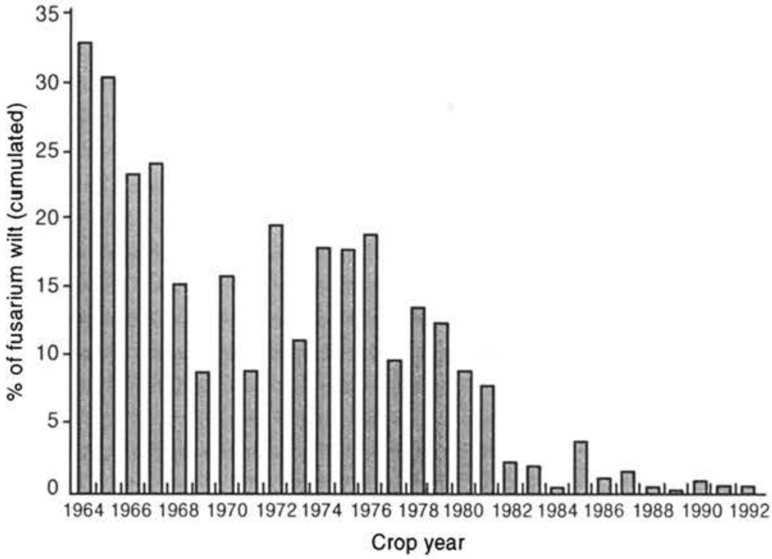


Fig. 2. Evolution of fusarium wilt in the Robert Michaux plantation (Ivory Coast; from Franqueville and Renard, 1990, updated by Franqueville and Diabate, 1995).

carried out by subjecting these clones to as high an inoculum pressure as possible.

The selection procedure adopted seems to be based on a polygenic type of resistance (Meunier *et al.*, 1979). There is no significant interaction between the geographic origin of the isolates of the pathogen and the performance of plant material inoculated with it. Grouping of the same range of crosses remains identical, irrespective of whether this range is compared with isolates from an old forest area or with a savanna precedent (Franqueville, 1991). This also seems to be the rule in all countries and the only differences observed are in the degree of aggressiveness of the pathogen (Mepsted *et al.*, 1994). Obviously this does not exclude a high variability of the pathogen, a variability that can be found using vegetative compatibility group techniques or with the help of molecular markers (see the chapter on Pathogens).

Selection techniques through inoculation no doubt give conclusive results, but they are costly in terms of time and number of oil palm seedlings. In order to have a better understanding of the mechanisms involved, the study of phenol metabolism, begun in the 80s (Taquet *et al.*, 1985), has helped to demonstrate the differences in the response depending on the genotype of oil palm attacked by the parasite (Diabate *et al.*, 1990; Ledeme *et al.*, 1992). Research efforts are therefore directed towards the optimisation of selection techniques.

HEVEA RUBBER

Genetic control of hevea diseases is a delicate application. This is particularly so in the case of rots, for example, *Fomes lignosus*, which attacks the rootstock. Researches are underway to find rootstocks resistant to the disease from different families of artificially infected seedlings. Plants which have survived a massive inoculation are selected for multiplication by shoot tip grafting. However chemical control methods and cultural techniques are also available.

For some foliar diseases such as the one caused by *Colletotrichum* in Central Africa, cultural techniques have helped to find a solution (see the chapter on Rational chemical control and cultural techniques). Genetic control is considered inevitable for the foliar disease, South American leaf blight of hevea (Salb), caused by *Microcyclus ulei*.

South American leaf blight

The Ford company was the first to launch a genetic breeding programme in 1937. Initially, selection was done mainly in Brazil and also in Costa Rica and Guatemala. However, the devastation caused by this disease in its plantations forced Ford to abandon its heroic enterprise in 1946. It was taken over in 1949 by the American company Firestone, which built up a network comprising Guatemala (Finca Clavellinas), Brazil (Fazenda Tres Pancadas in Bahia State), Florida (quarantine station) and Liberia.

The first resistance sources came from wild populations of *Hevea brasiliensis* found in the lower and middle Amazon basin and also in the upper Amazon basin where trees with high resistance levels were found: Acre (Brazil), Madre de Dios (Peru) and the region common to Brazil, Peru and Colombia between Leticia and Equitos. It is thought that it is in this vast region that highly resistant populations of *B. brasiliensis* are to be found (Holliday, 1970).

Two other species, *H. benthamiana* (Rio Negro) and *H. pauciflora*, were used for their high resistance level, especially the former and particularly the clone F 4542 (Ford 4542), which was used as the resistant parent in later crossing programmes. The latter, *H. pauciflora*, is totally resistant to the South American leaf blight but non-productive and is interesting because of its vigour and absence of wintering (Chee *et al.*, 1986).

Three other species, *H. guianensis*, *H. microphylla* and *H. spruceana*, have been used for producing interspecific hybrids with *H. brasiliensis*, but these hybrids were later discarded because they do not possess satisfactory agronomic characters (Pinheiro and Libonati, 1971).

The best results for improving the resistance of hevea to the disease were obtained by interspecific crosses between *H. brasiliensis* and *H. benthamiana*. However the genetic base for resistance is essentially limited to the clone F 4542 (*H. benthamiana*) mainly because of its resistance to *Phytophthora* leaf disease (Holliday, 1970).

The primary sources of resistance in *H. brasiliensis* for conducting the preceding crosses came from Acre (Brazil) and were limited to the clones F 351, F 409 and FA 1717 (Ford selections).

A large number of primary crosses were also carried out with highly productive clones from the east, such as Pb 86-186 (Malaysia), Tjir 1, Tjir 16 (Java) and Avros 49-183-363 (Sumatra). The best progenies were then backcrossed or crossed with the same eastern clones.

These last are generally extremely susceptible to *M. ulei*, because they were produced away from all pressure exerted by this parasite. It is also acknowledged that their common genetic base has been limited to only 22 trees in about a century of hevea culture and that millions of trees now planted have these individuals as their ancestors. Although repeated crossings have helped to increase the productivity to a level almost equal to that of the eastern clones of the 60s, it is a matter of regret that nearly all the South American selections obtained from these crossing programmes have only the clone F 4542 as the common parent and a source of resistance to *M. ulei* (Pinheiro and Libonati, 1971).

Further, Townsend (1960) reported a poor transfer of resistance from clone F 4542 to the F_2 and F_3 generations obtained by backcrossing with a susceptible eastern parent. This may explain the fact that the clones recommended and most widely planted in South America are clones of the first generation (F_1) including the following:

H. brasiliensis × *H. benthamiana* = FX (Ford cross) 3810-3899-3925, IAN 717 (Belém);

H. brasiliensis × *H. brasiliensis* = FX 25-3864-4098, IAN 710-713-873 (Holliday, 1970; Chee *et al.*, 1986).

These clones are still being planted on a commercial scale in places where *Microcyclus* does not allow the cultivation of eastern clones.

Hevea cultivation in South America is therefore confronted by the double problem of variability of the parasite, which is still not clearly known and a reduced genetic base on which the resistance of the plant material now planted depends. Besides, the production potential of this material is now surpassed by modern clones.

Considering the capacity of the pathogen to adapt to modifications in the host population, it is now necessary to be concerned not only about resistance of the specific or total type, but also with another kind of resistance called partial, which is more durable in nature because it is non-specific (Simmonds, 1982).

New resistance sources should therefore be found. Two surveys were made in the Amazon in 1974 and 1981. They helped to enrich the gene pool of hevea significantly and a fund of resistance to foliar maladies could be observed (Nicolas *et al.*, 1994). This new material was selected to constitute a core collection in which certain clones could serve as parents for creating clones (Clément-Demange *et al.*, 1995).

Researches have been carried out in French Guyana since 1982 (Rivano *et al.*, 1989), on the one hand to evaluate the degree of genetic variability of the parasite and on the other, to identify some components of partial resistance among the available clones (old and new) that could serve as the base in a new genetic breeding programme for hevea in Latin America (Rivano, 1992).

These researches are directed mainly to the study of the performance of species of the genus *Hevea*, their hybrids and clones with good agronomic characters under ecological and climatic conditions that are very favourable for South American leaf blight.

Collections were constituted and are being continuously enriched since nearly fifteen years. Fields with experimental clones were set up on a small scale (large number of clones, number of individuals reduced to less than 50 per clone) as well as on a larger scale (smaller number of clones, number of trees more than 300 per clone). These sampling plots are complemented by a plant pathology laboratory where a large collection of isolates of the fungal parasite is cultivated.

These experiments have helped to collect information on the adaptation of plant material to the environment and especially on its susceptibility to *M. ulei* and other leaf parasites. They have helped to distinguish between the effects of host-climate interactions through the phenology of the tree from those due to parasite-climate interactions in the complex relationship which links the plant to the pathogen. A first fall-out of these basic studies is in the development of a method for evaluating the general field resistance of hevea to foliar diseases and especially to *M. ulei* (Rivano, 1997).

The principal manifestations of the disease that can be quantitatively evaluated in the field are the abscission rate of leaves, intensity of distortion of young leaves and percentage of necrotic leaf area on adult leaves. The clones tested could be classified into three statistically homogeneous groups for each of these three expressions of the disease. Apart from a few exceptions, clones of South American origin were significantly more resistant than Asian materials; some of them were even totally resistant to the disease from more than ten years (Fig. 3).

Furthermore, the preponderant role of phenology, the natural phenomenon of defoliation and refoliation manifested every year during the dry season from the fifth year of planting, in protecting trees confronted by fungal attacks was demonstrated. It is a reflection of the adaptation of clones to the ecological and climatic conditions under which they are planted. In favourable cases this is expressed by a homogeneous and rapid refoliation of all the trees during a period of the year when the climatic conditions are unfavourable for the growth of the fungus. Given that only leaves less than 15 days old are susceptible to *M. ulei*, this natural phenomenon would enable certain clones to escape the disease by reconstituting their foliage during the dry season and would thus restrict the development of epidemics to the rainy season (Rivano, 1992).

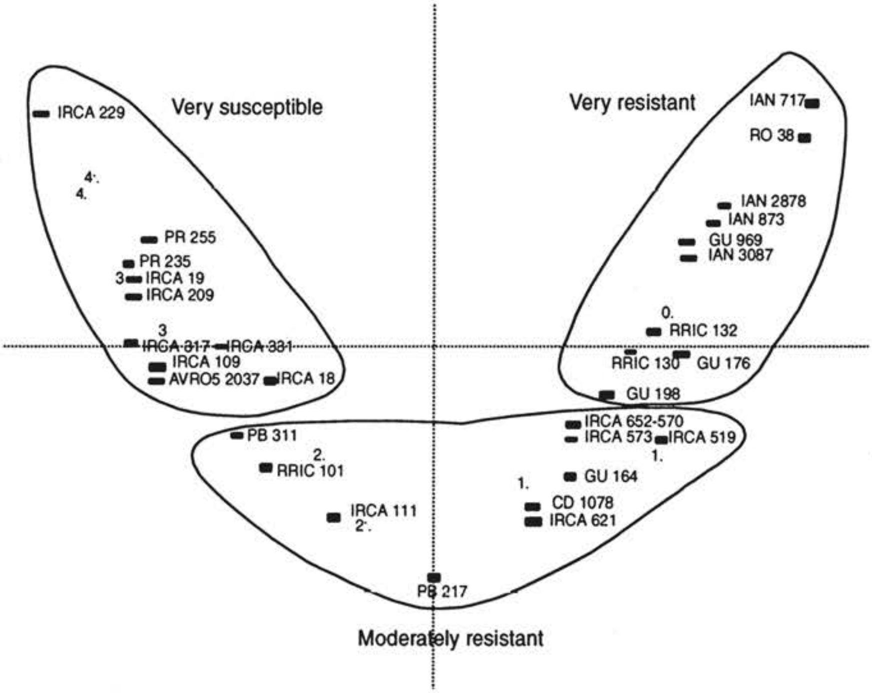


Fig. 3. Distribution of clones based on factorial correspondence analysis (fca) from observations of intensity of *Microcyclus ulei* infection on young (0 to 4) and old (0' to 4') leaves (from Rivano, 1997).

A complementary approach is to study about a dozen components of partial resistance to hevea under controlled conditions by artificially inoculating potted plants with *M. ulei*. This enables a comparison of clones on a quantitative basis and at the same time helps to consolidate the results obtained in the field (Rivano, 1992).

The results of these inoculations have very often revealed interactions of a quantitave nature between the clones and strains, which do not allow a global and final judgement of the level of partial resistance of a clone or the degree of aggressiveness of a pathogenic strain. In fact, we cannot rely on the inoculation of a single strain to appreciate the partial resistance of a clone and vice versa.

These interactions forbid us to state that partial resistance does not exercise any pressure on the aggressiveness of the pathogen population and that it is durable in nature. Contrary to Van der Plank's hypothesis (1968), it must be acknowledged that aggressiveness could evolve in function of the force exercised on it by the resistance mechanisms brought into play by the host.

The display could reside in the association of various defence mechanisms in the same genotype of hevea, but this implies that we have a fairly good knowledge of these mechanisms in the plant.

We can no more envisage making the best use of reinforced partial resistance without using it as a strategy conceived for prolonging its durability and efficiency. When hevea cultivation is introduced in a new region where *M. ulei* is still absent, we can plan to bring together in the same clone forms of efficient partial and total resistance whose circumvention would be judged as least probable. Total resistance would ensure efficient protection at least during the juvenile phases of the tree's growth, a period during which the absence of a defoliation-refoliation rhythm makes it particularly vulnerable. Partial resistance would then take over by slowing down the progress of the damage.

A separate study on the components of partial resistance under controlled conditions of infection also revealed that none of the clones in the experiment showed the best characteristics for all the manifestations of partial resistance. From this point of view, everything looks as if the selections made in South America in the presence of the disease and included in our experiments had been carried out partly blindly. A material may show very good characters associated with others which are less so.

These results have helped to launch a new genetic breeding programme for hevea in Brazil for creating material that is resistant to South American leaf blight by associating several elements of partial resistance, now dispersed in different clones, in the same genotype and at the same time raising its production level.

FRUIT CROPS

Citrus gummosis caused by *Phytophthora*

Genetic control of citrus gummosis caused by *Phytophthora* appeared to be very interesting right from the beginning. It quickly became universal mainly because of the choice of resistant varieties, which could be used as rootstocks (Boccas and Laville, 1978; Laville, 1984).

Their selection depends on several factors. First of all, the association of rootstocks with the commercial varieties should be compatible with the presence of viral diseases of citrus, especially tristeza. The rootstocks should also be well adapted to the soil and climate so that the fruit harvest is of a good quality. This is why the majority of clementine orange orchards are grafted either on Seville orange or *Poncirus trifoliata* or Troyer citrange.

With respect to *Phytophthora* infections, Seville orange is still considered to be correctly resistant on condition the trunks and roots are not injured, because it is known that any change in the bark and cortical zones of the roots considerably diminishes the resistance of this rootstock variety.

Poncirus trifoliata is clearly more resistant to both insidious attacks on roots as well as attacks on the base of the trunk. Wounds do not alter its resistance and cicatrisation takes place without secondary infection by *Phytophthora* (Laville and Blondel, 1979; Jacquemond and Blondel, 1986).

Resistance in Troyer citrange is also of a good level but the association of this rootstock with clementine posed a few problems in some orchards in Corsica. In fact, some cracks were observed in the bark on the outgrowth of the graft, near the union of the scion and rootstock. These injuries are often due to gummosis, which then quickly spreads to the susceptible clementine part. As these cankers appear on the trunk very close to the ground, they rapidly invade the base of the low branches. Hence despite appearances, it cannot be said that Troyer citrange is susceptible to gummosis, but this type of infection on the graft is found to be more common in Troyer citrange-clementine associations (Boccas and Laville, 1978).

This kind of attack as well as direct infections on the low branches on the grafted part of the trunk (very low plantations) or on roots can only be treated chemically.

Researches on the nature of host-parasite relationships indicate that in the citrus-*Phytophthora* pair, two categories of relationships are in play: one is the polygenic type and the other is oligogenic (Laville, 1975; Vallavieille, 1983). The latter type is more easily detected in a relatively susceptible host population belonging to the same group as in the case of orange, or when only the grafted variety is different. In contrast, the former seems to be preponderant on the one hand when all the citrus varieties are compared, from the most susceptible to the most resistant, and on the other within resistant host groups such as *Poncirus*.

These results indicate that it is clearly preferable to select new resistant varieties from hybrid populations obtained by interspecific crossings. In fact when the main characteristics of *Phytophthora* diseases of citrus are compared, we observe a high potential variability of the parasites, a low variability of the hosts and a strong selection pressure on parasite populations. Therefore, using horizontal resistance (high partial resistance) is undoubtedly the best guarantee for durability and efficiency in the different geographic zones.

Cercosporiosis of citrus

Evaluation of citrus cercosporiosis, caused by *Phaeoramularia angolensis* in the field, had been carried out for several years in Cameroon. About 120 citrus accessions were evaluated and none of them was found to be totally resistant (Bella Manga *et al.*, 1991; Rey *et al.*, 1986; Kuate, 1993; Kuate *et al.*, 1994). These different studies nevertheless suggest a considerable variation in varietal performance, ranging from a more or less pronounced partial resistance (lime, lemon, pampelmouse and some mandarin trees) to high susceptibility (pomelo, sweet lime and other mandarin trees). However, there is no information on the components which are in play during these interactions between the host and parasite and which could modulate the level of partial resistance. Analyses of these interactions, which should be done under standardised conditions (for both host and inoculum pressure), can be done by using experimental inoculation techniques that have already been perfected (Nzoumba, 1985). These data are indispensable for directing the work of varietal screening for which resistance to *P. angolensis* is the biggest challenge. Exploitation of resistance sources present in the species complex requires a good knowledge of genetic determinism and inheritability of partial resistance. This aspect will be studied in the near future for the two main methods of creating varieties which have now been perfected for citrus, viz., sexual recombination and somatic hybridization (Ollitrault *et al.*, 1944a, 1944b).

Bacterial citrus canker

The susceptibility of citrus and more broadly of the family Rutaceae, to bacterial or Asian canker, is generally quite similar in all the cultivars that comprise the plant species. However, there are some distinct differences in the susceptibility in the true cultivars of sweet lime and pampelmouse. The susceptibility of the major citrus species is summarised in Table 5 (Vernière, 1992).

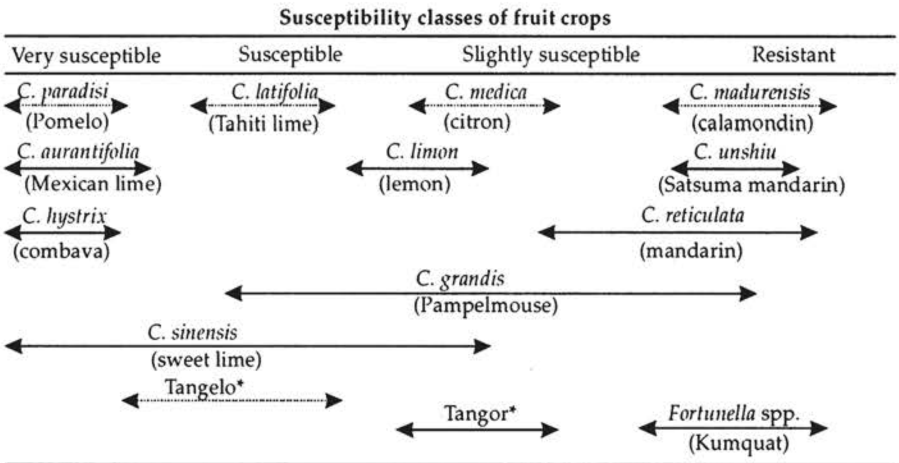
Black spot disease of mango

A large collection of mango trees has been established in Réunion since the 1960s. The cultivars in this collection are mainly from Florida and the Mascarene archipelago (most of these or their parents were probably introduced from India during the massive migrations in the nineteenth century). Observations made over a decade indicated that the majority of these cultivars were very susceptible to the black spot disease caused by *Xanthomonas* sp. *mangiferaeindicae*. Following these observations, three cultivars, viz., José, Auguste and Early Gold, were distributed to growers from the early 1980s: The José and Early Gold cultivars were distributed in Réunion as there is a high local demand for Indian type fruits. These were selected because they were the least susceptible among cultivars of this type and their fruiting periods are spread over four to six weeks. Hence these two cultivars are already harvested by the time the rainy season begins in Réunion. Data gathered since the 80s have helped to verify the good global performance of the Auguste cultivar. The José cultivar, which is very late, is often subject to severe infections linked to the heavy rains of the cyclonic season.

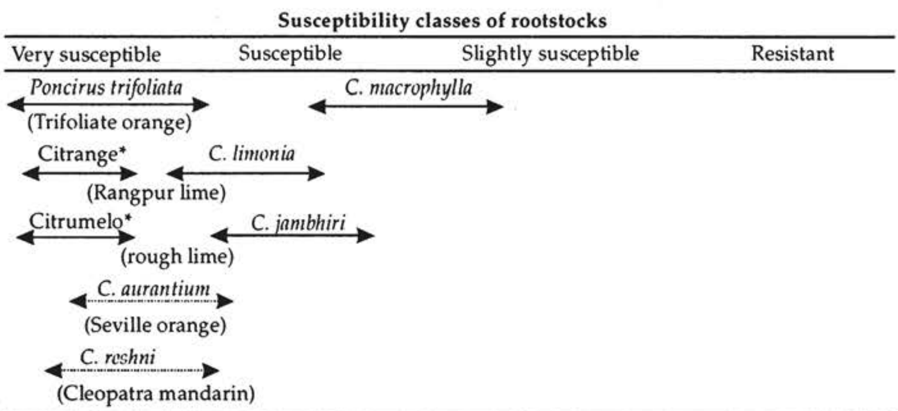
The good performance of the Early Gold cultivar in Réunion could be verified in a large number of commercial orchards established since the early 1980s. Studies have helped to demonstrate the following points:

- the intrinsic susceptibility of fruits of the Early Gold cultivar to the disease is high, whether the infection takes place through injuries or through lenticels (Pruvost and Luisetti, 1991);

Table 5. Susceptibility of citrus to *Xanthomonas axonopodis* pv. *citri*.



* Hybrid cultivars Tangelo: *C. reticulata* × *C. paradisi*;
Tangor: *C. sinensis* × *C. reticulata*



* Hybrid cultivars Citrange: *C. sinensis* × *Poncirus trifoliata*; Citrumelo: *Poncirus trifoliata* × *C. paradisi* cv. Swingle

— in producing orchards it was observed that trees of this cultivar have very few lesions on the leaf when compared to highly susceptible cultivars. Moreover, in the case of several cultivars in Réunion and South Africa, it was shown that there exists a clear relationship between the disease level recorded on leaves during the winter season and the percentage of infected fruits at the time of harvesting (Manicom, 1986; Pruvost *et al.*, 1990). The low susceptibility of leaves of the Early Gold cultivar was verified by comparing it with the more susceptible Maison Rouge, Haden and Irwin cultivars.

