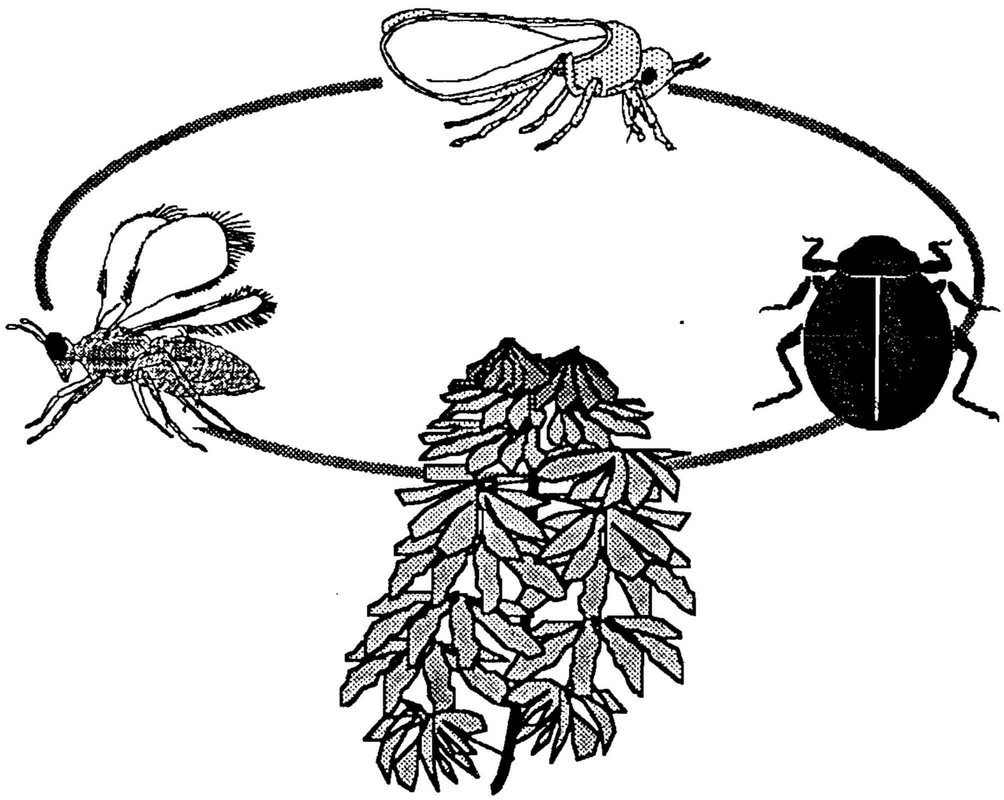
ORSTOM
INSTITUT FRANÇAIS DE RECHERCHE SCIENTIFIQUE POUR LE DEVELOPPEMENT EN COOPERATION
BP. V 51 ABIDJAN (COTE D'IVOIRE)

NATURAL ENEMIES OF *BEMISIA TABACI* (GENN.) IN COTE D'IVOIRE



Research report of
Godwin Limberg and Teus van Lingen.

May 1988

under the direction of Dr. L.D.C. Fishpool and Dr. C. Fauquet
Virology department, ORSTOM

ACKNOWLEDGEMENTS

We would like to thank all the people who helped us with this study and enabled us to get the best results possible. We are especially grateful to Dr. L.D.C. Fishpool and Dr. C. Fauquet, who were our tutors during our stay in Ivory Coast. They guided us in the course of the research. Further, we would like to thank Dr. J.-C. Thouvenel, who was always willing to help solve practical problems.

In Holland we were helped by W. Takken and Prof. A. van Huis. They enabled us to to carry out entomological research in the tropics. We would also like to thank Dr. A Polacsek of the British Museum (Natural History), London for determining the aphelinid material.

SUMMARY

The aim of this research was the study of the natural enemies of the whiteflies *Bemisia tabaci* and *B. hancocki*, (Homoptera; Aleyrodidae), occurring on cassava, in the coastal region of Ivory Coast. Firstly an inventory of the parasites and predators found was made. Thereafter the role of individual species was assessed. To obtain an idea of the range and abundance of natural enemies present, their numbers and distribution in two fields of regularly monitored cassava, were recorded. In addition, predation and parasitisation experiments were carried out where relevant.

The most important natural enemy found during this study, was *Encarsia transvena* (Timberlake) (Hymenoptera; Aphelinidae). This wasp parasitises late instar whitefly nymphs. The parasitisation level of *Bemisia* spp. nymphs by *E. transvena* was found to be as high as 50 %. Compared with this, the other natural enemies encountered were of minimal importance. A coccinellid was found to be a predator of whitefly nymphs. It showed no preference for any particular instar and the average predation rate was approximatelyof 4.5 nymphs per coccinellid per day. An estimate of the overall impact of the coccinellids in the field indicated that the level of predation was approximately 0.2 % of the whitefly population per day. Mites (Acari) were also found to affect whitefly nymph numbers. Firstly, entomophagous species preyed directly on the nymphs, while it was also found that where there were large populations of phytophagous mites, few *Bemisia* nymphs occurred.

RESUME

Le but de cet étude était de étudier les enemies naturel de mouches blanches (*Bemisia* spp.). Premièrement il était necessair de faire un inventair de parasites et predateurs, trouvés dans la region côtier de Côte d'Ivoire. Ci-après le rôle des espèces individuel devrait être estimer. Pour obtenir un idée des enemies naturels présents, deux champs étaient suivi regulièrement. Une fois quand un enemie était découvert, il était inclus dans les comptes du champs et essais a été executés.

L'enemie le plus important, trouvé pendant cet étude, était *Encarsia* spp. *(Hymenoptera*: fam. *Aphelinidae)* C'est un espèce parasitant les stades plus agées.de mouches blanches. Le niveau de parasitation par *Encarsia* sp. pourriait être jusqu'à 50 % de dernier stade larval et des pupes. Comparé avec cet niveau, les autres enemies sont d'aucun importance. En dehors d'*Encarsia* sp. un espèce de coccinellid a été trouvé d'être un prédateur de nymphs de mouches blanches. Ils ont pas montrer un préférence pour un stade particulier et la consommation par jour était bas: 4.5 stades immatures par coccinellid par jour. Un estimation de consommation total par les coccinellids dans le champs indique que le niveau de prédation est environ 0.2 %. De plus acarides influencent le nombre de mouches blanches. D'un côté il y a des espèces prédateur, de l'autre côté la présence de haute nombre de acarides (suceur de plante) ont un influence négatif sur la pouplation de mouches blanches.

SAMENVATTING

Dit onderzoek geeft een beeld van de natuurlijke vijanden van witte vliegen (Bemisia spp.), zoals deze in de kuststrook van Ivoorkust zijn aangetroffen. Allereerst is er een inventarisatie gemaakt van de voorkomende parasieten en predatoren. Vervolgens is de rol van de afzonderlijke soorten onderzocht. Observaties in twee velden gaven een beeld van da aanwezige natuurlijke vijanden. Als een natuurlijke vijand was ontdekt werd deze opgenomen in de veldtellingen en werden er experimenten uitgevoerd om een idee te krijgen van het belang van de soort, als natuurlijke vijand van witte vliegen.

De belangrijkste natuurlijke vijand die in dit onderzoek gevonden werd was *Encarsia* sp.(H*ymenoptera*: fam.*Aphelinidae*).Deze soort parasiteert de oudere larve stadia van de witte vlieg. Het niveau van parasitering kan oplopen tot 50 % van het laatste larve stadium en de poppen. Vergeleken met dit niveau zijn de andere natuurlijke vijanden van gering belang. Behalve *Encarsia* sp. is er een coccinellid sp. gevonden, die predator is van witte vliegen larven. Ze vertoonden geen voorkeur voor een bepaald stadium.De gemiddelde dagelijkse consumptie was vrij laag: 4,5 larven per coccinellid per dag. Een schatting van de totale consuptie in het veld geeft aan dat het niveau van predatie ongeveer 0,2 % is. Verder beinvloeden mijten de aantallen witte vlieg. Aan de ene kant zijn er soorten die predatoren, aan de andere kant hebben hoge aantallen (sap zuigende) mijten een negatieve invloed op de witte vlieg populatie.

1 INTRODUCTION

In large parts of Africa cassava (*Manihot esculentus*) is an extremely important food crop. One of the problems confronting the cultivation of cassava in Africa is the disease caused by African Cassava Mosaic Virus (ACMV) which is capable of inflicting substantial crop losses. The virus is transmitted by man and through the continued and widespread planting of contaminated cuttings, the virus has become widespread. In addition the virus is transmitted by the whitefly *Bemisia tabaci*, (Gennadius), (Homoptera; Aleyrodidae).

Bemisia tabaci is a known vector of many viruses (for example, Okra Leaf Curl Virus, Tomato Yellow Leaf Curl Virus (Sharaf, 1982), Cotton Leaf Curl Virus (Mound, 1983) and ACMV). In 1980 ORSTOM (*Institut Français de Recherche Scientifique pour le Developpement en Cooperation*) began an investigative study of African Cassava Mosaic Virus. This work has been undertaken in Ivory Coast, in an area where cassava is the basic staple food and where considerable yield losses attributable to ACMV, occur annually, (Fauquet, 1987). Initially the programme concentrated largely on the virus and the plant itself but in 1986 a more detailed study of the vector was begun. This work is concerned mainly with an investigation of the population dynamics of *B. tabaci*. We participated in the entomological research programme from January to July 1988. Our studies included an investigation of a second species of whitefly *B. hancocki*, a possible vector of ACMV, and in this report we describe work undertaken on the natural enemies of *B. tabaci*. Both investigations form part of our MSc studies.

The structure of this report is as follows: in the first chapter an introduction to the local climatic conditions is given and the specific aims of our work stated. The second chapter provides an outline of the literature relating to the natural enemies of *B. tabaci* with emphasis on those groups of relevance to this study. In Chapter 3 the field work is described and the results presented and discussed. The final chapter offers some conclusions drawn from the earlier sections.

