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

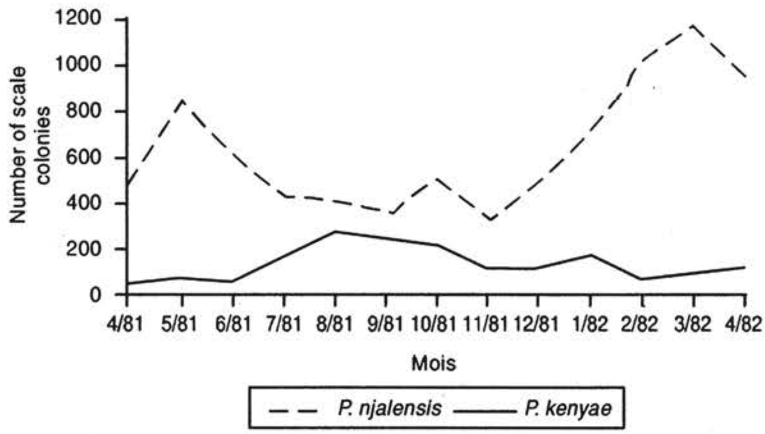

Fig. 1. Population dynamics of *P. njalensis* and *P. kenyae* on 25 trees in Tové (from Nguyen Ban, 1985).

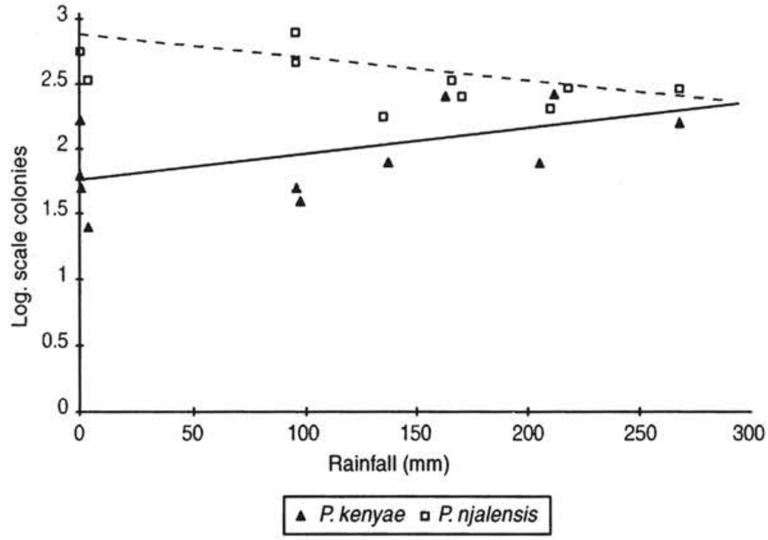

Fig. 2. Correlations between number of scale colonies and rainfall in Tové (from Nguyen Ban, 1984).

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

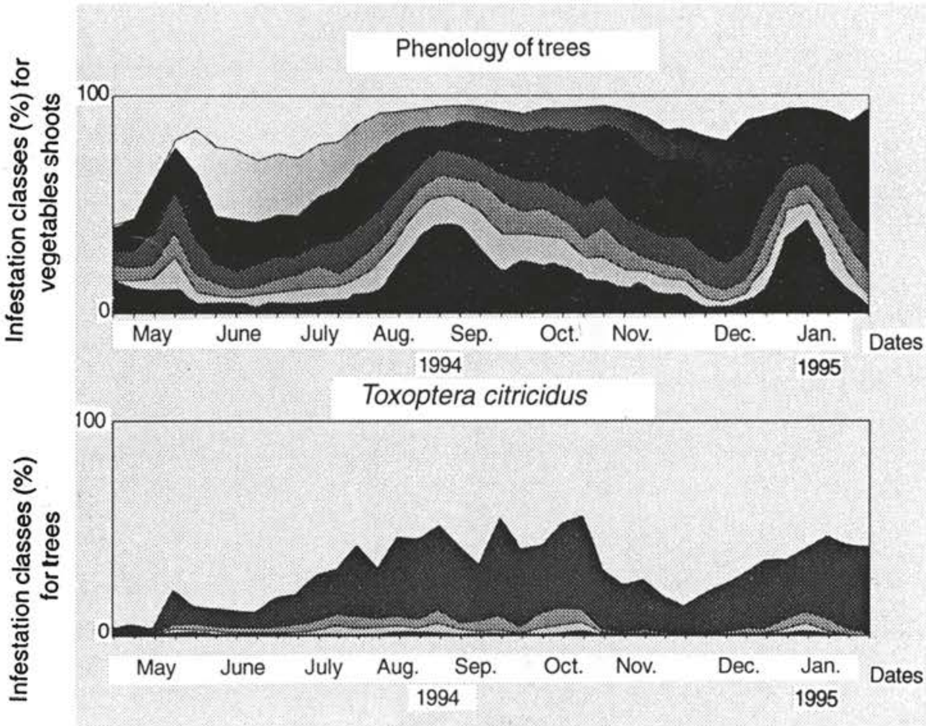

Fig. 3. Population dynamics of citrus aphids in Réunion (from Rochat, 1995). The grey levels are related to intensity classes for vegetative shoots and infestation classes for *Toxoptera citricidus*.