— the presence of water is indispensable for infection to take place.

If the lower foliar susceptibility plays a role in the global performance of the Early Gold cultivar, it is important to emphasise that it is among the earliest cultivars of the initial collection. Hence in Réunion most of the harvesting is done every year before the onset of the rainy season. This case is thus a good example of the adaptation of a cultivar to ecological conditions.

In South Africa, where the rainy season commences at the beginning of November, the performance of the Early Gold cultivar is relatively mediocre.

Several other cultivars show interesting levels of resistance. The Sensation cultivar, although very late, has been described in literature as resistant to the disease. It has not been distributed in Réunion because in view of the difficulties encountered with the José cultivar, the emphasis was on the distribution of early cultivars. However its resistance level, confirmed by several research teams, makes it a potentially interesting cultivar. It has been widely used in breeding programmes in Australia and South Africa for creating varieties with a view to obtaining resistant lines (Du Plooy, 1991; Whiley *et al.*, 1993). Researches carried out in South Africa have led to the recent distribution of four cultivars selected for their resistance to black spot disease in South Africa: Ceriese, Heidi, Neldica and Neldawn (Du Plooy, 1991). The resistance mechanisms are still not known. The agronomic performance of the Sensation, Heidi and Neldawn cultivars and their susceptibility to this disease are currently being evaluated in Réunion.

Black spot disease of mango probably originated in the Indian subcontinent. The typical symptoms were observed on herbarium specimens collected in 1880. It is probably in this region that the longest confrontation between the host and pathogen has taken place. The genetic diversity of the pathogen among the Indian sources is distinctly wider than the genetic diversity in strains originating from other countries (Gagnevin *et al.*, 1997). It would therefore be interesting to prospect for sources resistant to the disease in this region. Furthermore, until now there is no information available on the susceptibility of other species of the genus *Mangifera* to the disease. Resistance sources could exist in this material.

Recent works have shown the existence of a fairly wide phenotypic and genetic variability in *Xanthomonas* sp. *mangiferaeindicae* (Gagnevin *et al.*, 1997). It is important to take this variability into consideration while evaluating the susceptibility of mango cultivars to bacterial black spot disease.

Citrus tristeza

Host plants of citrus tristeza virus

By host plant we mean plants capable of multiplying the citrus tristeza virus in their tissues, irrespective of the expression of symptoms. This capacity is usually tested by injecting the plants with an Elisa dose of the viral antigen.

The host range of the citrus tristeza virus is essentially restricted to the family Rutaceae. Nevertheless more than 100 species belonging to 38 other families have been found to be unharmed by the citrus tristeza virus after mechanical inoculation or after exposure to insect vectors. Only a few Passifloraceae species could be infected experimentally. However in Réunion, where the disease is efficiently transmitted by a vector, passifloras are very rarely infected by the citrus tristeza virus under natural conditions. Thus after two years of exposing 400 lianes (mainly *Passiflora edulis*) to natural vector populations, only one was found to be infected.

Resistance and tolerance sources in Rutaceae

The striking form of tristeza (quick decline) attacks especially sweet lime and mandarin orange trees when they are associated with certain rootstocks, particularly Seville orange. This is due to an incompatibility between the rootstock and scion provoked by the virus and has resulted in the loss of millions of trees grafted on Seville orange throughout the world. In the case of sweet lime and mandarin orange, the damage can be remedied by using rootstocks which can confer a tolerance or resistance to the association. About 20 lines of rootstock were tested with the Beauty mandarin. These associations, which were screened in Réunion in the presence of severe viral strains, helped to identify different rootstocks showing a good degree of resistance to the virus and at the same time possessing satisfactory agronomic characters (Grisoni, 1995; Grisoni *et al.*, 1989). On the other hand, several hybrids with Seville orange and *P. trifoliata* as parents proved to be deceptive. The natural hybrid of Gao-Tao Seville orange shows a good degree of resistance to quick decline but it was found to be susceptible to stem pitting under the conditions prevailing in the island of Réunion.

The resistance in *P. trifoliata* to citrus tristeza virus has already been put to use for producing rootstocks. Other sources resistant to the virus could be found in some Rutaceae and used in varietal breeding programmes.

The Carrizo citrange (hybrid of *P. trifoliata* and *Citrus sinensis*) has been retained for development programmes in the nurseries in Réunion Island. The same rootstock had also been selected in French West Indies long before the recent introduction of citrus tristeza virus and the aphid *Toxoptera citricidus* (Kirkaldy), which has helped to considerably reduce the impact.

Protection of directly susceptible species

Several species are themselves susceptible to the citrus tristeza virus (irrespective of the rootstock used). This is especially so with sour *Citrus* species such as lime, combava and pomelo. This susceptibility is expressed by symptoms of stem pitting, which is often accompanied by a more or less drastic reduction in the vigour of the plants. The intensity of symptoms varies greatly depending on the nature of the viral strains. This variability and the presence of interactions among viral isolates help to protect susceptible species from damage caused by severe strains by preinoculating the plants with a mild isolate. The protecting isolates for combava were selected in Réunion

Island (Aubert and Bové, 1984, Grisoni, 1995). Protection provides a lasting guarantee for the productivity of combavas in an environment where severe strains of tristeza virus are prevalent (Fig. 4).

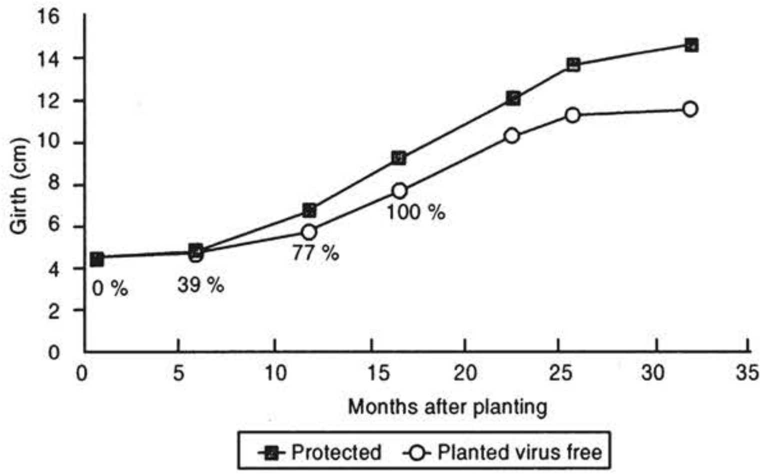


Fig. 4. Growth of grafts between combava, planted free of CTV and plants protected by the TR 26 isolate. Rate of contamination in plants planted free of the virus (from Grisoni, 1995).

CONCLUSION

The studies described in this chapter have often helped to jugulate diseases of tropical tree crops thanks to a profound knowledge of the evolution of the plant in its environment and thus helping to define selection strategies integrating the different parameters of economic interest.

However, these researches faced, or are still facing, several hurdles that cannot be ignored. Firstly, they concern the very nature of the tree crops because their reproductive and cultivation cycles generally impose long delays before results can be obtained and exploited.

Consequently it is necessary to develop early tests that are reliable, quick and reproducible. In most cases, knowledge of the causal organism or its vector has led to developing screening methods whose results can now be observed in full force. Nevertheless precautions have to be taken by adapting appropriate strategies against risks related to the development of resistance which is quickly overcome by the pathogen (for example, orange rust of coffee, South American leaf blight of hevea). Similarly, the plant material that is distributed should not depend on a very narrow genetic base, which is still the case with vascular wilt of oil palm in West Africa. The appearance of new pathogens may then prove to be disastrous.

Recent advances in biotechnology give reason to hope for new developments in the domain of breeding for varietal resistance. It is thus that analysis of plant pathogen populations and their diversity, characterised with the help of molecular markers, has helped to target isolates that are most representative of the different production zones. This progress should lead to a better evaluation of resistance and help in defining new breeding strategies based on selection aided by markers. The genetics of resistance, whose study is related to genome mapping of plants and identification of resistance genes, helps increasingly to plan a better management of host-parasite relationships and the mechanisms governing them.

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4

Insect Vectors

Dominique Mariau

All types of diseases are transmitted or vectored by insects. They are indispensable in the case of diseases caused by intraphloem pathogens: phytoplasma, certain viruses, bacteria and trypanosomatids. Insects may play a role in the transmission or development of other organisms such as nematodes or even fungi. When the insect feeds, some of these organisms are sucked into its alimentary system and travel through the intestine to reach the salivary glands; this is the persistent kind of transmission. They can then multiply and undergo transformations inside the body of the insect. Insects may also be simple vectors, non-specific accidental and non-obligatory for the transmission of a disease, which is known as non-persistent transmission. It was thus that a large number of stinging and boring insects were suspected of being vectors in a purely mechanical manner of the coconut disease of the viroidal type called *cadang-cadang* in the Philippines, although there was no formal proof. On the other hand, it is known that mechanical injuries caused by stinging and boring insects enable the growth of a foliar fungus on oil palm. Lastly, a wide range of insects may be responsible for the simple transmission of pathogenic organisms from a diseased plant or organ to a healthy plant. These insects also transmit fungi and nematodes. The demonstration and then the study of these various vectors are of great importance because in the majority of the cases they are part of the general strategy for the control of these diseases.

VIRAL TYPE DISEASES

Foliar decay of coconut

Foliar decay of coconut which, with the exception of local varieties, affects all the coconut trees introduced in Vanuatu (New Hebrides) in varying degrees, is found only in this archipelago. Of the various working hypotheses proposed, that of a pathogenic agent transmitted by an insect has been accepted.

A study of the insect fauna of coconut leaves in the archipelago enabled the demonstration of a homopteran (Fulgoroidea, Cixiidae) found almost exclusively in the disease centres, where it represented nearly 90% of all the homopteran species observed (Julia, 1982). This observation gave rise to a strong suspicion that this insect was involved in the transmission of the disease.

This insect was then introduced into an insect-proof cage in order to have direct proof of its role. Under these experimental conditions, more than 90% of the plants were affected by the disease, whereas the plants in other cages into which a mixture of other insects was intoduced were unaffected.

This test, confirmed by other experiments, clearly demonstrated the role of this homopteran, Cixiidae, in the transmission of the causal organism which had not yet been characterised at that time. The insect was identified as belonging to the genus *Myndus*, already implicated in the transmission of the lethal yellowing disease of coconut. The species was new: *M. taffini* Bonfils, about 3-4 mm in length, with the wings largely covering the abdomen and the head bearing a pair of carinae (photo 95).

It was observed that the disease centres developed especially near the borders of the plantations when their edges were occupied by groves of *Hibiscus tiliaceus*, locally called *bourrao*. Observations of the root system revealed the presence of larvae of *M. taffini* which were detected only in this particular environment, whereas the adults were found only on the leaves of coconut trees. This *Hibiscus* species, which is widely planted, serves as a live hedge for demarcating plots. Elimination of this plant helps to get rid of this insect and consequently of the disease itself when the coconut plantation is established with introduced plant material. If it is not possible to root out the *Hibiscus* plants, the disease can be controlled only by using tolerant plant material.

Dry bud rot of coconut

Dry bud rot of coconut is found mainly on young nursery seedlings in West Africa. Considering the symptoms observed, the etiological agent, which is yet to be identified, is most probably of viral origin. In contrast to the foliar decay of coconut, it was not easy to suspect one insect rather than another by simply observing the fauna found on coconut plants in the nursery, insofar as there were no areas that were preferentially affected. Hence, the insects—potential vectors of the disease—were introduced systematically: by family, then by genus, then by species (Julia, 1982; Julia and Mariau, 1982).

In this way it was possible to successively specify the family Delphacidae, the genus *Sogatella* and the species *S. kolophon* Kirkaldy and *Tagosodes cubanus* (Crawford); (photo 96). When a third species of the same genus was introduced into the cage, it did not reproduce the disease.

An average of more than 200 individuals per plant was introduced in one cage. Despite this very large number, the number of young trees affected was much lower than 100%. It was therefore concluded that only some individuals were capable of transmitting the disease. Experiments conducted at different periods seem to indicate that the number of insect vectors varies over time. By introducing insects over short periods, it was estimated that the incubation period is about fifty days.

Disease incidence is extremely variable from one year to another. It is probable that these variations are partly related to fluctuations in the vector populations. However, it is not the only factor because it was not possible to establish relationships between the number of individuals and the disease rate obtained for different periods. These observations clearly show that the insect certainly transmits a pathogen and that the disease cannot be linked to the activity of a salivary toxin.

Disease control is naturally through the control of vectors. The *Sogatella* populations can be reduced by eliminating the Graminae hosts of the insects in the larval stage in the nursery and surrounding areas. Spraying of systemic insecticides in the form of bagged granules complements the effect of weeding.

Ring spot disease of oil palm

Although the etiological agent of the American disease called ring spot has not been identified, taking into account the symptoms observed it is probably of viral origin. The development of this disease seems to be closely linked to the presence of certain Graminae (Dzido *et al.*, 1978), especially the Guinea grass, *Panicum maximum* Jacq. In a 2-year old plantation in Ecuador, the disease incidence went up to 90% in an area invaded by this grass. The systematic elimination of this grass resulted in a spectacular reduction in disease incidence. In a neighbouring area almost completely covered by *Penisetum purpureum* Schum. et Thonn, the disease rate was less than 5%. Other grasses may also be associated with the disease. Thus, in Peru, *Paspalum virgatum* L. was found to be very dominant in a highly infested region.

The transport of young oil palm plants in plastic bags in a susceptible zone for a few months gave a disease rate which was significantly higher than that of plants remaining permanently in a region unaffected by the disease. Further experiments could not be carried out but everything points to one or several insect species being involved in transmission of ring spot disease. Here also elimination of the grasses involved is the best control method.

Swollen shoot of cocoa

The swollen shoot disease of cocoa, which is of viral origin, is devastating in some cocoa producing countries in West Africa (see the chapter on Symptomatology and economic importance). It was mainly in Togo that entomologists of CIRAD carried out studies on the insect vectors of this disease. These vectors had been studied earlier in Ghana and identified as belonging only to the family Pseudococcidae or mealy bugs (Posnette and Strickland, 1948). Ten species have been counted in Togo (Dufour, 1991). Except for *Maconellicoccus ugandae* (Laing), all the other species were found to be capable of transmitting the Agou 1 form of the virus. The species *Delecoccus tafoensis* (Strick) could not be tested because of its extreme rarity. However, this species was found to be a vector of the New Juaben form in Ghana.

The relative importance of the different species is related more to the edapho-climatic conditions and shade (natural or auto-shade) of the cocoa trees rather than to the age of the trees (Table 1; Dufour, 1991). *Pseudococcus coccoides* is highly dominant over all the other species when there is heavy

Table 1. Importance of different species of Pseudococcidae vectors of swollen shoot disease in function of the environment

Plot	1	2	3	4
Age	4 years	4 years	14 years	14 years
Shade	Natural, dense discontinuous cover	Natural, light discontinuous cover	Natural, dense continuous cover (auto-shade)	Without shade continuous cover (auto-shade)
Number of coconut trees observed	232	193	53	56
Average number of individuals per tree	30.28	2.7	12.66	39.36
Species observed (percentage of presence)				
Planococcoides njalensis (Laing)	93.2	5.4	80.1	84.3
Planococcus citri (Risso) and *P. kenyae* (Le Pel)	4.4	40.3	11.8	12.3
Ferrisia virgata (Ckll.)	1.4	3.8	7.5	3.3
Pseudococcus longispinus (Targ. Tozz.)	0.4	1.0	0.4	0.1
Phenacoccus hargreavesi (Laing)	0.02	0.2	0.1	0.01
Tylococcus westwoodi Strick	0.4	22.9	0	0
Maconellicoccus ugandae (Laing)	0.05	26.4	0	0
Dysmicoccus brevipes (Ckll.)	0.03	0	0.03	0
Delococcus tafaoensis (Strick)	0	0	0.03	0

shading, whereas *P. citri/kenyae*, *Tylococcus westwoodi* and *M. ugandae* are dominant when shading is poor.

These variations are in perfect concordance with those demonstrated earlier by Nguyen Ban (1984). This author studied the fluctuations in the populations of different species in function of the rainfall. In the region of Kloto in Togo, the evolutive cycle of *P. kenyae* over a year includes a long period of activity which extends throughout the last semester (photo 97). In young plantations in Agou Etoe, this period of activity is preceded by two peaks of rapid multiplication in January and March-April, respectively (date of resumption of rainfall). These periods of activity are separated by resting periods whose duration varies in function of the seasons (Fig. 1). Rainfall seems to be the determinant factor for the variations in the growth cycle of this species and positive correlations could be demonstrated between the monthly rainfall and the number of individuals present on young cocoa plants ($r = 0.793$) and in adult plantations ($r = 0.624$) after two months (Fig. 2). The influence of rainfall is inverse and becomes a limiting factor for the species *P. njalensis*. This species reproduces actively during the first semester of the year (dry period), while the lowest populations are found between July and November. The regression line clearly shows a significant negative correlation ($r = -0.694$) with rainfall.

Scales are attacked by a number of parasitoids belonging to the family Encyrtidae (Hymenoptera) (Dufour, 1991). The main species attacking *P. njalensis* is *Neodiscodes abengourou* (Risbec), whereas species belonging to the group *P. citri/kenyae* are parasitised mainly by *Leptomastix bifasciata* Compere. Several predators feed on them to the detriment of the scales such as

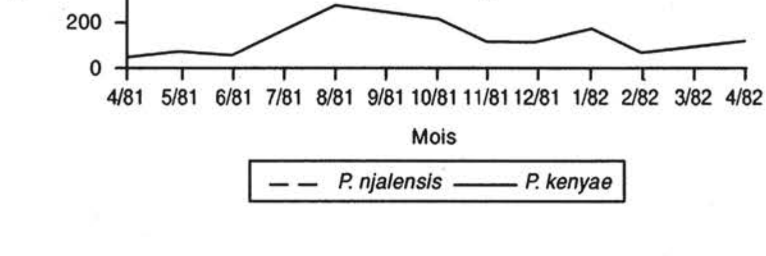

Fig. 1. Population dynamics of *P. njalensis* and *P. kenyae* on 25 trees in Tové (from Nguyen Ban, 1985).

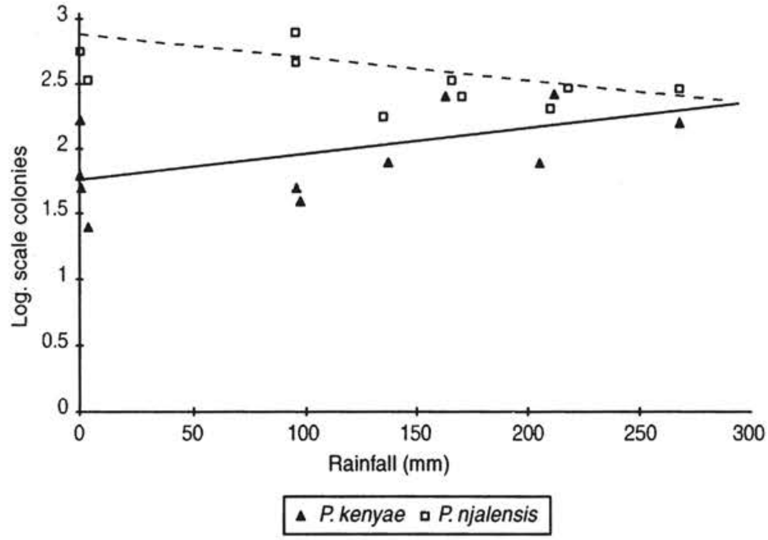

Fig. 2. Correlations between number of scale colonies and rainfall in Tové (from Nguyen Ban, 1984).

Cecidomyiidae (Diptera) and Coccinellidae (Coleoptera). Lastly, several ant species live in association with these scales, feeding on their honey and protecting them, and thus favouring their multiplication. Thirty-nine species of ants were listed in Togo but only a few of them are common, including several species of the genera *Crematogaster* and *Pheidole* (Dufour, 1991).

It is possible to protect young cocoa plants through chemical treatments by spraying or painting the collar. Painting with monocrotophos 40 ensures protection for young cocoa plants against scale invasion over a period ranging from 30 to 50 days (Nguyen Ban, 1982). On adult cocoa trees, chemical control becomes much more uncertain and unrealistic.

In the chapter on Varietal resistance, we saw that only selection of plant material can provide a really satisfactory solution in the fight against this disease, since susceptibility tests can be conducted by using these scales.

While awaiting the availability of this material, some cultural practices can be recommended along with the elimination of virus-infected cocoa trees:

— eliminating host plants of the virus which are, for example, shrubs such as *Ceiba pentandra* and herbs such as *Commelina erecta*;
— planting 2-3 lines of coffee plants around the cocoa plantation;
— controlling the scales when the plants are still young by using systemic insecticides.

Encouraging results have been obtained with these different techniques (Paulin *et al.*, 1993).

Tristeza disease of citrus

Ten species of aphids have been described as capable of transmitting the citrus tristeza virus (CTV). However, four of these aphids —*Toxoptera citricidus* (Kirkaldy), *T. aurantii* Boyer de Fonscolombe, *Aphis gossypii* Glover and *Aphis spiraecola* Patch—seem to play a predominant role as vectors of the disease. The citrus tristeza virus is transmitted in a semi-persistent manner, i.e., the aphids become infectious only after feeding on a virus-infected plant for a certain period of time (optimum is 24 hours). Moreover, the infecting power is lost 24 hours after feeding on a healthy plant and also after moulting.

A. gossypii, *A. spiraecola* and *T. aurantii* are highly polyphagic and have a worldwide distribution. Their efficiency in transmitting the citrus tristeza virus is much less than that of *T. citricidus*. Nevertheless, *A. gossypii* (photo 98) ensures wide dissemination of severe strains of the citrus tristeza virus in regions where *T. citricidus* is absent, for example in Spain, California and Israel.

T. citricidus, the brown citrus aphid (photo 99), is the vector with the highest intrinsic efficiency as a carrier, with an individual transmission rate of around 20%. Its distribution area is vast and is still expanding, especially in America, where it spread along the Caribbean Arc to reach Florida in 1996. Detected for the first time in Martinique in 1991, the oubreak of the disease observed on this island between 1994 and 1995 was the consequence of the introduction of this species (Leclant *et al.*, 1992). We now find it in most citrus growing regions. Only the countries around the Mediterranean and the eastern coast of the United States are free of this disease. However, *T. citricidus* is found in the islands of Madera and Hawaii.

In contrast to other vectors, the brown citrus aphid is oligophagic and strictly confined to Rutaceae. The colonies grow mainly along the stems of young shoots. The population dynamics of *T. citricidus* is therefore strongly correlated to the rhythm of the vegetative shoots of citrus plants. Besides, in tropical regions where *T. citricidus* is present, its populations are highly dominant when compared to other species colonising citrus plants. Thus, in Reunion brown aphid colonies can be observed throughout the year and very high infestation levels have been recorded at the time of sprouting of young shoots on citrus plants (Rochat, 1995; Fig. 3). The combination of a high intrinsic capacity for transmission of the citrus tristeza virus and a clear feeding preference for the host species of the virus (particularly *Citrus*) makes *T. citricidus* the most formidable vectors of the tristeza disease. Under the conditions prevailing on the island, where most of the citrus cultivated is infected by the virus, plots planted with uninfected plants are completely contaminated within a time span of 9 to 33 months, depending on the plots.

