EARLY DETECTION, MONITORING AND CONTROL OF GREENHOUSE WHITEFLIES ON CUCUMBER USING YELLOW STICKY TRAPS AND *ENCARSIA FORMOSA*

by

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ABSTRACT

A review of the literature on the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) and its parasite, *Encarsia formosa* (Gahan), revealed that a major reason for the failure of *E. formosa* to control whitefly populations in greenhouses on cucumber is that introductions are made when whitefly numbers are too high to be controlled below tolerable levels.

A yellow trap coated with Stiky Stuff®, was developed for early detection, monitoring and control of whitefly adults. Although a bright yellow paint was the most attractive color to *T. vaporariorum* of those tested under laboratory conditions, no color was significantly more attractive than the others under greenhouse conditions. Traps hung at the level of the top of the canopy caught significantly more whiteflies than those hung 30 cm above or below that level.

In trials conducted in a small greenhouse, traps placed at a density of 1 per plant caught 62 per cent of whitefly adults introduced. Traps introduced at this density into a heavily-infested crop reduced whitefly numbers in the greenhouse by 71 per cent in 28 days.

Trials in a large commercial greenhouse showed that whitefly adults could be detected on traps hung at densities of 1 per 2 plants, 1 per 5 plants and 1 per 10 plants before they could be found on the plants. Traps at a density of 1 per 2 plants also provided accurate estimates of the numbers of whiteflies on the tops of the plants. A regression equation was calculated between

the numbers of whiteflies on the traps and the numbers of whiteflies on 9 upper leaves below each trap each week. Traps at a density of 1 per 2 plants in conjunction with *E. formosa* were most effective at controlling whiteflies at low levels when traps were introduced before whiteflies had become established on the crop. When introductions were made into progressively larger whitefly infestations, whitefly numbers increased at progressively faster rates. Small infestations could be reduced by a complete inundation of traps into the area. However, a large whitefly population in the greenhouse could not be controlled by traps placed at a density of 1 per 2 plants.

Management practices also affected whitefly control. The removal from the greenhouse of leaves and shoots bearing parasitized whitefly scales in spring and an insecticide application for thrips in summer severely reduced *E. formosa* numbers. An examination of leaves and shoots for presence of parasites prior to removal from the greenhouse are recommended to reduce such losses. Preventative measures such as removal of non-crop plants from inside and immediately around the greenhouse can be taken to reduce the risk of whitefly infestations early in the season.

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INTRODUCTION

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood)(Homoptera: Aleyrodidae), is one of the most important insect pests on greenhouse cucumber crops throughout the world. Whitefly adults and nymphs or scales feed by sucking on the plant foliage. This causes a reduction in growth of the plant and can induce wilting in strong sunlight (O'Reilly 1974). In addition, honeydew, excreted by all stages of the whitefly (Hussey *et al*. 1958) accumulates on the foliage and the fruit and becomes sites for the development of sooty molds, *Cladosporium* sp. These molds reduce photosynthesis and make the fruit unmarketable. Therefore, growers must wash the honeydew-coated fruit which increases production costs. Untreated greenhouse tomato crops yield 20 to 25 per cent less fruit than crops treated regularly for whiteflies (Linquist *et al*. 1972). In cucumber crops, similar or even greater losses could be expected, although this has not been determined, as whiteflies reproduce faster on cucumber than on tomato (van de Merendonk and van Lenteren 1978). Cucumber yields are reduced when whitefly populations exceed 40 adults per leaf (Anon. 1976). Whiteflies can also transmit viral and fungal diseases (Duffas 1965; Yamashita *et al*. 1979). In Japan the greenhouse whitefly transmits the pathogen causing yellowing disease on cucumber (Yamashita *et al*. 1979).

In British Columbia, the primary and preferred method of whitefly control on cucumber in greenhouses is biological, using the parasitic wasp, *Encarsia formosa* (Gahan). Insecticides registered for whitefly control on greenhouse cucumber do not control outbreaks and are often not compatible with the use of other biological agents by growers (R.A. Costello and B. Mauza[1], pers. comm.). Biological control of whitefly by *E. formosa* has achieved only limited success on cucumber because cucumber is a good host for whitefly (Woets and van Lenteren 1976) and the long leaf hairs and thick leaf venation slow down the parasite's walking speed (Woets and van Lenteren 1976; Woets *et al.* 1980; Milliron 1940; Hulspas-Jordaan and van Lenteren 1978). The long hairs also trap a larger amount of honeydew than less hairy plants so that parasites walking on a honeydew-coated leaf have to stop more frequently to clean themselves, reducing the time they can search for hosts (Woets and van Lenteren 1976). These factors make it important to introduce *E. formosa* into incipient infestations.

Whiteflies are difficult to detect at low population levels because of their sedentary behavior on plants (Ekbom 1980a). They also form clumped distributions (Eggenkamp-Rotteveel Mansveld *et al.* 1982; Åhman and Ekbom 1981; Ekbom 1980a; Yamada *et al.* 1979; van Lenteren *et al.* 1976a) which makes random sampling unreliable for detecting infestations (Eggenkamp-Rotteveel Mansveld *et al.* 1978; Xu 1982). Therefore, growers rely on their observation of whiteflies on the plants before they begin introductions of parasites. This practice

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often results in the introduction of parasites into whitefly populations too large to be controlled below damaging levels (R.A. Costello and B. Mauza[1], pers. comm.; Ekbom 1977, 1980; Foster and Kelly 1978).

Another problem which limits the success of *E. formosa* in British Columbia is that parasites sometimes disappear from some greenhouses later in the season after they have become established, probably as a result of insecticide spraying or other grower practices (B. Mauza[2], pers. comm.). A subsequent rapid rise in the whitefly population forces the grower to switch to chemical control.

The objectives of this thesis were twofold. The first was to review the literature on *T. vaporariorum* with emphasis on chemical and biological control, the factors affecting the relationship between *T. vaporariorum* and *E. formosa*, and alternative control methods to *E. formosa*. The second objective was to determine the efficacy of using yellow sticky traps for early detection, monitoring and control of whitefly.

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PART A

LITERATURE REVIEW

CHAPTER I

TRIALEURODES VAPORARIORUM

Systematics, Origin and Distribution

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westw.) was first described as *Aleyrodes vaporariorum* by Westwood (1856) in the "Gardener's Chronicle" (p.852). This genus was altered in spelling to *Aleurodes* (first by H. Burmeister, "Handbuch der Entomologie", volume 2, page 82, 1839). Later *Aleurodes vaporariorum* was placed in the genus *Asterochiton* (Maskell) by Quaintaince and Baker (1915) and in the subgenus *Trialeurodes*. *Trialeurodes* was elevated to generic status by Quaintance and Baker in the corrigenda to Part 2 of their "Classification of the Aleyrodidae" (1915), at which time *Asterochiton vaporariorum* became *Trialeurodes vaporariorum*. A complete account of the synonomy of the species is given by Russell (1948).

T. vaporariorum is probably indigenous to tropical or sub-tropical America (Milliron 1940). Russell (1948) more specifically limited its point of origin to the western and southwestern United States.

Today, *T. vaporariorum* has a worldwide distribution (Russell 1963, 1977; Mound and Halsey 1978). It has been reported in about 48 countries on every continent and is almost ubiquitous in greenhouses. In North America it is found throughout Canada and the United States including Alaska.

Biology and Description of Life Stages

Two races of the greenhouse whitefly have been described (Russell 1948) based on the work of Hargreaves (1915), Morrill (1903), Schrader (1920, 1926), Thomsen (1925) and Williams (1917). The less common race is found in the United Kingdom and consists largely of females which develop from unfertilized eggs. Males, produced from fertilized eggs are rare. The other race was first found in North America and differs in that females develop from fertilized eggs, males are produced from unfertilized eggs and comprize 30 to 40 per cent of the total population (Hussey and Scopes 1977; Schrader 1926). Today the North American race has largely displaced the parthenogenetic United Kingdom race which occurs only in isolated areas of the United Kingdom, often in areas in which *T. vaporariorum* shows pesticide resistance (Wardlow *et al.* 1976).

The life stages of *T. vaporariorum* have been described by Hargreaves (1915), Lloyd (1922), Weber (1931), Milliron (1940), Hussey *et al.* (1969), Nechols and Tauber (1977a,b) and Vet *et al.* (1980). The developmental times for each stage on tomato at 22°C (van Lenteren and Woets 1977) are given below. The egg, 0.2 to 0.25 mm long and oval-shaped, is initially pale yellow but becomes darkened after 2 to 3 days. It is attached to the underside of the leaf by a short stalk. Eggs may be laid in a circle consisting of between 15 and 40 eggs (Hargreaves 1915; Hussey *et al.* 1969) or they may be scattered at random across the underside of the leaf. Eclosion occurs after 8 days.

The first instar nymph is 0.29 mm long. It is pale green with well-developed antennae and legs (Fig. 1a). Soon after emergence it usually crawls a few millimeters, settles down and begins to feed. The functional legs are then lost and the nymph secretes a wax covering through pores in the dorsal body surface. This covering protects all of the immature stages. The mouthparts, which are the same in all stages including the adult are designed for penetrating the phloem cells and sucking out the contents. This stage lasts 6 days.

The second instar nymph is 0.39 mm long. It is almost transparent, sedentary (Fig. 1a) and becomes flattened out on the leaf which makes it difficult to detect. The legs and antennae are vestigial. This stage lasts only 2 days.

Third instar nymphs are 0.52 mm long, similar in appearance to the second instar nymphs and continue to secrete wax. This stage lasts 3 days.

The fourth instar nymph is 0.73 mm long and passes through 3 substages (van Lenteren *et al.* 1976b): an early fourth instar, a "prepupa" and a "pupa" (Fig. 1b). The early fourth instar nymph is initially flattened and transparent. Its 11 pairs of erect dorsal spines are more pronounced than in earlier instars, which make it easily recognizable. It lasts 3 days. The opaque prepupa becomes elevated on wax rods and increases in thickness. It has unpigmented eyes and lasts 1 day. The pupa is similar to the prepupa but the eyes of the developing adult are red and the color of the scale becomes increasingly yellow as the adult approaches the completion of its development. The pupal stage

Fig. 1a. First (A) and second (B) instar scales of *T. vaporariorum* . Fig. 1b. Healthy (white) and parasitized (black) "pupae" of *T. vaporariorum*.

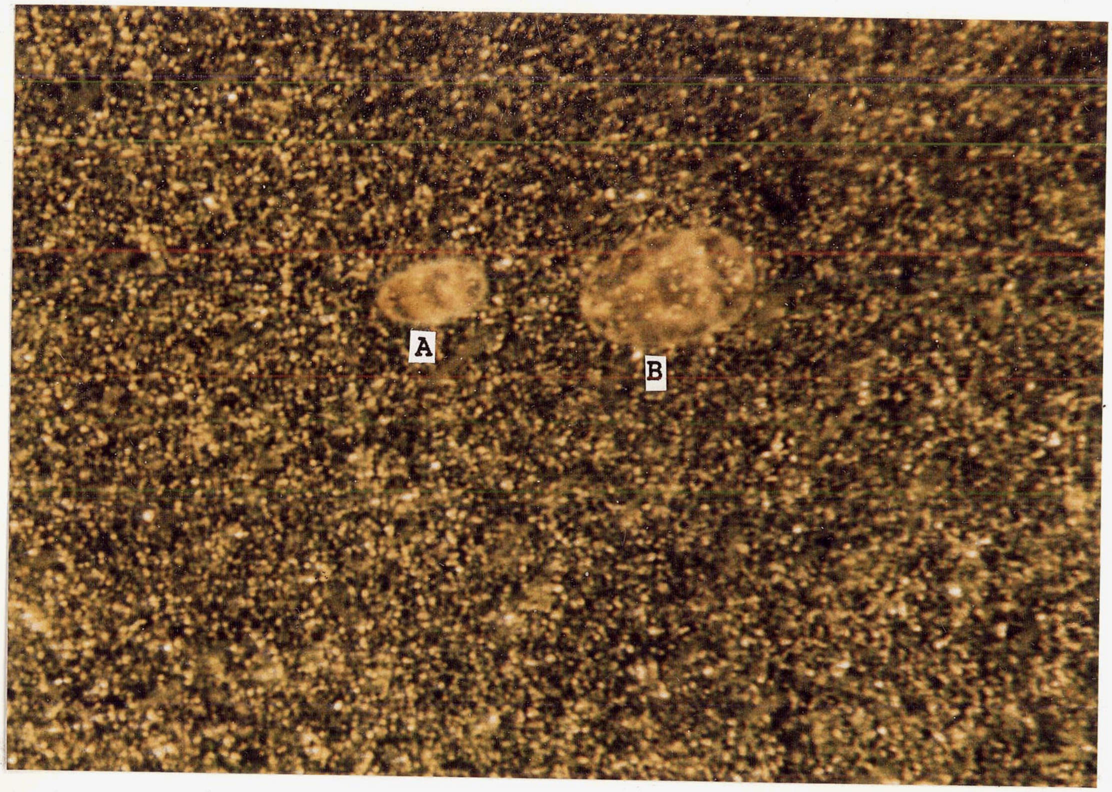


Fig. 1a

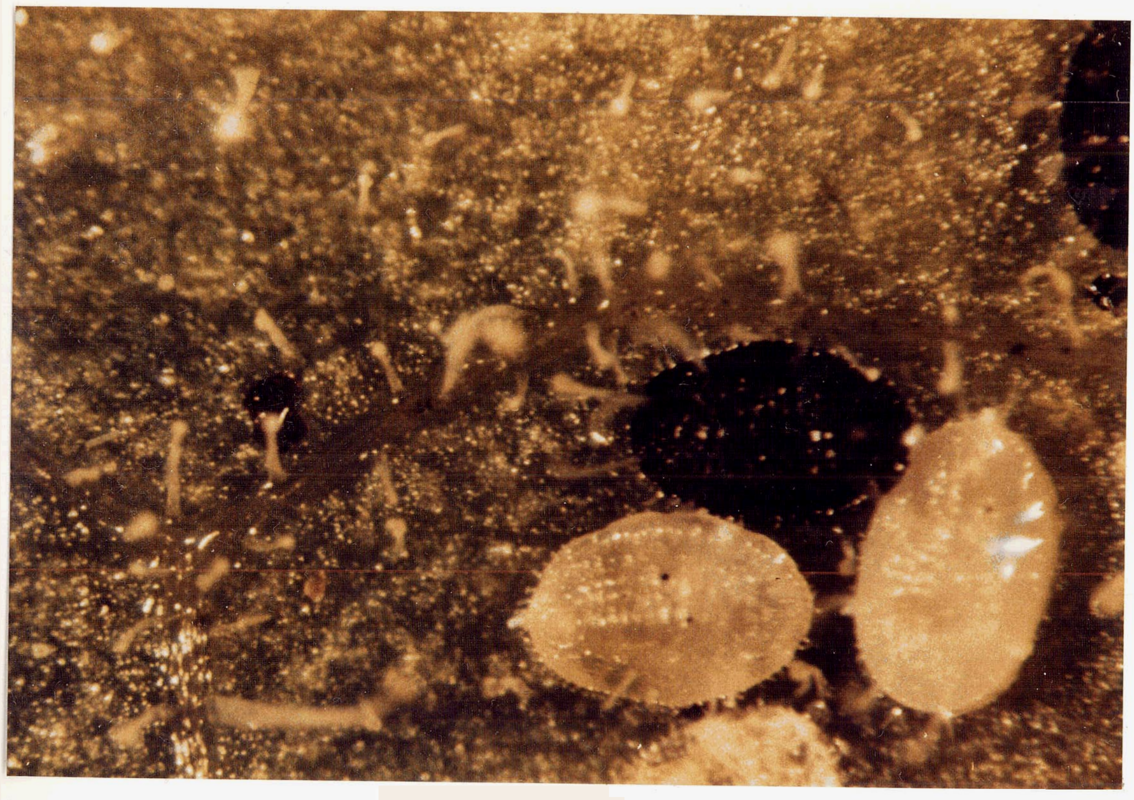


Fig. 1b

lasts 5 days.

