BIOLOGICAL CHARACTERISTICS AND FORECASTING OUTBREAKS OF THE WHITEFLY, *BEMISIA TABACI*, A VECTOR OF VIRUS DISEASES IN SOYBEAN FIELDS

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ABSTRACT

The tobacco whitefly, Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae), is an important pest of a wide range of crops belonging to many different botanical families. This paper reviews biological characteristics of B. tabaci, and discusses the reliability of various sampling methods. We also attempt to clarify factors influencing fluctuations in the population density of B. tabaci by using data obtained in soybean fields in Indonesia. Several parasitoids seem to be potentially useful as biological control agents, in combination with the use of other control methods. Yellow sticky traps and vacuum sampling both seem to give reliable indications of the general population trends of B. tabaci. The major factor influencing the population density of B. tabaci seems to be spatio-temporal variations in the quantity of host plants in the area. If host plants are cultivated continuously in time and space, there will be more serious damage to fields planted later in the season.

INTRODUCTION

Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae), the tobacco whitefly, is a polyphagous insect. It is widely distributed throughout the tropics and subtropics, occurring as far north as southern Europe, Japan and the southern United States (Hill 1987). *B. tabaci* is an important pest of a wide range of crops belonging to many different botanical families. Mound and Halsey (1978) have listed 350 plant species attacked by *B. tabaci.* It causes direct damage by feeding, and also causes indirect damage from its heavy secretion of honeydew on the plants, which serves as a growing medium for sooty mold fungus. The tobacco whitefly is also an important vector of virus diseases (Byrne *et al.* 1990).

The present paper reviews the biological characteristics of *B. tabaci*, and sampling methods which can be used to obtain basic information for implementing a sound integrated pest management program. We also attempt to clarify factors influencing fluctuations in population density.

Keywords: Life history, migration, natural enemy, population dynamics, sampling technique, the quantity of food resources, yellow sticky trap

BIOLOGICAL CHARACTERISTICS

Taxonomy

The majority of whitefly species cannot be identified by the morphological characters of the adults. Genera and species are usually defined according to the structure of the fourth nymphal instar, the so-called "pupal case" (Mound and Halsey 1978). Unfortunately, polyphagous whitefly species such as *Trialeurodes vaporariorum* (Westwood) and *B. tabaci* vary in the appearance (shape and size) of their pupal case, depending on the cuticle of the host plant on which they feed. This host-correlated morphological variation and host-plant diversity have led to a large number of synonyms of *B. tabaci* (Lopez-Avila 1986), which have been listed by Mound and Halsey (1978).

Infestation with *B. tabaci* has recently been reported to induce silverleaf syndrome of squash, and irregular ripening of tomato fruits (Bharathan *et al.* 1990, Yokomi *et al.* 1990, Schuster *et al.* 1990, Matsui 1992a). Concerning the whitefly which causes squash silverleaf disease, Perring *et al.* (1993) have proposed that this particular whitefly species, which is morphologically indistinguishable from *B. tabaci*, is a distinct species on the basis of results of allozymic frequency analyses, crossing experiments, and mating behavior studies. They therefore refer to this new species, previously called the poinsettia strain, as "silverleaf whitefly". The whitefly which causes irregular ripening of tomato fruits may also be the silverleaf whitefly. However, we are not convinced it is a separate species, and in this paper refer to it as the silverleaf strain.

History of Occurrence and Injury

B. tabaci was first described as a pest of tobacco in Greece in 1889. Outbreaks in cotton occurred in the late 1920s and early 1930s in India, and subsequently in the Sudan and Iran from the 1950s, in 1961 in El Salvador, in 1962 in Mexico, in 1968 in Brazil, in 1974 in Turkey, in 1976 in Israel, in 1978 in Thailand, and in 1981 in Arizona and California (Horowitz 1986). Outbreaks of *B. tabaci* in soybean fields took place in 1972-73 in Brazil (Kogan and Turnipseed 1987) and in 1981-82 in Indonesia (Samudra and Naito 1991). In greenhouses, *B. tabaci* was recorded to cause serious damage to vegetables in 1974 in Turkey, and to poinsettia in 1986 in USA and in 1989 in Japan (Ohto 1990). The whitefly found on poinsettia in 1986 in USA was the silverleaf strain (Perring *et al.* 1993), and that first recorded in 1989 in Japan may also belong to the same strain.

Life History

The eggs are about 0.2 mm long and pear-shaped. They are laid on the undersurface of young leaves. After hatching, individuals during their immature stages also stay on the undersurface of leaves. The first instar nymphs (crawlers) move a very short distance over the leaf surface until they find a suitable site for feeding. Once settled, they remain sessile until they reach the adult stage, except for brief periods during molts. The fourth instar (the so-called "pupa") is about 0.7 mm long. Its red eye spots, which become eyes at the adult stage, are characteristic of this instar.

