STUDIES ON POPULATION DYNAMICS OF THE SCARLET MITE, *BREVIPALPUS PHOENICIS*, A PEST OF TEA IN INDONESIA

P. A. OOMEN

633.72:632.654:632.9(910)

P. A. OOMEN

STUDIES ON POPULATION DYNAMICS OF THE SCARLET MITE, *BREVIPALPUS PHOENICIS*, A PEST OF TEA IN INDONESIA

Proefschrift
ter verkrijging van de graad
van doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C. C. Oosterlee,
hoogleraar in de veeteeltwetenschap,
in het openbaar te verdedigen
op vrijdag 28 mei 1982
des middags te vier uur in de aula
van de Landbouwhogeschool te Wageningen.

H. VEENMAN & ZONEN B.V. – WAGENINGEN – 1982

PIETER A. OOMEN

Department of Entomology
Agricultural University
P. O. Box 8031
6700 EH Wageningen
The Netherlands

Research Institute for Tea and Cinchona, Gambung
P.O. Box 148
Bandung
Indonesia

Cover: A scarlet mite (♀) of tea, *Brevipalpus phoenicis* GEIJSKES, drawn by Françoise Oomen-Kalsbeek. Design: W. C. T. Middelplaats.

This thesis is also published as Mededelingen Landbouwhogeschool Wageningen 82-1 (1982)
(Communications Agricultural University Wageningen, The Netherlands)

STELLINGEN

1.

Aanplant van meer resistente klonen uit het beschikbare sortiment kan plagen van oranje mijt in thee voorkomen.

Dit proefschrift.

2.

Een biologische bestrijding van plagen is beter mogelijk in eenvoudige dan in complexe ecosystemen.

B. SECHSER, 1970. Zeitschrift für angewandte Entomologie, **66**, 145–160.
Dit proefschrift.

3.

De 'World Conservation Strategy' besteedt ten onrechte zeer weinig aandacht aan de noodzaak om de bevolkingsgroei in de wereld af te remmen.

I.U.C.N., World Conservation Strategy.
Gland, I.U.C.N., 1980. 4 losse delen in map.

4.

De traditionele teeltmethoden in ontwikkelingslanden verdienen meer landbouwkundig onderzoek.

J. HANLON, 1982. New Scientist, **93** (1292), 393.

5.

Termen van latijnse of griekse oorsprong moeten niet gemengd gebruikt worden voor begrippen of begrippenparen met een verwante betekenis op straffe van een babylonische spraakverwarring.

Voorbeelden: insect – entomologie,
alaat – apteer,
gynopara, andropara.

6.

Onvoorspelbaarheid van verkeerssituaties is nuttig als oefening in oplettendheid van de verkeersdeelnemers.

7.

Ontwikkelingswerkers staan onder druk ('culture shock') om zich aan te passen aan en te verdiepen in de gewoonten en cultuur van het ontwikkelingsland. Repatriëring daarna leidt dikwijls tot een 'reverse culture shock'.

8.

Het vragen naar het sociale milieu van sollicitanten door de Rijks Psychologische Dienst bij psychologische testen bergt het risico in zich van bevooroordeelde aanstellingsadviezen aan de eventuele werkgever.

Standaard vragenformulier RPD.

9.

De merkwaardige schrijfwijze van 'oecologie' naast 'economie' suggereert dat oecologen vrezen als 'ecologen' met economen geassocieerd te worden op dezelfde wijze waarop astrologen geassocieerd worden met astronomen.

10.

De hedendaagse tendens om informatie weer te geven in pictogrammen en vignetten is een terugkeer naar het analfabetisme.

Proefschrift van P. A. OOMEN
Studies on population dynamics of the scarlet mite, *Brevipalpus phoenicis*, a pest of tea in Indonesia.

Wageningen, 28 mei 1982

CONTENTS

KEY WORDS

Acarina, Tenuipalpidae, Phytoseiidae, Stigmaeidae, bionomics, abundance, numerical fluctuations, cultural measures, plant resistance, biological control, natural enemies, predation, exclusion pesticides, DDT, maneb, copper fungicides.

ABBREVIATIONS

A.	*Amblyseius* or *Agistemus*
B.	*Brevipalpus*
DDT	dichlorodiphenyltrichloroethane
df	number of degrees of freedom
EC	emulsifiable concentrate
L.	*Lasioseius* or *Lestodiplosis*
LAI	Leaf area index
ln	natural logarithm (with base e)
log	logarithm (with base 10)
NS	non-significant
P.	*Phytoseius*
PH 60–42	insecticide manufactured by Duphar B.V., the Netherlands
RITC	Research Institute for Tea and Cinchona, Indonesia.
SD	standard deviation
SE	standard error
sp.	species
T.	*Typhlodromus*
W.	*Wollastoniella*
WOTRO	Stichting voor Wetenschappelijk Onderzoek van de Tropen
WP	wettable powder
Z.	*Zetzellia*

SYMBOLS

*	statistically significant ($P \leqslant 0.05$)
**	statistically very significant ($P \leqslant 0.01$)
∅	diameter
I	index of population trend
n	number of observations
P	probability level
r	correlation coefficient (PEARSON)
r	mean vector
r	instantaneous rate of increase
®	registered trade mark
r_m	intrinsic rate of increase
R_o	rate of multiplication in one generation
T	mean generation time

1. INTRODUCTION

Brevipalpus phoenicis is distributed widely over the world, primarily throughout the tropics (HARAMOTO, 1969). A more intensive search for this mite would probably establish that it is present in most tropical countries. The mite is also common outside the tropics. It has been found as far north as the Netherlands (where it was described from the *Phoenix* palm in a glasshouse by GEIJSKES, 1939) and as far south as Argentina (HARAMOTO, 1969).

Brevipalpus phoenicis has several common names in English: red-and-black-flat mite in Hawaii (HARAMOTO, 1969), scarlet mite in India and Sri Lanka (DAS, 1961; BANERJEE, 1969, 1971; BAPTIST and RANAWEERA, 1955; CRANHAM, 1966; DANTHANARAYANA and RANAWEERA, 1970, 1974), red-crevice mite in East Africa (PREBBLE, 1972; LAYCOCK and TEMPLER, 1973; BANERJEE, 1976). To designate *B. phoenicis* the common name 'scarlet mite' will be used throughout this publication.

Scarlet mites are common on many crops in tropical and subtropical countries. PRITCHARD and BAKER (1958) list 63 host plant genera; NAGESHA CHANDRA and CHANNABASAVANNA (1974) found 35 genera as host plants of scarlet mites in India. Important crops on which scarlet mites occur as a pest include papaya and passion fruit (HARAMOTO, 1969), citrus (JEPPSON, 1978), tea and coffee (BANERJEE, 1976).

On citrus, apart from causing feeding damage, scarlet mites transmit the virus disease 'citrus leprosis' (CARTER, 1973; KITAJIMA et al., 1972) and can cause '*Brevipalpus* gall' and 'halo scab' with '*phoenicis* blotch' – a combination of fungus and mite attack (KNORR and DENMARK, 1970; CARTER, 1973). On coffee it transmits ringspot virus disease (CHAGAS, 1973).

In most tea producing countries, scarlet mites constitute a serious pest problem in this crop (e.g. Sri Lanka: KING, 1936; BAPTIST and RANAWEERA, 1955; CRANHAM, 1966; DANTHANARAYANA and RANAWEERA, 1970; India: DAS 1961; BANERJEE, 1965; 1971; RAO, 1974a; Bangladesh: ALI and HAQ, 1973; Kenya: PREBBLE, 1972; Malawi: FINDLAY, 1971; Mauritius: RAMLOGUN, 1971).

Tea is a national drink in Indonesia. Intestinary infections, common in tropical countries as a consequence of infected water, are prevented by habitual tea drinking. The production provides many rural communities with a modest living. The production however, is affected by pests of which I found the scarlet mite to be one of the most important. Tea bushes without scarlet mites are difficult to find. In random leaf samples from tea estates all over West Java (the main tea growing area of Indonesia) and some of Central Java, I found scarlet mites on 57% of the leaves, while in North Sumatra the same percentage of leaves was infested. Only in exceptional cases did the samples not contain scarlet mites. A survey of 21 tea estates on Java and Sumatra revealed that 16 managers sprayed routinely between one and sixteen times annually against scarlet

mites. According to unpublished statistics for 1976, of a large organization of tea estates, Perseroan Terbatas Perkebunan 12, 14% of this whole tea area of 12,000 ha was treated three times, predominantly against scarlet mites, even though it was no exceptional mite year.

The scarlet mite was early recognised as an important pest of tea in Java (KONINGSBERGER, 1903; BERNARD, 1909). Since then, it has frequently been studied. The morphology, life history, host plants, distribution on the host plant and symptoms of attack were well studied. Methods of chemical control are standard in the later publications (BERNARD, 1909; HOMBURG, 1955; LIEFSTINGH-HARDICK, 1955; RAZOUX SCHULTZ, 1961; NARA et al., 1972; WARDOJO et al., 1974). However, little is known of the background information necessary for a rational control, such as on the ecology and the abundance of the scarlet mite, the relation between this and crop loss (economic injury level), and the possibilities of biological and cultural control. The climatological conditions, cultural methods and plant material in Indonesia are different to those in other tea producing countries, so papers from these countries contain little information relevant to Indonesia, other than the biology of the scarlet mites and the sensitivity to acaricides.

The increased use of pesticides in the Indonesian tea industry, the size of the pest problems in tea and the expectation that the pests could be controlled by natural and cultural means, made a need apparent for a change to integrated control of tea pests. These arguments seemed especially applicable to the scarlet mites. This made the scarlet mites and the population dynamics a suitable subject for study as a foundation for integrated control, as it was felt that the mite problems are in some way related to the extensive use of pesticides, especially the copper fungicides. These considerations led to a study on the scarlet mites, carried out at the Research Institute for Tea and Cinchona (RITC, Gambung, West Java) from 1975 to 1980. Practical aspects such as the recognition of mites and the signs of attack, the economic injury level, and the efficiency of acaricides, were studied from 1975 to 1977 and will be published elsewhere. Fundamental aspects of the population dynamics of the scarlet mites were studied by descriptive and experimental approaches especially during the second period of the study. The results are published in this paper.

In the laboratory, the development and reproduction of scarlet mites were studied under favourable conditions within the range of local conditions (chapter 4.1.). Observations on the migration of scarlet mites are included in the same chapter. In the field, the abundance of scarlet mites was studied as influenced by: the host plant, time after pruning, weather, and pesticide application notably copper fungicides (chapter 4.2.).

Particular attention was given to the predators of scarlet mites. Predators of mites on leaves were collected and identified in detail on one RITC tea estate at Gambung in West Java, and more generally on tea estates elsewhere in Java and Sumatra (chapter 4.3.). The predatory behaviour, development and repro-

ductive potential of the most common predators reared on a diet of scarlet mites were studied in the laboratory (chapter 4.4.).

The role of predators in natural scarlet mite control and regulation was investigated by manipulation of the predators in the field. Predators were excluded as far as possible from plots by the pesticidal check method (DEBACH et al., 1976), one of the methods for quantitative assessment of the effectiveness of natural enemies reviewed by KIRITANI and DEMPSTER (1973). This method employs selective toxic chemicals in one series of plots to kill a large proportion of the natural enemies while, ideally, having little or no adverse effect on the pest population (DEBACH and HUFFAKER, 1971). In the laboratory, potential pesticides for this experiment were tested as to the way they affected the mortality, fecundity etc. of the pest. Three pesticides were used in different plots, with the intention of killing respectively all predators, the predatory mites, and the predatory insects. The experiment was continued for about 16 months during which the numerical fluctuations of both scarlet mites and predators were followed, together with the species composition of the predatory fauna. The importance of the predators for the control of scarlet mites was assessed by studying the correlation between the densities of the prey and different predator species after the populations were considered to have adapted to the experimental treatments (chapter 4.5.).

The significance of the factors studied, and the prospects for their manipulation, are discussed in chapter 5.

2. THE OBJECT AND CONDITIONS OF STUDY

2.1. TAXONOMIC STATUS OF *BREVIPALPUS PHOENICIS*

Brevipalpus mites belong to the family Tenuipalpidae, the superfamily Tetranychoidea, the order Prostigmata, the subclass Acari and the class of Arachnida. The genus *Brevipalpus* DONNADIEU 1875 is separated into two major groups according to the number of marginal hysterosomal setae (GONZALEZ, 1975). The larger group has 6 pairs of these setae and contains 46 species including *B. australis* (syn: *B. californicus*) (PRITCHARD and BAKER, 1958). The other group has 5 pairs of these setae and contains 9 species including *B. phoenicis* and *B. obovatus* (syn: *B. inornatus*). The division of this group is further based on the number of sensory rods (solenidia) on the distal part of tarsus II. Up till 1975 only *B. phoenicis* possessed a full combination of key characters (5 pairs of marginal hysterosomal setae and 2 solenidia), but in that year GONZALEZ described another 4 species sharing these characters, among them *B. tarus*. Especially the reticulation of the dorsomedian propodosomal area and the length of the propodosomal setae distinguish *B. phoenicis* from the new species.

The majority of the adults collected from the tea crop in Java has both key characters. One specimen out of about 50 from 5 tea estates in West Java was identified by Dr. G. L. van Eyndhoven as *B. obovatus*; all others as *B. phoenicis*. Mr. C. F. van de Bund identified more than 100 specimens as *B. phoenicis* and one specimen as *B. tarus* according to the new revisions of GONZALEZ (1975) and MEYER (1979). These mites originated from 7 tea estates in West Java and 3 in North Sumatra.

The specimens from the tea in West Java which were collected for this study are stored in alcohol and microscopic slides at the Laboratory for Entomology, Binnenhaven 7, Wageningen, Holland, and in the Museum Zoologi, Bogor, Indonesia.

Brevipalpus mites on tea in countries other than Indonesia share many morphological, biological and ecological features with *B. phoenicis* but seem to include other species as well. BAPTIST and RANAWEERA (1955) collected three species from tea in Ceylon, *B. phoenicis*, *B. obovatus* and *B. australis*, the latter being the commonest. Later publications from Ceylon usually refer to this inventarization, in particular to *B. australis*. Reports on tea pests in South India refer to *B. australis* (RAO et al., 1970; RAO 1974a); in North India to *B. phoenicis* (DAS, 1963; BANERJEE, 1969). The identification of these species has not been well documented, or has been outdated by the revisions of PRITCHARD and BAKER (1958) and GONZALEZ (1975). It is desirable that these species are again identified.

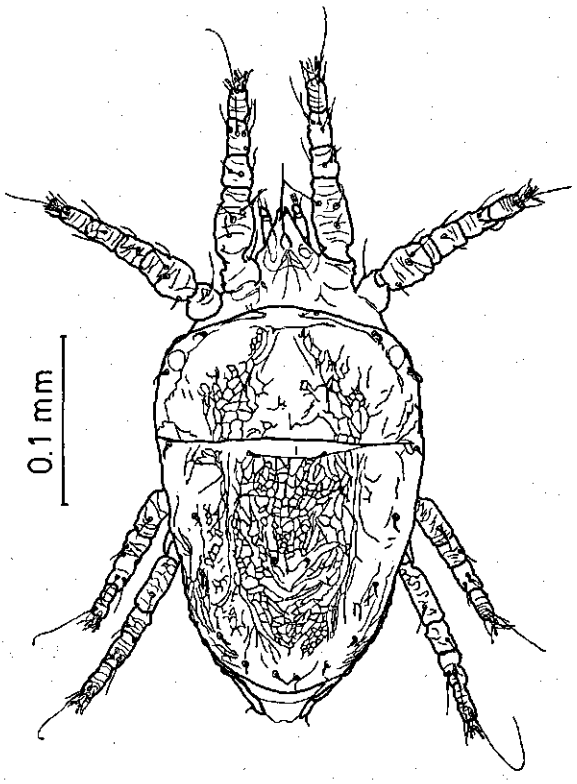


Fig. 1. A female scarlet mite, *Brevipalpus phoenicis* (drawing by F. Oomen-Kalsbeek).

2.2. Life history of the scarlet mite

The scarlet mite (fig. 1) is small and difficult to see with the naked eye (adult size is 0.28 × 0.16 mm). The typical flat body is red with some black, which explains another common name: 'red-and-black-flat mite'. The eggs and juveniles are also red. The mites stay on the undersurface of the maintenance (= mature) leaves of tea and move around slowly. They do not spin as suggested by Bernard (1909) and Kalshoven (1950). The morphology of the scarlet mite has been described in detail by Bernard (1909), Baptist and Ranaweera (1955)*, Homburg (1955), Haramoto (1969), Lal (1978) and many others. Baptist and Ranaweera (1955)*, Ananthakrishnan (1963)*, Das (1965), Haramoto (1969), Zaher et al. (1970), Banerjee (1965, 1971, 1976) studied the life cycle. After hatching from the egg, scarlet mites pass through three active and three inactive (-chrysalis) stages, before reaching maturity. The life cycle is egg – larva – protochrysalis – protonymph – deutochrysalis – deutonymph – teleiochrysalis – adult. The immobile eggs and chrysalis stages remain stuck to the leaf substrate.

*Predominantly *B. australis*

The reproduction of scarlet mites is parthenogenetic (thelytokous). Both male and female are haploid and have two chomosomes (HELLE et al., 1980). The significance of the rare males and the mechanism of sex determination in the thelytokous *Brevipalpus* species is not clear (PIJNACKER et al., 1980). Males do copulate but the transfer of sperm is ineffective (HELLE, pers. comm.). Males in populations of *B. phoenicis* are few, on tea about 1.5% (RAZOUX SCHULTZ, 1961), on papaya about 1% (HAROMOTO, 1969). To simplify calculations on multiplication, in this publication scarlet mite adults have all been considered female.

Many plants are known as hosts of scarlet mites (see introduction). In the vicinity of infested tea gardens rose (*Rosa* sp.), rose mallow (*Hibiscus rosa-sinensis*), geranium (*Pelargonium zonale*), aster (*Aster amellus*), passion fruit (*Passiflora edulis*) and citrus (*Citrus* sp.) were found to harbour some scarlet mites.

2.3. FEEDING AND SYMPTOMS OF THE SCARLET MITE

Scarlet mites live on the undersurface of tea maintenance leaves, on petioles and twigs with the exception of the lignified parts. Young leaves are invaded if the maintenance leaves become overcrowded. A small proportion of the mite population is occasionally found on the upper surface of the leaves, varying from negligible numbers during rainy periods up to 20% after prolonged periods of drought.

The mites prefer to stay at the midrib and other veins, in cracks, crevices (which explains the common name 'red crevice mites'), pits, curled edges and axils. The most favoured places are those where these characteristics converge: the leaf base and petiole. Consequently, these areas are most severely damaged by the feeding of the mites.

Tenuipalpidae feed in the same way as Tetranychidae by continuously punching the leaf epidermis with their chelicerae (JEPPSON et al., 1975). The sap that oozes out of the wounded cells of the leaf is mixed with saliva and imbibed into the digestive tract of the scarlet mite (HARAMOTO, 1969). The necrotic spots are visible as a brownish shaded area on the affected leaves. Concentra-

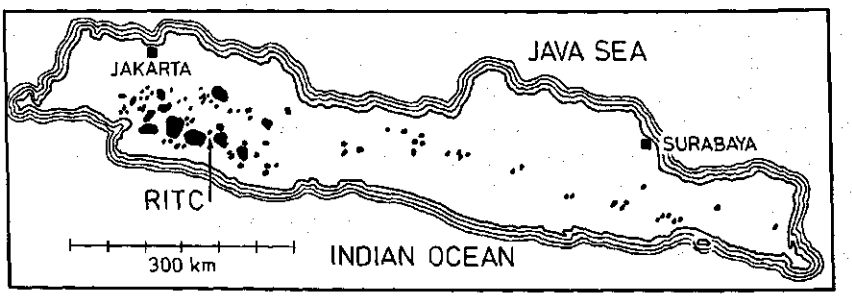


Fig. 2. Tea estates and tea areas on Java (after SCHOOREL, 1950).

Fig. 3. The plucking table of a tea bush heavily affected by scarlet mites. Few maintenance leaves remain.

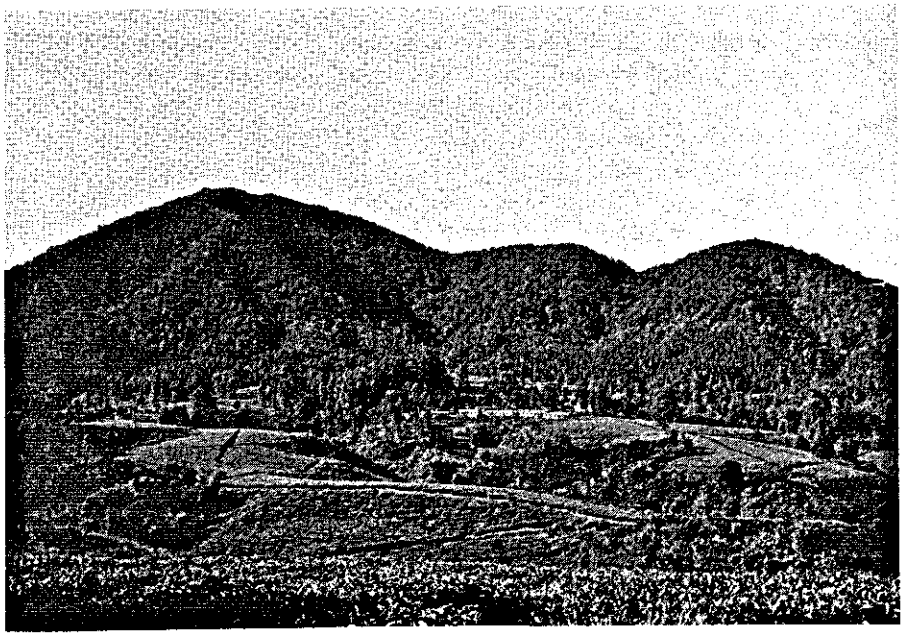


Fig. 4. The Tilu mountain with on the NW slope the Research Institute for Tea and Cinchona (RITC) and surrounding tea gardens.

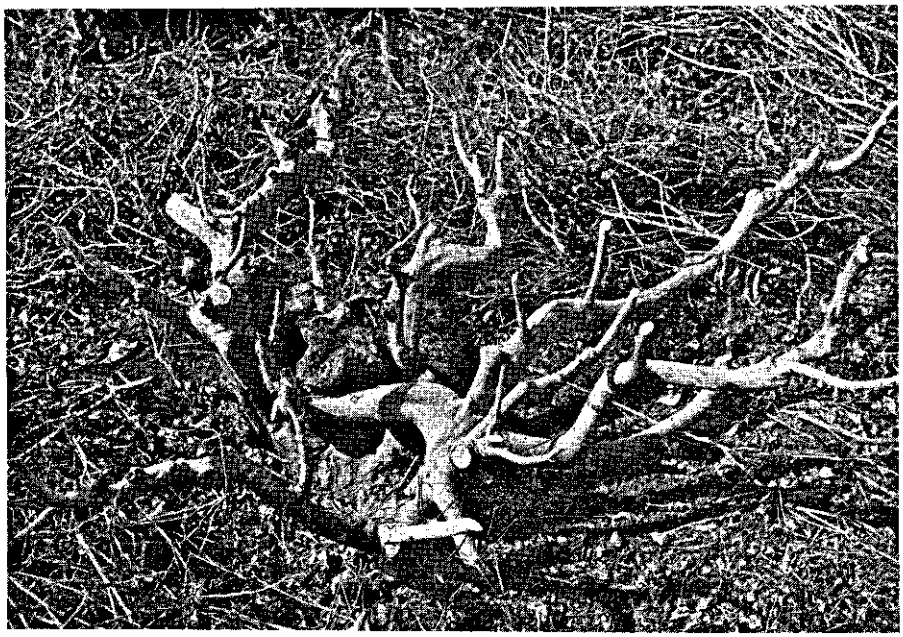


Fig. 5. A tea bush just after pruning. Only the frame of thick branches is left intact.

Fig. 6. A tea bush 12 weeks after pruning.

tions of mites or eggs are just visible to the naked eye as red spots. Affected areas are dotted by white, empty skins. The affected areas extend along midrib and borders of the leaf. The whole underside of the leaf may become brown. Most of the leaves are shed by the tea bush long before this severe stage is reached (fig. 3). The bark of the twigs cracks, exposing more shelters that can soon be filled with eggs. I found no tea bushes killed by scarlet mites as reported by GREEN (1900), BERNARD (1909) and BAKER (1949). It is typical for affected bushes that they have a thin canopy of maintenance leaves. The increased light penetration into the frame of the bush permits the growth of mosses and lichens. This is a traditional indication to tea planters that the bushes are in a poor condition, although they are often not aware of the relation with scarlet mite infestation.

2.4. LOCATION, TIME AND CLIMATE

The study was carried out at the Research Institute for Tea and Cinchona (RITC) in Gambung, West Java (fig. 2) from September 1975 to September 1980. The RITC experimental tea gardens and laboratory are situated on the NW slope of the Tilu mountain between 1200 and 1600 m above sea level (fig. 4), and about 30 km SSW of Bandung. The soil of these tea gardens is 82% andosol, 14% regosol and 4% latosol (DARMAWIJAYA and PARTOYO, 1976). On this estate of about 300 ha, the tea plants are 60–80 years old, mainly seedlings of the assam variety.

The mountain climate in West Java up to an altitude of 3000 m is everwet with an almost evenly distributed rainfall of 3000–4000 mm per year (VAN STEENIS, 1972). The dry season (May–October) still has ample rain well distributed over the whole period. The relative humidity at the level of the tea plant is high. The amplitude of the fluctuations in temperature is small, somewhat larger in the dry season (11–28 °C) than in the rainy season (14–26 °C). For details see fig. 25 and 33. The annual variation in photoperiod at the latitude (-7°) of Java is 49 minutes (VAN AGT, pers. comm.).

2.5. THE TEA CULTURE

The Indonesian tea culture is concentrated in West Java which has 41400 ha under tea (fig. 2). Smaller areas are found in North Sumatra (10200 ha), East Java (2600 ha) and Central Java (2700 ha) (BIRO PUSAT STATISTIK, 1978).

The plantations of tea (*Camellia sinensis*) in Indonesia traditionally consist of bushes of the assam variety that occupy about 1 m^2 each. Most plantations originate from seed and therefore have a large genetic variability. There are few modern plantations of homogeneous clones. The natural shape of the tea bush (fig. 9) is changed by pruning and plucking into a flat 'plucking table' of 1–1.50 m high (fig. 7). The frame of the young plants is formed by bending,

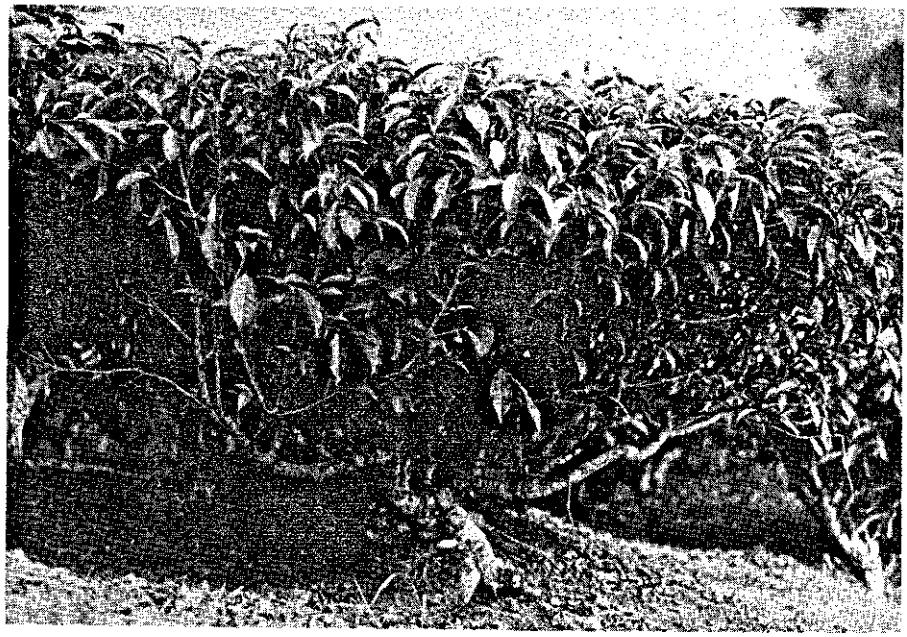


Fig. 7. A tea bush 3 years after pruning.

Fig. 8. The pruning of a tea bush. Note the thin layer of maintenance leaves just below the plucking table.