The light-yellow adult (Fig. 2) is 1.5 mm long. It emerges head-first through a slit-like opening in the dorsum of the puparium. It coats itself with powdery wax which it takes from its abdominal plates with its hind- and forelegs. Males are similar in appearance to females but slightly smaller.

The developmental period from egg to adult can vary depending on the temperature and type of host plant (van de Merendonk and van Lenteren 1978; Woets and van Lenteren 1976). In British Columbia the developmental period on cucumber takes about 4 weeks at normal greenhouse temperatures (Costello *et al.* 1984).

Adults begin feeding almost immediately after emergence. They mate within 2 days, often on the same leaf on which they developed as scales. The adult then abandons the older leaf in search of young upper leaves upon which to feed and oviposit. Males disperse to new leaves in a more random manner and are found further away from the leaves upon which they emerged than the females (Åhman and Ekbom 1981). The average life span of the adult is 3 weeks. Females produce from 28 to 534 eggs (Milliron 1940). An average of 175 eggs is laid on cucumber (Woets and van Lenteren 1976).

During the winter, whitefly adults often seek out weeds or household plants in the greenhouse upon which to feed until the crop plants are reintroduced. They may also overwinter on plants outside the greenhouse, and in England were reported to survive under snow and frost conditions (Lloyd 1922).

Fig. 2. Adult *T. vaporariorum*.

Ecology

Distribution

The clumped distributions of whitefies are caused largely by the sedentary behavior of the adults. On cucumber, adult females seek the young upper leaves of the plant upon which to oviposit (Yamada *et al*. 1979). Thus dispersal is upwards rather than outwards (Ekbom 1980a). Once settled on a cucumber leaf, the female will often remain there for her entire life unless she is disturbed or encounters a shortage of space (Åhman and Ekbom 1981). This behavior ensures that the next whitefly generations will be concentrated in these areas.

A sex pheromone emitted by the greenhouse whitefly female, discovered by Yin and Maschwitz (1983), is effective only over distances of less than 3 cm.

Host Selection

The whitefly infests plants in 249 genera belonging to 84 families (Russell 1977). Initial landing of a whitefly on an object is largely mediated by color and little by olfaction (Vaishampayan *et al*. 1975a, b). Colors that elicit the highest level of responses are in the yellow to yellow-green region of the visible spectrum (Vaishampayan *et al*. 1975a; MacDowall 1972), comprising a major portion of the reflectance from green leaves (Vaishampayan *et al*. 1975a).

Only after landing on a leaf can a whitefly judge whether or not the host is suitable (Verschoor-van der Poel and van Lenteren 1978). The suitability of a certain host plant for whitefly is probably determined using chemical cues from the plants (van Lenteren *et al.* 1979; Verschoor-van der Poel and van Lenteren 1978). Mechanical barriers on the leaves such as thickness of the cuticle, or distances between the cuticle and the phloem cells do not deter whitefly adults or nymphs from feeding (van der Kamp and van Lenteren 1981).

Given a choice of various hosts, whiteflies tend to select those on which their fecundity and life span are maximized (Woets *et al.* 1980; van Boxtel *et al.* 1978; van de Merendonk and van Lenteren 1978). Woets and van Lenteren (1976) found that whiteflies aggregated preferentially on eggplant and cucumber over tomato and paprika. On these "preferred" hosts, there were more eggs laid per female, a higher oviposition frequency, a longer life span of adult females, a shorter developmental period and a lower mortality than on "less-preferred hosts". Similarly, van Sas *et al.* (1978) found that eggplant, cucumber and gherkin were preferential over tomato paprika and melon. Gerbera, in tests with these plants, was the only plant which did not show this pattern. Certain aspects of this plant indicated a good host-plant quality for whitefly whereas other aspects of this plant indicated a bad quality.

Controls

History of Chemical Control

The first successful control of whitefly was achieved using chemical fumigants: hydrocyanic acid gas (Morrill 1905, Lloyd 1922), naphthalene and tetrachlorethane (Lloyd 1922) and calcium cyanide (Weigil 1925, 1926). Their use persisted until the 1940's and 1950's when synthetic pesticides such as DDT, parathion and malathion (in the form of smokes) replaced them (Smith *et al.* 1970a). Some aerosols such as tepp, dichlorvos and parathion, applied for spider mite control also gave good or satisfactory control of whitefly (Smith *et al.* 1947, 1948, 1962). The availability of a variety of chemicals for control of greenhouse pests led to the establishment of chemical control programs in most greenhouses (Buscher 1967).

Whiteflies soon developed widespread resistance to organochlorine and organophosphate insecticides (Wardlow *et al.* 1972). Prior to this event the control of whiteflies in greenhouse ornamental and vegetable crops had been similar. The 2 industries have since diverged in their methods of pest control.

In the greenhouse flower industry, traditional chemical control programs remained in effect. The limited tolerance to cosmetic damage from insect pests on flower crops and the greater variety of insect pests on these crops required the use of a broad-spectrum, fast-acting insecticide. The relative ease with which chemicals were registered for use on ornamentals as opposed to a food crop provided flower growers with a diverse choice of chemical insecticides. This has discouraged the implementation of alternative control methods.

In the 1970's the pyrethroid insecticides largely replaced the organochlorine and organophosphate insecticides for whitefly control (Oetting and Morishita 1980). However, whiteflies have already developed resistance to these chemicals (Wardlow 1985; Wardlow *et al*. 1984). Other chemicals, e.g. insect growth regulators (Fischer and Shanks 1979; van de Veire *et al*. 1974), are being studied as alternatives but their costs may be prohibitive.

On greenhouse cucumber crops the development of resistance by the two-spotted mite, *Tetranychus urticae* (Koch) to organochlorine and organophosphate insecticides became a serious problem before whiteflies became resistant to these chemicals. New miticides were expensive to develop and slow to be registered on food crops. The ensuing difficulties of maintaining effective control together with increasing costs of finding new chemicals directed attention towards biological control.

The success of the predatory mite, *Phytoseiulus persimilis* (Athias-Henriot), in controlling the two-spotted mite on cucumber resulted in the establishment of biological control programs in greenhouses (Hussey and Bravenboer 1971; Hussey *et al*. 1965; Gould 1971). The sensitivity of *P. persimilis* to insecticides precluded the use of many of the chemicals used to control whiteflies. Therefore, there was renewed interest in biological control of *T. vaporariorum* by *E. formosa*.

History of Biological Control

Biological control of *T. vaporariorum* by a parasitic wasp, *Encarsia sp.*, was first observed in England in 1914 ("Gardeners' Chronicle", Vol. lviii, 4th September 1915, p. 154). The species was presumed to be *E. formosa* (Gahan) but it is probable that it was a different species of *Encarsia* (Speyer 1927). The first attempt at utilizing this parasite for control of whitefly was made in 1926 by Speyer (1927) who then studied the biology, life history and habits of *E. formosa*. Later, *E. formosa* was introduced into Australia, Canada and New Zealand (McLeod 1938; Tonnior 1937) for whitefly control in greenhouses. No precise methods of introduction of the parasite were developed which probably accounted largely for its unpredictability as a control agent (Hussey and Bravenboer 1971; Lindquist 1977). Plant material containing parasitized whitefly scales was simply hung in the greenhouse with variable results. The use of *E. formosa* was suspended in 1954 with the advent of the synthetic organic pesticides.

When interest in *E. formosa* returned in the 1970's, research was undertaken at The Glasshouse Crops Research Institute in England and The Glasshouse Crops Research and Experimental Station in The Netherlands to develop improved introduction methods of the parasite. In addition, the biology and ecology of *T. vaporariorum* and *E. formosa* including the factors which affect their relationship in the greenhouse were examined.

Integrated Control

Integrated control is the practice of using more than one type of control to kill pest organisms while inflicting minimal damage on beneficial species. The success of integrated control programs often depends on the limited use of selective chemicals when one or more species of pests become too numerous to be controlled by biological agents. Several pesticides are recommended for use in integrated control programs on cucumber crops (Kowalska *et al.* 1980; Ledieu 1979; Costello *et al.* 1984).

However, a "good" spray for use in an integrated control program for whitefly does not exist. Recommended chemicals often kill an inadequate number of whiteflies in addition to harming the plants and/or beneficial insects. The selectivity of some chemicals has been improved by spraying only the upper leaves of the plants in the early season (Harbaugh and Mattson 1976) to kill whitefly adults. Immature whitefly nymphs on the lower leaves are conserved for attack by parasites,which remain relatively unharmed. By spraying the upper leaves of the plant, it is possible to eliminate a portion of the adult whitefly population while leaving the parasite population relatively unharmed.

CHAPTER II

ENCARSIA FORMOSA

Systematics, Origin and Distribution

Encarsia formosa (Gahan) was first described by Gahan in 1924 from specimens taken in Ohio. Although its origin is unknown, some characteristics of its habits suggest that it had a tropical origin (Speyer 1927). Following its discovery in England in 1914 and Ohio in the 1920's it has been reported in Australia, New Zealand, Canada, and several European countries and in most areas of the United States (Gerling 1966; Milliron 1940; Weber 1931; Tonnoir 1937; Speyer 1927).

Biology and Life History

Encarsia formosa reproduces parthenogenetically, the population consisting almost entirely of females. Mating occurs only rarely (Hulspas-Jordaan, pers. comm., reported in Vet *et al.* 1980). Males can appear after a lengthy session of low temperatures (Speyer 1927; Milliron 1940) and can also occur as a result of the hyperparasitic habit of *E. formosa* when the parasite-host ratio is high (Gerling 1966). Under these conditions, the female parasite may lay eggs in her own larvae, which causes males to be produced.

The life history is summarized from Speyer (1927). The egg, 0.13 mm long and 0.4 mm wide, is elongate-oval and yellowish-white. It grows in size and after 3 days, the mature embryo can be seen through the chorion to move around. Eclosion occurs after 4 days.

The larva, 0.24 mm long and 0.04 mm wide, is slightly yellowish and semi-transparent with indistinct segmentation. For 6 days it feeds on the internal contents of the body of the whitefly nymphs, molts 3 times and grows to a length of 1.01 to 1.04 mm and a width of 0.29 to 0.31 mm. Meanwhile, the parasitized whitefly scale develops to the pupal stage. Eight days following parasitism, it turns grey and in 1 to 2 days turns black (Fig. 1b), the integument becoming dry and brittle.

The pupa, 0.67 mm long and 0.29 to 0.34 mm wide, is yellow-cream with dark grey spots on its head. It follows a prepupal stage which lasts 1 day. Neither the prepupa nor the pupa feeds. In the 2-day old pupa, pale rose pink eyes become visible. On the fourth day, the eyes become dark red, the head becomes blackish, and the wing rudiments become dark grey. The head and thorax turn black on the fifth day. The adult emerges on the sixth or seventh day.

The adult, 0.6 mm long, emerges through a hole it chews in the anterior dorsal surface of the pupal case. The female (Fig. 3) is easily distinguished by its dark-brown head with red eyes, black thorax with yellow sides and yellow abdomen with a protruding ovipositor. Males are slightly larger and have a dark-brown abdomen.

Adults begin feeding on whitefly honeydew and host hemolymph within a day of emergence (Agekyan 1981; van Alphen *et al.* 1976; Gerling 1966). In addition to energy, the hemolymph provides

Fig. 3. Adult female *E. formosa*.

19b

nutrients including proteins essential to egg maturation (Agekyan 1981). Whitefly scales turn brown and die as a result of being fed upon (Hussey *et al.* 1969).

Oviposition begins 1 or 2 days following adult emergence and continues throughout the female's life. Each female produces from 50 to 100 eggs (Parr *et al.* 1976; Milliron 1940; Tonnoir 1937; Costello *et al.* 1984) and of the scales that turn black, approximately 92 percent produce adults (Burnett 1949).

The life cycle from egg to adult averages 1 month (Speyer 1927; Milliron 1940) at temperatures between 21 and 24°C.

Ecology

The important attributes of a "good" natural enemy (Debach 1974; Harris 1973; Huffaker *et al.* 1971; van Lenteren 1980) include: 1) good searching ability; 2) high degree of host specificity; 3) high reproductive capacity with respect to the host; and 4) good adaptation to and tolerance of the environmental conditions in which the prey or host may be located. By these criteria, *E. formosa* qualifies as a good natural enemy of the whitefly.

Encarsia formosa is a good searcher (Ledieu 1976; van Lenteren *et al.* 1976a; Harbaugh and Mattson 1976), and relies on the whitefly as its sole host. Although it is often attracted to areas of high host densities, *E. formosa* can locate and parasitize scales in low host density areas (Eggenkamp-Rotteveel Mansveld *et al.* 1982). Female parasites are attracted to their hosts by a volatile substance present in the whitefly honeydew (Ekbom 1980a; Ledieu 1976, 1977; Hussey *et al*. 1976). The degree of attraction varies with the density of whitefly scales. After landing on a leaf the parasite walks across it at random. Upon contacting a host with her antennae, the parasite drums it with her antennae. If it is suitable for oviposition, she will lay an egg in it. Usually a single egg is laid per host as the wasp can detect whether or not the scale has been parasitized (van Lenteren *et al*. 1980). When an overabundance of parasites is present, superparasitism of whitefly scales may occur although only 1 parasite egg will ultimately develop into an adult (Agekyan 1981). Preferred stages for oviposition are the third and fourth instars and the prepupa (Nell *et al*. 1976; Nechols and Tauber 1977a; Speyer 1927). In these hosts, the percentage mortality of parasite eggs and larvae is lowest and the developmental period is shorter than in first or second instar nymphs.

Second instar nymphs and pupae of the whitefly are preferred for feeding. The first instar nymphs can walk away when contacted by the antennae of the parasite. Hosts used for oviposition are not used for feeding. Van Àlphen *et al*. (1976) observed that appoximately 7 percent of all the hosts encountered by *E. formosa* were used for feeding while approximately 35 per cent were used for oviposition.

The parasite is particularly suited to greenhouse cucumber environmental conditions. Temperatures generally do not drop below 20°C, which favors an increase of parasites over whiteflies. According to Woets and van Lenteren (1976), *E. formosa* has a lower pupal mortality and develops faster than its host at temperatures above 18°C. In the early season when temperatures below 18°C are encountered, repeated introductions of parasites are needed to prevent whiteflies from increasing faster than the parasites.

Encarsia formosa can be reared on a variety of plants bearing whitefly scales (Scopes 1969; Scopes and Biggerstaff 1971; Costello *et al.* 1984). In British Columbia, it is reared on whitefly-infested tobacco leaves for sale to growers by Applied Bio-Nomics Ltd., Sidney, B.C.

Introduction Methods

Parasite introduction methods were developed by researchers in the Glasshouse Crops Research Institute in Littlehampton, England (Parr *et al.* 1976) and the Glasshouse Crops Research and Experiment Station in Naaldwijk, The Netherlands (Woets 1973, 1976, 1978).

Pest-in-First Method

This method, also known as the classical method was developed in England by Parr *et al.* (1976), Gould *et al.* (1975) and in Holland by Woets (1973). Parr (1971) regarded an even distribution of the pest as essential for successful biological control on cucumbers and a program of pest introductions based on this premise was initiated. It requires the grower to distribute the whitefly evenly throughout his crop at a prescribed rate, followed 2 to 3 weeks later by an introduction of black parasitized whitefly scales.

One benefit of this method is that parasite introductions can be made at the time that the majority of whitefly scales are in a suitable stage for parasitism, thereby maximizing the parasitism rate (Gould *et al.* 1975). The other advantage is that parasites are introduced into a low level whitefly infestation, enabling the parasites to control whitefly. Gould *et al.* (1975) found that this introduction method achieved predictable control on cucumbers while other methods in which parasites were introduced following the sighting of natural whitefly infestations on the crop produced inferior control.