Numerous natural enemies (parasitoids, predators and entomopathogens) of *T. citricidus* have been listed throughout the world, but their capacity to reduce the proliferation of this species seems to be poor. Mulching seems to

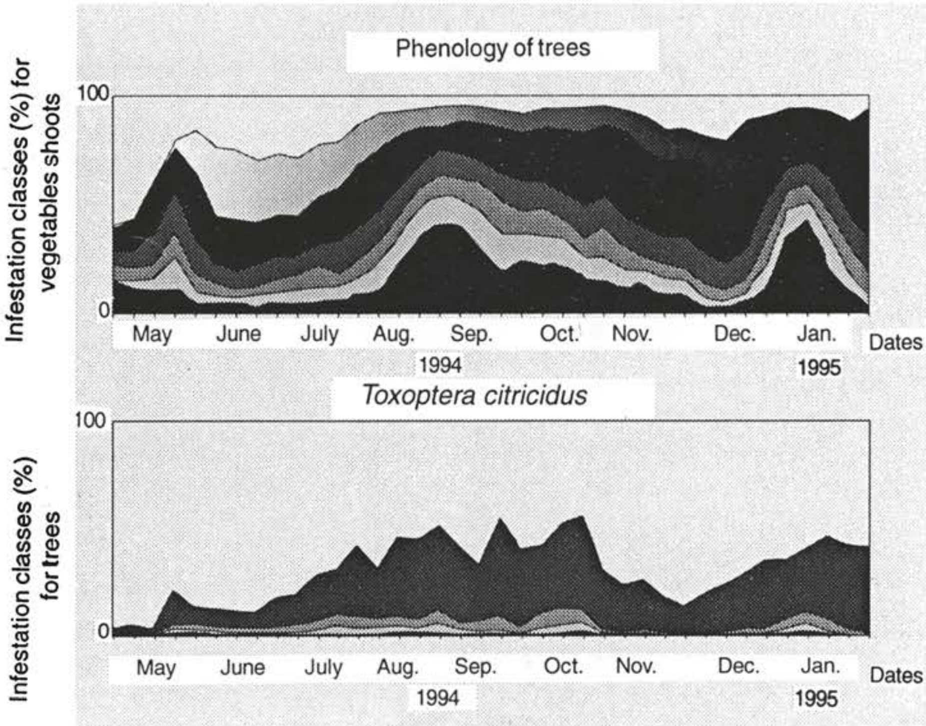

Fig. 3. Population dynamics of citrus aphids in Réunion (from Rochat, 1995). The grey levels are related to intensity classes for vegetative shoots and infestation classes for *Toxoptera citricidus*.

have an appreciable influence on the rate of infestation of citrus by *T. citricidus*, helping to defer contamination of plants by the citrus tristeza virus (Grisoni and Rivière, 1997). However, this technique is not adequate to provide lasting protection for young orchards. We have seen that selection of resistant rootstocks and using protective isolates are the techniques to be adopted for controlling this disease.

PHYTOPLASMA DISEASES

Lethal yellowing of coconut

Lethal yellowing of coconut is linked to the development of a phytoplasma. This serious disease is manifested in two distinct geographical areas: in the Caribbean region on the one hand and in Africa, on the other. In the former, the homopteran species, *Myndus crudus* Van Duzee (Cixiidae), has been identified as the carrier of the disease (Howard *et al.*,1983).

In West Africa, another family Cixiidae was observed on coconut trees (Taffin and Franqueville, 1989), which was subsequently identified as *M. adiopodoumeensis*. As this homopteran was strongly suspected to be the vector of the disease in this region, detailed studies were carried out on it (Dery *et al.*, 1996). By placing sticky traps in the crown of the coconut tree, it was possible to study the population dynamics of the different species of Homoptera visiting the foliage of coconut trees. It was noticed that *M. adiopodoumeensis* populations were appreciably lower during the dry period (Fig. 4). Moreover, it was observed that they were more than three times higher in plantations contaminated by the disease and at the beginning of gradation than in healthy plots, while the populations were inverse for other homopteran species. All these species together are 1.3 times more in healthy zones. These observations support the hypothesis according to which *M. adiopodoumeensis* is the vector, or a vector of lethal yellowing in West Africa. The nymphs of this *Cixiidae* are capable of growing in the root system of a large number of herbaceous plants, including *Pennisetum polystachion* L. Schult and *Paspalum scrobiculatum* L., the latter being the most common. *Rottboellia cochinchinensis* (Lour and Clayton) is also an important host along with *Panicum maximum* Jacq. (Poaceae) and *Mariscus cylindristachyus* Stendel (Cyperaceae).

Experiments to reproduce the disease in cages by introducing a large number of *M. adiopodoumeensis* were not very conclusive. However, it must be remembered that research workers in the Caribbean have always encountered enormous difficulties in reproducing the disease and were able to obtain only a few cases. In contrast to a number of diseases described in this chapter, control of the lethal yellowing disease cannot be achieved by controlling the vector. Repeated injections of tetracycline into the trunk helped to cure coconut trees in the initial stages of the disease or to prevent the infection. This

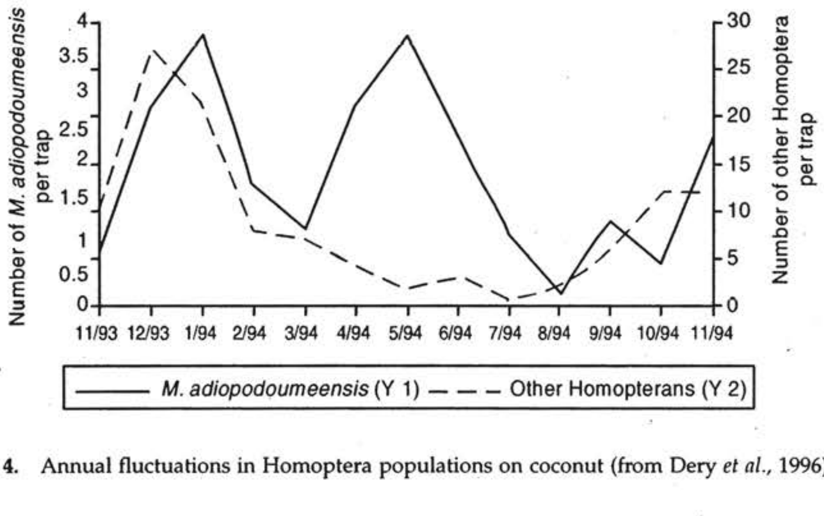

Fig. 4. Annual fluctuations in Homoptera populations on coconut (from Dery *et al.*, 1996).

method could be used, for example in Florida, to save ornamental palms but cannot be retained as the control method in coconut plantations. It is only through selection of tolerant plant material that a solution can be found.

Blast disease

Blast disease, which is capable of completely wiping out oil palm nurseries in West Africa, can be effectively controlled by providing shade during the development period of the disease. It was thought that modification of climatic conditions under shade inhibited the development of the organism (Bachy, 1958). Implementation of large plantation programmes made it increasingly difficult to provide shade for nurseries over several hundreds of acres. This is the reason why researches were undertaken once again in the 70s.

In the beginning, experiments were conducted to try and shield the plants from the disease, either by putting them in cages of various types, or by providing shade during different periods of the day (Renard *et al.*, 1975).

Cages which are completely closed ensure almost total protection. Protection is still very good in cages without muslin roof and hence without any shading. Curiously, it is shade provided at night which is most effective; shading at the beginning and at the end of the day also showed a certain degree of efficiency. These experiments helped to formulate a hypothesis according to which the blast disease is transmitted by insects and that these insects were active from night to early morning and that after twilight, just providing shade considerably reduced their flight towards oil palm plants.

The final experiment consisted of reproducing the disease with one or several species, the difficulty being that about 200 hemipteran species visited the plants in the nursery. As in the case of dry rot of coconut, different types of introductions were made—first by family, followed by genus, then a group of species and finally just one species. The results obtained are summarised in Table 2.

This experiment thus helped to demonstrate the role of *Recilia mica* Kramer in the transmission of the disease (photo 100). The first symptoms appear two weeks after the first introductions, this period representing the incubation period of the blast (Desmier de Chenon, 1979). Other species are also present: *R. colabra* Kr. and *R. canga* Kr. are impossible to distinguish in introductions,

Table 2. Rate of blast disease obtained with different species of Hemiptera

Insects introduced	Disease rate (%)
Hemipterans mixed	98 and 84
Small jassids mixed (20 species)	64 and 94
Big blue jassids	0
Small green and yellow jassids	0
Small grey jassids (*Recilia mica*)	92

but only the species *R. mica* is found in large numbers and is present during the development period of the disease. Various species of Graminae are the host plants of these insects.

In order to study the population dynamics of the insect and its capacity to transmit the disease, samplings were taken from Graminae species under uniform conditions throughout the year and the insects sampled were introduced in cages (Franqueville *et al.*, 1991). It is during the season favourable for the development of the disease (October to January) that the insects are most numerous (Fig. 5). During one period of the year (May-June) the insects cannot transmit the disease, but it is not necessarily during the favourable period (October and November) that *R. mica* is most efficient in transmitting the pathogen. The palm plants remained healthy although they were stung by hundreds of individuals, which makes us think that the individuals capable of transmitting the disease are small in number. It was also observed that males ensured beter transmission of the disease (54%) than females (35%). Lastly, it appears that young plants with four leaves are more susceptible to the malady (95%) than older plants with eight leaves (45%).

Following these diverse experiments, it was possible to develop a control method directed against the vector by substituting insecticides for shading, which is often not only difficult to install but also disturbs the growth of the plant considerably. Introduction of insects into a cage helped to quickly test the efficiency of various insecticides against high disease pressure (Table 3).

The results obtained under actual treatment conditions are summarised in Fig. 6 (Desmier de Chenon *et al.*, 1977). The fight against these insects can also be complemented by elimination of grasses in the nursery and its surrounding areas. A plot separated by about 50 m of leguminous plants was almost completely free from infection by the blast disease.

This disease, attributed for long to the action of a fungal complex is, therefore, linked to an organism of the phytoplasma type (see the chapter on Pathogens) transmitted by insects. These researches have enabled the development of an efficient and well-adapted control method.

PHYTOMONAS DISEASES

In Latin America, oil palms infected by *marchitez* and coconut trees affected by *hartrot* contain Trypanosomatidae members of the genus *Phytomonas* in their sieve tubes. These organisms are known to be transmitted by bugs of the Pentatomidae family. Researches were therefore carried out on this kind of vectors (Desmier de Chenon, 1984). Young palm trees recently afflicted by the disease in equatorial Amazonia were dissected. The presence of sometimes large populations of 100 to 200 individuals belonging to the genus *Lincus* was systematically observed in the leaf axils. The species was identified as *L. lethifer* Dolling (photo 101).

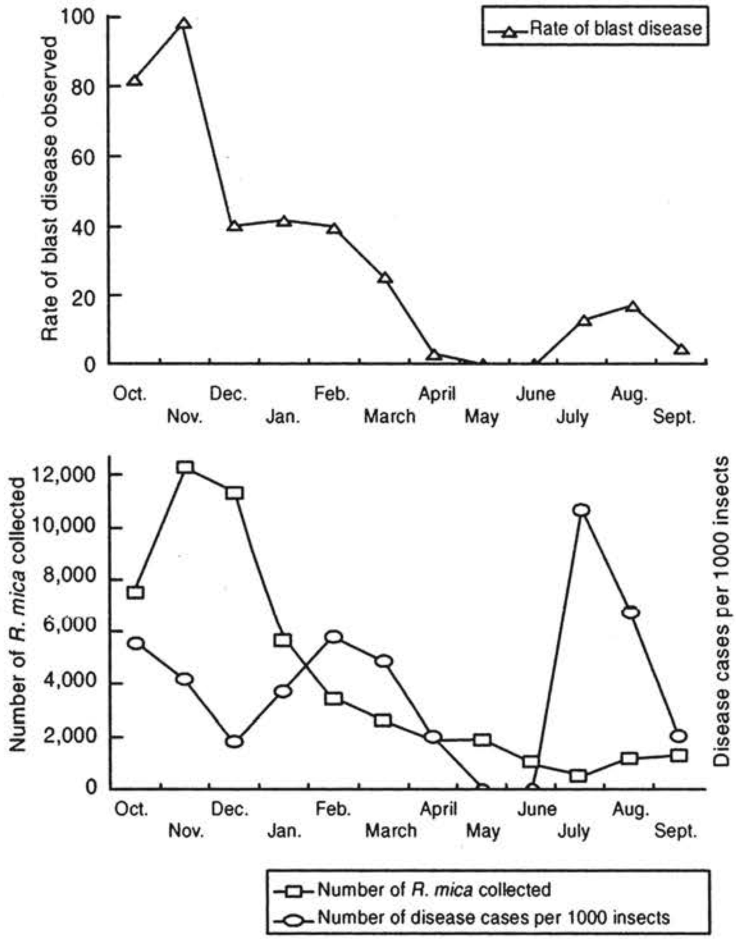

Fig. 5. Incidence of blast disease on oil palm in function of time and *Recilia mica* (from Franqueville *et al.*, 1991).

Table 3. Efficiency of insecticides against the vector of blast disease

Insecticide and dosage	Disease rate observed
aldicarb 0.2 g/plant	10
oxamyl 0.2 g/plant	30
metamidophos 0.2 g/plant	15
omethoate 0.2 g/plant	17.5
Control	100

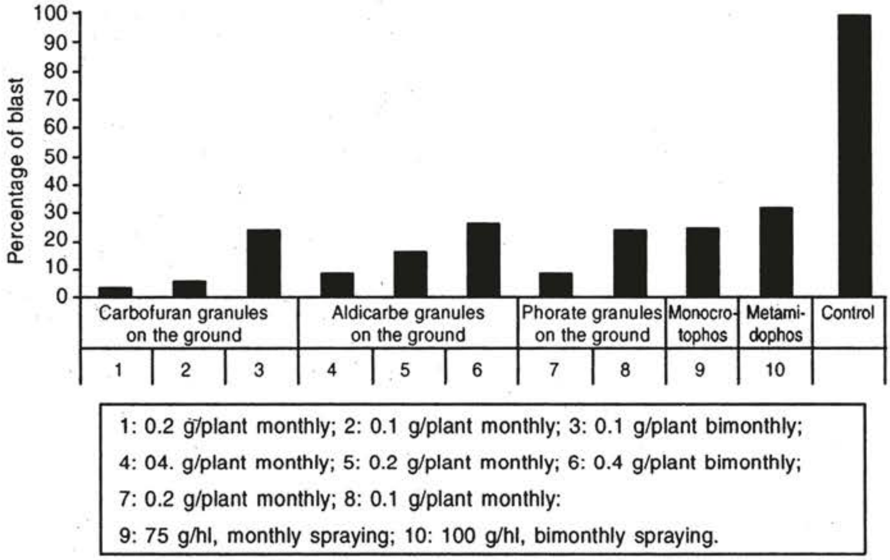

Fig. 6. Efficiency of various insecticides against the vector of blast disease (from Desmier de Chenon *et al.*, 1977).

Other observations led to a strong suspicion that these bugs were responsible for the transmission of the causal organism. This hypothesis was later confirmed by introducing the insect into an insect-proof cage (Perthuis *et al.*, 1985). In Guyana, similar results were obtained with a mixture of three species of *Lincus*, with *L. croupius* Rolston greatly dominant over *L. appolo* Dolling and *L. dentiger* Breddin (Louise *et al.*, 1986).

The eggs of *L. lethifer* are laid in batches of 16 to 18. After an incubation period of 7 to 9 days, they hatch and young larvae, about 2 mm in length, emerge. After 5 stages, the last moulting frees an adult about 10 mm long and blackish-brown in colour with yellow spots on the thorax and scutellum. The total duration of the life cycle is 3 to 3.5 months. Observations carried out on coconut trees showed that more than 80% of the population is found in the axils of the seven oldest leaves, i.e., in the place where plant debris is accumulated and then transformed into humus favourable for the maintenance of high humidity which, together with darkness, constitutes an environment highly favourable for the development of the insect.

Other species of *Lincus* are found in South America. Thus the following species were observed on oil palms and coconut trees: *L. vandoesburgi* Rolston and *L. lamelliger* Breddin in Surinam and Guyana; *L. lobuliger* Breddin and *L. spathuliger* in Brazil; *L. tumidifrons* Rolston in Venezuela and Colombia; *L. spurcus* Rolston, in Peru (Dollet *et al.*, 1993). Other species, especially of the genus *Astrocaryum*, were observed on various palms.

The genus *Lincus* is however not present everywhere. A species of Pentatomidae was observed in a coconut plantation in Para State in Brazil and identified as *Ochlerus*, a closely related genus (Mariau, 1985a). This insect was introduced in a cage containing coconut trees of the Malaysian Yellow Dwarf type. The first symptoms of the disease were observed after a few months (Renard, 1987).

As the etiological agent of an eventual vector was still not known, preventive measures were undertaken in several plantations in Latin America to prevent a catastrophic outbreak of the disease. The root system was treated with highly persistent insecticides, the root-boring caterpillar *Sagalassa valida* Walker being wrongly thought to be the cause at that time (Lopez *et al.*, 1975). These treatments had a spectacular effect, resulting in a considerable reduction in disease incidence.

In one of these plantations, several hundreds of cases were observed every month before treatment; the number was reduced to a few dozens three months after the commencement of remedial operations. A similar result was obtained for coconut trees in Guyana when an organochloride was sprayed on the growth sites of *Lincus* (Louise *et al.*, 1986). Tests performed with deltamethrine at the rate of 2 gm per hectolitre also gave results close to 90% mortality. Cultural techniques unfavourable for the vector can be adopted to complement chemical control. Thus, in Brazil it was observed that the disease developed mainly at the margin of the forest, the region of origin of *Ochlerus* (Renard, 1987). Keeping these border areas very clean contributed to reducing the vector populations. Furthermore, it was observed that the insects gained entry to the crown of coconut trees mainly through the medium of the lower leaves in contact with the ground. Pruning the coconut fronds helped to considerably reduce the impact of the disease. Therefore it is by the combination of a chemical control method directed against the vector (by treating the centres of disease development) and appropriate cultural techniques that it is possible to effectively control *Phytomonas* diseases.

FUNGAL DISEASES

Insects can be passive carriers of the spores of a large number of fungi. However, insects act more directly in a certain number of cases by either enabling the entry of a fungus into the plant through the wounds they cause, or by aiding fungal growth thanks to their sweet secretions.

Phytophthora disease of cocoa

Insects, in whose front ranks the ants can certainly be placed, play an important role in the dispersal of spores from the soil which represents the main conservation niche of fungi. Thus it was observed that cocoa trees, the base of whose trunks was ringed with glue, were less rapidly contaminated by *Phytophthora* than control cocoa trees (Muller, 1974). In contrast, the presence of the ant *Wasmannia auropunctata* Roger seems to limit the growth of *Phytophthora*. Without harming the cocoa tree, this ant raises several species of scales, of which at least one belongs to family Pseudococcidae or mealy bugs. These hemipterans seem to have an inhibitory effect on the germination of the spores of *P. palmivora* (Blaha and Bruneau de Miré, 1971). These observations are very similar to those of Attafuah (pers. comm.) in Ghana; he was able to isolate a bacterium, *Pseudomonas aeruginosa*, from *Planococcoides njalensis*. Cultures of this bacterium seem to have an inhibitory influence on the growth of *P. palmivora*. It is worth continuing these studies because we already know that *W. auropunctata* greatly limits *Miridae* bug populations, which cause immense damage to cocoa trees in Africa (Bruneau de Miré, cited in Mariau *et al.*, 1996).

On several occasions, a sudden spurt in the disease was observed concomitant with a proliferation of drosophilas. Lastly, snails and beetles can also ensure dissemination of the fungus (Muller, 1974).

Pestalotiopsis on oil palm

In a large number of oil palm plantations in Latin America, the leaves are sometimes invaded by a fungus of the genus *Pestalotiopsis* (Melanconiaceae). This fungus grows as a halo, which begins as a small speck and gradually becomes bigger (photo 102). When the infection is severe, the lesions join together and leading to an almost complete withering of the leaflets or even of the whole plant. If such destruction affects most of the leaf area, production may drop drastically by 40% or even more (Mariau, 1994). In the case of a very dry season, the humidity necessary for fungal growth is lacking. However, these conditions rarely exist and a large number of plantations suffer from such defoliations.

However, *Pestalotiopsis* can enter the leaves only through wounds caused by different kinds of insects. Thus two species of Hemiptera (Tingidae) have been observed: *Leptopharsa gibbicarina* Froeschner (Genty *et al.*, 1975) and *Pleseobyrsa bicincta* Monte (Ojeda Pena and Bravo Calderon, 1994). The adults are 2.7 to 3.4 mm long and have the characteristics typical of the family with large elytrae and lace-like lateral expansions (*chinche encaje* in Spanish; photos 103 and 104). The adults and larvae sting the lower surface of the leaves and each sting could be a potential point of entry for the fungus. *L. gibbicarina* is more dangerous because the insects visit the whole leaflet whereas *P. bicincta* remains localised on the lower leaflets of the palm which play a smaller role in photosynthesis. In some cases, *L. gibbicarina* may be infected by an entomopathogenic fungus, *Sporothrix insectorum*. However, in the majority of cases this fungus does not grow in a way that can guarantee low population levels of the insect. It is by controlling the bugs that we can also control attacks by the fungus. Root absorption of systemic fungicides, such as monocrotophos, helps to obtain high insect mortality rates. Moreover, this kind of treatment is environment friendly in the sense that it does not act directly on the fauna associated with the pests.

However these insects are not the only ones which enable the development of *Pestalotiopsis*. Numerous species of Lepidoptera (*Euclea diversa* Druce, *Euprosterna elaeasa* Dyar, *Norape* sp., etc.) scour the lower surface of the leaves during the initial stages of larval development. This kind of damage, which causes very little direct defoliation, is often the main point of entry for the fungus. Controlling these defoliators alone can help to limit the spread of the parasite.

Phthiriosis of coffee

Roots of the coffee plant are often colonised by insects of the Coccidae group. *Phanococcus citri* Risso was observed in Africa and *Formicoccus greeni* Vays in Madagascar (Lavabre, 1964). These scales are transported and then taken care of by terricolous ants belonging to the genus *Paratrechnia* which exploit the entire root system of the coffee plant thanks to an extensive underground gallery. The attention given by the ants is related to the fact that these bugs secrete an abundance of honey. This sweet secretion is not only a source of food for the ants but also a substrate for the growth of a fungus belonging to the genus *Polyporus* which forms a mantle around the roots and slowly suffocates the plant. The development of this fungus has the appearance of a rot, which may lead to some confusion in identification. Although phthiriosis is quite widespread in Africa and Asia, the economic loss is not very heavy. It is only on the eastern coast of Madagascar that it has spread rapidly with very high rates of infestation requiring the application of chemical control methods to restrict the infection. Organochlorides and some organophosphates such as parathion have given the best results providing the root system is very well drenched.