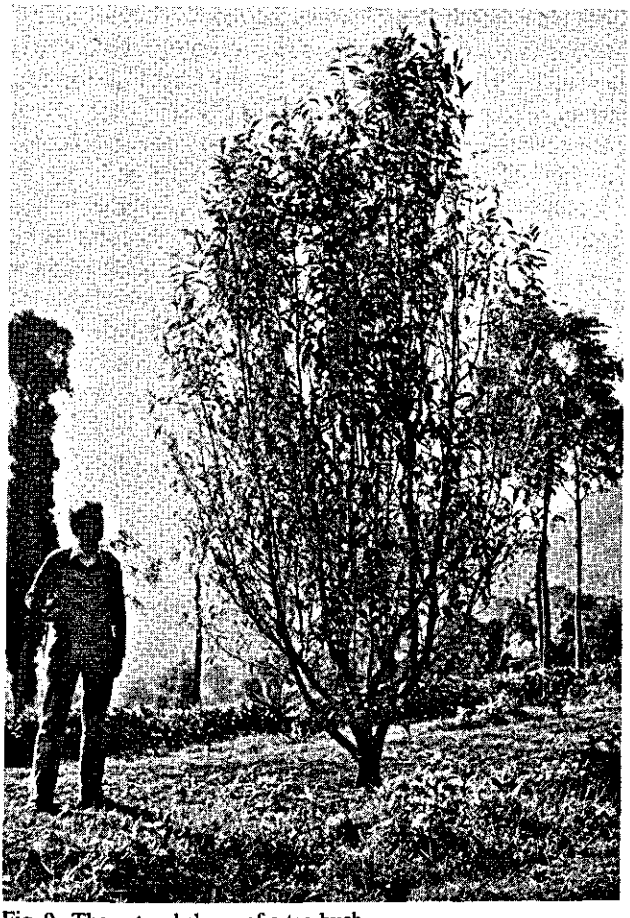


Fig. 9. The natural shape of a tea bush.

pruning and tipping, and after about 4 years the young bushes bear well. Tea is harvested manually by plucking the young shoots once in 7–14 days, depending on the season. A proportion of the young shoot is not harvested but left in order to maintain the plant. The leaves on this shoot mature and are aptly called maintenance leaves. Especially these form the substrate of scarlet mites. Every four years the bushes are pruned rigorously. All leaves, twigs and thin branches are removed. Only the frame of thick branches is left intact (fig. 5). Four months after pruning these bushes produce again. Gradually the leaf canopy and plucking table rise (fig. 6, 7 and 8) until the next pruning. Some tea bushes in the gardens of RITC have survived this rigorous treatment for a 100 years! Normal garden maintenance in Indonesian tea estates further includes frequent manual and chemical weeding as well as fertilizing with NPK or urea. Shade trees are no longer present except on smallholdings.

Important insect pests are the mosquito bugs *Helopeltis theivora* and *H. an-*

tonii (Heteroptera: Miridae), the leaf roller *Homona coffearia* (Lepidoptera: Tortricidae) and several species of looper caterpillars (Lepidoptera: Geometridae) (KOCH, 1978; DHARMADI, 1979). These pests are locally harmful and are usually controlled by a variety of insecticides (DHARMADI, 1979).

Tea suffers from five mite pests: scarlet mites (*Brevipalpus phoenicis;* Tenuipalpidae), purple mites (*Calacarus carinatus:* Eriophyidae), pink mites (*Acaphylla theae:* Eriophyidae), yellow mites (Tarsonemidae) and red spider mites (*Oligonychus coffeae:* Tetranychidae). Of these, I found the scarlet mite to be the most common and the most important. Control by applying the acaricides dicofol or binapacryl is usual.

The fungus disease 'blister blight', *Exobasidium vexans* (Exobasidiales: Exobasidiaceae), is a key problem in the tea culture during the wet period of the year (November–April). Protective applications of copper fungicides are usual after each plucking round.

Spraying is performed by gangs using knapsack hand or motor sprayers.

3. GENERAL TECHNIQUES

Techniques and methods generally used are described in this chapter. When applied only in single experiments or series of observations, the technical specifications are given at the appropriate place in chapter 4.

3.1. MITE SAMPLING, COUNTING AND REARING

3.1.1. *Sampling and counting*

Mites were counted on 50 maintenance leaves collected at random from the inner area of the fields, in the morning after moisture had evaporated (fig. 10). Samples were packed in plastic boxes and, when stored at room temperature, remained fresh for 3 weeks. Counting was done, however, within 3 days. Half the underside of each leaf was inspected, using the 10× magnification of a dissection microscope. Mites and eggs were counted separately. The few mites on the upper surface were not counted.

A mite brushing machine (HENDERSON and MCBURNIE, 1943) was also used (fig. 11) although this method gave no information on the distribution of mites over the leaves and predators were usually damaged and could not be identified. Counts showed that brushing yielded 94%, on average, compared with direct counting.

3.1.2. *Accuracy of sampling and mite counting*

The combined egg and mite counts in samples of 50 leaves from 58 single bushes and 35 fields of tea (chapter 4.2.4.2.) were expected to be distributed over the leaves according to the negative binomial distribution (cf. PERECIN and OLIVEIRA, 1979). The parameters p and k of the negative binomial distribution with expectation pk and variance pk(1+p), were estimated by the maximum likelihood method for each sample and tested for goodness of fit by PEARSON's X^2-test. Only 8 out of 93 distributions showed a poor fit at P = 0.05; the other 85 showed no evidence of lack of fit to the negative binomial distribution.

The number of units in a sample required to attain a certain degree of accuracy of the estimated population mean in a negative binomial distribution can be calculated according to SOUTHWOOD (1966, 1978) with corrections by VAN MONTFORT (pers. comm.):

$$N = \frac{u^2_{\alpha/2}}{f^2}\left(\frac{1}{pk} + \frac{1}{k}\right)$$

with N: the number of units (leaves) in a sample.

$u_{\alpha/2}$: value from the normal distribution with upper tail area $\alpha/2$.

f: the desired accuracy, expressed as a fraction of the expected number of mites per unit at the confidence level of $1-\alpha$.

Fig. 10. Sampling of maintenance leaves for scarlet mites by student Anita H. Sutadiredja.

Fig. 11. The use of the 'mite brushing machine' by student Anita H. Sutadiredja.

p and k: parameters of the negative binomial distribution.

Conversely, with N fixed, the accuracy can be assessed. At N = 50, the accuracy is fairly low (table 1) but sufficient for our purpose. To achieve an accuracy of f = 0.1, the samples would have had to consist of N = 800 leaves approximately. This large number was not practical.

Table 1. Mean accuracy with SD of the mite estimates in 93 samples of 50 leaves each. The accuracy f in each sample is calculated at the confidence level $1-\alpha = 0.95$.

Number of samples	Origin of samples	Accuracy	
		mean	SD
58	bush	0.41	0.15
35	field	0.38	0.06

3.1.3. *Reference of leaf surface*

The fresh weight of 50 leaves, of varying size and origin, was significantly correlated with the leaf area, as determined by planimeter ($r = 0.96$, $P < 0.001$). The average quotient of weight (g) to area (cm^2) was 0.0304 with SD = 0.0054. Hence, sample weight could be used to estimate the leaf area. The average weight of 108 samples of 50 leaves was 43.4 g with SD = 2.78 g, corresponding to 1427 cm^2, or 28.6 cm^2 per leaf.

The mite densities throughout this paper are expressed as numbers of mites per leaf. As the variation of sample weights, and hence of sample surfaces, was small, correcting the mite counts for deviations from average leaf area was not considered necessary. The influence of these deviations is negligible relative to the inaccuracy of the estimates of the number of mites.

3.1.4. *Reference to ground surface*

In order to enable conversion of densities per leaf surface to absolute densities per ground surface, a leaf area index (LAI, i.e. the ratio of leaf area to ground area) was calculated. Sixteen bushes of four different ages (11–27–34–48 months after pruning) were completely defoliated after measuring the area of the bush projected on a horizontal ground surface. The leaves of each bush were weighed and the total leaf area estimated from the known correlation of weight on surface (chapter 3.1.3). The LAI was then calculated. It appeared that the difference in LAI between the ages was not significant. The average LAI of all 16 bushes was 2.91 with SD = 0.67.

3.1.5. *Rearing*

Scarlet mites were reared to study the life cycle, fecundity, survival, multiplication under favourable conditions, effects of pesticides, etc. Young, mature maintenance leaves including 5 cm of non-lignified stalk of the mite-sensitive clone Cin 143 (chapter 4.2.2) were collected from the clonal garden of RITC.

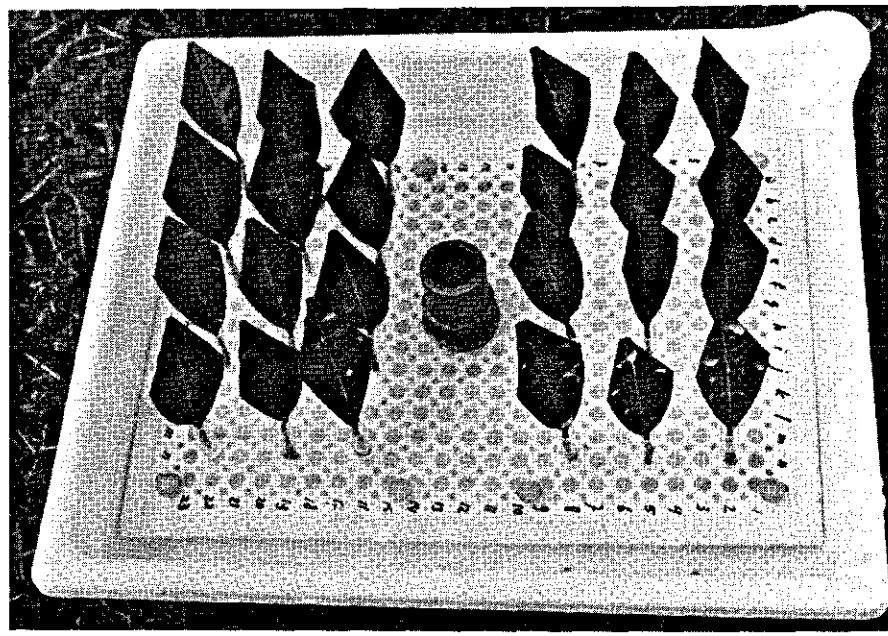


Fig. 12. Water tray with cut tea leaves for rearing scarlet mites.

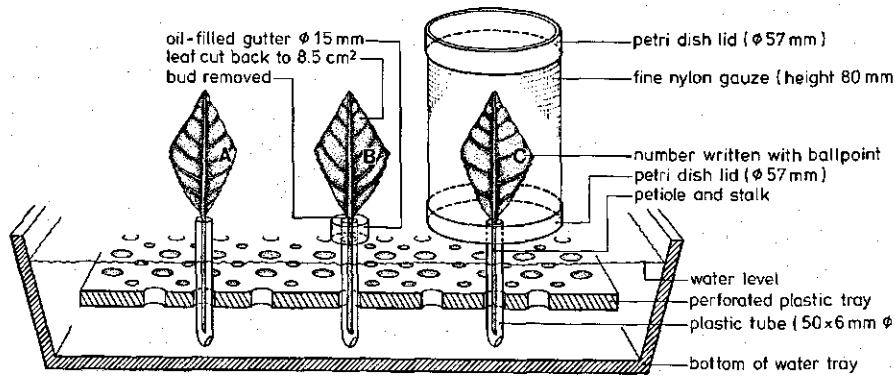


Fig. 13. Maintenance leaves of tea installed in a water tray for rearing scarlet mites (A), predatory mites (B) and predatory insects (C).

Terminal leaves with a sleeping bud ('burung' or 'bandji' shoot) were chosen whenever possible. The leaves were cut in the laboratory to a fixed size of 5.6 × 3.1 cm^2, resulting in a diamond shape of 8.5 cm^2. The axillary bud was removed. The leaves were cleaned by scrubbing with tap water and placed upright in tubes in a water tray (fig. 12 and 13). The leaves were then inoculated with young, field-collected females. Adults can be recognised as young for a few days after their last moult by their colouring and brilliance (HARAMOTO, 1969).

The leaves could easily be inspected under a dissection microscope and remained fresh for up to one year (!), unless they were damaged by the mites. The mites were kept in a well ventilated position under a window in the laboratory, at ambient temperature and humidity, but protected from direct sun. The temperature and relative humidity were registered continuously.

3.2. Predator sampling and rearing

3.2.1. *Sampling*

The numbers of scarlet and predatory mites on the 50 leaves of a sample were counted simultaneously. Both sides of the leaves were inspected under a dissection microscope at 10× magnification. Eggs and other predatory mite stages were counted separately but normally these were combined in further calculations. Because there were fewer predators than scarlet mites, the counting accuracy was also lower.

Predatory insects and mites were both sampled from the experimental plots of the predator check experiment, by vigorously beating the overhanging side of a bush over a large (70 × 42 cm^2) cotton funnel net (fig. 14). In the morning after moisture had largely evaporated, arthropods in about one liter of debris were collected by beating 25 branches per plot. The collected material was transported to the laboratory in closed plastic containers and placed in a Berlese funnel for extraction of animals smaller than about 1 cm (fig. 15). The animals were collected in 60% ethanol. Animals remaining on the funnel sides were washed into a 0.1 mm sieve and added to the others. The collected animals were sorted out and counted under the dissection microscope at 10× magnification.

A device for sampling arthropods with a concealed way of life, consisted of a 5 cm wide collar of corrugated cardboard, wrapped around the stems of tea bushes at a height of about 20 cm. The collars were left in place from 4 to 12 months to serve as a shelter for small animals. The animals inside the collars were extracted by means of a Berlese funnel either into 60% alcohol, and sorted and counted under the dissection microscope, or otherwise used alive for rearing and testing purposes.

3.2.2. *Rearing*

Predatory mites and insects were reared on leaves in the laboratory as described in chapter 3.1.5., with scarlet mites as prey. The predatory stigmaeid mites did not escape from the leaves that were surrounded by water. The predatory phytoseiid mites however appeared too mobile and vagrant, and easily escaped. A small gutter surrounding the holding tube and filled with a repellent of castor oil-canada balsam (the same mixture as used for this purpose by Swirski et al., 1967) did not prevent these escapes. Predatory insects hardly escaped from the leaves as long as they could not jump or fly. The more mobile insects were contained by a small cage of fine nylon gauze enclosing the leaf (fig. 13).

Fig. 14. The sampling of predators by beating branches of the tea bush over a funnel net by student Wahyu Widayat.

Fig. 15. The extraction of predators from beating net samples in a large Berlese funnel by F. Oomen-Kalsbeek.

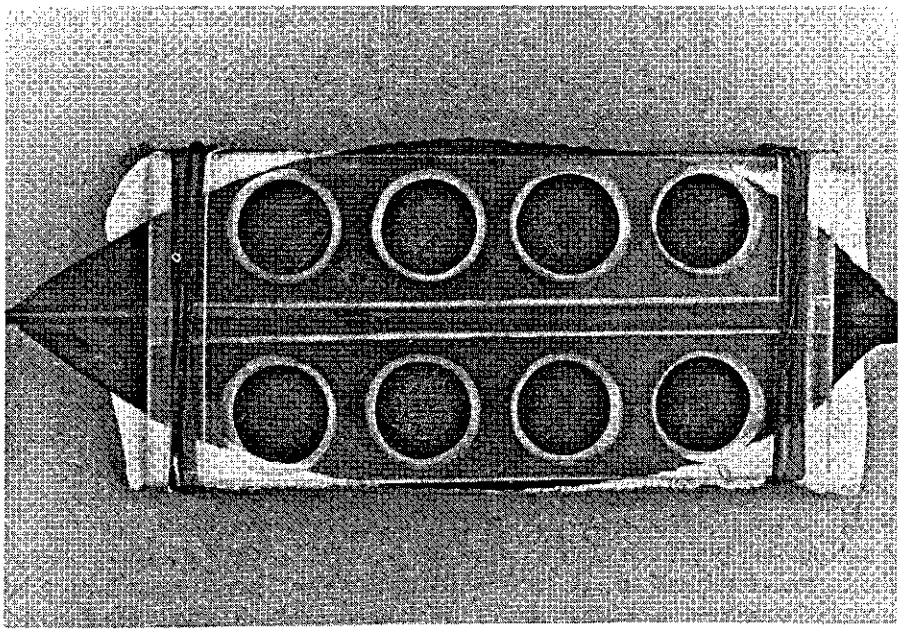


Fig. 16. Cells for rearing predatory mites on scarlet mite prey with a maintenance leaf of tea as a substrate.

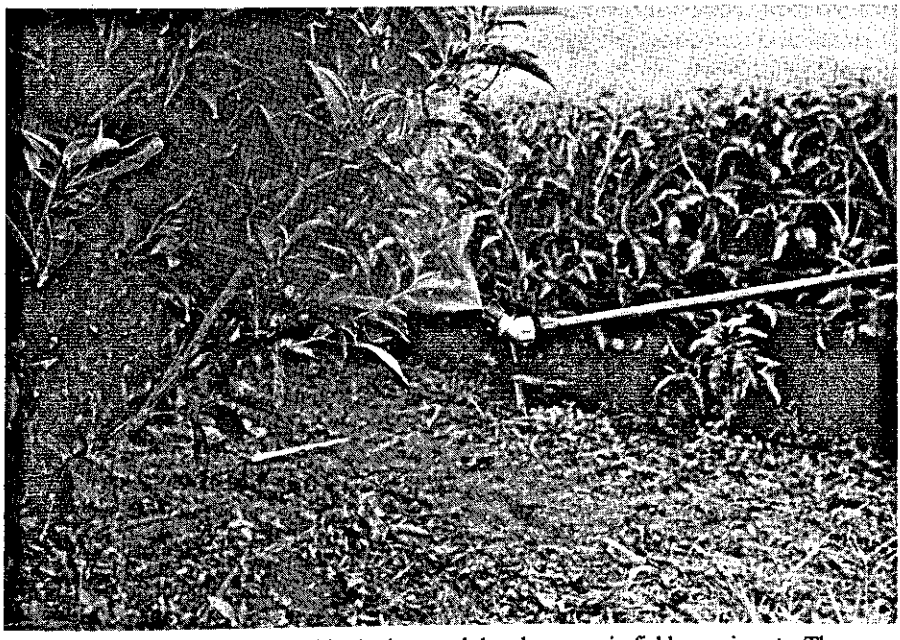


Fig. 17. The application of pesticides by knapsack hand sprayer in field experiments. The spray is directed to the undersurface of the maintenance leaves.

In addition to the open method, Phytoseiidae were reared in closed cells to prevent escape. A perspex plate (100 × 50 × 5 mm) was pressed to the underside of a fresh, cleaned maintenance leaf by means of rubber bands and a corresponding plywood counterpiece. The vein was accommodated in a 2 mm deep and 6 mm wide slit. At both sides of the slit, 4 conic holes (∅ 15 mm) were drilled, forming the cells. Prey mites were brushed into the cells, the predators introduced on a wet brush, and the cells closed with a cover glass and adhesive tape (fig. 16). The leaves were kept fresh for many weeks with the stalk in water. The cells could be inspected easily under a dissection microscope. The addition of more prey and the removal of predators or offspring required much caution and patience. Compared to the method of rearing on open leaves, the method in cells was much more laborious, and permitted little ventilation. Sometimes this resulted in the condensation of water and growth of fungi that could adversely affect the predator and prey.

3.3. Recognition and identification of predators

Insects and mites that were suspected of predatory behaviour, were captured manually, by Berlese extraction (fig. 15) from beating net collections or by means of a wet brush from leaf samples. They were transferred to leaves or cells (fig. 13 and 16) together with a known number of immature scarlet mites and eggs. A significant decrease in mite numbers was supposed to be indicative of predatory behaviour, especially when found in combination with prolonged survival and reproduction. Predatory behaviour was verified by direct observation.

The studied insects were photographed and stored in 60% ethanol for classification and reference. The studied mites were stored in Oudemans' fluid or cleared immediately in hot acetic acid and glycerine (Karg, 1971) and mounted in Hoyers' medium (Evans et al., 1961). Microscopic drawings were made using a camera lucida. Slides and stored specimens of predators were submitted to specialists for identification. A description of several new species is in preparation. Undescribed species are classified in this publication by a code name.

3.4. Pesticides

3.4.1. *Pesticides and applications*

The effect of a series of pesticides (table 2) on scarlet mites and predators was studied both in the laboratory and in the field. The animals to be tested in the laboratory were reared on leaves as described in chapter 3.1.5. The leaves were dipped in the pesticide solution for 10 seconds. In the fields, 15 l of pesticide solution was sprayed on experimental plots of 200 m^2 by knapsack handsprayer, the nozzle directed upward to reach the underside of the maintenance leaves (fig. 17). More technical details will be given in chapter 4.5.

Table 2. The pesticides studied for the effects on scarlet mites and predators.

Technical name	% a.i.	Formulation	Trade name	Ex firm
Carbaryl	85	WP	Sevin 85 S	Agrocarb Indonesia
Permethrin	25	EC	Ambush 25	ICI
DDT[1]	72	WP	–	–
Mancozeb	80	WP	Dithane M 45	Rohm & Haas
Maneb	80	WP	Manzate D	DuPont
Dinocap	25	WP	Karathane 25 WD	Rohm & Haas
Copper oxychloride	50	WP	Cobox 50 WP	BASF
Copper oxyde	50	WP	Perenox 50 WP	ICI
PH 60-42	25	flowable	–	Duphar

[1] DDT was received unlabeled. It was analyzed by the Dutch Plant Protection Service as 71.8% DDT.

3.4.2 *Calculation of the dip/spray ratio*

In order to compare the laboratory and field experiments, the average dose of pesticide per leaf area in both experiments was calculated. The pesticide dose of 10 leaves in the laboratory experiment was determined by weighing the leaves before and after dipping. The difference represented the quantity of diluted pesticide per leaf. With the concentrations of the solution and the leaf surfaces known, the average amount of pesticide per dipped leaf area was calculated. The pesticide dosage in the field, based on the assumption of a complete even distribution over all the leaves without losses, was calculated per ground area and – with the leaf area index known – per leaf area. The quantity of pesticide per leaf area thus calculated was 5.2 × higher on the dipped leaves than on the sprayed leaves.

The losses of sprayed pesticides to non-target surfaces are normally considerable. The losses to the soil alone may amount to 33% (MATTHEWS, 1979). Apple trees in full foliage retain only 30% of the pesticide following different methods of application (MORGAN, 1975). If losses in tea are the same, the dip/spray ratio increases to 7.7 or even 17.2.

3.4.3. *Spraying efficacy*

The spraying efficacy, or the distribution of the sprayed pesticide, was tested in the field (according to STANILAND, 1959) by mixing a fluorescent pigment (0.1% saturn yellow) with the 15 l pesticide that was sprayed as usual, by knapsack handsprayer. A sample of 50 maintenance leaves from the experimental plot of 200 m^2 was collected from the upper part of the canopy as for mite counting. A sample of 50 older leaves was collected with a beating net from the lower part of the canopy as for predator sampling. The leaves were inspected under an ultraviolet light (386 nm) for presence of pigment and judged for spray efficacy in the arbitrary qualities of no pigment, traces or a fair amount. The lower and upper surface were judged separately. The results (table 3) show that coverage by a single spray is fairly incomplete, especially

Table 3. Distribution of fluorescent spray material on 50 leaves, collected as a leaf sample from high in the canopy (chapter 3.1.1) or a beating sample from low in the canopy (chapter 3.2.1).

	Number of leaves with fluorescent deposit		
	no traces	traces	fair amount
Leaf sample:			
upper surface	7	24	19
lower surface	24	18	8
Beating sample:			
upper surface	4	13	33
lower surface	4	10	36

on the leaves from the upper part of the canopy. Spray penetration is hampered here by the dense foliage. Repeated applications are probably necessary to achieve a sufficient effect.

4. RESULTS

4.1. CHARACTERISTICS OF SCARLET MITES ON TEA AS A HOST PLANT

Several aspects of the life cycle of scarlet mites in tea were studied in the laboratory. Temperature and humidity conditions were registered continuously during the experiments in the laboratory as well as in the field (table 4). Fluctuations of temperature and relative humidity are smaller in the laboratory than in the field. The average temperatures in the laboratory during the 40 days of experimentation (rainy season) were about 1.5°C higher than in the field. Therefore, the temperatures in the laboratory may be considered as more or less representative for the conditions in the field.

4.1.1. *Pre-adult development: duration and survival*

The duration of the development from egg to adult was studied in egg waves on isolated leaves (clone Cin 143) under favourable laboratory conditions. A large number of females was left to oviposit on a leaf for a maximum of 48 hours, and then removed. The eggs and developing stages were frequently inspected (at least once in three days) and counted until each specimen had become an adult.

The percentage of individuals that reached each successive stage is plotted cumulatively as a function of age in fig. 18. Starting with 158 eggs, 125 mites developed into adult: a survival of 79%. The median duration of all stages in the development of scarlet mites to adult can be measured in the figure at the 50% level.

In table 5, these values are compared with the data obtained by several other authors. The total development to adult is in the same range as reported by these authors; temperature in this study apparently was suboptimal.

Table 4. Temperature and humidity conditions in experiments on the life cycle of scarlet mites. The laboratory experiments were carried out during the rainy season.

	Laboratory		Field					
	rainy season		rainy season		dry season		whole year	
Daily measurements	mean[1]	SD	mean[1]	SD	mean[1]	SD	mean[2]	SD
Minimum temperature °C	19.1	0.69	15.8	0.78	15.1	1.40	15.2	1.41
Maximum temperature °C	23.4	1.42	23.6	1.56	23.8	0.75	24.1	1.36
Minimum relative humidity %	87.2	6.28	67.2	10.13	57.4	9.35	65.5	10.52
Rainfall mm	–	–	11.9	11.38	1.7	5.42	8.1	14.11

[1] mean of 40 days.
[2] mean of 365 days.

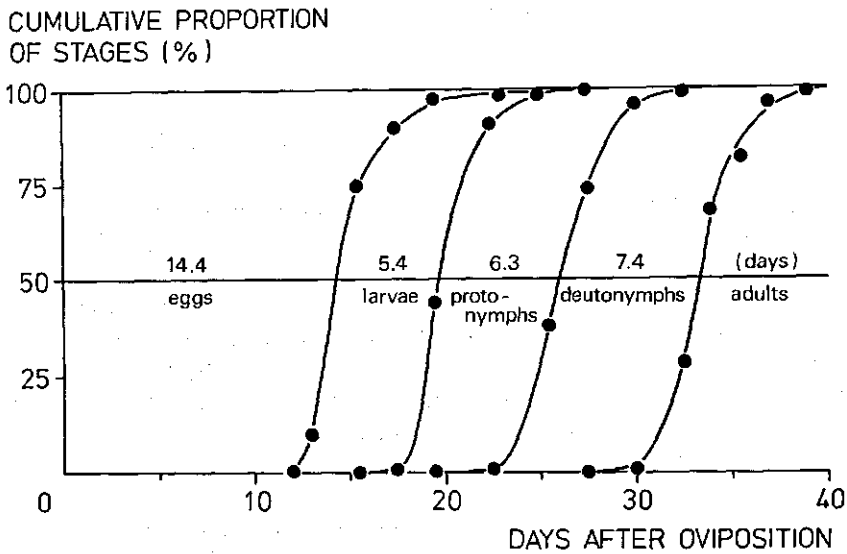


Fig. 18. Development of a synchronized population of scarlet mites in the laboratory. The population started with 158 eggs laid within 48 hours on three leaves of clone Cin 143.

Table 5. Duration of the life cycle of scarlet mites (*B. phoenicis*) as recorded by several authors.

	Duration (days)					
Stages	this report[1]	RAZOUX SCHULTZ 1961[2]	BAPTIST & RANAWEERA 1955[3]	HARAMOTO 1969[2]	HARAMOTO 1969[2]	LAL 1978[2]
Egg	14.4	9.4	13	21.6	9.4	9.0
Larva + protochrysalis	5.4	5.6	7.5	10.4	6.5	6.6
Protonymph + deutochrysalis	6.3	5.8	8.0	8.4	6.5	6.8
Deutonymph + teleiochrysalis	7.4	6.9	8.3	7.3	6.9	6.2
Total (egg-adult)	33.5	27.7	36.8	47.7	29.3	28.6
Host plant	tea	tea	tea	papaya	papaya	*Oroxylum* sp.
Temperature °C	19.1–23.4	20–33	17.8–23.3	20	25	21.2

[1] median values.
[2] average values.
[3] average values in *B. australis*

4.1.2. *Age specific oviposition and survival of adults*

The average oviposition per day per female and the survival of these ovipositing females were recorded in populations of 20 young females, collected from the field and reared on three isolated leaves of clone Cin 143. They were maintained for multiplication under favourable conditions in the laboratory. The eggs, immature stages and adults were counted almost daily until the appearance of the first adults of the second generation.

The average oviposition per female per day, and the percentage survival is plotted in fig. 19. At 14 days after the start of the experiment, the daily oviposition reached a maximum of 1.36 eggs per female. In this period, half the eggs have been produced. The average daily oviposition over 27 days was 0.96 eggs per female. The oviposition decreased strongly after 27 days and was further neglected. At that moment, survival was still 88%. In a preliminary experiment, females were reared individually on water surrounded leaf discs. At 34 days after adult emergence, survival was 50%; at 66 days survival was approximately zero. The many drowned animals in this experiment were neglected.

In view of the rapidly declining fecundity and the imminent rise in mortality in females ovipositing for 27 days and longer, it is not likely that these ageing females contribute substantially to the multiplication of the population.