The reluctance of growers to introduce whiteflies into their greenhouses (Woets 1978) has prevented implementation of this introduction method (Stacey 1977; Ekbom 1977) in most countries except Britain.

There are some disadvantages with this method. Extra costs are incurred in the rearing and introduction of the pest organism. In addition, growers who do not encounter whitefly problems until late in the season are not likely to introduce whiteflies at the beginning.

Banker Plants

The banker plant method, developed by Stacey (1977), requires the grower to place banker plants, which contain parasitized whitefly scales, throughout the greenhouse soon after the crop has been planted. Parasites which emerge on the banker plants, leave to parasitize whitefly scales on the crop. In the absence of whiteflies in the greenhouse, the whitefly scales present on the bankers provide a source of food for the parasites, which ensures their survival. Preferred hosts of the whitefly are chosen as banker plants to maximise the confinement of the whitefly to these plants. *Encarsia formosa* freely searches through the crop for whitefly scales. The method has not been tested on other crops and is not in use today as growers are reluctant to introduce whitefly-infested plants into their greenhouses.

Multiple Release Methods

Parasite introduction into greenhouses by a series of releases at timed intervals was developed in The Netherlands by Woets (1974) and van Lenteren *et al.* (1976a) and in England by Gould *et al.* (1975) and Parr *et al.* (1976). Parasite releases are initiated either at the time the crop is planted in the greenhouse or shortly after the first whitefly has been observed on the crop.

The first method of parasite release requires the grower to introduce parasites every 2 weeks beginning from the time the crop is planted until black scales can be seen on the plants. One benefit of this practice is that whitefly infestations which remain undetected will be controlled. Parasites are present throughout the season and can prevent outbreaks from occurring. This method has been successful in trials on tomatoes (Gould *et al.* 1975) but the number of introductions required for establishment of the parasite can vary from 4 to 10 or more (Stenseth and Aase 1983). Growers who experience whitefly problems late in the season should not adopt this method due to the high cost of repeated parasite introductions.

The second multiple-release method requires the grower to make the first parasite introduction only after the first whitefly has been seen in the greenhouse. An initial introduction is made 2 weeks following the first sighting of a whitefly, followed by 2 to 4 more introductions at 2-week intervals (Ekbom 1977; Stenseth and Aase 1983; Costello *et al.* 1984). In commercial greenhouse cucumber and tomato crops in British Columbia, parasites may be introduced in 2 ways. The first method developed by Costello and Elliott (1981) requires the grower to make a minimum of 4 bi-weekly parasite introductions, beginning 2 weeks following the first sighting of a whitefly on the crop. However, as the adult whitefly may oviposit over a 3-week period, giving rise to multiple whitefly generations, weekly introductions over an 8- to 9-week period have also been recommended (Costello *et al.* 1984). The obvious attraction of this method is the lower cost to the grower. Its success is dependent on the growers' ability to detect whitefly infestations early. This prerequisite makes the method less predictable than the previous one (Parr *et al.* 1976). However, it is the only one that is acceptable to most growers.

A final multiple-release parasite introduction method, which is a variation of the pest-in-first method, has been developed by Nedstam (1980). In this method parasitized black scales and whitefly scales are introduced concurrently. The whitefly scales supply the parasites with a source of food in the absence of any whiteflies on the crop. The method has reportedly been successful but like the pest-in-first and the banker plant methods, has not been accepted by growers.

CHAPTER III

FACTORS AFFECTING THE PARASITE-HOST INTERACTION

The population dynamics of *E. formosa* and its host *T. vaporariorum* were first studied by Burnett (1960, 1964, 1967). The host and parasite populations follow a cyclic pattern throughout the season with the host population reaching a peak density a few days ahead of the parasite population (Burnett 1960). Factors which can affect the shape and magnitude of these fluctuations include humidity, temperature, light, initial host density, number and timing of parasite introductions and the use of insecticides. The success of *E. formosa* in controlling whiteflies depends on recognition of these factors by growers.

Timing

Timing of the initial parasite introduction is the decisive factor for success in controlling whiteflies by *E. formosa* (van Alphen *et al*. 1976; Eggenkamp-Rotteveel Mansveld *et al*. 1978; Nedstam 1980; Kowalska and Pruszynski 1976; Nechols and Tauber 1977a; Stenseth 1976; Woets 1976). A major reason for failure is late parasite releases into a large whitefly population (Foster 1980; Ekbom 1980a). Stenseth and Aase (1983) concluded that the establishment of *E. formosa* on whiteflies at low- level populations with the pest-in-first method was probably the major reason that long-lasting control of whitefly was achieved on cucumbers in their experiments. Gould *et al*. (1975) and Helgesen and Tauber (1974) state that successful biological control programs are achieved if parasite introductions are made at the time of planting or soon after. A large initial introduction of parasites into a large whitefly population will only result in large parasite and host fluctuations, with the hosts increasing sharply to damaging levels before the end of the growing season (Stenseth 1976).

Optimal timing for establishment of the parasite will ensure that the occurrence of adult parasites and availability of susceptible stages of the host coincide (Helgesen and Tauber 1977). In the absence of third instar and early fourth instar nymphs, the parasite lays eggs in the first and second instar nymphs, causing their death and preventing establishment of the parasites (Gould *et al*. 1975; Woets and van Lenteren 1976).

Number, Frequency and Rate of Parasite Introductions

The number, frequency and rate of parasite introductions necessary to achieve successful control of whitefly is determined by the number of whiteflies present at the time of the initial introduction and by the quality of the host plant for *T. vaporariorum*. Consequently, Gould *et al*. (1975), Stenseth and Aase (1983) and Ekbom (1977) report crop-related differences in rates and numbers of introductions which achieved successful control of *T. vaporariorum* in greenhouses. Higher rates are needed on cucumber than on tomato (Costello *et al*. 1984). Ekbom (1977) found that successful control of whitefly in a tomato crop by *E. formosa* required 2 parasite introductions of 5 black scales per $100m^2$ area of greenhouse space while in a cucumber crop, a total of 2 to 3 introductions of 7 to 10 black scales per $100m^2$ were required. Control was unsuccessful in cases where whitefly densities exceeded 10 adults per $100m^2$ at the time of parasite introductions. Foster and Kelly (1978) concluded that 1 adult per 10 upper leaves was the maximum allowable number of whiteflies prior to parasite introductions if successful biological control was to be achieved on tomato. Stenseth and Aase (1983) concluded that an initial number of 10 to 30 adults of *T. vaporariorum* per 100 cucumber plants required 3 parasite introductions at a rate of 5 per plant while less than 1 whitefly adult per 100 plants required a rate of 3 parasites per plant in each introduction. The elimination of infestations and consequent elimination of the parasite by the introduction of too many parasites is unlikely as whiteflies at the peripheries of an infestation usually escape parasitism (van Lenteren *et al.* 1976a). Frequently whitefly populations are eliminated on a single plant by parasites but reappear on a neighbouring plant (Eggenkamp-Rotteveel Mansveld 1982).

Environmental Conditions

Temperature

Temperature is an important factor governing the success of *E. formosa* in greenhouses. The parasite's unreliability at low temperatures and low light is a fundamental cause of failure (Parr *et al.* 1976). The effects of temperature on the rate of development of *T. vaporariorum* and *E. formosa* have been well studied (Burnett 1949; Stenseth 1977).

Disagreement exists on the minimum temperature at which *E. formosa* should be used. Burnett (1949), found that at temperatures less than 24°C, whitefly females lived longer, laid more eggs and had a higher rate of oviposition than the female parasites. At temperatures above 24°C there was a rapid decline in adult whitefly longevity, rate of oviposition and fecundity. Subsequent studies supported this finding. Gerling (1966) found that *E. formosa* was unable to control *T. vaporariorum* at temperatures below 24°C. Helgesen and Tauber (1974) achieved successful control of whitefly on poinsettias with *E. formosa* by maintaining an average temperature of 23.3°C. Other studies by Hussey *et al.* (1969), Woets and van Lenteren (1976) and Ekbom (1980a) indicated that 18°C is the threshold temperature for successful control of whitefly by *E. formosa*. Their findings showed that at temperatures below 18°C, the whiteflies developed faster than the parasites but at temperatures above 18°C, the parasites developed faster than the whiteflies and the pupal mortality of the parasites was lower than at temperatures below

18°C.

At very low temperatures (i.e. at 5 to 10°C) the parasite females can survive (Kajita 1982) but they lay very few eggs, and very few of these mature (Kajita and van Lenteren 1982). The thermal threshold for the development of the parasite from the egg to the adult stage is 12.7°C (Osborne 1982).

Light

Several studies indicated that light affects the efficiency of *E. formosa* (Parr *et al*. 1976; Scopes 1973). Reproductive capacity of the parasite was reduced at light intensities below 7300 lux and severely reduced below 4200 lux (McDevitt 1973, cited in Vet *et al*. 1980). Mortality of the parasites also varies at different light intensities. At light intensities of less than 4200 lux, the mortality of parasites was greater than 83 per cent while at 5200 lux and 7300 lux, the mortality was 37 per cent and 17 per cent, respectively (Scopes 1973).

Light intensities can contribute to the failure of biological control early in the season. The whitefly exhibits no diel peaks in activity under short-day conditions whereas the parasite is minimally active during the first 3 morning hours (Ekbom 1982). The apparent time lag between sunrise and the most active periods for *E. formosa* may affect the parasite's efficiency when daylength is short (i.e. early spring) (Ekbom 1982).

Humidity

The effect of humidity on parasite efficiency has been poorly studied. Milliron (1940), found that the greatest percent parasitism of *T. vaporariorum* occurred at relative humidities between 50 and 70 percent. Burnett (1948) reported that parasites tended to avoid higher humidities. Ekbom (1977) concluded that less successful cases of biological control tend to occur in a higher relative humidity than successful ones. The humidity in cucumber greenhouses is higher than in tomato greenhouses and could be partially responsible for the lack of success of the parasite to control whiteflies on cucumber.

<u>Plant Type</u>

The influence of host-plant quality on the whitefly accounts for the varying degrees of success of *E. formosa* for whitefly control on different crops (Vet *et al*. 1980). On tomato (a less-preferred host) success is more often achieved with *E. formosa* than on cucumber (a preferred host). The effect of leaf structure also determines parasite efficiency on different plants. Woets *et al*. (1980) found that parasites walked 3.5 times faster and improved their parasitism efficiency by 20 percent on cucumbers of a hairless variety. Attempts to breed glabrous cucumbers are presently being made (dePonti 1980).

Insecticides

Insecticide applications for pests other than whiteflies can upset the parasite-host balance by eliminating some or all of the parasite population (Ekbom 1980a). This impact allows the host to increase and escape control. Applications of diazinon are frequently employed for control of fungus gnats and sometimes for tobacco thrips. However, diazinon is harmful to *E. formosa* and cannot be used in greenhouses where biological control of whitefly by *E. formosa* is practiced (Stenseth and Aase 1983). Of the insecticides registered for whitefly control on cucumbers in greenhouses in British Columbia, all are harmful to *E. formosa* (Costello *et al*. 1984). Insecticidal soap is less toxic to the parasite than to whitefly when used at rates below those recommended for whitefly.

CHAPTER IV

OTHER CONTROLS

Plant Resistance

Resistance to whitefly infestation has been studied in greenhouse tomato varieties (Berlinger 1980a; Curry and Pimentel 1971; Gentile *et al*. 1968). However, no whitefly-resistant strains of greenhouse cucumber plants have been reported in the literature.

Other Parasites

Insect Parasites

Little is known about parasites of whitefly other than *E. formosa*. Vet *et al*. (1980) lists 12 species of parasites of *T. vaporariorum*, but detailed information on many of them is lacking. Other parasites have been studied mainly to determine their efficacy in controlling whiteflies at low temperatures (Vet and van Lenteren 1981; Buijs *et al*. 1981; Christowitz *et al*. 1981). In most instances, these other parasites have provided inferior control of *T. vaporariorum*.

Other parasites have been sought that would search in a different fashion than *E. formosa* (van Lenteren *et al*. 1979) because of the difficulty *E. formosa* has moving on cucumber leaves. No one thus far has been discovered.

Fungal Pathogens

Verticillium lecanii (Zimm.), a fungus parasitic on whitefly, is registered under the name, Mycotal® for greenhouse whitefly control in Europe. The fungus is not suited to the high temperatures (Kanagaratnam *et al*. 1982) nor low humidities (Easwaramoorthy and Jayaraj 1976) of the summer and is primarily used in the spring when conditions are more favorable for its use and the activity of *E. formosa* is reduced (Ekbom 1982). Hall (1982) showed that the fungus is compatible with the parasite although it does attack a small portion of black scales (Ekbom 1979). The efficacy of *V. lecanii* as a complementary control measure to *E. formosa* on *T. vaporariorum* is currently under investigation in British Columbia.

Aschersonia aleyrodis (Webber), a fungal pathogen of several aleyrodids, is effective against the scales of *T. vaporariorum* (Ramakers and Samson 1984). Adults of *T. vaporariorum*, *E. formosa* and other arthropods are not affected. This specificity makes *A. aleyrodis* a logical choice for use in an integrated control program for whitefly using *E. formosa*. However, this fungus will probably not replace *E. formosa* because of its failure under normal greenhouse conditions to reinfect spontaneously. Further research is needed to determine its suitability for practical use.

Predators

Predators of whitefly have not been well-studied. Vet *et al.* (1980) reviewed the literature on predators of *T. vaporariorum* and concluded that none showed promise of becoming potential biological control agents in greenhouses. Ekbom (1981) tested the predator, *Anthocoris nemorum* (L.) as a prospective biological control agent for *T. vaporariorum* on tomato and cucumber but found that the mortality it inflicted on a whitefly population was too low to consider it as a practical biological control agent.

Traps

The attraction of *T. vaporariorum* to yellow (Lloyd 1922) was exploited by Kring (1969, unpublished, reported in Webb and Smith 1980) to catch whiteflies on yellow sticky stakes. Webb and Smith (1980) found that 25 x 25 cm yellow sticky boards were effective in trapping whiteflies from old and newly-established infestations on tomato plants. In a small commercial greenhouse, the traps also prevented uninfested geranium cuttings from becoming infested. Trap color and sticky substance preferences of greenhouse whitefly have since been investigated by Webb *et al.* (1985) and Affeldt *et al.* (1983).

Evaluations of yellow sticky traps in large commercial greenhouses have been conducted in Italy (Nucifora and Vacante 1980) and Belgium (Van de Veire and Vacante 1984). With the combined use of 20 cm diameter sticky plates and *E. formosa*, significant reductions of whiteflies were achieved on tomato crops. *Encarsia formosa* was not caught on the traps, provided there was no shortage of whitefly (van de Veire and Vacante 1984). As whitefly numbers declined, the parasites were caught on the traps in increasing numbers. *Encarsia formosa* may be weakly attracted to yellow.

Yellow sticky traps have been used to obtain trends in whitefly populations. Berlinger (1980b) developed a yellow petri dish trap for monitoring numbers of *T. vaporariorum* and the sweet potato whitefly, *Bemisia tabaci* (Gennadius), in greenhouse experiments.

Light traps have been suggested as a potential control for whitefly (MacDowell 1972; Ekbom 1980a). However, the high costs associated with their design and purchase has probably been a deterrent to their use.