Fumagine on coconut

Fumagine, an Ascomycetes fungus, belongs to the heterogeneous family of *Capnodiaceae* which groups together species which always grow on plants. They are not parasites in the strict sense of the term. They do not have any anataomical relationship with the plant which is only a support. Fumagine grows thanks to the abundant sugary substance secreted by various species of aphids, including *Cerataphis lataniae* Boisduval, which is present on coconut trees (Mariau, 1996). In the Yellow Dwarf and Green Dwarf varieties of coconut which are susceptible to attacks by this insect, the spear leaf may be completely covered with fumagine. In the most severe but rare cases, the entire foliage is invaded by the fungus. In this way it forms a screen against light thus disturbing the process of photosynthesis. The same phenomenon was observed on a number of other plants: cocoa, coffee and, more commonly, citrus plants where the fumagine grows on the sweet secretions of various species of aphids and scales.

BACTERIAL DISEASE

Citrus greening

About twenty years ago, two species of Hemiptera belonging to family Psyllidae were found to be particularly harmful to citrus plants in Réunion (Quilici, 1993). The distribution of the African psylla *Trioza erytreae* Del Guercio is confined to South and East Africa up to Sudan as well as Madagascar (photo 105). In Reunion, they are found mainly in the cold and humid zones above elevations of 500 m. Another species, called Asian, *Diaphorina citri* Kuwayama, was also reported in Brazil and Saudi Arabia. This species thrives in leeward regions which are hot and drier. Adults of the Asian species are covered with a waxy, whitish secretion and the wings, which are rounded at the tips, bear brown spots. These features help to distinguish this species from *T. erytreae*. Adults of the latter are not covered by wax, and their wings are transparent with pointed tips.

Direct damage caused by these psyllids (gall formation on the lower surface of the leaves) is generally not serious, but they transmit a very serious bacterial degenerating disease called greening to citrus plants. Only the adults of *T. erytreae* can transmit the infection, wheras in the case of *D. citri*, even the 4th and 5th larval stages can be carriers. The bacteria can multiply inside the body of the insect, which thus remains infectious throughout its life after a single acquisition. Until the late 70s, this disease was the most important limiting factor for citrus cultivation in Réunion. Natural enemies (a parasite and a few predators) were not adequate to arrest the rapid proliferation of their hosts (Etienne, 1978).

Hence, with a view to developing a biological control method, efforts were made to find the most promising natural enemies of psyllids in the countries of their origin. Two species of Eulophidae (Hymenoptera), ectoparasites on larvae, were therefore introduced: *Tamarixia dryi* Waterston, of South African origin from 1974 to fight against *Trioza erytreae* and *Tamarixia radiata* Waterston, of Indian origin in 1978 with a view to controlling *Diaphorina citri* (Aubert and Quilici, 1992).

These insects were studied and multiplied in an insectarium (Quilici *et al.*, 1992) and then freed in the field at the rate of 30 to 50 adults per km^2. Within the space of two years, the two parasites had caused a spectacular reduction in the populations of their respective hosts (Fig. 7). This biological control programme was highly successful and is probably a unique case in terms of

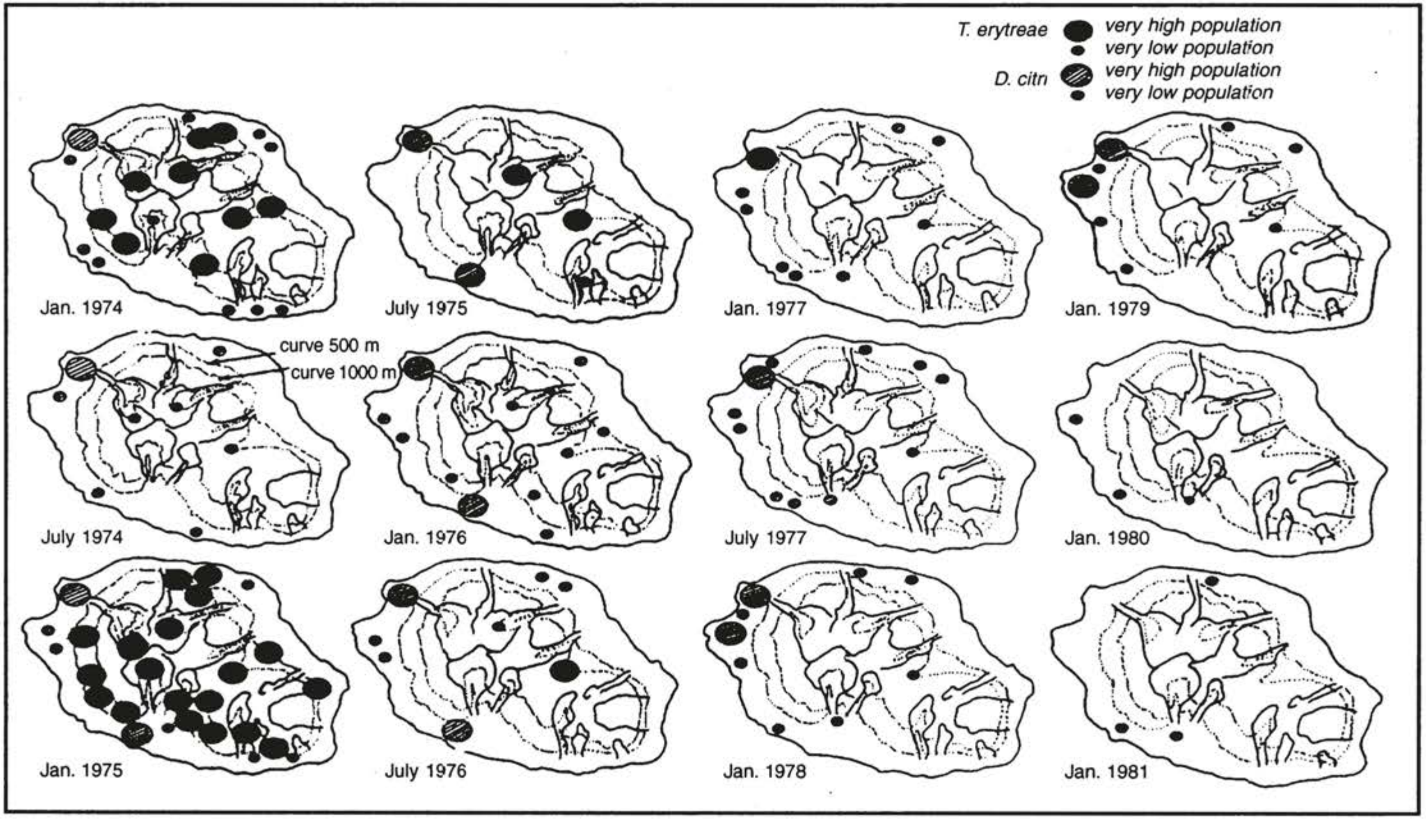

Fig. 7. Evolution of *Trioza erytreae* and *Diaphorina citri* populations in Réunion Island (from Aubert and Quilici, 1985).

biological control through acclimatisation against insect vectors of a disease in an insular environment (Aubert *et al.*, 1979).

NEMATODE DISEASES

Red ring of coconut and oil palm

Although several nematode diseases have been enumerated on tropical tree crops, only the red ring disease of palms involves insects as disease carriers. *Rhadinaphelenchus cocophilus* (Coob) may be transmitted to the plant through the root system. However, the South American species of the palm weevil, *Rhynchophorus palmarum* (L.), plays a very important role in the dissemination of the nematode (photo 106). In a plantation in Brazil, where the disease rate was less than 0.5% per year, the percentage of adult rhynchophore nematode carriers was 4.8% and 2.9% in 1984 and 1985 respectively (Mariau, 1985b). In another plantation with very high mortality rates (20 to 80% cumulated on crops of 10 to 20 years), the percentage of rhynchophores carrying the nematodes was distinctly higher: 13.4% in 1984 and 14.5% in 1985 (Renard, 1985).

It was possible to reproduce the disease by keeping adult rhynchophores enclosed in small grilled cages in the axils of the palm leaves, the first symptoms appearing just a month after the commencement of the experiment (Morin, 1986).

Control of red ring disease is therefore effected by limiting the populations of the main vector, which can be done in two ways. As the larvae of rhynchophores grow inside the living tissues of the palm, development of their populations should be restricted by removing the trunks of the palm trees infected by the disease, or by making them unsuitable for the development of the insects by local application of insecticides. It would be desirable to complement this important preventive measure with a method to capture the adult weevils. They are strongly attracted to wounds on the palm trees where they deposit their eggs and also feed on the sap. This behaviour has been utilised to attract the adults into traps containing pieces of palms or of other plants such as sugarcane. Furthermore, the presence of a pheromone aggregate produced only by the males when they feed on the host plant has been demonstrated (Rochat *et al.*, 1991). The rate of capture is ten times more when this pheromone is added to the pieces of plant debris kept in the trap, and thus helps to quickly eliminate a much larger number of potential vectors.

CONCLUSION

In a very large number of cases of diseases transmitted or vectored by various species of insects, control measures are generally through the control of the insects responsible for the transmission. This control can be practised in several ways thanks to well directed chemical treatments as done in oil palm and coconut nurseries, and often through biological control methods. Appropriate cultural techniques could, for example, help to reduce or even eliminate a vector, as in the case of foliar decay of coconut in Vanuatu. Trapping insect vectors can also contribute in a large measure to reducing the impact of a disease such as the red ring disease of palms in tropical America. Lastly, strict biological control with the help of parasites has helped to eliminate the vectors of citrus greening in the island of Réunion.

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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).

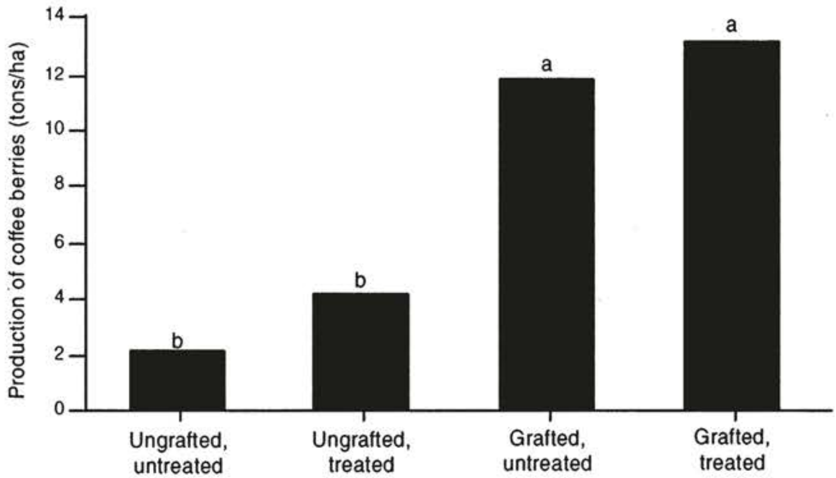


Fig. 1. Control of *Pratylenchus* sp. by grafting and nematicides (from Villain *et al.*, 1996).

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

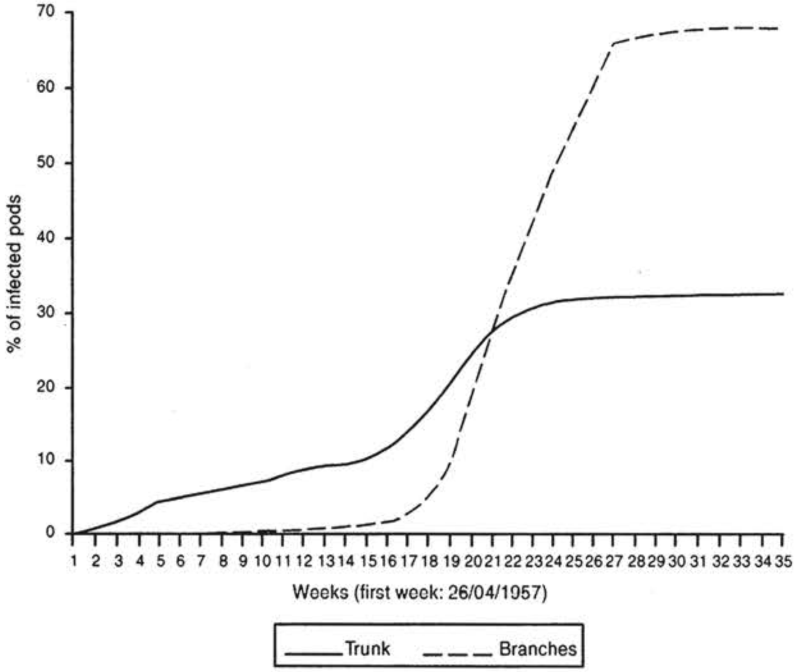


Fig. 2. Percentage of pods (cumulated weekly) infected by *Phytophthora* sp. at different levels of trees (from Muller, 1974).

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.

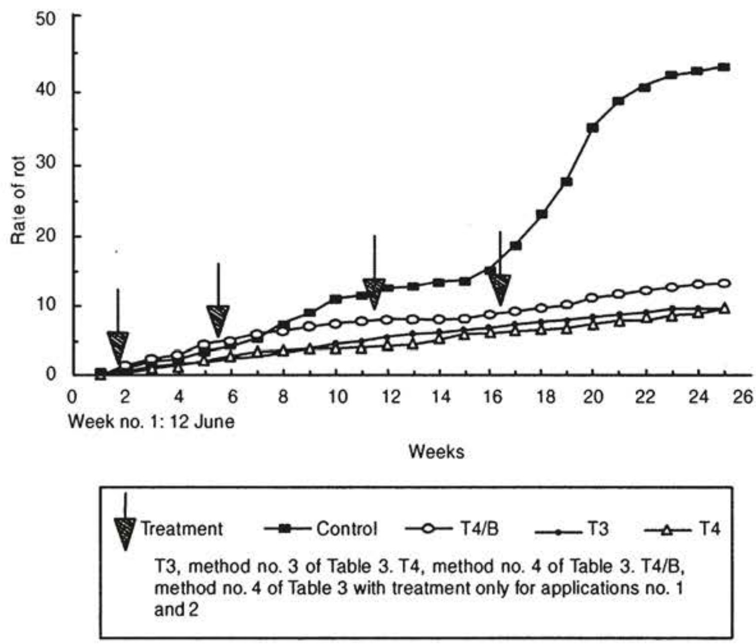


Fig. 3. Chemical control of brown pod rot of cocoa in Cameroon (from Berry and Tafforeau, 1991.

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).

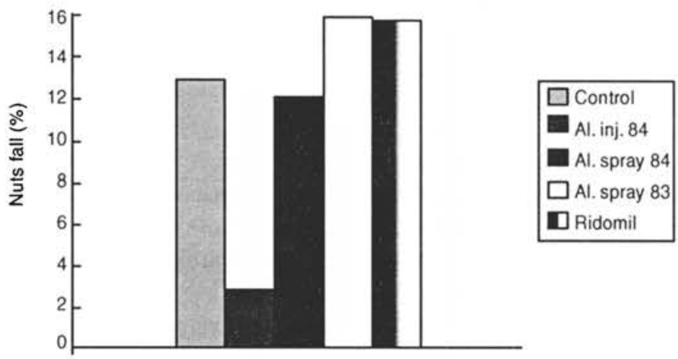


Fig. 4. Control of *P. katsurae* of coconut: nuts fall over harvests of two years (from Franqueville and Renard, 1989).

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.

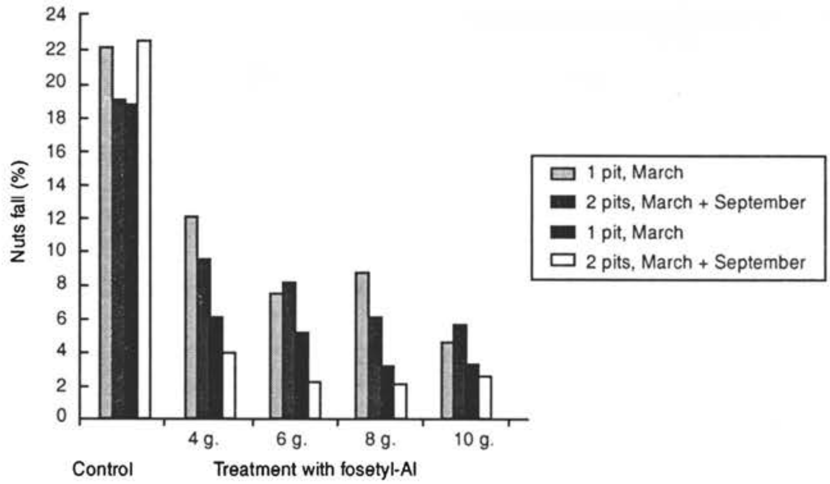


Fig. 5. Nuts fall of coconut over harvests two years after different types of treatments with fosetyl-Al injections (from Franqueville and Renard, 1989).

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.

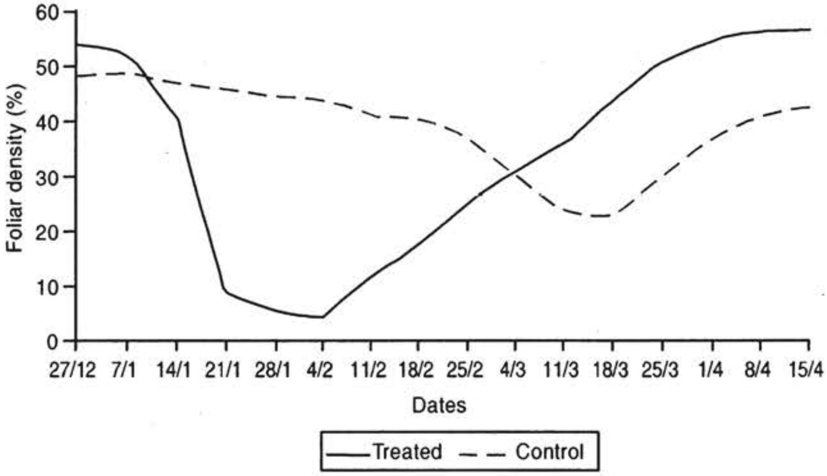


Fig. 6. Evolution of foliar density in hevea plots after artificial defoliation and without defoliation (from Guyot, unpublished)

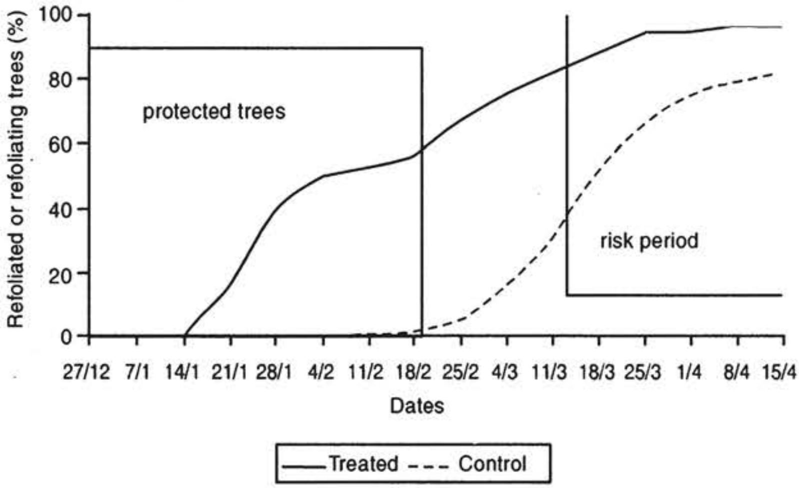


Fig. 7. Rate of refoliation in hevea plots after artificial defoliation and without defoliation (from Guyot, unpublished).

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).

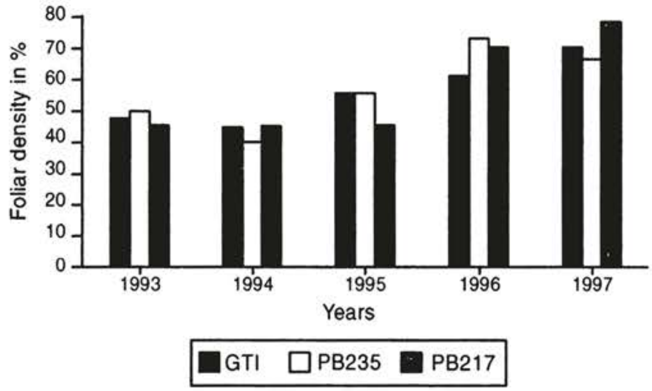


Fig. 8. Evolution of foliar density in a hevea plantation (from Guyot, unpublished).

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,

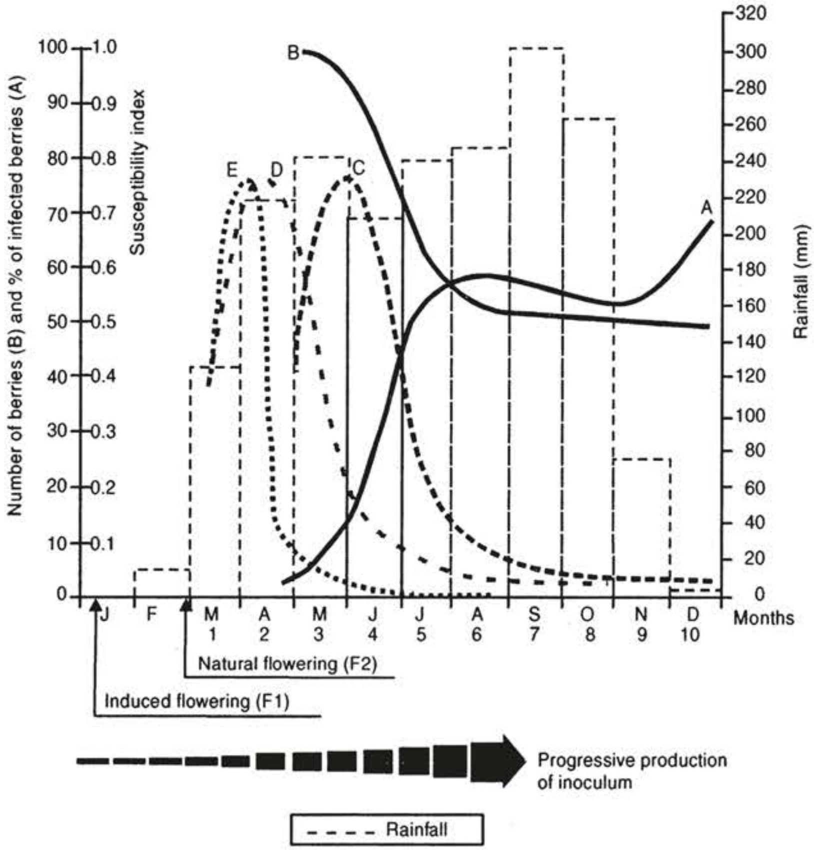


Fig. 9. Coffee berry disease: evolution of the infection (A), total number of berries (B), susceptibility of berries to flowering date (C, D, E) (from Muller, 1978).