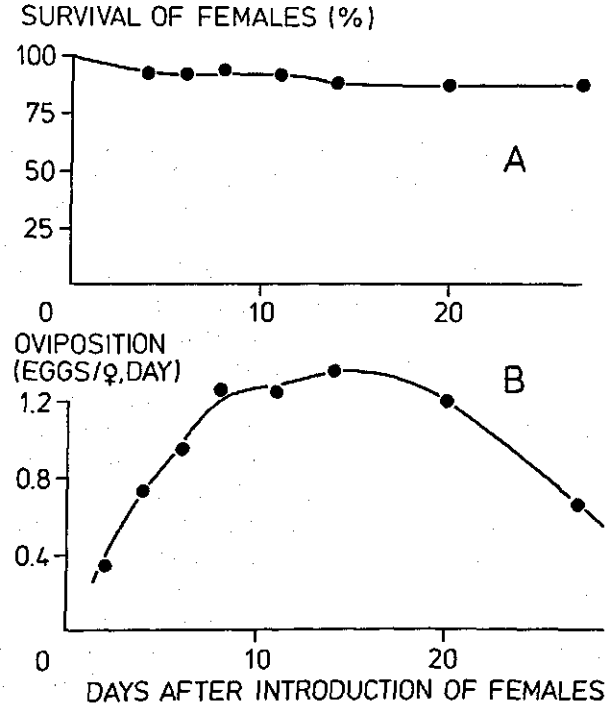


Fig. 19. The average oviposition per female per day and the percentage of adult (= female) survival of a scarlet mite population, started with 60 young, field collected females on a substrate of 3 leaves of clone Cin 143.

4.1.3. *Multiplication*

A graph (fig. 20), representing the multiplication of scarlet mites in which oviposition data, adult and juvenile survival as well as reproduction by the second generation under favourable growing conditions are combined, was derived from the experiment described in chapter 4.1.2. The number of each developmental stage in the second generation since the start of oviposition is plotted in this graph.

The net reproductive rate R_0, the intrinsic rate of increase r_m and the mean length of a generation T are calculated according to BIRCH (1948). The data used for calculation are: the age specific survival and fecundity of females (fig. 19), the survival and duration of development from egg to adult (chapter 4.1.1.), the duration of the pre-oviposition period (fig. 20), and the sex ratio (chapter 2.2.). The net reproductive rate is calculated from:

$$R_0 = \Sigma\, l_x m_x$$

were x is the pivotal age in days of each age class (duration 2 days), l_x is the age specific survival rate and m_x is the age specific fecundity rate. The intrinsic rate of increase r_m is calculated by iteration from:

$$\Sigma\, e^{-r_m x} l_x m_x = 1$$

The mean length T of a generation is calculated from:

$$T = \frac{\ln R_0}{r_m}$$

The graph on the multiplication of scarlet mites (fig. 20) shows that the minimal duration of a generation (egg-to-egg period) is about 36 days and that the pre-oviposition period lasts about 3.5 days. After 36 days 1755 eggs had been laid by the original 60 females.

The net reproductive rate R_0 is the rate of multiplication in one generation. The intrinsic rate of (natural) increase r_m is the instantaneous coefficient of population growth r under conditions of an unlimited environment and a stable age distribution. For scarlet mite in tea these values were $R_0 = 21.9$ and $r_m = 0.0610$ respectively. The last value can be considered as an estimate of the maximum rate of natural increase since the rearing conditions had been kept as favourable as possible within the range representative of the local conditions. The mean length of a generation was T = 50.6 days.

Based upon the laboratory observations of HARAMOTO (1969) on scarlet mite in papaya, I calculated that at 25 °C the net reproductive rate and the intrinsic rate of increase were respectively $R_0 = 28.7$ and $r_m = 0.0662$. These rates were considerably lower at 20 °C and 30 °C. The mean generation time was T = 50.7 days. The multiplication characteristics of scarlet mite on tea and papaya, respectively in Indonesia and Hawaii, seem to differ very little from each other. However, the intrinsic rate of increase r_m of scarlet mites is low compared to several species of spider mites, e.g. *Tetranychus neocaledonicus:* $r_m = 0.356$ (BLOMMERS, 1976) and *T. mcdanieli:* $r_m = 0.187$ (TANIGOSHI et al., 1975).

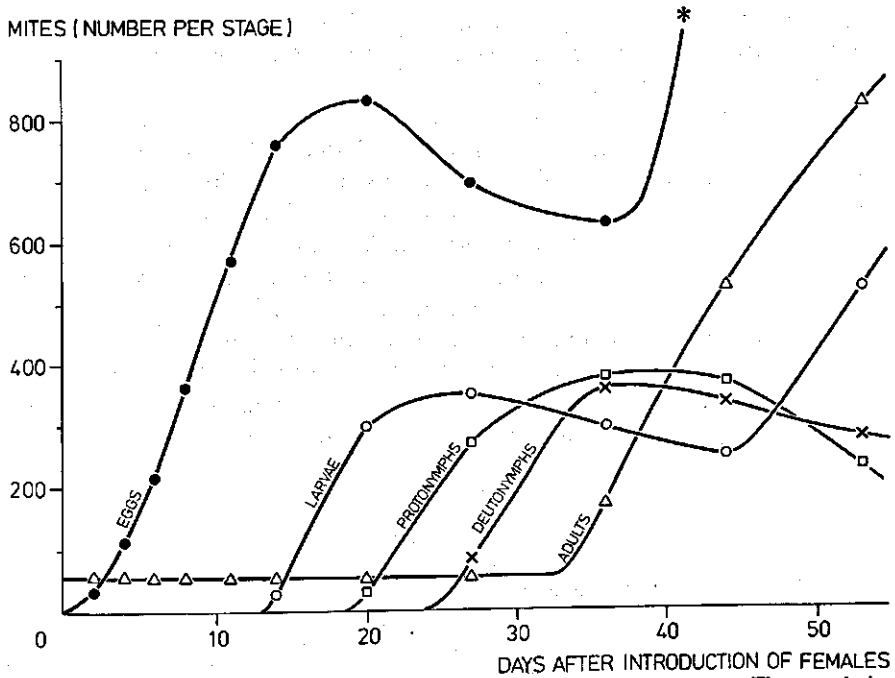


Fig. 20. The development of a population of scarlet mites in the laboratory. The population started with 60 young, field collected females on a substrate of 3 leaves of clone Cin 143.
*continuation: 1533 eggs at day 44; 2577 eggs at day 53.

4.1.4. *Migration and orientation*

LAL (1978) observed that adult scarlet mites on *Oroxylum indicum* and *Clerodendron siphonanthus* are sedentary and do not show any tendency to move about. This appeared true in tea as well. Scarlet mites reared on tea leaves (chapter 3.1.5) showed no tendency to move from the leaf, unless the quality of the leaf started to deteriorate. Then adults, followed by juveniles, started to migrate and clustered on the petiole where finally all were trapped in the surrounding water. Colonization of adjacent leaves via leaves that were in contact with each other was rare. The clustering on the petiole indicates that migration mainly occurs along the petiole and twigs.

The orientation of scarlet mite during migration was studied in the laboratory in arenas of plastic petri dishes (∅ 8.5 cm). These were surrounded by paper cylinders (length 21 cm, ∅ 8.5 cm), illuminated from 1.5 m distance by a white, 20 Watt neon tube light. A central emergence hole was connected to a deteriorating, mite infested leaf and admitted migrating mites into the centre of the arena. The distribution of the light and/or the gravity served as a clue for orientation. At the perifery a ring of insect glue (Tanglefoot®) trapped the mites after orientation. The number of mites trapped in each of 8 sectors was scored after several days. The score, reflecting the orientation of the mites, was tested for deviation from a uniform circular distribution by the Rayleigh test (BATSCHELET, 1965).

The migrating scarlet mites showed a very significant positive phototactic orientation (fig. 21). Neither sharp contrasts (fig. 21A and B) nor gravity (fig. 21C) influenced the chosen direction.

In the field, few mites migrate downwards. The number of scarlet mites extracted form collars of corrugated cardboard (chapter 3.2.1.) around the stems of tea bushes was negligible. Old leaves mostly harboured juveniles and some eggs. Young maintenance leaves mostly harboured adults and eggs.

The observations from the laboratory and the tea field lead to the following conclusions. Scarlet mites have a low mobility. The limited migration is oriented towards higher light intensities and leads especially the adult mites, to explore the higher and younger layers of leaves in the tea bush, in accordance with the behaviour observed in Tetranychidae (JEPPSON et al., 1975; SUSKI and NAEGELE, 1963). Scarlet mites tend to remain on the same bush while migrating, thus keeping the mite populations of the bushes separate.

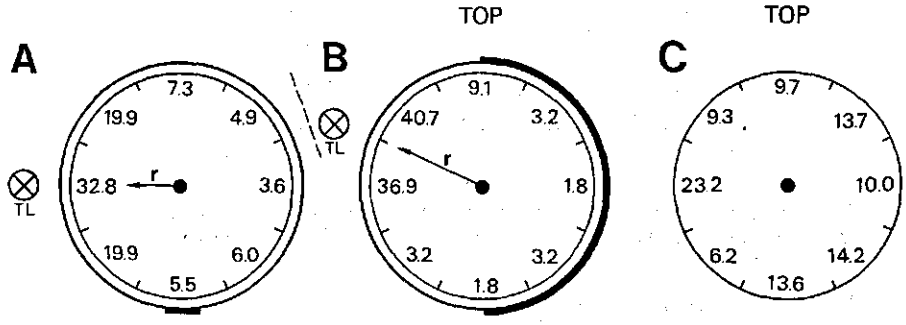


Fig. 21. The orientation of scarlet mites emigrating from a deteriorating tea leaf. The number of mites trapped in each of the 8 sectors per arena (∅ 85 mm) is given in percentages. The mean vector r indicates the preferred direction of the orientation. The length measures the concentration around the preferred direction (BATSCHELET, 1965).

A. A horizontal arena, surrounded by a white paper cylinder with a 1 cm wide, black strip. A neon lamp at 1.5 m distance illuminates the cylinder from the left. Number of mites: n = 1727. Rayleigh test: z = 433, P < 0.0001. The orientation deviates very significantly from random and shows a positive phototaxis.

B. A vertical arena, surrounded by a paper cylinder that is half black, half white. A neon lamp at 1.5 m distance illuminates the white side. Number of mites: n = 4105. Rayleigh test: z = 2022, P < 0.0001. The orientation deviates very significantly from random and shows a positive phototaxis.

C. A vertical arena in complete darkness. Number of mites: n = 1059, Rayleigh test: z = 2.30, P > 0.05. The orientation does not deviate significantly from random.

4.2. THE ABUNDANCE OF MITES IN TEA FIELDS

4.2.1. *Relative abundance of the developmental stages*

All stages of scarlet mites are found throughout the year in all populations. A parameter useful to qualify the age structure of a population is the percentage of eggs. The average egg percentage over 10 populations (8 single bushes, 2 fields comprising many bushes) and 11 samplings in a year is 48.7%, with

a standard deviation of 7.3%. An analysis of variance of these 110 data showed that the differences between the times of sampling are not significant (F ratio = 0.85; $P > 0.25$). Therefore, the egg percentage and hence the age structure of the populations can be considered stable throughout the year. It means that generations overlap and that diapause or other synchronizations of the development are absent. An illustration of the relative abundance of the developmental stages in two populations, which were widely separated in season and situation in the tea garden, is given in table 6.

Table 6. Relative abundance (percent of total number of mites) of developmental stages in two populations of scarlet mites in different seasons and different parts of the tea garden.

	Relative abundance (%)				Total number	
Season	eggs	larvae	nymphs	adults	mites	leaves
Rainy (February 1976)	51.9	17.6	20.4	10.2	2326	130
Dry (August 1980)	46.0	17.4	21.0	15.6	5116	400

4.2.2. *Influence of different tea bushes and clones on abundance*

Scarlet mite is very common on Indonesian tea. Bushes without this mite are hard to find. Mite density varies strongly in different spots and bushes. I often found heavily infested bushes touching unaffected bushes. The distribution of mite densities as counted in a row of 20 seedling bushes in 2 old tea fields can be considered to be independent of the densities in the neighbouring bushes; deviations from independence appeared to be far from significant at $P = 0.05$, according to the Von Neumann-test (OWEN, 1962). Characteristics of the host plants were supposed to contribute to the independent distribution.

The importance of host plant characteristics in determining the abundance of scarlet mite was studied by comparing the mite densities on different tea clones grown in two clonal gardens of RITC, numbered I and II. Each garden consisted of 80 plots, divided into 5 replicates with 16 clones. There were 80 bushes of each clone per plot. The plantations were respectively two and three years old and not yet being picked. Pesticides other than herbicides were not used. Random samples of 10 maintenance leaves were taken from each plot and the number of scarlet mites was recorded. This count was repeated the next year in garden I (then three years old). The counts were normalized by $^{10}\log$ transformation. Differences were tested by analysis of variance and Duncan's Multiple Range test (GOMEZ and GOMEZ, 1976).

Large differences in mite densities were found between clones; these differences appeared to be very significant (table 7). The mite densities in the clones of garden I correlated very significantly in the two successive years (correlation coefficient $r = 0.79$, $P < 0.005$) although the average mite density was much lower in the second year. The two gardens had 4 clones in common, of which the ranking was identical. In all counts, the most infested clones sustained a

mite population which was on average 30 – 100 × as large as the least infested clones. The significant differences between clones which were recorded in two consecutive years, together with the independent distribution of mite densities within seedling plantations, confirm that host plant characteristics play an essential role in determining the density of scarlet mite populations.

4.2.3. *Influence of pruning on abundance*

Immediately after clean pruning, tea gardens harbour very few mites. I could not find scarlet mites on the stumps. A negligible number of leaves escaped pruning and harboured some mites. Pruning, which removes nearly all the foliage of a plantation, profoundly influences a scarlet mite population. This was confirmed by relating mite densities to the time elapsed since pruning.

Scarlet mites were counted within the relatively short period of one month in a number of tea fields which had been pruned on different dates. A large number of leaves (10 samples of 50 leaves, from 10 different locations) was collected in order to record the average mite density. The data on mite densities were normalized by a $^{10}\log$ transformation. The effect of the time that had elapsed since pruning on the abundance of scarlet mites was studied by a correlation and regression analysis.

The mite density on the new foliage first increases and levels off later (fig. 22). The transition from the increasing to the levelled off stage is about in the middle of the pruning cycle. The cycle is broken arbitrarily into halves in fig. 22. A linear regression line fits very significantly ($P < 0.001$) to the transformed data of the first two years. The increase therefore can be considered to be exponential during this period. A negative but non-significant correlation was found between the mite densities and age since pruning over het second period of two years. The density level during this period changes little, with an insignificant ($P > 0.1$) tendency to decrease. The differences between populations of the same ages are considerable.

It is concluded that pruning reduces the scarlet mite populations to practically zero. The few survivors then start to increase slowly and exponentially. The increase levels off about two years after pruning.

4.2.4. *Time related changes in abundance*

4.2.4.1. Location and method

During two years the numerical fluctuations of 11 local populations of scarlet mites were followed on 8 single bushes and in 3 whole tea fields. The observed tea plantations consisted of 60 year old, seedling bushes and were bordered by footpaths. The plantations were normally picked and manured, and weeded manually. Two bushes (1 and 7) were selected because of the high mite density; the others were selected haphazardly. Two fields (2 and 3) and two bushes (7 and 8) received the usual copper fungicide sprays to control blister blight. All fields and bushes were situated within 450 m of a weather station.

The observations started two years after the last pruning and were completed

Table 7. Clones of RITC-garden I (in 1976 and 1977) and II (in 1977), ranked in order of ascending scarlet mite infestation.

Clonal garden I (1976)				Clonal garden I (1977)				Clonal garden II (1977)			
clone		log[1] mites	significance[2]	clone		log[1] mites	significance[2]	clone		log[1] mites	significance[2]
PS	324	1.02		RB	3	0.53		Skm	118	0.62	
RB	3	1.21		TRI	2024	0.76		TRI	2025	1.16	
TRI	2024	1.45		PS	324	0.77		TRI	2024	1.41	
PG	18	1.46		RS	1	1.11		Kiara	8	1.63	
RB	1	1.49		SA	40	1.13		Cin	176	1.63	
RS	1	1.52		PG	18	1.26		Mal	4	1.74	
SA	40	1.70		PG	9	1.37		Cin	149	1.82	
PS	1	1.84		Kiara	8	1.45		PS	1	2.08	
PS	400	1.90		RB	1	1.63		PS	354	2.11	
Kiara	8	1.93		PS	400	1.65		SA	63	2.15	
KP	4	2.21		PS	1	1.67		KP	4	2.26	
SA	35	2.35		Cin	143	1.69		Cin	56	2.27	
SA	73	2.44		SA	35	1.74		Skm	116	2.29	
PG	9	2.47		SA	73	1.87		Cin	81	2.30	
RB	2	2.59		KP	4	1.96		PS	385	2.46	
Cin	143	2.77		RB	2	2.05		Mal	1	2.60	
Analysis of variance:											
error mean square:		0.103				0.151				0.103	
grand mean:		1.896				1.416				1.892	
F value clones:		13.80**				6.79**				15.61**	
F value replicates:		4.29**				3.00*				4.24**	

[1] log mites: average of 5 replicates of $^{10}\log$ (mites/10 half leaves).

[2] Any two infestations on clones not followed by the same line are significantly different at P = 0.05 according to Duncan's Multiple Range Test.

by the next pruning. The populations were assessed once in about five weeks. The period is about equivalent to the minimum duration of a mite generation. The sample size was smaller than 50 leaves in bush 1 during the whole experiment and in bush 4 during the first year (20 leaves per sample). These bushes were too small to stand a stronger defoliation.

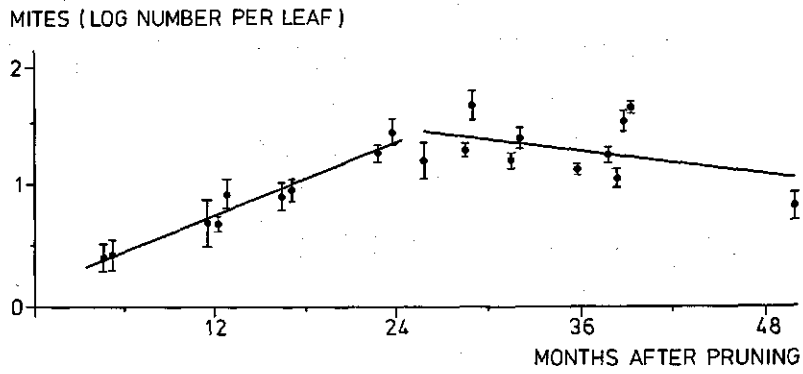


Fig. 22. The densities of scarlet mites at different times since pruning, counted in May 1979. The average (^{10}log transformed) mite densities with the standard errors are given per age since pruning, in series of 10 samples of 50 leaves. A linear regression line (of the average transformed densities on the age in months) is fitted to the first period and the second period of two years of the pruning cycle. Regression line and correlation coefficient in the first period: $y = 0.049x+0.15$, $r = 0.98$, $n = 9$, $P < 0.001$, second period: $y = -0.016x+1.83$, $r = -0.44$, $n = 11$, $P > 0.1$.

4.2.4.2. Numerical fluctuations

The amplitude and average density level of the numerical fluctuations are rather variable between the populations (fig. 23). Most populations have a stable, low average density (fig. 23B) or a stable, intermediate average density (fig. 23C and D). Only the two bushes selected because of the mite infestation harbour an unstable, high average density population (fig. 23A). A seasonal pattern of fluctuations seems strongest in the high density, low stability populations and in the intermediate populations. Maxima seem most pronounced at the end of the dry season (August-October). These are followed by a sudden decrease at the onset of the rainy season (October–November).

An exception of this seasonal pattern is the population of bush 7 in 1976. This bush got acaricide (dicofol) treatments in May and June 1976 after which the population collapsed. In September the population resurged to very high densities, in contrast to the trend in the other populations. The density of mites remained high until the end of the observations. The deposits of copper fungicides on this exposed bush were considerable.

The densities of the populations appear in general to be stable during the period of study, i.e. during the last two years of the pruning cycle. As stated before (cf. chapter 4.2.3.), the average density during this period tends to decrease rather than increase. All populations show certain fluctuations with the seasons, least clear in the low-density populations.

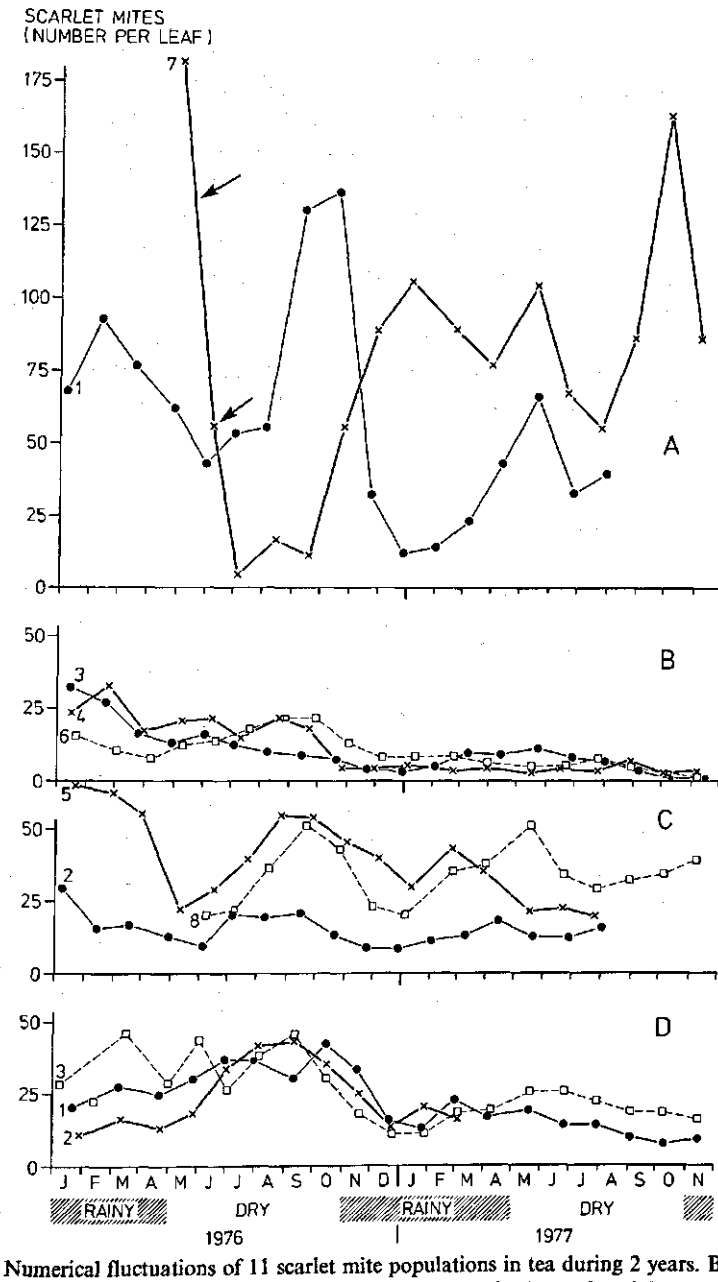


Fig. 23. Numerical fluctuations of 11 scarlet mite populations in tea during 2 years. Bushes and fields are identified by a number at the left of the curves. The bushes 1, 2 and 5 were abandoned early because of uprooting.

A. Unstable, high density populations on single bushes. Bush 7 is treated by acaricides on the dates indicated by arrows.

B. Relatively stable, low density populations on single bushes.

C. Relatively stable, intermediate density populations on single bushes.

D. Relatively stable, intermediate density populations in whole tea fields.

4.2.4.3. Effects of season and weather

Simultaneous fluctuations in the abundance of adjacent mite populations, are likely to be caused by common influences such as season and weather. In order to make the simultaneous fluctuations in populations of different sizes comparable, an 'index of population trend' (SOUTHWOOD, 1966) is calculated for each mite sampling during the population study. The index of population trend I is defined: $I = N_{t_2}/N_{t_1}$ in which N is the total number of mites in a population, and t_1 and t_2 are two consecutive times of sampling. Since $t_2 - t_1$ (usually 35 days) does not differ too much from the mean generation time T = 50.6 days, I is related to the net reproductive rate R_0. Where the index crosses the unity level, population maxima or minima are attained (see fig. 24). Between the index and several weather factors, correlation coefficients are calculated.

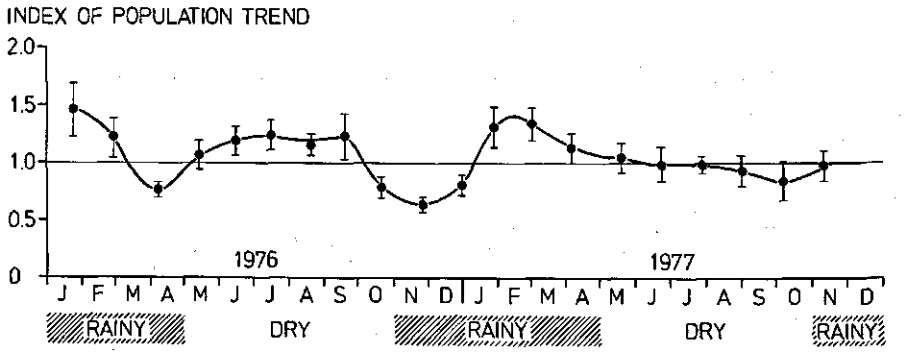


Fig. 24. The average 'index of population trend' with standard error of the scarlet mite populations in the tea during 2 years. The unity level represents an unchanging population density.

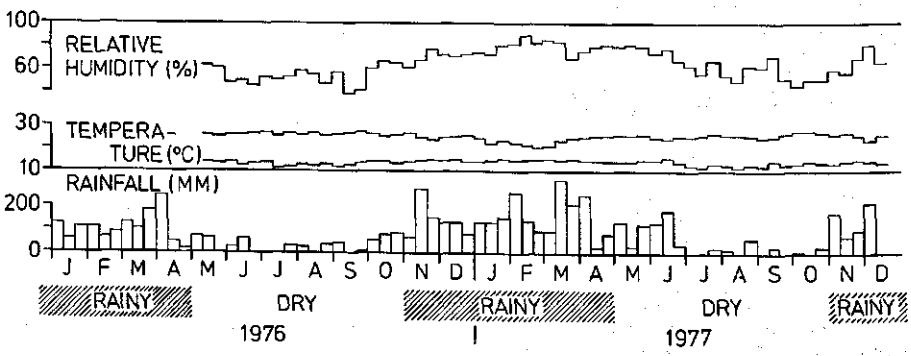


Fig. 25. The weather conditions during two years of mite population studies, measured in a tea field at 1.20 m height in a Stevenson hut. Minimum relative humidity, minimum and maximum temperature data are 10-day averages. Rainfall data are 10-day totals. The maximum daily relative humidity was practically always 100%. Measurements of temperature and relative humidity started later than the population studies.

It appears that in all populations during the whole period of study, the index never deviates far from unity, and rarely exceeds a factor 2.5 or 0.4 with even the strongest fluctuations.

An average index with standard error is calculated for each census over the sampled populations, and plotted in fig. 24. The populations show simultaneous fluctuations in multiplication during the season. The relation to the weather conditions (fig. 25), however, is not clear. The average index of population trend is found to be uncorrelated at $P = 0.05$ with several measured weather parameters (average maximum and minimum temperature, average minimum relative humidity, total amount of rainfall, all calculated over the periods between sampling).

Although the population development is doubtlessly influenced by weather, the effects are still too complicated to unravel.

4.2.4.4. Effects of copper fungicides

An experiment to assess the effect of copper fungicide sprays on mite populations was carried out in a tea garden of RITC, planted with about 60-years old seedling bushes. The distance to the weather station was 1100 m. Except for pesticide treatments, the garden maintenance was normal. The experiment started 2 years after the last pruning. Experimental plots of 10 × 10 m were laid out in a randomized complete block design, with a minimal distance of 4 m to a garden road and foot path. The plots were marked by bamboo poles and plastic ribbon, and separated by 2 m wide strips. Four plots were left untreated. The other four were sprayed once in three weeks with copperoxychloride (Cobox® 50% WP, concentration 0.06% or 6 g in 10 l per plot). This resulted in the same dosage as in routine treatments for the control of blister blight. Application was by knapsack hand sprayer in order to prevent drift. The nozzle was directed upwards (fig. 17) to reach the maintenance leaves, especially the undersides. Time of application was between 10 and 12 a.m. Random samples of 50 maintenance leaves were collected from the inner area of the plots once in three weeks. The scarlet mite density was assessed in these samples using the mite brushing machine (see chapter 3.1.1.).

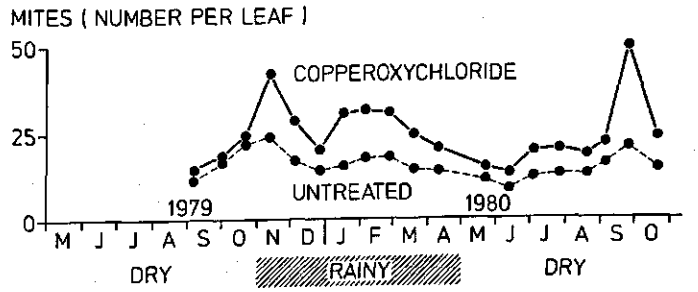


Fig. 26. Numerical fluctuations of scarlet mite populations (average of four replicates) in untreated and copper fungicide treated plots. The matching weather conditions are shown in fig. 33.