PART B

EFFICACY OF YELLOW STICKY TRAPS FOR MONITORING AND CONTROL OF THE GREENHOUSE WHITEFLY

CHAPTER V

INTRODUCTION

A main factor in preventing the successful control of *T. vaporariorum* by *E. formosa* on cucumber in greenhouses is the lack of an early detection method. Yellow sticky traps have been used for control of greenhouse whitefly (Nucifora and Vacante 1980; van de Veire and Vacante 1984), but have not been tried for early detection. Ekbom (1980b) considered yellow traps for early detection of *T. vaporariorum* but thought they should be recommended only as a complement to weekly inspections of plants in the greenhouse. Webb and Smith (1980) showed that yellow traps could protect uninfested geranium cuttings from becoming infested. Whiteflies were attracted to the traps more than they were to the plants. Vaishampayan *et al*. (1975b) found that yellow croton leaves (a non-host) elicited twice as many whitefly landings as green bean leaves (a preferred host). Traps could be effective in a cucumber crop, provided the whiteflies could see them before they could land on the plants. A high density of traps would likely be required on cucumber to ensure early detection of *T. vaporariorum*, as the thick foliage could obscure traps on nearby plants.

The objectives of the following research were to develop an effective yellow sticky trap for *T. vaporariorum*, and to test its reliability for early detection. In addition, the traps were tested as a monitoring tool for whitefly and as a complementary control measure to *E. formosa*.

CHAPTER VI

TRAP DEVELOPMENT

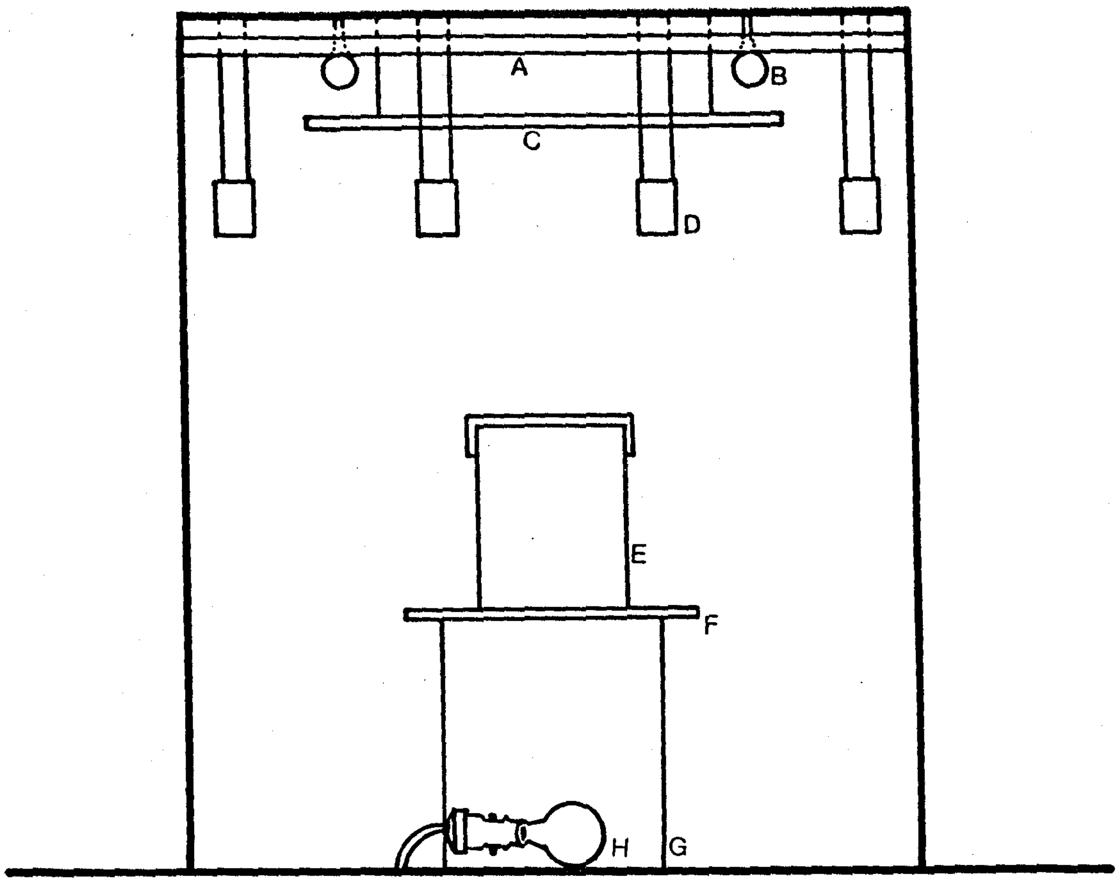
Materials and Methods

To be acceptable to growers, traps must be inexpensive and easy to use and must not interfere with workers in the greenhouse. My final trap design was based on these considerations.

The effectiveness of the trap in capturing *T. vaporariorum* was tested by 4 criteria: color, sticky substance, shape and height. An inexpensive trap material, white cardboard (4-ply Railroad Board, Domtar Fine Papers, Toronto, Ont.) was used to make all traps. Colors were formulated as semi-gloss enamel paints and applied to 1 side of each trap. In tests of all the criteria except the sticky substance, the painted sides of the traps were given a coat of Stiky Stuff® (Olson Products Ltd., Medina, Ohio) 24 hours prior to each test.

An area 1 x 1 x 1.2 m high (Fig. 4) in which to test the effects of trap color, shape and sticky substance on catch of adult whiteflies was cordoned off inside a walk-in growth chamber kept at a temperature of 25°C. White mesh material was hung from the top of the growth chamber to form 4 walls. The test area or chamber was lit from above by 12 fluorescent lights (Westinghouse Cool White, F96T12/CW/SHO, 1500ma) and eight 75-watt incandescent light bulbs. A black sheet of cardboard was placed just below the lights in the center of the chamber to

Fig. 4. Front view of test chamber in which the effects of trap color, shape and sticky substance on catch of adult whiteflies were tested.



LEGEND

A–FLUORESCENT LIGHT

B–INCANDESCENT LIGHT

C–BLACK CARDBOARD

D–TRAP

E–HOLLOW TUBE CONTAINING WHITEFLIES

F–GLASS PLATE

G–WOODEN BOX

H–INCANDESCENT LIGHT

stop whiteflies from flying directly into the lights. A 20 cm strip around the perimeter remained lit. Traps were hung from the top along each side, 10 cm below the lights and 5 cm inside the walls.

Whiteflies were collected in a 30 cm long by 25 cm diameter black cardboard tube, sealed at one end by white mesh. This tube was held over a young cucumber plant bearing newly-emerged whitefly adults while the leaves were gently tapped and dislodged whiteflies flew up into the cylinder. Approximately 500 whiteflies were trapped for each test.

The collecting cylinder was placed with the capped end up on top of a 30 x 30 x 40 cm light box, and covered by a sheet of plate glass painted white. The incandescent light helped to disperse the whiteflies over the glass while the cap was removed. After removal of the cap, the light in the box was switched off and the overhead lights were switched on. Whiteflies flew upwards at first and then outwards to the traps. After 15 minutes, the lights were switched off, the traps were removed and the number of whiteflies on each counted. The effects of color and shape on whitefly catch were tested in a randomized block design experiment which was repeated twice. Individual trap catches for each block were converted to proportions of total whiteflies caught in that block.

Effect of color on trap catch

Colors approximating those reported to be most attractive to *T. vaporariorum* by Vaishampayan *et al.* (1975a) were tested together with an orangy-yellow paint, Rust-Oleum 659 yellow (The Rust-Oleum Corporation, Evanston, Ill.), used in a whitefly trapping program by Webb and Smith (1980), and a pale yellow semi-transluscent, 5 cm wide plastic tape (Olson Products Ltd.), sold commercially for whitefly, thrips and leafminer trapping. All traps were cut into 5 x 8 cm rectangles and hung vertically for the tests. In the first experiment, 2 hues of yellow, yellow (E-776) (Cloverdale Paint and Paper Ltd., Surrey, B.C.) and a pale yellow, (source unknown) were tested together with the Rust-Oleum 659 yellow and the plastic tape.

In the second experiment, the most effective trap color from the first experiment was tested against 3 greenish-yellow hues: a bright green, green (E-785) (Cloverdale Paint and Paper Ltd.) and YYG and YGG, produced by mixing different amounts of the most effective trap color from the first experiment and the green together.

In each experiment, 4 traps, each of a different color were hung 10 cm apart on each side of the chamber in a randomized block design.

The colors were also tested in a randomized block design in a commercial greenhouse. All 6 colors and the plastic tape were tested together in 5 selected areas with a low to medium whitefly density. Traps were cut into 5 x 8 cm rectangles and hung 10 cm apart along the middle of a row of plants, level with the top of the canopy. The traps were removed after 6 weeks and examined.

Effect of shape on trap catch

Square traps and rectangular traps, hung vertically and horizontally, each with an area of 23 cm^2, were painted yellow (E-776) and hung on each side of the test chamber in a randomized block design.

Effect of sticky substance on trap catch

Three insect trapping compounds, Stikem Special® (Seabright Enterprises, Emeryville, Ca.), Stiky Stuff® (Olson Products Ltd.) and Tanglefoot® (Tanglefoot Company, Grand Rapids, Michigan) and a heavy oil, STP® Oil Treatment (STP Corporation, Ft. Lauderdale, Florida) were tested in the laboratory for their adhesive and repellent characteristics in a series of 6 experiments conducted 6 hours, 1 day and 1 week after application of each adhesive. Coated traps were kept at a temperature of 22°C until tested. The test chamber described previously was modified slightly for this experiment. The sides and top of the chamber were covered with black plastic to block out all light. Only a 30 cm strip along the top of one side of the chamber was left uncovered to illuminate the 5 X 8 cm traps painted yellow (E-776) and hung on this side. Four young cucumber plants bearing 1 to 3 day-old whitefly adults were placed against the inside of the chamber opposite the traps as a whitefly source. A substantial depletion of whiteflies during the experiments was not observed because of the large initial numbers of whiteflies on these plants.

The sticky substances were compared with each other according to the following procedure. Two traps, each bearing a different sticky substance were hung 7.5 cm apart on the illuminated side for a period of 10 minutes during which whiteflies flew from the plants to the traps. The traps were then removed and 2 fresh traps bearing the 2 same sticky substances were hung so that the positions of the sticky substances in the chamber were reversed. This procedure was repeated twice for each of the 6 comparisons.

During each test, the number of whiteflies escaping from each trap was counted through a plastic window from the outside of the chamber. The total number of whiteflies landing on each trap was calculated by adding the number of whiteflies which escaped to the number which were caught on the trap. The ability of the sticky substance to hold the whitefly in each replicate was calculated by dividing the number of whiteflies which remained on the trap by the total number which landed on the trap. The durability of sticky substances in a greenhouse was also investigated. Traps were kept in an area of the greenhouse, free of insects and tested in the chamber after 3 and 5 weeks. Temperatures during these weeks reached highs of 25 to 30°C and reached lows of 8 to 12°C.

Effect of height on trap catch

Traps hung at 3 heights were tested in a commercial greenhouse. Yellow (E-776), 18 x 18 cm traps were coated on both sides with Stiky Stuff and hung between 2 rows of moderately-infested plants 30 cm above the plant canopy, level with the top of the plant canopy and 30 cm below the plant canopy. The total numbers of whiteflies on 20 traps at each height were recorded after 4 weeks.

Results and Discussion

Effect of color on trap catch

Trialeurodes vaporariorum dispersed to all sides of the test chamber. Although traps on 1 side consistently caught more whiteflies than those on other sides and those on 1 side caught fewer whiteflies, the differences were not significant.

Yellow (E-776) was significantly more attractive than all other yellow hues and the plastic tape (Table I). The pale yellow was significantly more attractive than Rust-Oleum 659 and the plastic tape.

Yellow (E-776) was also more attractive to *T. vaporariorum* than the bright green (E-787) and 2 yellow-green hues (YYG,YGG) (Table II).

The most attractive color to *T. vaporariorum* in this study, yellow (E-776), is very similar in reflectance to the most attractive yellow (Y1) to *T. vaporariorum* found by Vaishampayan *et al.* (1975a) (Fig. 5). The spectral reflectance curves of the

Table I. Mean proportion of total *T. vaporariorum* captured on yellow sticky traps of 4 different hues (n=8)

COLOUR	MEAN PROPORTION OF TOTAL TRAPPED[1]
Yellow E-776	0.37a
Pale Yellow	0.28b
Rust-Oleum 659 Yellow	0.18c
Plastic tape	0.16c

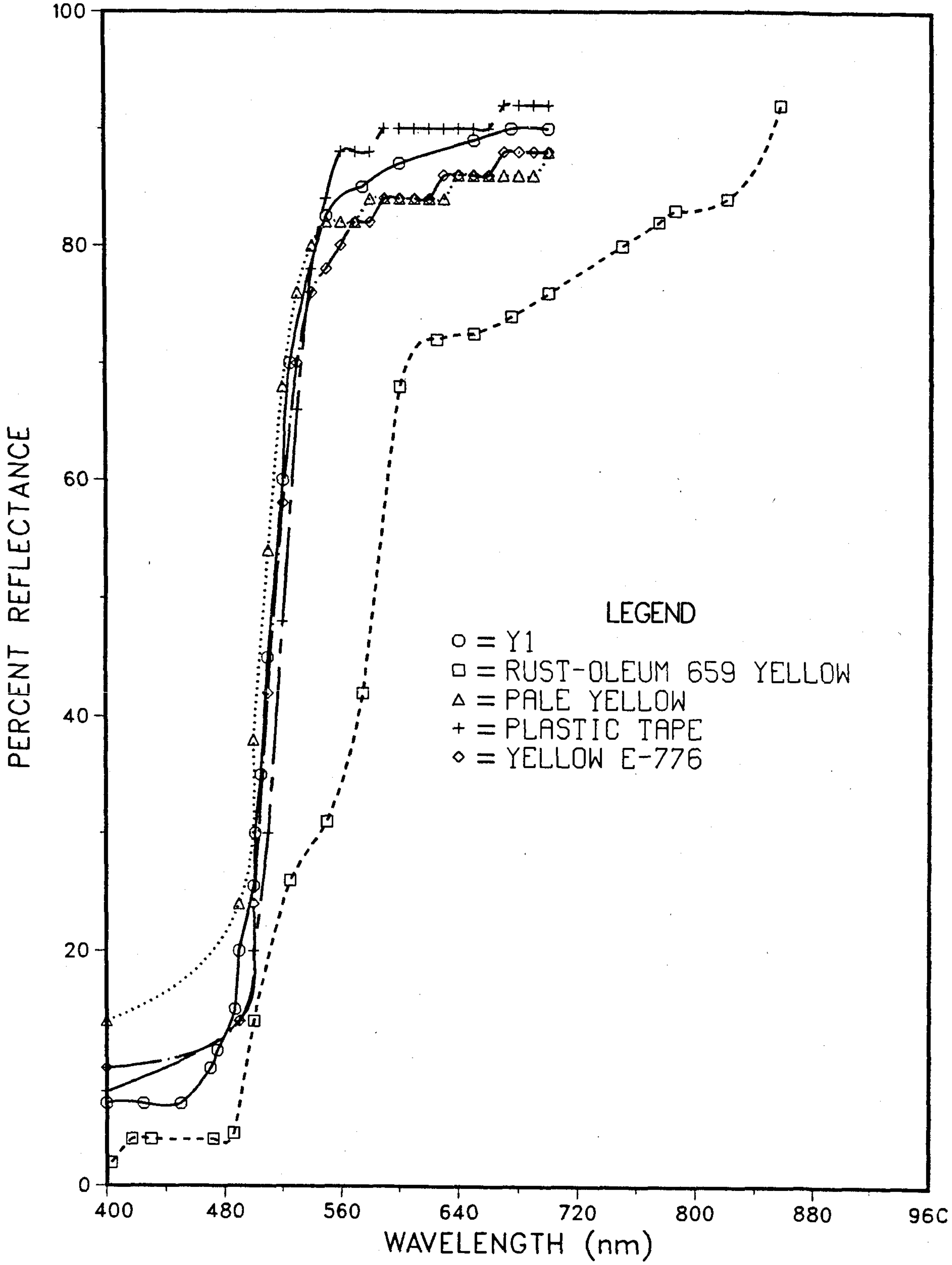
1 ANOVA performed on proportions after transformation by arcsin $\sqrt{p}$. Means not followed by the same letter are significantly different, Ryan-Einot-Gabriel-Welsch Multiple F Test ($P \leq 0.05$).