1.1. DESCRIPTION OF THE ENVIRONMENT

The work described in this report was carried out at the ORSTOM field station of Adiopodoumé situated in the forest zone of southern Ivory Coast. The site is located some 20 km west of Abidjan. Figure 1.1 shows the average monthly rainfall for Adiopodoumé. These are averages over the past 40 years. Also shown is the rainfall recorded during the research period. It is clear that the rainfall during the months January to May 1988 was below normal. The influence of the rainfall on whitefly numbers is discussed in Chapter 3.

Figure 1.2. shows the average monthly field temperatures recorded at Adiopodoumé: mean, maximum and minimum. It can be seen that there is little monthly fluctuation.

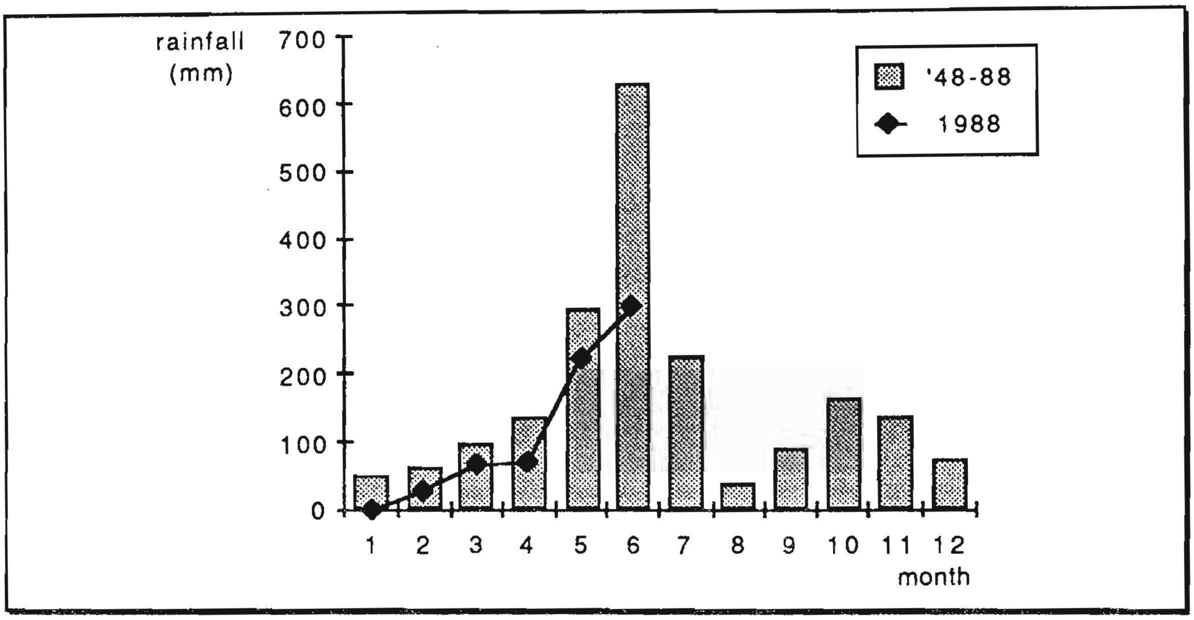


Figure 1.1. Distribution of rainfall at Adiopodoumé (Ivory Coast); average monthly rainfall over the past 40 years and rainfall in 1988 (January - June) - *pluviometrie;à Adiopodoumé (Côte d'Ivoire);moyenne de 40 annees et pluviometrie en 1988.*

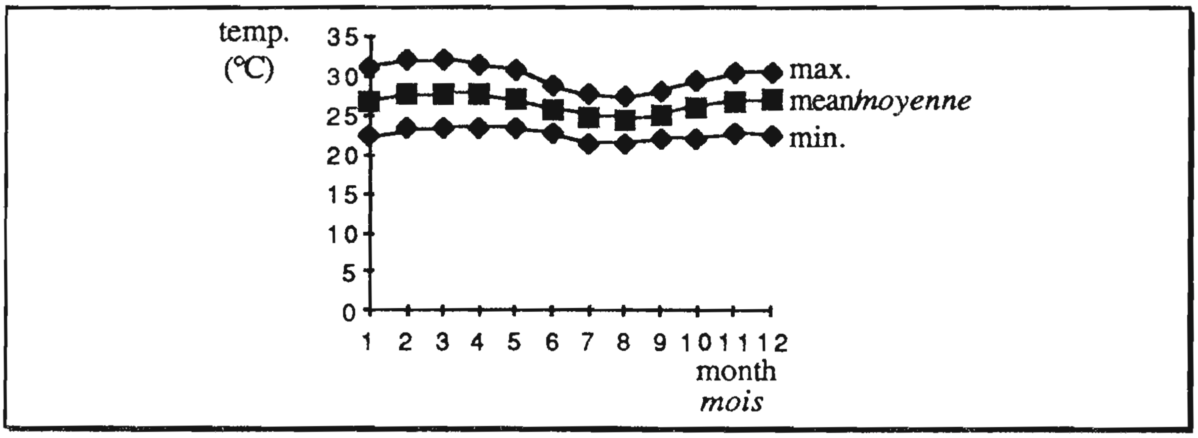


Figure 1.2. Average monthly temperatures at Adiopodoumé (Ivory Coast)- *Fluctuation annuelle de la température à Adiopodoumé (Côte d'Ivoire).*

1.2. AIMS OF THE STUDY

Since chemical control of *B. tabaci* would be completely uneconomic for a subsistence crop such as cassava and of doubtful effectiveness in any case, the possibilities of biological control need to be studied. As a first step field surveys need to be made to discover the range of natural enemies of *B. tabaci*.

The following report is a contribution to such work and provides an inventory and some details of the natural enemies found on cassava in southern Ivory Coast.

2. NATURAL ENEMIES OF BEMISIA TABACI- a literature survey

Much of the literature on the natural enemies of *B tabaci* concerns aphelinid wasps. With the doubtful exception of one species, all reported parasitoids of *B. tabaci* belong to the Aphelinidae (Lopez-Avila,1986). In addition, *Chrysopa* spp. (Neuroptera), a number of coccinellid beetles and several species of mite are known predators, (Lopez-Avila, *loc. cit.*). To date most studies have been either taxonomic or laboratory investigations of bionomics. The only field study involving *B. tabaci* on cassava has been the work of Robertson, (1985), in Kenya. In the following, some aspects of the life cycle and population dynamics of *B. tabaci* are presented. Thereafter the Aphelinidae are briefly described. A general outline of their behaviour is given, followed by an assessment of their possible role in the biological control of whiteflies. Finally, two sections on mites and fungi recorded attacking whitefly nymphs complete the chapter.

2.1. BIOLOGY OF *BEMISIA TABACI*

Those aspects of the life cycle of *B. tabaci* of particular relevance to this study are the duration of the immature stages and the size of the nymphal whitefly populations in the field.

egg	7	days
first instar	2-6	
second	1-5	
third	2-7	
fourth	2-3	
pupa	2-4	
	16-32	days

Table 2.1. Developmental periods of immature stages of *B. tabaci* in days - *la durée de vie approxomative du développement des stades larvales de* B. tabaci *en jours.* (reported in Lopez- Avila, 1986).

Table 2.1. gives an indication of the length of the developmental periods of the different stadia at around 25 °C under field conditions. These durations vary with environmental temperature. Apart from the first instar all other instars and the pupa are sessile.

In order to assess the effects of the various natural enemies on the nymphal whitefly populations in the field, estimates of the size of the host population are required. Predation of adult whiteflies was not studied. Two years before the same field had been used in a study of the population dynamics of *B. tabaci* (van Helden and van Halder, 1986). Although a different cassava variety was used, which may affect whitefly numbers, (van Lingen and Limberg, 1988), their data on whitefly population size are used for comparison with our observations; the corresponding data for this year not yet being available. Figure 2.1. shows the phenology of the whitefly populations, over the same time period as this study. As can be seen the total number of immature stages per plant may be large: up to a maximum of 5000.

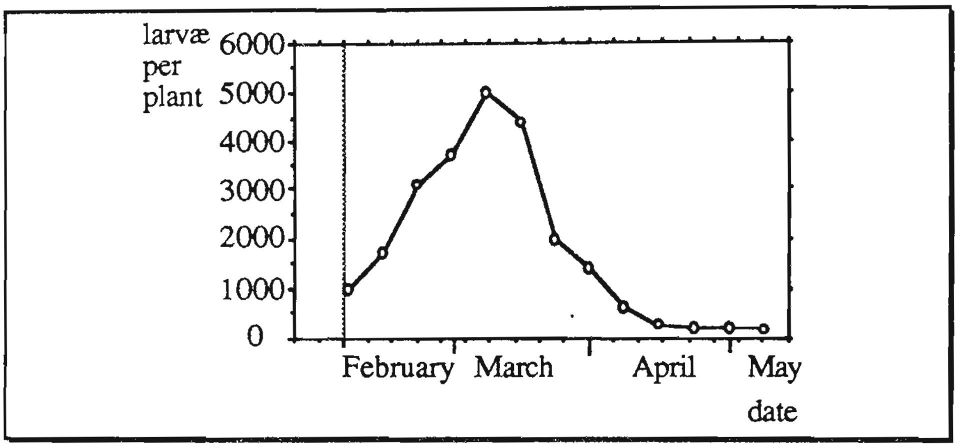


Figure 2.1. Total number of whitefly nymphs per plant - Nombre *de nymphs de mouche blanche par plante* (from van Helden and van Halder, 1986).

2.2. APHELINIDAE

The Aphelinidae are minute Hymenoptera rarely exceeding 1 mm in length. Most aphelinids are parasitoids of species of the sub-order Sternorrhyncha (Homoptera). Viggiani gives a review of adult behaviour. The following description is taken largely from his work (Viggiani, 1984).

2.2.1. Reproduction

Most aphelinid species are biparental. Mated females can lay both fertilized (diploid) eggs and unfertilized (haploid) eggs. The former develop into females, the latter into males. Unmated females lay only haploid eggs, which develop into males. Thus a female can produce both male and female progeny during her life time. The ratio of male to female eggs is affected by mating and suitable hosts (Ferrière, 1965).

2.2.2. Feeding

Adult aphelinids feed mainly on sugary substances such as nectar and honeydew. In addition they may feed on the host directly themselves. The act of inserting the ovipositor, moving it and withdrawing it, causes body fluids to issue from the body of the host. These fluids may then be ingested by the female. Such feeding from the host, which need not be accompanied by oviposition, can cause the death of the host. Debach and Sundby (1963), found that 'predation' by hostfeeding could lead to almost the same level of mortality of the host as parasitism by that parasitoid.