The numerical fluctuations in the plots treated with copper fungicide appear to be parallel but on a higher density level than in the untreated plots (fig. 26). The seasonal maxima especially seem to have increased. The differences between the densities in treated and untreated plots (averages over the whole experiment) are significant (t-test: $t = 5.03$, $df = 3$, $P < 0.025$). The average ratio of treated/untreated densities is 1.67 (SE = 0.065). Pre-treatment densities in the treated plots, however, started at a somewhat higher level than in the other plots (fig. 26). After correcting for this difference, the treated plots still harboured an average density 1.30 times higher than the untreated plots. These differences are just short of significance (t-test: $t = 2.69$; $df = 3$; $P < 0.1$). At the dosage of copper fungicide that is usual for protection against blister blight, the increase in mite density is small. Some road sides and field corners, however, receive large quantities of copper fungicides because of an exposed position. I often observed a heavy scarlet mite infestation especially on those bushes. The increasing effect of the copper fungicide may act cumulatively and lead to outbreak densities.

4.2.4.5. Multiplication of field populations

The maximum 'index of population trend' (I) and maximum 'instantaneous rate of increase' (r) (for definition see respectively chapter 4.2.4.3. and 4.1.3.) that are found in scarlet mite populations in the field, are given in table 8. These parameters should be compared to the rate of multiplication (R_0) and the instrinsic rate of increase (r_m) of a population developing under favourable laboratory conditions (chapter 4.1.3.). It appears that the maximum increase observed in any field population is considerably less than in the laboratory population. This means that the field conditions during the population study were never as favourable for mite development as the laboratory conditions.

The same parameters (I and r) of the average rate of multiplication during the first and the second half of the pruning cycle (see chapter 4.2.3) are given

Table 8. Index of population trend and instantaneous rate of increase of scarlet mites during the pruning cycle, and of some field populations of scarlet mites.

Populations studied	Index of population trend (I)	Observation period in days (t_2–t_1)	Instantaneous rate of increase (r)
First 2 years of pruning cycle[1]	11.01	730	0.0037
Last 2 years of pruning cycle[1]	0.26	790	–0.0012
Natural population (bush 2)[2]	2.17	33	0.0235[4]
Resurgent population (bush 7)[2]	4.98	36	0.0446[4]
Copper sprayed population (plot 7)[3]	2.59	21	0.0453[4]

[1] data calculated from regressionline in fig. 22 (chapter 4.2.3)
[2] maximum increase observed (chapter 4.2.4.2)
[3] maximum increase observed (chapter 4.2.4.4)
[4] calculation according to ODUM (1971): $r = (\ln N_{t_2} - \ln N_{t_1})/(t_2 - t_1)$

in table 8. These too are much lower than the parameters of the laboratory population. It means that the average rate of multiplication of the scarlet mite populations under field conditions is very low.

4.3. NATURAL ENEMIES AND OTHER TEA LEAF INHABITING ARTHROPODS

4.3.1. *Phytophagous arthropods*

The scarlet mite is the most common and widespread phytophagous inhabitant of tea leaves. Other common mites found on these leaves are the purple mite (*Calacarus carinatus* GREEN), the pink mite (*Acaphylla theae* WATT) and the yellow mite (*Polyphagotarsonemus latus* BANKS), these are all common pests. The spider mite (*Oligonychus coffeae* NIETNER) is an incidental pest. Common at low densities are Tydeidae, Oribateidae, Saproglyphidae (*Czenspinkia* sp.), and various unidentified mite species. Insects found on tea leaves are: Psocoptera and Thysanura, both very common, thrips, an incidental pest, coccids (crawlers) which are very common as are ants, cicadellids, and a variety of unidentified low density insect species. I did not observe interactions between these arthropods and the scarlet mite.

4.3.2. *Natural enemies*

4.3.2.1. Inventarization and distribution

Natural enemies of the scarlet mite were surveyed by examining sampled maintenance leaves under the microscope, by the Berlese method of extracting beating net samples and stem collars, and by manual collection in the field (chapter 3.1. and 3.2.). These methods were applied intensively in the experimental garden of RITC at Gambung. Samples of maintenance leaves from many other estates and smallholdings in Java and Sumatra were inspected microscopically for natural enemies. Suspected predators were collected and reared in the laboratory on a diet of scarlet mites. Besides direct observations of the predation process, prolonged survival and especially reproduction of the animals was considered as an indication of predation on scarlet mite. The adults were mounted for examination by microscope.

The identification of Indonesian predatory mites is difficult. Many species have not been described. Some species were identified or described by professional specialists (marked by a footnote in table 9). The other predatory mites were identified as far as possible with the available literature, and otherwise classified by microscopic drawings and a code name. A definitive identification of the predatory mites will be published later.

Scarlet mites were found on more than half of the leaves. No indications were found of parasites or diseases of mites. Sometimes common epiphytic fungi (among other a sooty mould) were found growing over the scarlet mite eggs. There are no indications, however, that the eggs were killed by the fungi.

Table 9. Survey of suspected predators collected from tea, and reared on scarlet mites. The table records direct observations of predatory behaviour and reproduction as well as the maximum period of survival observed. A conclusion as to whether the animal should be considered as a predator of scarlet mites is added.

Identity	Observations			Conclusion
	predation observed	survival (days)	reproduced	
Phytoseiid mites:				
Amblyseius largoensis[1] MUMA	+	25	+	predator
Amblyseius deleoni MUMA et DENMARK	+	42	+	predator
Amblyseius tamatavensis BLOMMERS	+	48	+	predator
Amblyseius syzygii GUPTA	–	10	–	predator[4]
Amblyseius w (near *A. newsami* EVANS)	–	10	+	predator
Amblyseius x (possibly *Iphiseius* sp.)	+	21	+	predator
Amblyseius y (near *A. newsami* EVANS)	+	50	+	predator
Amblyseius z (near *A. caudatus* BERLESE)	+	21	+	predator
Typhlodromus jackmickleyi[1] DE LEON	+	71	+	predator
Typhlodromus ndibu PRITCHARD et BAKER	–	5	+	predator
Phytoseius crinitus[1] SWIRSKI et SHECHTER	–	15	+	predator
Podocinid mites:				
Lasioseius p	–	27	–	no predator[4]
Lasioseius q	–	38	–	no predator[4]
Stigmaeid (Raphignatid) mites:				
Zetzellia a	+	49	+	predator
Zetzellia b	+	25	+	predator
Zetzellia maori GONZALEZ	+	22	+	predator
Agistemus terminalis[2] QUAYLE	+	35	+	predator
Agistemus denotatus[2] GONZALEZ	+	70	+	predator
Agistemus fleschneri SUMMERS	+	10	+	predator
Agistemus arcypaurus GONZALEZ	+	39	+	predator
Agistemus e	+	24	+	predator
Agistemus f	+	33	+	predator
Agistemus g	+	26	+	predator
Bdellid mites	–	54	–	no predator[4]
Cunaxid mites	+	30	–	predator
Anystid mites	–	6	–	no predator[4]
Smariid mites	–	1	–	no predator[4]
Insects:				
Lestodiplosis oomeni[3] HARRIS	+	64	–	predator
Wollastoniella testudo[3] CARAYON	+	96	–	predator

[1] Identified by C. F. van de Bund.
[2] Identified by F. M. Summers.
[3] Described in 1982.
[4] Supposition.

A survey of suspected predator species, the survival, reproduction and observed predatory behaviour on scarlet mite, is given in table 9. Very rare species are not mentioned. Two insect species and 22 mite species were found to prey upon scarlet mite. The other species mentioned belong to groups that are generally predatory according to BAKER and WHARTON (1952) but I did not observe them to prey upon scarlet mite.

The distribution of these mite species is reflected in table 10. The frequency of each identified species in samples of 50–200 leaves is given for each tea estate outside Gambung. The average number of predatory mites (including eggs) per scarlet mite infested leaf outside Gambung was 0.64 (SD = 0.86). *Amblyseius deleoni* and *Agistemus denotatus* appear to be respectively the most frequent and widespread Phytoseiid and Stigmaeid predator.

4.3.2.2. Predators in copper stimulated mite populations

Scarlet mite densities appeared to increase after frequent copper fungicide applications (chapter 4.2.4.4.). One possible explanation is the toxicity of pesticides with respect to the natural enemies (HUFFAKER et al., 1970). This was verified in parts of the tea garden of RITC where copper fungicide was sprayed intensively. Leaf samples were collected from the experiment on mite stimulation by copper fungicide treatments (chapter 4.2.4.4.) and from roadside bushes that had received high doses of copper fungicide. The average frequency per leaf of the several predatory mites in the samples was determined.

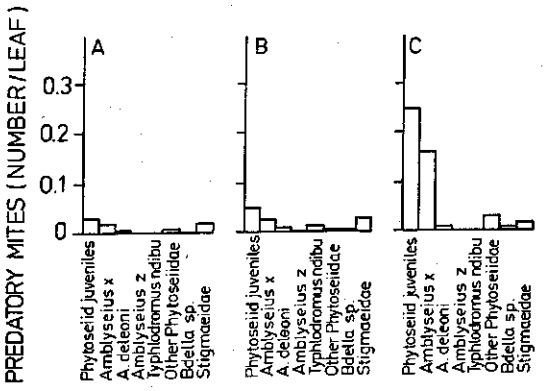


Fig. 27. The frequency of the predatory mites on leaves with different doses of copper fungicide.
A. 200 leaves from 4 untreated plots.
B. 200 leaves from 4 plots sprayed once in 3 weeks with 15 l 0.06% copperoxychloride 50 WP per 100 m^2.
C. 575 leaves from 12 roadsides treated intensively with copper fungicides.

Table 10. The distribution of suspected predatory mites over tea estates in West and Central Java and North Sumatra. The frequency represents the times a species was identified in samples of 50–200 leaves.

Estates	Predator species	Phytoseiidae:								Typhlodromus		Phytoseius	Podocinidae:		Stigmaeidae:										Miscellaneous:				
		Amblyseius largoensis	*A. deleoni*	*A. tamatavensis*	*A. syzygii*	*A. w*	*A. x*	*A. y*	*A. z*	*jackmickleyi*	*T. ndibu*	*crinitus*	*Lasioseius p*	*L. q*	*Zetzellia a*	*Z. b*	*Z. maori*	*Agistemus terminalis*	*A. denotatus*	*A. fleschneri*	*A. arcypaurus*	*A. e*	*A. f*	*A. g*	Bdellidae	Cunaxidae sp. a	Cunaxidae sp. b	Anystidae	Smariidae
West Java																													
Baku Negara		1	2		4		3											1	1					1				
Cibeurum			7										3															
Cibuni			7									1										2						
Cigaru			5										1			1	1		3									
Cisaruni		2	3	2			2																	1				
Gambung[1]		2	22	4	1	3	20	11	23	16	5	8	1	2	62	3		21	5	1		9	11	2	9	9	1	5	2
Goalpara							1																1						
Gunung Mas							1				1								2									
Malabar											1																	
Papandayan			8				1						2		2				3			5	4					
Pasir Nangka			1	1	1	2						1	2			1	1		5					1	1	1		
Pasir Sarongge													1						2									
Patuahwattee													1												1			
Purwakarta						1																						
Ranca Bolang			6					3																				
Ranca Suni				5		1						1	1						3									
Rongga																			1									
Santosa																												
Surangga			1			9									1	1	1											
Tambakan					1																							
Central Java																												
Bedakah																		1	1									
Tandjong Sari													1															
North Sumatra																												
Bah Butong							2																					
Bah Birong Ulu		1																										
Toba Sari		3																		2		6						

[1] The number of leaves from Gambung inspected for predators is not comparable (> 10000) to the other estates.

The predatory mite densities in both the untreated and copper fungicide treated plots are low, and hardly different in numbers and species composition (fig. 27). Of the predatory insects, only *Lestodiplosis oomeni* is present (average per leaf: 0.035 and 0.005 in the copper treated and untreated plots respectively). Scarlet mite densities are not high in these plots (fig. 26) and purple mite density is negligible. In contrast, the roadside samples are heavily infested by scarlet mites and purple mites (these mites were not counted). The population of predatory mites in the roadside samples does not seem to deviate in composition from those in the untreated plots except that *Amblyseius x* and juveniles are more frequent (fig. 27). The predatory insects *Wollastoniella testudo* and *Lestodiplosis oomeni* are both found in these samples (average per leaf: 0.009 respectively 0.061).

These observations do not indicate that treatment by a copper fungicide is harmful to predators. Therefore the increase in scarlet mite abundance after treatment by copper fungicide is not likely to be caused by adverse effects of the fungicide on the predators.

4.4. Predator characteristics

4.4.1. *Characterization per species*

A number of predators that could be important in keeping the scarlet mites in check were studied in the laboratory to find out which species and what stage of the prey was preferred, the amount of prey consumed, the reproduction on a diet of scarlet mites and the character of parthenogenesis.

The size of the dorsal shield of a specimen was measured by means of a micrometer in the dissection microscope. Preference for the stage of prey that was attacked (eggs or active stages) and the amount consumed were explored experimentally. Single predators were transferred to leaves (see chapter 3.2.2) infested by a known number (20–200) of eggs and immature scarlet mites. After 1–3 days, counting of the prey was repeated. A decrease in a certain stage represented the consumption and a preference for that stage. The results of this exploratory experiment (8 or more replicates) varied greatly. I took the maximum value observed as the best estimate of the species' predatory potential.

To explore the preference of predators for the different mites, tea leaves well infested by pink mites or purple mites were collected. The leaves were cut to standard size (see chapter 3.1.5) and inspected. Unwanted animals were removed. Female scarlet mites were introduced and left to oviposit. After some days, the females were removed, eggs and immature scarlet mites counted and predators introduced. Scarlet mites, Eriophyidae and predators were counted once in 1–3 days. Prolonged survival and reproduction of the predators without a decrease in the scarlet mite numbers was judged as an indication of a preference for the eriophyid prey[1]. A decrease in scarlet mite numbers in com-

[1] Eriophyidae were often found to decrease spontaneously, apparently as a consequence of unfavourable rearing conditions.

Table 11. Characteristics of scarlet mit predators.

Characteristics.	Predator species	*Amblyseius deleoni*	*A. x*	*A. y*	*A. z*	*Typhlodromus jackmickleyi*	*T. ndibu*	*Phytoseius crinitus*	*Zetzellia a*	*Agistemus terminalis*	*A. denotatus*	*Lestodiplosis oomeni*	*Wollastoniella testudo*
Length (μm) of dorsal shield of ♀		390	356	317	338	353	333	332	297	277	269	1500[1]	1250[1]
Scarlet mite consumption:													
preference for eggs		+	+	+	+	+	+	+	+	+	+	+	
preference for active stages													+
max. number of prey/♀, day[2]		6	14	1	30	40	.	.	7	3	4	3	185
in the presence[3] of pink mites		+	−	.	−	+	−	−	+	+	.	−	+
in the presence[3] of purple mites		+	−	+	+	+	+	+	+	+	.	−	+
Rearing:													
number of generations[4]		3	1	<1	3	5	<1	1	>12	>12	3	<1	<1
tendency to escape		+	+	+	−	−	−	−	−	−	−	+	−
Parthenogenesis:													
thelytokous		.	.	.	.	+	.	.				.	.
arrhenotokous									+	+	+		
Occurrence[5]													
common		+	+							+	+	+	
locally common				+					+				+
rare					+	+	+	+					

[1] approximate total length
[2] maximum consumption observed
[3] scarlet mite consumption maintained in spite of eriophyid prey also being present
[4] number of generations reared on scarlet mite prey
[5] according to table 10
+ yes/large
− no/small
. no data available

bination with a prolonged survival and reproduction of the predators was judged as an indication of a preference for scarlet mites.

As most Phytoseiidae are transparent, the colour of the intestine is a clue to the colour of the prey consumed. A pink or cream colour indicates consumption of pink mites; an orange, red or brown colour indicates consumption of scarlet and/or purple mites. Starved animals have flat, transparent bodies. These characteristics were used to interprete the preference for prey species, in addition to the criterium mentioned above.

Reproduction by unfertilized females indicates parthenogenesis. A purely male offspring of such a female indicates and *arrhenotokous* reproduction; a purely female offspring a *thelytokous* reproduction.

The predator characteristics are summarized in table 11. All predatory mites seem to prefer eggs to the active stages of the scarlet mite. The maximum consumption of prey observed is low in all but few predator species. Two species, *Amblyseius x* and *L. oomeni* seem to reject scarlet mites as prey when Eriophyidae are available. The other Phytoseiidae too seem to prefer Eriophyidae to scarlet mites. The reverse seems true with the Stigmaeidae. The three most common Phytoseiidae (*A. deleoni, A.x* and *A.y*) all showed a great tendency to escape, in spite of a water and oil barrier around the leaf. As such a large number of the Phytoseiidae escaped, few observations could be made on prey consumption or preference. This often led to a low rating in prey consumption. In contrast, *T. jackmickleyi* and the Stigmaeidae seem to prefer scarlet mite to eriophyid prey. These predators are not likely to escape and could be kept long enough to be able to determine the amount of prey consumed, the species preferred as well as the character of the parthenogenetic reproduction.

4.4.1.1. Phytoseiidae

Amblyseius deleoni MUMA et DENMARK

This species was long confused with *A. largoensis* MUMA until EHARA (1977) clearly distinguished *A. deleoni* from *A. largoensis* by having the spermathecal cervix widened internally. This predator accepted or even preferred pink mites and probably purple mites as alternative prey to scarlet mites. Pollen of rose mallow (*Hibiscus rosa-sinensis*), marrow (*Cucurbita pepo*) and ice plant (*Mesembryanthemum cristallinum*) were also accepted as food. The predator was kept alive for more than 25 days on pollen but reproduction was low and there was a great deal of cannibalism. On a diet of scarlet mites, the predator survived (maximum 42 days) and reproduced well (see chapter 4.4.2.1) but cannibalism was very evident even when prey was abundantly available. Lack of affinity to the scarlet mite is probably a cause of the cannibalism and the strong tendency to escape. High densities were never achieved in breeding experiments.

Field collected predators sometimes died within a few days, changing colour from transparent to completely white opaque. This may be caused by a patho-

gen. In Japan this predator can suppress *Panonychus ulmi* to a density well below the economic injury level (TANAKA and KASHIO, 1977). It has been observed as a predator of *B. phoenicis* on papaya in Hawaii (HARAMOTO, 1969). KAMBUROV (1971) described this predator as very polyphagous and cannibalistic in Israel.

A. deleoni is the most common and wide spread predator of scarlet mites.

Amblyseius x

This *Amblyseius*-like species has some taxonomic characteristics in common with the genus *Iphiseius*. The species and the genus are probably not described (VAN DE BUND, pers. comm.).

This species easily accepted pink an purple mite as well as scarlet mite as prey. Pollen of rose mallow, marrow and ice plant (cf. *A. deleoni*) were accepted as food. Reproduction and development were poor and cannibalism strong on a diet of pollen or scarlet mites. In contrast, reproduction and development were fast when pink or purple mite prey were available, resulting in high predator densities.

Amblyseius x is a common and often the most numerous predatory mite in tea. The predator was normally abundant on leaves infested by purple and scarlet mites after intensive copper fungicide treatments.

Amblyseius y

This species is taxonomically near to *A. newsami* EVANS and probably has not been described. Consumption of eriophyid prey could not be confirmed. On a diet of scarlet mites, reproduction and development was slow. *Amblyseius y* is rare but sometimes locally common.

Amblyseius z

This species is taxonomically near to *A. caudatus* BERLESE and has probably not been described. Besides scarlet mites, purple and especially pink mites were accepted as prey. Reproduction and survival were good on a diet of scarlet mites, but high densities were never attained. *Amblyseius z* was a rare predator though abundant in plots treated frequently with DDT.

Typhlodromus jackmickleyi DE LEON

This species belongs to the subgenus *Anthoseius*. Consumption of eriophyid mites could not be confirmed. On a diet of scarlet mites, reproduction (see chapter 4.4.2.1.) and survival (maximum 70 days) were good. The reproduction was thelytokous; males were never found. *T. jackmickleyi* is a rare predator and the densities are always low.

Typhlodromus ndibu PRITCHARD et BAKER

This species belongs to the subgenus *Neoseiulus*. Besides scarlet mites, pink mites were also accepted as prey. However, it was not certain if purple mites were accepted. On a diet of scarlet mites, reproduction and development was

poor. *T. ndibu* was a rare predator though common in plots treated frequently with DDT.

Phytoseius crinitus SWIRSKI et SHECHTER
This species accepts and probably even prefers pink mites to scarlet mites; acceptance of purple mites was however not certain. On a diet of scarlet mites, reproduction and development was poor. *P. crinitus* is a rare predator of scarlet mites.

Several other phytoseiid species were found in tea preying upon scarlet mites. All species were rare and few data on predatory behaviour are available. These species are *Amblyseius largoensis* MUMA, *A. tamatavensis* BLOMMERS, *A. syzygii* GUPTA, *Amblyseius w* (near *A. newsami* EVANS).

4.4.1.2. Stigmaeidae
Stigmaeid mites are easier to rear than Phytoseiidae. They are smaller and less mobile than the latter. The size, habitus and predatory behaviour of the different stigmaeid species are all very similar. All species show some preference for scarlet mite eggs above the eriophyid mites, and also prey on the common tydeid mites. The reproduction of the investigated species is arrhenotokous. Eggs and new-born larvae are bright yellow. This colour changes to orange, red or brown when scarlet mites are eaten.

Zetzellia a
This species – probably not described – accepted pink and purple mites as a prey but seemed to prefer scarlet mites. On a diet of scarlet mites reproduction and development were high: a population was reared on scarlet mites for a whole year in the laboratory. Densities up to 30 individuals/10 cm^2 of leaf surface were attained. *Zetzellia a* is locally a common predator of scarlet mites.

Agistemus terminalis QUAYLE
Although this species accepted pink an purple mites as prey, it seemed to prefer scarlet mites. On a diet of scarlet mites reproduction and development were high. The species was reared for a whole year in the laboratory on scarlet mites. Densities up to 20 individuals/10 cm^2 of leaf surface were attained. *A. terminalis* is locally a common predator of scarlet mites.

Agistemus denotatus GONZALEZ
This species reproduced (see chapter 4.4.2.1.) and survived (maximum 80 days) well on a diet of scarlet mites, and is a common predator in tea.

Agistemus f
This species – probably not described – reproduced and developed well on a diet of scarlet mites, and is locally a common predator in tea.

Besides the species mentioned above, more stigmaeid species were found on tea, preying on scarlet mites. All these species fed readily and developed and reproduced well on a diet of scarlet mites. They were rare or locally common. These species include *Agistemus fleschneri* SUMMERS. *A. arcypaurus* GONZALEZ, *Agistemus e, Zetzellia b* and *Z. maori* GONZALEZ.

4.4.1.3. Other suspected predatory mites

Two species of cunaxid mites were found to prey on the eggs of scarlet mites. The predation was however low and there was no reproduction. Both cunaxid species were rare.

Three relatively large (ca. 1 mm) mite species were found, belonging to the predatory families Bdellidae, Anystidae and Smariidae (BAKER and WHARTON, 1952). However, there were no indications of actual predation on scarlet mites. The suspected predators were usually not collected in leaf samples but were sometimes abundant in beating samples. The *Bdella* species (Bdellidae) could survive for long periods among scarlet mites, gradually becoming thinner but predation was not observed. No species reproduced in the laboratory.

4.4.1.4. Predatory insects and other arthropods

Many tea leaf inhabiting arthropods (e.g. *Scymnus* sp., *Stethorus* sp. and several other Coccinellidae, beetles, bugs, spiders and centipeds) were tried for predatory behaviour (see chapter 3.3), but most did not prey upon scarlet

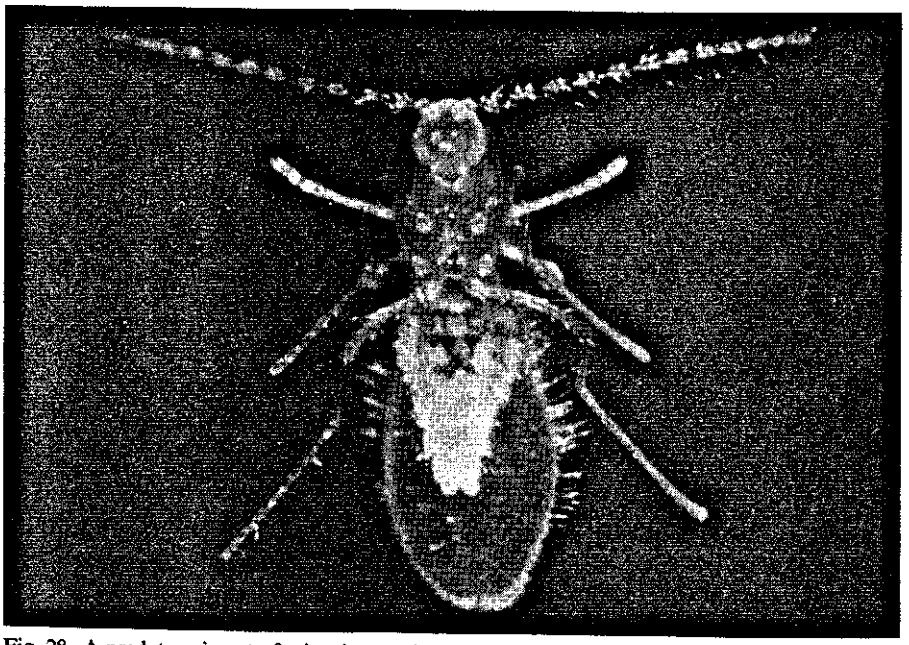


Fig. 28. A predatory insect of mites in tea, the gall midge *Lestodiplosis oomeni* (Diptera: Cecidomyidae). Magnification approximately 60×.

Table 12. Size, duration and scarlet mite consumption of the successive stages of an individual *Wollastoniella testudo* specimen (Hemiptera: Anthocoridae) as observed on a tea leaf in the laboratory.

Predator development			Scarlet mites consumed		
nymphal stage	size (mm)	duration (days)	eggs	juveniles	adults
1	.	.	.	.	.
2	0.4	6	67	3	9
3	0.6	6	28	6	74
4	0.7	12	249	183	0
5	1.25	10	406	513	0
adult	1.25	55	2169	598	430

mites. An anthocorid bug and a gall midge larva were recognised as predators of scarlet mites. Some characteristics of these insects are described below.

Lestodiplosis oomeni HARRIS (Diptera: Cecidomyidae)

The specimens collected during the study have been described recently by HARRIS (1982).

The larva of this gall midge is a voracious predator of purple and pink mites. When hungry, it also preys on scarlet mites, Phytoseiidae, Psocoptera and larvae of its own species. The larvae survived for long periods (over 2 months) on a diet of scarlet mites but hardly developed. Only mature larvae could be reared to the adult stage. After a pupal stage of two weeks, a minute adult (fig. 28) emerged. The gall midge could not be bred since couples were never available.

L. oomeni is a common predator. It is normally found as a maggot on the underside of maintenance leaves, especially where purple mites are abundant and treatment by copper fungicide is intensive. Adults are too small to be sampled in a beating net. The pupa is parasitized by a small wasp (family Ceraphronidae[1]) that leaves after emergence a characteristic hole in the pupal spinnings. The abundance of the holes indicated that parasitation was common.

Wollastoniella testudo CARAYON (Hemiptera: Anthocoridae)

The specimens collected during this study have been described recently by CARAYON (1982). Size, scarlet mite consumption and duration of the development of one specimen of this predatory bug is given in table 12. The quantity of prey consumed is very large in comparison to the other predators. The development from egg to adult probably takes longer than that of the scarlet mite (cf. chapter 4.1.1.). Juvenile stages developed easily on a diet of scarlet mites when these were abundantly available. The predator seemed to prefer moving prey to eggs and quiescent stages of the scarlet mite. I did not observe accep-

[1] Gratefully acknowledged identification by K. W. R. ZWART.

tance of pink or purple mites as prey. The predator soon died of starvation when prey was scarce – a common drawback of insect predators (FLAHERTY and HUFFAKER, 1970). The predator could not be bred since couples were never available. *W. testudo* is locally a common predator on those tea bushes which are heavily infested by scarlet mites.

4.4.2. *Bionomics of some predators*

4.4.2.1. Multiplication of three characteristic predatory mites

The bionomics of three characteristic predatory mites were studied in the laboratory. *Amblyseius deleoni* (the most common phytoseiid), *Typhlodromus jackmickleyi* (a voracious but rare phytoseiid), and *Agistemus denotatus* (the most common stigmaeid) were reared in closed cells (see chapter 3.2.2) and given plenty of scarlet mites. The survival and fecundity rate of respectively 7, 4 and 5 females of each species were determined in relation to age (cf. chapter 4.1.1–4.1.3). The sex ratio of field collected animals was assessed. Based on these data, the net reproductive rate R_0, the intrinsic rate of increase r_m and the mean generation time T were calculated according to BIRCH, 1948 (see chapter 4.1.3). The narrow range of temperatures in the laboratory remained well within the range of the field conditions (cf. table 13 and table 4).

The life parameters R_0, r_m and T of the tested predator species are given in table 13, together with those of the scarlet mite on tea (from chapter 4.1.3). Although their life cycles are rather different, the intrinsic rate of increase r_m of the two most common predators (*Amblyseius deleoni* and *Agistemus denotatus*) are about equal. These rates are considerably higher than that of the scarlet mite. Consequently, these predators are able to multiply quicker than the prey – a useful characteristic of natural enemies (HUFFAKER et al., 1970). In contrast, the intrinsic rate of increase of *T. jackmickleyi* falls short of that of the prey and the other predators. This result is rather unexpected in view of the large consumption of scarlet mites by females of this predator (cf. table 11). *Amblyseius deleoni* and *Agistemus denotatus* of the three species tested are potentially the only effective predators of scarlet mites.