The adults are about 1 mm long with white wings covered in a waxy powder. By applying morphometric analysis, Byrne and Houck (1990) revealed sexual dimorphism in wing forms: the fore- and hindwings of females were larger than those of males. The mean wing expanses of females and males are 2.13 mm and 1.81 mm, respectively (Byrne and Bellows 1991).

The developmental time of *B. tabaci* from egg to adult is significantly different according to the host plant it feeds on (Coudriet *et al.* 1985). Butler *et al.* (1983) studied the development of *B. tabaci* on seedlings of cotton plants kept in cabinets at constant temperatures. The average developmental time, from egg to adult, was 23.6 days at 25°C, and 17.8 days at 27.5°C. Eggs failed to hatch when temperatures were 36.0°C.

Most information on the fecundity of *B. tabaci* has been obtained from whitefly on cotton. Even with regard to cotton there are variations in fecundity and longevity, ranging from an average of 81 to 309 eggs per female at 25°C - 27°C at different locations (Table 1). Sudanese populations of *B. tabaci* appear to be much more prolific than those from other parts of the world. Gerling *et al.* (1986) speculated that the Sudanese strains were probably induced by repeated insecticide applications. Bethke *et al.* (1991) also demonstrated significant differences in fertility and pupal size between the cotton strain and the poinsettia strain (= the silverleaf strain) of *B. tabaci* in California. The silverleaf strain also processes more plant phloem sap during feeding, thus excreting a higher volume of honeydew waste product (Perring *et al.* 1993).

Gerling *et al.* (1986) has summarized our knowledge of the life span of *B. tabaci* adults obtained in the field. Females live 10-15 days during

Table 1. Life history traits of *B. tabaci* on cotton under laboratory conditions

Conditions	30°C	29°C	27°C	26.7°C	25-26°C	25-26°C	25.5°C
Average no. eggs per female	95.5	73.8	127.5	81	>309	309	171.6
Female longevity (days)	9.5	20.9	12.9	8	29.4	29.4	22.8
Developmental time from egg to adult (days)	17.7	—	—	17.8**	—	—	—
Location where samples were collected	Israel	California, USA	Sudan	Arizona USA	Sudan	Sudan	California, USA
Reference	Horowitz* (1983)	Powell and Bellows (1992)	Von Arx* *et al.* (1983)	Butler *et al.* (1983)	Hassan* (1982)	Dittrich *et al.* (1986)	Powell and Bellows (1992)

* After Gerling *et al.* (1986)
** under 27.5°C

the summer (temperatures in the high twenties) and 30-60 days in winter (temperatures around 14°C).

Sex Ratios

Since *B. tabaci* is arrhenotokous, it can lay unfertilized eggs which develop into males only. The data on sex ratio changes throughout the season are too few and too variable to enable us to draw any conclusions (Gerling 1986).

Migration

The flight of *B. tabaci* occurs during the morning up until midday, and has a single peak (Byrne and Bellows 1991). *B. tabaci* adults have limited ability to direct their flight (Byrne *et al.* 1990). The adults demonstrate two distinct flight patterns: short- and long-distance flight. Short-distance flights occur under the plant canopy. Long-distance flights occur when adults take off from their host plant, get caught in an air current and drift passively (Lenteren and Noldus 1990). The longest flight distance measured was 7 km (Cohen 1990).

Natural Enemies

Predators and Parasitoids

Nineteen species of insects belonging to four families (Chrysopidae, Miridae, Anthocoridae and Coccinellidae) and eleven species of mites belonging to two families (Phytoseiidae and Stigmaeidae) are recorded as being predators of *B. tabaci* (Lopez-Avila 1986, Gerling 1990).

Twenty-eight species were recorded to be parasitoids of *B. tabaci.* These are: Aphelinidae (*Aphelosoma*: 1 species, *Encarsia*: 20 species, *Eretmocerus*: 6 species), and Platygasteridae (*Amitus*: 1 species) (Lopez-Avila 1986, Gerling 1990, Kajita personal communication).

Predators and parasitoids do not seem to be effective agents in reducing *Bemisia tabaci* populations under field conditions (Coudriet *et al.* 1986, Gerling *et al.* 1980, Gerling 1986, 1990, Kajita *et al.* 1992). In glasshouses, however, several parasitoids seem to be effective in controlling *B. tabaci.* Matsui (1992b) showed that the density on tomato grown in a glasshouse of *B. tabaci*, probably the silverleaf strain, was suppressed successfully by releasing *Encarsia formosa*. Several parasitoids have been proposed as potentially useful biological control agents, in combination with the use of other control methods: *Eretmocerus haldemani* in cotton fields in California, USA (Gerling 1967), *Eretmocerus mundus* in cassava fields in Zimbabwe (Gerling 1985), *Encarsia lutea* in cotton fields in Sudan (Cock 1986), *Eretmocerus aligarhensis* in cotton fields in Pakistan (Cock 1986).