2.2.3. Host selection and oviposition

The four major phases of host selection by parasitic insects are a) habitat selection, b) host finding, c) host acceptance, and d) host suitability. Little is known about habitat selection and the influence of host plants on the searching behaviour of parasitoids. Host finding may involve a random search on the surface of the host plant.

During host acceptance the antennæ of the wasp play an important role. By drumming with the antennæ on the host the female identifies the host, whether it is already parasitized and whether it is the preferred developmental stage, (Foltyn and Gerling, 1985). To investigate host stage preference Foltyn and Gerling, (*loc. cit.*), offered all instars simultaneously to a mated female of *Eretmocerus mundus* Mercet.

(another aphelinid parasitoid of *B. tabaci*). In repeated tests *E. mundus* showed a statistically significant preference for third instar *B. tabaci* nymphs.

2.2.4. Level of parasitism

To evaluate the potential of parasitoids for biological control it is necessary to monitor the levels of parasitism by any given species that occur under natural conditions. Since this is largely dependent upon local circumstances figures found in the literature can only give an indication.

Species of whitefly	n°. of white fly nymphs dissected	n°. of nymphs parasitised
Dialeurodes kirkaldyi	122	-
Aleurotrachilus citri	86	-
Siphoninus granati	140	-
Aleurodes proletella	100	68
Bemisia tabaci	100	83

Table 2.2. Levels of parasitism of 5 whitefly species by *Eretmocerus mundus -niveau de parasitisme de 5 espèce de mouche blanche par* Eretmocerus mundus (from: Hafez *et al*,1983).

Sharaf studied parasitism of *B. tabaci* on *Lantana camara* L. The two species of parasitoids recorded were *Eretmocerus mundus* and *Prospaltella* sp. He found 40-50% parasitism during 8 months of the year. During the remainder the level dropped to 25% (Sharaf, 1982). In the Gezira in Sudan, parasitism by *Encarsia lutea* and *Eretmocerus mundus* of *B. tabaci* on cotton ranged from 6 % to a maximum of 44 % (Gameel, 1969). In a laboratory experiment 83 % of a population of *B. tabaci* nymphs were parasitised by *Eretmocerus mundus*, (Hafez, Tawfik, Awadallah & Sarhan, 1983), (Table 2.2). As can be seen in the Table, of the five whitefly species tested, only *Aleorodes proletella* and *B. tabaci* were parasitised. This indicates that *E. mundus* is oligophagous. Gerling states that oligophagy is widespread among *B. tabaci* parasitoids. He explains this by an apparent readiness of whitefly parasitoids to adapt to new host species. This may also be the reason why the cosmopolitan *B. tabaci* is attacked in many parts of the world by parasites that are of local or restricted distribution (Gerling, 1986).

2.2.5. Biological control

The results of investigations into the control of *B. tabaci* by its natural enemies in the field have been quite varied. Avidov (1956) found that *B. tabaci* was already a severe pest in Israel before the introduction of insecticides. However in other regions *B. tabaci* became a pest only after intensive use of insecticides. This may have been caused by reductions in the parasitoid populations (Gerling, 1986). Sharaf (1982) reported very low levels of parasitism in various plots after having been treated with insecticide. One month after treatment the percentage of parasitism was, with one exception, zero.

As in all biological control programmes care has to be taken that insecticide applications do not interfere with natural control. Control of *B. tabaci* by parasitoids has not so far been extensively investigated. Out of the 18 species listed as being potentially useful, only 7 have been studied in depth (Gerling, 1986). Any method of control of *B. tabaci* in cassava is hampered by the fact that cassava is a subsistence crop, (Godo, 1987). This creates problems in the implementation of a biological control programme as high costs would make it prohibitive to farmers.

Another aspect increasing the difficulty of the control of *B. tabaci* is the fact that it is found on more than 500 plant species, both cultivated crops and weeds. Thus crops are potentially exposed to a continual immigration of whitefly from elsewhere, (Greathead, 1986).

2.3. MITES

From literature studied it was clear that identification of mite species is very difficult, (Muma, 1961; Pritchard and Baker, 1962; Yaninek, 1984). Several reviews of mite classification have been published but there is still much disagreement about their systematics. In this section two important families (Tetranychidae and Phytoseiidae) are considered briefly.

Mites, Acari, are arthropods of the subphylum Chelicerata. They are recognisable from other arachnids by their inconspicious or absent body segmentation.

The Tetranychidae is a large family of phytophagous mites. They are found worldwide and some are important agricultural pests. The identification of tetranychids can be tedious and difficult work. Many species are polymorphic and numerous synonyms have resulted. Genera and species are not only identified using morphological characters, but also through the circumstances in which they occur. This may include hostplant species, feeding damage, geographical location etc. (Yaninek, 1984). Their relevance here is that they occurred in very large numbers in the cassava crop during part of the period of observartion and seemed to competitively affect the numbers of whitefly present.

Phytoseiid mites are important predators of tetranychid mites. They also prey on insects. They live in close association with their host. Recently biological control programmes have looked at the possible introduction and use of phytoseiid mites in controlling pests (e.g. Cassava Green Mite) (IITA, 1986).

The various stadia of predaceous phytoseiid mites are usually larger than those of their prey. The eggs are oval, very white and about three times the size of the eggs of tetranychids (Yaninek, 1984). The active stages move relatively fast when disturbed or when searching for food. Adults may vary from white to amber or red, depending on the colour of their host. Normally they are found on the under surface of the leaf. When resting they are found near the major veins.

Meyerdirk and Coudriet carried out several experiments to investigate predation of whitefly by *Euseius scutalis*. They investigated whether or not *E. scutalis* could survive and reproduce when fed on *B. tabaci* eggs and nymphs. Their experiments showed that mites fed on freshly laid eggs were longest lived and had the highest fecundity in comparison with mites fed on other immature stages, (Meyerdirk and Coudriet, 1986).

2.4. FUNGI

In the literature only one species of fungus has been recorded attacking *B.tabaci*: *Paecilomyces farinosus* (Dickson & Fries) Brown & Smith (Balakrishnan and Nene, cited in Cock, 1986). This was observed in India. At least one species of fungus of the genus *Cladosporidium* has been found attacking whitefly nymphs on cassava in our experimental plot, the incidence of which we investigated. It is not yet clear however, to what extent such fungi are pathogenic or simply invade damaged or dead nymphs. The samples were identified by Dr. H. Evans of the Commonwealth Mycological Institute, London.

3. NATURAL ENEMIES OF *BEMISIA TABACI*

Because of time constraints the study was largely restricted an inventory of the most important parasites and predators found. Parasites and predators were observed in the field during the months of fieldwork. To verify that they were indeed natural enemies of *B. tabaci* some experiments were carried out as necessary. In performing these experiments it was also possible to get an idea of the importance of the parasitoid or predator.

3.1. MATERIAL AND METHODS

The work on the natural enemies started with field observations. Our tutor, Dr. Fishpool made some suggestions concerning probable parasitoids and predators to be looked for. As a result observations were started on a 1 ha cassava field. The plan of this field and its orientation is shown in Fig. 3.1. The field was planted with cassava on 26 November 1987. The variety used was Kasimbidgi Green, of Kenyan origin. Our observations began in February and continued until mid-June during which time the complex of *B. tabaci* and its enemies was sampled regularly. In addition to the main field a second smaller plot on the northern side of the main field was also used for counts. In this plot ten plants were sampled. The counts began on 23 March and continued until 18 May.

In the main field 13 plants were selected and all leaves on the plant were sampled over a period of two months; these were the same plants sampled for a concurrent study of *B. hancocki*, (van Lingen and Limberg, 1988). Whitefly adults and nymphs are virtually confined to the undersurfaces of the leaves, and hence their natural enemies are too. The leaves therefore had to be gently turned over to be sampled. The field was orientated with respect to the wind such the south-westerlies prevailing at this time of the year, crossed the upwind field border at right angles, (Fig. 3.1). The 13 plants were chosen with the aim of investigating the influence of the wind on the dispersal of *B. hancocki*. They were also used however to sample levels of parasitism of *Bemisia* pupae and to investigate the distribution of parasitised pupæ within the field.

The most commonly encountered natural enemy was the parasitoid *Encarsia transvena* (Timberlake). Of the material so far examined all has proved to be this species though it is possible that others were present. *Bemisia* pupæ parasitised by *E. transvena* are easily recognisable. Such pupæ are completely black with a red spot at the caudal end, instead of the egg-yellow colour of normal pupae. The red spot is the meconium, (excretory products), of the *Encarsia* larva, while the black colour results from the wasp pupa being visible through the translucent integument of the host. In addition to monitoring parasitised pupæ, adult *E. transvena* found on the cassava plants were also counted. The small size and the rapid flight of the adults made them difficult to count accurately. On the one hand some adults may have left the leaf before being counted through disturbance, on the other hand others may have been counted twice by moving from a sampled to a non-sampled leaf. The number of adults recorded per plant therefore are at best only an approximation of the numbers actually present.

At the beginning of March large numbers of coccinellid larvæ were observed on the cassava leaves amidst the whitefly nymph populations. Although it was not then known whether they were predaceous, their numbers on the sampled plants were recorded. Neither was it not known what the adults of the larvae looked like. A few adult coccinellids were seen but their numbers not recorded. The adults were approximately 4 mm long and 1 mm wide and were completely black.