Table II. Mean proportion of total *T. vaporariorum* captured on yellow and green sticky traps of 4 different hues (n=8).

COLOUR	MEAN PROPORTION OF TOTAL TRAPPED[1]
Yellow E-776	0.34a
YYG	0.27b
YGG	0.20c
Green E-787	0.18c

1 ANOVA performed on proportions after transformation by arcsin $\sqrt{p}$. Means not followed by the same letter are significantly different, Ryan-Einot-Gabriel-Welsch Multiple F Test ($P \leq 0.05$).

Fig. 5. Spectral reflectance curves of the 4 yellow hues tested and of the most attractive yellow hue (Y1) to *T. vaporariorum* found by Vaishampayan *et al*. (1975a).


100
80
60
40
20
0
PERCENT REFLECTANCE
400
480
560
640
720
800
880
96C
WAVELENGTH (nm)
LEGEND
○ = Y1
□ = RUST-OLEUM 659 YELLOW
△ = PALE YELLOW
+ = PLASTIC TAPE
◇ = YELLOW E-776

pale yellow and the yellow tape are also similar to yellow E-776. Although the reflectance curve of the yellow tape is also similar to these yellow hues, its true reflectance was significantly less than the other 2 yellow hues because it transmitted a large portion of light. For the spectral reflectance analysis, the tape had to be folded several times and placed against a white background.

In the second experiment, the attraction of the yellow-green hues became less, probably because the colors reflected less in the yellow region (Fig. 6). In a commercial greenhouse, yellow (E-776) and YYG were significantly more attractive than green (E-787), but not significantly more attractive than any of the other hues (Table III). Different light conditions and whitefly behavior in the greenhouse may have accounted in part for the whitefly response. Shading of the traps at different times could have made attractive hues less attractive than normal to *T. vaporariorum* during flight activity periods. However, the greater part of the whitefly response is likely attributable to the contrast of the majority of trap colors against the dark green background of the cucumber crop. Background can be a major factor in determining color attractiveness (Prokopy and Owens 1983). These results indicate that although an optimal color for attracting whiteflies may exist, traps of this color may not catch significantly more whiteflies than a moderately attractive yellow in the greenhouse, where contrast and light conditions are important factors. This lack of discrimination could be advantageous if

Fig. 6. Spectral reflectance curves of the yellow-green hues tested.

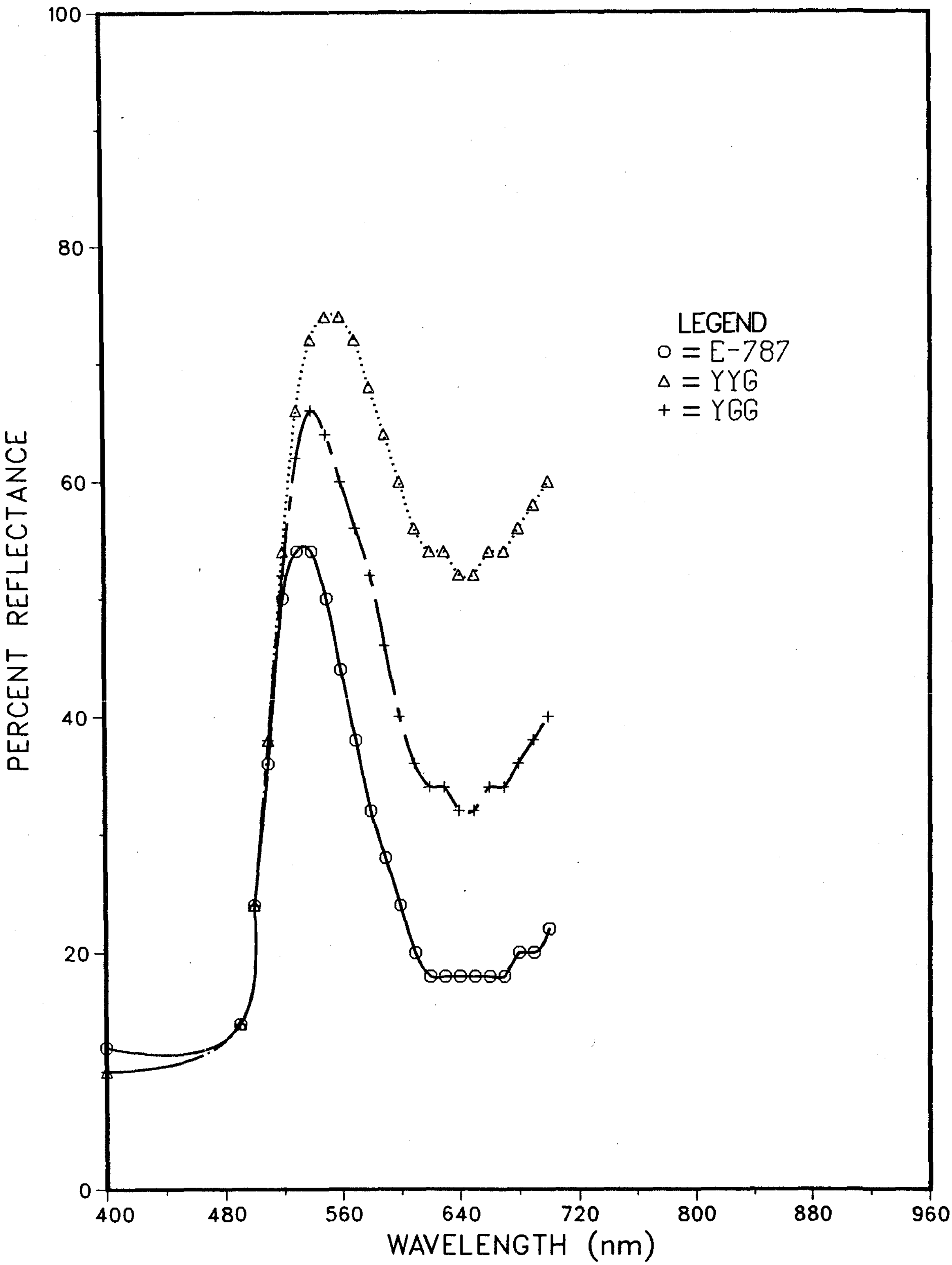

LEGEND
o = E-787
Δ = YYG
+ = YGG
PERCENT REFLECTANCE
WAVELENGTH (nm)
0
20
40
60
80
100
400
480
560
640
720
800
880
960

Table III. Mean proportion of total *T. vaporariorum* trapped on different colored sticky traps in a large greenhouse (n=5).

COLOUR	MEAN PROPORTION OF TOTAL TRAPPED[1]
YYG	0.18a
Yellow E-776	0.17a
Plastic Tape	0.15ab
Pale Yellow	0.15ab
YGG	0.13ab
Rust-Oleum 659 Yellow	0.12ab
Green E-787	0.09b

1 ANOVA performed on proportions after transformation by arcsin $\sqrt{p}$. Means not followed by the same letter are significantly different, Ryan-Einot-Gabriel-Welsch Multiple F Test ($P \leq 0.05$).

yellow traps are designed to monitor and/or control thrips and/or leafminers. A yellow color could be selected based on its attractiveness to other pest species and still be effective at catching whiteflies.

Effect of shape on trap catch

Square traps and rectangular traps, hung vertically and horizontally caught mean proportions of the total whiteflies captured of 0.34, 0.34 and 0.32 respectively. This lack of a significant difference between these capture rates (ANOVA, $P \leq 0.05$) is expected, when one considers that *T. vaporariorum* has a wide variety of hosts comprising a multitude of shapes and sizes. A visual generalist such as *T. vaporariorum* should not exhibit marked sensitivity in orienting to specific host plant visual characters such as shape (Prokopy and Owens 1983). However, a significant interaction between side and shape did occur in this experiment. This could have been caused by a fan inside the growth chamber which might have disrupted the flight activity of *T. vaporariorum*.

Effect of sticky substance on trap catch

STP was very effective at holding whitefly adults after 1 week while Stiky Stuff performed at an intermediate level (Table IV). Stikem Special and Tanglefoot were very poor at holding whiteflies and were not tested further. These results disagree with those of Webb *et al.* (1985) who reported that Stikem Special applied to plastic board traps caught 78 percent of whitefly adults landing on them after 1 week. The adhesives in

Table IV. Mean percentage of landing *T. vaporariorum* retained on cardboard traps coated with different sticky substances and tested at varying times following application (n=12).

	MEAN PERCENTAGE OF WHITEFLIES RETAINED ON TRAPS[1]				
STICKY SUBSTANCE	6 HOURS	1 DAY	1 WEEK	3 WEEKS	5 WEEKS
STP	100.0a	100.0a	100.0a	65.3a	41.2a
Stiky Stuff	67.0b	64.8b	65.2b	60.7b	61.3b
Tanglefoot	14.1c	18.0c	11.8c	NT	NT
Stickem Special	8.1d	8.3d	5.8d	NT	NT

[1] Percentages for each replicate were transformed by Arcsin $\sqrt{p}$ prior to ANOVA. Means not followed by the same letter are significantly different, Ryan-Einot-Gabriel-Welsch Multiple F Test ($P \leq 0.05$). NT=not tested.

my tests were applied to cardboard rather than plastic traps which could explain the different results, especially if very thin applications were used.

In the greenhouse STP began to lose some of its effectiveness after 3 weeks but still continued to catch significantly more whiteflies than Stiky Stuff. STP subsequently dried out quickly and was not reliable after 5 weeks. Another disadvantage of STP was that whiteflies trapped on its surface became instantly coated with oil and appeared as brown specks which were difficult to distinguish on the traps. STP also was absorbed into the cardboard which caused darkening of the trap color. These 3 factors made STP unsuitable as an adhesive on traps used for early detection.

Stiky Stuff, although not initially as effective as STP, remained effective for 4 to 5 months and did not alter the color of traps. The longevity of Stiky Stuff is important for growers who cannot afford to change traps frequently. Moreover, whiteflies captured on Stiky Stuff remain easily visible for several months.

None of the 4 sticky substances was consistently less repellent or more attractive than the others in the comparison tests (Table V). Traps coated with tanglefoot caught significantly more whiteflies when tested against the other 3 substances but only after 1 day. Its low trapping efficiency thereafter, made it unsuitable for whitefly trapping.

The sticky substances may have been repellent or attractive to some degree to *T. vaporariorum*, but the design of the test

Table V. Total number of *T. vaporariorum* landing on traps coated with different sticky substances and tested 6 hours, 1 day and 1 week later in pairwise comparisons (n=2).

	TOTAL WHITEFLIES LANDING ON COATED TRAPS		
COMPARISON TESTS	6 HOURS AFTER COATING	1 DAY AFTER COATING	1 WEEK AFTER COATING
Stickem Special	80*	127	119
Stiky Stuff	108	156	129
Stickem Special	188	137*	133*
Tanglefoot	206	192	174
Stickem Special	216	145	132
STP	182	176	152
Stiky Stuff	153	104*	134
Tanglefoot	176	199	120
Stiky Stuff	171*	148*	139
STP	213	194	135
Tanglefoot	134	150*	114
STP	153	194	142

* Significant difference between paired totals (CHI-square test, $P \leq 0.05$).

did not enable this to be shown. Air currents in the test chamber could have mixed the odor plumes from each trap together. However, no adhesive attracted or repelled significantly more whiteflies than the others, even at close range where the odors on individual traps might have been distinguishable by the whiteflies. In a greenhouse where air currents are constantly changing, the repellency or attractancy of sticky substances in relation to trap effectiveness is probably minor. The olfactory responses of *Trialeurodes vaporariorum* to other stimuli have been shown to play a minor role (Yin and Maschwitz 1983; Vaishampayan et al. 1975b).

Effect of trap height on whitefly catch

Traps hung level with the top of the plant canopy caught a total of 1232 whiteflies whereas traps hung 30 cm above and 30 cm below caught 785 and 649 whiteflies respectively. These results agree with those of Ekbom (1980b) and Webb *et al.* (1985). Traps raised above or below the tops of the plants caught progressively fewer whiteflies. Traps placed below the top of the plant canopy were often shaded and therefore less conspicuous to whiteflies. They became easily entangled in the plant foliage. Traps hung 30 cm above the plant canopy were too high to catch the whiteflies congregated at the top of the canopy. They were also blown about frequently by air currents created by open windows which probably made it difficult for the whiteflies to land on them.

CHAPTER VII

PRELIMINARY GREENHOUSE TRIALS

Materials and Methods

Preliminary greenhouse trials to test trap effectiveness for early detection and control of whitefly were conducted in a 9 X 11 m wooden-framed greenhouse covered with polyethylene plastic. Two rows of 7 cucumber plants each, separated by a 91 cm aisle were planted at the beginning of July, 1984, and used for both trials.

Square, 18 x 18 cm traps, painted yellow (E-776) on both sides, were used in all greenhouse trials. Larger traps were not practical to use because they became entangled in the plants. Stiky Stuff was applied to both sides of the square trap by dipping it into a container filled with Stiky Stuff and pulling it through a pair of copper rollers. Traps were hung at a density of 1 per plant within each row (Fig. 7) and level with the top of the plant canopy. A string-holding device made from a bent 20 cm length of 0.8 mm gauge spring wire, a 1.2 m length of string and a paper clip (Fig. 8) were used to suspend each trap. Twine was tied to greenhouse support structures, 30 cm above each row of plants. The bent wires were twisted around the twine to prevent them from falling when disturbed by spraying, pruning or winds created as a result of open vents. The string, wound around the ends of the wire (Fig. 8) facilitated raising and lowering the trap to the level of the plant canopy.

Fig. 7. Layout of the small greenhouse, showing positions of plants and traps.