Fungi

Fransen (1990) has summarized the data related to entomopathogenic fungi infecting *B. tabaci.* Although research into fungi as control agents of whitefly is still at an early stage, four species of entomopathogenic fungi have been recorded to infect *B. tabaci.* These are *Paecilomyces fumosoroseus, P. farinosus, Erynia radicans*, and *Aschersonia aleyrodis.* In the laboratory, *P. farinosus* caused 90% mortality of adults of *B. tabaci*, but no data on field applications or natural epizootics are available. *Verticillium lecanii*, an entomopathogenic fungus, seems to be promising as a potential control of the greenhouse whitefly, *Trialeurodes vapo-rariorum*, in experiments in glasshouses.

The data suggest that entomopathogenic fungi may be a useful control method for use in greenhouses.

SAMPLING TECHNIQUES FOR MONITORING THE OCCURRENCE OF *B. TABACI*

Sampling Immature Stages

So far, it has been difficult to estimate accurately the population density of whitefly by taking samples. The distribution of whitefly on plants is far from random, since they tend to select both particular plants and particular parts of the plant (Ekbom and Xu 1990). Eggs and young nymphs occur mostly on the uppermost and youngest leaves, and the sessile early stages mature on the leaves, so that older nymphs and pupae are found on older leaves. Thus random or stratified-random sampling methods, in which leaves are taken from the upper, mid, and lower parts of the plants, may result in an incorrect estimate of the whitefly population level (Horowitz 1986),

Horowitz (1986) has reviewed the various non-random techniques applied in cotton fields. Melamed-Madjar *et al.* (1982) sampled the sixth to the eighth leaf from the top, depending on the season. Gerling *et al.* (1980) sampled the leaf most infested with pupae, and Von Arx *et al.* (1984) sampled the red-eye nymphs on the most heavily infested leaf located on the main stem. The reliability of non-random techniques should from now on be examined statistically.

Sampling Adults

Adult whiteflies are attracted to yellow/green surfaces (Lenteren and Noldus 1990). Yellow sticky traps have come into common use for monitoring adult populations of *B. tabaci* (Ohnesorge and Rapp 1986). The reliability of yellow sticky traps, however, has not been proven (Horowitz 1986). Melamed-Madjar *et al.* (1982) showed a significant correlation between the number of adults caught by yellow traps and the numbers of larvae found in leaf samples in a cotton field ($r=0.91$, $p=0.01$). Matsui (1992b) showed the same correlation in tomato grown in a greenhouse infested with *B. tabaci*, probably the silverleaf strain ($r=0.88$, $p<0.05$). Gerling and Horowitz (1984) and Horowitz (1986) showed a high correlation ($r=0.99$, $p<0.001$) between the number of adults caught by vacuum cleaner and those sampled by direct visual methods in a cotton field. Yellow sticky traps and vacuum sampling seem therefore to reflect at least general population trends.

FACTORS INFLUENCING FLUCTUATIONS IN WHITEFLY POPULATIONS

Using life table analysis, Horowitz *et al.* (1984) studied the population dynamics of *B. tabaci* in cotton fields in Israel. The highest mortality rate occurred among first instar larvae. Mortality and disappearance during that stage were attributed mainly to climatic factors such as humidity and temperature. Parasitism was not a decisive factor. Gerling *et al.* (1986) wrote that extreme relative humidities, both high and low, were unfavorable for the survival of immature stages. In Sudan, heavy rain was usually followed by a drop in population levels (Horowitz 1986).

B. tabaci is known to be a pest of soybean (*Glycine max* (L.) Merr.) and mungbean (*Vigna radiata* (L.) Wilczek) in Indonesia (Tengkano *et al.* 1991). We used yellow sticky traps to monitor *B. tabaci* populations in soybean fields in the northern part of West Java, Indonesia. The traps were rectangular, measuring 20 by 25 cm, and were placed vertically 5 cm above the canopy of soybean plants. In the main experiment, traps were set in each fixed experimental plot in six subdistricts, but to provide data for a preliminary analysis for clarifying the mechanisms of *B. tabaci* population fluctuations, we chose two experimental plots. One was in the Plumbon Subdistrict of Cirebon Prefecture, and the other in the Campaka Subdistrict of Purwakarta Prefecture, about 150 km away.