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).

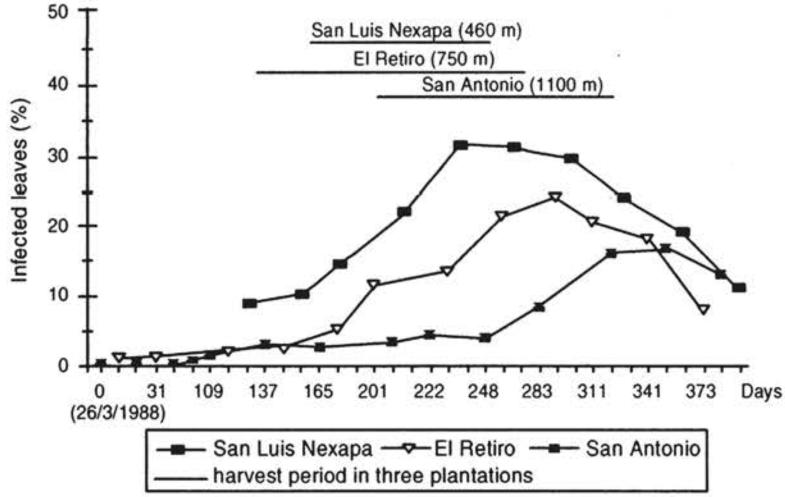
Fruit load

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.



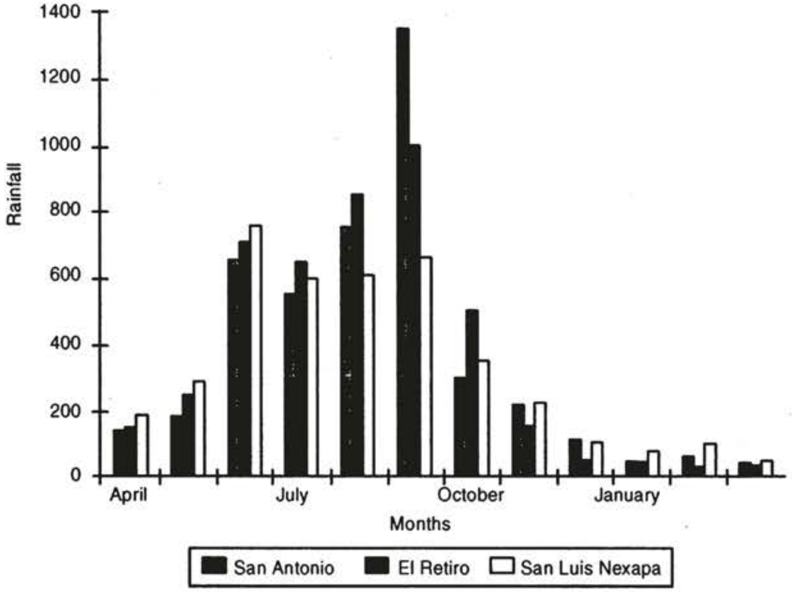


Fig. 10. Evolution of the percentage of young leaves of coffee plants infected by orange rust in three plantations in south-eastern Mexico (from Avelino *et al.*, 1991).

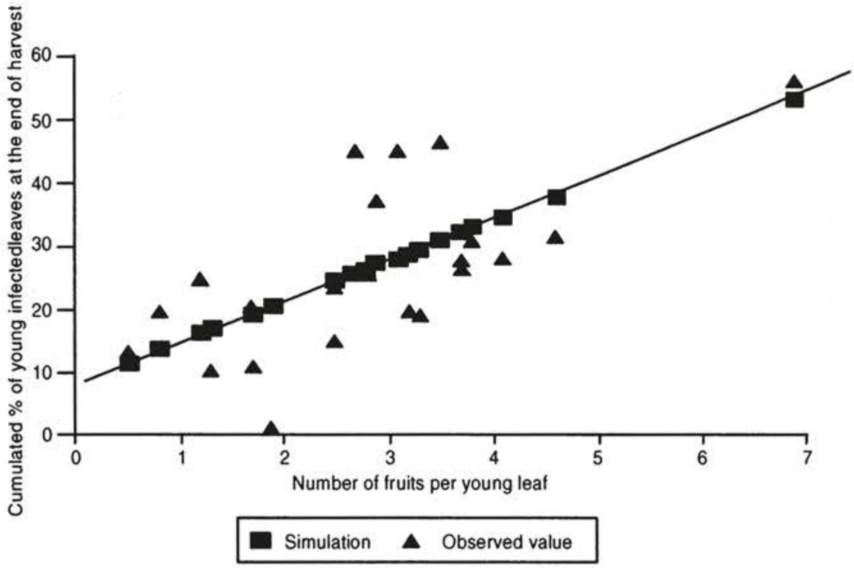


Fig. 11. Effect of fruit load on coffee rust (from Avelino *et al.*, 1993).

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

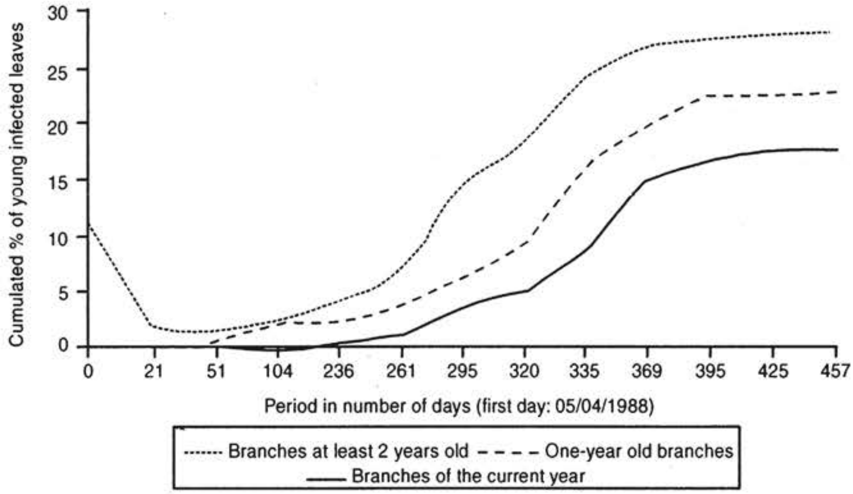


Fig. 12. Development of coffee rust over time according to the position of branches on the plant in a plantation situated at an elevation of 730 m (from Avelino *et al.*, 1991).

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

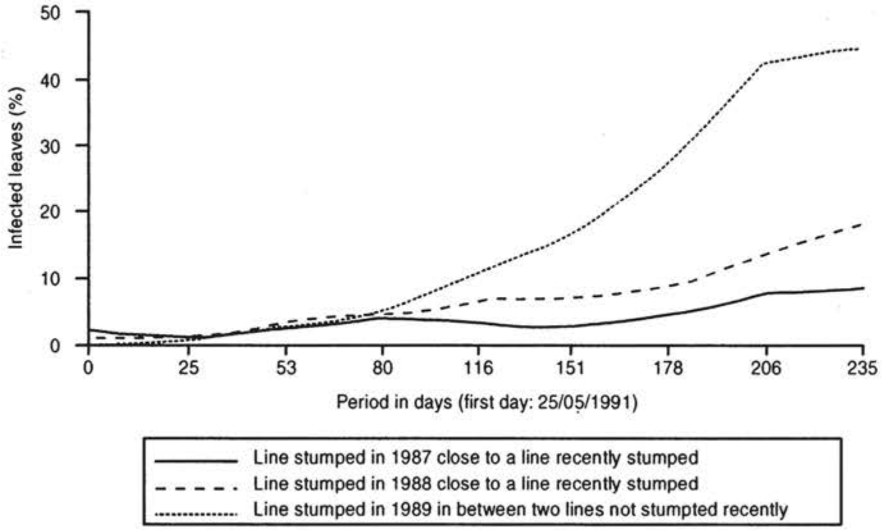


Fig. 13. Effect of line stumping on American leaf spot of coffee in a plantation situated at an elevation of 1200 m (from Avelino *et al.*, 1992).

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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6

Healthy Plant Material and Certification

Christian Vernière

Crop protection, in its widest approach, should take into account the cost of treatment for the producer, loss of homologation of some phytosanitary products, problems concerning environmental protection and the demand for quality products by the consumer. Furthermore, the development of a control strategy should take into consideration three kinds of factors directly or indirectly affecting the health of the trees and quality of the crops: abiotic factors (structure of the crop, cultural practices, environment), biotic factors (host resistance, nature of the rootstock, physiology, competition) and policies (sanitation programme and registration of the plant material, quarantine, eradication). The joint management of these factors should result in the development of the best possible control method. The policy component appears to be of prime importance for crop protection because it helps to propose strategies so that the grower is guaranteed the good quality of the plants before planting and to prevent the introduction of contaminated plants in a region.

INTERESTS AND OBJECTIVES OF A SANITATION AND CERTIFICATION PROGRAMME

Regulation methods are mainly powerful in two kinds of situations where they have proved to be an efficient barrier. In the first situation, when a disease is not yet present in a region, the first defence is to avoid its introduction and to get rid of the pathogen should it be introduced. Quarantine is a very effective means of controlling the passage of infected plants and detecting the presence of healthy carriers contaminated but not showing disease symptoms. Sanitation programmes and production of healthy plants therefore helps to satisfy the demand of professionals and thereby check the uncontrolled or illegal introduction of material whose sanitary status is not known. The second situation is represented by the appearance of a new disease with a low incidence. Here control is through reduction of the inoculum or its elimination through an eradication programme and distribution of healthy plant material which prevents the diffusion of infected plants.

The objectives of sanitation and certification programmes are to provide propagation materials and plants which are free of the major degenerative diseases and whose true-to-typness is recognised.

Since 1994, all plant material has to be accompanied by a phytosanitary passport for free circulation among the countries of the European Union. This passport, which is issued following the approval of the plant protection service, guarantees that the plant is free of quarantine plant pathogens, which are organisms subjected to control in the European Union. This phytosanitary passport is given only for plants coming from a zone known to be free of these plant pathogens or produced under a certification programme.

For example, to satisfy this European directive, citrus plants produced in Corsica should be produced under such a programme because *Spiroplasma citri*, agent of stubborn disease and a quarantine organism, is present on the island.

To illustrate how a sanitation programme is conducted, examples will be given of different fruit crops, especially citrus plants for which such a programme has been built since the early 1960s in Corsica. A number of studies have been carried out on this crop, subjected to strong pathological constraints, and have conducted to formulate a national certification programme since 1996.

INTRODUCTION AND SAFE MOVEMENT OF PLANT MATERIAL

Exchange of plant material always carries a risk of accidental introduction of plant pathogens. Pathogens present on symptomless hosts acting as healthy carriers are therefore particularly risky. Measures should be taken while selecting and collecting material, and also when material is exported and imported. Plant material should be disinfected and despatch of rooted plants should be banned if another solution can be found. In the case of transport of vegetative material, quarantine measures have to be enforced (observation of plants in a protected place, requirement of indexing procedures). The measures described below for various species could be combined whenever possible for a better sanitary control of plant material.

Citrus

For research or for production, it is desirable to introduce new plant species or cultivars produced from hybridisation or mutations and potentially interesting for certain pedoclimatic conditions. This tranfer can sometimes be done without any phytosanitary risk. Such is the case with polyembryonic citrus varieties for which the seeds can be exchanged with practically no risk of transmitting pathogenic organisms. However, very often introduction is through vegetative propagation, which may result in importing new pests and diseases because there are a large number of healthy carriers depending on the host-pathogen interaction. Establishment of a quarantine offers a sanitary guarantee for the introduction of vegetative material. It prevents contamination of neighbouring plants by managing potentially infected plant material during its passage from the introduction until its use by nurserymen and growers. This quarantine functions following three main principles: control and isolation of introduced material, regeneration and indexing (Navarro *et al.*, 1984).

As soon as the plant material is received, it should be examined to detect any anomalies, especially if it comes from a region where a serious degenerative disease is known to exist. This material is then disinfected; for example, the stems of citrus scions are immersed in a solution of sodium hypochlorite containing a wetting agent (Frison and Taher, 1991; Navarro *et al.*, 1984).

These rules should also be applied when distributing the plant material so that exchange of pathogens and pests is limited as much as possible.

New pathological problems which have appeared recently and the existence of severe strains with geographic limits make it necessary to adopt special control measures to restrict these threats (citrus variegated chlorosis, witches' broom, chlorotic dwarf, severe strains of citrus tristeza virus).

Coffee and cocoa

It is strongly recommended that exchanges of plant material among producing countries should first pass through a non-producing country to undergo a quarantine. With this objective, the CIRAD undertook measures to conserve, enrich and safeguard the biodiversity of coffee and cocoa by establishing a quarantine in Montpellier in order to ensure intercontinental exchanges of plant material by providing adequate sanitary guarantees.

Recommendations have been proposed to ensure the collection and transport of plant material with minimum risk.

Movement from a producing country

Before any despatch of plant material from a collecting area, it is advisable to avoid collecting from a region where the disease is present. If this is not possible, only healthy looking plant material should be taken—which, however, is not an absolute guarantee—ensuring very strict selection.

Various procedures are adopted depending on the plant parts to be exported.

If the material is taken in the form of ripening or ripe fruits or pods, the fruits or pods must have a healthy appearance. In the case of coffee, the seeds are depulped, washed and dried if possible; if not they are preserved as they are. In the case of cocoa it is preferable to take the whole pod.

The seeds should be treated with a fungicide and an insecticide powders and then put into plastic bags. The pods should be sprayed or immersed in a fungicidal solution.

If the material is taken in the form of budwood or cuttings, the stems with or without leaves should be collected from healthy looking material. They should be immersed in an appropriate fungicidal and insecticidal solution and packed in newspaper moistened with this medicated solution.

For material taken in the form of rooted cuttings or plants, the good sanitary condition of the plant should be controlled, paying special attention to the roots. The roots should be washed and the plant debris and mud as well as the necrotic parts should be removed.

Rooted plants should be sprayed or immersed first in an insecticide solution and then in a fungicide solution and then packed in newspaper moistened with this medicated solution.

Reception of plant material in the quarantine laboratory

Sanitary control of the material received is carried out and all doubtful material is destroyed. The plant material is placed in an isolated compartment with limited visitors. Plant fragments remaining after taking the material, as well as the packing material, are destroyed by incinerating in an autoclave.

Under certain conditions, when a plant material is introduced in vitro and passes through a greenhouse, the presence of an eventual fungal or bacterial pathogen would be revealed in the culture medium and in such cases it should be eliminated as a contaminating agent. This elimination is done even without knowing the nature of the contaminant. Thus the introduction of a fungal or bacterial parasite is highly improbable.

The situation is different in the case of viruses (swollen shoot of cocoa) because the conditions for the survival of the virus are not well known. In this case, the only precaution that can be taken is to avoid any introduction of plant material coming from regions where the disease is present or to ensure the healthy status of the plant material by electrophoretic analysis (Amefia *et al.*, 1988).

Export of plant material

After passing the required time in the quarantine and sanitary control, the plant material can be re-exported to production areas where it will once again pass through a quarantine for a brief period under tropical conditions before it is ultimately planted in the nursery or field.

Important diseases

For coffee, the major diseases are orange rust—although rust-free countries are now very few, the transport of more or less virulent strains has to be avoided—and coffee berry disease, at present limited to Central and East Africa. In many countries, the dispersal of nematodes belonging to the genera *Pratylenchus* and *Meloidogyne* should be taken into consideration. Strict treatments should be carried out in nurseries (disinfection of the substrate with methyl bromide and periodic treatment with nematicides such as aldicarb, carbofuran, terbufos, etc.) in order to distribute rigorously healthy plants to coffee planters.

For cocoa, several redoubtable diseases are still confined to a group of countries or a continent: swollen shoot disease in Ghana and Togo, moniliosis and witches' broom in a number of South American countries. Genus *Phytophthora,* which causes brown pod rot of cocoa, has a worldwide distribution, but in the chapter on Pathogens it was seen that species, or rather strains, can show varying degrees of aggressiveness.

Hevea

Production of healthy plant material mainly concerns *Microcyclus ulei* with a view to preventing the spread of this serious South American disease to other continents. A phytosanitary station, similar to the one set up for coffee and cocoa, was established in Guadeloupe where there is no hevea outside the station, and where the plant material comes from Guyana in the form of grafted rootstocks. Before despatch, the material is kept under observation for at least one year. In Guadeloupe *Microcyclus* has never been observed in a tree park containing 300 genotypes.

Oil palm and coconut

Exchange of plant material between countries or continents is done only in the form of pollen or seeds.

Disease transmission through seeds has never been observed, except of course external contamination which is always possible. As an additional precautionary measure, despatch of plant material from countries or regions contaminated by virus or viroid diseases is prohibited. FAO's (Food and Agricultural Organization) guidelines may be referred for additional information on these diseases.

The pollen is collected under very strict conditions for obvious reasons of legitimacy. Preparation is done in a sterile enclosure; the pollen is dried, kept in vacuum and then preserved at a low temperature.

Before despatch, the seeds are treated with a mixture of standard fungicides and insecticides to avoid eventual external contamination. Depending on the sanitary regulations of the receiving country, additional sanitary measures are undertaken on request.

In vitro material can also be exchanged but once received it must undergo adequate indexing procedures.

Besides all this, preventive measures can be taken by providing information to the public through posters about the risks of contamination while tranporting plants (Roistacher *et al.*, 1977). Technical guidelines indicating the rules to be followed for safe movement of plant genetic resources are regularly published by the FAO in collaboration with IPGRI (International Plant Genetic Resources Institute). These are available for species such as citrus, coconut and cocoa.

SANITARY IMPROVEMENT: THE CASE OF CITRUS

Availability of healthy varieties or free of the major degenerative diseases is a trump card in citriculture management. Although all virus-like diseases are transmitted vegetatively, a few are mechanically transmissible (Bové, 1995). Only one virus of citrus, the agent of psorosis, can be transmitted by the seed (Campiglia *et al.*, 1976) and some diseases may be transmitted by pollen (Vogel and Bové, 1976). The absence of seed transmission enables the production of rootstocks from seeds with a good sanitary guarantee. It has also enabled regeneration of polyembryonic varieties through nucellar selection. However, this procedure cannot be applied to monoembryonic varieties and a longer persistence of juvenile characters in nucellar plants has been observed.

Certain pathogens reduce the choice of rootstocks. For example, the tristeza virus can cause decline of varieties grafted on sour orange and the exocortis viroid can alter *Poncirus trifoliata* and its citrange type hybrids, thereby restricting the growth and production of the trees. Regeneration of citrus varieties allowed the use of these rootstocks by eliminating the major citrus pathogens (virus, viroids, phytoplasmas, spiroplasmas, endocellular bacteria).

Regeneration by shoot-tip grafting

The technique of shoot-tip grafting, developed by Navarro *et al.* (1975), has been used at the INRA-CIRAD agronomic research station in San Giuliano (Corsica) since 1978. Additionally to the elimination of the juvenile characters associated with the nucellar selection, it allowed to recover true-to-typness plants from monoembryonic varieties (Nicoli, 1985; Vogel *et al.*, 1988a). Shoot-tip grafting involves the aseptic isolation of meristems from infected plants and then grafting them on young seedlings of etiolated rootstocks that had been grown in vitro.

The shoot tips, composed of the apical meristem and two or three leaf primordia, are excised from the young shoots obtained from plants cultivated in isolation cages or sticks which are forced in a phytotron at 32°C (Vogel *et al.*, 1988a). The temperature selected is a compromise between elimination of the virus and survival of the plant. This thermotherapy is applied depending on the origin of the plants and the pathogens that could be potentially present (psorosis virus, tatter leaf virus). The meristem is kept at the base of an inverted. T shaped incision done on the in vitro rootstock (Photo 107). The percentage of recovery at the end of the shoot-tip grafting experiment is about 36% and varies from 23 to more than 60% depending on the species (Vogel *et al.*, 1988a). When the grafted plantlet has a few expanded leaves, acclimatisation of the young plant is done by grafting on a vigorous well-rooted rootstock in a pot which is then put in a polythene bag (Photo 108). The plant is thus made up of three species: the rootstock in the pot, the sandwiched in vitro rootstock and the variety that is left to grow. Under these conditions, the transfer on a bearing plant has improved the results of acclimatisation by direct transplantation in a substate (Navarro *et al.*, 1975; Nicoli, 1985). Considering the rate of recovery during the second grafting, the percentage of shoot-tip grafted and acclimatised plants obtained is around 25% on an average. The plants are then cultivated in a greenhouse and indexed for the major graft-transmissible diseases.

Indexing and sanitary control

Indexing methods that are reliable and easy to implement are necessary and have been developed for sensitive detection and reliable identification of pathogens. Serological and molecular detection techniques have been recently proposed for routine use and combine speed with specificity. However, for viruses that are poorly described and for unknown pathogens, these detection methods are not available or are not sensitive enough. In such cases, biological indexing through inoculation or mechanical transmission is the only detection method possible (Roistacher, 1991; Spiegel *et al.*, 1993).

Biological indexing

Indicative symptoms of a viral infection may appear on plants from which the material for regeneration had been taken and can thus direct a diagnosis. Nevertheless, the existence of symptomless tolerant species, which are healthy carriers of certain pathogens, makes it necessary to use susceptible indicator plants for detecting a certain number of pathogens (Bové, 1995; Roistacher, 1991).

Expression of symptoms of various diseases may require the application of an appropriate temperature. For example, in citrus plants the symptoms of psorosis and related diseases (concave-gum, *cristacortis, impietratura*) express at temperatures of around 20-25°C, whereas symptoms of stubborn and viroid diseases (exocortis and cachexia) are better expressed at temperatures of 32-34°C. In practice, implementation of such an indexing programme requires two independent compartments, each devoted to the detection of these different diseases (Frison and Taher, 1991; Roistacher, 1991).

For every indexing series, a positive and a negative control should be incorporated; they would serve as proof of the good application of environmental conditions and of effects other than those induced by the pathogen (Roistacher, 1991). This requires the constitution of a pathogen bank which will attempt to conserve mild strains.

Serological techniques

These immunological methods are based on the specificity of the reaction between antibody and antigen. A given antibody is produced against an antigenic determinant or a specific epitope. A population of antibodies, called polyclonal antibodies, is synthesised in response to the presence of several epitopes. Under a certification programme, if the pathogen exhibits wide antigenic variability, an antibody or a mixture of antibodies will be selected to enable detection of all the strains of the pathogen.