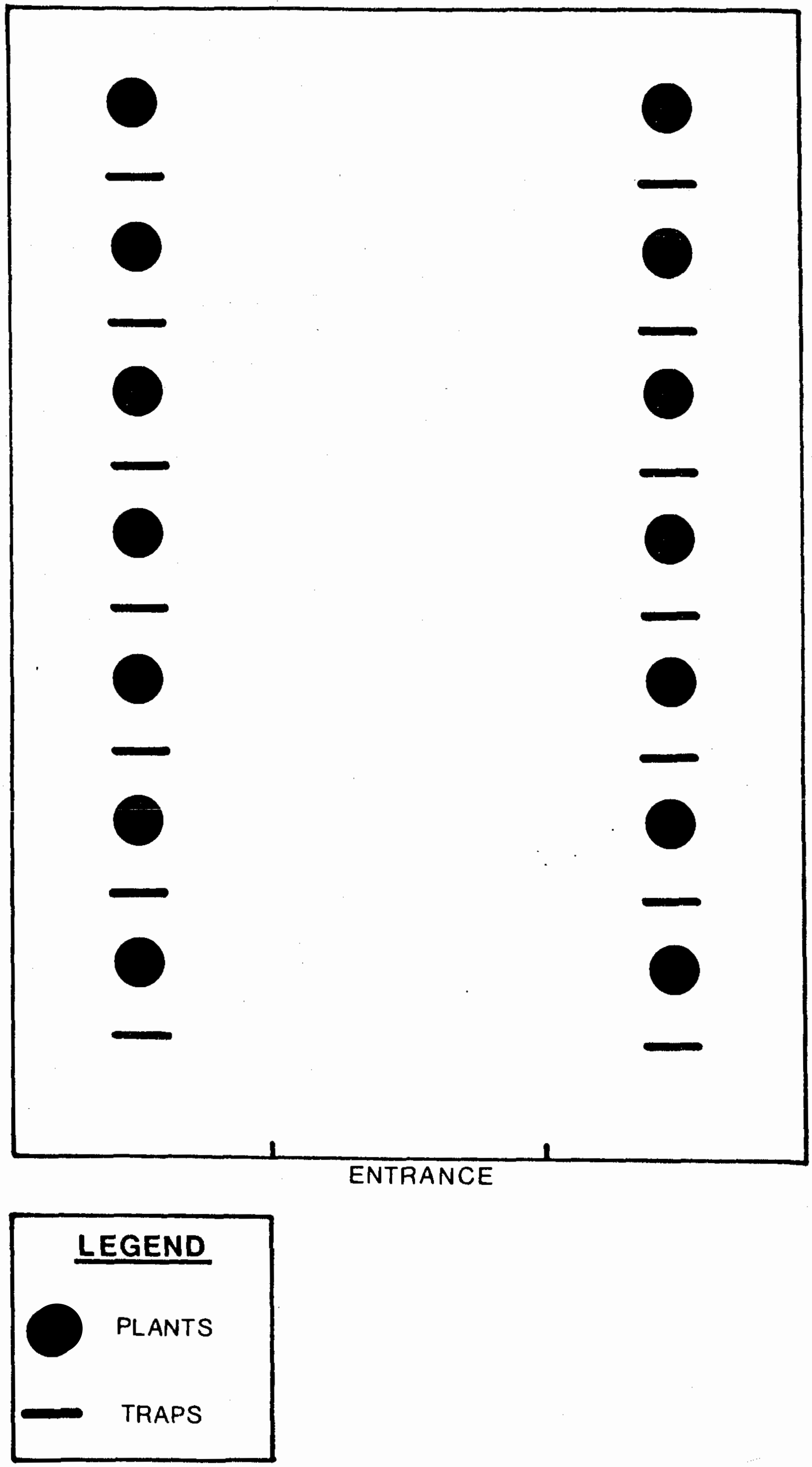
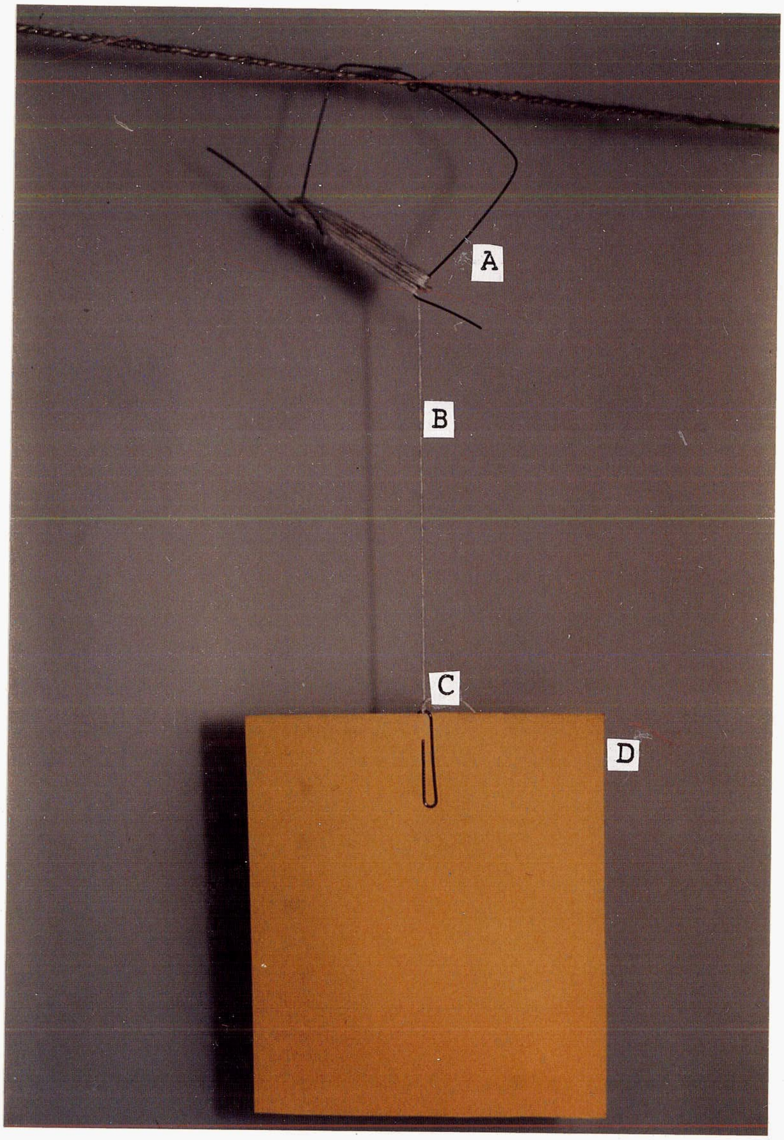

ENTRANCE
LEGEND
PLANTS
TRAPS

Fig. 8. Device used to suspend traps in the greenhouse. A, bent wire; B, string; C, paper clip; D, trap.


A
B
C
D

Prevention of whitefly establishment by traps

This trial was conducted in July, 1984, with temperatures in the greenhouse ranging from highs of 30 to 40°C to lows of 10 and 12°C. Traps were hung at a density of 1 per plant between the plants at canopy height. A cucumber leaf bearing approximately 50 mature whitefly pupae was introduced into the center of the greenhouse. After 5 days, in which approximately 95 percent of the adults had emerged, the number of whiteflies on the plants and on the traps were counted. This experiment was repeated 3 times.

Efficacy of traps for control

This experiment was conducted in September, 1984, with temperature highs ranging from 20 to 30°C and lows ranging from 6 to 10°C.

Traps were introduced into a multiple-generation whitefly population. The numbers of whitefly adults on the top 5 leaves of each plant and on each trap were recorded at 2-day intervals for 30 days. Parasites were not introduced so that the effect of the traps alone could be evaluated.

Results and Discussion

Prevention of whitefly establishment by traps

The traps intercepted 62 percent of whitefly adults introduced, indicating that traps are an effective early detection. Since the traps are only 65 percent efficient in holding adults (Table IV), their effectiveness in attracting whiteflies is considerably greater. If the stickiness of the traps could be enhanced by using a different trap surface (e.g. a plastic compound) their effectiveness could be increased even more.

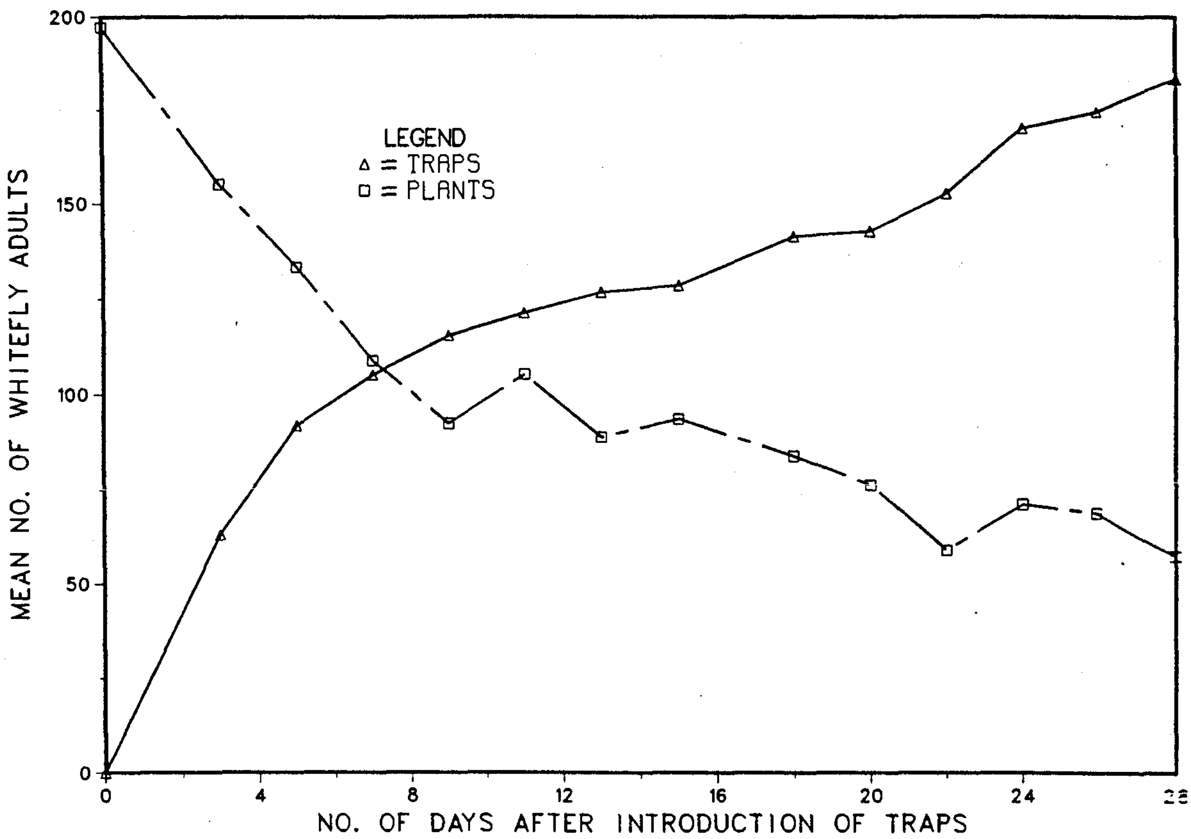
The use of traps to detect whiteflies at low levels could improve control by *E. formosa*, as successful biological control of whitefly is contingent upon the introduction of parasites into incipient whitefly infestations. The traps could also reduce the number of whitefly infestations that develop by preventing the establishment of immigrant whitefly adults.

Efficacy of traps for control

Traps reduced whitefly numbers in the small greenhouse by 71 percent in 28 days (Fig. 9). However, the host plants were less vigorous than those in commercial greenhouses which made the traps more visible to the whiteflies.

Traps were particularly effective at attracting adults leaving a host. Traps near a dying plant caught the majority of whiteflies leaving that plant, indicating that the traps were more attractive than the other healthy plants. The importance of the early introduction of the traps into the greenhouse is thus emphasized. Immigrating whiteflies could be intercepted on traps before they land on the plants.

Fig. 9. Mean number of whitefly adults on the top 5 leaves of each of 14 cucumber plants and on each of 14 traps over a 28-day period in a small greenhouse.



LEGEND
△ = TRAPS
□ = PLANTS
MEAN NO. OF WHITEFLY ADULTS
0
50
100
150
200
0
4
8
12
16
20
24
28
NO. OF DAYS AFTER INTRODUCTION OF TRAPS

CHAPTER VIII

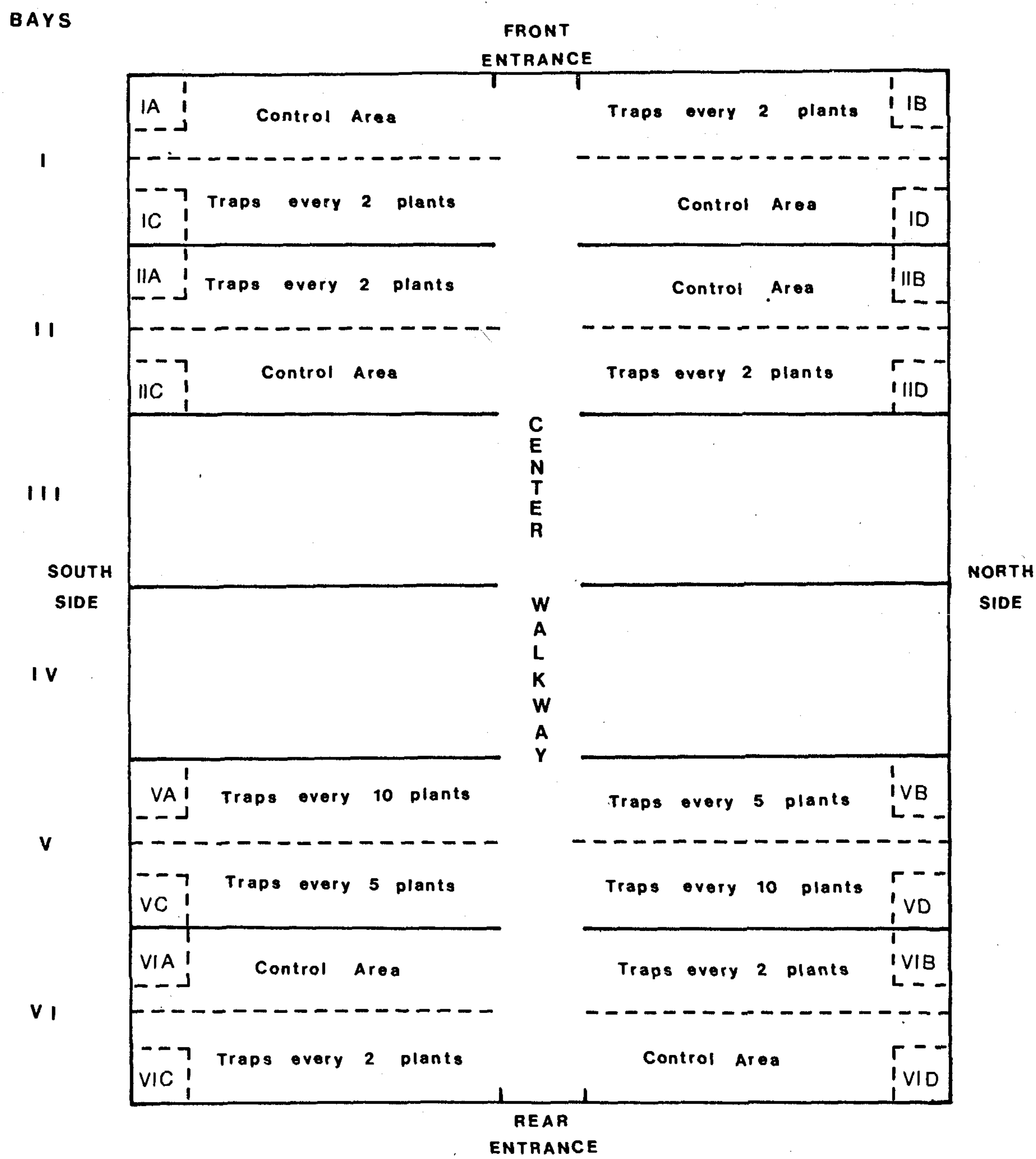
COMMERCIAL GREENHOUSE TRIALS

Materials and Methods

Traps were tested in a commercial greenhouse with an area of 5580 m^2 in Surrey, British Columbia. Early detection of whitefly was tested with trap densities of 1 trap per 2 plants, 1 trap per 5 plants and 1 trap per 10 plants. Although these densities were high, I felt they were necessary because of the large size of the plants which can easily obscure the traps and the sedentary behavior of whiteflies once they settle on a leaf. If used by growers, traps could be checked by workers when attending to the plants. Traps were tested as a control measure in conjunction with *E. formosa* at a density of 1 trap per 2 plants.

The layout of the commercial greenhouse is shown in Fig. 10. A center walkway divided each bay in half and each half was divided in half again in the north-south direction for the study. Each quarter of a bay contained 4 rows of 53 plants each. Traps were placed at a density of 1 trap per 2 plants in bays I, II and VI, selected at random. Traps were hung in 2 of the 4 quarters of each bay. The other 2 quarters represented control areas. In bay V, traps were placed at a density of 1 trap per 5 plants and 1 trap per 10 plants. Four introductions of *E. formosa* at the recommended rate of 5 per plant (Costello *et al.* 1984) were made throughout the greenhouse at 2-week intervals

Fig. 10. Layout of the commercial greenhouse consisting of 6 peaked roofs (bays) joined together at the sides. Solid lines between bays are shown only to differentiate bays. Each quarter-section of a bay, designated A,B,C, and D, was a treatment area.