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

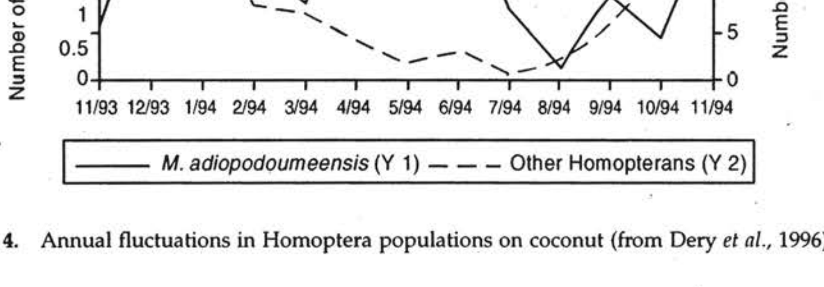

Fig. 4. Annual fluctuations in Homoptera populations on coconut (from Dery *et al.*, 1996).

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).

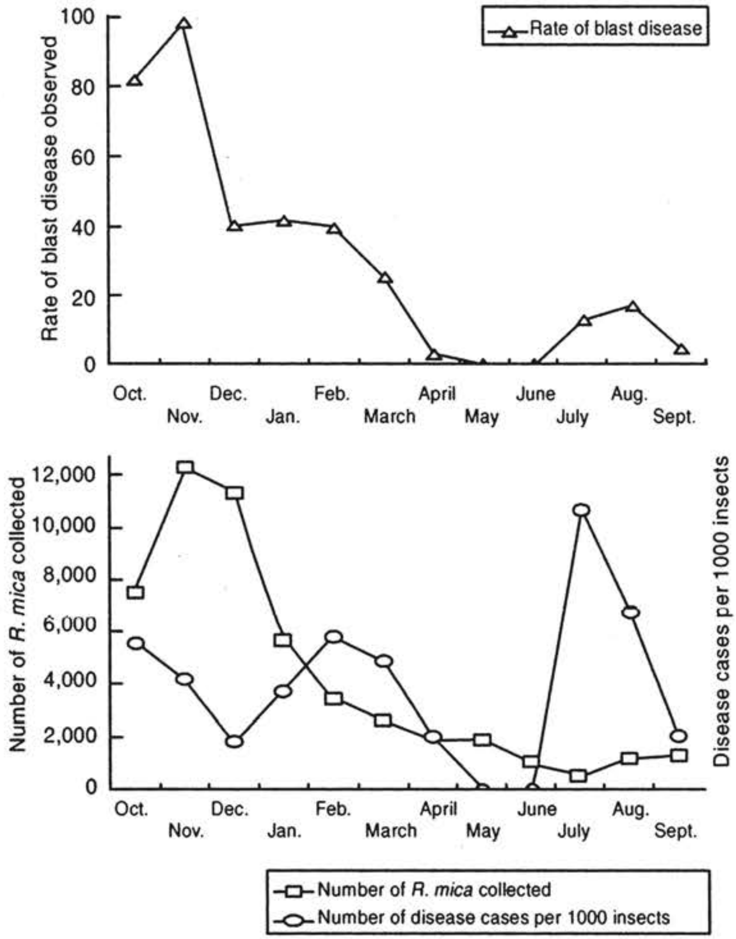

Fig. 5. Incidence of blast disease on oil palm in function of time and *Recilia mica* (from Franqueville *et al.*, 1991).