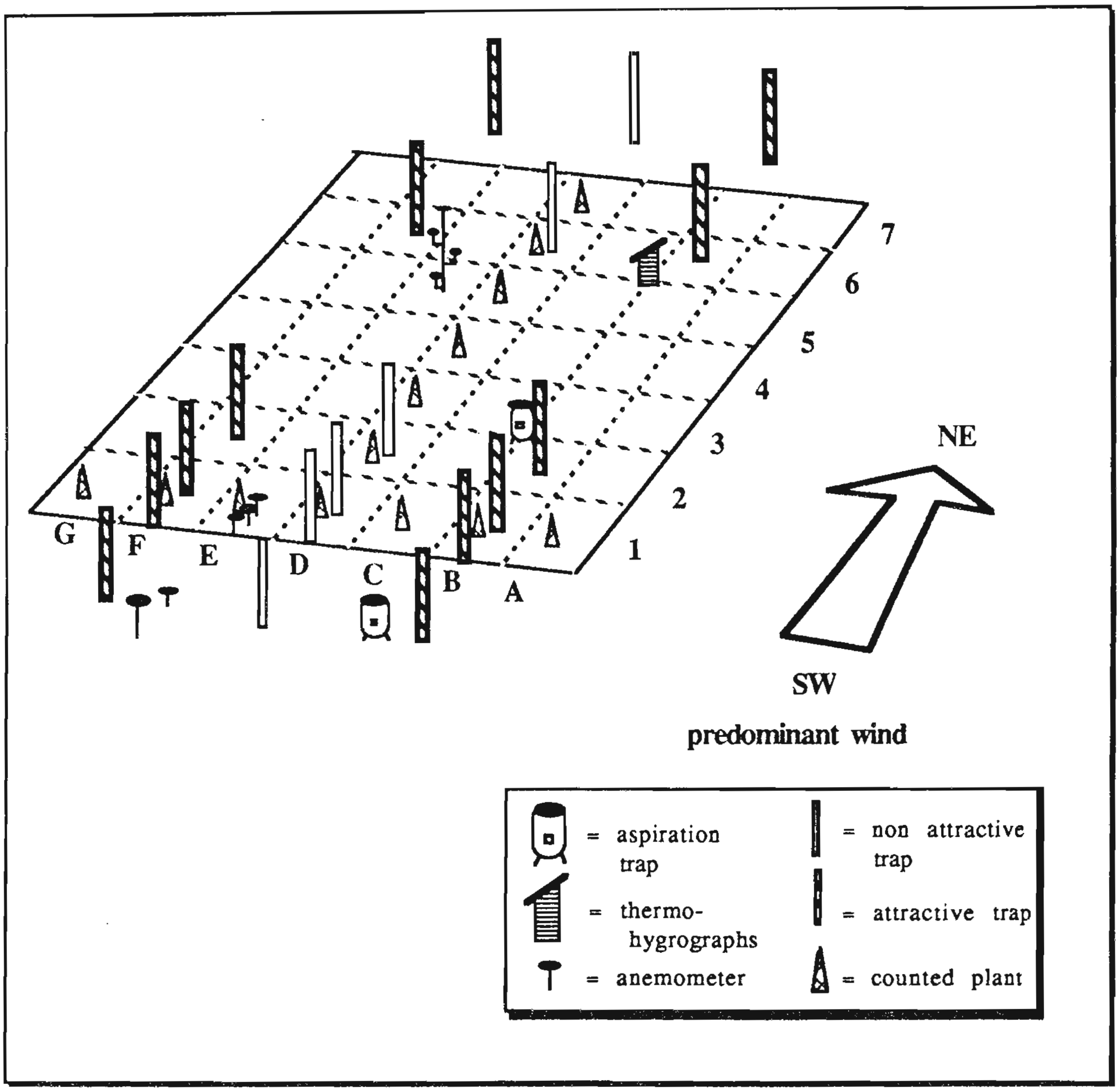


Figure 3.1. The main field with all traps and equipment *in situ*. The numbering system and the sampled plants are indicated. - *Le premier champ avec tous les pièges et toute apparature mis en place. La numérotation et les plantes comptées sont indiquées.*

Experiments were carried out to establish whether these larvæ were predators of whitefly nymphs and to rear adults from them. It was shown that the black adult coccinellids did develop from these larvae; as a result the adults were then included in the field counts and predation experiments with them were performed.

To investigate predation by larvæ and adults a cassava leaf foliole bearing *B. tabaci* nymphs was put in a petri-dish. Some wet filter paper was put on the bottom of the dish to prevent the leaflet of drying out. The number and stage of the whitefly nymphs were recorded and coccinellids - either larvae or adults - were introduced into the dishes. After 24 hrs the number of whitefly nymphs were counted again. In each experiment seven petri-dishes were used. The experiments were repeated several times: twice for the larvæ and five times for the adults.

Other causes of mortality of *Bemisia* nymphs recorded in the field were: fungal attack, predation by mites and parasitism by a second aphelinid, *Eretmocerus* sp.

In the field it was difficult to distinguish adult *Eretmocerus* sp. from *E. transvena*. It is therefore possible that some *Eretmocerus* sp. were included in the *E. transvena* counts. It was only at the beginning of May that *Eretmocerus* sp. was found; their numbers were relatively small.

The other causes of mortality were recorded both in the field counts and the destructive counts. The destructive counts involved removing an entire plant from the small plot and examining all leaves under a binocular microscope. The number of larvæ attacked by fungi was recorded. It was thought that fungal attack was not necessarily the primary course of death. The dead larvæ may have been secondarily contaminated by fungi.

Mites also had important effects on the numbers of *B. tabaci* nymphs found on the cassava. On the one hand there was the direct effects of predation. On the other large numbers of phytophagous mites, present on some of the cassava plants, were seen to reduce the number of whitefly nymphs present. This probably resulted from disruptive effects of the mites on the whitefly adults causing decreased feeding and oviposition. At least five visually distinguishable types of mite were found; samples have been sent for identification but no names are yet available. One species was probably the Cassava Green Mite (C.G.M.), (*Mononychellus* sp.). This is a phytophagous species, which can cause severe damage to cassava plants.

During the destructive counts numerous apparently perfect *Bemisia* nymph exoskeletons were found, white in colour and entirely lacking in body contents. It was thought that these nymphs had been subject to attack by a sucking predator. The most likely candidates were predaceous mites. Experiments were carried out with one species to investigate if the mite species was predaceous. By the time these experiments began only one species was present in the field in any numbers. The C.G.M., another green coloured species and two red/orange coloured species had almost completely disappeared. The remaining species was white in colour and thought to be predaceous. The experiments were carried out in the same way as those with the coccinellids. On each occasion one mite was introduced to each of seven petri-dishes containing a cassava leaf foliole bearing a known number of whitefly nymphs. The number of immature stages remaining after 24 hrs was counted.

From the destructive counts estimates of levels of mortality attributable to fungal attack, parasitoids and mites were obtained.

3.2. RESULTS

In this section the sampling and the experimental results are presented and commented upon. Most of the data concerns parasitism by *Encarsia transvena,* but the other natural enemies are also considered.

3.2.1. *Encarsia transvena.*

The number of pupæ parasitized by *E. transvena* were counted both in the field and in the destructive counts. The results of the field counts are presented in Table 3.1. As Least Significant Difference Tests showed there was no difference between plants from the different blocks, only the total mean number of pupae and the mean number of parasitised pupae per plant are given. These figures are the means of the 13 plants counted. The number of parasitised pupæ differs significantly with date - 13 out of 21 comparisons were significantly different at the 5 % level. The distribution of the parasitised pupæ was found not to be dependant upon the dominant wind direction.

The numbers of parasitised pupæ rose rapidly and thereafter dropped back to a low level. No field observations are available to establish how levels vary during the rest of the year. In Fig. 3.2. the mean numbers of parasitised pupae found in the field counts and the destructive counts are shown. This makes it clear that although the numbers in the destructive count were higher, overall the trends in the figures are the same.

As was shown by the data of van Helden and van Halder (1986), the whitefly populations increase rapidly from the planting of the crop in November until mid-February when they sharply decline to reach a low by mid-March. Although the data for this year are not yet available, observations showed that the same pattern of events occurred. Thus the rise and subsequent decline in numbers of the parasitoid largely mirror that of its host. During period of observation the overall level of parasitism remained relatively stable however. The number of parasitised pupæ as a proportion of the total number of immature stages (eggs included) was on average 3.2 % and ranged from 1.9 % to 5.6 %.

The mean figure 3.2 % can be compared with those of Robertson, (1985). His field observations, from the coastal region of Kenya, were made over a period of six months. He found 2.4 % of the total whitefly (*B. tabaci* and *B. hancocki*) population (all immature stages) on cassava, parasitised. The main parasites in this case were *Encarsia sublutea* (a synonym of *E. transvena*) and *Eretmocerus mundus. E. mundus* was not recognized until late in the season. The highest level of parasitism related closely to the peaks of the host population at four locations studied, (Robertson, 1985). Thus, our observations largely agree with his.

date	4/2	11/2	18/2	25/2	3/3	10/3	24/3
total	430	816	1113	1254	1026	706	193
par.pup/plnt	33.1	62.8	85.6	96.5	78.9	54.3	14.3

Table 3.1. Mean number of parasitised pupæ in the main field on different dates - *Nombre des pupes parasitées dans le grand champ à differentes dates.*

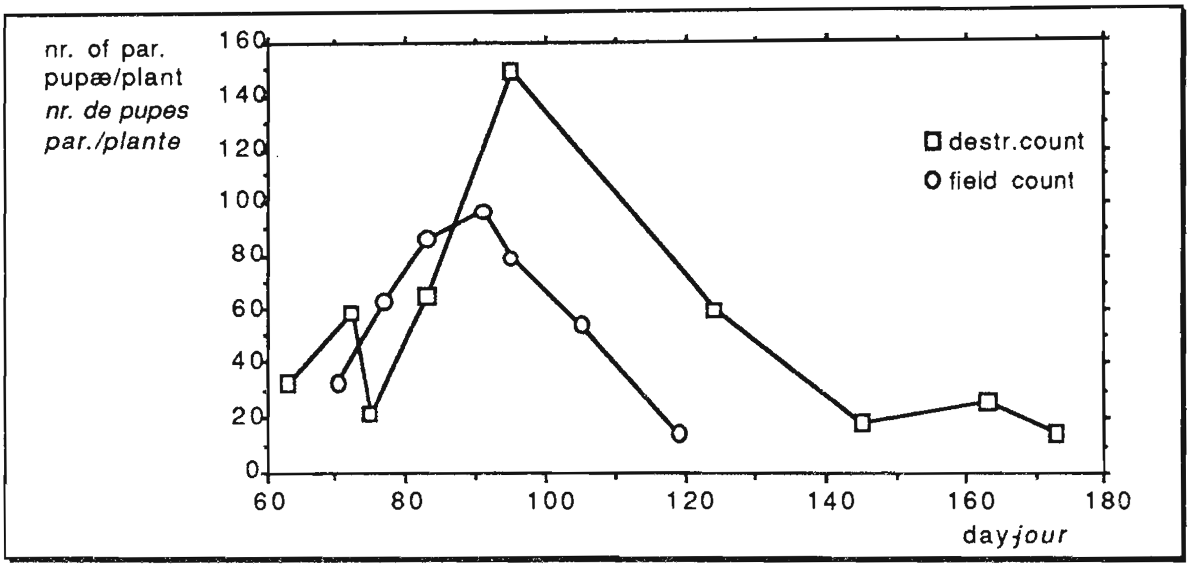


Figure 3.2. Mean numbers of pupæ parasitised by *E. transvena* per plant on different dates, from destructive counts and samples from the main field, day = days after planting - *Nombre de pupes parasitées par* E. transvena *par plante à date different, dans les comptages destructifs et dans le grand champ, jour = jour après planter.*

Because levels of mortality of whitefly eggs and early instars are high, a more realistic estimate of the effects of parasitism is given by the proportion of fourth instars and pupæ parasitised by *E. transvena*. It is also of interest to examine how this percentage changes with time. These results are shown in Fig. 3.3 and are calculated from the destructive count data.