Table 13. Life parameters of scarlet mites and some of the predators, determined in the laboratory. The percentage of females is derived from field populations. The temperatures during the study in the laboratory are given as averages of the daily extremes.

Species	Temperature °C	%Female	Life parameters		
			R_o	r_m	T(days)
Brevipalpus phoenicis[1]	19.1–23.4	100	21.9	0.0610	50.6
Amblyseius deleoni	17.4–21.8	87	5.37	0.0846	19.9
Typhlodromus jackmickleyi	17.3–21.5	100	3.84	0.0530	25.4
Agistemus denotatus	17.0–23.1	75	14.6	0.0840	31.9

[1] data from chapter 4.1.3

4.4.2.2. Suppression of scarlet mites by three stigmaeid predators

Common stigmaeid predator species were studied and the ability to keep scarlet mites in check compared. On 12 isolated leaves (clone Cin 143) a scarlet mite population was started by introducing 10 young females per leaf. After 3–5 days, 3 eggs or larvae of the predator were introduced onto each leaf. The predators were *Agistemus terminalis, Agistemus f,* and two strains of *Zetzellia a;* the suppressing effect of each was studied in 3 leaf replicates. The experiment (chapter 4.1.2) on the multiplication of scarlet mites was used as a (non-simultaneous) control. Eggs, juveniles and adults of scarlet mites were counted once in two weeks; predators and adult scarlet mites were counted weekly. The experiment was continued for 60 days.

Three out of 12 mite populations tested, developed high densities (table 14). The juvenile predators introduced onto these three leaves turned out to be all male, unable to multiply and incapable of keeping the mites in check. These leaves succumbed to mite damage shortly after the 60-day census.

The mite multiplication in the 9 remaining leaves was more or less effectively suppressed. The three species of predators appeared almost equally capable of suppressing the mites. Although prey mite densities in some cases became very low, the predators did not become extinct during the experiment. After the end of the experiment, however, some populations turned all male and died out. This is a likely consequence of the arrhenotokous reproduction and the isolation of the experimental ecosystem.

The stigmaeid species studied proved to be able to keep the scarlet mites at a low density without a considerable risk of becoming extinct when prey becomes scarce. The high intrinsic rate of increase of these species when compared to that of scarlet mites and the low food requirements suggest that the stigmaeid species are able to control the scarlet mites efficiently.

Table 14. Prey density in 12 predator-prey systems (leaves) as an indication of the efficacy of control by 3 Stigmaeid species. The number of scarlet mites per leaf is given at 60 days after the introduction of 10 female scarlet mites and 3 Stigmaeid eggs or larvae per leaf. The experiment had 3 replicates.

Predator species	Scarlet mites/leaf		
Zetzellia a (strain 1)	505	29	31
Zetzellia a (strain 2)	8	14	28
Agistemus f	49	644	654
Agistemus terminalis	235	118	99
No predator[1]	900	842	767

[1] Non-simultaneous control: data from the experiment in chapter 4.1.2.

4.5. Experimental manipulation of predators

The role of predators in natural pest control can be evaluated by experimental exclusion or by interference with the predators in the pest populations under observation. A practical interference technique is the frequent spraying of pesticides that selectively kill the predators without affecting the pest (*predator check method*). A high degree of selectivity however is essential.

4.5.1. *Preliminary tests: toxicity effects*

Pesticides that would be able to kill predators of scarlet mites in field plots were selected from the literature. Selective toxicity to different groups of predators (predatory insects and mites, predatory insects, predatory mites especially Phytoseiidae) were criteria for selection. Candidate pesticides were further screened by comparative tests in the laboratory for toxic or stimulative effects on scarlet mites. One pesticide caused an unexpected change in the predatory fauna in the field experiment, so it was studied in the laboratory for its toxicity to the main species of predators.

4.5.1.1. Candidate pesticides for predator exclusion

The toxicity of pesticides to predators, particularly those of spider mites, has been studied extensively in literature. The predatory mites studied mainly belong to the family of Phytoseiidae. Stigmaeidae have rarely been studied. When it appeared that phytoseiid predators predominated in the field selected for the predator check experiment, no further attention was paid to pesticides toxic to Stigmaeidae. Overmeer and Van Zon (1981) compared the effect of 10 pesticides upon 3 species of phytoseiid mites. They found the LC 50 values of most pesticides to be similar in the 3 species. Since the sensitivity to pesticides was found to be comparable between phytoseiid species, it seemed justified to select the pesticides for use in the predator experiment on the basis of literature about phytoseiid species in general.

The predatory insects were expected to belong to widely separated families, therefore broad spectrum insecticides were looked for. A high toxicity to Coleoptera was considered useful, for this order contains a number of important mite predators (McMurtry et al., 1970).

According to the literature, pesticides suitable for killing predatory insects and predatory mites are *carbaryl* (McMurtry et al., 1970; Hussey and Huffaker, 1976; Croft and Brown, 1975; Croft and Nelson, 1972); *permethrin* (Hoy et al., 1979); Hoy and Roush, 1978; Hoyt et al., 1978; Rock, 1979; *DDT* (McMurtry et al., 1970; Hussey and Huffaker, 1976; Croft and Brown, 1975; Delattre, 1974; Readshaw, 1975). Pesticides for killing predatory mites: *mancozeb* (Coulon and Barres, 1976); *maneb* (McMurtry et al., 1970; Hussey and Huffaker, 1976; Croft and Brown, 1975; Nelson et al., 1973; Overmeer and Van Zon, 1981); *dinocap* (McMurtry et al., 1970; Van Zon and Wysoki, 1978; Croft and Brown, 1975; Croft and Nelson, 1972; Delattre, 1974; Nelson et al., 1973). Pesticides for killing predatory insects:

PH 60–42 (GRUYS and VAN DER MOLEN, 1977). This experimental insecticide (a pyrazoline compound) made by Duphar, Holland, was considered promising because of the strong and selective action it has upon insects, especially upon Coleoptera.

Finally, two fungicides (copperoxychloride and copperoxyde) were included in the test series because these were observed to increase the scarlet mite abundance in the field (chapter 4.2.4.4).

4.5.1.2. Toxicity test on scarlet mites

Twelve leaves for the rearing of mites (see chapter 3.1.5) were collected from clone Cin 143, cleaned and cut to the required size. Twenty young, field collected adult scarlet mites were transferred to each leaf. After 2 days of adaptation, mites were again counted and if necessary complemented. The leaves were divided into 4 treatments with 3 replicates. The treatments consisted of dipping the whole leaf for 10 seconds in a solution of the pesticide, or in water for the control. The pesticide concentrations were in proportion of 16:4:1 (see table 15). After dipping, the droplets were taken off and the leaf stored as usual in water (fig. 12 and 13). Adult mites and offspring were counted at least every six days under a dissection microsope. The four treatments were evaluated as to the fecundity of the females (average oviposition/♀), the survival of the females (% survival) and the multiplication of the populations after a period of 16–27 days. The results of each pesticide experiment were tested by Duncan's Multiple Range Test at $P = 0.05$.

The average survival, oviposition and multiplication in each pesticide test is given as a percentage of the average control value in table 15. Several pesticides appear only slightly to influence the multiplication of the populations (i.e. the combined effect of survival and reproduction). Deviations from the development in the control (= 100%) are significant in the permethrin, DDT, mancozeb and maneb treatments.

Permethrin appears to be very toxic to scarlet mites in all concentrations, contrary to the results of a preliminary test. HEUNGENS and VAN DAELE (1977) too reported permethrin as an efficient acaricide for controlling *Brevipalpus obovatus* on azalea.

DDT seems to be neutral to scarlet mite development in the middle concentration, it may be somewhat stimulative (though not significant) in the low concentration and is toxic in the high concentration.

Mancozeb is toxic to scarlet mites in all three (high) concentrations. The toxicity may even not be expressed fully in the test because the leaves were not dipped completely. The petioles of the leaves remained untreated, and a disproportionally large part of the mite populations managed to survive and thrive on the petioles.

Maneb too is toxic to scarlet mites in all three (high) concentrations. The leaves in the test were dipped completely. It seems that maneb in its lowest concentration is somewhat less toxic to scarlet mites than mancozeb. The mite

Table 15. The effect of pesticides on the development of scarlet mite populations in the laboratory. The survival of the parental females, the oviposition per female and the multiplication of the population during the indicated number of days after treatment is given as a percentage of the (water treated) control.

Treatment		In percentage of untreated			After days
pesticide	% active ingredient	survival	oviposition	multiplication	
	0	100 a	100 a	100 a	
Carbaryl	0.0032	121 a	92 a	110 a	27
	0.0128	108 a	97 a	104 a	
	0.0511	131 a	96 a	126 a	
	0	100 a	100 a	100 a	
Permethrin	0.0031	2 b	0 b	2 b	18
	0.0125	0 b	0 b	0 b	
	0.0500	0 b	0 b	0 b	
	0	100 ab	100 a	100 ab	
DDT	0.0068	107 a	126 a	139 a	16
	0.0270	78 bc	103 a	80 ab	
	0.1080[1]	62 c	70 a	46 b	
	0	100 a	100 a	100 a	
Mancozeb	0.0800	46 ab	28 b	28 b	26
	0.3200	19 b	20 b	20 b	
	1.2800	14 b	3 c	2 b	
	0	100 a	100 a	100 a	
Maneb	0.0800[1]	40 b	54 b	31 b	25
	0.3200	12 b	5 c	1 c	
	1.2800	0 b	3 c	0 c	
	0	100 a	100 a	100 a	
Copper	0.0019	97 a	113 a	109 a	18
oxy-chloride	0.0075	103 a	106 a	106 a	
	0.0300[1]	102 a	111 a	113 a	
	0	100 a	100 a	100 a	
Copper	0.0019	84 a	92 a	77 a	23
oxyde	0.0075	99 a	88 a	88 a	
	0.0300	99 a	94 a	69 a	
	0	100 a	100 a	100 a	
PH 60–42	0.0019	91 a	93 a	84 a	19
	0.0075	85 a	92 a	79 a	
	0.0300[1]	90 a	103 a	94 a	

[1] Concentration also used in field experiment.
a, b, c. Any two percentages in each pesticide test, not followed by the same letter, are significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Table 16. Pesticides used in the predator check experiment.

Pesticide	Formulation	Target predators	Origin	Spray concentration
PH 60–42	25% flowable	insects	Duphar	0.12%
Maneb	80% WP	mites	Dupont	0.10%
DDT	72% WP[1]	insects + mites	unknown	0.15%

[1] Analyzed by the Dutch Plant Protection Service.

multiplication in none of the other treatments deviated significantly from the control. Carbaryl is not found to be toxic to scarlet mites, contrary to the results of a preliminary test. PH 60-42 and the copper fungicides may be considered as being inert to scarlet mites.

4.5.1.3. The exclusion pesticides

As exclusion pesticides I chose respectively DDT to kill the predatory mites and insects, maneb to kill the predatory mites and PH 60-42 to kill the predatory insects (table 16).

The average dose per leaf applied by field sprays is calculated to be in the order of 8 to 17 times lower than when applied by leaf dipping (chapter 3.4.2). These figures are based on the presumption of a completely even distribution of the pesticide over het sprayed field and an estimated loss to non-target surfaces of 30–70%.

The toxic effects of these doses of DDT and maneb to scarlet mites may be considered negligible. Therefore, I considered these pesticides acceptable for use in the predator check experiment (chapter 4.5.2) in spite of the toxicity to scarlet mites in high dosages.

4.5.1.4. Verification of DDT toxicity on predators

The toxicity of DDT on predators was studied in the laboratory. From clone Cin 143, 24 leaves for mite rearing (see fig. 12 and 13), were collected, cleaned and cut to standard size. Ten field collected adult scarlet mites were transferred to each leaf and left to multiply for a week. Then half of all the leaves was dipped for 10 seconds in a DDT-solution (0.15% DDT 72 WP), the same concentration as used in the field experiment. The larger droplets were removed and the leaves dried, predators were then introduced individually to a treated and an untreated leaf. Phytoseiid predators, which tended to escape from the leaf, were also tested in closed cells. A clean tea leaf was dipped in the DDT solution and another left untreated. Cells were constructed as usual (chapter 3.2.2). Excessive quantities of scarlet mite prey were brushed into the cells. The cells were closed with the aid of a cover glass and adhesive tape after the introduction of individual Phytoseiidae. Survival of the predator was verified every other day. The experiments were repeated several times. The number of predators available was unfortunately insufficient to permit statistical analysis. DDT was judged to be toxic to the studied species when survival on all treated leaves appeared considerably shorter than on the untreated leaves.

Table 17. Survival of predators (in average duration in days, with standard deviation SD and number of observations n) reared on untreated and DDT-treated leaf substrates. Rearing units were leaves surrounded by water, or closed cells. A reduced survival on DDT treated leaves compared to untreated leaves is judged as a toxicity of DDT.

Species	Rearing unit	Survival (days)						Toxicity of DDT[1]
		untreated			DDT-treated			
		mean	SD	n	mean	SD	n	
Phytoseiidae:								
Amblyseius deleoni	leaf	14.1	11.4	4	1.1	0.24	7	toxic
	cell	8.2	3.0	3	2.5	2.1	2	
Amblyseius x	leaf	2.0	1.2	4	1.0	0	4	toxic
	cell	5.5	0.7	2	1.0	0	3	
Amblyseius y	leaf	13.9	21.7	5	1.0	0	2	toxic
	cell				1.5		1	
Amblyseius z	leaf	3.7	4.6	3	2.5	2.1	2	toxic
	cell	5.8	2.3	3	1.6	0.5	4	
Typhlodromus	leaf	5.0	2.8	2	7.5		1	non toxic
jackmickleyi	cell				5.0	1.4	2	
Stigmaeidae:								
Zetzellia a	leaf	14.3	15.7	4	7.2	5.9	8	non toxic
Agistemus terminalis	leaf	9.1	7.7	4	7.8	8.8	2	non toxic
Agistemus denotatus	leaf	17.7	11.0	3	21.8	22.5	3	non toxic
Agistemus g	leaf	21.5	17.2	4	12		1	non toxic
Agistemus e	leaf	17.5	7.8	2	7.5	2.1	2	non toxic
Insects:								
Lestodiplosis oomeni	leaf	11.9	16.5	6	6.5	7.1	4	non toxic
Wollastoniella testudo	leaf	24		1	0.5		1	toxic

[1] This assessment of the toxicity of DDT is not based on a statistical analysis.

The average survival period of the predator species studied in the DDT-treated and untreated series is given in table 17 with an assessment of the toxicity of DDT. The pesticide appeared to be toxic to most Phytoseiidae, and not or only slightly toxic to most Stigmaeidae. *Lestodiplosis oomeni* of the hexapod predators was hardly affected, but *Wollastoniella testudo* appeared to be sensitive to DDT.

4.5.2. *Predator check experiment*

4.5.2.1. Location and method

A predator interference or check experiment (DEBACH and HUFFAKER, 1971) was carried out in the tea gardens of RITC in Gambung from May 1979 to October 1980. The experiment was located in a tea plantation 64 years old. Except for pesticide treatments, the garden maintenance was normal, with plucking at intervals of 7–14 days, manuring and manual weeding. The experiment

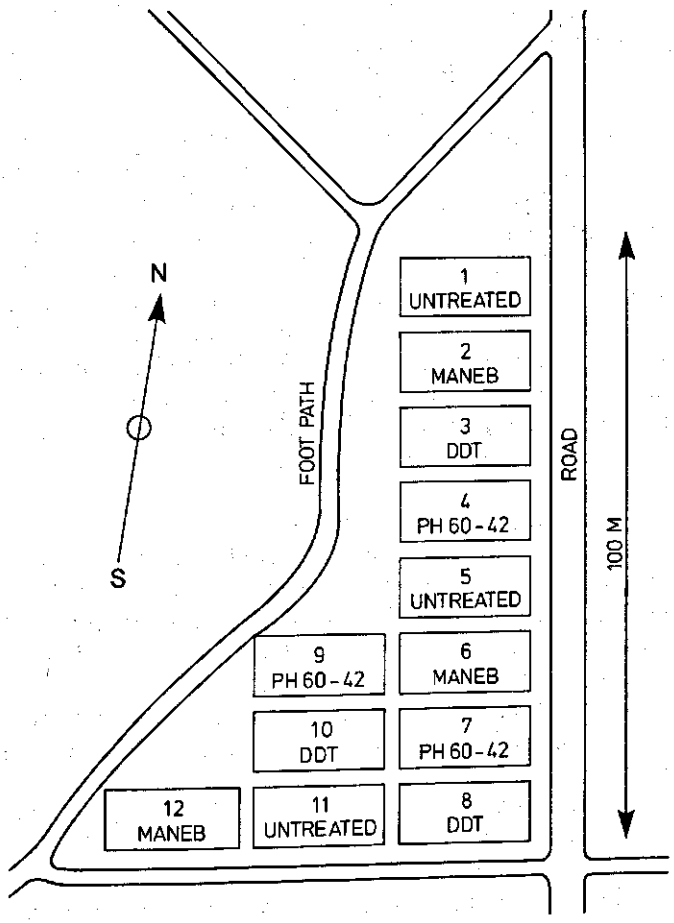


Fig. 29. Lay-out of the predator check experiment. The plot numbers and treatments are indicated.

started 2 years after the last pruning.

Twelve experimental plots of 10 × 20 m were laid out in a randomized complete block design, modified to fit the shape of the field (fig. 29). Four meter wide border strips between plots and an adjacent road or footpath were maintained where possible. The plots were marked by bamboo poles and plastic ribbon, and separated by 2 m wide strips. The twelve plots were divided into 4 treatments with 3 replicates. The 3 control plots were left untreated. The other plots were sprayed once in 3 weeks (in total 24 times) with the pesticides chosen for a selective killing of different groups of predators (table 16). Per plot of 200 m^2, 15 l of fluid was applied by knapsack hand sprayer. The bushes were sprayed from below, with the nozzle directed upward to reach the underside of the maintenance leaves (fig. 17). Time of application varied between 10 and 12 a.m.

Scarlet mites and predators were counted in leaf samples with intervals of

6 weeks during the first period of the experiment (May-October 1979), and later with intervals of 9 weeks. The first sampling was carried out just before the first pesticide treatment. Especially the counts on leaves were used for correlation analysis between the densities of scarlet mites and predators as having the same substrate as a measure of reference. In 25 places per plot, overhanging branches were beaten over a funnel net to sample predatory insects and mites (see chapter 3.2.1). Hidden arthropods were sampled once from collars of corrugated cardboard around the stems of 5 tea bushes per plot (see chapter 3.2.1).

It was supposed that the populations of predators and mites required some time to adapt to the selective stress of the exclusion pesticides. As a – rather arbitrary – period for a numerical adaptation, I chose a period of 5 months after the start of the experiment (June – October 1979). This period equals about 3 generations of the scarlet mite and 5 or more of the common predators (cf. table 13). The second period was chosen to commence simultaneously with the rainy season and to cover (nearly) one year.

4.5.2.2. The checking of the predators

Negligible numbers of predatory insects were found in the treated fields. In table 18 only the totals for the whole final year are given per treatment and per sampling method. These total figures are low. It is therefore concluded that the contribution of the predatory insects to the natural control of scarlet mites was negligible in the predator check experiment.

The composition of the predatory mite fauna during the first and the second period of the experiment is given in fig. 30A respectively 30B and C. Few predatory mite species are found in *more* than negligible numbers. These are in the leaf samples *Amblyseius x*, *A. deleoni*, *A.z* and the Stigmaeidae, and in the beating net samples *A. deleoni*, *A.z*, *Bdella* sp. and the Stigmaeidae (fig. 30B and C respectively). The diverging results of both techniques may be caused by a difference in the microhabitat sampled (leaves or branches) and in the behaviour of the predators (e.g. tenacity to the substrate, escape behaviour, sensitivity to disturbance).

In the untreated plots, all species are rather poorly represented, except *A. deleoni* in some beating net samples. In the PH 60-42 treated plots, the species

Table 18. The total number of predatory insects sampled in the predator check experiment. These totals are found by summation over the 3 replicates and 6 censuses of the last 12 months.

	Lestodiplosis oomeni	*Wollastoniella testudo*	
	leaf samples	beating net	stem collars
Untreated	11	20	1
PH 60–42	8	31	3
Maneb	18	14	3
DDT	1	3	7

composition largely corresponds to that in the untreated plots, but phytoseiid juveniles, *Amblyseius z* and the Stigmaeidae are often more numerous. In the maneb treated plots, Phytoseiidae are fewer than in all other treatments, but the Stigmaeidae are more abundant than in the untreated plots. In the plots treated with DDT *Amblyseius x* has disappeared and *A. deleoni* has very nearly disappeared directly after the start of the applications. *Bdella* sp. is also less numerous than elsewhere. Simultaneously, *Amblyseius z* and the Stigmaeidae (mainly *Agistemus f*) have consistently increased.

These results suggest that the repeated treatments by the exclusion pesti-

Fig. 30A.

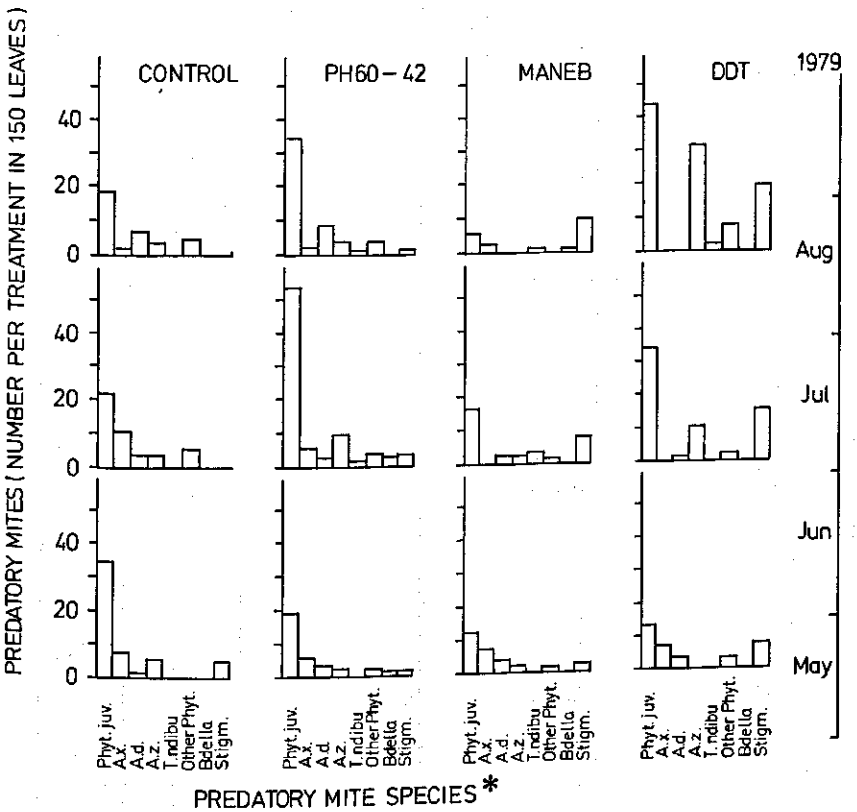
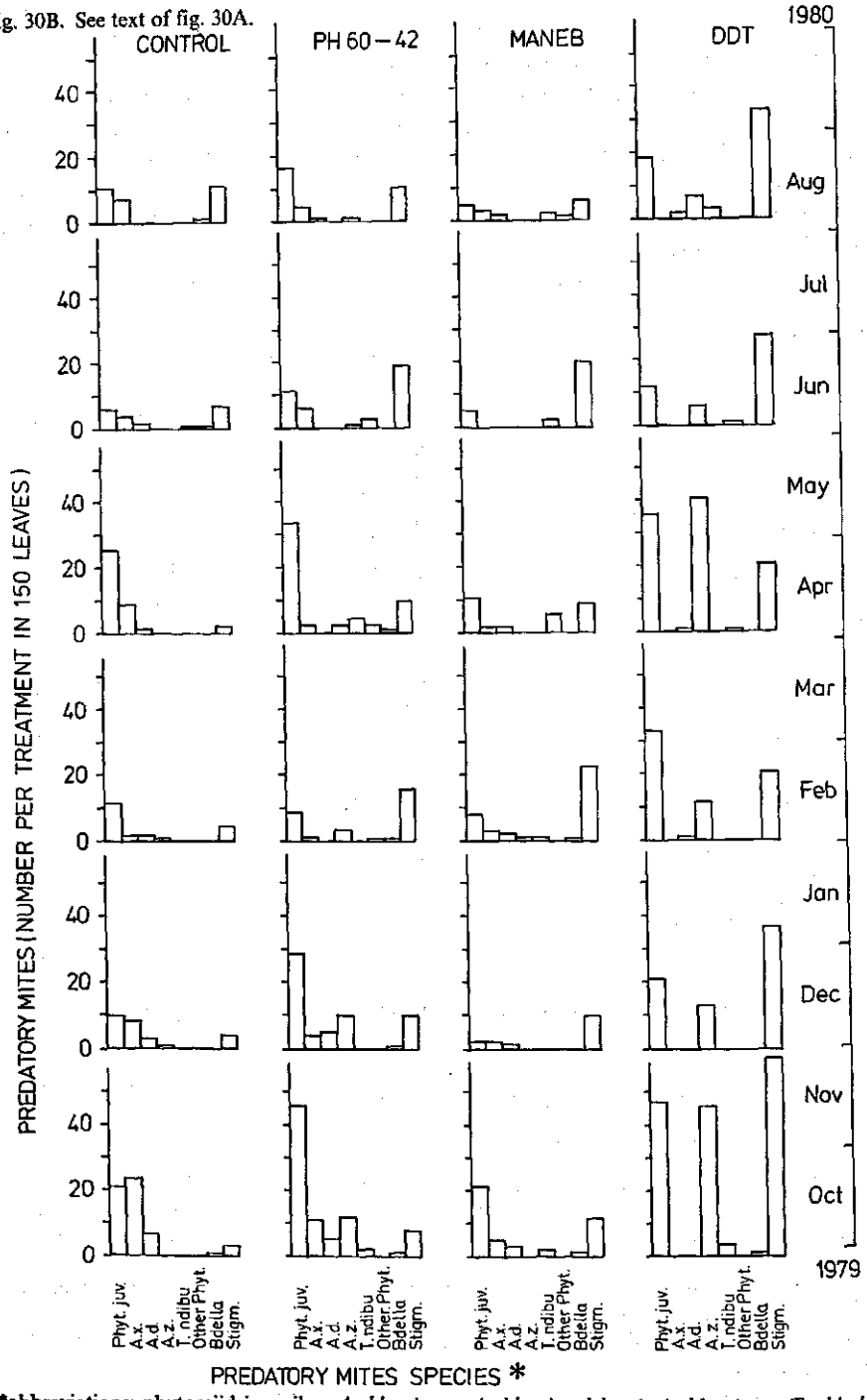


Fig. 30A, B and C. The frequency of the predatory mites in the predator check experiment. The counts from the 3 replicates within each treatment are combined. The predators are counted in leaf samples (fig. A and B) and in beating net samples (fig. C). The right hand scale indicates the date of each sampling.

The period covered by fig. A contains a pre-treatment sampling and two samplings during a period of numerical adaptation to the selective pressure by the exclusion pesticides. During the period of numerical adaptation to the selective pressure by the exclusion pesticides. During the second period (covered by fig. B and C) the populations are considered to have adapted to this selective pressure.