Soybean seeds were sown in one of three fields within the experimental plot every month, from January 1987 to January 1988 in Plumbon. From March 1988 they were sown alternately in two neighboring fields every two months to March 1991 in Plumbon, and from November 1988 to March 1991 in Campaka. The duration of one cropping season of soybean, from sowing to harvesting, was about three months. The variety of soybean planted in both experimental plots was Lokon, except for the period of January 1987 to April 1987, when Orba, another variety of soybean, was sown at Plumbon. No insecticides were applied. Three traps were set in each experimental field until March 1989, and six traps per field thereafter. The number of *B. tabaci* captured on the traps was counted once a week.

Fig. 1 shows a typical example of changes in the number of *B. tabaci* caught in a trap during one cropping season. The number of whitefly caught in the trap rose slowly early in the season, reached a peak late in the season then leveled off and finally declined. Since it takes about three weeks for eggs to develop into adults, the adults caught on traps during the first month after sowing are considered to be immigrants from neighboring fields. The population decline occurred when they left old soybean plants in response to deterioration of the foliage, in search of better feeding or oviposition sites.

The maximum number of adults per trap in each cropping season in the two experimental plots showed a similar marked seasonal trend. The traps caught more whiteflies during the cropping seasons which began in September and November than in any other cropping season (Fig. 2). This trend cannot be attributed to seasonal changes in temperature, because the average monthly atmospheric temperature in this part of Java is nearly constant throughout the year at around 27°C. In West Java, the rainy season is usually from October to March, so the high numbers of *B. tabaci* per trap corresponded to the first half of the rainy season.

As mentioned above, extreme relative humidities, both high and low, adversely affect the survival rate of immature stages (Horowitz *et al.* 1984; Gerling *et al.* 1986). We therefore examined whether rainfall influenced fluctuations in *B. tabaci* populations. Fig. 3 shows no clear relationship between the maximum number of *B. tabaci* per trap and precipitation during the preceding 30 days in either experimental plot.

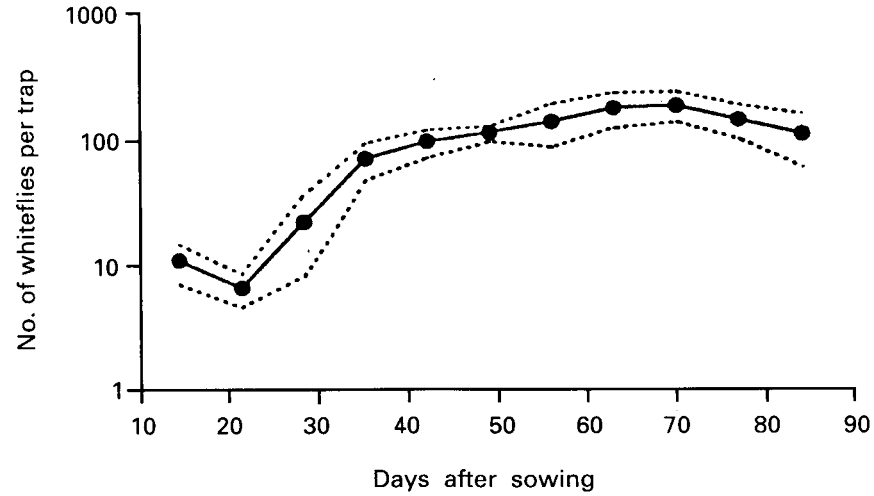

Fig. 1. Changes in trap catches of *Bemisia tabaci* in one cropping season of soybean. Dotted lines represent 95% confidence limits. Data were obtained by traps set in an experimental field in Campaka, West Java. Soybean seeds were sown on January 3, 1990.

The Pest Observer Data of Central Java, covering the period April 1984 to March 1988, was analyzed to confirm the relationship between population changes of *B. tabaci* and rainfall. There are 157 observation units in the Province of Central Java, to which 285 officials of the central government are assigned as pest observers. Patrol surveys are carried out in each observation district every two weeks. The surveys record the area under soybean cultivation, and the area of soybeans infested with *B. tabaci*.

Fig. 4 shows the relationship between the ratio of the infested area (*RI*) and precipitation (*RM*). *RI* is the area of soybean fields infested by *B. tabaci* compared to the total area under soybean cultivation at that time, and *RM* is the average monthly precipitation over two successive months. There exists no clear relationship between the two variables (Fig. 4). Although precipitation may not correspond exactly to relative humidity, these results suggest that climate is not a major factor influencing changes in the populations of *B. tabaci* in Java.