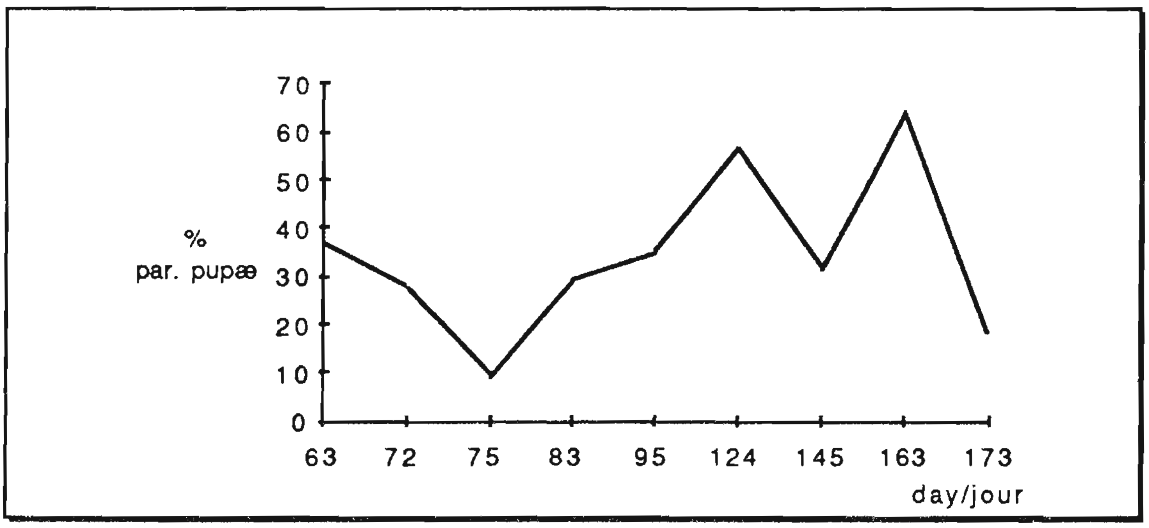


Figure 3.3. Variation in the percentage of parasitised whitefly pupæ expressed as proportions of total numbers of 4th instars and pupæ-*Fluctuation de pourcentage de pupes de mouches blanches parasitées calculé par la proportion de 4 -ème stade et pupes cumulés.*

As can be seen in Fig. 3.3. when expressed this way there is a fairly large variation in the proportions of parasitised pupæ. This variation is possibly explained by the fact that the figures are derived from observations from one plant only in each case. The average level of parasitisation for all the observations is 34.3 % but varies between 9.3 % and 64.3 %.

The number of *Encarsia* adults found on plants in both fields were far lower than the numbers of pupæ parasitised by *E. transvena*. In the main field numbers found varied from 1.8 per plant at beginning of the observation period to a maximum of 10.3 per plant on 10 March. On the last observation date, the mean figure was 0.9 per plant, (Fig. 3.4.).

Observations were also made in the small field. Here both the numbers of parasitised pupæ and of adults of *E. transvena* were very low. In Fig. 3.4. the data for the numbers of adult *E. transvena* in both the main field and the small plot are given. There is a conspicuous difference between the two fields. The most likely explanation of this is the different planting date and the related lower numbers of whiteflies in this plot.

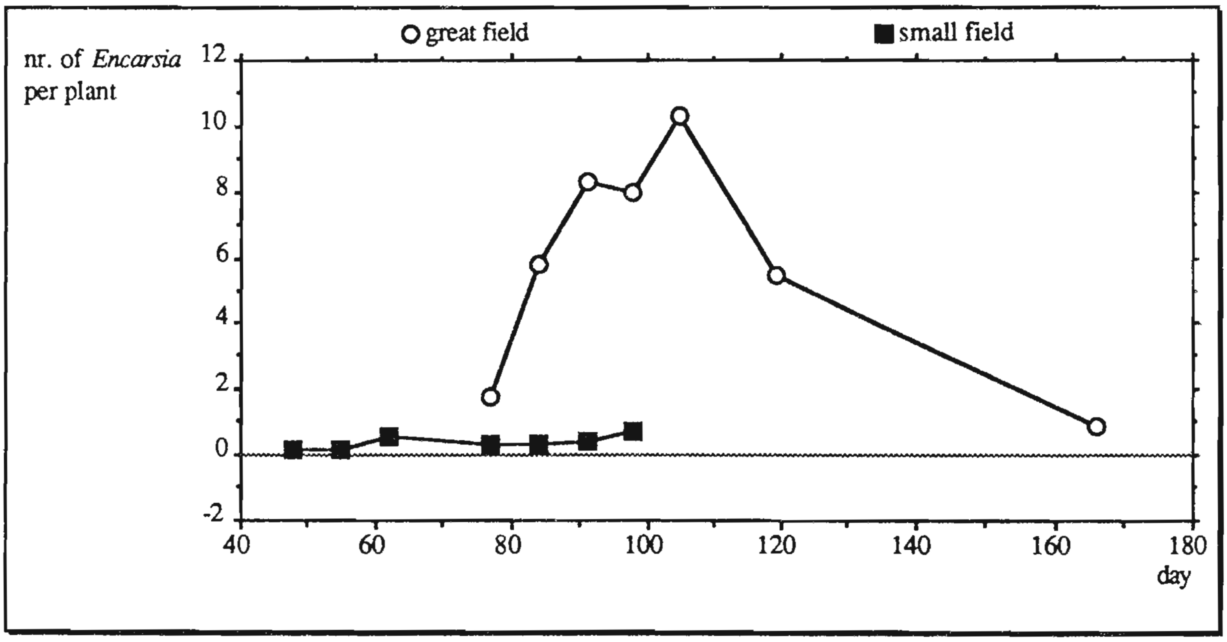


Figure 3.4. Number of *E. transvena* adults per plant in the main field and the small plot on different dates - *Nombre des adults d'*E. transvena *par plantes dans le grand et le petit champ observé à dates differentes*.

3.2.2. Coccinellids

The coccinellids were first monitored on 2 March. From that date the coccinellid larvæ were included in the field counts. At the same time, predation experiments in the laboratory were started. It very soon became clear that the larvæ were not predators of whitefly nymphs. No predation at all was recorded in the first experiment. Thereafter no further experiments with coccinellid larvæ were performed.

Instead the behaviour of the adults was investigated. When it was discovered that the adults did feed on whitefly nymphs, (see below), the numbers of them found in the field were included in the field samples. The data from both the main field and the small plot are given in Fig. 3.5. Instead of giving the date, the number of days after the crop was planted is given. In this way it is possible to include the data from the two fields in the same Figure. The first 5 data points are from the small plot, while the other 4 are from the main field. A curve can be fitted through these points, with a very high correlation coefficient, (R=0.97).

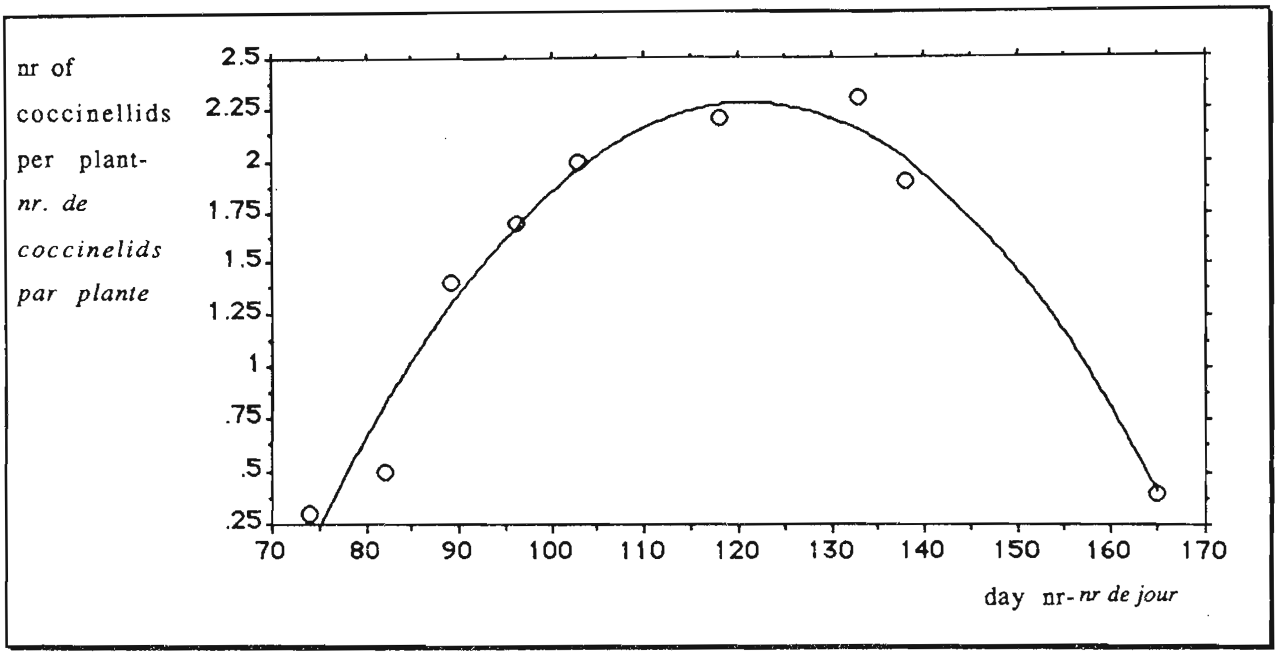


Figure 3.5. Number of adult coccinellids per plant related to the number of days after planting.-*Nombre de coccinellids par plant en relation avec le nombre de jours après plantation.* R= 0.97

Fig. 3.5. indicates there is a rapid build up of the adult coccinellids population. The population peak occurs four months after planting. This largely coincides with the peak in the whitefly population. Unfortunately it was not possible to continue observations in the small plot, as it would have been of interest to see whether a similar curve would have been obtained.