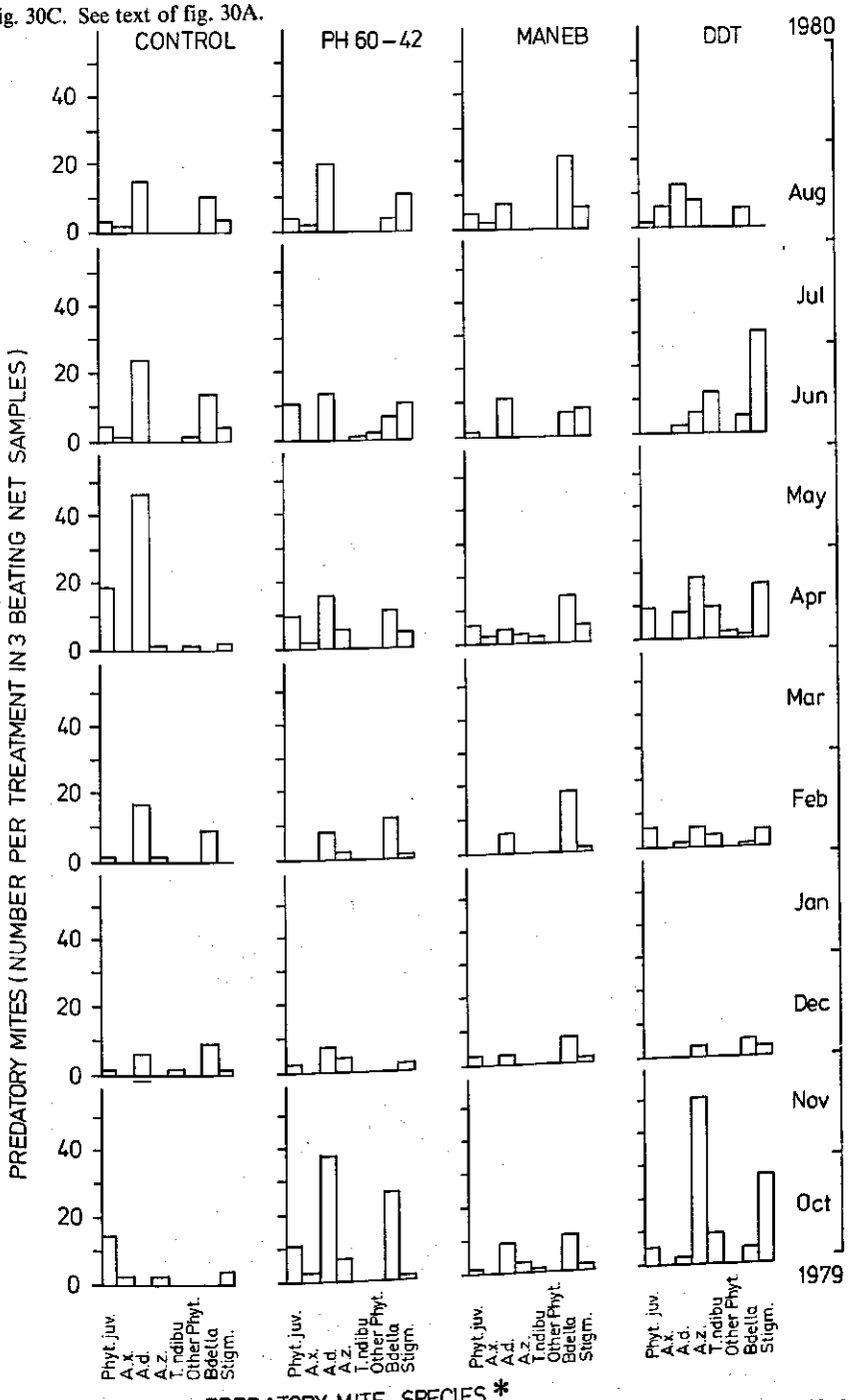
*abbreviations: phytoseiid juveniles, *Amblyseius x, Amblyseius deleoni, Amblyseius z, Typhlodromus ndibu*, other Phytoseiidae, *Bdella* sp., Stigmaeidae.

Fig. 30B. See text of fig. 30A.



*abbreviations: phytoseiid juveniles, *Amblyseius x*, *Amblyseius deleoni*, *Amblyseius z*, *Typhlodromus ndibu*, other Phytoseiidae, *Bdella* sp., Stigmaeidae.

Fig. 30C. See text of fig. 30A.



*abbreviations: phytoseiid juveniles, *Amblyseius x, Amblyseius deleoni, Amblyseius z, Typhlodromus ndibu,* other Phytoseiidae, *Bdella* sp., Stigmaeidae.

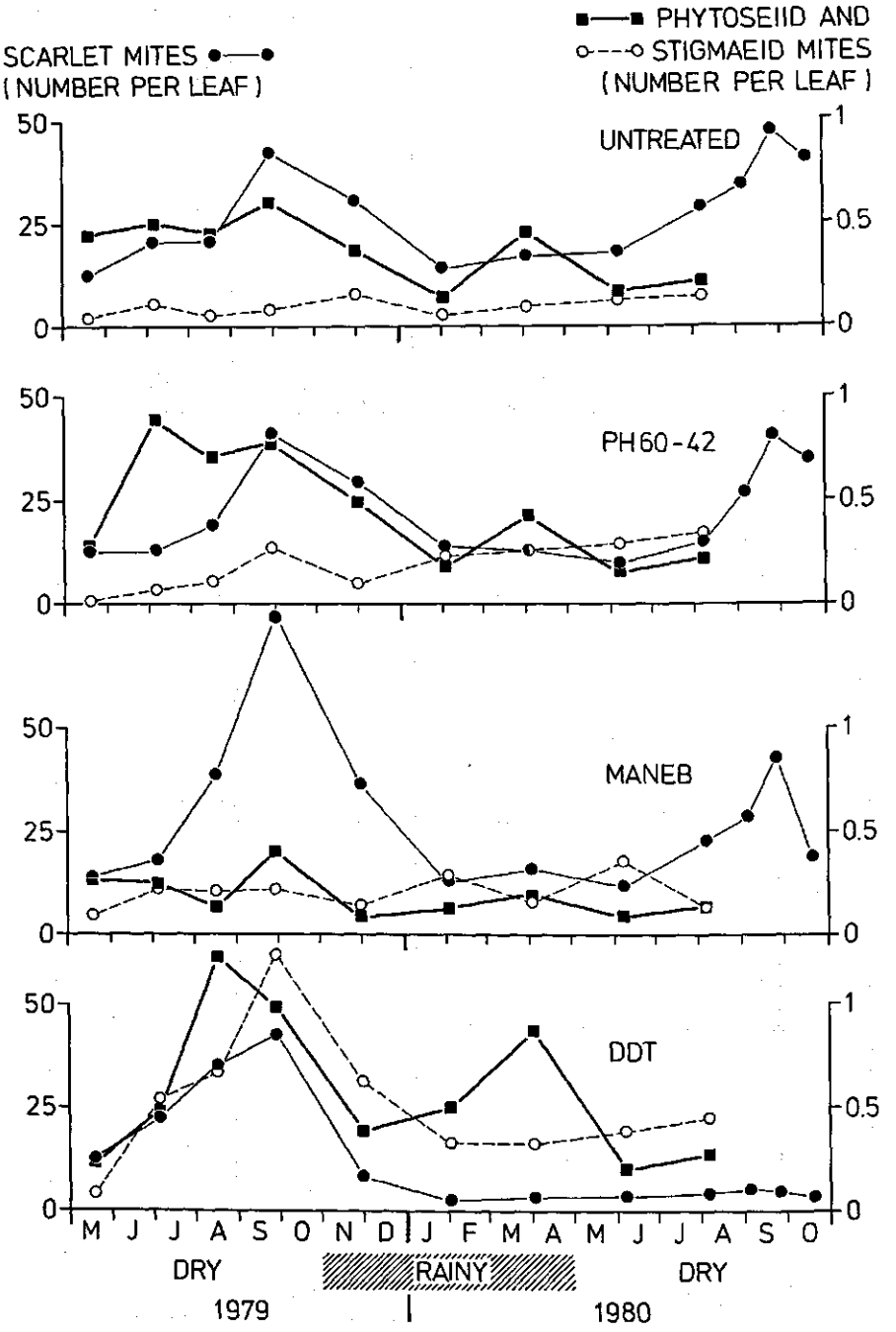


Fig. 31. The numerical fluctuations of the scarlet and predatory mite populations in the 4 treatments of the predator check experiment. The counts from the 3 replicates within each treatment are combined.

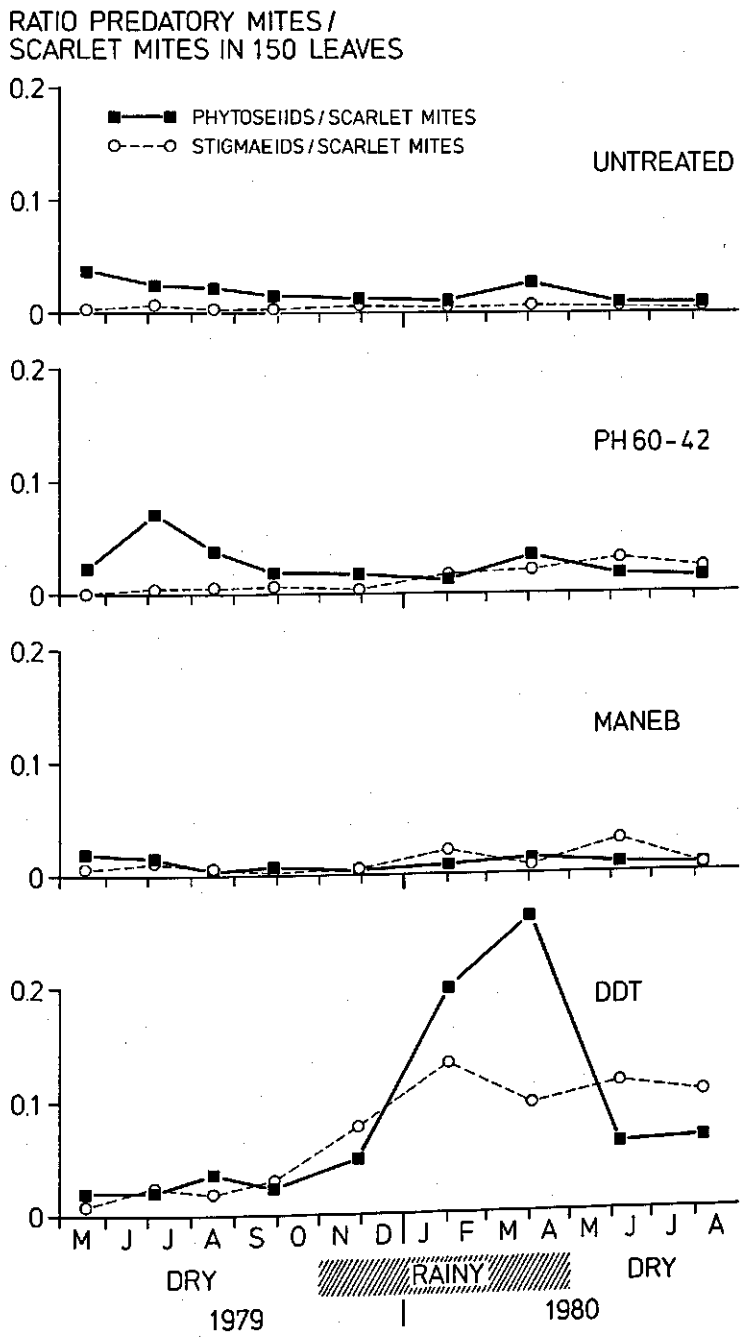


Fig. 32 The fluctuations of the predatory mite densities relative to the scarlet mite densities in the 4 treatments of the predator check experiment. The counts from the 3 replicates within each treatment are combined.

cides failed to kill a large proportion of the target group of predators as intended (except *A. deleoni* and *A.x* in the DDT treatments). Nevertheless, the treatments appeared successful in diversifying the predator abundances in the respective fields. Fortunately the experimentally diversified predator abundances permit analysis of the role of predation in the natural control of scarlet mites no less than the intended diversification by excluding predators from part of the experimental fields would have allowed.

4.5.2.3. Numerical fluctuations of scarlet mites and predators

The numerical fluctuations of scarlet mites during the whole predator check experiment are given per treatment in fig. 31 (left hand scale). The treatment values are averages of the 3 replicates. Corresponding weather conditions are given in fig. 33.

During the only rainy season and the two dry seasons covered by the experiment, the numerical fluctuations of scarlet mites in all treatments showed a common pattern. Corresponding to the numerical fluctuations described before (chapter 4.2.4.2), the pattern consists of a numerical increase of the populations during the dry season reaching a maximum at the end (September), followed by a strong drop in mite numbers during the transition to the rainy season (October). A deviation from this pattern is apparent only in the three DDT treated populations. The densities here receded to a very low and constant level when the rainy season began. A numerical increase during the subsequent dry season was absent in these populations; the density remained low and constant (fig. 31).

The numerical fluctuations of the phytoseiid and stigmaeid predators (not distinguished into species) are given as average densities of the 3 replicates in fig. 31 (right hand scale), and in average densities relative to those of the scarlet mite in fig. 32. The pattern of numerical fluctuations of the predators is less

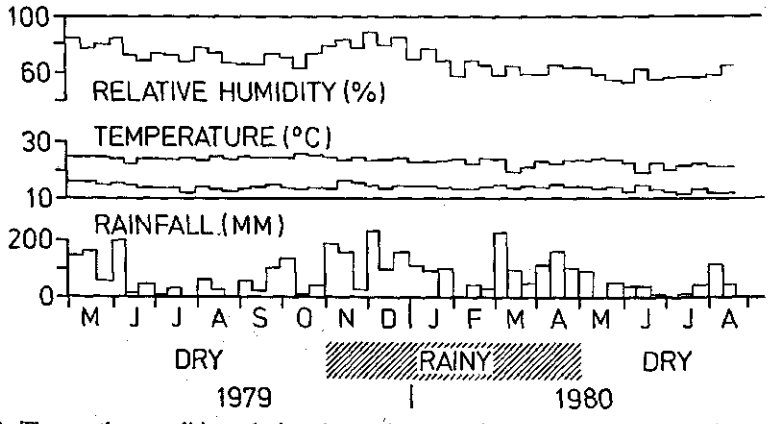


Fig. 33. The weather conditions during the predator check experiment, measured in a tea field at a height of 1.20 m in a Stevenson hut. The minimum relative humidity, minimum and maximum temperature data are 10-day averages. The rainfall data are 10-day totals.

clearcut then that of the scarlet mites. In the untreated and PH 60-42 treated plots, phytoseiid numbers seem to fluctuate more or less parallel to the fluctuations of scarlet mites. In the maneb treated plots such a development is absent; phytoseiid fluctuations remain low and erratic. In the experimental plots (untreated, PH 60-42 and maneb) the stigmaeid density remains at a rather low and constant level (fig. 31 and 32). In general, the differences between these three treatments appear to be minor.

The treatment by DDT results in a very different development. It was intended that all the predators would be killed; instead the Phytoseiidae attained high densities, especially in relation to the density of scarlet mites during the wet season (fig. 32). The fluctuations of the stigmaeid density seem to be more or less parallel to those of the scarlet mites (fig. 31) but the density relative to that of the scarlet mites starts to increase strongly at the end of the first dry season (fig. 32). The conclusion is that after an initial period roughly equal to the dry season, in the DDT treatment a relative increase in density of both the phytoseiid and stigmaeid predators is combined with a decrease in the density of scarlet mites and a suppression of the usual dry season maximum.

The influence of either Phytoseiidae or Stigmaeidae on the abundance of scarlet mites is not evident from these numerical fluctuations. Classical oscillations between predators and prey are absent. The populations of scarlet mites and predators seem to be too stable, and the predatory mites insufficiently distinguished into species to make such influences evident. An analysis of the abundances of the scarlet mite and of each species of predatory mite that could be identified is given below.

4.5.2.4. Evaluation of the effectiveness of predators

A method for quantitative evaluation of natural enemy effectiveness is by correlation between the numbers of the prey and the numbers of the natural enemy in an ecosystem, provided that there is evidence of a direct causal relationship (KIRITANI and DEMPSTER, 1973). A positive correlation then may indicate a numerical dependence of one (usually the predator) on the other (the prey). A positive correlation is often found with alternating fluctuations of prey and predator numbers (e.g. DABROWSKI, 1970; DELATTRE, 1974; NACHMAN, 1981; WHITE and LAING, 1977b) but it has little value as an argument for control of the prey by the predator.

A negative correlation means that the abundance of one (the prey) is inversely proportional to that of the other (the predator). This kind of correlation is especially meaningful when the abundances have more or less stabilized and the predator abundances are for some reason diverse. Likewise, COLLYER (1964a) demonstrated the importance of *Typhlodromus pyri* in the natural control of *Panonychus ulmi* in England by experimentally diversifying the predator densities which later led to inversely proportional densities of prey and predator. This negative correlation is a strong argument in favour of control of the prey by natural enemies.

To evaluate the natural enemy effectiveness in the predator check experi-

Table 19. The correlation coefficients (r) between the abundances (^{10}log transformed densities in leaf samples) of scarlet mites and predatory mites per census in the 12 plots of the predator check experiment. A linear regression line of the (average transformed) abundances of scarlet mites on those of the predatory mites is calculated over the period November 1979 – August 1980.

	Correlation coefficients				
	Stigmaeidae	Phytoseiidae			
Month of sampling	all species	all species	*Amblyseius x*	*A. deleoni*	*Amblyseius z*
May 1979	–0.63*	0.36	0.20	0.62*	0.31
July	0.13	0.29	0.12	0.52	0.50
August	0.34	0.29	0.35	0.05	0.29
September	–0.23	0.10	0.28	0.45	–0.23
November	–0.66*	–0.30	0.20	–0.03	–0.53
February 1980	–0.60*	–0.59*	0.38	–0.01	–0.71*
April	–0.65*	–0.57	0.45	0.26	–0.92**
June	–0.65*	–0.39	0.24	0.46	–0.84**
August	–0.70*	–0.22	0.62*	0.08	–0.86**
November 1979–August 1980	–0.72*	–0.51	0.59*	0.33	–0.92**
Regression analysis (November 1979 – August 1980):					
-coefficient	–0.67	–0.59	+1.13	+0.22	–1.02
-constant	+3.12	+3.08	+2.28	+2.34	+2.71

Significance: * $P \leq 0.05$; ** $P \leq 0.01$

ment, linear correlation coefficients and regression lines were calculated after normalizing the data on abundance by logarithmic transformation: $y = {}^{10}\log$ (scarlet mites/sample); $x = {}^{10}\log$ ((predators + 1)/sample). The coefficients (r) are calculated separately per census and per predator (table 19). The levels of abundance during the second period of the experiment (November 1979–October 1980) appeared sufficiently constant to permit correlation and regression analysis of the *average* abundances of mites and predators.

Between the abundances of the combined phytoseiid species (as plotted in fig. 31 and 32) and of the scarlet mite (fig. 31), the correlation is not significant except once (census of February 1980: table 19). The analysis is elaborated for the separate species of the Phytoseiidae but not for the separate stigmaeid species (table 19 and fig. 34) since identification of these species was not feasible.

The abundances of scarlet mites and *Amblyseius x* respectively *A. deleoni* seem to be correlated positively but rarely in a significant way. The abundances of scarlet mites and of *Amblyseius z* respectively the Stigmaeidae consistently show a very significant, negative correlation during the second period. However, outside the DDT treated plots, *A.z* is rare (fig. 30). Hence, the correlation depends heavily on the data from the DDT treated plots (fig. 34). The Stig-

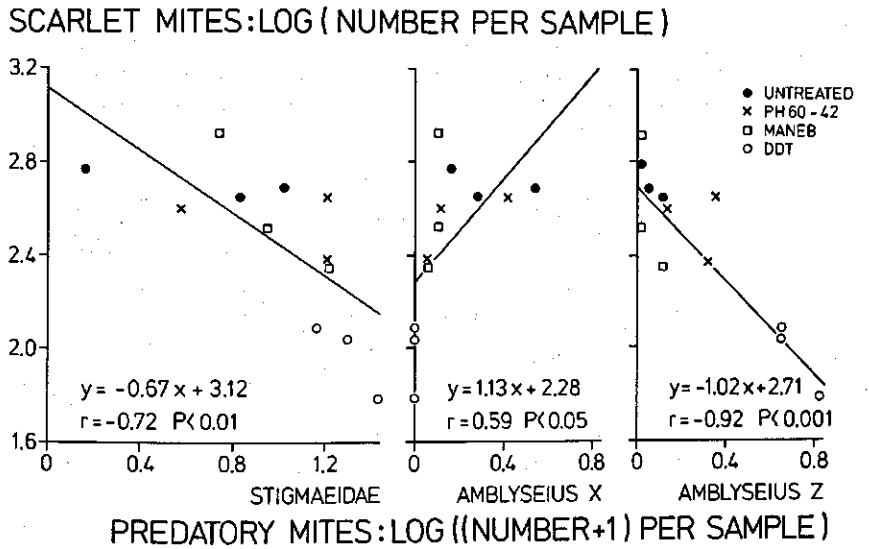


Fig. 34. Linear regression lines of the abundances of scarlet mites on those of predatory mites in the 12 predator check plots. The correlation coefficients (r) are given with their probability level (P). The abundances in samples of 50 leaves are averaged over the period November 1979 – August 1980 after ^{10}log transformation.

maeidae on the other hand are common in all treatments. The correlation is far less dependent on the data from any single treatment than in the case of *A.z* (fig. 34).

These results suggest that *A.x* and *A. deleoni* as predators are not important for the natural control of scarlet mites in the experiment. The abundance of these predators may depend to a certain extent on the abundance of scarlet mites. The results indicate that the contribution of *A.z* and the Stigmaeidae to the natural control of scarlet mites is significant. The control by the Stigmaeidae seems to occur in all plots although different in intensity. The control by *A.z* is practically limited to the DDT treated plots.

An alternative interpretation of the cause of the negative correlation – by opposite effects of an external influence (DDT) on mites (reduction) and predators (increase) – is also possible, but does not agree with other observations. In the field experiment, DDT treatment caused a remarkable decrease in the abundance of scarlet mites (chapter 4.5.2.3) while the laboratory experiments found the reverse: some mite increase at low dosage (though not significant: chapter 4.5.1.2). CRANHAM (1966) reported that DDT can markedly increase the numbers of scarlet mites in tea fields in Ceylon. No indications for stimulative effect by DDT on predatory mites was found in the laboratory experiment (chapter 4.5.1.4). Scarlet mite in the laboratory is readily accepted as prey by *Amblyseius z* and the Stigmaeidae (chapter 4.4.1). These observations contradict the alternative interpretation and confirm the interpretation of the negative correlation by a significant control of the scarlet mites by *A.z* and the Stigmaeidae.

Table 20. Impact of predatory mites on the abundance of scarlet mites at three predator densities. The average densities of the Stigmaeidae and *Amblyseius z* during the second period of the predator check experiment as well as a zero density are substituted into the regression formula (fig. 34). The impact of the predators (i.e. the mite density with predator control) is expressed as a percentage of the extrapolated mite density without predators.

	Individuals per leaf					
	Stigmaeidae			*Amblyseius z*		
	DDT plots	control plots	without predators	DDT plots	control plots	without predators
Average density of predators	0.84	0.24	0	0.22	0.01	0
Corresponding mite density	6.7	14.4	52.7	3.2	17.8	21.5
% Reduction of scarlet mites	13	27	100	15	83	100

4.5.2.5. Impact of the predatory mites

The controlling effect of the predators can be quantified by the ratio of the average prey abundances in the presence and absence of the predators (LAWTON and MCNEILL, 1979). These abundances can be estimated by substituting the average abundance of the predatory mites during the second period of the predator check experiment into the formula of the linear regression line of scarlet mite on predatory mite abundance (fig. 34), as well as by substituting a zero predator abundance. The resulting estimates are fairly crude.

In the untreated control, *Amblyseius z* would reduce the scarlet mite abundance to 83% of the abundance without this predator, and the Stigmaeidae to 27% (table 20). In the DDT treatments, *A.z* would reduce the mite abundance to 15% and the Stigmaeidae to 13% of the abundance without these predators. The role of the predatory mites in the natural control of the scarlet mites is estimated only very roughly by these ratios.

5. DISCUSSION

5.1. Evidence for restricting factors

The intrinsic rate of increase (r_m) of scarlet mites, reared under favourable laboratory conditions, is fairly low in comparison to that of spider mite species (4.1.3). Nevertheless, the offspring of a single female would soon attain astronomical abundance (2.10^{19} in 2 years) if this rate of increase was not restricted. The populations of scarlet mites in tea fields, however, increased very slowly (4.2.3. and 4.2.4). Even the maximum increase observed in any field population was well below the increase in the laboratory (4.2.4.5). It follows that the populations in the field are largely restricted by factors in the environment. Understanding the mode of action of the main factors restricting unlimited population increase may open a door to manipulation of these factors and to the control of the pest.

5.2. The pruning cycle

The constancy of climate and the continuity of the tea culture in Java permit a continuous development of the fauna on tea. The scarlet mites do not hibernate or aestivate (4.2.1). The only interruption in the development seems to be the pruning of the tea bushes, which occurs about every four years.

Pruning reduces the populations of scarlet mites as a catastrophe to practically zero (4.2.3). A few survivors form an inoculum that starts to multiply on the newly formed leaves. This inoculum is likely to be supplemented from outside. Haramoto (1969) reported wind to be an important disseminating agent of scarlet mites in papaya stands. Wind dispersal may be less important in Indonesian tea. Sticky microscope slides, installed 2 m high in densely infested tea gardens, did not trap any scarlet mite during one week of dry weather. Several scientists mention phoresy to be an important mechanism for the dispersal of scarlet mites (Haramoto, 1969; Cranham, 1966; Prebble, 1972). The personnel in tea gardens may carry mites on their clothing and disperse them to all parts of the plantation. The tea culture requires every bush to be picked every 7–14 days, which permits on a large scale dispersal of mites by phoresy. It is likely, therefore, that every tea bush is well inoculated with scarlet mites soon after pruning.

During the first two years after pruning, the populations multiply slowly and more or less exponentially (4.2.3). Exponential growth means that the growth rate is constant per individual and hence independent of density (Pielou, 1974). The average rate of increase is considerably lower than the intrinsic rate of increase (4.2.4.5). It follows that environmental factors strongly restrict population growth and that these are largely independent of density.

About two years after pruning, the average population growth levels off (4.2.3). High mite densities are not likely to occur much earlier. *B. australis* normally reaches this stage about 3 years after pruning in Ceylonese tea (BAPTIST and RANAWEERA, 1955), and *B. phoenicis* requires about one year to build up harmful densities on Hawaiian papaya (HARAMOTO, 1969). Two years after pruning of Indonesian tea, mite populations incidentally develop high densities that may fluctuate strongly (4.2.4.2). These outbreaks are considered to be harmful. The densities in most mite populations, however, remain low and constant (4.2.4.2). Pruning interrupts this constancy and determines the basic periodicity of the development of scarlet mite populations in tea.

5.3. HOST PLANT RESISTANCE

Resistance is the potential of the host to reduce the growth and activity of a parasite or herbivore (Nederlandse Planteziektenkundige Vereniging, Commissie voor de Terminologie: List of phytopathological terms, in preparation). The reduction is likely to result in a reduced abundance of the parasite or herbivore. There are several indications that resistance is an important factor restricting the multiplication of scarlet mites.

The significant and reproducible differences in density of scarlet mites on different clones of tea (4.2.2) can be explained only by differences in resistance of the clones. The low mobility of scarlet mites and the behavioural separation between mite populations on neighbouring bushes (4.1.4) eliminate preference as an explanation. Differences in resistance explain the independently distributed mite densities in traditional tea plantations (4.2.2). The bushes all originate from seed, each bush having a genetically determined resistance to scarlet mites which is different from the others. The separate (4.1.4) populations of mites in seedling bushes increase to different levels of abundance, dependent on the restricting effect of the respective resistances.

The initial increase in mite numbers after pruning appears to level off after about 2 years (4.2.3). The initial increase in volume of the foliage also levels off about 2 years after pruning when the loss of old leaves and growth of new leaves is about equal (SCHOOREL, 1950). These phenomena may be related. Old leaves which are poor in nutrients become more numerous at the end of the pruning cycle. This is probably detrimental to mite development and may be an important factor restricting the abundance of scarlet mites.

The abundance of scarlet mites increases after regular applications of copper fungicides (4.2.4.4). Similarly, *B. australis* in Ceylonese tea increases after the application of copper fungicides (CRANHAM, 1966). Increasing numbers of a pest after pesticide application are usually explained by two main hypotheses (VAN DE VRIE et al., 1972; HUSSEY and HUFFAKER, 1976) as being caused by, first, detrimental effects of the pesticides on the natural enemies, and second, an increased reproduction of the pest. However, the frequent application of copper fungicides in tea was not found to be harmful to the predators (4.3.2.2).

No acarophagous fungi were observed (4.3.2.1) the suppression of which could explain the increased mite numbers. Copper fungicides did not appear to stimulate directly the reproduction of scarlet mites in the laboratory (4.5.1.2). Trophobiosis, i.e. an increased reproduction of the pest because of a pesticide induced improvement in the nutritional quality (or decrease in resistance) of the leaf still may explain the phenomenon. CHABOUSSOU (1966, 1969) has collected much evidence for trophobiosis among which the increasing effect that copper fungicide treatments exert on the populations of spider mites. However, the observations in the chapters mentioned above do not discriminate sufficiently to confirm the mechanism of trophobiosis as an explanation.

Plant chemistry – an important part of mechanisms of resistance – was shown by LAWTON and MCNEILL (1979) to have a profound effect on the intrinsic rate of increase (r_m) of herbivores. They showed theoretically that small differences in r_m make big differences to the abundance of the herbivore. The differences in abundance of scarlet mites on different host plants, the levelling off of the numerical increase two years after pruning and the numerical increase of scarlet mites after application of copper fungicides are probably all caused by differences or changes in r_m of scarlet mites and consequently in the resistance of the host plant. Hence, resistance is very important as a factor restricting the multiplication of scarlet mites in tea.

5.4. WEATHER FACTORS

The development of scarlet mite populations in the field could not be correlated with averages of weather factors during the periods between successive censuses (4.2.4.3).

The development of the scarlet mites is not sensitive to variations in the relative humidity within a range of at least 65 to 90% (HARAMOTO, 1969). The variation in temperature during the year, however, was very much reduced (cf. fig. 25), probably too much to allow correlation with development.