The number of adults per trap in the experimental plot tended to increase when or after the area under soybean and mungbean cultivation in the subdistrict increased, and tended to fall when or after the planted area decreased (Fig. 2). The traps catch not only adults emerging in the experimental field, but immigrants from elsewhere. Thus, it is necessary to take into account the number of available host plants in neighboring fields when we consider seasonal changes in the population density of *B. tabaci*. The number of the maximum catch of *B. tabaci* per trap can thus be divided by the area under soybean and mungbean cultivation at that time in the subdistrict where the experimental field is located, to give an index of population density (*PD*). Fig. 5 shows seasonal changes in the population density of *B. tabaci* (*PD*), and monthly changes in the area under soybean and mungbean cultivation within each subdistrict. As with the number of adults per trap, the population density of *B. tabaci* tended to increase when or after the area planted with host crops increased, and decrease when or after this planted area fell (Fig. 5). This suggests that if the quantity of these food resources increases continuously over time in the area, the population density of *B. tabaci* will also increase because of the higher probability that the whiteflies will succeed in finding better feeding or oviposition sites during the dispersal process. The time lag between fluctuations in the quantity of food resources and population density of *B. tabaci* seems to be a result of the intrinsic rate of natural increase of *B. tabaci,* and its flight ability which enables it to find a favorable food resource quickly.

The mean number of whiteflies per trap in the Plumbon experimental plot was about double the number in the Campaka traps (Fig. 3). Plots of soybean and mungbean fields are scattered through-

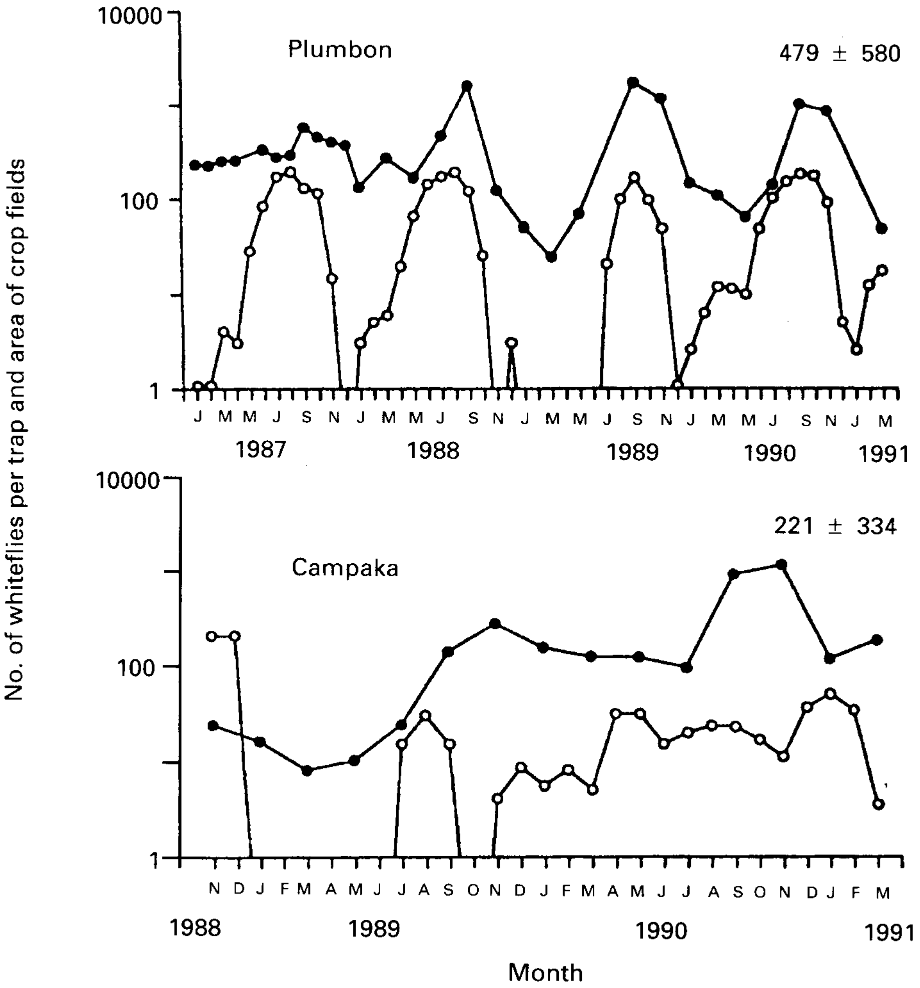

Fig. 2. Seasonal trends ( ) in the maximum numbers of *Bemisia tabaci* per trap in two experimental plots in different cropping seasons, and monthly changes (m) in areas (ha) under soybean and mungbean cultivation in each subdistrict. Soybeans were not sown on May 1987, July 1989 and January 1991 in the Plumbon experimental plot. The mean value of the numbers of whiteflies per trap and the standard deviation are given in the Figure. In the case of Plumbon, the data covering the period March 1988 to March 1991 (soybean being sown every two months) was used for the calculations.