The five predation experiments with adult coccinellids showed that they consumed on average approximately 4.5 whitefly eggs and nymphs per adult per day. Table 3.3. shows the differences between the five experiments. The Table also gives the Student's t values for the differences of the seven values in one experiment from the mean of that experiment. The first experiment in particular has a high t-value. Table 3.2. shows the numbers of immature stages eaten per petri-dish. These figures show there is a large range in number of larvæ eaten: 2 - 16 in experiment 1, 0 - 6 in exp. 2, 0 - 9 in exp. 3, 0 - 10 in exp. 4 and 0 - 7 in exp. 5. When tested with a Student's t-test all five experiments show a predation level significantly different from 0 (with a confidence level of 95 %). Also the overall mean is significantly different from 0. As might be expected, the t value is rather high.

petri-dish	1	2	3	4	5	6	7
number of exp.							
1	2	11	12	2	10	16	9
2	6	0	2	2	1	5	-
3	6	0	9	7	2	0	3
4	2	10	7	10	3	0	0
5	6	1	4	0	2	3	7

Tabel 3.2. Number of whitefly nymphs eaten by adult coccinellids per petri-dish in five experiments (- = no observation) - *Nombre de nymphs de mouche blanche mangé par coccinellids par boîte de petri dans cinq experiences (- = pas d' observation).*

exp. nr	sample mean	t-value	prob.
1	8.9	4.5	0.004
2	2.7	2.8	0.038
3	3.9	2.9	0.028
4	4.6	2.8	0.033
5	3.3	3.4	0.015
total	4.6	6.5	0.0001

Tabel 3.3.Predation by coccinellids; average nr. of immature stages eaten, t-tests and probability at 95% confidence level - *predation par coccinellids; moyenne, t-test et probabilité à 95 % niveau de confidance (sample mean=moyenne).*

The adult coccinellids showed no preference for eggs or particular instars. If the average daily consumption per adult is multiplied by the average maximum number of adult coccinellids found per plant, (2.3), a predation level of 10.4 whitefly eggs and nymphs per day is obtained. The total number of immature stages recorded per plant at the population peak was approximately 4,500. This is comparable to the numbers found by van Helden and van Halder (1986), on the same site two years previously; 5,000 immature stages per plant (Fig. 2.1.). Using the average of these figures, the coccinellids would eat 0.2 % of the population per day.

It should be pointed out that in the predation experiments the coccinellids were only given whitefly nymphs and no alternative prey. Under natural conditions the coccinellids may prefer other insects.

3.2.3 Mites

This section deals only with the mite predation experiments. In section 3.2.4. predation by mites found in the destructive counts is considered, in relation to other causes of mortality.

Unfortunately the mite predation experiments were started late. Thus only one species of mites could be investigated, although several others were suspected of being predaceous. In general predaceous mites were more active than phytophagous species. The predation experiments were performed in the same way as those with the coccinellids. The results of the experiments were variable. The first and the fourth experiment affirmed predation by this species. The second and the third experiment showed little predation, (Table 3.4.).

petri-dish	1	2	3	4	5	6	7
number of exp.							
1	7	15	7	7	10	5	4
2	2	1	3	3	0	3	1
3	1	1	0	0	3	8	0
4	2	3	9	2	2	1	10

Table 3.4. Numbers of whitefly nymphs eaten by mites per petri-dish in four experiments - *Nombre de nymphs de mouche blanche mangé par acarides par boîte de petri dans les quatre experiences.*

exp. nr	sample mean	t-value	prob.
1	7.9	5.7	0.0007
2	1.9	4.0	0.0034
3	1.9	1.7	0.0712
4	4.1	3.0	0.0128
total	3.9	5.4	0.0001

Table 3.5. Predation by mites; average nr. of immature stages eaten, t-tests. and probability at 95% confidence level - *predation par coccinellids; moyenne, t-test et probabilité à 95 % niveau de confidance (sample mean=moyenne).*

Table 3.5. shows the mean number of immature stages eaten by mites per experiment and the overall average. In the same Table, Student's t values and their probabilites are shown. These show the probabilities of the experimental means happening by chance, assuming no predation, with 95 % confidence limits.

From these data it is not possible to estimate the predation levels by mites per plant. This is because the predation experiments often necessitated the use of a variable number of cassava leaf folioles due to the low numbers of whitefly nymphs on the leaves at this time.

3.2.4 Other causes of mortality

The numbers of dead whitefly nymphs found during the destructive counts were recorded and where known, the cause of mortality noted. This was done for all the destructive counts, and so it is possible to follow the change with time of the different causes of mortality. Three causes of death were easy to distinguish: parasitism (by *E. transvena*), infestation by fungi and predation by mites. For others the cause of death could not be inferred with certainty. The trends in the causes of mortality are shown in Fig. 3.6.

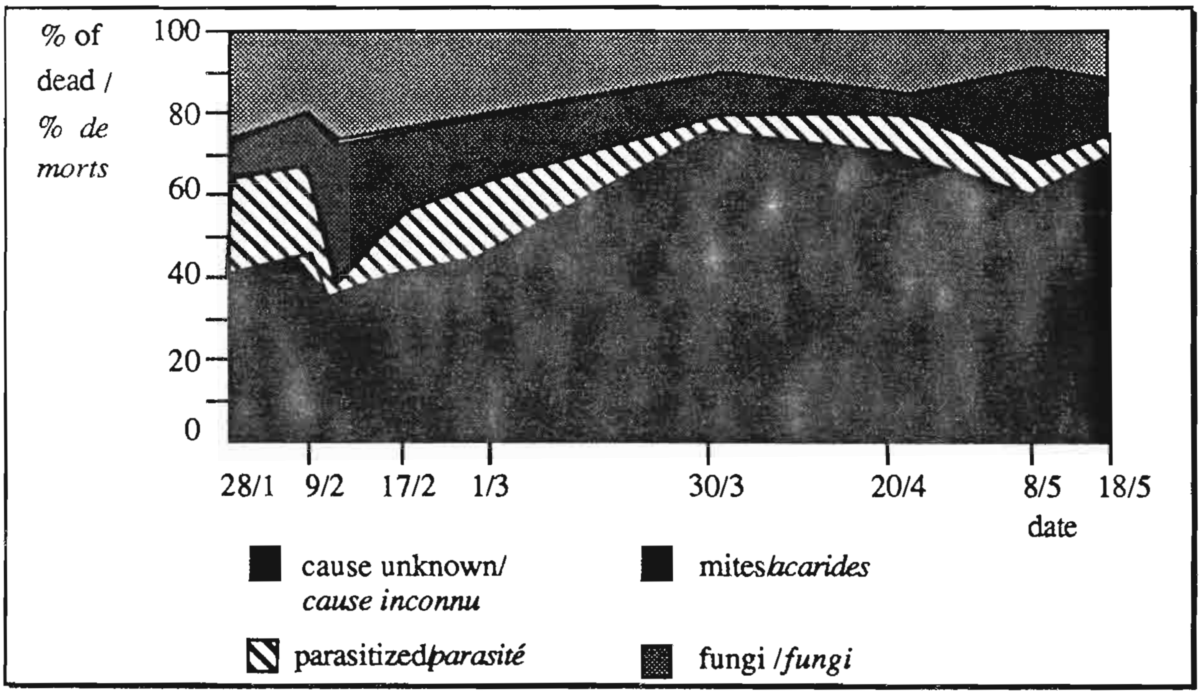


Figure 3.6. Changes with time of the causes of mortality of whitefly nymphs; data from the destructive counts- *Fluctuation dans les causes de mortalité, trouvé dans les comptages destructifs.*

In Appendix A Figures showing the changes with time of the individual causes of death are presented. The corresponding data are shown in Table 3.6. The following trends may be seen: firstly the percentage of death by unknown causes increases. During the first month of observation it was approximately 40 % of the total, later increasing to 65 %. The percentage number of parasitised pupae changes considerably. This has already been shown in section 3.2.1. The overall pattern shows there to be a steady decline from 18% to 7%.

date *date*	unknown *inconnu*	par. *par.*	mites *acarides*	fungi *fungi*
9/2	38.5	17.7	19.6	24.2
17/2	38.1	15.5	23.6	22.8
1/3	39.2	12.0	26.0	22.7
30/3	52.0	11.8	17.9	18.3
20/4	61.6	9.8	11.8	17.8
8/5	66.0	7.5	13.1	13.4
18/5	65.1	7.8	13.6	13.4

Table 3.6. Moving averages of the percentages of the different causes of mortality in the destructive counts - *moyenne flottante de pourcentages de cause de mortalité different dans les comptages destructifs.*

Mite predation reaches a peak which coincides with the peak in whitefly numbers. At the maximum mites were responsible for some 25 % of all whitefly mortality seen. Thereafter it drops back to a low of about 13%. This decrease is possibly attributable to deteriorating weather conditions, the decline coinciding with the start of the rains. A marked decrease in the numbers of all species of mite was observed at this time.

The numbers of fungus - attacked nymphs show a steady decline with time from 24% to 14%. This decline is broadly comparable to that of their host.

In order to obtain an idea of the significance of these figures and trends they need to be considered in relation to the contemporary numbers of living nymphs. The numbers of dead nymphs as percentages of the totals have been calculated (from the destructive count data) and are shown in Fig. 3.7.