BAYS
FRONT ENTRANCE
I
IA
Control Area
Traps every 2 plants
IB
IC
Traps every 2 plants
Control Area
ID
II
IIA
Traps every 2 plants
Control Area
IIB
IIC
Control Area
Traps every 2 plants
IID
III
CENTER WALKWAY
SOUTH SIDE
NORTH SIDE
IV
V
VA
Traps every 10 plants
Traps every 5 plants
VB
VC
Traps every 5 plants
Traps every 10 plants
VD
VI
VIA
Control Area
Traps every 2 plants
VIB
VIC
Traps every 2 plants
Control Area
VID
REAR ENTRANCE

beginning the same time that the traps were hung.

Efficacy of traps for early detection

Early detection of whitefly was evaluated in areas with a trap density of 1 trap per 2 plants by counting the total number of whitefly adults on the upper leaves of 2 plants on either side of the trap which had caught a whitefly. For trap densities of 1 trap per 5 plants and 1 trap per 10 plants, the total number of whitefly adults on the same upper leaves of 5 plants and 10 plants, respectively, on either side of a trap were counted.

Efficacy of traps for monitoring

To determine the accuracy with which the number of whitefly adults on traps could predict the number of whitefly adults on the upper leaves of the plants, weekly counts were made of the number of whitefly adults on 20 traps in each of sections Ib, IId and VIb and the total number on the 3 youngest leaves of 3 upper shoots beneath each trap. The same traps were used each week so that weekly counts could be obtained. The numbers of whiteflies on the traps and on the plants in each section were totalled each week and provided 3 estimates. After 15 weeks, the experiment was stopped and subjected to regression analysis.

Efficacy of traps for control

The efficacy of traps for control of whiteflies in conjunction with *E. formosa* was tested by counting the number of whiteflies on the 3 youngest leaves of 3 upper shoots of 20 plants in each of the areas with a trap density of 1 trap per 2 plants and comparing these numbers with similar counts made on 20 plants in the control areas of the same bay. Parasitism rates were calculated on each of the 20 plants by counting the numbers of parasitized and healthy whitefly pupae on 3 mature leaves of each plant. The effectiveness of traps in trapping out a small whitefly infestation was also investigated in a whitefly-infested area in bay Ic in April. Traps were cut into 5 x 18 cm strips and hung vertically at a density of 7 per plant on and among the first 8 plants in row 4. In adjacent rows, whiteflies were also present, but in lower numbers. Whitefly numbers on 9 upper leaves of each of the first 8 plants in rows 1 to 3 of this bay and in row 1 of the adjoining bay (IIa) were monitored for a 4-week period.

Results and Discussion

Grower Reaction

The construction and placement of the traps and trap suspension devices required about 4 weeks of work. The devices were very time-consuming to construct and put up but they would probably last for at least 5 years. The trap suspension devices made it easy to raise and lower the traps. However, the grower whose greenhouse was used in this study was not ready to use them because it required too much time to wind the traps every week. He was prepared to hang sticky traps in his greenhouse, at a density of 1 trap per 6 plants, but preferred to buy them pre-coated and hang them from the plant support wires. Since this study, a 5 by 60 cm, pre-coated plastic trap has been developed and is now marketed to growers by Applied Bio-Nomics Ltd. for whitefly and thrips trapping. This trap is more suitable to growers as it precludes the need for the suspension device. It also becomes less entangled in the leaves than the square traps. The large square surface areas of the traps in this study were very effective in trapping leaves in addition to whiteflies. Placement of the traps between the plants at the level of the top of the canopy was tolerable to the grower. The traps could be slid along the twine, out of the way of the workers, when necessary.

Stiky Stuff remained effective for up to 6 months provided the original application was moderately thick. Thin applications dried out quickly and were ineffective at holding whiteflies after 2 to 3 weeks. Another factor affecting the stickiness of the traps was the number of fungus gnats trapped. In areas of high fungus gnat densities, traps became blackened in 1 month, reducing their attractiveness and their ability to catch whiteflies. If traps lost their stickiness, they were replaced. Traps were discarded at the end of the season as Stiky Stuff was difficult to remove.

Whitefly Population Trends

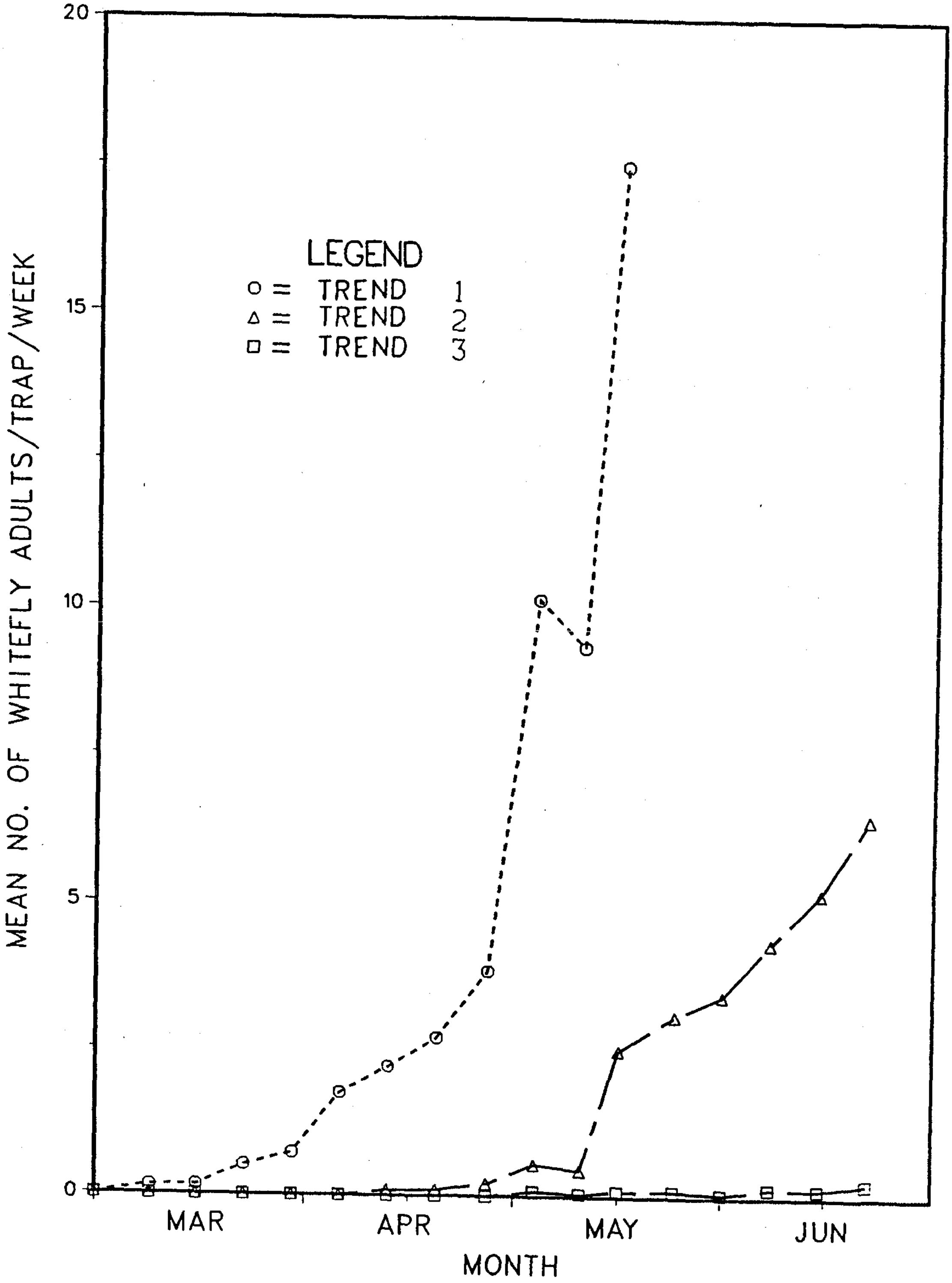
Whiteflies were present in the greenhouse when traps were introduced and increased to intolerable levels by mid-August. This damaging population, in addition to a severe thrips infestation, necessitated a switch to a chemical control program by the grower. Whiteflies escaped control by *E. formosa* because parasites were eliminated from the greenhouse partially through cultural practices and finally through chemicals. In the spring and early summer, traps functioned well for early detection and well in conjunction with *E. formosa* for control.

The whitefly populations on the traps in bays I, II, V and VI followed 3 trends (Fig. 11). In bay Ic (Trend 1), the whitefly population was higher than all other areas at the beginning of the monitoring period. Bay Vc also had high whitefly numbers and followed the same pattern of population increase. The populations rose gradually through March and April and then rose explosively at the beginning of May. The whitefly population increase in bay IIa is shown in trend 2. A similar pattern was observed in bay Va. The population rose very gradually during the first 2 months and increased at a moderately steep rate in May and June. In bay VIb (Trend 3), whiteflies were caught on a few traps early in the season but remained at a low level for the duration of the summer. Similar population patterns were observed in bays Ib, IId, Vb, Vd and VIc, which also had very low numbers of whitefly early in the season.

Efficacy of traps for early detection

Early detection of whitefly at a trap density of 1 trap per 2 plants was successful in all cases. In bay Ic, whitefly adults were seen before the traps were hung and were caught on the

Fig. 11. Three trends of whitefly population increase observed in the commercial greenhouse in the spring and summer of 1984.



20
15
10
5
0
MEAN NO. OF WHITEFLY ADULTS/TRAP/WEEK
LEGEND
○ = TREND 1
△ = TREND 2
□ = TREND 3
MAR
APR
MAY
JUN
MONTH

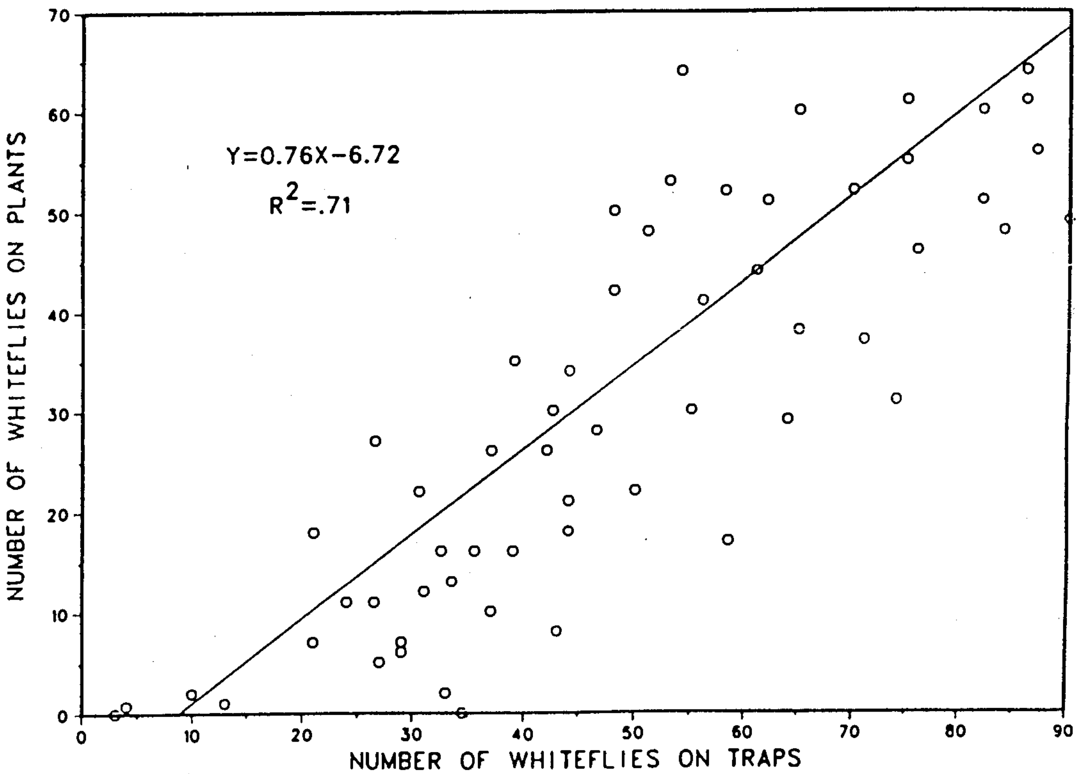
traps 2 days after trap introduction. Whiteflies were caught on traps in bay IIa after 1 week, but were not observed on the plants for 1 to 2 months. In bays VIb, Ib, IId and VIc, whiteflies were caught on traps in the last 2 weeks in March but were not observed on the plants until halfway through August. Whitefly adults were detected on plants only in areas in which 9 or more whiteflies had been caught on a trap in 1 week.

At lower densities of 1 trap per 5 plants and 1 trap per 10 plants, whiteflies were also detected on traps before they could be found on the plants. In bay Vc, traps at a density of 1 per 5 plants caught many whiteflies during the first week following trap introduction. Examination of the plants in this area revealed moderate whitefly infestations. In bay Va, traps at a density of 1 per 10 plants caught only a few whiteflies in late March and whitefly adults were not seen on the plants until late in April. In bays Vd (traps every 10 plants) and Vb (traps every 5 plants), whiteflies were trapped within the first month of monitoring but were not seen on the plants until the beginning of August.

Efficacy of traps for monitoring

Traps at a density of 1 per 2 plants provided accurate predictions of whitefly numbers on the top leaves of the plants. A relationship was established between the numbers of whiteflies on the traps and the numbers of whiteflies on 9 upper leaves of each plant per week (Fig. 12). At numbers below 9 adults on 1 trap per week, it was difficult to detect adults on the plants.

Fig. 12. Regression of the numbers of whitefly adults on 20 traps and on 20 plants below these traps per week in each of 3 areas of the greenhouse over a 15-week period ($F=137.6$, $P<0.0001$).


Y=0.76X-6.72
R2=.71
NUMBER OF WHITEFLIES ON PLANTS
NUMBER OF WHITEFLIES ON TRAPS
0
10
20
30
40
50
60
70
80
90

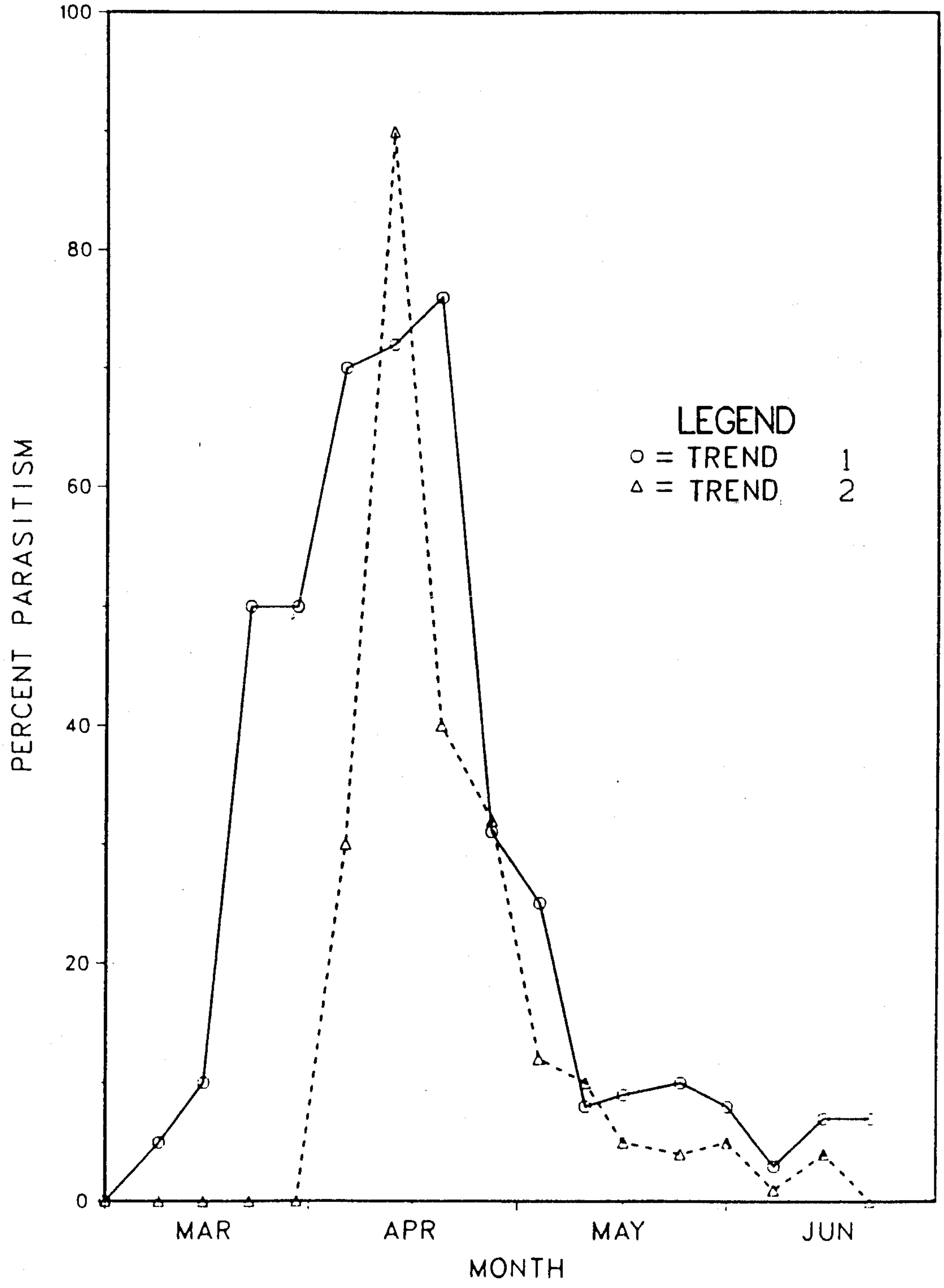
This density of traps is not feasible to monitor in a large greenhouse. However, it would be feasible to monitor a portion of these traps. At a density of 1 trap per 10 plants, whitefly population trends on the plants were reflected on the traps.