For several reasons the development of scarlet mites was expected to be correlated with rainfall. Mite populations decreased at the start of the rainy season (4.2.4.3). Scarlet mites are adversely affected by wetting in laboratory rearings (4.1.2). The variation in rainfall more than that of temperature and relative humidity appeared to be sufficient (cf. fig. 25) to allow the calculation of possible correlations but these were found to be insignificant. DANTHANARAYANA and RANAWEERA (1974) in Sri Lanka also expected a correlation between the development of *B. australis* in tea fields and rainfall, but the situation there was similar. They ascribed the lack of correlation to the protected living place of the mite. This argument is equally applicable to *B. phoenicis* in Indonesia. However, it does not seem to explain satisfactorily the seasonal variation in the multiplication of scarlet mites (4.2.4.3). Several other explanations could be given.

1. The simultaneously decreasing numbers in separate mite populations during the transitory periods between the dry and wet seasons suggest unmeasured

factors to be responsible. The mortality may be higher because the showers during the transitory periods are more vehement and therefore the rain can reach the protected mite populations. DANTHANARAYANA and RANAWEERA (1974) assumed that rainfall indirectly affects the development of mites on tea. They suggested that the red carotenoid pigment, rhodoxanthin, would be synthesized in tea leaves only during the dry months of the year and might act as a phagostimulant or a reproductive stimulant.

2. The effect of certain environmental factors on the population development may change as a consequence of adaptation by the mites. The mortality in populations of scarlet mites after the first shower of the rainy season is likely to be more severe than after subsequent showers. The mites adapt to the less favourable weather conditions and resume multiplication after an initial decrease in numbers.

3. Counteracting factors may obscure the effect of a factor with which the multiplication is correlated. An increased rate of multiplication in scarlet mites after an increase in temperature may be counteracted by – for instance – an increase in efficiency of predation as a restricting factor.

None of these explanations can be confirmed or denied by the results described. Clearly, the data are insufficient to unravel the doubtlessly complex effects of weather factors upon field populations of scarlet mites but nevertheless these effects may be considerable.

5.5. PREDATION

Control of scarlet mite by natural enemies has never been considered important. Some predators have been observed to prey upon scarlet mites in Ceylonese tea, but the possibilities for biological control were considered remote (CRANHAM, 1966). Many predators are found preying upon tea mites in India, but the degree of biological control exerted by the enemies was inadequate (RAO et al., 1970). The natural enemies of scarlet mites on tea have not been studied before in Indonesia. Predators of scarlet mites have been recorded on papaya in Hawaii (HARAMOTO, 1969), on citrus in Colombia (ZULUAGA and SALDARRIAGA, 1970) and on several crops in Egypt (ATALLA et al., 1972; YOUSEF, 1970; ZAHER et al., 1971) etc. The importance of scarlet mite control by predators on these crops has only been considered incidentally.

Intensive exploration of tea in Indonesia yielded a large diversity of arthropods that prey upon scarlet mites (4.3.2.1). Predatory insects are few, both in number of species and in number of individuals (4.3.2.1). The control of scarlet mites by the predatory insect *Lestodiplosis oomeni* is negligible because of its marked preference for other prey than scarlet mites (4.4.1.4). The voracious insect *Wollastoniella testudo* only thrives amid high densities of prey (4.4.1.4). Its incidental occurrence (4.5.2.2) suggests only incidental importance as an agent restricting high densities of scarlet mites.

The species of predatory mites are particularly numerous. A considerable

number seems to be new to science (cf. table 9). Though the diversity of predatory mite species may be large, the abundance is usually low in proportion to that of the prey (4.3.2.1; 4.5.2.2). The commonest phytoseiid *Amblyseius deleoni* was expected to be an important scarlet mite predator because it reproduced relatively quickly when preying upon scarlet mites (4.4.2.1), it was frequent and occurred generally (4.3.2.1). However, its polyphagous character, cannibalism and incessant escapes from rearing on scarlet mite prey (4.4.1.1) show that the affinity to scarlet mites is low. The second commonest phytoseiid, *Amblyseius x,* strongly prefers eriophyid prey and hardly reproduces when forced to prey upon scarlet mites (4.4.1.1). The low affinity to scarlet mites in both Phytoseiidae explain the limited correlation between the abundances of scarlet mites and these predators (4.5.2.4). Consequently, these Phytoseiidae contribute little to the control of scarlet mites.

Amblyseius z is the only phytoseiid that contributed significantly to the control of scarlet mites in the predator check experiment (4.5.2.4). However, the species was practically limited to the DDT-treated plots (4.5.2.2) and was never found in tea plantations outside the RITC gardens (4.3.2.1). Because of this limited distribution, the species cannot possibly play an important role in scarlet mite control. Other Phytoseiidae were rare (4.3.2.1; 4.5.2.2) and/or inefficient (4.4.1.1) and therefore not important. I presume that the role of Phytoseiidae in the natural control of scarlet mites in tea on Java is limited.

The role of Stigmaeidae in the regulation of mite populations is not well known (HUSSEY and HUFFAKER, 1976). DELATTRE (1974) considers the stigmaeid *Zetzellia mali* able to keep populations of the spider mite *Panonychus ulmi* on apple at a low level. WHITE and LAING (1977 a and b) consider *Z. mali* on apple as a less effective predator of *P. ulmi* than the Phytoseiidae because of its smaller size, lower mobility and relatively low intrinsic rate of increase. The Stigmaeidae in Indonesian tea have the same seemingly disadvantageous characteristics (4.4.1; 4.4.2.1). Nevertheless, there are several arguments to consider them as efficient predators of scarlet mites. Stigmaeidae eagerly accepted scarlet mite prey and reproduced well in laboratory experiments (4.4.1.2). The rate of increase of the studied species exceeded that of the prey (4.4.2.1). Stigmaeidae suppressed scarlet mite populations in the laboratory without immediately becoming extinct when prey became scarce (4.4.2.2). Stigmaeid predators are common and widespread (4.3.2.1). The consistent negative correlations between the abundances of scarlet mites and predatory mites in the predator check experiment show that the predators can suppress populations of scarlet mites in the field (4.5.2.4). The contribution of Stigmaeidae and *A.z* could not be distinguished in the DDT-treated fields, but in other fields only the Stigmaeidae were effective predators (4.5.2.4). In the DDT-treated and the untreated fields, Stigmaeidae reduced the abundance of scarlet mites to approximately 13% respectively 27% of the abundance without these predators (4.5.2.5). I conclude that Stigmaeidae are able to effectively control scarlet mites. This control is only partially realised in the normal untreated ecosystem of tea.

5.6. Numerical regulation by the restricting factors

A regulated population is one which tends to return to an equilibrium density following any departure from this level (Varley et al., 1973). The numerical constancy of many scarlet mite populations (4.2.4.2) suggests that these populations are regulated. The restricting factors may contribute to regulation in several respects.

A larger proportion of the mite population inhabits the upper surface of the leaf when the overall densities are high. These mites are more exposed to meteorological hazards (rainfall) than those on the lower surface. Leaves are shed when heavily infested and damaged by mites. This reduces the quantity of food and substrate available to the mites, and exposes the mites on nearby leaves more to meteorological hazards. The restricting effects of weather factors, especially of rainfall, are thus intensified as a consequence of crowding.

Some predators contribute to the regulation of their prey. Predacious mites in particular are known to keep phytophagous mites at a low density (Huffaker et al., 1970; Hussey and Huffaker, 1976; Rabbinge, 1976, etc.). The results of the predator check experiment do not prove that predation is a factor regulating scarlet mites. Nevertheless, a regulating effect of certain predatory mites became particularly apparent in the DDT-treated plots (4.5.2.3) in which, paradoxically, the predators functioned best.

The preference of the predatory mites for the eggs of scarlet mites (4.4.1) may contribute to regulation. In small ecosystems this preference delays the extermination of the prey by the predator, which in turn delays the extinction of the predator because of lack of prey. Similarly, Sabelis (1981) found phytoseiid predators to prefer young stages of the prey, the two-spotted spider mite. He suggests evaluating the consequences of this preference by dynamic simulation at the population level.

The importance of the mechanisms that contribute to the regulation of scarlet mites cannot be estimated with the available data. Since scarlet mites are only partially controlled by predators under natural, untreated conditions in tea (4.5.2.5), regulation by predators can be only partially effective under natural conditions.

5.7. Predator control and diversity

DDT-treatment of acarine predator-prey ecosystems usually causes the phytophagous mites to increase and the predators to decrease (Huffaker et al., 1970). It was surprising and important to note in the predator check experiment that predators kept scarlet mites effectively in check in the fields under a heavy DDT-stress, but only partially in the untreated fields with the usual diversity of predators (4.5.2.3). A consideration of the action spectrum of DDT and a hypothesis about the consequences may help to understand this result.

All *Amblyseius* species appeared sensitive to DDT-treatment in the laborato-

ry trials (4.5.1.4). *A.z* was however not killed by the DDT-treatments in the predator check experiment (4.5.2.2). This contradictory result is probably caused by unequal dosages in the field and the laboratory (3.4.2) and because *A.z* would be more tolerant to DDT than other *Amblyseius* species. Accordingly, DDT selectively killed *A. deleoni* and *A.x* in the field (4.5.2.2). Although I assessed the toxicity of DDT to predatory mites only roughly (4.5.1.4), the reactions of comparable species in the studied mite community diverged to an unforeseen degree. It means that laboratory trials are not sufficient to forecast the complicated reactions of a predator community in nature. Therefore, it was not justified to select the exclusion pesticides on the basis of a comparable sensitivity in phytoseiid species to pesticides (cf. 4.5.1.1).

The Phytoseiidae *A. deleoni* and *A.x* are relatively large, polyphagous species (4.4.1.1). It is hypothesized that the disappearance of these predators resulted in a reduced interference between the remaining predators. This may have benefitted *A.z* and especially the DDT-tolerant (4.5.1.4) Stigmaeidae. Because of reduced negative interferences by *A. deleoni* and *A.x*, the numbers of predatory mites could now react more directly to the density fluctuations of scarlet mites, resulting in a more effective control and regulation of the scarlet mite populations. The negative interference may have been predation by *A. deleoni* and *A.x* on the small and slow Stigmaeidae. This possibility was not considered during the laboratory studies. Hence no attacks of these Phytoseiidae on Stigmaeidae were recorded.

Observations more or less parallel to those discussed here exist. COLLYER (1964b) reported an increase in the abundance of the phytoseiid *Typhlodromus pyri* and no effects on the stigmaeid *Agistemus longisetus* after frequent application of DDT in New Zealand orchards. Both were predators of *Panonychus ulmi*. DABROWSKI (1970) reported a shift in species composition and a numerical increase of phytoseiid predators and the prey *P. ulmi* after application of some chlorinated hydrocarbons including DDT in Polish orchards. He stated that the application of pesticides in orchards changed the specific structure of the phytoseiid populations in which *Typhlodromus finlandicus* limited the increase of other phytoseiid species. *T. finlandicus* decreased after spraying and did not inhibit the other phytoseiidae from increasing (DABROWSKI, 1970). Both the observations from New Zealand and Poland resemble the results of the predator check experiment. The interpretation given by DABROWSKI largely corresponds to my hypothesis.

The hypothesis implies that the big disruption of the (diverse) acarine community by DDT allowed the predators to control scarlet mites more effectively. The disruption, i.e. the elimination of some predator species, is a simplification of the community at the trophic level of the predators. The effect of this simplification confirms the view of VAN EMDEN and WILLIAMS (1974) on the stability of ecosystems, stating that 'High diversity at any trophic level may lead to stability at that level to a point where that level may be insufficiently unstable to react to fluctuations in the level below'. This may well be the reason that the key natural enemies (i.e. the Stigmaeidae and *A.z*) were able to control scarlet

mite populations at a low density in the acarine communities simplified by DDT-treatments, but unable to do so in the more diverse, untreated communities. It is equally in line with the conclusion of CROFT and BROWN (1975) with regard to the biological control of mites in USA-orchards that 'the presence of Phytoseiidae and Stigmaeidae at the same time may not be the most favorable situation'. The same effect of diversity impeding biological control appears from the information available on the winter moth, *Operophtera brumata,* a pest of deciduous trees (SECHSER, 1970 a and b; EMBREE, 1971; VARLEY et al., 1973). They suggest that two introduced European parasites effectively control winter moth in Canada while a large complex (63 species) of endemic parasites in Europe is unable to keep the density at a low level.

The hypothesis that the Stigmaeidae, normally present in Indonesian tea plantations, are able to control scarlet mites effectively but are hampered by other (phytoseiid) predators, can be verified. Predator populations of different composition may be compared for the effect of the control exerted, measured by the level of abundance of scarlet mites. According to the hypothesis, lower levels are expected where stigmaeid predators predominate.

An experimental method should eliminate the phytoseiid predators but spare the stigmaeid predators and scarlet mites. A subsequent increase in stigmaeid abundance with a reduction in the abundance of scarlet mites would confirm the hypothesis. The Phytoseiidae may be eliminated by pesticide application. Attention should be given to the risk of complications as in this study (cf. 4.5.2.2 and 5.7) that pesticides may affect predators and prey in unforeseen ways. The selection of a suitable pesticide seems possible because Stigmaeidae in general have a strong pesticide tolerance, especially towards organophosphorous compounds (CROFT and BROWN, 1975). Phytoseiidae are sensitive to many kinds of pesticides (CROFT and BROWN, 1975; MCMURTRY et al., 1970). The sensitivity of scarlet mites to many pesticides was studied by RAO (1974b), DANTHANARAYANA and RANAWEERA (1970), ALI and HAQ (1973), FINDLAY (1971), FILHO et al. (1977) and others. Carbophenothion is a pesticide worth considering. It is harmless to the stigmaeid *Zetzellia mali* (PARENT, 1960; SANDFORD, 1967), toxic to some Phytoseiidae (SANDFORD, 1967; CROFT and BROWN, 1975) but also rather toxic to scarlet mites (RAO, 1974b; SUTADIREDJA and OOMEN, 1977). A suitable dosage and timing of the applications should be determined experimentally.

As a possible method for control, it seems rather far-fetched to stimulate biological control by chemical control of competing natural enemies. Only when few applications appear to suffice for long periods, e.g. one application per year, the method may become useful. Elimination of the Phytoseiidae by non-chemical methods would be more desirable. However, I am not aware of such a method.

5.8. CONTROL BY MANIPULATION OF FACTORS RESTRICTING SCARLET MITES

Most populations of scarlet mites in tea are present at a low and constant density, and require no control measures. At times some populations reach harmful outbreak densities and in these cases natural control is obviously insufficient. Outbreak densities are not likely to occur earlier than two years after pruning. The densities reach maximum values especially at the end of dry seasons. An imminent start of a rainy season renders special control measures unnecessary. Clean pruning is an effective measure of control.

A rather far-fetched method to improve the control of mite outbreaks by predators is described in the previous chapter (5.7). In general, it seems worthwhile to spare the predators, especially the Stigmaeidae and Anthocoridae (*Wollastoniella testudo*) by limiting the use of pesticides toxic to these predators. Biological control by means of field releases of *W. testudo* is promising, provided that mass-rearing is feasible.

A reduction in the rate of increase of the mites will result in a big reduction in mite abundance (LAWTON and MCNEILL, 1979). Limiting the amount of copper fungicides on tea leaves therefore will result in lower mite densities, especially on those exposed bushes where large amounts usually accumulate.

The use of resistant clones (4.2.2) seems an easy, effective and definitive way to solve the pest problems of scarlet mites, better than the manipulation of any other restricting factor. Future work should aim primarily at selecting and planting more resistant clones. The haploid thelytokous reproduction of this mite probably results in populations of a rather uniform composition. The changes of the scarlet mites to break the resistance of the clone are therefore small. In order to study the mechanisms of resistance and to further select resistant tea clones, the rearing technique described in chapter 3.1.5 offers excellent possibilities. The door to the control of scarlet mites by manipulation of restricting factors, especially resistance, is wide open.

6. SUMMARY

Tea is the national drink of Indonesia. The habitual consumption prevents intestinal infections; the production provides many Indonesians with a living. The production is affected by scarlet mites (*Brevipalpus phoenicis* GEIJSKES), an important pest of tropical and subtropical crops. It is one of the main pests of tea in Indonesia and inhabits virtually all tea bushes. The factors restricting the development of this mite on tea in West Java were studied by observations and experiments in the laboratory and the tea gardens of the Research Institute for Tea and Cinchona.

Scarlet mites multiply fast under favourable conditions. The intrinsic rate of increase ($r_m = 0.0610$) however is far less than that of some spider mites. The scarlet mite populations develop continuously in the field, without synchronization. The mites stay on the undersurface of the tea maintenance leaves and are rather sedentary. A deteriorating leaf quality triggers off migration with a positive phototactic orientation, i.e. towards younger leaves of the bush.

Different tea clones and seedlings sustain significantly different mite densities as a consequence of differences in host plant resistance. Tea bushes are pruned once in four years in West Java. This strongly reduces the abundance of scarlet mites. The populations build up slowly and exponentially to a mean equilibrium level which is attained around two years after pruning. Most populations have a low and rather stable density during the second two years of the pruning cycle; some populations have high and fluctuating densities. Generally speaking, the populations especially increase during the dry seasons and decrease during the transitory periods. Maxima are reached usually at the end of the dry season. The fluctuations are not directly related to the average minimum or maximum temperature, average minimum relative humidity or the total rainfall. Application of copper fungicides (copperoxychloride) increases the average mite densities and especially the seasonal maxima. The numerical multiplication of field populations always remained much below that of populations in the laboratory under favourable growing conditions.

Many other arthropods beside scarlet mites inhabit tea leaves. Predators of scarlet mites were collected from tea estates in Java and Sumatra. The diversity of predatory mite species appeared to be particularly rich. A considerable number of species probably has not been described and is identified provisionally in this paper by a code name. The predatory behaviour of most species (Phytoseiidae and Stigmaeidae), the reproduction of three typical species and the capacity of three stigmaeid species to keep scarlet mites in check were confirmed in laboratory experiments.

A series of pesticides was screened in the laboratory for (undesired) toxicity towards scarlet mites, DDT was screened for toxicity towards predators. Most Phytoseiidae appeared to be susceptible, and most Stigmaeidae appeared to be tolerant to DDT. DDT, maneb and PH 60-42 were selected as exclusion pesti-

cides with the intention of killing respectively: all the predators, the predatory mites and the predatory insects, without affecting the scarlet mites in a predator check experiment.

These exclusion pesticides were frequently applied in the field during the 16 months period of the predator check experiment. The effects deviated from the expectation in various respects but resulted in a sufficiently diversified predatory fauna to analyze the importance of several predator species as a factor restricting the development of scarlet mites. The effect of DDT was most unexpected. It killed the most common Phytoseiidae and permitted the Stigmaeidae and *Amblyseius z* to develop high densities. The density of scarlet mites decreased to a rather constant level below that of the (untreated) control, probably as a consequence of predation. The predators that made the most impact were the Stigmaeidae. They suppressed the level of abundance of scarlet mites in the DDT-treated and the untreated fields to 13% and 27% respectively of the abundance without these predators.

The more effective control by predators in the DDT-treated fields was interpreted by a selective killing with DDT of the less efficient predators (*Amblyseius x* and *A. deleoni*). The disappearance of these probably benefitted the other, more effective predators of scarlet mites (Stigmaeidae and *Amblyseius z)*. The diversity of the ecosystem at the trophic level of the predators appeared not to be related to the effectiveness of the control of scarlet mites. Suggestions for control, especially the planting of resistant clones, conclude this paper.

RINGKASAN

Tungau jingga (*Brevipalpus phoenicis* GEIJSKES) merupakan hama penting pada tanaman tropika dan subtropika. Tungau termasuk hama utama tanaman teh di Indonesia dan dapat ditemukan pada semua perdu teh. Ekologi populasi tungau jingga pada tanaman teh di Jawa Barat telah dipelajari dengan melakukan pengamatan-pengamatan dan percobaan-percobaan di laboratorium dan kebun-kebun teh di Balai Penelitian Teh dan Kina.

Tungau jingga berkembang biak dengan cepat. Meskipun demikian kecepatan pertumbuhan intrinsiknya (r_m = 0,0610) jauh lebih rendah daripada beberapa tungau labah-labah. Di kebun populasi tungau jingga berkembang secara terus-menerus, tetapi tidak serempak. Tungau ini menempati permukaan bawah daun dari lapisan daun pemeliharaan (maintenance leaves) dengan mobilitas yang kecil. Migrasinya dirangsang oleh menurunnya kualitas daun, dengan sifat fototaksis positif, yaitu menuju daun-daun yang lebih muda dari perdu tersebut.

Bermacam-macam tanaman teh klonal dan teh asal biji menunjukkan perbedaan kerapatan populasi tungau yang nyata. Di Jawa Barat pemangkasan tanaman teh dilakukan setiap empat tahun sekali. Pemangkasan dapat menyebabkan sangat menurunnya populasi tungau jingga. Populasi kemudian berkembang lagi secara perlahan-lahan dan secara exponensial menuju ke suatu tingkat keseimbangan rata-rata, dan hal ini dicapai sekitar dua tahun setelah pemangkasan. Pada umumnya kerapatan populasi rendah dan agak stabil pada tahun kedua dari daur pangkas; beberapa populasi mempunyai kerapatan yang tinggi dan berfluktuasi. Umumnya populasi meningkat selama musim kemarau, dan berkurang pada musim pancaroba. Populasi maksimum biasanya dicapai pada akhir musim kemarau. Fluktuasi tidak dipengaruhi secara langsung oleh suhu minimum atau maksimum rata-rata, kelembaban nisbi minimum rata-rata atau jumlah curah hujan. Fungisida tembaga (copper oxychloride) dapat meningkatkan kerapatan populasi tungau, terutama maksimum musimannya. Angka pertambahan populasi di lapangan selalu lebih rendah dari angka pertambahan populasi di laboratorium dengan syarat pertumbuhan yang baik.

Banyak arthropoda selain tungau jingga, hidup pada daun-daun teh. Predator-predator tungau jingga dapat ditemukan di perkebunan-perkebunan teh di Pulau Jawa dan Sumatera. Keragaman predator tungau ternyata sangat besar. Banyak speciesnya yang mungkin belum dikenal dan untuk sementara waktu hanya diidentifikasikan dengan nama kode saja. Sifat predator dari kebanyakan species Phytoseiidae dan Stigmaeidae, perkembangbiakan dari tiga species yang khas dan kemampuan dari tiga species Stigmaeid untuk mengendalikan tungau jingga telah di pelajari dan diteguhkan di laboratorium.

Beberapa pestisida telah diuji dalam laboratorium untuk mengetahui tingkat keracunan (yang tidak diinginkan) terhadap tungau jingga. DDT, maneb dan

PH 60-42 ternyata berturut-turut membunuh semua predator, tungau-tungau predator dan serangga predator tanpa mempengaruhi tungau jingga di dalam percobaan lapangan selama kurun waktu 16 bulan. DDT beracun terhadap hampir semua predator Phytoseiid tetapi tidak beracun terhadap predator Stigmaeid dalam uji lanjutan di laboratorium.

Penggunaan pestisida selektif tersebut di dalam percobaan penekanan predator telah dapat cukup membeda-bedakan fauna predator untuk dapat dianalisa pentingnya beberapa species predator dalam pengendalian tungau jingga. DDT memberikan pengaruh yang tidak diduga. Ini membunuh Phytoseiidae dan memungkinkan Stigmaeidae dan *Amblyseius z* berkembang, sehingga kerapatannya sangat tinggi. Kerapatan populasi tungau jingga menurun pada suatu tingkat yang agak konstan, yang lebih rendah daripada pada petak kontrol, yang mungkin desebabkan oleh kegiatan predator. Di antara semua predator, Stigmaeidae mempunyai pengaruh yang paling besar. Predator ini menekan derajat populasi tungau jingga di dalam petak perlakuan DDT dan petak yang tidak diperlakukan sampai 13% dan 27% dari derajat pembiakan populasi bila tanpa predator.

Pengendalian yang lebih efektif oleh predator dalam petak-petak perlakuan DDT diduga karena terbunuhnya secara selektif predator-predator yang kurang efisien (*Amblyseius x* dan *A. deleoni*). Hilangnya predator yang kurang efisien ini mungkin menguntungkan predator-predator tungau jingga yang lebih efektif (Stigmaeidae dan *Amblyseius z*). Keragaman ekosistim pada tingkat trofik dari predator nampaknya tidak berhubungan dengan efektivitas pengendalian tungau jingga. Buku ini diakhiri dengan beberapa saran pengendalian, terutama penanaman klon yang tahan.

SAMENVATTING

Thee is de nationale drank van Indonesië. De regelmatige consumptie voorkomt ingewandsinfekties, veroorzaakt door het drinken van besmet water; de produktie verschaft een bescheiden inkomen aan een groot aantal mensen. De produktie van thee wordt onder meer belemmerd als gevolg van aantasting door oranje mijt of palmmijt (*Brevipalpus phoenicis* GEIJSKES), een belangrijke plaag van tropische en subtropische gewassen, en van thee in het bijzonder. In Indonesië komt de mijt voor op vrijwel alle theestruiken. Dit boek verslaat een beschrijvend en experimenteel onderzoek aan het Research Institute for Tea and Cinchona (West Java) naar de faktoren die het aantalsniveau van oranje mijt op thee bepalen.

Oranje mijt kan zich onder gunstige omstandigheden snel vermeerderen. Haar potentiële snelheid van vermenigvuldiging doet echter onder voor die van sommige spintmijten. Populaties van oranje mijt in theetuinen ontwikkelen zich gedurende het hele jaar. De mijten bewonen de onderkant van volwassen theebladeren en zijn honkvast. Een afnemende kwaliteit van het blad echter zet migratie in de richting van hogere lichtintensiteiten in gang, d.w.z. in de richting van jongere bladeren van dezelfde theestruik.

In West Java worden theestruiken doorgaans eens in de vier jaar gesnoeid. Snoei vermindert de mijtendichtheid sterk. De populaties groeien daarna weer langzaam en exponentieel naar een gemiddeld dichtheidsniveau dat bereikt wordt na ongeveer twee jaar. De meeste populaties handhaven een laag en tamelijk stabiel niveau; sommige populaties echter fluctueren sterk en bereiken hoge dichtheden. De sterkste toename heeft plaats gedurende de droge tijd; de sterkste afname gedurende de overgangsperiode van droge naar regentijd. De aantalsveranderingen bleken echter niet gecorreleerd met de gemiddelden van de minimum of maximum temperatuur of van de relatieve vochtigheid, noch met de hoeveelheid regenval. Bespuiting met koperfungiciden deden de gemiddelde dichtheden stijgen, vooral de seizoensmaxima. De toename van populaties in het veld bleef altijd ver achter bij die onder gunstige omstandigheden in het laboratorium.

Naast de oranje mijt komen vele andere soorten arthropoden voor op thee. Predatoren van oranje mijt werden verzameld van thee-ondernemingen op Java en Sumatra. De diversiteit aan soorten roofmijten is opmerkelijk groot. Een aanzienlijk aantal soorten is waarschijnlijk nog onbeschreven. Deze worden in dit boek voorlopig aangeduid met een codenaam. In laboratoriumproeven werd van de meeste soorten roofmijten (Phytoseiidae en Stigmaeidae) het roofgedrag bevestigd, evenals de capaciteit van drie soorten Stigmaeidae om oranje mijt op een laag niveau te handhaven. De reproduktie van drie kenmerkende soorten roofmijten op een dieet van oranje mijten werd ook kwantitatief onderzocht.

Een reeks van bestrijdingsmiddelen werd in het laboratorium getoetst en ver-

geleken wat betreft (ongewenste) giftigheid voor de oranje mijt. DDT werd tevens onderzocht op giftigheid voor predatoren. De meeste Phytoseiidae bleken gevoelig voor DDT, maar de meeste Stigmaeidae tolerant. DDT, maneb en het insecticide PH 60-42 werden geschikt bevonden te dienen als uitsluitingsmiddel in een predator-uitsluitingsexperiment met het doel om respectievelijk alle predatoren, de roofmijten en de roofinsekten te doden zonder de oranje mijt rechtstreeks te beïnvloeden.

Deze uitsluitingsmiddelen werden gedurende 16 maanden geregeld gebruikt in de proefveldjes van het uitsluitingsexperiment. De uitwerking, vooral van DDT, was in sommige opzichten anders dan verwacht. De predatoire fauna werd er echter voldoende door gevarieerd om de rol van de verschillende soorten predatoren als beperkende factor van de ontwikkeling van de oranje mijt te kunnen vaststellen. DDT doodde de meer algemene Phytoseiidae maar liet hogere dichtheden van de Stigmaeidae en *Amblyseius z* toe. Oranje mijt nam hierbij af tot een tamelijk konstante dichtheid die lager lag dan in de onbehandelde proefveldjes, vermoedelijk als gevolg van predatie. Van alle predatoren bleken de Stigmaeidae het belangrijkst. Zij onderdrukten de aantallen oranje mijt in de DDT-proefveldjes tot 13% en in de onbehandelde veldjes tot 27% van de dichtheid zonder deze predatoren.

Het lagere dichtheidsniveau van de oranje mijt in de DDT-proefveldjes is waarschijnlijk het gevolg van een selectieve uitschakeling door DDT van enige weinig efficiënte predatoren (*Amblyseius x* en *A. deleoni*). Hun uitschakeling zou andere, effektievere predatoren van de oranje mijt (Stigmaeidae en *Amblyseius z*) ten goede zijn gekomen. Een grotere diversiteit van het ecosysteem blijkt daarom niet essentieel te zijn voor een effectief laag houden van de plaagdichtheid.