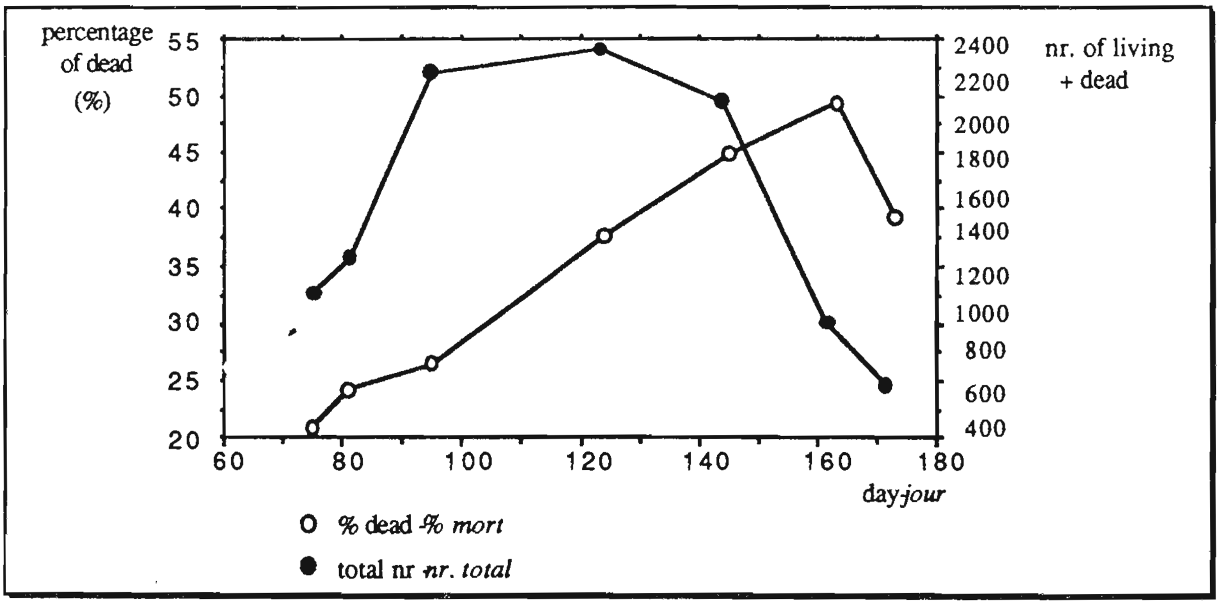


Figure 3.7. Dead immature stages as percentages of the total number of (living and dead) nymphs and pupae, from the destructive count data, and total numbers of immature stages - *stades immatures morts comme pourcentage de nombre total (vivant et mort) de stade immature, trouvé dans les comptages destructifs et nombre total de stade immature (vivant et mort).*

It can be seen in Fig. 3.7. that the percentage of dead immatures increases steadily, to a maximum of 50 %. At the time of peak numbers of immature stages the percentage number of dead is increasing. Appendix A shows that predation by mites, parasitism by *E. transvena* and attack by fungi are important causes of death in the period from the 75th day after planting to about day 110. Thereafter the proportion killed by unknown causes increases rapidly. During the same period the total number of immature stages also decreases to 25 % of the maximum.

It should noted that the numbers of immature stages do not include eggs. Only viable eggs were counted during the destructive counts as it was not possible to distinguish hatched eggs from dead ones.

4. CONCLUSION AND RECOMMENDATIONS

In this last chapter the previous chapters are reviewed. The results of the field work and the experiments are compared with the literature discussed in Chapter 2. In addition comment is made on the methods used in this study.

4.1. CONCLUSION

The results of this study make clear that in the coastal region of Ivory Coast *Encarsia transvena* is an important natural enemy of *B. tabaci*. The average number of pupæ parasitised by this species, found in the field during the observation period were low when compared to the total numbers of immature whiteflies. These numbers may reach 4500 per plant (Fig. 2.1.). However when the percentage of fourth instars and pupæ parasitised by *E. transvena* is calculated, the importance of this natural enemy is evident. The lowest level of parasitism recorded was 9 % on 9 February (Fig. 3.3.). On all other occasions the level was over 25 %. The overall average was 34.3 %. At the end of the observation period the level was decreasing rapidly.

In the literature most attention is given to members of the Aphelinidae as natural enemies of whitefly. Of this family the genera *Encarsia* and *Eretmocerus* are particularly important. The levels of parasitism described in the literature range from 25 % to 50 %. A very high level of parasitism of *B. tabaci* by *Eretmocerus mundus* was found by Hafez *et al* (1983): 83 %. However this was under laboratory conditions, and which may not be comparable therefore to events in the field.

The other natural enemies (coccinellids and mites) studied during this research were of little importance in controlling the whitefly population. The coccinellid species studied is probably polyphagous. Under field conditions predation of whitefly nymphs and pupæ by this species may thus be lower than found in the experiments, where the coccinellids were not given a choice of prey. The predation rate per adult was on average 4.5 immature stages per day. As calculated in section 3.2.2 this represents the consumption of 0.2 % of the contemporary field population per day.

Using the data from our studies it difficult to assess the role and importance of the different mite species as predators of whiteflies. In the predation experiments the average consumption per mite was 3.9 immature stages per day. Since no data on the number of mites in the field are available, it is not possible to estimate predation levels. Data from the destructive count indicate that mites cause between 10 % and 25 % of the total mortality (section 3.2.3. and Appendix A). From personal observation it was clear that the presence of high numbers of mites on a plant was definately correlated with low numbers of whiteflies.

4.2. RECOMMENDATIONS

As this study has made it clear that *Encarsia transvena* is the most important natural enemy of *Bemisia tabaci* on cassava in southern Ivory Coast, it is recommended that future research should concentrate on this parasite. More quantitative data are needed to understand its role fully. In addition to a better knowledge of its lifecycle, its population dynamics should be investigated more thoroughly. This requires more observations over an extended time period.

Another object of further research should be the influence of mites on the population dynamics of whiteflies. This study indicated that there is a relationship between the weather, the numbers of mites and the population of whiteflies. The exact nature of these interactions need to be fully investigated.

LITERATURE

AVIDOV, Z., 1956: Bionomics of the Tobacco White Fly (*Bemisia tabaci* Gennad.) in Israel. *Agric. Res. Station, Rehovot. 1956 Series, No. 153-E:* 25-41.

COCK, M.J.W. (ed.), 1986: *Bemisia tabaci* - a Literature Survey on the cotton whitefly with an annotated bibliography. *CAB Int. Inst. of Biol. Ctrl.* : 121pp.

DEBACH, P. and R.A. SUNDBY, 1963: Competitive Displacement between Ecological Homologues; *Hilgardia* **34** :105-166.

FAUQUET, C. and FARGETTE, D.,1987: Summary of the epidemiology of the African Cassava Mosaic Virus; in FAUQUET, C. & FARGETTE, D. (eds.) *A summary of the epidemiology of the African Cassava Mosaic Virus, ORSTOM, Abidjan, Côte d'Ivoire*: 1-4.

FERRIERE, C., 1965: Hymenoptera Aphelinidae d'Europe et du Bassin Méditerranéen. *Faune de l'Europe et du Bassin Méditerranéen* **1** : 4-33.

FOLTYN, S. and D. GERLING, 1985: The Parasitoids of the Aleyrodid *Bemisia tabaci* in Israel: development, host preference and discrimination of the aphelinid wasp *Eretmocerus mundus*. *Entomol. exp. appl.* **38** : 255-260.

GAMEEL, O.I.,1969: Studies on Whitefly Parasites *Encarsia lutea* Masi and *Eretmocerus .mundus* Mercet. Hym. Aphelinidae. *Rev. Zool. Bot. Afr.* **79** : 65-77.

GERLING, D.,1986: Natural Enemies of *Bemisia tabaci* , Biological Characteristics and Potential as Biological Control Agents: a Review. *Agriculture, Ecosystems and Environment*, **17**: 99-110.

GODO, G., 1987: Synthese Generale des Rapports des Representants Nationaux. *Resumés, la Mosaique Africaine du Manoic et son Controle; Séminaire International Yamoussoukro 4-8 Mai* : 3.

GREATHEAD, A.H., 1986: Host Plants in COCK, M.J.W. (ed.): *Bemisia tabaci* - a Literature Survey on the cotton whitefly with an annotated bibliography. *CAB Int. Inst. of Biol. Ctrl.* : 17-25.

HAFEZ, M., TAWFIK, M. F. S., AWADALLAH, K.T. and SARHAN, A.A., 1983: Studies on *Eretmocerus mundus* Mercet, a parasite of the cotton whitefly, *Bemisia tabaci* (Genn.) in Egypt (*Hymenoptera: Aphelinidae*). *Bulletin de la Société Entomologique d'Egypt* **62**: 15-22.

HELDEN, M van, and HALDER, I. van, 1986: Memoire de six mois de stage: Mouvements et comportement de *Bemisia tabaci* (Gennadius) vecteur de la Mosaïque Africaine du Manioc; *Unpublished report Phytovirology ORSTOM Abidjan, Côte d'Ivoire*: 88.

LINGEN, T.G. van, and LIMBERG, G.A., 1988: Some Observations on *Bemisia hancocki* (Corbett): *Unpublished report Phytovirologie ORSTOM Abidjan, Côte d'Ivoire*, (in prep.): 1-51.

LOPEZ-AVILA, A., 1986. Natural Enemies. in COCK, M.J.W. (ed.): *Bemisia tabaci* - a Literature Survey on the cotton whitefly with an annotated bibliography. *CAB Int. Inst. of Biol. Ctrl.* : 27-35.

MEYERDIRK, D.E. and D.L. COUDRIET, 1986: Evaluation of Two Biotypes of *Euseius scutalis* (Acari: Phytoseiidae) as Predators of *Bemisia tabaci* (Homoptera: Aleyrodidae). *Journal of Econ. Entom.* **79**: 659-663.

MUMA, M.H., 1961: Subfamilies, Genera, and Species of Phytoseiidae (Acari: Mesostigmata). *Bull. Florida State Museum* **5**: 267-301.

PRITCHARD, A.E. and E.W. BAKER, 1962: Mites of the Family Phytoseiidae from Central Africa, with Remarks on the Genera of the World. *Hilgardia* **33**: 205-236.

ROBERTSON, I.A.D., 1985: Cassava/ Whitefly project (Part of Crop Virology Project R3177 at the Kenyan Agricultural Research Institute) Final Report. *Unpublished report O.D.A. London*, 77pp.