out each subdistrict. Fig. 6 shows the monthly changes in the ratio (*Ra*) of the area under soybean and mungbean cultivation to the total surface area of each subdistrict. The mean ratio (*Ra*) in Plumbon was about seven times higher than in Campaka (Fig. 6). Since a higher ratio (*Ra*) means that the distance between patches of soybean and/or mungbean is shorter, there would be a higher probability that whitefly could find better feeding or oviposition sites. This seems to be the reason why the mean number of whiteflies per trap in Plumbon was higher than in Campaka.

From the above analysis it would seem that climatic factors are not a major factor in fluctuations in the population density of *B. tabaci* in regions such as Java, which have a mild climate. Neither were parasitoids important (Kajita *et al.* 1992). The major factor seems to be spatio-temporal variations in the quantity of host plants in the area. If large numbers of host plants are cultivated continuously in time and space, *B. tabaci* will cause greater damage to host plants grown later in the planting season. In fact, outbreaks of *B. tabaci* in Brazil occurred under such circumstances (Kogan & Turnipseed 1987).

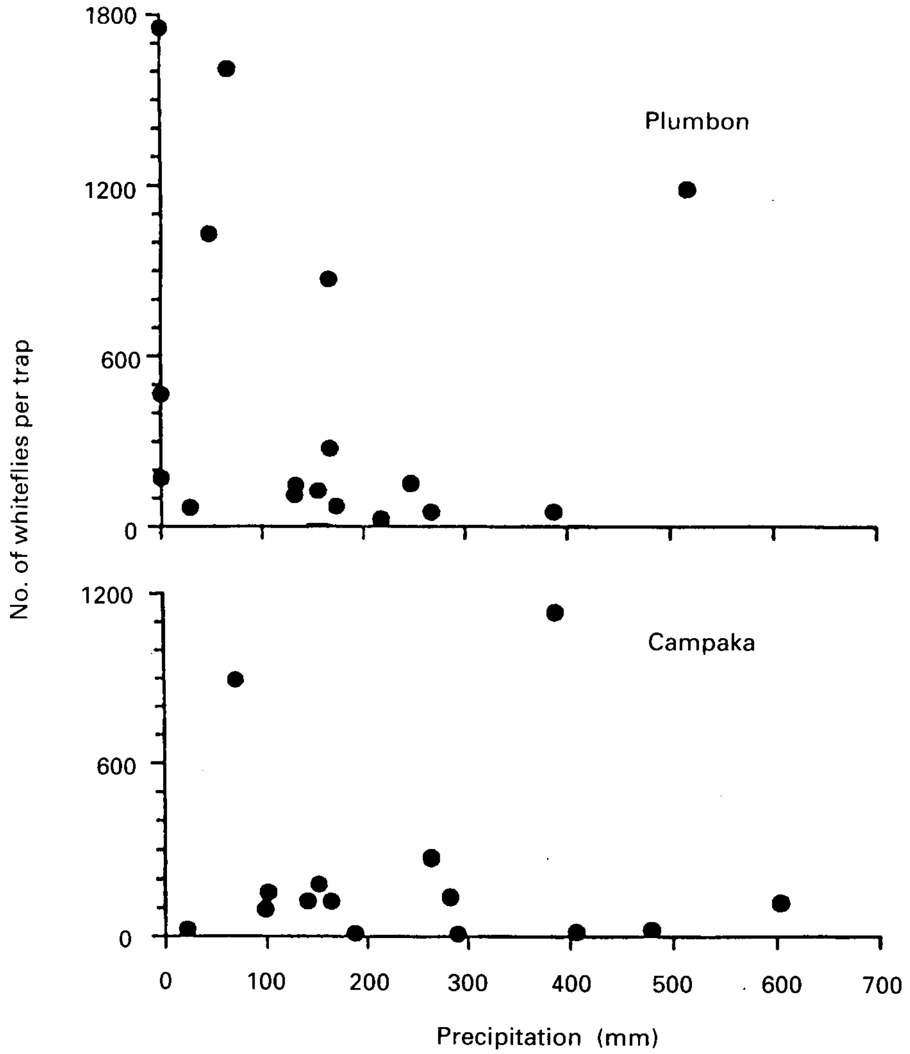

Fig. 3. Relationship between the maximum number of *Bemisia tabaci* per trap and total precipitation during the 30 days before the maximum catch of adults in each sowing season. There is no significant correlation between the two variables in either location (Kendall rank correlation, $p > 0.05$).