Enige aanbevelingen voor bestrijding van de oranje mijt, in het bijzonder aanplant van resistente klonen, besluiten dit boek.

ACKNOWLEDGEMENTS

The research for this publication was carried out from 1975 to 1980 at the Research Institute for Tea and Cinchona (RITC) at Gambung, Indonesia. During the first three years I was employed on the project ATA-51 by the Directorate General for International Cooperation (DGIS). For the last two years I worked at the same institute for the Agricultural University of Wageningen with a grant (W 89-34) from the Netherlands Foundation for the Advancement of Tropical Research (WOTRO). The latter also enabled the preparation of this thesis in 1980-81 at the Laboratory of Entomology, Wageningen.

The present research was proposed by Prof. dr. J. de Wilde and dr. ir. P. Gruys. The interest, cooperation, hospitality and criticism of professor De Wilde were a great support to me. Dr. Gruys has provided attentive, encouraging and effective backing and later constructive criticism of the manuscript.

The great hospitality and cooperation of prof. dr. ir. Haryono Semangun, who also translated the summary into Indonesian, is gladly acknowledged. The staff of RITC in Gambung, especially drs. Atik Dharmadi, ir. Martanto Martosupono and ir. Wenten Astika, showed much interest and cooperation. All the personnel of the RITC tea estate assisted with pleasure and efficiency, in particular Rulan Soedradjat, A'an Wijaya, Eddy Suwardi and Syafrudin. My former students, Anita H. Sutadiredja, Tinny S. Uhan, Djunaedi and especially Wahyu Widayat collected important data.

The former team leaders dr. ir. A. F. Schoorel and dr. ir. V. J. M. Koch stimulated and advised me. The Netherlands Embassy and mr. Sujud Sucherman of RITC effectively assisted in the hard task of extending visas and other documents. Drs. J. de Koning kindly intermediated which helped solve specific problems.

The taxonomists C. F. van de Bund, dr. G. L. van Eyndhoven, dr. S. Ehara, dr. F. M. Summers, dr. P. H. van Doesburg, dr. ir. R. H. Cobben and especially my wife F. Oomen-Kalsbeek helped identify many arthropods.

Duphar B.V. made available an experimental insecticide. Drs. A. Martijn of the Dutch Plant Protection Service and mr. Supria of RITC analyzed some insecticide samples.

During analysis of the data and construction of the manuscript I received indispensable assistance from dr. ir. M. A. J. van Montfort on statistical matters, from dr. B. van de Lustgraaf and dr. H. C. J. Oomen who read the manuscript critically, from dr. W. Helle, dr. F. J. Verheyen, dr. ir. M. Sabelis who criticized parts of the manuscript, from dr. ir. A. van Huis for his inspiring example and from S. G. Wever and W. C. T. Middelplaats (drawings), J. W. Brangert (photographs) and G. P. Bruyn (typing).

I wish to thank sincerely and profoundly all those named and unnamed who contributed in any way to this publication.

Pieter A. Oomen

REFERENCES

ALI, M. A. and M. I. HAQ, 1973. Scarlet mite of tea and its control. Tea Journal of Bangladesh, **9**, 17–22.

ANANTHAKRISHNAN, N. R., 1963. Some biological notes on the scarlet mite, *Brevipalpus australis* TUCKER on tea. Report Scientific Department (Tea Section) for 1962–1963, United Planters' Association South India, 59–61.

ATALLA, E. A. R., M. ZAHER and N. EL-ATROUZY, 1972. Studies on the population density of mites associated with truck crops. Agricultural Research Review, **50**, 71–88.

BAKER, E. W., 1949. The genus *Brevipalpus* (Acarina: Pseudoleptidae). The American Midland Naturalist, **42**, 350–402.

BAKER, E. W. and G. W. WHARTON, 1952. An introduction to acarology. The MacMillan Company, New York. 465 pp.

BANERJEE, B., 1965. Mites of tea and ancillary crops. Two and a Bud, **12**, 4–7.

BANERJEE, B., 1969. Shade and manurial experiments at Murmuria: a report on the incidence of mites. Two and a Bud, **16**, 93–96.

BANERJEE, B., 1971. The threshold values in mite pest control. Two and a Bud, **18**, 20–21.

BANERJEE, B., 1976. Development of the red crevice mite *Brevipalpus phoenicis* (GEIJSKES) on coffee and tea (Acarina: Tenuipalpidae). Zeitschrift für angewandte Entomologie, **80**, 342–346.

BAPTIST, B. A. and D. J. W. RANAWEERA, 1955. The scarlet mites of the genus *Brevipalpus* as pests of tea in Ceylon. Tea Quarterly, **26**, 127–137.

BATSCHELET, E., 1965. Statistical methods for the analysis of problems in animal orientation and certain biological rhythms. Monograph, American Institute of Biological Sciences, Washington, D. C. 57 pp.

BERNARD, C., 1909. Over de ziekten der theeplant veroorzaakt door mijten. Mededeelingen van het Proefstation voor Thee, Buitenzorg, **3**, 1–121.

BIRCH, L. C., 1948. The intrinsic rate of natural increase of an insect population. Journal of Animal Ecology, **17**, 15–26.

BIRO PUSAT STATISTIK, 1978. Statistical yearbook of Indonesia 1976. Biro Pusat Statistik, Jakarta. 1087 pp.

BLOMMERS, L., 1976. Capacities for increase and predation in *Amblyseius bibens* (Acarina: Phytoseiidae). Zeitschrift für angewandte Entomologie, **81**, 225–244.

CARAYON, J., 1982. *Wollastoniella testudo* n. sp., Hémiptère Anthocoridae prédateur d'un Acarien nuisible au Théier à Java. Bulletin Zoologisch Museum, Universiteit van Amsterdam **8** (16), 141.

CARTER, W., 1973. Insects in relation to plant disease. Wiley-Interscience, New York. Second edition, 759 pp.

CHABOUSSOU, F., 1966. Die Vermehrung der Milben als Folge der Verwendung von Pflanzenschutzmitteln und die Biochemischen Veränderungen, die diese auf die Planze ausüben. Zeitschrift für angewandte Zoologie, **53**, 257–276.

CHABOUSSOU, F., 1969. Recherches sur les facteurs de pullulation des acariens phytophages de la vigne à la suite des traitements pesticides du feuillage. Thèse, Faculté des Sciences de Paris. 238 pp.

CHAGAS, C. M., 1973. Associação do ácaro *Brevipalpus phoenicis* (GEIJSKES) a mancha anular do cafeeiro. Biológico, **39**, 229–232.

COLLYER, E., 1964a. A summary of experiments to demonstrate the role of *Typhlodromus pyri* SCHEUT. in the control of *Panonychus ulmi* KOCH in England. Acarologia, **6**, 363–371.

COLLYER, E., 1964b. Phytophagous mites and their predators in New Zealand Orchards. New Zealand Journal of agricultural Research, **7**, 551–568.

COULON, J. and P. BARRES, 1976. Etude de laboratoire concernant la toxicité des produits phytosanitaires pour *Phytoseiulus persimilis*. Union Internationale des Sciences Biologiques: Bulletin Section Regionale Ouest Paléarctique, **4**, 45–63.

CRANHAM, J. E., 1966. Insect and mite pests of tea in Ceylon and their control. Monographs on tea production in Ceylon, No. 6. Tea Research Institute, Talawakelle, Ceylon. 122 pp.

CROFT, B. A. and A. W. A. BROWN, 1975. Responses of arthropod natural enemies to insecticides. Annual Review of Entomology, **20**, 285–335.

CROFT, B. A. and E. E. NELSON, 1972. Toxicity of apple orchard pesticides to Michigan populations of *Amblyseius fallacis*. Environmental Entomology, **1**, 576–579.

DABROWSKI, Z. T., 1970. Factors determining the increase of density of predatory mites (Acarina: Phytoseiidae) in apple orchards treated with pesticides. Part I. (Polish; english summary). Polskie Pismo Entomologiczne, **40**, 141–189.

DANTHANARAYANA, W. and D. J. W. RANAWEERA, 1970. The red spider mite and the scarlet mite of tea and their control. Tea Quarterly, **41**, 19–33.

DANTHANARAYANA, W. and D. J. W. RANAWEERA, 1974. The effects of rainfall and shade on the occurrence of three mite pests of tea in Ceylon. Tea Quarterly, **44**, 47–58.

DARMAWIJAYA, M. I. and PARTOYO, 1976. Hasil survai tanah perkebunan teh di Indonesia sampai saat ini. (Soil survey of tea estates in Indonesia). Paper, Simposium Teh I, Bandung, July 7–10, 1976. Sidang IIIa, No. 5, 20 pp.

DAS, G. M., 1961. Scarlet mite. Two and a Bud, **8** (3), 3–4.

DAS, G. M., 1963. Some important pests of tea. Newsletter Tocklai Experimental Station, **10** (2), 1-8.

DAS, G. M., 1965. Pests of tea in North East India and their control. Memoir, Tea Research Association, Tocklai, **27**, 115 pp.

DEBACH, P. and C. B. HUFFAKER, 1971. Experimental techniques for evaluation of the effectiveness of natural enemies. In: Biological Control, C. B. HUFFAKER (Ed.), p. 113–140. Proceedings of an AAAS Symposium on biological control, Boston, 1969. Plenum Press, New York. 511 pp.

DEBACH, P., C. B. HUFFAKER and A. W. MACPHEE, 1976. Evaluation of the impact of natural enemies. In: Theory and practice of biological control, C. B. HUFFAKER, P. S. MESSENGER (Eds.), p. 255–285. Academic Press, New York. 788 pp.

DELATTRE, P., 1974. Etude de l'efficacité prédatrice de *Zetzellia mali* (Acarina: Stigmaeidae) vis-à-vis du Tétranyque du pommier, *Panonychus ulmi* (Acarina: Tetranychidae). Entomophaga, **19**, 13–31.

DHARMADI, A., 1979. Serangga hama pada tanaman teh, dan pengendaliannya dengan insektisida. (Insect pests on tea plantations; its control with insecticides). Paper, Kongres Entomologi I, Jakarta, January 9–11, 1979. 10 pp.

EHARA, S., 1977. A review of taxonomic studies on natural enemies of spider mites in Japan. Review of Plant Protection Research, **10**, 29–48.

EMBREE, D. G., 1971. The biological control of the winter moth in eastern Canada by introduced parasites. In: Biological Control, C. B. HUFFAKER (Ed.), p. 217–226. Proceedings of an AAAS Symposium on biological control, Boston, 1969. Plenum Press, New York. 511 pp.

EMDEN, H. F. van, and G. F. WILLIAMS, 1974. Insect stability and diversity in agro-ecosystems. Annual Review of Entomology, **19**, 455–475.

EVANS, G. O., J. G. SHEALS and D. MACFARLANE, 1961. The terrestrial acari of the British isles. An introduction to their morphology, biology and classification. Trustees of the British Museum, London. 219 pp.

FILHO, N. S., A. F. CINTRA, I. MYAZAKI, D. A. OLIVEIRA and J. T. SOBRINHO, 1977. Comportamento do 'acaro da leprose' *Brevipalpus phoenicis* (GEIJSKES 1939) em relação a alguns acaricidas na zona de Limeira. Biológico, **43**, 21–24.

FINDLAY, C., 1971. Scarlet mite (*Brevipalpus* sp.). Quarterly News Letter of the Tea Research Foundation of Central Africa, **22**, 6–8.

FLAHERTY, D. L. and C. B. HUFFAKER, 1970. I. Role of *Metaseiulus occidentalis*. Hilgardia, **40**, 267–331.

GEIJSKES, D. C., 1939. Beiträge zur Kenntnis der europäischen Spinnmilben, mit besonderer Berücksichtigung der niederländischen Arten. Mededelingen Landbouwhogeschool Wageningen, **42**(4), 1–68.

GOMEZ, K. A. and A. A. GOMEZ, 1976. Statistical procedures for agricultural research, with emphasis on rice. International Rice Research Institute, Los Baños. 294 pp.

GONZALEZ, R. H., 1975. Revision of the *Brevipalpus phoenicis* 'complex' with discriptions of new species from Chile and Thailand (Acarina: Tenuipalpidae), Acarologia, **17**, 81–91.

GREEN, E., 1900. Tea-mites, and some suggested work against them. Circular 17, series 1. Royal Botanic Gardens, Ceylon, 202–203.

GRUYS, P. and J. P. VAN DER MOLEN, 1977. Proeven met PH 60-41 en PH 60-42 op schadelijke en nuttige insekten in boomgaarden, 1974–1976. Internal report, Schuilenburg and IPO. 6 pp with 7 appendices.

HARAMOTO, F. H., 1969. Biology and control of *Brevipalpus phoenicis* (GEIJSKES) (Acarina: Tenuipalpidae). Technical Bulletin No. 68, Hawaii Agricultural Experiment Station, Hoholulu. 63 pp.

HARRIS, K. M., 1982. *Lestodiplosis oomeni* sp. n. (Diptera: Cecidomyiidae), a predator on the carinate tea mite *Calacarus carinatus* (GREEN) (Acarina: Eriophyiidae) and on other mites on tea plants in Indonesia. Entomologische Berichten **42**, 20–24.

HELLE, W., H. R. BOLLAND and W. R. B. HEITMANS, 1980. Chromosomes and types of parthenogenesis in the false spider mites (Acari: Tenuipalpidae). Genetica, **54**, 45–50.

HENDERSON, C. F. and H. V. MCBURNIE, 1943. Sampling technique for determining populations of citrus red mite and its predators. Circular No. 671, U.S. Department of Agriculture, 11 pp.

HEUNGENS, A. and E. VAN DAELE, 1977. De bestrijding van *Brevipalpus obovatus* tijdens de winter in de azaleateelt. Mededelingen Faculteit Landbouwwetenschappen Rijksuniversiteit Gent, **42**, 1463–1469.

HOMBURG, K., 1955. Het optreden van mijt in de thee-cultuur. Bergcultures, **24**, 55–67.

HOY, M. A., D. FLAHERTY, W. PEACOCK and D. CULVER, 1979. Vineyard and laboratory evaluations of methomyl, dimethoate and permethrin for a grape pest management program in the San Joaquin Valley of California. Journal of Economic Entomology, **72**, 250–255.

HOY, M. A. and R. T. ROUSH, 1978. Spider mite predator tested for pesticide resistance on pears. California Agriculture, **32**(8), 11–12.

HOYT, S. C., P. H. WESTIGARD and E. C. BURTS, 1978. Effects of two synthetic pyrethroids on the codling moth, pear psylla, and various mite species in northwest apple and pear orchards. Journal of Economic Entomology, **71**, 431–434.

HUFFAKER, C. B., P.S. MESSENGER and P. DEBACH, 1971. The natural enemy component in natural control, and the theory of biological control. In: Biological Control, C. B. HUFFAKER (Ed.), p. 16–67. Proceedings of an AAAS Symposium on biological control, Boston, 1969. Plenum Press, New York. 511 pp.

HUFFAKER, C. B., M. VAN DE VRIE and J. A. MCMURTRY, 1970. II. Tetranychid populations and their possible control by predators: an evaluation. Hilgardia, **40**, 381–458.

HUSSEY, N. W. and C. B. HUFFAKER, 1976. Spider mites. In: Studies in biological control, V. L. DELUCCHI (Ed.), p. 179–228. Cambridge University Press, Cambridge, 304 pp.

JEPPSON, L. R., 1978. Bionomics and control of mites attacking citrus. Proceedings of the International Society of Citriculture, 1977, volume 2, 445–451.

JEPPSON, L. R., H. H. KEIFER and E. W. BAKER, 1975. Mites injurious to economic plants. University of California Press, Berkeley. 614 pp.

KALSHOVEN, L. G. E., 1950. De plagen van de cultuurgewassen in Indonesië. W. van Hoeve, 's Gravenhage. Part 1, 512 pp.

KAMBUROV, S. S., 1971. Feeding, development and reproduction of *Amblyseius largoensis* on various food substances. Journal of Economic Entomology, **64**, 643–648.

KARG, W., 1971. Die freilebenden Gamasina (Gamasides), Raubmilben. 59. Teil, Die Tierwelt Deutschlands, M. DAHL and F. PEUS (Eds.). Gustav Fisher Verlag, Jena. 475 pp.

KING, C. B. R., 1936. Tea mite pests. Tea Quarterly, **9**, 144–153.

KIRITANI, K. and J. P. DEMPSTER, 1973. Different approaches to the quantitative evaluation of natural enemies. Journal of Applied Ecology, **10**, 323–330.

KITAJIMA, E. W., G. W. MULLER, A. S. COSTA and W. YUKI, 1972. Short, rod-lik particles associated with citrus leprosis. Virology, **50**, 254–258.

KNORR, L. C. and H. A. DENMARK, 1970. Injury to citrus by the mite *Brevipalpus phoenicis*. Journal of Economic Entomology, **63**, 1996–1998.

KOCH, V. J. M., 1978. Report on activities and research of the plant protectionist. In: Final report, Tea Research Project ATA 51, V. J. M. KOCH (Ed.), 5 pp. International Technical Assistance Department, The Hague. 111 pp.

KONINGSBERGER, J. C., 1903. Ziekten van rijst, tabak, thee en andere cultuurgewassen, die door insecten worden veroorzaakt. Mededeelingen uit 's Lands Plantentuin, Batavia, **64**, 109 pp.
LAL, L., 1978. Biology of *Brevipalpus phoenicis* (GEIJSKES) (Tenuipalpidae: Acarina). Acarologia, **20**, 97–101.
LAWTON, J. H. and S. MCNEILL, 1979. Between the devil and the deep blue sea: on the problem of being a herbivore. In: Population dynamics, R. M. ANDERSON, B. D. TURNER and L. R. TAYLOR (Eds.), 223–244. The 20th Symposium of the British Ecological Society, London 1978. Blackwell, Oxford. 344 pp.
LAYCOCK, D. H. and J. C. TEMPLER, 1973. Pesticides for East African Tea. Pamphlet No. 23/73, Tea Research Institute of East Africa. 15 pp.
LIEFSTINGH-HARDICK, F. B., 1955. Laboratoriumproeven inzake bestrijding oranje mijt (*Tenuipalpus obovatus* DONN). Bergcultures, **24**, 477–481.
MATTHEWS, G. A., 1979. Pesticide application methods. Longman, London. 334 pp.
MCMURTRY, J. A., C. B. HUFFAKER and M. VAN DE VRIE, 1970. I. Tetranychid enemies: their biological characters and the impact of spray practices. Hilgardia, **40**, 331–390.
MEYER, M. K. P. S., 1979. The Tenuipalpidae (Acari) of Africa. Entomology Memoir No. 50, Department of Agricultural Technical Services, Republic of South Africa. 135 pp.
MORGAN, N. G., 1975. Spraying intensive top fruit orchards. SPAN, **18**, 68–71.
NACHMAN, G., 1981. Temporal and spatial dynamics of an acarine predator-prey system. Journal of Animal Ecology, **50**, 435–451.
NAGESHA CHANDRA, B. K. and G. P. CHANNABASAVANNA, 1974. Host plants of *Brevipalpus phoenicis* GEIJSKES (Acarina: Tenuipalpidae) in India. Acarology News Letter, **2**, p. 3.
NARA, J., B. SOEPADMO, SARDJONO and RUSWANDA, 1972. Pengudjian beberapa djenis akarisida tungau djingga pada teh. Menara Perkebunan, **40**, 121–125.
NELSON, E. E., B. A. CROFT, A. J. HOWITT and A. L. JONES, 1973. Toxicity of apple orchard pesticides to *Agistemus fleschneri*. Environmental Entomology, **2**, 219–222.
ODUM, E. P., 1971. Fundamentals of ecology. Saunders, Philadelphia. Third edition, 574 pp.
OVERMEER, W. P. J. and A. Q. VAN ZON, 1981. A comparative study on the effect of some pesticides on three predacious mite species: *Typhlodromus pyri, Amblyseius potentillae* and *A. bibens* (Acarina: Phytoseiidae). Entomophaga, **26**, 3–9.
OWEN, D. B., 1962. Handbook of statistical tables. Addison-Wesley Publishing Company, Reading. 580 pp.
PARENT, B., 1960. Effets de certains produits antiparasitaires sur *Typhlodromus rhenanus* OUDMS. et *Mediolata mali* EWING, deux acariens prédateurs du Tétranyque rouge du pommier. Annales de la Société Entomologique de Québec, **6**, 55–58.
PERECIN, D. and C. A. L. de OLIVEIRA, 1979. Análise estatistica de contagens de *Brevipalpus phoenicis* (GEIJSKES 1939), na cultura do citrus, baseada na distribuição binomial negativa. Científica, **7**, 211–219.
PIELOU, E. C., 1974. Population and community ecology. Gordon and Breach, New York. 424 pp.
PIJNACKER, L. P., M. A. FERWERDA, H. R. BOLLAND and W. HELLE, 1980. Haploid female parthenogenesis in the false spider mite *Brevipalpus obovatus* (Acari: Tenuipalpidae). Genetica, **51**, 211–214.
PREBBLE, K. F., 1972. Red crevice mite, *Brevipalpus phoenicis*. Tea in East Africa, **13**, 27–30.
PITCHARD, A. E. and E. W. BAKER, 1958. The false spider mites (Acarina: Tenuipalpidae). University of California Publications in Entomology, **14**, 175–274.
RABBINGE, R., 1976. Biological control of fruit-tree red spider mite. Pudoc, Wageningen. 228 pp.
RAMLOGUN, H. G. S., 1971. The pests and diseases of tea in Mauritius. Revue Agricole et Sucrière de l' Ile Maurice, **50**, 48–67.
RAO, G. N., 1974a. Control of tea mites in South India-I. Planters' Chronicle, **69**, 91–94.
RAO, G. N., 1974b. Control of tea mites in South India-II. Planters' Chronicle, **69**, 111–114.
RAO, V. P., B. DATTA, G. RAMASESHIAH, 1970. Natural enemy complex of flushworm and phytophagous mites on tea in India. Scientific Publications Series No. 5, Tea Board, India. 53 pp.
RAZOUX SCHULTZ, L., 1961. Enkele notities over de oranje mijt, *Brevipalpus phoenicis* GEIJSKES, op thee in Indonesië. Mededelingen Landbouwhogeschool Gent, **26**, 1694–1702.
READSHAW, J. L., 1975. The ecology of tetranychid mites in Australian orchards. Journal of Ap-

plied Ecology, **12**, 473–495.
ROCK, G. C., 1979. Relative toxicity of two synthetic pyrethroids to a predator *Amblyseius fallacis* and its prey *Tetranychus urticae*. Journal of Economic Entomology, **72**, 293–294.
SABELIS, M. W., 1981. Biological control of two spotted spider mites using phytoseiid predators. Part 1. Modelling the predator-prey interaction at the individual level. Agricultural Research Reports, **910**. Pudoc, Wageningen. 242 pp.
SANDFORD, K. H., 1967. The influence of spray programs on the fauna of apple orchards in Nova Scotia. Canadian Entomologist, **99**, 197–200.
SCHOOREL, A. F., 1950. De landbouwkundige grondslag van snoei en pluk bij assamthee. Proefschrift, Landbouwhogeschool Wageningen. 155 pp.
SECHSER, B., 1970a. Der Parasitenkomplex des Kleinen Frostspanners (*Operophtera brumata* L.) (Lep., Geometridae) unter besonderer Berücksichtigung der Kokonparisiten. I. Teil. Zeitschrift für Angewandte Entomologie **66**, 1–35.
SECHSER, B., 1970b. Der Parasitenkomplex des Kleinen Frostspanners (*Operophtera brumata* L.)(Lep., Geometridae) unter besonderer Berücksichtigung der Kokonparasiten. II Teil. Zeitschrift für Angewandte Entomologie, **66**, 145–160.
SOUTHWOOD, T. R. E., 1966. Ecological methods. Chapman and Hall, London. First ed, 391 pp.
SOUTHWOOD, T. R. E., 1978. Ecological methods. Chapman and Hall, London, Second edition, 524 pp.
STANILAND, L. N., 1959. Fluorescent tracer techniques for the study of spray and dust deposits. Journal of Agricultural Engineering Research, **4**, 110–125.
STEENIS, C. G. G. J. VAN, 1972. The mountain flora of Java. Brill, Leiden. 90 pp.
SUSKI, Z. W. and J. A. NAEGELE, 1963. Light responses in the two-spotted spider mite. 2. Behavior of the 'sedentary' and 'dispersal' phases. Advances in Acarology **1**, 445–453.
SUTADIREDJA, A. H. and P. A. OOMEN, 1977. Percobaan efikasi Trithion 4E terhadap tungau jingga teh (*Brevipalpus obovatus*). Report, Research Institute for Tea and Cinchona, Gambung, 5 pp.
SWIRSKI, E., S. AMITAI and N. DORZIA, 1967. Laboratory studies on the feeding, development and reproduction of the predacious mites *Amblyseius rubini* and *Amblyseius swirskii* (Acarina: Phytoseiidae) on various kinds of food substances. Israel Journal of Agricultural Research **17**, 101–119.
TANAKA, M. and T. KASHIO, 1977. Biological studies on *Amblyseius largoensis* MUMA (Acarina: Phytoseiidae) as a predator of the citrus red mite, *Panonychus citri* MCGREGOR (Acarina: Tetranychidae). Bulletin Fruit Tree Research Station, Japan, **D1**, 49–67.
TANIGOSHI, L. K., S. C. HOYT, R. W. BROWNE and J. A. LOGAN, 1975. Influence of temperature on population increase of *Tetranychus mcdanieli* (Acarina, Tetranychidae). Annals of the Entomological Society of America, **68**, 972–978.
VARLEY, G. C., G. R. GRADWELL and M. P. HASSELL, 1973. Insect population ecology: an analytical approach. Blackwell, Oxford. 212 pp.
VRIE, M. VAN DE, J. A. MCMURTRY and C. B. HUFFAKER, 1972. III. Biology, ecology and pest status, and host plant relations of Tetranychids. Hilgardia, **41**, 343–432.
WARDOJO, S., RUSWANDA and M. K. AMIDJAYA, 1974. Pengujian beberaja jenis akarisida untuk pemberantasan tungau jingga pada teh. Menara Perkebunan, **42**, 115–119.
WHITE, N. D. and J. E. LAING, 1977a. Some aspects of the biology and a laboratory life table of the acarine predator *Zetzellia mali*. Canadian Entomologist, **109**, 1275–1281.
WHITE, N. D. and J. E. LAING, 1977b. Field observations of *Zetzellia mali* (EWING) (Acarina: Stigmaeidae) in Southern Ontario apple orchards. Proceedings of the Entomological Society of Ontario, **108**, 23–30.
YOUSEF, A. A., 1970. Mites associated with vine trees in the U.A.R. (Acarina). Zeitschrift für angewandte Entomologie, **67**, 1–6.
ZAHER, M. A., A. H. RASMY amd B. A. ABOU-AWAD, 1971. Ecological studies on mites infesting deciduous fruit trees in Lower Egypt. Zeitschrift für angewandte Entomologie, **69**, 59–64.
ZAHER, M. A., A. K. WAFA and A. A. YOUSEF, 1970. Biology of *Brevipalpus phoenicis* (GEIJSKES) in Egypt (Acarina: Tenuipalpidae). Bulletin de la Société entomologique d'Egypte, **54**, 177–183.
ZON, A. Q. VAN, and M. WYSOKI, 1978. The effect of some fungicides on *Phytoseiulus persimilis*

(Acarina: Phytoseiidae). Entomophaga, **23**, 371–378.
ZULUAGA C., I. and A. SALDARRIAGA V., 1970. Reconocimiento, identificación y algunas observaciones sobre dinámica de poblaciones de ácaros en cítricos del Valle del Cauca, Colombia. Acta Agronomica, Colombia, **20**, 113–141.

CURRICULUM VITAE

1946	3 september geboren te Nijmegen
1965	Diploma Gymnasium β, Canisius College, Nijmegen
1965	Aanvang studie biologie, Rijks Universiteit Utrecht
1968	Kandidaatsexamen; aanvang doktoraalstudie vergelijkende fysiologie, met landbouwdierkunde en biofysica
1968–1971	Student-assistent bij genetica, bij vergelijkende fysiologie en bij statistiek
1971	Doktoraal examen biologie (cum laude)
1970–1971	Docent COVALU, school voor zoologisch analysten
1971–1974	Mexico. Assistent-deskundige FAO, Cd. Valles S.L.P. Toegepast ecologisch onderzoek van een plaag van schuimcicaden in graslanden. Docent aan het Instituto Tecnológico de Estudios Superiores de Monterrey.
1974–1975	Boven-Volta. Assistent-deskundige FAO, Bobo Dioulasso. Toegepast ecologisch onderzoek aan rijstplagen.
1975–1978	Indonesië. Assistent-, later gewoon deskundige DGIS, Gambung. Toegepast ecologisch onderzoek aan mijtenplagen van thee.
1978–1980	Indonesië. Wetenschappelijk ambtenaar Landbouwhogeschool voor WOTRO, Gambung. Onderzoek omtrent de populatie dynamica van oranje mijt in thee.
1980–1981	Wetenschappelijk ambtenaar Landbouwhogeschool voor WOTRO, Wageningen. Voorbereiding promotie.

Present adress: Pieter A. Oomen
Tarthorst 503
6708 HR Wageningen
The Netherlands