Enzyme labelling of antibodies has led to the development of two techniques which are widely used in diagnosis: the ELISA test and the dot-blot immunoassay. These techniques are used for detecting pathogens because they are easy to perform in routine manipulations. In the case of citrus pathogens, they enable the detection of the tristeza virus, *Spiroplasma citri* (agent of stubborn disease) *Xanthomonas axonopodis* pv. *citri* (agent of citrus canker) and the satsuma dwarf virus (Civerolo and Fan, 1982; Garnsey *et al.*, 1993; Roistacher, 1991).

Molecular techniques

For serological detection, the antigen protein must always be expressed in the infected plant, which could be a limiting factor. Molecular techniques which can directly detect the presence of nucleotide sequences help us to overcome this constraint besides being highly specific. Two methods are mainly used to detect and identify plant pathogens: molecular hybridisation and polymerase chain reaction (PCR). Molecular hybridisation is based on the capacity of two complementary chains to separate and reassociate depending on salinity and temperature. Labelled monocatenary sequences, or probes, can then hybridise with targeted sequences and their presence can then be detected. In routine operations, cold probes are preferred to radioactive probes, which are more sensitive but have a short half-life period and are more difficult to use. In polymerase chain reaction, a DNA sequence is amplified with the help of specific primers of targeted strands and a thermostable polymerase DNA. Repetition of a denaturing cycle, annealing of the primers and DNA synthesis results in amplification of the targeted sequence which can be observed on agar gel.

Polymerase chain reaction improves the sensitivity of molecular hybridisation, whose degree of response is found to be limited by the number of targeted sequences present in the sample. Although these methods are still not routinely applied in sanitary indexing programmes for citrus, their ongoing development for some pathogens should help to considerably improve their detection (*Liberobacter* for huanglongbin or greening disease, *Spiroplasma citri* for stubborn disease).

To enable the detection of a RNA virus requiring a retrotranscription phase or to limit inhibitory effects from plant extracts, a preliminary purification may be necessary. Immunocapture is a solution which helps to quickly treat a large number of samples and can be routinely used.

This technique is used for indexing with a view to produce healthy material, free of *Xanthomonas axonopodis* pv. *citri*, in the island of Réunion where—and this is true in many other tropical regions where citrus is cultivated—the primary inoculum is often brought to the plantation by nursery plants. The sanitary status of the plants in the nursery is therefore a factor that has to be vastly improved. In Réunion it was shown that the present way of managing the nurseries—in open air with overhead irrigation system—is highly favourable for the development of bacterial canker. Moreover, heavy rainfall of high intensity but short duration is most propitious for the dispersal of the pathogen through projection. The efficiency of modified cultural techniques in the nursery to restrict the development of bacterial canker lies in the evaluation phase. The production programme retained is as follows: conservation of mother trees serving as the source for scions and rootstock seedlings in insect proof greenhouse and raising grafted plants in a plastic tunnel with drip irrigation.

It is also very important that the sanitary state of the mother trees serving as the source for scions be regularly reevaluated. For this, the technique to detect *Xanthomonas axonopodis* pv. *citri*, based on immunocapture—nested-polymerase chain reaction assay (Ic-n-pcr)—developed by Hartung *et al.* (1996), has proved to be very sensitive. It enables the detection of about 100 bacterial cells per gram of tissue.

A few experimental orchards were set up with grapefruits which are extremely susceptible to bacterial canker and produced under conditions where *Xanthomonas axonopodis* pv. *citri* was not detected by Ic-n-pcr. These orchards help to evaluate the durability of a strategy based on the production of plants free of symptoms, and carriers of population levels that are lower to the detection level of the Ic-n-pcr, compared to plants obtained following a standard integrated control strategy. Preliminary results show that because of the almost systematic presence of infected citrus plants within a boundary that enables dissemination by wind and rain, the plants in experimental orchards get infected during cyclones (climatic conditions favourable for the long distance dispersal of *Xanthomonas axonopodis* pv. *citri* prevail). Hence under the conditions prevailing in Reunion, it is very difficult to grow citrus crops which are very susceptible to bacterial canker (grapefruit, lime, combava).

CHOICE OF A TECHNIQUE

Three criteria should guide the choice of an indexing technique in a sanitation or certification programme: its sensitivity, specificity and easy application. The cost of a test is also an important factor to be taken into account, but it is relative to the value of the indexed plants (mother trees, producing plants).

An ideal sensitivity level is one which enables the detection of pathogens in the latent phase, in small samples or trees where the pathogen is irregularly distributed. The highly sensitive molecular tests offer these qualities and they should be developed despite the difficulties in their handling.

The specificity of a test is primordial for excluding a given quarantine organism. Nevertheless polyvalent techniques are useful in indexing programmes for reducing the cost of a test. For example, a single procedure associating amplification on a susceptible host and electrophoresis under denaturing conditions helped to detect the eleven viroids of citrus (Duran-Vila *et al.*, 1988). On the other hand, varietal management of an orchard may require the identification of races or pathotypes within the same pathogen species and hence a wider specificity.

Lastly, detection techniques should be simple and rapid. They should enable the treatment of a large number of samples (automation) at minimum cost. The choice of a test from an array of existing techniques should take into account these advantages and constraints.

CERTIFICATION PROGRAMMES

The success of an orchard depends on the quality of the plants used while planting. For this the grower should be able to obtain plants with the best sanitary and pomological qualities from nurseries, whether it is for rootstock or for variety.

Sanitary and pomological guarantee

Sanitation programmes are available for obtaining healthy plants (Vogel *et al.*, 1988b). They can be developed for specific pathogens depending on the constraints. With certification, the true-to-typness of the healthy lines of the foundation block, guaranteeing the physico-chemical characters of the fruits, is confirmed (Vogel *et al.*, 1988a). An initial plant is selected to serve as the base for vegetative multiplication. Sanitary and pomological selection of citrus conducted in the INRA-CIRAD research station at San Giuliano served as the starting point for a certification programme set up for citrus fruit plants (Vernière, 1995; Fig. 1). After regeneration and sanitary certification, the plants are registered and maintained in insect-proof cages. They are multiplied and planted in an orchard for the authenticity of the variety.

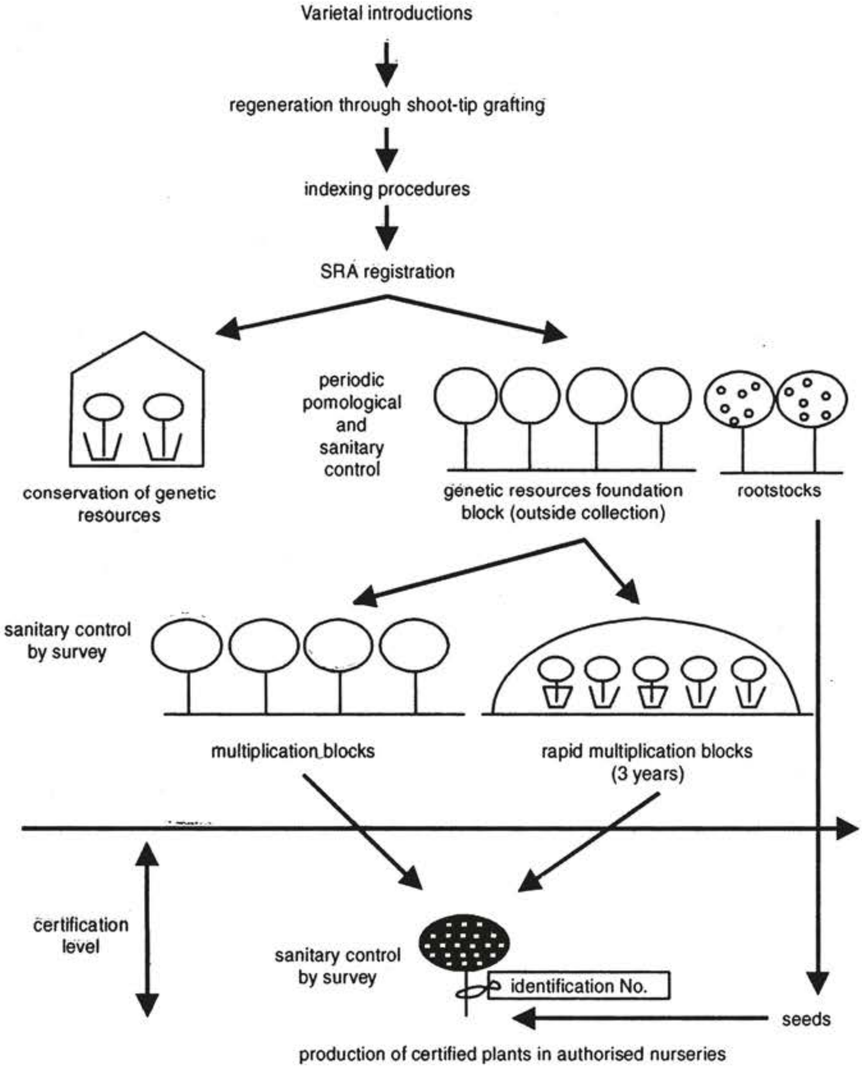

Fig. 1. Procedure for a phytosanitary certification programme: the case of citrus (from C. Vernière, 1995).

The exceptional phytosanitary situation in Corsica with respect to the major degenerative diseases facilitates observation of these genetic resources in open air. In order to conserve this status as much possible, the tests are performed by the plant protection service for certain quarantine agents for quick eradication in case of an introduction. Multiplication blocks are planted according to the requirements of professionals. Rapid multiplication blocks can be established to fulfil an order as quickly as possible and thus enable a significant increase in the production of budwood (Roistacher, 1992).

Plantation guarantee

A certification programme should be conducted under the supervision of an official organization. Plants are produced from scions and seeds of certified rootstocks following certain specifications. An agreement is granted to nurserymen who undertake to respect it. After testing the sanitary state and varietal authenticity, the plants are individually labelled with the information necessary for their identification.

CONCLUSION

The first condition to guarantee the success of a plantation is to have perfectly healthy plant material. Sanitary and certification programmes take on a particularly important character for citrus plants affected by a large number of diseases, especially the viral type in a broader sense, which are often difficult to detect.

The creation of such a sanitary and pomological improvement programme in Corsica in the early 1960s, and now integrated into an official certification programme, has helped to eliminate most of the graft-transmissible diseases in Corsican orchards and to protect the latter from the major degenerating diseases. However, to succeed, the whole citrus sector should be taken into account. In the case of citrus, ornamental plants do not come under the current certification programme, whereas pathogens do not have any barrier for fruit plants. The establishment of quarantine and certification programmes is nevertheless the main barrier for eliminating undesirable pathogens and for reducing the inoculum potential. However, for such a programme to succeed, it should be strictly and fully followed by professional nurserymen and cultivators.

Moreover, with increasingly frequent exchanges of plant material between continents, the risks of spreading serious diseases, which are often still localised, are high. Lastly, even for a disease with a global distribution, all the pathogen strains do not have the same aggressiveness. For these reasons, quarantine departments have a very important role to play.

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Conclusion

Dominique Mariau

To the end of this book the reader will able to measure the considerable impact that numerous diseases have on the growth of most tropical tree crops. Leaf blight caused by *Microcyclus* is an impediment to hevea cultivation in the majority of cases in Latin America. The same fate would have befallen the oil palm in Africa if plant material resistant to fusarium wilt had not become available. The cocoa plant—which is particularly vulnerable to diseases—is highly endangered. The Ghanaian grower still does not have plant material that is truly resistant to the swollen shoot disease, which is devastating for his cocoa plantation. Although they are not mortal, the South American diseases of moniliosis and witches' broom disease are a major handicap for cocoa cultivation. *Phytophthora* and viroid diseases have destroyed vast areas of coconut plantations in many places throughout the world. Coffee has disappeared in Sri Lanka because of orange rust disease, while the coffee berry disease can destroy a major part of the production of Arabica coffee plants in Africa. Of late nematodes have assumed considerable economic importance for coffee, particularly in Central America. Finally, citrus plants are prey to a large number of diseases, especially bacterial, viral and fungal. Some of them such as cercospora disease, have spread considerably. With international exchanges becoming increasingly common and despite the protection barriers that have been put up, countries unaffected by a particular disease could expect the worst. Who can guarantee that *Microcyclus* will never reach rubber plantations in South-East Asia, where plant material, that is high yielding but susceptible to the disease, has been widely introduced? Swollen shoot disease represents a huge threat in the Ivory Coast, the largest producer of cocoa in the world. The lethal yellowing disease of coconut is also on the threshold of this country.

It was observed that disease control begins by planting healthy plant material. This is all the more indispensable when the disease is not yet present in a country (or region), thus emphasising the extreme importance of quarantine stations through which plant materials have to transit before exchanges between countries and continents.

On examining the tables in the annex, which are a synthesis of the present state of control methods with respect to the major diseases of tropical tree crops, it can be quickly seen that selection of resistant or even tolerant plant material is the main tool of plant pathologists and the subject of numerous research works. This control method, sometimes the only one possible, is generally the major objective of specialists. It is a long term job, considering that the agronomic cycle of tree crops lasts several decades. Besides, plant pathologists and breeders are committed to selecting only plant material that possesses a stable resistance to a particular disease to the extent where plantations are established to last for thirty to fifty years. As of now, agronomists can propose high-yielding plant material that is also highly resistant to some diseases. For example, for oil palm against fusarium wilt, even though this selection has considerably reduced its genetic variability. Soon we will have coffee plants resistant to nematodes in Central America. In many cases, the studies carried out can already recommend the choice of material to be planted, for example for black pod rot, but it is still not possible to propose plant material that is truly resistant. Lastly, in other cases researchers still have much work to do before being able to provide the appropriate plant material: for example, moniliosis of cocoa and cercospora disease of citrus plants.

For a good number of diseases transmitted by insects, a very effective control method was found to be possible by reducing, or eliminating, the vector populations, either through rational chemical control methods, by cultural techniques or by resorting to biological control. Phytoplasma diseases of palms and citrus greening belong to this category. However some diseases transmitted by insects cannot be treated in this way, for example lethal yellowing of coconut and citrus tristeza disease.

Rational chemical control, whether or not complemented by appropriate cultural practices, could comprise a group of very effective control methods that are relatively easy to use and not too polluting for the environment. This is so, for example, for *Phytophthora* diseases of coconut, avocado and citrus, as well as for rots. However, in many cases they are provisional methods whose efficiency is irregular and doubtful, constraining and polluting, which discourage planters who have plantations that are not very profitable and less and less efficient. They are proposed while awaiting the availability of resistant plant material, for example control methods for black pod rot of cocoa and coffee berry disease.

In rare cases, such as orange rust of coffee, an array of methods is available: more resistant plant material, chemical control and varied cultural techniques, helping to reduce disease pressure. It is therefore possible to implement a veritable integrated pest management to the extent where planters have acquired adequate technical skills.

Lastly, for some afflictions such as citrus decline caused by *Ceratocystis* or American leaf blight of hevea, nothing can be proposed as yet to agriculturists except, for the latter, to plant in the crop's marginal zones where disease pressure is less.

Although solutions are available for most diseases, there is still much to be done. CIRAD is working on a large number of diseases but some of them, such as bud rot of oil palm in America and swollen shoot disease of cocoa, require much more intensive research. Lastly, it is difficult to assume the development of some diseases which are not very disturbing at present.

The recent advances in science, especially in the domain of knowledge of genomes, have opened a vast field for plant pathologists to explore thanks to the collaboration of geneticists. In the world of agriculture, acquisition in this topic has been spectacular for many plants during the last few years. Selection aided by molecular markers, Qtl (quantitative trait loci) research, demonstration of resistance genes and their incorporation in varieties which do not have them and in which they can be expressed, enable us to glimpse the powerful investigative methods available to researchers. Here we enter the field of genetically transformed plants, a domain that is still little explored for tropical tree crops, full of promise but also full of snares to be avoided.

Despite the confidence that can be placed in a particular technique, it is often preferable to be able to propose several control methods used individually or in an integrated manner, in order to take into consideration the nature of the agricultural exploitation and the socio-economic context in which we find ourselves. It may be that funds are inadequate for the purchase of intrants whose distribution itself may be inadequate. In other cases, the plant material may be difficult to obtain or the popularising services may be faulty. We often observe a hiatus among the recommendations, results of researches and their application in the field, which follows the implementation of a research-development as necessary as the first. The desired efficiency can be achieved only through the close collaboration of researchers from the North who, historically and geographically, are now focused more on theoretical researches and researchers of the South who are and will be the only ones to have field experience.

Annex

Major diseases and control methods

Plants	Plant material resistance	Control of insect vectors	Rational chemical control	Cultural techniques
Oil palm				
Fusarium wilt	Material available indispensable	—	—	Secondary efficacy
Blast	—	Chemical control Cultural techniques	—	—
Bud rot	Breeding interspecific hybrids indispensable	—	—	—
Red ring	—	By trapping Elimination of insect refuges	—	—
Marchitez	—	Chemical control	—	—
Ring spot	—	Elimination of host plants	—	—
Cercosporiosis	—	—	In the nursery	Favourable conditions for the growth of the young plant
Ganoderma	—	—	Preventive to restrict the spread	Preventive. Field preparation.
Coconut				
Bud rot and nut rot caused by *Phytophthora*	More or less susceptible material	—	Systemic treatments	—
Lethal yellowing	Preliminary results indispensable	—	—	—
Hartrot	—	Chemical control	—	—
Cadang-cadang	—	—	—	—
Dry bud rot	—	Chemical control Cultural techniques	—	—

Helminthosporiosis	Very susceptible to hypersusceptible material		In the nursery	
Red ring	—	By trapping Elimination of insect refuges	—	—
Coffee				
Orange rust	Resistance easily overcome	—	By spraying	Intervention of several factors
Coffee berry disease	Research underway Preliminary results Material awaited	—	By spraying	Reduction in parasite pressure: collecting infested seeds
Tracheomycosis	Resistance related to situations	—	—	—
Nematodes	Resistant rootstocks		In the nursery	Endomycorrhization Shading
American leaf bight	—	—	Preventive with Bordeaux mixture	—
Cocoa				
Brown pod rot	Research underway Preliminary results Material awaited	—	Locally indispensable	Complement chemical control
Swollen shoot	Preliminary results Material not distributed	—	—	—
Witches' broom	Underway Preliminary results	—	Preventive or in the nursery	Elimination of diseased parts
Moniliosis	Indispensable	—	Very difficult to implement	Not very effective
Vascular streak dieback	Elimination of susceptible plant material	—	—	—

Hevea				
Microcyclus	Research underway Indispensable	—	—	—
Rots	A few indices	—	Valid globally for all crops affected by rots. Mainly preventive. Prevention by restricting their spread	
Leaf anthracnose	—	—	—	Escape by precocious defoliation
Black stripe	—	—	Preventive control	—
Citrus				
Ceratocystis	—	—	—	Disinfection of pruning instruments
Gummosis	Through rootstock	—	Spraying Injecting collar with a fungicide	Land selection (good drainage), avoiding wounds, aeration
Cercosporiosis	Research underway for general resistance (leaves, fruits) Indispensable	—	—	—
Bacterial canker	Very susceptible to resistant varieties	—	Cupric compounds	Avoiding injuries No sprinkler irrigation
Tristeza	Through rootstock-scion combinations	—	—	—
Greening	—	Biological control	—	—
Other fruit trees				
Black spot of mango	Through escape Search for resistant sources		Cupric compounds	Avoiding injuries No sprinkler irrigation
Phytophthora rot of avocado	A few indices through rootstocks		Foliar treatment Systemic fungicides	Slightly wet land
Fruit anthracnose			Pre- and post-harvest treatment	Elimination of inoculum sources and adequate aeration through thinning

Diseases not treated in this book

F: Fungi, V: Virus or virus-like, N: Nematodes
Except for citrus, most often these diseases are not economically destructive at the global level

Plant	Name	Remarks	References
Coconut			
	Kerala root wilt Phytoplasma	Yellowing. Cessation of production. Serious in India	Lal S.B., 1968. Root (wilt) disease, résumé of work done since 1964. Paper third session FAO technical working party on coconut production, protection and processing, Jog Jakarta (Indonesia).
	Root disease Causal organism not known	Centripetal drying of roots Nut fall. India (Travancore)	
	Leaf scorch F. *Botryodiplodia theobromae*	Death of the tree South and north-east Sri Lanka	Maramorosch K., 1964. A survey of coconut diseases of unknown etiology. FAO, Rome, Italy.
	Socoro wilt Causal organism not known	Death of the tree Philippines (Mindoro)	Abad R.G. et al., 1980. A wilt disease of coconut in the Philippines. Philippine Journal of Coconut Studies 5 (1): 1-9.
	Lethal bole rot F. *Marasmiellus cocophilus?*	Slow decay Kenya, Tanzania	Bock K.R. et al., 1970. Lethal bole rot disease of coconut in East Africa. Ann. Biol. 66: 453-464
	Poroca Causal organism not known	Production of short leaves Colombia, Panama (Atlantic coast)	Ferrand M., 1960. Observations sur une maladie indécise du cocotier. C.R. Acad. Agric. 46 (12): 706-707.
	Foliar disease F. *Corticium salmonicolor*	White mycelium resembling a spider web on the lower side of leaves Wilting	Tey C.C., Chan E., 1980. Disease of coconut palms in Peninsular Malaysia, In: Proc. of the Int. Conf. on Cocoa and Coconut, Kuala Lumpur, Malaysia, 21-24 June 1978. Mardi 692-707.