Efficacy of traps for control

The effect of traps and *E. formosa* on whitefly control compared to just *E. formosa* could not be measured as whiteflies infested the areas with traps before the control areas.

However, the success of traps in conjunction with *E. formosa* at controlling whiteflies at low levels in this experiment was dependent on the numbers of whiteflies present when the controls were implemented. In trend 1, whiteflies were established on the plants prior to trap introduction. Whitefly numbers continued to increase over the next 8 weeks at a moderate rate, partially suppressed by the parasites. Parasitism in this area increased to a maximum of 75 percent after 7 weeks but dropped dramatically in the succeeding weeks (Fig. 13). The resulting drop in parasitism probably allowed the whitefly population to explode. The traps by themselves had little effect on suppressing the whitefly population. Further introductions of parasites at twice the recommended rates could not prevent a whitefly increase. Thick honeydew secretions on the leaves by this time also made parasitism more difficult for *E. formosa*. It is possible that the whitefly population depicted here would have been brought under control before reaching intolerable levels had the parasites not disappeared.

Fig. 13. Parasitism rates on plants in trends 1 and 2.


100
80
60
40
20
0
PERCENT PARASITISM
MAR
APR
MAY
JUN
MONTH
LEGEND
○ = TREND 1
△ = TREND 2

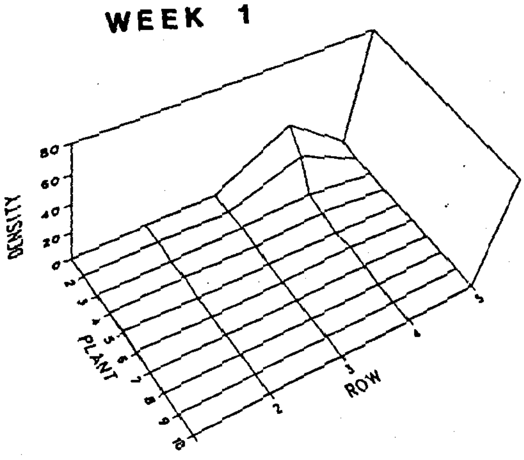
In trend 2, the whitefly population was kept at a low level until the parasites disappeared. The rise in the whitefly population in May coincides with the loss of parasites in April. This trend suggests that the parasites were partially responsible for keeping the whiteflies at a low level in this area. Parasites became established on a small whitefly population which prevented an increase of whiteflies. However, a drop in the parasitism rate at the end of April allowed the whitefly population to rise at a moderate to steep rate. The parasitism rate shows large fluctuations in weeks 6 to 8 due to a low number of pupae sampled.

The whitefly population in trend 3 was extremely small at the time of trap introductions. No parasitism rate is given because no white or black pupal scales were found on the plants in this area. Traps were likely introduced before the establishment of whiteflies on the plants. Although several whiteflies were caught in March on some traps, more were not trapped until late in July. A loss of parasites in April did not cause a rise in the whitefly population perhaps because whiteflies were caught on the traps before they could become established on the plants.

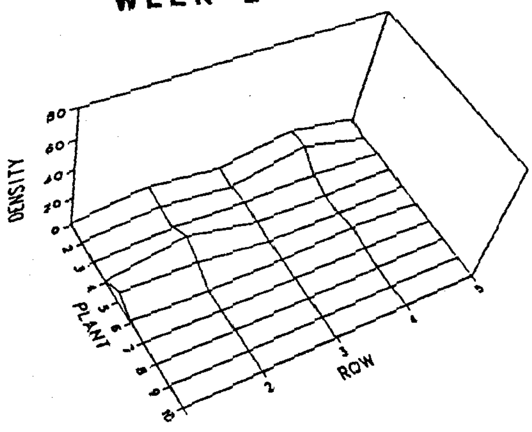
The high density of traps around the 8 plants in row 4 of bay Ic were very effective in reducing the number of whiteflies to a low level. In 4 weeks, whiteflies were reduced from levels as high as 55 per plant to levels below 10 per plant while whitefly numbers on plants in adjacent rows increased to levels as high as 58 per plant (Fig. 14). Isolated whitefly

Fig. 14. Whitefly population trends on the first 8 plants in the first 4 rows of bay Ic and the first row of bay IIa (labelled row 5), following the inundation of the first 8 plants of row 4 with traps.

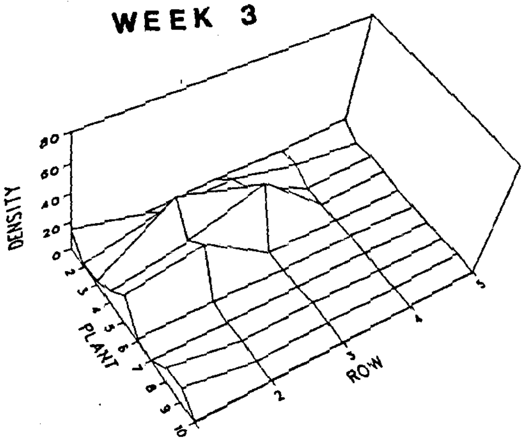
WEEK 1



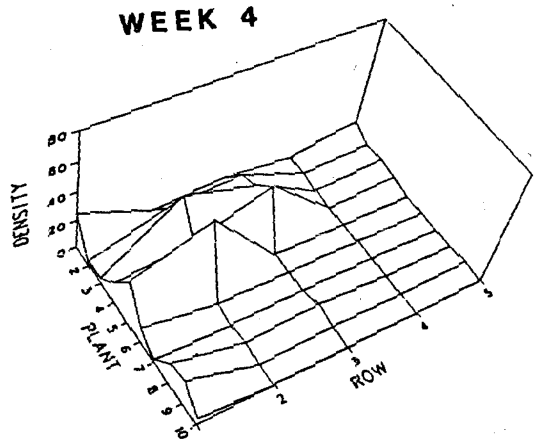
WEEK 2



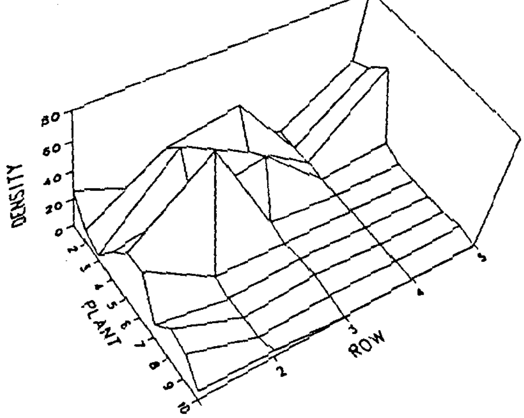
WEEK 3



WEEK 4



WEEK 5



infestations in the greenhouse could be reduced to low levels with this method without the need of a chemical spray. If traps were placed around all infested plants in an infestation, whiteflies could be prevented from spreading to surrounding plants.

Grower Practices

Greenhouse cucumbers are grown hydroponically in sawdust bags. Carefully measured amounts of nutrients and water are fed to the roots of the plants at various times throughout the day. The result is that plants grow very fast and become very bushy. Growers therefore constantly have to prune out the old and new shoots. The mature leaves on the main stem are also removed periodically to allow more light to penetrate through the canopy. These practices conflicted with the maintenance of adequate numbers of parasites in the greenhouse throughout the season. Growers need to manage the parasites as well as the plants. In many instances, *E. formosa* is introduced and then ignored. The dramatic drop in parasitism in this study was largely due to the removal of parasites from the greenhouse on mature leaves which were removed from the main stems in April before the parasites had emerged. An examination of the leaves 1 day following their removal and immediate disposal outside the greenhouse indicated that on some leaves as much as 80 percent of the black, parasitized scales still contained pupae of *E. formosa*. Parasites may also be discarded in the pruning process. Periodic examinations of cucumber shoots which had been pruned and removed from the greenhouse revealed black scales containing *E. formosa* pupae. As black scales are often found on the leaves of older shoots, they are susceptible to being removed. If growers do not manage their parasite population, they continue to have problems with whitefly control.

Some growers did not pay attention to the importance of introducing parasites immediately after sighting the first whitefly. Delays in introductions result in large parasite and whitefly populations. Parasites were also introduced at insufficient rates to be successful.

Pesticide use also reduced *E. formosa* numbers in this study. After an application of lindane and diazinon for a thrips infestation in late June, parasites were virtually impossible to locate. Diazinon is one of the most commonly used pesticides in the greenhouse. It is not toxic to the predatory mite, *Phytoseiulus persimilis* (Athias-Henriot) but is toxic to *E. formosa*. Growers realize that diazinon is not toxic to *P. persimilis* and often assume that it is also harmless to *E. formosa*. Growers who use diazinon frequently are therefore risking whitefly problems later in the season.

The presence of non-crop plants in the greenhouse contributes to whitefly infestations. Growers can reduce or prevent the risk of whitefly infestations early in the season by removing ornamental plants such as fuschias from their greenhouses. Whiteflies live on these plants during the winter and fly to the crop seedlings in the spring. The seedlings upon which whitefly adults have oviposited are then distributed at random throughout the greenhouse. Infestations develop on the new crop, often without the knowledge of the grower. If parasite introductions are made too late, the whitefly population escapes control.

Whitefly adults can also overwinter on plants outside the greenhouse and be a source of early infestation in the spring. Several whitefly adults were found on the innermost leaves of broccoli plants in a garden adjacent to the commercial greenhouse in this study in late November of 1984. The whiteflies could not be located again in the spring as it is unlikely that they were able to survive the unusually cold and long winter of 1984. In the normally mild winters of coastal British Columbia, however, overwintering whiteflies outside the greenhouse could be a perennial source of infestation.

CONCLUSIONS

Biological control with *E. formosa* is the most promising and preferred method of whitefly control in greenhouses. Chemical control is a short-term and an unpleasant solution in an enclosed environment. Biological control when successful is also more economical than chemical control. Biological control agents generally produce a return on investment of 30 to 1 whereas the average return of a chemical pesticide is only 5 to 1 (van Lenteren 1980). For the grower, a reduction in chemical pesticide applications usually results in increased crop yields and decreased labor costs (Tauber 1977).

Biological control of whitefly on cucumber with *E. formosa* has achieved limited success for the following reasons:

1. Parasites are released too late into whitefly-infested crops and at insufficient rates to be effective in controlling whiteflies below tolerable levels.

2. The parasite-host balance is upset by the use of insecticides such as diazinon.

3. Grower practices such as pruning disrupt the predicted host-parasite interaction in favor of the host.

4. Poor sanitation practices contribute to increased whitefly problems early in the season.

All of the above practices have contributed to the failure of *E. formosa* to control whitefly on cucumber in greenhouses in British Columbia. However, early detection can improve control. Early detection of whitefly by yellow sticky traps is possible at a trap density of 1 trap per 10 plants. Introductions of *E. formosa* into a crop at the first sign of whitefly on the traps should ensure the establishment of parasites at low whitefly levels. Whitefly levels can be monitored accurately by traps placed at a density of 1 per 2 plants. However, whitefly population trends on the plants are reflected on traps placed at a density of 1 per 10 plants.

The maintenance of parasite levels during the season are dependent on the grower. Proper introduction and management of parasites in the greenhouse must be conducted by the grower if control of whitefly is to be successful.

Traps are most effective when introduced at the time the crop is planted in the greenhouse as whiteflies entering the greenhouse are attracted to the traps more strongly than to the plants. Early trap introduction prevents or delays the establishment of whiteflies on the plants. If small whitefly infestations do develop early in the season, inundations of infested areas with traps can reduce the whitefly numbers to low levels; concurrent parasite introductions should keep these infestations at low levels.

The use of chemicals toxic to *E. formosa* can be reduced. Regular monitoring of fungus gnats in the greenhouse could reduce the number of insecticide applications considerably (Rutherford *et al.* 1985). Biological control agents are currently in use on a trial basis in commercial cucumber greenhouses for control of thrips and fungus gnats. If successful, the use of chemicals toxic to *E. formosa* on greenhouse cucumber will be virtually eliminated.

RECOMMENDATIONS

A biological control program for whitefly on greenhouse cucumber using yellow sticky traps for early detection should follow these rules:

1. Traps should be hung above the seedlings in the propagation house at a density of 1 trap per 50 plants prior to planting to prevent establishment of whitefly on newly-planted seedlings.

2. For early detection of whitefly, traps should be hung throughout the greenhouse at a density of 1 trap per 10 plants.

3. For monitoring of whitefly populations, traps should placed at a density of 1 trap per 2 plants.

4. For control of whitefly, traps should be introduced at a density of 1 trap per 2 plants at the time the crop is planted.

5. Parasite introductions should be conducted weekly or bi-weekly beginning 2 weeks after the first sighting of a whitefly on a trap. For rates and number of introductions refer to Costello *et al*. (1984).

6. Small whitefly infestations can be controlled by introducing traps at a high density, e.g. 7 traps per plant, into the infested areas.

7. Use of chemicals such as diazinon should be avoided. If they need to be used, parasitism rates should be checked following application and more parasites introduced if necessary. Growers unsure about which chemicals they should use should consult the Ministry of Agriculture and Food or its

equivalent in other areas.

8. Old leaves and shoots which are removed from the plants should be examined for parasite emergence and if necessary kept in the greenhouse for several days until the parasites emerge.

9. Traps should be inspected once a week for increases in whitefly numbers. If whitelies are increasing and there are more white pupal scales than black, parasitized scales on the mature leaves, further parasite introductions should be made.

10. Preventative measures to reduce whitefly infestations early in the season should be extended to the removal of non-crop plants from inside and immediately around the greenhouse.

Since this study, an early detection program for whitefly and thrips has been implemented in greenhouses on cucumber in British Columbia. Traps consisting of 60 cm strips cut from 5 cm-wide rolls of yellow tape (Olson Products Ltd., Medina, Ohio), and coated with Stiky Stuff are hung at a density of 1 trap per 50 plants. Whiteflies can be detected on the traps before they can be seen on the plants even at this density. However, a higher density of traps in the crop would be more desireable in delaying the establishment of whiteflies on the crop and in controlling infestations later in the season.

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