CONCLUSION

Infestation by *B. tabaci* is not likely to be serious in an environment where the host plants are grown discontinuously in time and space. If large numbers of cultivated host plants are grown in an area, farmers should plant their crops simultaneously in order to avoid the high-density occurrence of *B. tabaci* later in the cropping season.

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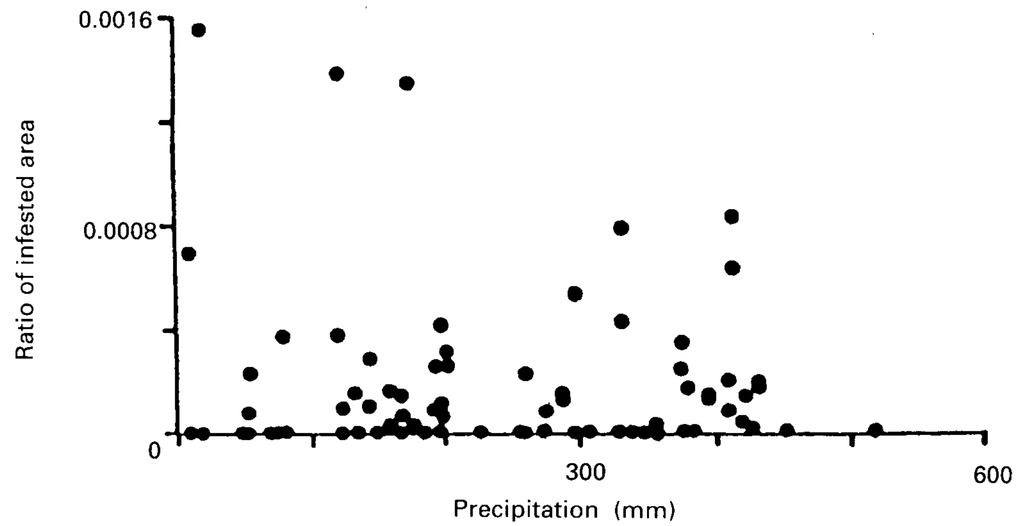

Fig. 4. Relationship between the ratio of the area of soybean infested by *B. tabaci* (*RI*) and precipitation (*RM*) in the province of Central Java. There is no significant correlation between the two variables (Kendall rank correlation, $p>0.05$).

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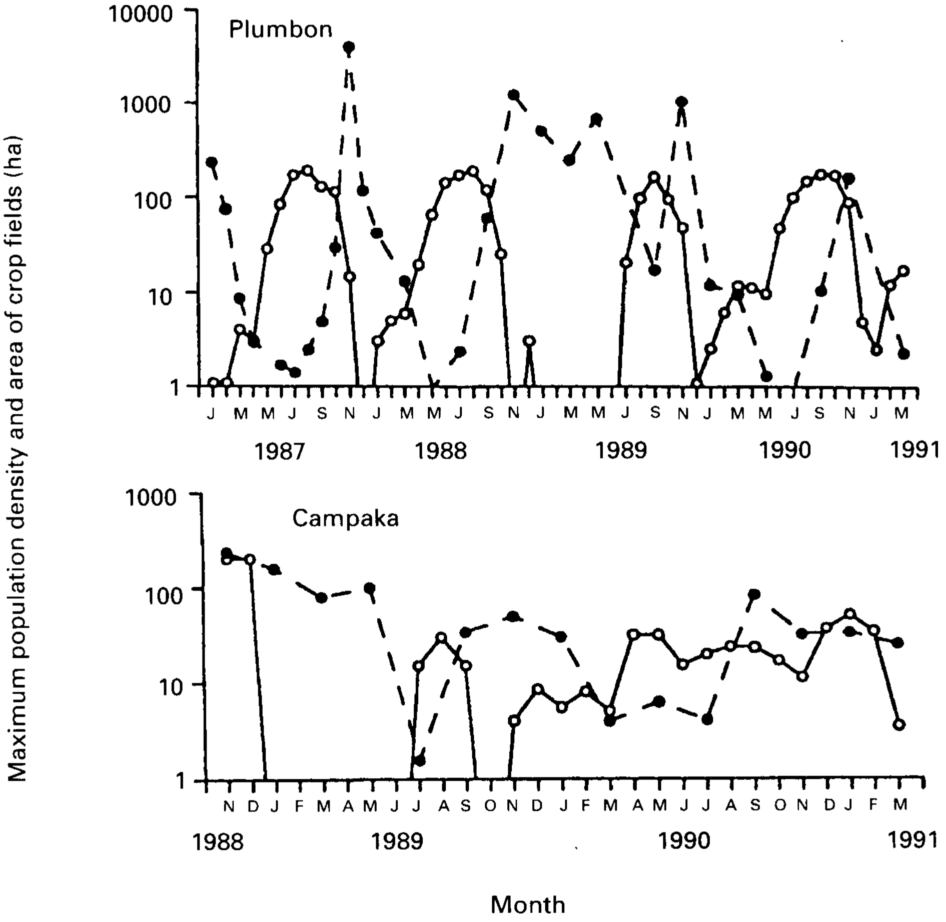

Fig. 5. Seasonal changes ( ) in maximum population density (PD) in each cropping season, and monthly changes (m) in the area used for soybean and mungbean cultivation in each subdistrict.