SHARAF, N.S., 1982: Parasitisation of the Tobacco Whitefly *Bemisia tabaci* Genn., (Hom., Aleyrodidae) on *Lantana camara* L. in the Jordan Valley. *Z. ang. Ent.* **94:** 263-271.

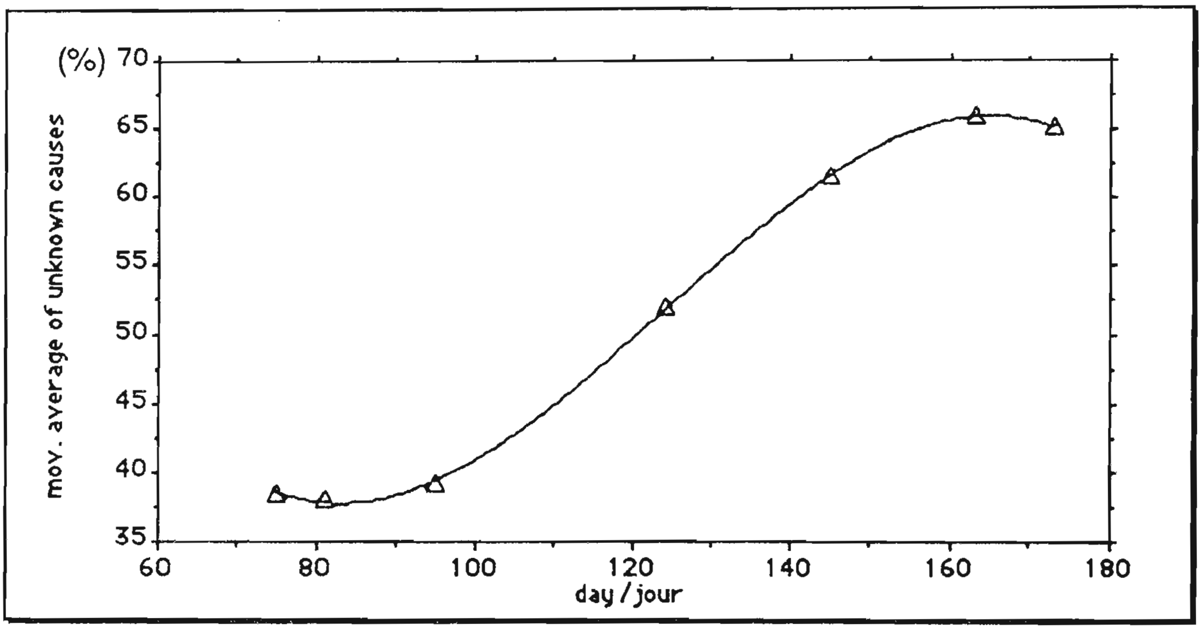
VIGGIANI, G., 1984: Bionomics of the Aphelinidae. *Ann. Rev. Entomol.* **29**: 257-276.

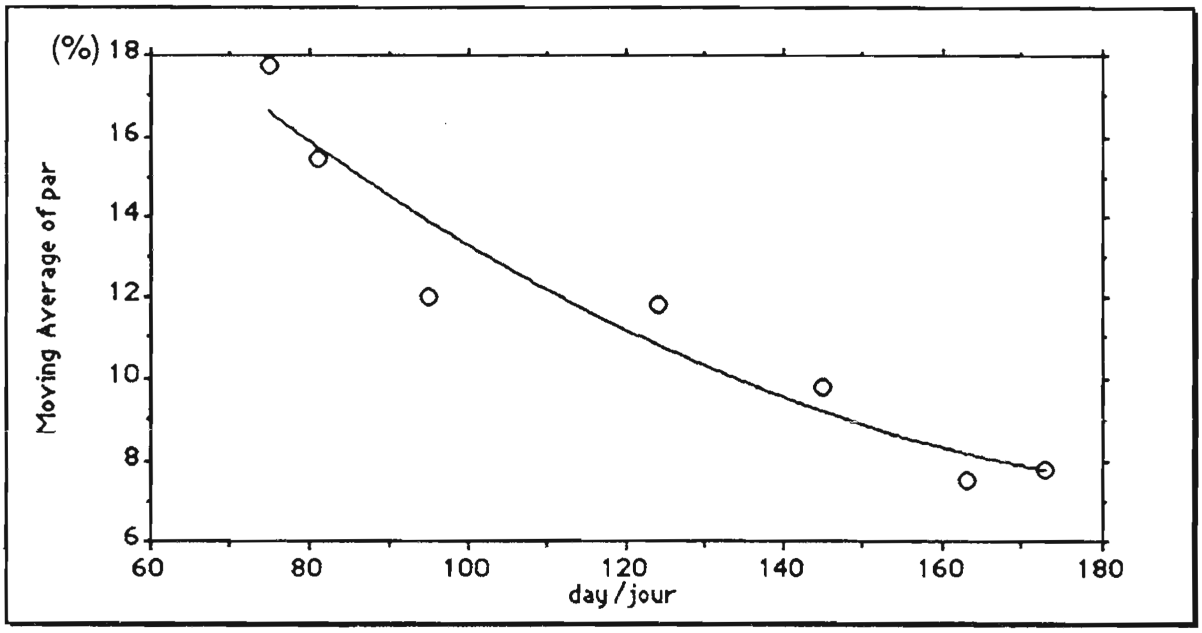
YANINEK, J.S., 1984: Recognizing and Identifying Phytophagous and Predaceous Mites found on Cassava. *Proc. of a Regional Training Workshop in East Africa 30 April- 4 May* : 25-30.

LIST OF TABLES

LIST OF FIGURES

APPENDIX A

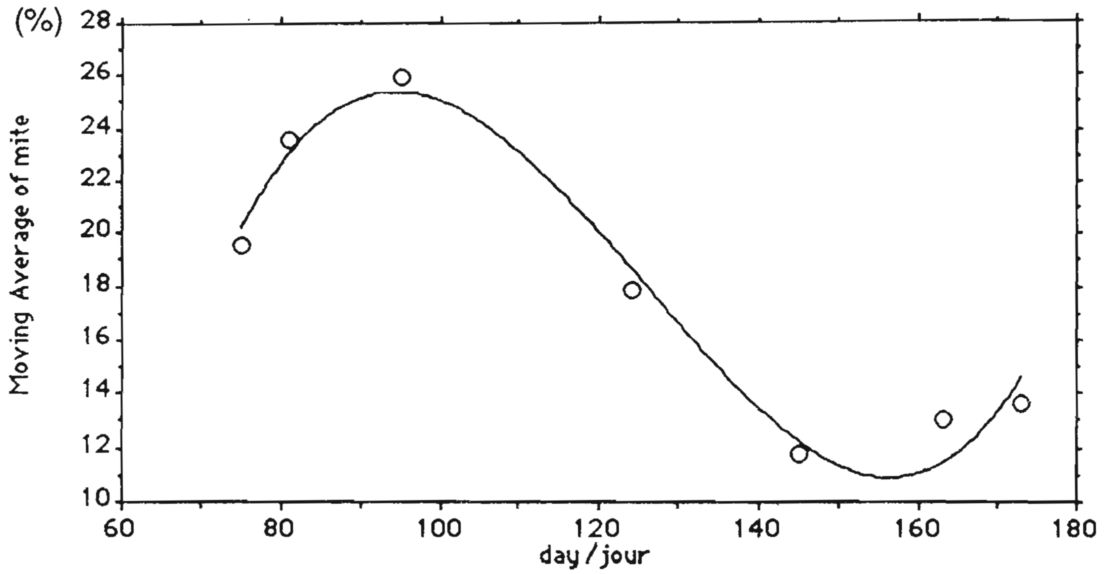


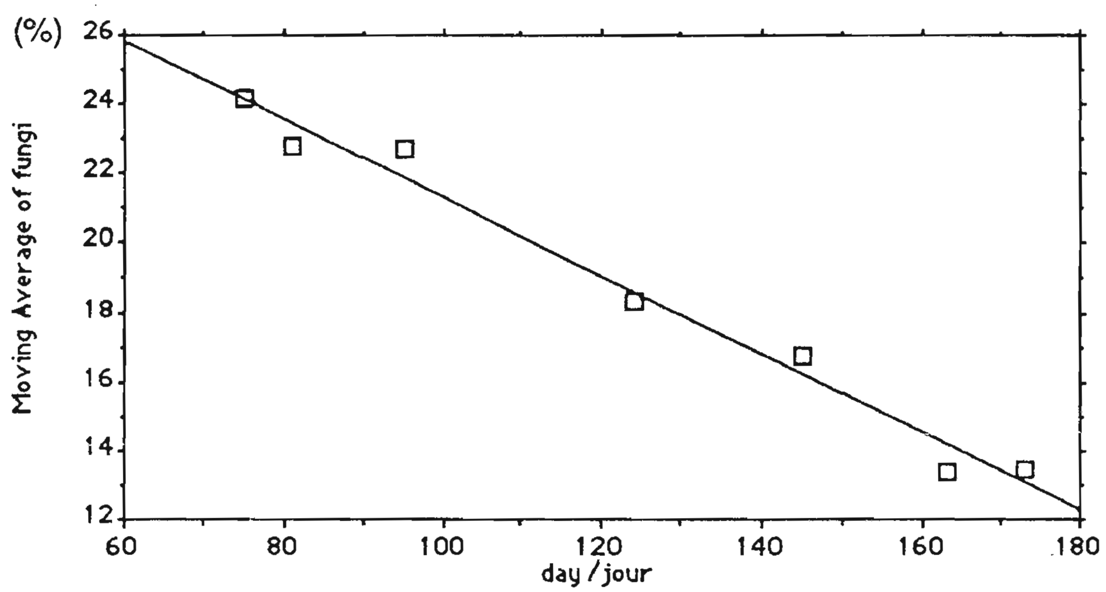


Fitted curves of percentages of mortality causes found in the destructive counts -

Curves adaptés de pourcentages de causes de mortalité, trouvé dans les comptages destructifs.

APPENDIX A





Fitted curves of percentages of mortality causes found in the destructive counts -

Curves adaptés de pourcentages de causes de mortalité, trouvé dans les comptages destructifs.