Oil palm		
F. *Curvularia* sp. *Dreschlera* *Helminthosporium*	Foliar diseases in nurseries in South-East Asia and Africa	Jonston A., 1959. Oil palm seedling blight. Malay. Agric. J. 42: 14.20.
Dry basal rot F. *Ceratocystis paradoxa*	Disease similar to stem bleeding of coconut	Robertson J.S., 1962, Dry basal rot, a new disease caused by *Ceratocystis paradoxa* (Dade) Moreau. Trans. Brit. Myc. Soc. 45: 475-478.
Basal rot of trunk F. *Ustulina* sp.	Not a serious disease observed in Colombia	Thompson, A., 1936. *Ustulina zonata* on the oil palm. Malay Agric. J. 34: 222-226.
Coffee		
Damping off F. *Rhizoctonia* sp.	Collar rot. In nurseries. Worldwide. Linked to maintenance	Coste R., 1989. Caféiers et cafés. Maisonneuve et Larose, Paris, France, 373 pp.
Brown eye spot disease F. *Cercospora coffeicola*	Brown spots on leaves which fall off. In nurseries. Worldwide. Arabica is more susceptible	Clifford M.N., Wilson K.C. (eds.), 1987. Coffee. Croom Helm. USA, 457 pp.
Bark disease F. *Fusarium*	Collar canker. *C. arabica*. East Africa	
Pink disease F. *Corticium salmonicolor*	On the trunk and branches. Excess humidity	
Dieback F. *Colletotrichum* sp.	Cracking of tips. Physiological disease. Not to be confused with *C. kahawae*, causal organism of the African coffee berry disease	
Coffee burn F. *Corticium coleroga*	Browning and leaf fall. Humid zones.	
Root rots F. *Rosselinia brivoides* and *pepo*	On Arabica (El Salvador) Black rot on the bark of roots	
Rot	Brown crust on the surface of roots	

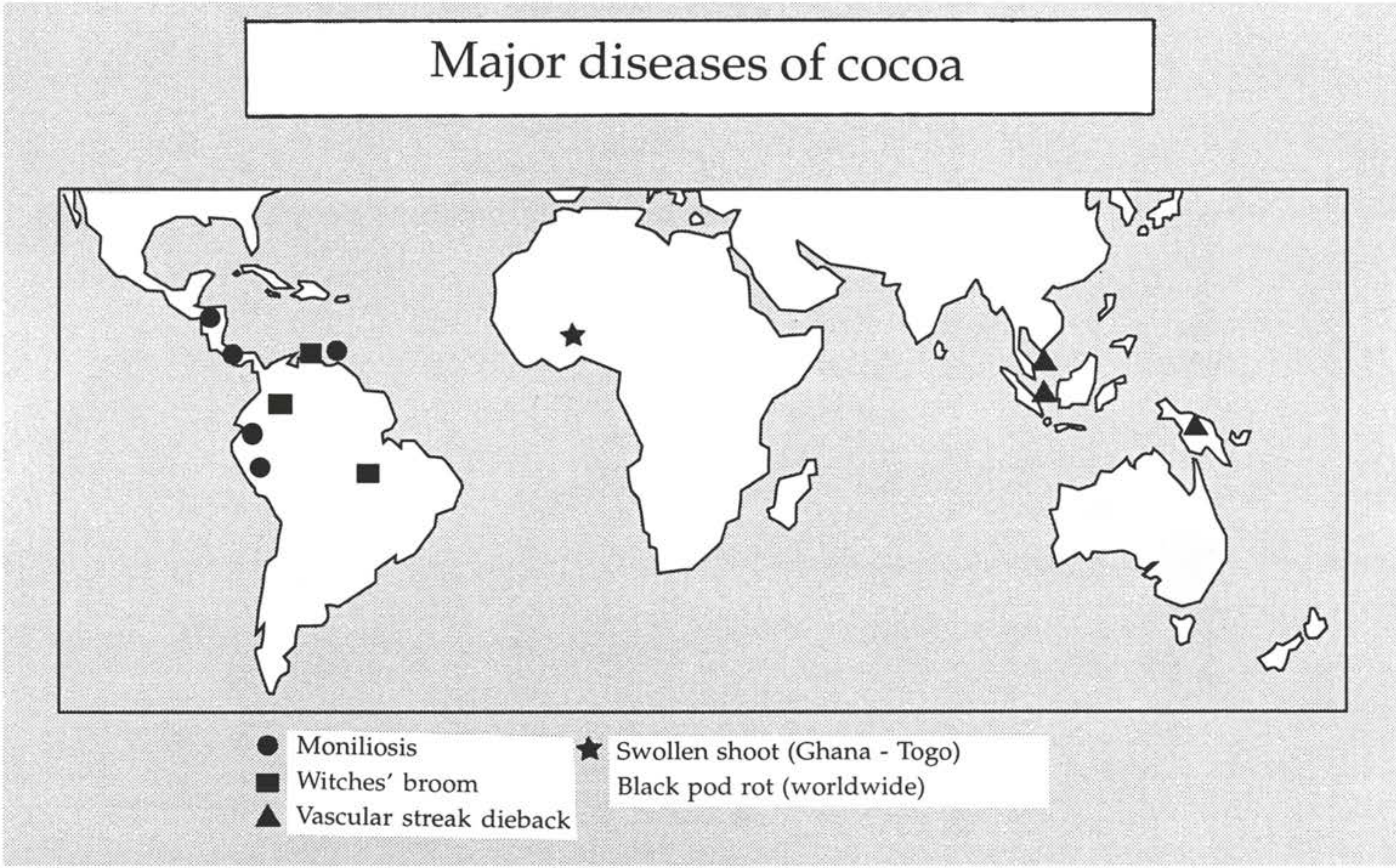
	F. *Phellinus lamoensis*		
	Mancha mantecosa F. *Colletotrichum* sp.	Nursery leaf disease. Secondary. South America.	
Cocoa			
	Mealy rust F. *Trachysphaera fructigena*	Parasite of injuries on pods. Not serious. Africa	Braudeau J., 1969. Le cacaoyer. Maisonneuve et Larose, Paris, France, 304 pp.
	Anthracnose F. *Colletotrichum* sp.	Not severe on pods. Defoliation sometimes. Worldwide distribution	Wood G.A.R., Lass R.A., 1985. Cocoa. Longman Scientific and Tech., USA, 620 pp.
	Tracheomycosis F. *Calonectria* sp.	Wilting of foliage. Worldwide. Wound parasite	
	Vascular streak dieback (Vsd) F. *Oncobasidium theobromae*	Yellowing of plant followed by wilting. Serious on susceptible varieties. South-East Asia	
	Machete disease F. *Ceratocystis fimbriata*	Sudden wilting of foliage. Wound parasite. America, Asia. Also found on coffee	
	Descending tracheomycosis F. *Fusarium decemcellulare*	Centriptal wilting of plant related to strong attacks by mirids (Africa)	
	Mycelial diseases common to coffee Basidiomycetes fungi – white mycelia: *Pellicularia koleroga* – spider web: *Marasmius scandeus* – pony tail: *M. equicrinis*	Except locally in Mexico, Guatemala and Honduras, secondary diseases related to unadapted agronomic conditions (excessive humidity)	
	Warty disease of pods	Africa: formation of warts, followed by rot of fruits	Kébé B.I., Thouvenel J.-C., 1989. La maladie verruqueuse des cabosses du cacaoyer en Côte d'Ivoire. Café, Cacao, Thé, 33 (3):83-99.
	F. *Botryodiplodia theobromae?*	Pathogen's entry is favoured by insects. Secondary	

Tea			
	Blight F. *Exobasisium vexons*	Asia. Translucent spots on young leaves resulting in swellings. Can be serious	Bonheure D., 1998. Le Théier. Le technicien d'agriculture tropicale. Maisonneuve et Larose, Paris, France, 160 pp.
	Pink disease F. *Corticium salmonicolor*	Wilting of leaves and branches	Eden T., 1976. Tea. Longmans.
	Branch canker F. *Macrophoma theicola*	Affects injured branches. Dark spots on the bark which falls off	Hainsworth E., 1952. Tea Pests and Diseases and Their Control, Cambridge.
Hevea			
	Ganoderma. Red root disease F. *G. psudoferreum* *G. philipii*	Serious in Asia, but not in Africa. On roots	Belgrave W.N.C., 1916. Agriculture Bulletin, Federal Malay States, Vol. 4, p. 347.
	F. *Ustulina zonata*	On roots. Sometimes on trunk and branches. Could be disturbing in Cameroon and Guatemala	Hawksworth, 1972 Commonwealth Mycological Institute. Fungia and Bacteria, no. 360.
	Stinking root rot F. *Sphaerostilbe repens*	On roots. Not serious	Booth, Holliday P., 1973. Commonwealth Mycological Institute. Fungia and Bacteria, no. 391.
	F. *Poria hypobrunnea*	On roots. Not serious	Patch T., 1921. The diseases and pests of the rubber tree. Macmillan, London.
	F. *Phellinus noxius*	On roots. Can be quite serious in Malaysia and Sri Lanka	Langford M.H., 1953. Hevea disease of the Amazon valley. Boletim Tecnico do Instituto de Pesquisa Agropecuaria do Norte, no. 27.
	Pink disease F. *Corticium salmonicolor*	On trunk and branches. Not serious except in Malaysia and Indonesia	Brooks F.T., Sharples, A., 1914. Pink disease. Department of Agriculture, Federated Malay States. Bulletin no. 21.
	Mouldy rot F. *Ceratocystis fimbriata*	Sometimes serious on renewed bark under highly humid conditions	Morgan J., 1967. Commonwealth Mycological Institute. Fungia and Bacteria, no. 141.
	Bark necrosis	On tapping panels. Often at high	Saccas A.M., 1959. Une grave maladie des hévéas

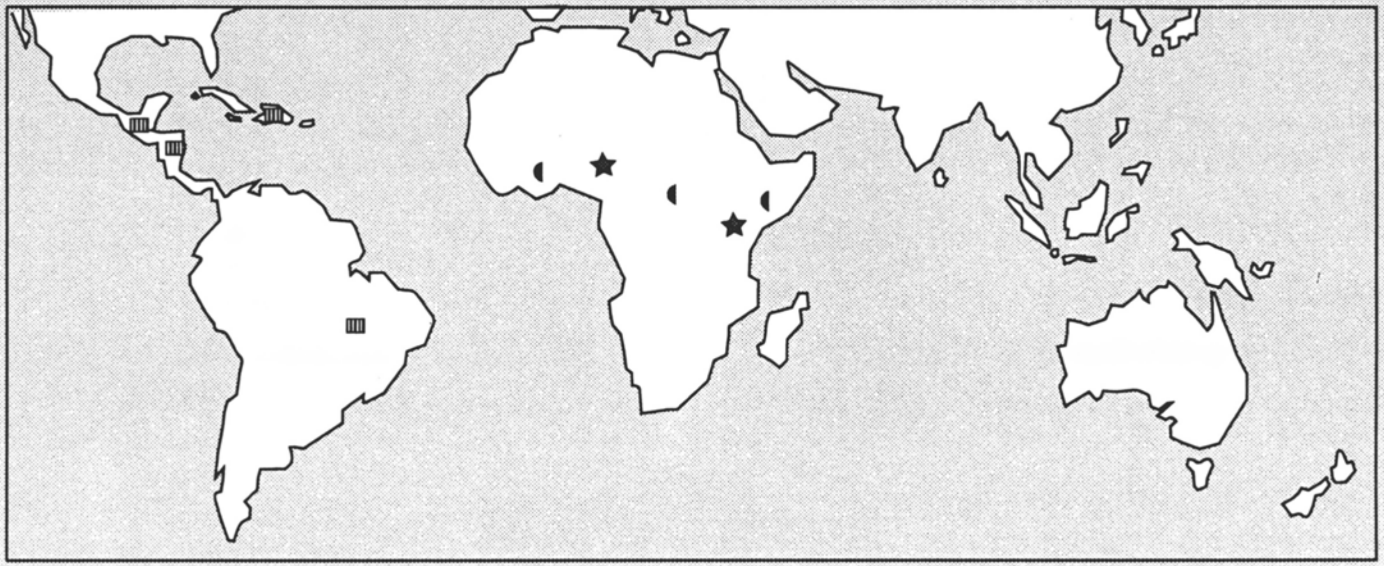
	F. *Fusarium* sp. *Colletotrichum* sp.	elevations	des Terres Rouges en Oubangui Chari. L'Agronomie Tropicale 14: 409-459.
	Abnormal leaf fall F. *Phytophthora* sp.	Five species cause leaf fall	Chee K.H., 1969. Variabilityof *Phytophthora* from *Hevea* brasiliensis. Transactions of the British Mycological Society 52: 425-436.
	Powdery mildew F. *Oidium hevea*	Leaf disease. Sometimes at high elevations	Sivanesan A., Holliday P., 1976. Commonwealth Mycological Institute. Fungia and Bacteria no. 508.
	Bird's eye spot leaf F. *Helminthosporium heveae*	Most important foliar disease in the nursery	Hilton R.H., 1952. Bird's eye spot leaf disease of the hevea tree caused by *Helminthosporium heveae*. Journal of the Rubeer Research Institute of Malaya 14: 42-92.
Citrus			
	Alternaria brown spot F. *Alternaria citri*	Fruit disease	Cook A.A., 1975. Diseases of tropical and subtropical fruits and nuts. Hafner Press, London, U.K., 317 pp.
	Alternaria leaf spot of rough lemon F. *A. citri*	Serious problem in nurseries	Fawcett H.S., 1936. Citrus diseases and their control. Ed. McGraw Hill, London, U.K., 656 pp.
	Anthracnose F. *Gloeosporium limetticola*		Whiteside J.O., Garnsey S.M., Timmer L.W., 1988. Compendium of citrus diseases. APS Press. 80 pp.
	Black spot F. *Phyllostictina citricarpa*	Fruit disease Worldwide except USA and the Mediterranean	Bové J.M., Garnier M., 1997. Major diseases and pathogens of citrus of citrus in the Mediterranean region and Western Asia: today and tomorrow. 10th Congress of Mediterranean Phytopathological Union. Proceedings, pp. 1-10. Ed. SFP. ORSTOM.
	Gummosis F. *Dothiorella gregaria*	On the trunk and low branches	
	Fusarium wilt F. *F. oxysporum* f. sp. *citri*	Vascular disease	
	Greasy spot F. *Mycosphaerella citri*	On fruits and leaves Worldwide	

	Lime anthracnose F. *Gloeosporium limetticola*		
	Mal Secco F. *Phoma tracheiphila*	Vascular disease	
	Melanosis F. *Diaporthe citri*	On leaves and fruits	
	Rosellinia root rot F. *Rossellinia* sp.	Rot. Root infection	
	Scab F. *Elsinoe fawcettii*	On leaves and fruits. Immature stages very susceptible.	
	Septoria spot F. *S. citri*	On leaves and fruits	
	Virus and virus-like diseases	A large number of diseases in all countries	
	Stubborn *Spiroplasma citri*	Dwarfism and small fruits	Laflèche D., Bové J.M., 1970. Mycoplasme dans les agrumes atteints de greening de Stubborn ou de maladies similaires. Fruits, 25: 455-465.
	Slow decline N. *Tylenchulus semipenetrans*	Slow more or less serious degeneration. Worldwide.	Duncan L.W., Cohn E., 1990. Nematode parasites of citrus. *In:* Plant parasitic nematodes in subtropical and tropical agriculture: M. Luc, R.A. Sikora and J. Bridge (eds.). Wallingford, U.K. CAB International pp. 28-29.
	Spreading decline N. *Radopholus citrophilus* *(= R. similis)*	Mortality within a few years. Florida	
Mango			
	Mango malformation F. *Fusarium moniliforme*	On infloresences, panicles and young fruits, Worldwide	Cook A.A., 1975. Diseases of tropical and subtropical fruits and nuts. Hafner Press, London, U.K., 317 pp.

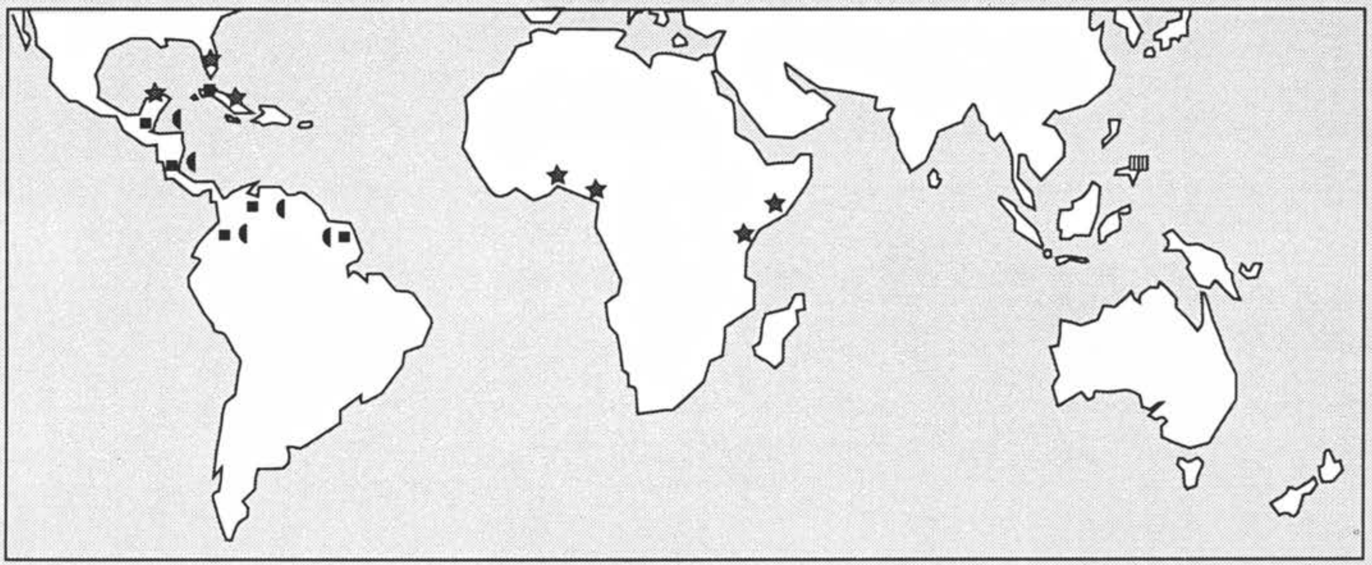
	Powdery mildew F. *Oidium mangiferae*	On inflorescences, panicles and young fruits. Worldwide	
	Scab F. *Elsinoe mangiferae*	On leaves, branchlets and fruits. Worldwide. Serious in nurseries	
Avocado			
	Sport blotch F. *Cercospora purpurea*	On leaves and fruits. Worldwide. Same control method as anthracnose	Broadley R.H., 1951. Avocado pests and disorders. (ed.) QDPI, Brisbane, Australia 74 pp.
	Root rot F. *Dematophora necatrix*	Rot. Attacks roots and collar	Gaillard J.-P., 1987. L'avocatier. Sa culture, ses produits. Ed. Maisonneuve et Larose, Paris, France, 419 pp.
	Stem canker F. *Dothiorella gregaria*	On branches and branchlets	Gaillard J.-P., Godefroy J., 1993. L' Avocatier. Le technicien d'agriculture tropicale. Ed. Maisonneueve et Larose, Paris, France, 207 pp.
	Scab F. *Sphaeroceloma persea*	On leaves and fruits	Cook A.A., 1975. Diseases of tropical and subtropical fruits and nuts. Hafner Press, London, U.K., 317 pp.
	Verticillium wilt F. *V. dahlia*	Vascular disease. North America and South Africa	
	Avocado sunblotch V. Viroid	Transmitted through wounds and seeds	
	Root knot N. *Meloidogyne* sp.	Secondary disease	
	Root lesion N. *Pratylenchus brachyrus*	Secondary disease	


Major diseases of cocoa
Moniliosis
Witches' broom
Vascular streak dieback
Swollen shoot (Ghana - Togo)
Black pod rot (worldwide)