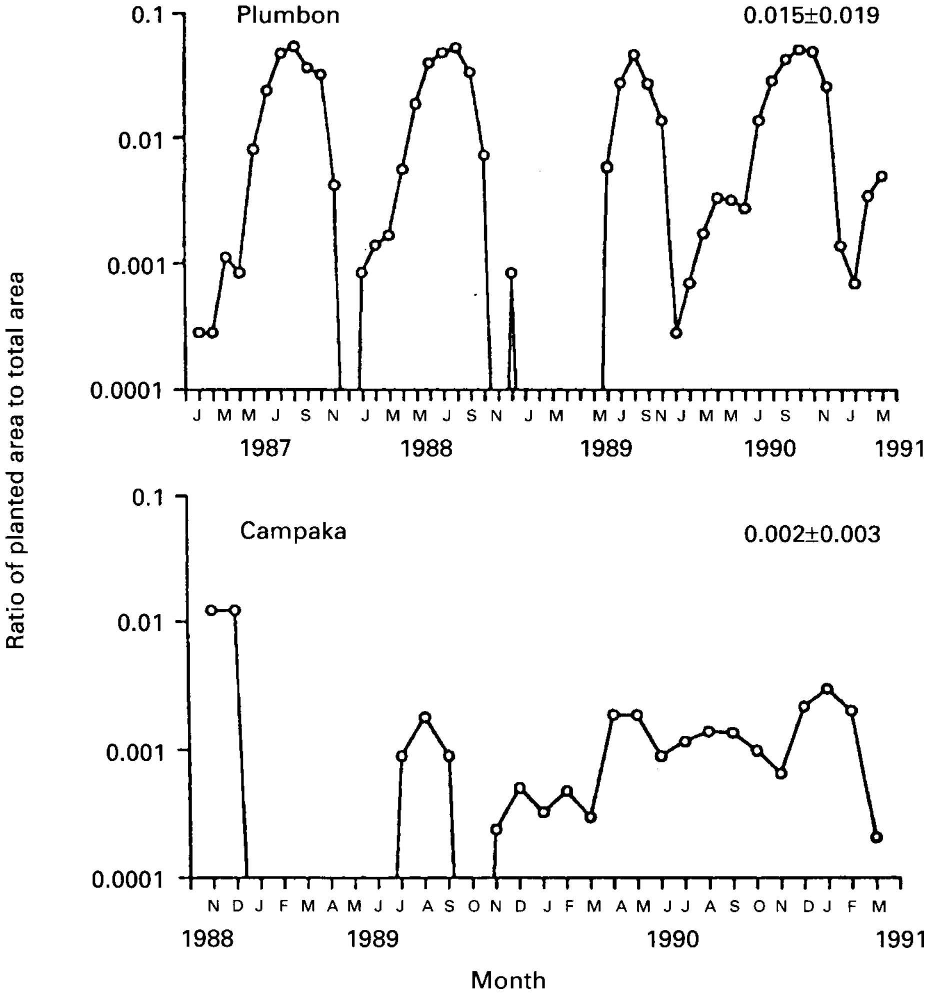

Fig. 6. Monthly changes in the ratio of the area planted with soybean and mungbean to the total surface area of each subdistrict. The mean value of the ratio and the standard deviation are given in the figure. In the case of Plumbon, the data covering the period March 1988 to March 1991 was used for the calculations.

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DISCUSSION

Dr. La asked about the virus diseases of soybean in Java which are transmitted by whitefly. Dr. Hirano mentioned that only cowpea mild mottle virus has been detected. Dr. Su referred to the two strains of *Bemisia tabaci* described in Dr. Hirano's paper, the cotton strain and the poinsettia strain, and asked which strain attacked tobacco. Dr. Hirano replied that the cotton strain is very common all over the world, and seems to attack tobacco. Dr. Su pointed out that poinsettia leaves infested with leaf curl virus show symptoms identical to tobacco leaf curl, and suggested that it is possible that the poinsettia strain also attacks tobacco.