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

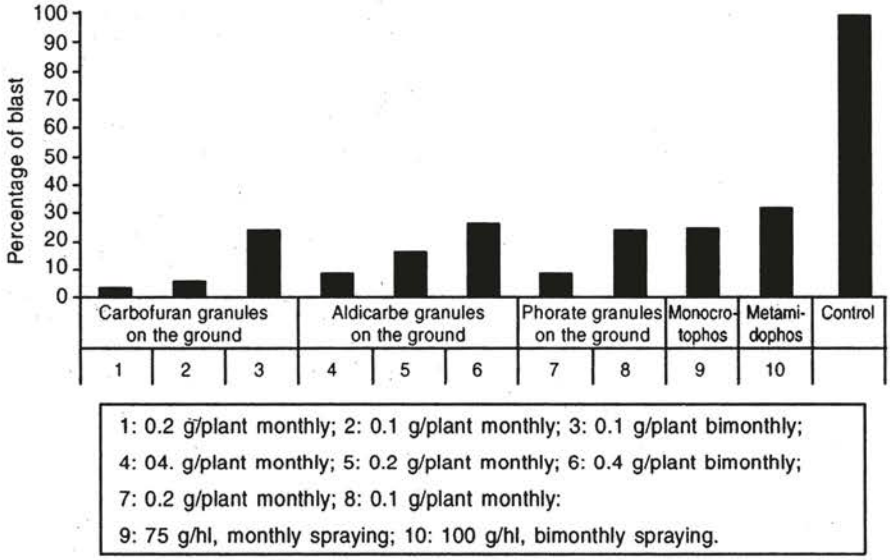

Fig. 6. Efficiency of various insecticides against the vector of blast disease (from Desmier de Chenon *et al.*, 1977).

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

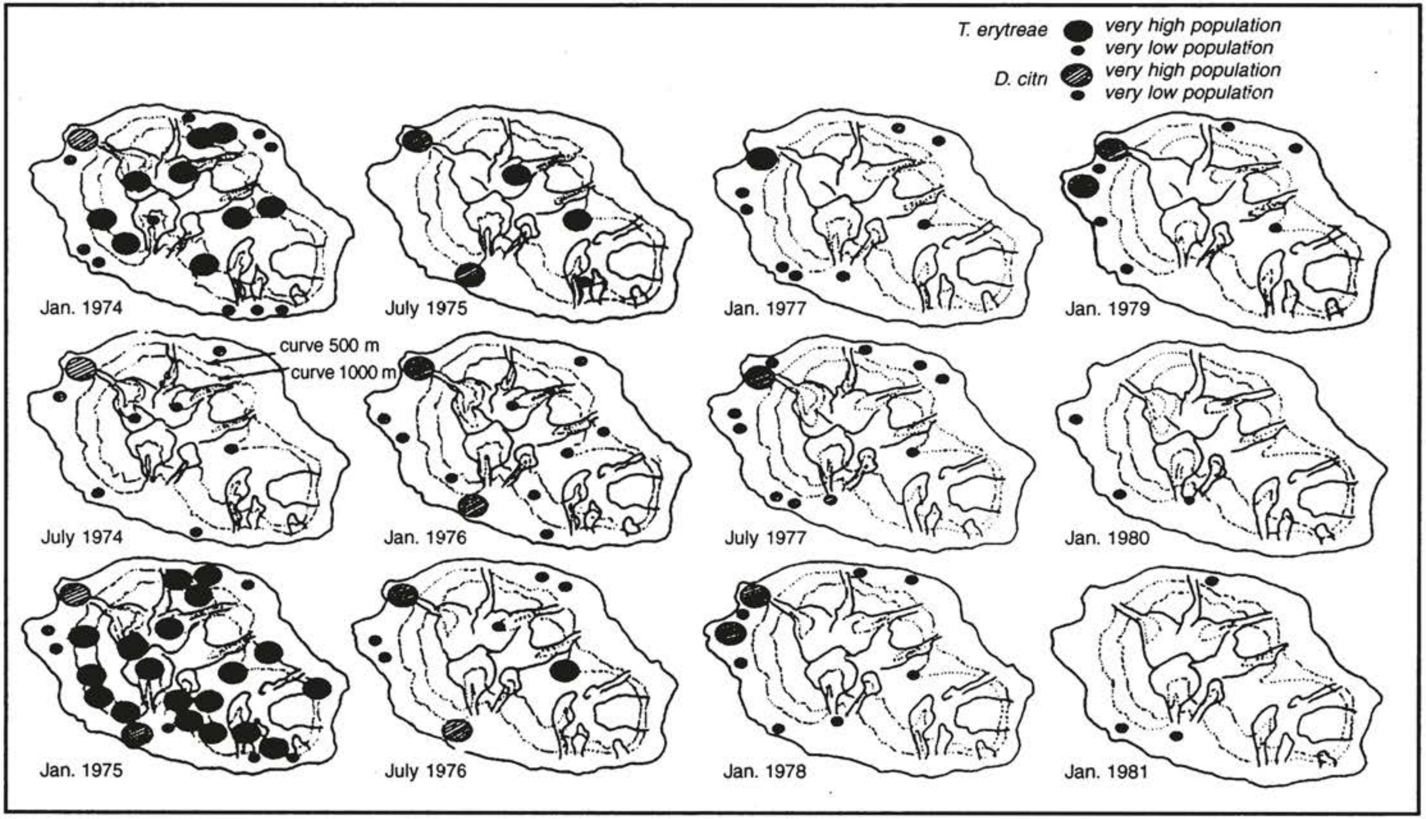

Fig. 7. Evolution of *Trioza erytreae* and *Diaphorina citri* populations in Réunion Island (from Aubert and Quilici, 1985).

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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