Major diseases of coffee

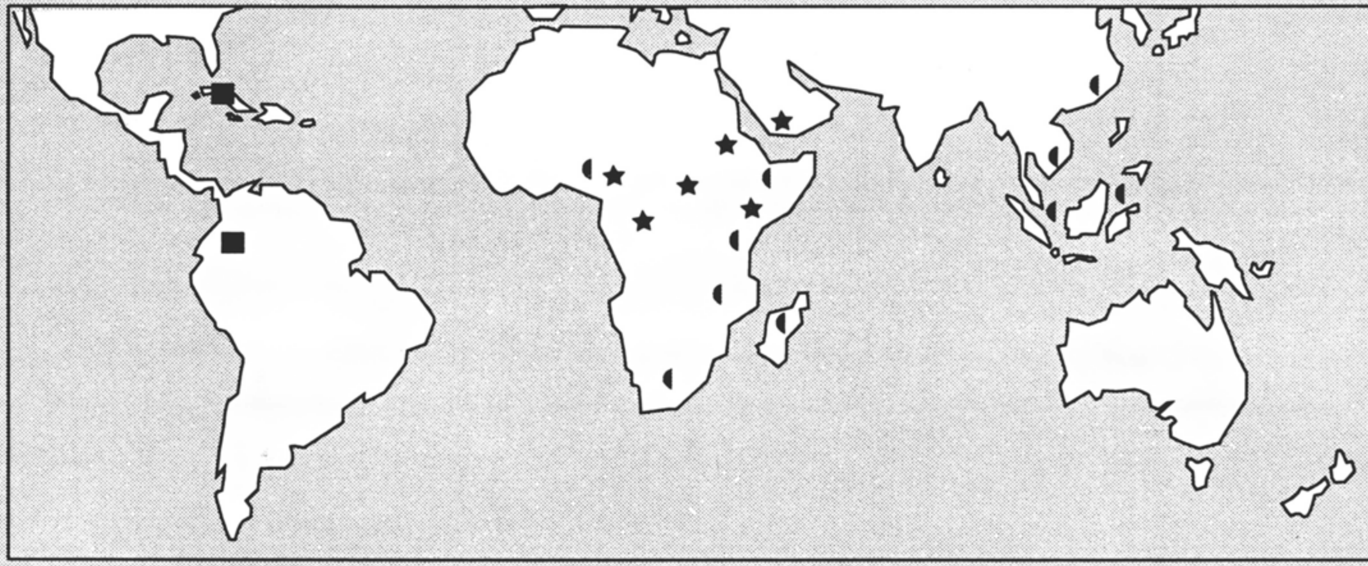


Major diseases of coconut

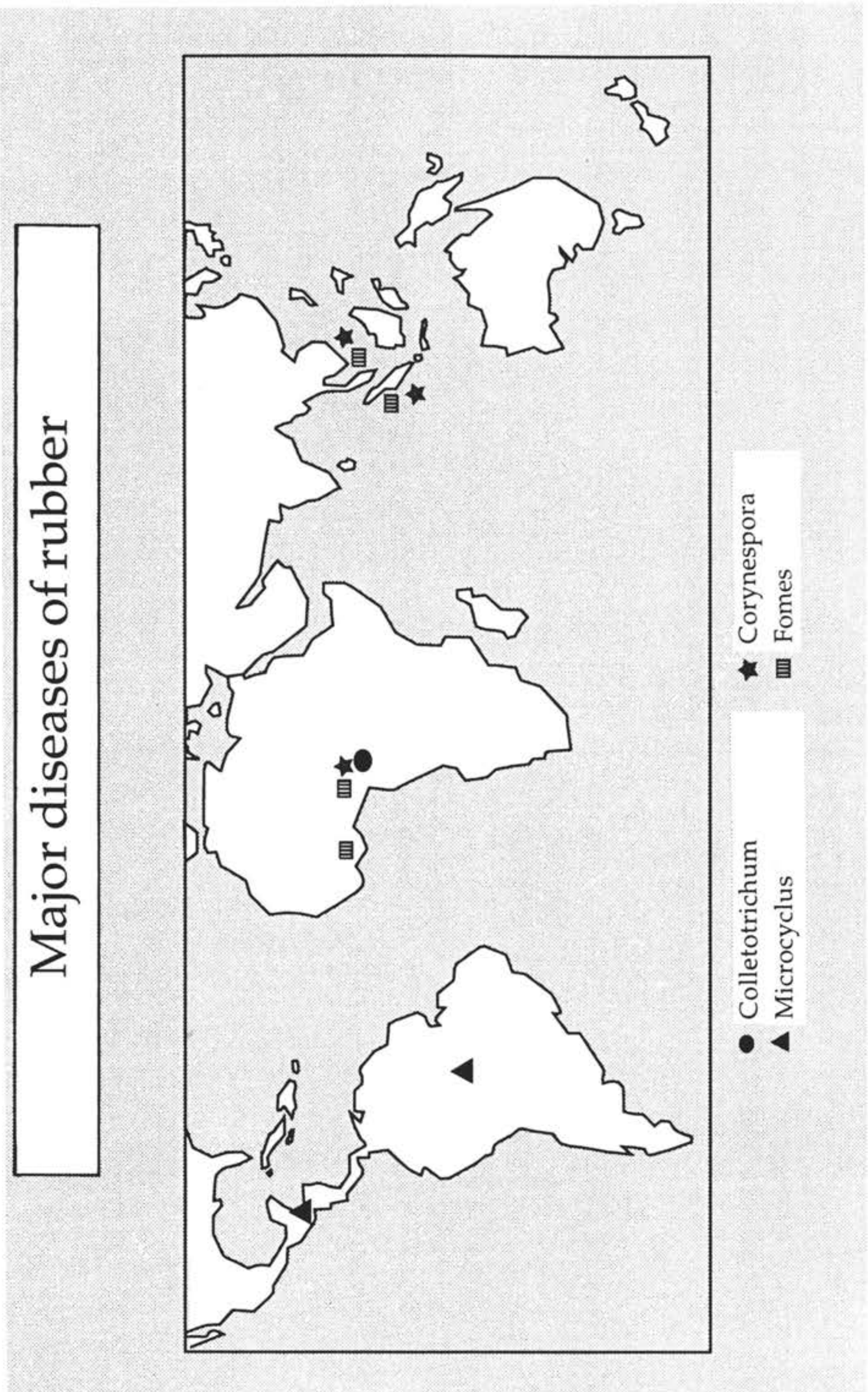


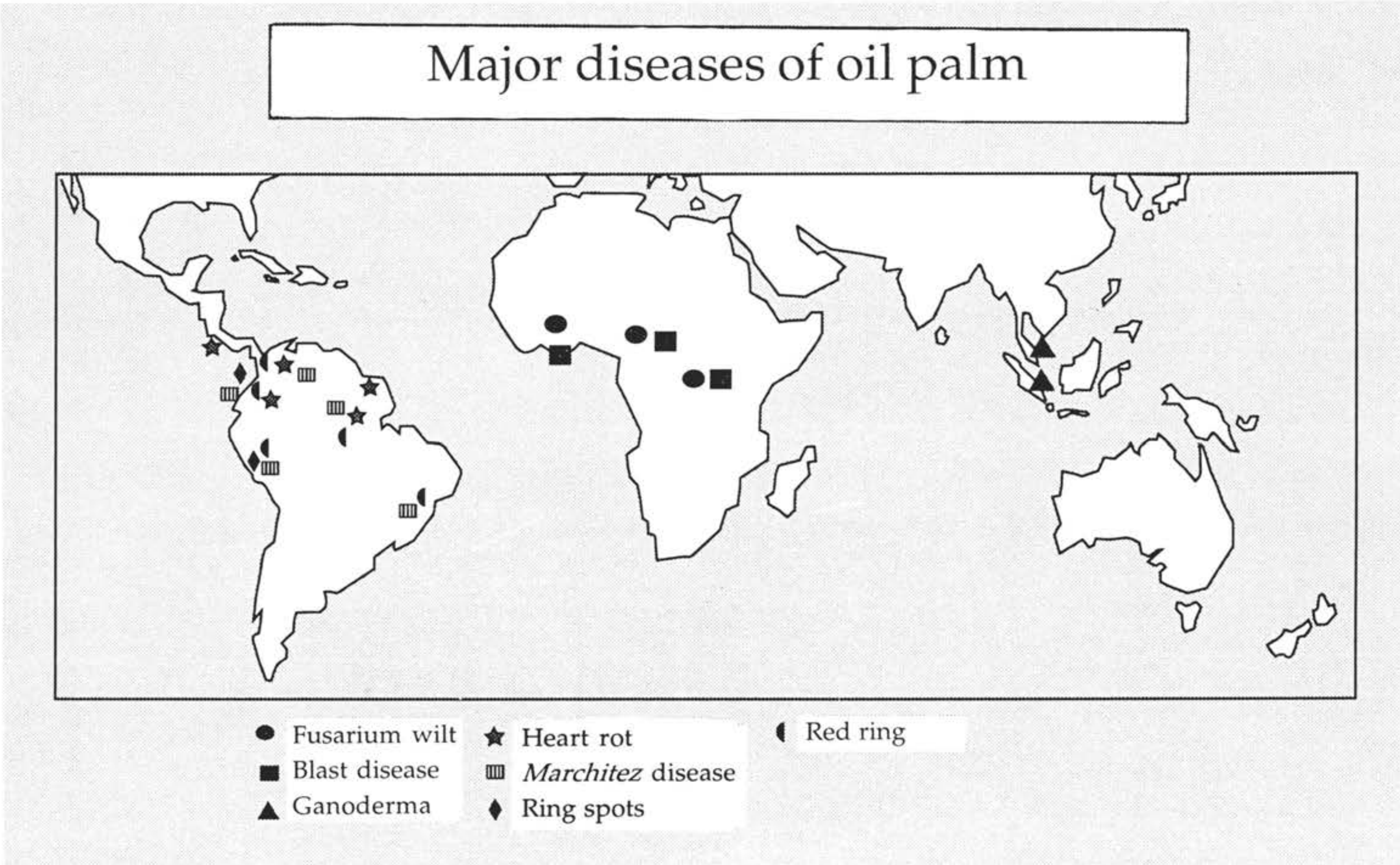
★ Lethal yellowing
■ Bud rot *Hartrot*
▥ Cadang-cadang
◖ Red ring
Phytophthora (worldwide)

Major diseases of citrus and other fruit trees



■ Citrus ceratocystis	Citrus tristeza virus (worldwide)	*Phytophthora* of avocado(worldwide)
★ Citrus cercospora disease	Citrus gummosis (worldwide)	Fruit anthracnosis (worldwide)
◖ Citrus greening	Citrus bacterial canker (see page 43)	Black spot of mango (see page 41)
	Citrus viroids (worldwide)	


Major diseases of rubber
Colletotrichum
Microcyclus
Corynespora
Fomes


Major diseases of oil palm
Fusarium wilt
Blast disease
Ganoderma
Heart rot
Marchitez disease
Ring spots
Red ring

List of Abbreviations

AD	Amazonian Dwarf (cocoa selection)
AFLP	Amplified Fragment Length Polymorphism
ANACAFE	Asociación Nacional del Café, Guatemala
AT	Amazonian Tall (cocoa selection)
AVROS	Algemene Vereeniging van Rubberplanters ter Costkust van Sumatra (hevea selection)
C	Catimor Selection (coffee selection)
CATIE	Centro Agronómico Tropical de Investigación y Ensenanza, Costa Rica
CBD	Coffee Berry Disease
Cc	Costa Rica (cocoa selection)
CCAVd	Cachexia Virus Viroid
CCCVd	Coconut Cadang-Cadang Viroid
CD	Clavellinas Disease (hevea selection)
CEVd	Citrus Exocortis Viroid
CFD	Coconut Foliar Decay
CIFC	Centro de Investigação das Ferrugens do Cafeeiro, Portugal (coffee selection)
CIRAD	Centre de Cooperation Internationale en Recherche Agronomique pour le Développement
CRU	Coconur Research Unit
CSSV	Coconut Swollen Shoot Virus
CTFT	Centre Technique Forestier Tropical
CTV	Citrus Tristeza Virus
CvdIIb	Form of Citrus Cachexia Viroid
CvdIIc	Form of Citrus Cachexia Viroid
Cvpd	Citrus Vein Phloem Degeneration
DTBIA	Direct Tissue Blotting Immuno Assay
EBC	Colombian Origin (cocoa selection)
EEC	European Economic Community
ELISA	Enzyme-Linked Immunosorbent Assay
Et	Ethiopian (coffee selection)
F	Ford Hevea Native (hevea selection)
FAO	Food and Agricultural Organization

FCA	Factorial Correspondence Analysis
GCA	General Combining Ability
GRE	General Reciprocal Effect
Gu	Guyana (cocoa selection)
Gu	Guatemala (Firestone) (hevea selection)
Hr	Heart rot (oil palm)
IAN	Instituto Agronomico do Norte (hevea selection)
IAPAR	Instituto Agronomico do Paraná, Brazil (coffee selection)
Ic-n-pcr	Immuno Capture Nested Polymerase Chain Reaction
ICS	Imperial College Selection (cocoa selection)
IGC-T	International Germplasm Collection of Trinidad
IMC	Iquitos Mixed Calabacillo (Peru) (cocoa selection)
INEAC	Institut National pour l'Etude Agronomique du Congo belge
IOCV	International Organization of Citrus Virology
IOM	International Organization of Mycoplasmology
IPGRI	International Plant Genetic Resources Institute, Rome
IRCA	Institut de Recherches sur le Caoutchouc en Afrique (hevea selection)
IRCC	Institut de Recherches du Café et du Cacao
IRFA	Institut de Recherches pour les Fruits et Agrumes
IRHO	Institut de Recherches pour les Huiles et Oléagineux
K7	Kenya (coffee selection)
LCTEEN	London Cocoa Trade, Ecuador (cocoa selection)
LMC	La Mé Clone (Ivory Coast) (palm selection)
LPGA	La Providencia (Venezuela) (cocoa selection)
MLO	Mycoplasma-Like organism
Oc	Ocumare (Venezuela) (cocoa selection)
P	Pound (Peru) (cocoa selection)
PB	Prang Besar (Malaysia) (hevea selection)
pcr	Polymerase Chain Reaction
PDA	Potato Dextrose Agar
Pr	Proofstation v. Rubber (Indonesia) (hevea selection)
qtl	Quantified Trait Loci
Rapd	Random Amplified Polymorphism DNA
RLO	*Rickettsia*-Like Organism
Ro	Rondonia (Brazil) (hevea selection)

RRIC	Rubber Research Institute of Ceylon (Sri Lanka) (hevea selection)
RS	Rume Sudan (coffee selection)
S	Sarchimor (coffee selection)
Salb	South American leaf blight
SCA	Specific Combining Ability
Sca	Scavina (Amazonian Tall) (cocoa selection)
Snk	Station Nkoemvone Cameroun (cocoa selection)
Spec	Specimen (Colombia) (cocoa selection)
SPOT	Satellite pour l'Observation de la Terre
SPV	Service de la Protection des Végétaux
SRE	Specific Reciprocal Effect
T	Typica (coffee selection)
T38	Ghana hybrid (cocoa selection)
Thd	Timor hybrid (coffee selection)
Thy	Trinidad hybrid (CRU) (cocoa selection)
Tijr	Tjirandji (Indonesia) (hevea selection)
Tsh	Trinidad Selection Hybrid (Ministry of Agriculture) (cocoa selection)
Uf	United Fruit, Costa Rica (cocoa selection)
UpA	Upper Amazon (cocoa selection)
vcg	Vegetative Compatibility Group
Ven	Venezuela (cocoa selection)

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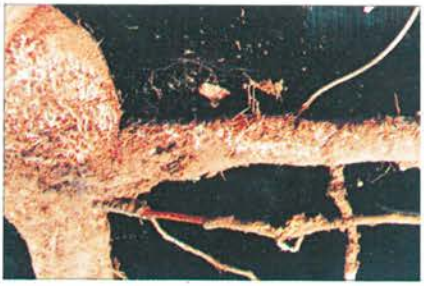

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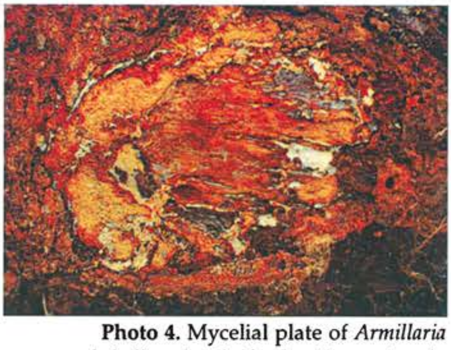

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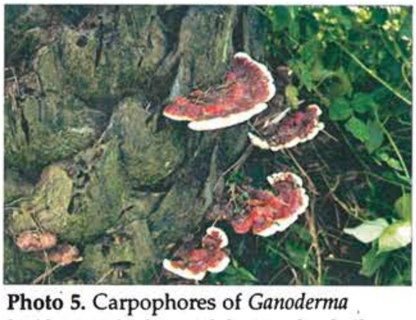

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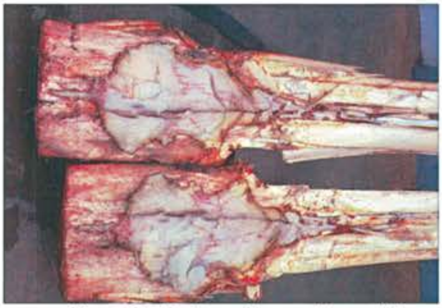

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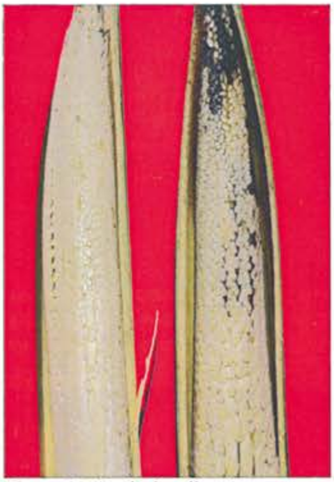

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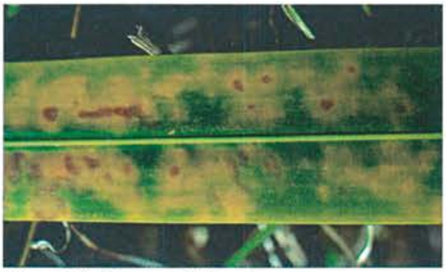

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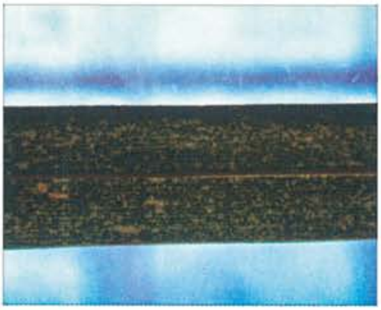

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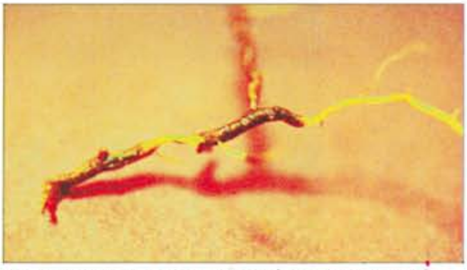

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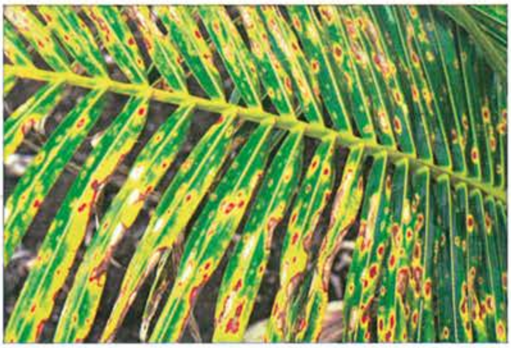

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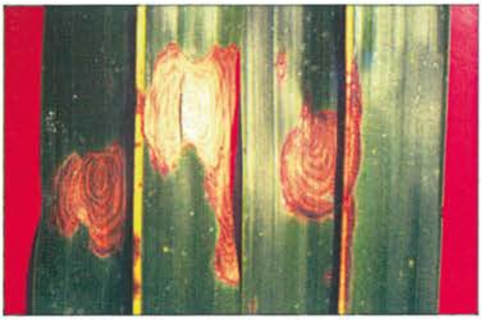

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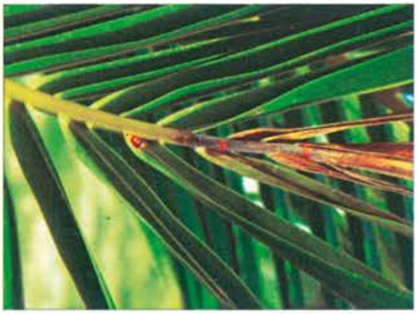

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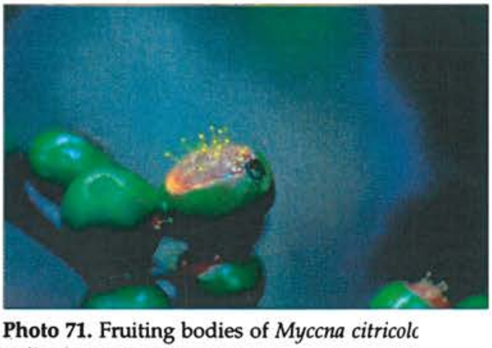

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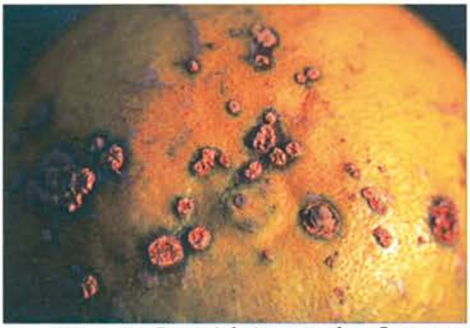

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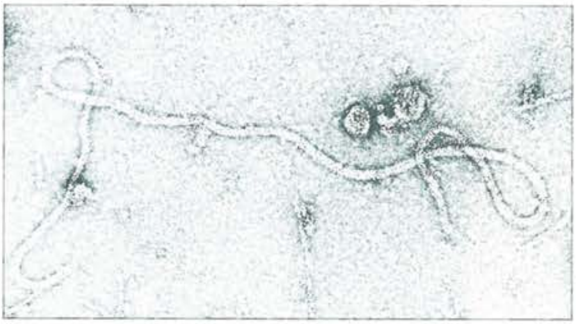

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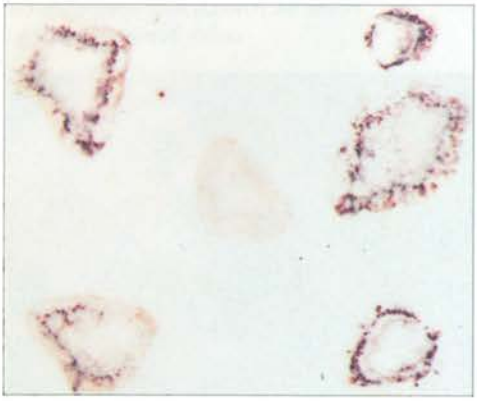

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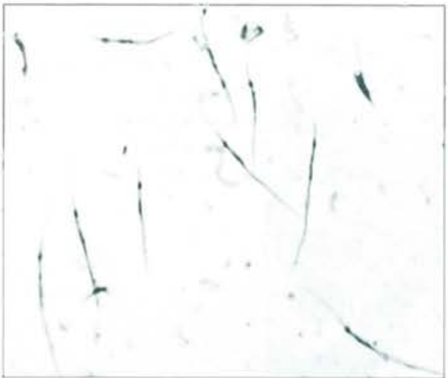

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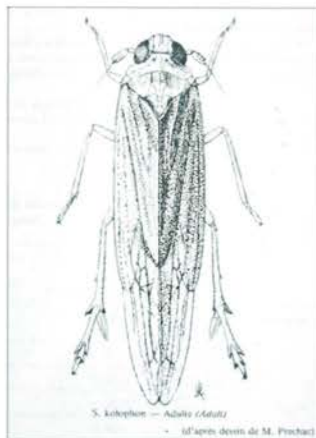

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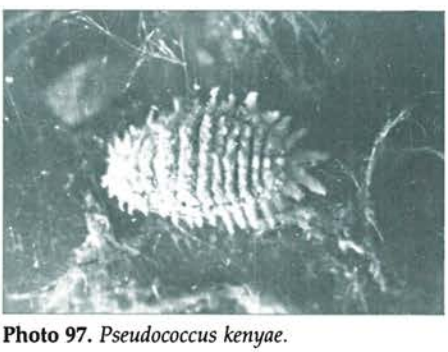

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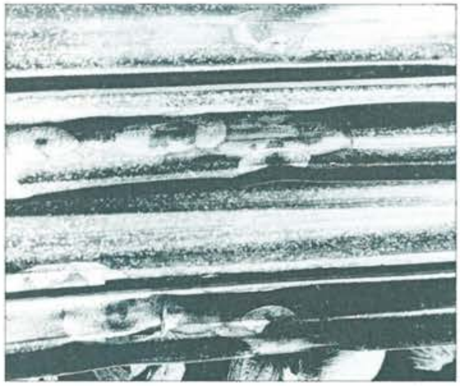

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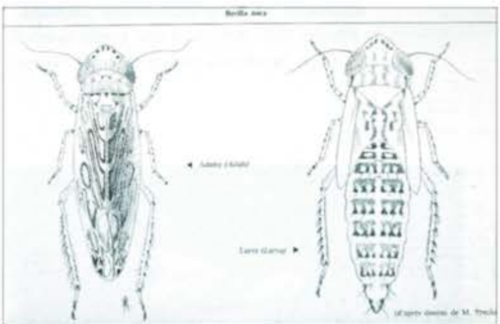

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About the Book

This work summarises several decades of laboratory and field research by specialists from the Tree Crops, Fruit and Horticultural Crops, and Forestry Departments of CIRAD (Centre de Cooperation Internationale en Recherche Agronomique pour le Développement). Their results are the fruit of extensive laboratory and field research. The authors have described about fifty often serious diseases that can cause very substantial yield losses, thereby threatening and sometimes even preventing the cultivation of several crops in different parts of the world. In-depth knowledge of the biology, genetic diversity and pathogenicity of the pathogen is essential for the development of a control method. Breeding resistant planting material is the most widely practised and often the only possible method of control. It calls for extensive research by both plant pathologists, for developing inoculation techniques, and breeders, for producing resistant cultivars. Research on genetically modified planting material is still in its infancy but appears to be very promising. Plant pathologists still often resort to using pesticides, particularly synthetic substances, whilst striving to reduce the dosage and treatment frequency as part of a rational chemical control strategy. In many cases, these methods are complemented by crop techniques in order to reduce pathogen pressure and make the environment less favourable for pathogen development. Viral diseases—phytoplasmas and phytomonas—are generally transmitted by insects of the hemipteran group. Lowering insect population levels has proved to be a very effective control method in several cases.

Drastic measures have to be taken to prevent the spread of diseases or pathogens, especially through plant material exchanges, which should be subjected to strict quarantine regulations. Developing a control method often means integrating different techniques, whose development must take the socio-economic context of rural populations into consideration. Only close collaboration between specialists and produce managers will enable farmers to fully benefit from advances made in their research.

About the Editor

Dominique Mariau has spent most of his career studying oil palm and coconut insects worldwide, and has written numerous articles and books on the subject. He was formerly Head of the Crop Protection Research Unit at the CIRAD Tree Crops Department (CIRAD-CP).

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